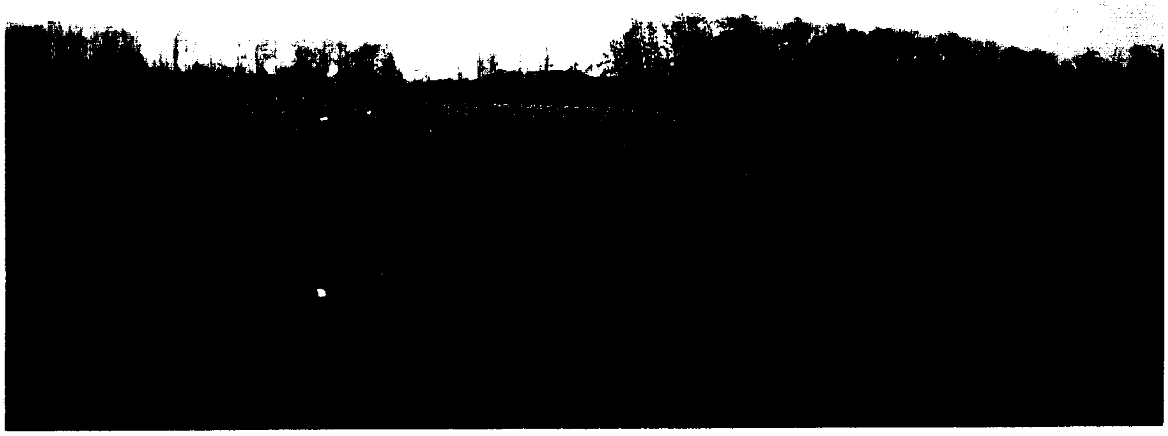
Holocene Palaeoenvironmental Reconstruction of *The Lows*, East Anglian Fenlands



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DISSERTATION ABSTRACT

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Degree for which dissertation will be submitted: BA (Hons) Geography

Dissertation Title:

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Abstract

Wetlands such as the East Anglian Fenlands (UK) are important storage areas for sediments that formed during the Holocene (the 10,000 years since the Devensian glacial). This study has used a multi-proxy approach in the palaeoenvironmental reconstruction of a fen site in the Little Ouse valley of Fenland. A focused coring survey of ten borings was employed collecting samples for lithostratigraphic and biostratigraphic (principally pollen and diatom) analysis. This revealed a complex sequence up to five metres deep and possibly extending to the Late Glacial. It is composed of up to three metres of surface peat overlying marl, clay and basal sand units. Significant lateral and vertical variations in the positioning and depth of sediment units suggest the dominance of local (site-specific) factors in sediment genesis. Pollen analysis, in particular, has aided correlation of the local vegetational regime at *The Lows* with previous research in this region, and has enabled a relative dating framework to be employed. The suggestion of a Late Glacial to post-glacial lake underlying the fens in this area has been investigated, as has the possibility of direct marine influence due to sea-level change. A summary model of Holocene environmental change at the site has been put forward.

Acknowledgements

I would like to thank Adrian Yallop (Site Manager of Blo'Norton Fen) for his help in organising the fieldwork and for sharing his local knowledge of the area, and Brian Warby for allowing access to the farmland adjacent to the study site. I am extremely appreciative of the support of Patrick Robinson and English Nature through the CEL (College English Nature Links) scheme, details of which are filed in the appendix. I would like to thank the laboratory staff who have helped me and to express my gratitude to Dr. Rossell-Mele, Dr. Horton, Professor Shennan, Dr. Zong, Dr. Long and Matt Wright for their advice at various stages of this research.

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1.
Introduction, Aims & Study Setting

1.1 Introduction- the importance of wetlands in palaeoenvironmental investigation

Wetlands cover 6% of the world's land surface and are among the most fertile ecosystems, accounting for 24% of the world's net primary productivity (Williams, 1990). Their global importance is such that they are the only ecosystem to be protected by a specific international agreement called the RAMSAR Convention. Ellwood & Crump (1998) state that 200,000 sq. km of wetland has consequently been preserved. The most vital feature of wetlands is that they are wet or waterlogged, and the resulting anaerobic or oxygen-deficient conditions slow down the decomposition of biomass, often allowing peatlands to develop (Moore & Bellamy, 1974).

Wetlands are an essential component in the study of global environmental change. The importance of a better understanding of their formation has been a major motivation in this dissertation. Indeed, the principle of uniformitarianism, i.e. the present is the key to the past is a focus of this investigation and much wetland research worldwide (Lyell, 1830). It means that the fossil records stored in sediments can be extracted and used as proxies for past climate and vegetation, e.g. during the Holocene. A comprehension of past environmental variability is also justified in a reverse-uniformitarianism context because the data produced can act as a tool for modelling future climate change (Plater *et al*, 2000a).

1.2 Chapter Structure

This chapter seeks to clarify the overall aims and objectives of the investigation followed by an introduction to the study site in Section 1.4. A series of research questions is then presented in Section 1.5 based on the examination of previous investigations in this area, allowing certain specific research problems to be addressed.

1.3 Aims and Objectives

This study intends to achieve two overall aims:

1) To examine the Holocene environmental changes at the study site using proxy methods, principally pollen and diatom analysis, and to correlate the results with other studies of the region.

2) To investigate the evidence for a Late Glacial/ post-glacial lake and possible marine influence.

1.4 Study setting

The East Anglian Fenlands is a flat, low-lying region surrounding the Wash embayment (Waller, 1994). It is contained within a vast, shallow basin drained by an extensive fluvial network of rivers such as the Nene, Great Ouse, Little Ouse and Welland (Godwin, 1978). The region was formerly a coastal wetland and has an approximate area of 4,000 km^2, in parts of Norfolk, Suffolk, Lincolnshire and Cambridgeshire. Wheeler & Shaw (1992) assert that it has a higher concentration of fen ecosystems than any other part of lowland England of similar area.

Bellamy & Rose (1961) and Wheeler & Shaw (1992) have recognised that the Fenlands can be split up into two broad categories based on vegetation, hydrological inputs and topography. Firstly, there are the 'flood-plain mires' of wide, flat fens between Cambridge and the Wash where proximity to slow-moving rivers maintains a high water table throughout the year. Secondly, and more commonly, there are the 'valley fens' often cut into the glacial clays and sands of Norfolk and Suffolk, and which have soligenous inputs.[1]

[1] Soligenous fens are those irrigated primarily by groundwater springs and seepages (Wheeler & Shaw, 1992).

The study site at which environmental reconstruction has been attempted is *The Lows*, an area of church-owned land adjacent to Blo'Norton Fen (SSSI) situated south east of Thetford, south west of Diss on the Norfolk/ Suffolk border in the Little Ouse valley. It can be classed under the aforementioned 'valley fen' category (Wheeler & Shaw, 1992). The grid reference is OS 033793 and the site is 22m Ordnance Datum. Figure 1 shows the location of Blo'Norton within the Fenlands. Figure 2 then illustrates in more detail the situation of *The Lows* study site.

Figure 1- The location of the study site within the Fenlands (adapted from Tallantire 1953, p363).

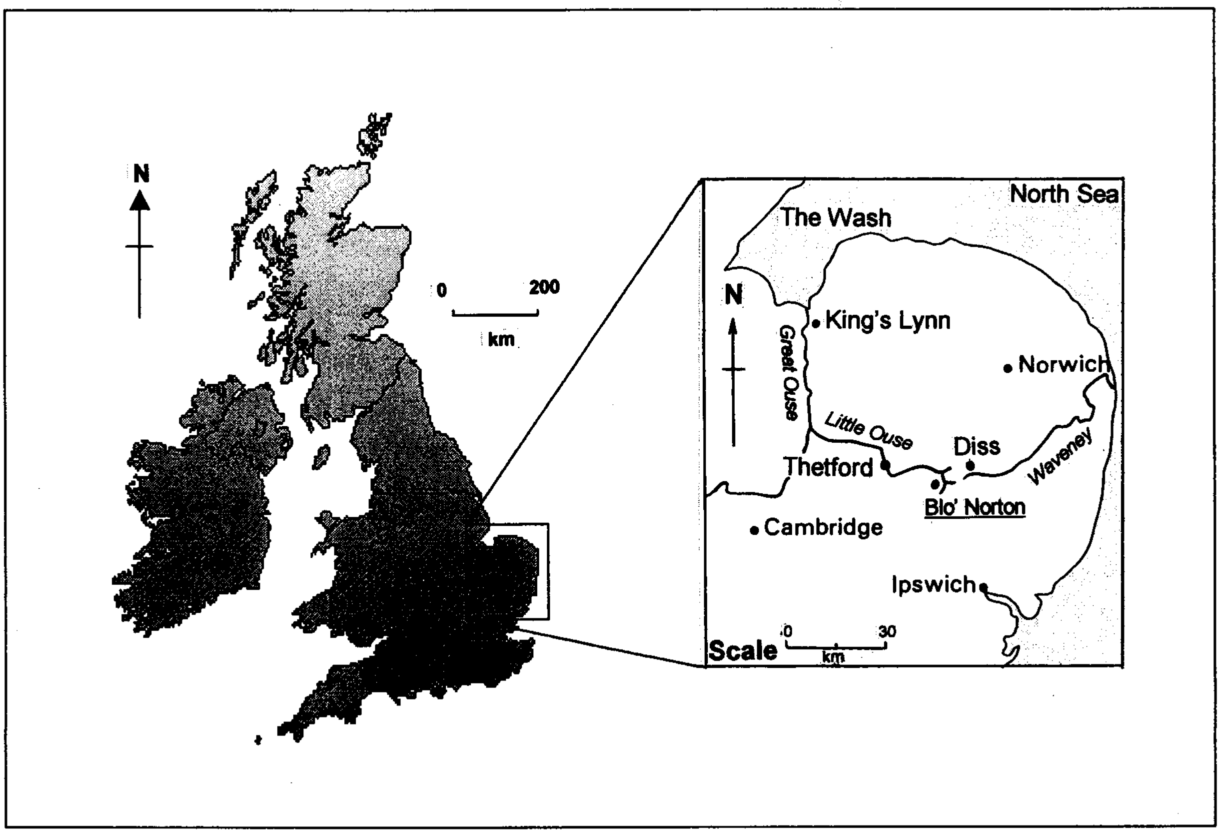
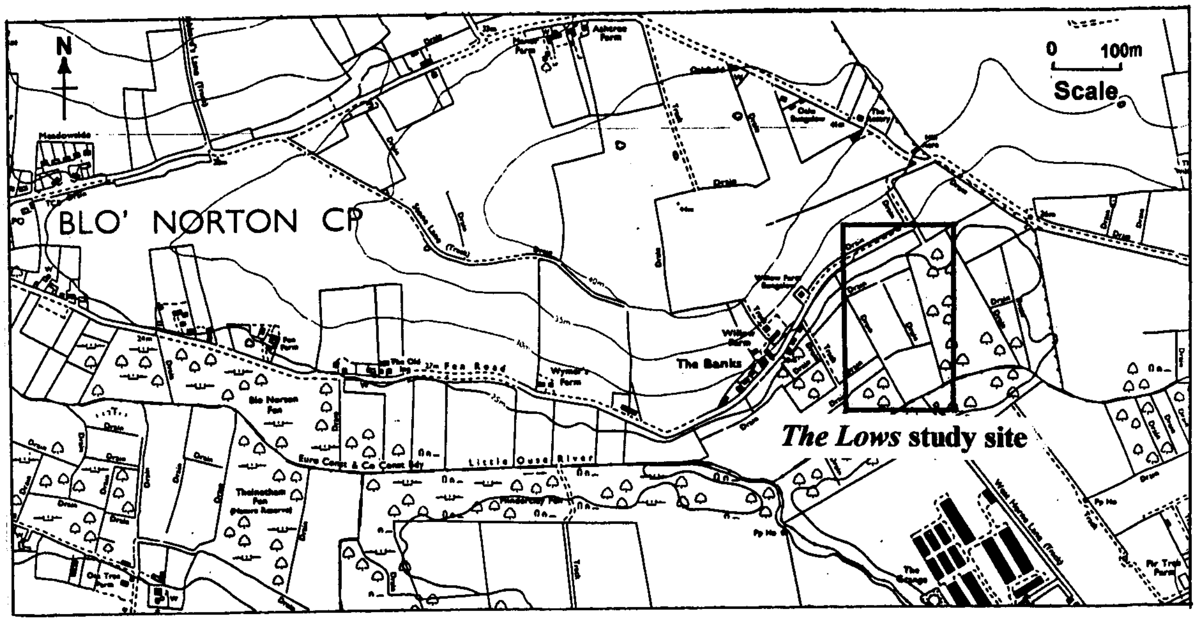


Figure 2-(below) The situation of *The Lows* study site at Blo'Norton (adapted from personal communication)



Investigations at areas such as *The Lows* are of pressing importance not only to expand the regional database of information, but also because authors like Godwin (1978) and Waller (1994) have highlighted peat wastage as one of the major threats to the sediment record. Peat wastage is a knock-on effect of the major drainage works that began in the 17th century in this region. As Waller (1994, p44) explains:

"The loss of water causes an initial contraction in sediment volume. Organic sediments will then begin to waste, i.e. to decompose through biochemical oxidation..."

There have been few studies into the exact effects of sediment consolidation. Clearly further studies into the depositional environment of Fenland are important and necessary before techniques like peat stratigraphy become less feasible.

1.5 Research Questions

The reconstruction techniques used in this investigation attempt to help answer five research questions:

1) What is the specific Holocene vegetation chronology at the site and what correlation can be made with similar studies of the region?

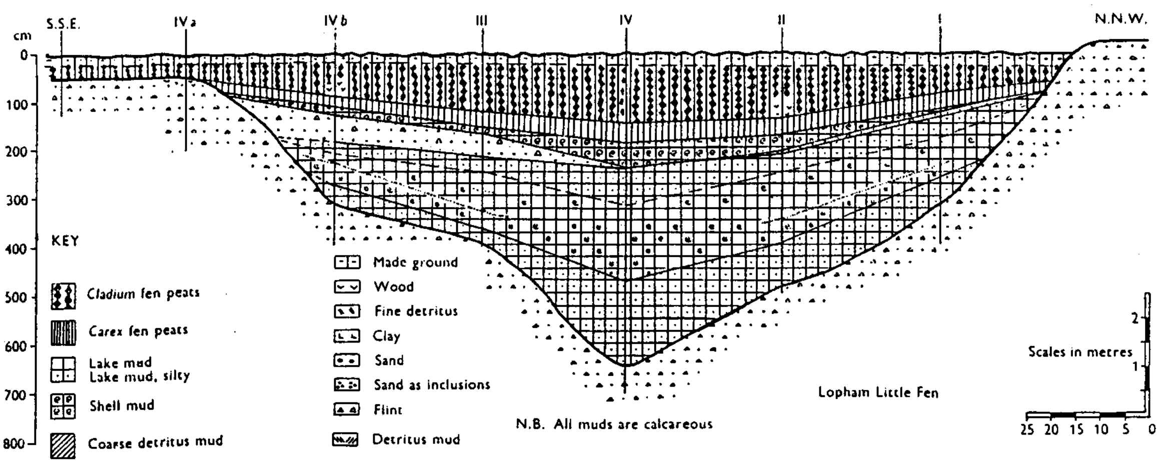
The vegetation successions at *The Lows* can be interpreted using the lithostratigraphy (nature and composition) and biostratigraphy (fossil content) of sediment cores. However, this investigation has not used a radiometric dating technique such as radiocarbon due to the expense of processing such samples. Correlation of the new results with previous research (e.g. by the Fenland Project) is therefore imperative to establish an accurate chronology for sediment formation. The Fenland Project started in 1982 and has collected samples from over 30 different sites with detailed chronostratigraphic analysis (Waller, 1994). Their use of pollen analysis has allowed the construction of pollen assemblage zones from sites such as Hockham Mere in Breckland, Peacock's Farm and Redmere in the southeastern fens, thus providing recent data comparable to *The Lows*.

2) Is Tallantire's (1953+1969) stratigraphic model, which suggests a post-glacial lake, upheld by biostratigraphic and lithostratigraphic data collected from *The Lows*?

Tallantire (1953) was one of the first to sample the deposits of the Little Ouse valley fens, which led to the discovery of Late Glacial lake deposits beneath Lopham Little Fen. Further peat borings by Tallantire (1969) suggest that there is, in fact, a system of Late Glacial/ post-glacial lakes underlying not only Blo'Norton, but also the adjacent Lopham, Thelnetham, Crackthorn and Bridge Fens.

Tallantire (1953) argues that Lopham Little Fen, for instance, experienced a hydroseral succession from lake muds to fen peat. He deciphered the Late Glacial to post-glacial boundary as being represented by both a decisive increase in the pollen frequency, and a rise in Birch values simultaneously occurring with a fall in Pine values. It is clear that more detailed investigation into these deposits is required, especially into Tallantire's (1953+1969) suggestion that much of the lake systems formed in the Allerød[2] interstadial as illustrated by Figure 3 of a lake sequence at a site within 1km of *The Lows*.

Figure 3- Section through the Late Glacial basin at Lopham Little Fen, showing laminations of the Allerød period organic muds between mineral layers (Tallantire, 1953, p364)



[2] The Allerød interstadial is one of the Late Glacial interstadial stages lasting in northwest Europe from c. 12,000 BP to 10,800 BP. Birch and Pine briefly became prominent in southern Britain due to warmer temperatures. (Whittow, 1984).

3) What is the effect of the valley topography on the stratigraphy across *The Lows*?

Bellamy & Rose (1961) argue that the structure of the Little Ouse valley fens is dominated by the topography and drainage patterns in this area, which is why attention has been focused on them in this investigation. There has been much debate concerning the formation of the Waveney-Little Ouse valleys. Baden-Powell & Moir (1944) have argued that the sinuous sand outcrops in these valleys indicate the presence of braided channels over which fen peat developed. Such channels may have acted as overflows for melt water impounded in the Fenland by the Hunstanton[3] ice sheet. Further coring at *The Lows* may elucidate the factors involved in the formation of these valleys.

4) Does the stratigraphy support Shennan's (1986a+b) model of marine transgressions in Fenland?

As the structure of the Fenlands as a whole has been dominated by two overwhelming marine factors, it has been necessary to examine their significance in this investigation. Firstly, the inundations of marine water during periods of relative sea-level (RSL) rise have been responsible for clastic sedimentation in a landwards direction (Waller, 1994). Secondly, during periods of RSL fall, the influence of freshwater from a large catchment area of surrounding upland has extended peat development seawards (Godwin, 1978). As a result, many of the Flandrian deposits are comprised of a series of intercalated clastic and organic layers (Waller, 1994).

Shennan (1986a+b) describes how the Flandrian deposits of Fenland provide ample stratigraphic evidence for RSL change. He maintains that since 6,500 BP, this region has been affected by seven periods of positive sea-level tendency (i.e. an increase in marine influence with the development of transgressive overlaps of clastic sedimentation). There have also been six periods of negative sea-level tendency during this time characterised by

[3] The Hunstanton glaciation is the regional name for a phase of the Last Glacial Maximum (25-18ka BP) in eastern England when ice sheets reached the Wash Basin at their furthest limits and deposited till at Hunstanton.

RSL fall and a seaward movement of freshwater sedimentation. The names of the marine transgressions/ regressions and their dates can be seen in Table 1. Further site-based investigation of the intercalated peat and clastic sediments is required in order to advance Shennan's (1986a+b) model of sea-level tendency.

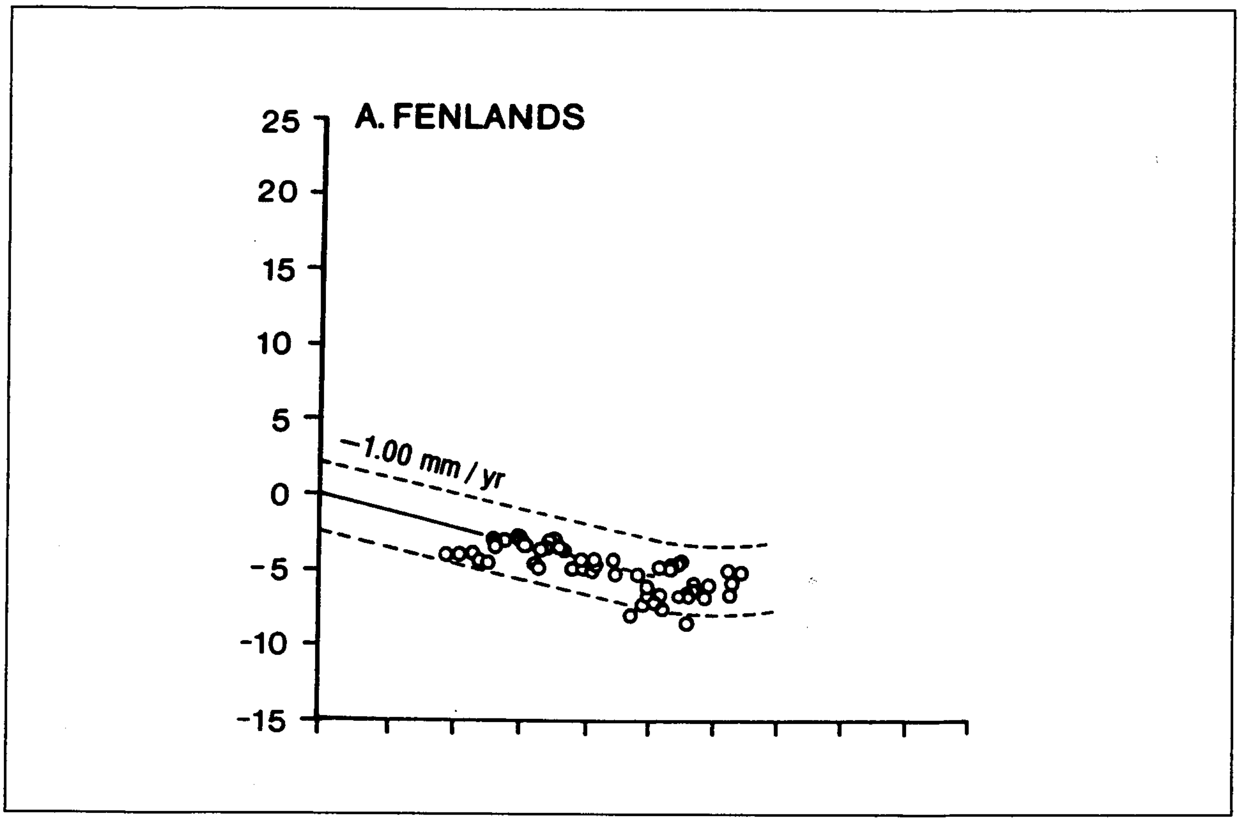
Table 1- Holocene RSL transgressions and regressions in The Fenland (adapted from Shennan, 1986b, p158)

Period	Date (BP)
Wash I	prior to c.6300
Fenland I	c.6300 to c.6200
Wash II	c.6200 to c.5600
Fenland II	c.5600 to c.5400
Wash III/IV	c.5400 to c.4500
Fenland IV	c.4500 to c.4200
Wash V	c.4200 to c.3300
Fenland V	c.3300 to c.3000
Wash VI	c.3000 to c.1900
Fenland VI	c.1900 to c.1550
Wash VII	c.1550 to c.1150
Fenland VII	c.1150 to c.950
Wash VIII	c.950 onwards

5) What are the relative effects of regional factors (e.g. eustasy and glacio-isostasy) and local factors (e.g. sediment supply) on the study site?

A major influence on RSL in this region has been the subsidence of the Fenland embayment and much of southeast England. This has largely been a result of the collapse of the Fennoscandian fore bulge (the crustal displacement involving up bulging beyond the margins of the Scandinavian ice sheet) at the end of the last glaciation and lasting until 3,000 BP (Bell & Walker, 1992). Shennan (1989) has produced scatterplots of linear rates of uplift or subsidence in Britain. In the Fenlands, a subsidence rate averaging 0.86 ± 0.10mm per yr since 6,500 BP has been calculated that is summarised in Figure 4. In any reconstruction, the effects of such regional processes need to be separated from the local factors. The latter should become more evident following analysis of the sediment cores.

Figure 4- Scatter plot of net subsidence in the Fenland (Shennan, 1989, p84)



1.6 Chapter Summary

The introductory chapter has outlined the two overall aims of this investigation. Five specific research questions have also been posed in order to add focus to the study and in an attempt to expand on the previous research in this area. The methodology described in Chapter 2 attempts to achieve these aims and help answer the research questions. Reference should be made to Chapter 5 (Discussion) for a critical appraisal of the research questions in the light of the new data produced by this investigation.

2.
Palaeoenvironmental Techniques

2.1 Palaeoenvironmental Techniques used at *The Lows*

Palaeoenvironmental reconstruction is a complex process, e.g. due to the ecological uncertainties that exist concerning the preferences and thresholds of former flora and fauna. Certain organisms may yield misleading information about the environmental conditions at a site. To reduce this problem therefore, Quaternary scientists increasingly use a multi-proxy approach (Lowe & Walker, 1997). It is possible to make more accurate and reliable interpretations of former environments when using several lines of evidence, particularly because certain proxies may not span the entire sedimentary sequence. This is why this investigation has employed five proxy measures, as detailed in this chapter.

2.2 Chapter Structure

Section 2.3 describes the coring survey conducted at the field site itself followed by a brief discussion of the five main proxy techniques employed and reasons for using them in Section 2.4. The laboratory procedure is then described in Section 2.5 for each of the proxy techniques. As factors such as the sampling strategy were vital to this study and its research conclusions, it seemed appropriate to give prominence to this in the main body of the study, and to relegate the specific and standardised laboratory procedure to the appendix. Section 2.6 shows the important decisions made in collaborating the data using the TILA and TILIA GRAPH programs, versions 2.0.b.4 (Copyright Grimm, 1991-1993).

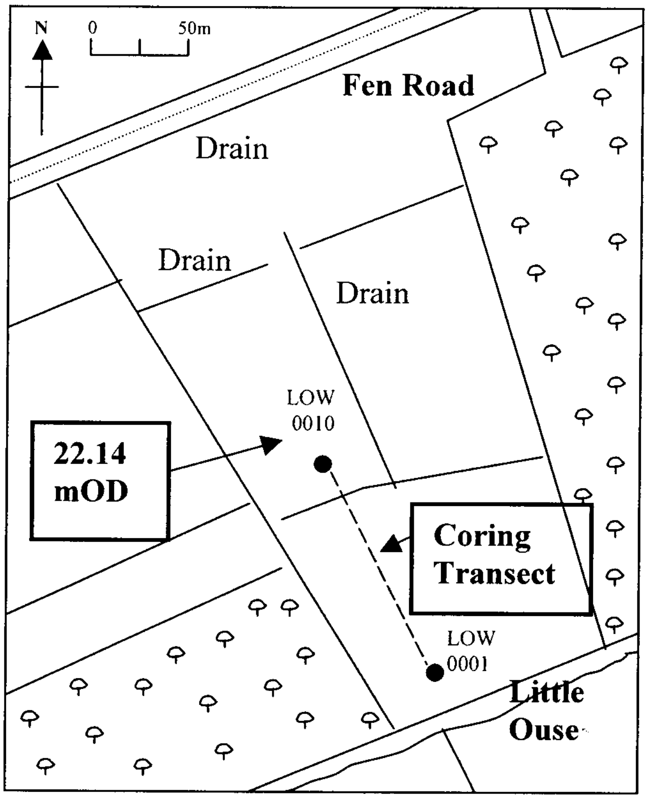
2.3 The Coring Survey

A pilot study was conducted on 26/02/2000 at *The Lows* study site to test its viability for the planned research and to determine the parameters of the coring survey. A quick pollen test on some of the initial samples showed that pollen was adequately preserved. A gouge corer had proved effective in sediment extraction during the pilot study so this was again used in the main period of fieldwork taking place over two days from the 20/3/2000 to the 21/3/2000. Photograph 1 illustrates the gouge corer in use.

Photograph 1- Gouge coring at *The Lows.*

A total of ten cores was drilled along a transect of 135m and at 15m intervals (as shown by Figure 5). The author reasoned that such a high resolution strategy would cover a large enough area to show the major lateral variations between cores whilst also providing a manageable framework of sampling given the time and resources available. Each boring was levelled to a local benchmark (obtained using the Edina Digimap online service). This allowed the altitude in metres Ordnance Datum (the UK National Datum) to be accurately determined and the topography along the transect to be recorded. Aaby & Berglund (1986) note the difficulty in levelling in mires due to problems such as sediment consolidation. They therefore suggest a levelling error of ± 2cm per 1,000m.

Figure 5- The location of the coring survey (adapted from Edina Digimap)



The stratigraphy of each core was detailed according to the Troels-Smith (1955) system of sediment classification, as shown in Photograph 2. The importance of recording the character and structure of the sediments in this way is highlighted by Faegri & Iversen (1989). They argue that for proper evaluation of a pollen diagram, for example, there must be some understanding of the make-up of the matrix from which the grains were retrieved. The semi-objective Troels-Smith (1955) approach allows the detailed description of changes in the volumetric proportions of the main elements down core. It uses a 5-point scale (0-4) to record the physical properties, humification and composition of the sediment (Aaby & Berglund, 1986).

Photograph 2- Description of the sediment using the Troels-Smith (1955) technique

Indeed, Birks & Birks (1980) have outlined the advantages of this versatile technique in that it is a) essentially descriptive and does not involve inferences about the processes leading to sediment deposition, and b) there is recognition that sediments are often mixtures of different components. In addition, Long *et al.*, (1999, p274) praise the Troels-Smith (1955) scheme because it allows *"graphical quantification of the original stratigraphic data."*

Following the extraction of each metre of sediment, the gouge corer was cleaned thoroughly using rags and water. The sediment samples were subsequently stored in metre length plastic tubes and sealed in plastic bags to prevent contamination by contemporary pollen. At Durham, the cores were placed in a storage fridge at 4°C to 8°C to inhibit desiccation and reduce the decomposition rate from microbial activity.

2.4 Proxy Techniques

In addition to the stratigraphical field assessment, this studyhas used five proxy techniques for palaeoenvironmental reconstruction, each of which will be dealt with in turn.

1) Pollen Analysis- the quantitative technique of pollen analysis was pioneered by Lennart von Post in 1916 and has become an invaluable palaeoecological technique due to the abundance of fossil pollen preserved in Quaternary sediments (Birks & Birks, 1980). Pollen grains and spores are usually dispersed in large numbers and over a wide area in order to increase their chances of successful pollination (Lowe & Walker, 1997). They may be transported by wind, streams or by living vectors such as insects and animals. However, only a fraction of the total dispersed performs its reproductive function; the rest may become incorporated within fens, lakes and bogs.

The exine or outer layer of the pollen grain enhances its preservation because it is composed of a protective, waxy material called sporopollenin. Ranging in size from approximately 5μm to 100μm, the pollen grains can be identified, using a light microscope, to family and sometimes to species level. Classification is possible due to morphological factors such as shape, surface sculpturing and the grain apertures (Moore *et al*, 1991).

2) Diatom Analysis- Diatoms are unicellular algae that live in a wide range of aqueous and sub-aqueous environments and constitute 80% of the world's primary producers (Lowe & Walker, 1997). Alderton (1994) emphasises that pollen cannot always be used to infer past environmental conditions, particularly when inorganic sedimentation commences. Therefore, diatom communities can be used because a) they are more sensitive and can respond more quickly than pollen to an environmental variable such as lake chemistry, and b) they are reliable indicators of the primary productivity of a particular environment.

Classification is possible because they are composed of a siliceous shell called a frustule, which gives them distinctive shapes and sculpturing. They range in size from 5μm to 2mm. (Lowe & Walker, 1997). Since diatoms have very particular nutrient, salinity and chemical requirements, they are excellent palaeoecological indicators. It is therefore possible to reconstruct changes in specific water chemistries through time, termed 'chemical pathways' by Williams *et al.*, (1998).

The Kolbe-Hustedt system of diatom classification based on contemporaneous salinity parameters has proved most useful in thalassic (coastal) areas. According to this scheme, species range from *Polyhalobous* (salt tolerant types which prefer salt concentrations of >30%), to *Halophobous* diatoms (salt intolerant species that prefer completely freshwater conditions) (Battarbee, 1986). Although this study was not strictly based in a coastal ecosystem, the Kolbe-Hustedt system has been applied nonetheless to investigate any marine influence, and in particular to help evaluate any evidence for Tallantire's (1953+1969) lake theory.

3) Particle Size Analysis- This technique was used to help quantify the major lithostratigraphic transitions occurring and hence to explain the changing regime of sediment deposition.

4) Loss-on-Ignition- The Carbon content of any sample can be determined using the LOI technique. This is useful for illustrating transitions between organic and non-organic matter, and thus any productivity variations in the sequence.

5) Moisture loss- The moisture content was calculated to help determine the factors leading to peat initiation and vegetation successions. However, the technique is severely limited since the water content of each sample depends on present day drainage processes.

2.5 Laboratory Procedure

Based on the stratigraphy shown by Figure 7, the author made an informed decision to take sub-samples from boring LOW 0010 (farthest from the river). The reasons for this are threefold: firstly, LOW 0010 contained the deepest body of retrievable sediment which logically could/ might contain the longest record of environmental change out of all of the borings.

Secondly, it was assumed that LOW 0010 was the least likely core to have been affected by drainage modifications to the Little Ouse channel, or by periodic flood deposits built up in close proximity to the river banks and which could subdue the pollen record. Third, it was decided that pollen analysis was to be the principal palaeoecological technique because it provides a relative chronology of environmental change, which can be correlated with other studies. Since LOW 0010 contained the largest amount of peat type sediments (e.g. peat and clay), it was hoped that the pollen signal would be clearest and best preserved in this boring.

1) Pollen analysis was the first technique to be utilised. Initially, a skeleton of 12 sub-samples was taken from carefully selected areas of the core. Attention was focused on the major stratigraphical boundaries in order to pick up any significant vegetation variations occurring concomitantly with changes in the stratigraphy. It was also ensured that at least one sub-sample was taken in each major sediment unit to allow a detailed representation of the core as a whole. Sampling did not take place immediately at the surface due to the likelihood of disturbance there. However, preliminary pollen counting soon revealed gaps where further sampling was needed in order to better explain the transitions occurring. Consequently, four additional samples were taken, three of which were from the well-humified peat layer, and one from the lower clay unit.

Samples were prepared for pollen analysis using standardised techniques described among others by Faegri & Iversen (1989) and outlined in Appendix 1. This helps to isolate the pollen grains from the sediment matrix to allow easier identification. Horrowitz (1992) outlines the quandary existing in palynology between an ideal count for statistical purposes, and what is practical in the time available. Clearly, as many grains as possible should be counted. Statistical techniques do not indicate how many, but rather the degree of uncertainty (confidence interval) for a taxa sum. A count of 200 gives an error bar of 3-4%, but to decrease this error to 2% would require a doubling of the sample on each slide (Berglund, 1986).

With this in mind, it was decided that a count of 200 grains from each pollen sample would be statistically representative enough of the environmental transitions, but also achievable given the time constraint. In those samples where there was an abundance of spores, it was ensured that 150 grains of the total count were of land pollen (trees, shrubs and herbs). This is because spores and aquatics can be more unpredictable in both dispersal and production than the terrestrial pollen and hence less appropriate for this type of environmental reconstruction based on percentage counts (Lowe & Walker, 1997). Identification was possible with the aid of pollen keys for northwest Europe, principally Moore *et al.*, (1991).

2) Diatom analysis: 15 samples were taken at strategic intervals. Each sediment unit was covered, but attention was focused on the lower peaty clay and clay layers below 300cm in order to investigate fully the layers beneath the peat that Tallantire (1953+1969) suggested could be representative of a lake system. The specifics of diatom preparation are dealt with in Appendix 2 and follow a commonly used procedure for percentage counting, outlined among others by Battarbee (1986).

A count of 200 valves on each slide was attained for the same statistical and practical reasons as for pollen analysis. Identification was possible principally using a key produced by

Sims *et al.,* (1996). Categorisation according to salinity parameters was then possible using both this guide and the Durham University Master Diatom Dictionary, which classes taxa according to various environmental factors.

3) Particle Size, 4) Loss-on-Ignition and 5) Moisture loss methodology are detailed in Appendices 3 to 5 respectively because they followed standardised preparation procedures. 12 samples were taken for each of these techniques from the same places in the core as for the original pollen samples.

2.6 Collaboration of Results

Pollen and diatom count data were entered into the TILIA spreadsheet in order to create assemblage diagrams in TILIA GRAPH. In preparation for the Constrained Incremental Sum of Squares (CONIS) data analysis program, values of taxa less than 2% were deleted to allow any major trends to appear more clearly. Cluster analysis was employed which uses numerical calculations to objectively separate objects into different groups according to their characteristics (Kovach, 1995). In this study, cluster analysis has been stratigraphically constrained because the samples are contiguous and are best analysed in the original order in which they were laid down (Berglund, 1986).

Two cluster analysis functions were used within CONIS to ensure greater statistical robustness in the zonation. Firstly, the Standardised Euclidian Distance function was employed which doesn't transform the original data in any way. Secondly, Edwards & Cavalli-Sforza's chord distance function was used, which increases the significance of the minor taxa (TILIA read me file, Grimm, 1993). The zonation can then be accepted with a greater degree of confidence if the clusters produced in the two types of analysis are the same or very similar. Cushing (1967) highlights the need for pollen zones to be defined numerically and without preconceptions based on sediment lithology. The CONIS function is therefore invaluable for such an objective approach and can be easily repeated in future studies (Birks & Birks, 1980). Despite the advantages of techniques like cluster analysis, sound ecological reasoning must also be applied to the interpretation.

2.7 Chapter Summary

This chapter has described the implementation of the techniques considered appropriate for palaeoenvironmental reconstruction at *The Lows*. It has been recognised that the results produced are to some extent influenced by the sampling strategy and statistical techniques employed, which is why this chapter has placed so much emphasis on them.

3.
Results

3.1 Results Chapter Structure

The results have been separated from the interpretation and discussion sections so as to avoid confusion between the results produced at *The Lows* and any subsequent correlation with other research. The chapter is split up into a lithostratigraphy section (including a summary diagram of *The Lows* transect), and a biostratigraphy section that describes the fossil content of the selected core, LOW 0010, in relationship to the aforementioned lithostratigraphy.

3.2 Lithostratigraphy

Figure 7 illustrates the variations in lithostratigraphy along *The Lows* transect. The sediment sequence becomes deeper with distance from the Little Ouse, reaching a maximum thickness of 505cm at LOW 0008. All of the borings contained an upper dark brown, *Cladium* fibrous peat unit of varying thickness. This upper layer was thickest in cores LOW 0007 to LOW 0010. For instance, in LOW 0007, the upper peat extends to a depth of 328cm or 20.24mOD. There are *Phragmites* remains and rootlets present in this poorly humified layer.

Underlying the upper peat unit in cores LOW 0001 to LOW 0006 are marl type sediments containing abundant mollusc shells. This marl layer is interrupted in cores LOW 0002 and LOW 0004 by a peat horizon, e.g. in LOW 0002 between 151cm and 215cm where there is a dark brown peat layer containing numerous wood chunks.

The marl layer grades gradually in cores LOW 0001 to 0006 to clay type sediment, e.g. at 315cm depth or 20.46mOD in LOW 0004. In some cores, there is a lowerpeat layer, e.g. in core LOW 0003 between 388cm and 400cm, and LOW 0004 between 470cm and 485cm, (shown by Figure 7). Such cores were re-drilled several times to make sure that the return of the peat below the marl/ clay layers was not simply being picked up due to contamination as the gouge corer was retrieved.

The particle size results are displayed in Figure 8. There are significant fluctuations in the percentage of sediment composed of silt, e.g. a shift from 0.25% at 200cm to 81.9% at 420cm in the lower clay layer. In some respects, the results appear to contradict the field descriptions, e.g. at 255cm, a particle size result of 57.7% clay was produced even when the stratigraphical report described a fibrous peat layer. Additionally, the results suggest that 99.75% of the sample at 200cm in the fibrous peat layer was composed of sand. The interpretation of such anomalies is presented in Chapter 4

Figure 9 displays the results of the Loss-on-Ignition (LOI) experiment. There is a broad negative correlation meaning that the organic content tends to decrease with depth down core. One of the lowest results for Carbon loss is in the lower clay layer, e.g. at 420cm where the LOI value is only 7.96%. This increases in the peaty clay layer to a value of 30.63% at 390cm. Within the upper fibrous peat layer, the LOI value rises to 76.23% at 255cm, but then falls to a trough of 4.39% at 200cm. This represents a difference of 71.84% from the previous value within 55cm of sediment. The Carbon content then fluctuates before reaching a peak of 78.53% at 50cm or 22.99mOD.

There are fluctuations in the moisture content of the LOW 0010 sequence, as illustrated by Figure 10, which shows no strong positive or negative correlation. The water content is low in the lower clay layer, e.g. only 6.2% at 420cm. This increases to a maximum value of 16.65% at 390cm. In addition to the small Carbon content at 200cm in the fibrous peat layer, the moisture content at this depth is only 6.49%.

Having noted the differences in lithostratigraphy along the transect, the author considered it prudent to produce two summary cores, as shown by Figure 6. **Core A** is representative of

LOW 0001 to LOW 0005, whilst **Core B** corresponds with LOW 0006 to LOW 0010. There are several limitations of such an over-simplification of the lithostratigraphy, but the diagram is useful for comparing the riverside sediment suite with the landward suite.

Figure 6- Summary cores of *The Lows* transect

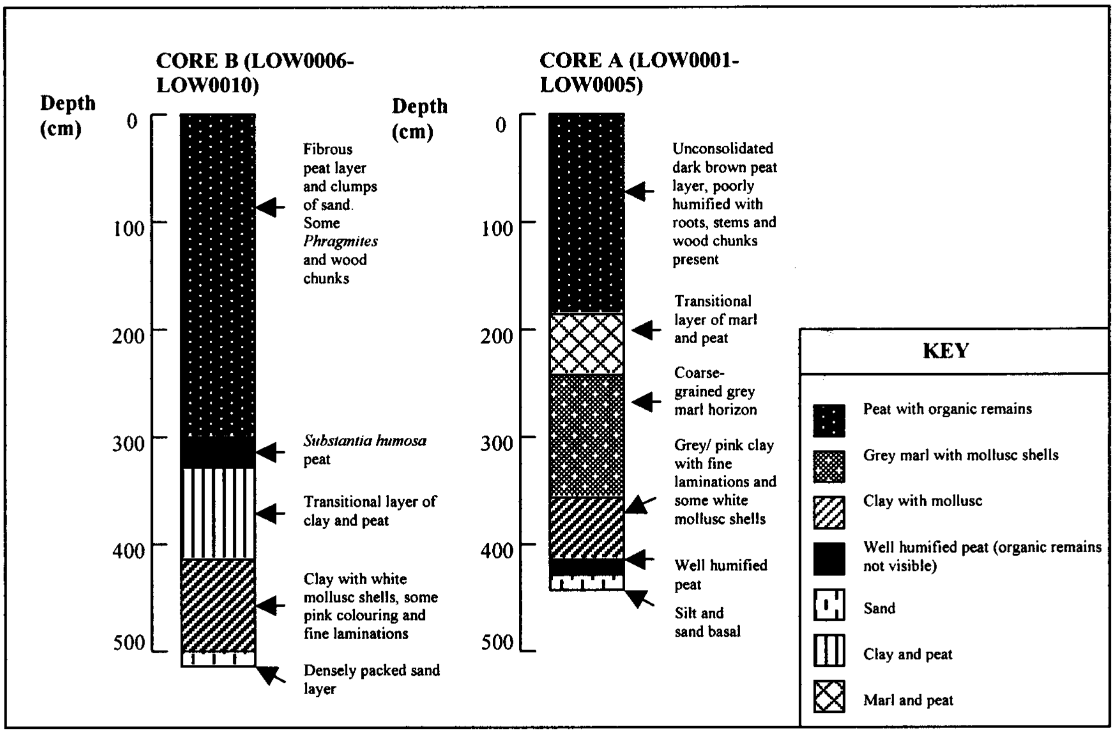


Table 2 shows the four lithostratigraphic units of the sub-sampled core (LOW 0010). There is a transition from the lower grey clay containing abundant mollusc shells to olive brown clay with a higher organic content and eventually to peat layers above 337cm.

Table 2- Troels-Smith (1955) lithostratigraphic description of LOW 0010.

Depth (cm)	Description	*Nig*	*Strf*	*Sicc*	*Elas*	*Lim Sup*
0-260	Dark brown fibrous homogenous peat layer with *Phragmites* and red wood chunks- some in excess of $3cm^3$. Greater humification of organic remains towards base. Peat is very soft and wet at base. Th2, Tl2. Gradual boundary with layer beneath >1cm.	3	0	2+/3	0	0
260-337	Black *Substantia humosa* peat layer with majority of organic components unrecognisable, but some isolated wood chunks. Sh3, Tl1.	4	0	2	0	0
337-385	Transition layer of peat with olive brown clay. Isolated large shells up to $1cm^3$. Clayey texture. Sh2, As2. Very diffuse boundary with layer below.	4	0	2+	0	0
385-500	Homogenous clay layer with small white shells (generally <$3mm^3$). Clay is medium grey and relatively dry; some organics like roots are present, but well humified. Compacted sand at 500cm meant boring below this depth was impossible. As4[test.(moll.)+].	2++	0	3	0	0

3.3 Biostratigraphy

a) Pollen- Figures 11 and 12 show the pollen assemblage produced in LOW 0010. Land pollen counts are displayed in percentage form whilst aquatics and spores have been left as raw counts because this is common practice in relative pollen diagrams (Lowe & Walker, 1997). Unidentified pollen has not been included in the pollen sum. For clarity, the following description of the pollen assemblage is categorised according to the pollen assemblage zones produced with the aid of CONIS cluster analysis. The relationship between these bio-zones and the aforementioned lithostratigraphy must again be emphasised.

Cluster Analysis

The two types of cluster analysis employed (chord distance and standardised Euclidian distance) are displayed as dendrograms in Figures 11 and 12 respectively. The clusters are broadly similar on both diagrams meaning that the pollen assemblage zones can be accepted with some degree of confidence. However, cluster analysis is only an aid for interpreting a pollen diagram, and the designation of the assemblage zones still partly depends on the analyst. The author has recognised five main pollen assemblage zones each of which will be dealt with in turn. Justification for designating some of the less recognisable zones is also given.

Pollen Assemblage Zone 1 (PAZ1)

Three samples constitute PAZ1 within the lower homogenous grey clay layer. Arboreal taxa are the prevailing pollen type in this zone with 92% of Total Land Pollen (TLP) at 450cm, for instance. *Betula* has an overbearing influence, making up 69%, 72% and 69% of TLP at 480cm, 450cm and 420cm respectively. *Pinus* values also reach their highest level anywhere in the sequence in this lower layer, e.g. *Pinus* contributes 12% TLP at 480cm and 10% at 450cm. *Filicales* spores are much less frequent in PAZ1 than in the other bio-zones, e.g. at 480cm, no *Filicales* type whatsoever were counted. Meanwhile, *Corylus* and *Ulmus* frequencies remain relatively constant at values of about 7%. There is some small aquatic influence in this zone, e.g. five *Nymphaea* type were counted at 420cm. This zone is clearly the most recognisable and is covered by one of the most significant splits in the cluster analysis.

<u>Pollen Assemblage Zones 2 and 3 (PAZ2 and PAZ3)</u>

PAZ2 starts near to the boundary of the lower clay and peaty clay at about 408cm, whilst PAZ3 marks a transition from the peaty clay to the humified peat above, and commences at about 370cm depth. Both zones are statistically fairly similar with both being characterised by *Betula*, *Graminae* and *Filicales*, meaning that some analysts might class them as a single category. However, this investigation has kept them as separate zones because there are subtle differences between them.

For example, *Filicales* values are much higher in PAZ2 (34 grains at 390cm) than in PAZ3 (with only seven grains at 332cm). Further, *Graminae* is more important in PAZ2 (e.g. 28% TLP at 280cm) than in PAZ 3 (only 14% TLP at 342cm). It seemed prudent to class such bio-zones as full pollen assemblage zones rather than sub zones because this appears to be an important transitional phase in the diagram where shrub and herb pollen are beginning to challenge the dominance of the arboreal types.

There is a wider range of pollen types in PAZ2 and PAZ3 than in the zone below. *Alnus* and *Quercus* are more abundant in these zones than in PAZ1, e.g. *Alnus* reaches a value of 10% at 332cm in PAZ3. *Betula* fluctuates in both PAZ2 and 3, but is present at lower values than in PAZ1, e.g. as low as 20% at 390cm. *Tilia* and *Salix* are also present in both zones at values of between 2% and 4%.

<u>Pollen Assemblage Zone 4 (PAZ4)</u>

PAZ4 is positioned within the amorphous peat layer and is characterised by a significant decline in the frequency of *Betula* from a high of 51% TLP at 332cm to 5% at 265cm. This represents a decrease of 46% within 67cm of sediment. A further significant feature of this zone is the overall decline in tree pollen and sharp rise in herbs, especially of *Graminae,* which accounts for two thirds of TLP at 290cm. Nevertheless, tree pollen of *Quercus* and *Alnus* remain fairly prominent, e.g. with 7% and 16% of TLP at 300cm respectively.

Pollen Assemblage Zone 5 (PAZ5)

This bio-zone covers a greater depth of sediment than any of the other zones. It starts at about 270cm in the well-humified peat and stretches to the surface. There are several sub-zones in this upper layer, but they are not statistically significant enough to be classed as zones in their own right. There is a clear importance of *Quercus*, *Alnus*, *Graminae* and *Filicales* taxa in this upper layer. Indeed, *Alnus* values reach a peak of 36% at 150cm whilst *Quercus* attains its highest frequency anywhere in the sequence with 25% TLP at 255cm before remaining relatively constant at frequencies of about 12% towards the surface. By contrast, *Betula* has virtually no significance in this layer.

Graminae values are also relatively constant in those samples near to the surface with values of about 30% between 200cm and 50cm. *Filicales* is dominant at 50cm depth attaining a count of 58 grains. Figures 11 and 12 also show the relatively minor taxa present in this layer including *Malvaceae* type which reaches its peak of 20% at 100cm. *Fagus*, *Ulmus* and *Cerealia* are present in small quantities throughout this layer. A qualitative note was made that there are many crumpled grains in the upper peat layer, as shown by Appendix 7. For example, 12 unidentifiable grains were counted at 50cm.

b) Diatoms- Valves were present in only five of the 15 diatom samples taken, and only in the lower half of the sequence. There were no diatoms present in the upper fibrous peat layer and samples were barren in most of the humified peat layer except at its lower boundary at 332cm. Similarly, there was an absence of diatoms in the middle section of the lower clay unit between 495cm and 390cm, as shown by Figure 13, which displays the counts as percentages of the Total Diatom Valves (TDV).

According to the Kolbe-Hustedt system of categorisation, all species were found to be either *Oligohalobous* (normally living in salt concentrations of less than 0.2%) or *Halophobous* (freshwater types) (Battarbee, 1986). Due to an absence of species in many of the samples, it was not possible to adequately perform CONIS on the diatom assemblage, which is why Figure 13 does not include a dendrogram.

Nevertheless, the following features should be mentioned: *Navicula radiosa* is strongly represented in all of the five usable samples, e.g. at 495cm and at 332cm, it makes up 28% and 25% TDV respectively. *Epithemia hyndmani* is also important throughout the full samples, and becomes prevalent at 342cm with 24% TDV whilst *Navicula radiosa* contributes 22% TDV at this depth.

The *Halophobous* type *Eunotia flexuosa* increases from 7% TDV at 495cm to a high of 15% at 342cm. The frequency then decreases to 12% at 332cm. Further, *Epithemia adnata* is present in the samples at 495cm, 390cm, 380cm and 342cm at values of up to 12%, but at 332cm (in the *Substantia humosa* peat), this species disappears altogether. There are many broken diatoms at 332cm.

3.4 Biostratigraphy Summary

The two cluster analyses used on the pollen assemblage recognised a number of sub-zones. It appears, however, that there are five main pollen assemblage zones, as shown by Figures 11 and 12. *Betula* is clearly dominant in PAZ1 contributing up to 72% of TLP. In zones two to five, there is a greater variety of taxa, with shrubs and herbs becoming more significant, especially in PAZ4 where *Graminae* is particularly abundant. The top zone (PAZ5) shows a period of relative stability in terms of the frequency of tree pollen, but there is a greater abundance of spores in this zone.

Despite the broad similarities between the two types of cluster analysis, there are certain differences to draw attention to. First, PAZ3 is of greater importance as a cluster using the standardised Euclidian distance function than it is using chord distance. Second, the clusters in PAZ5 are also given greater importance by the Euclidian distance function than by chord distance analysis. The author suggests however, that the sub-zones in PAZ5 are not significant enough to be classed as separate zones.

The diatom assemblage shown in Figure 13 expresses the overall dominance of the *Halophobous* species especially at 342cm where they make up 85% of the entire assemblage. Attention must also be drawn to the presence of white mollusc shells in the peaty clay and lower clay layers, but whose classification was beyond the scope of this project.

Figure 7 - Stratigraphy of *The Lows*

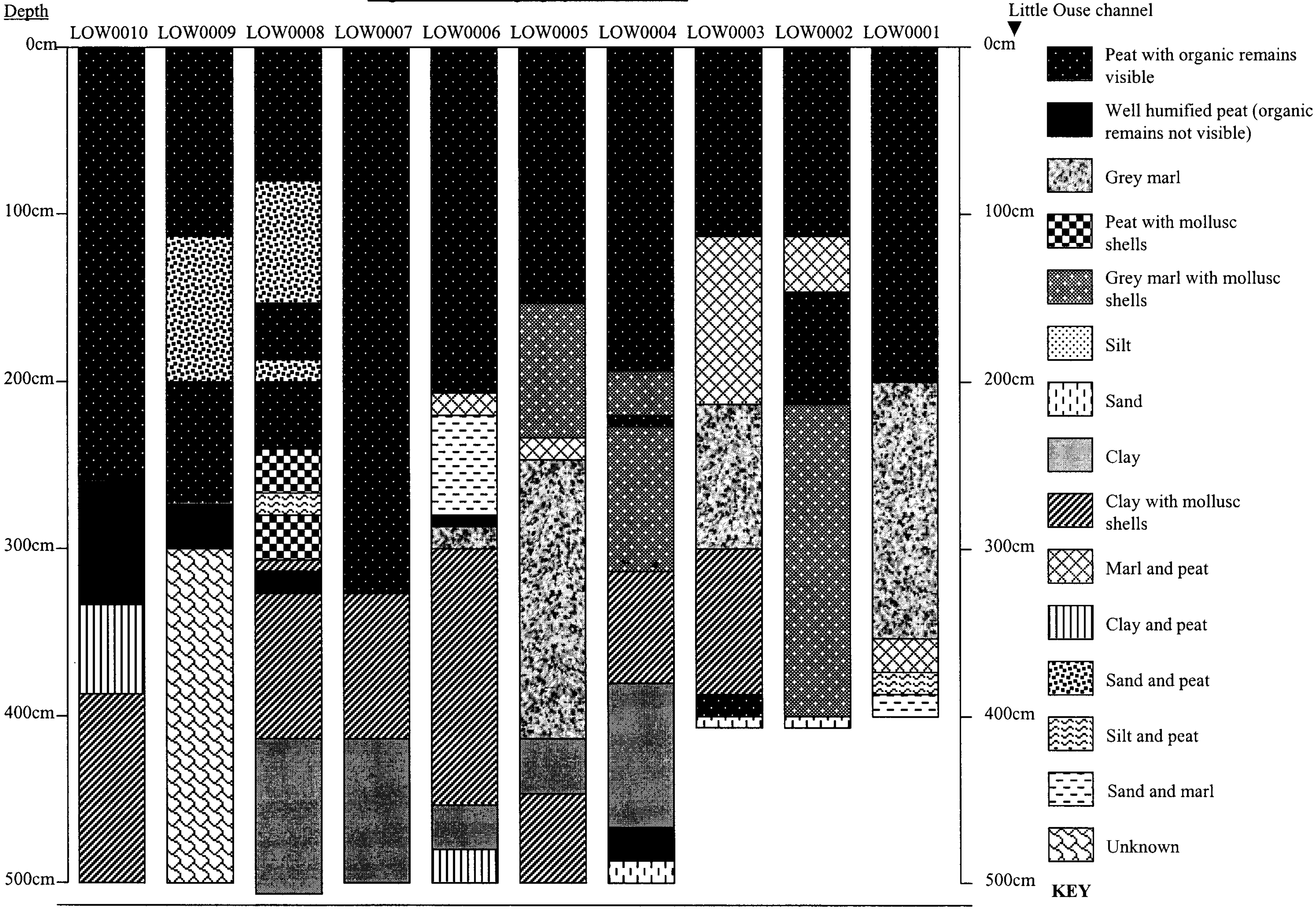


Figure 8- Particle size for LOW 0010

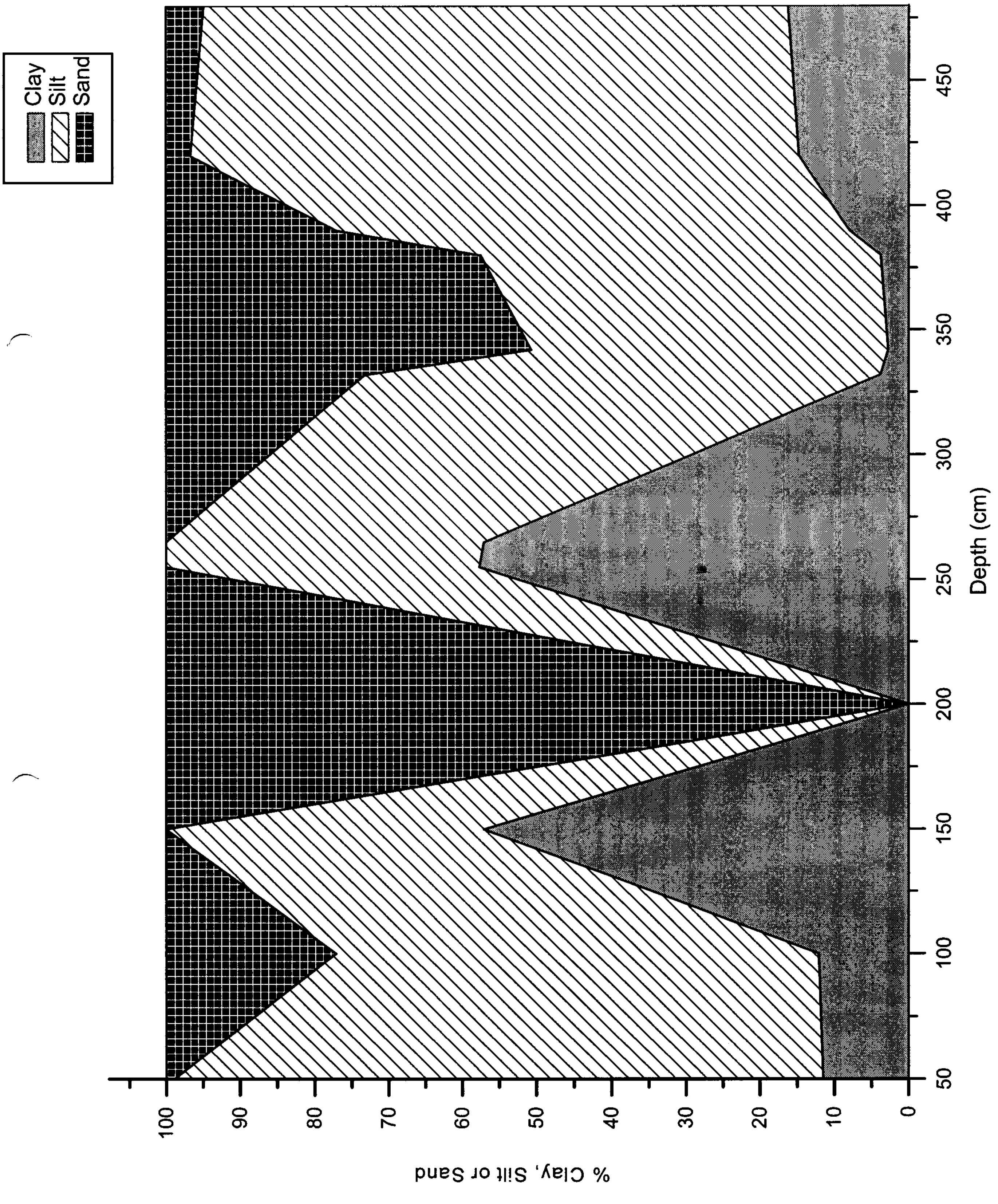


Figure 9- Loss-on-Ignition for LOW 0010

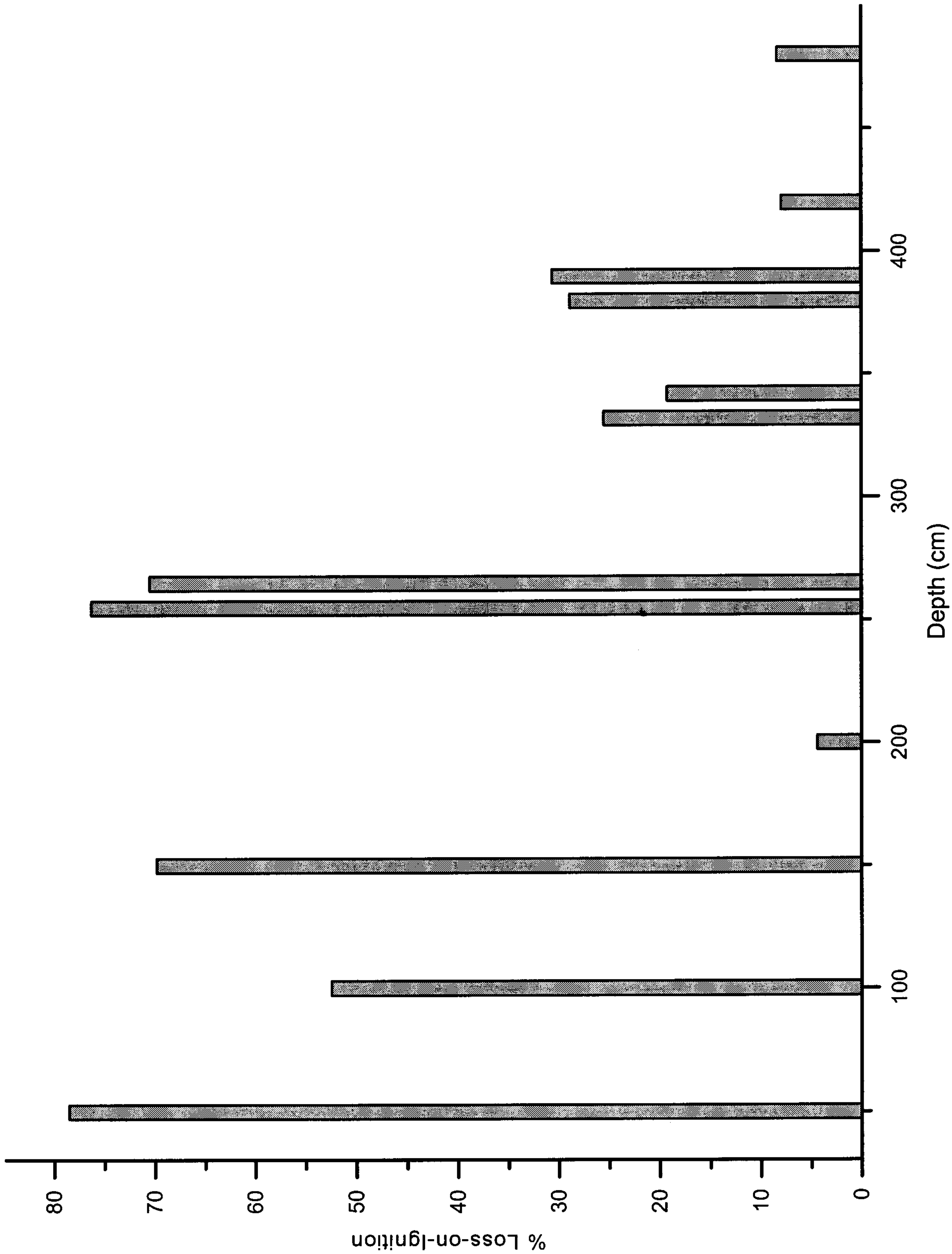
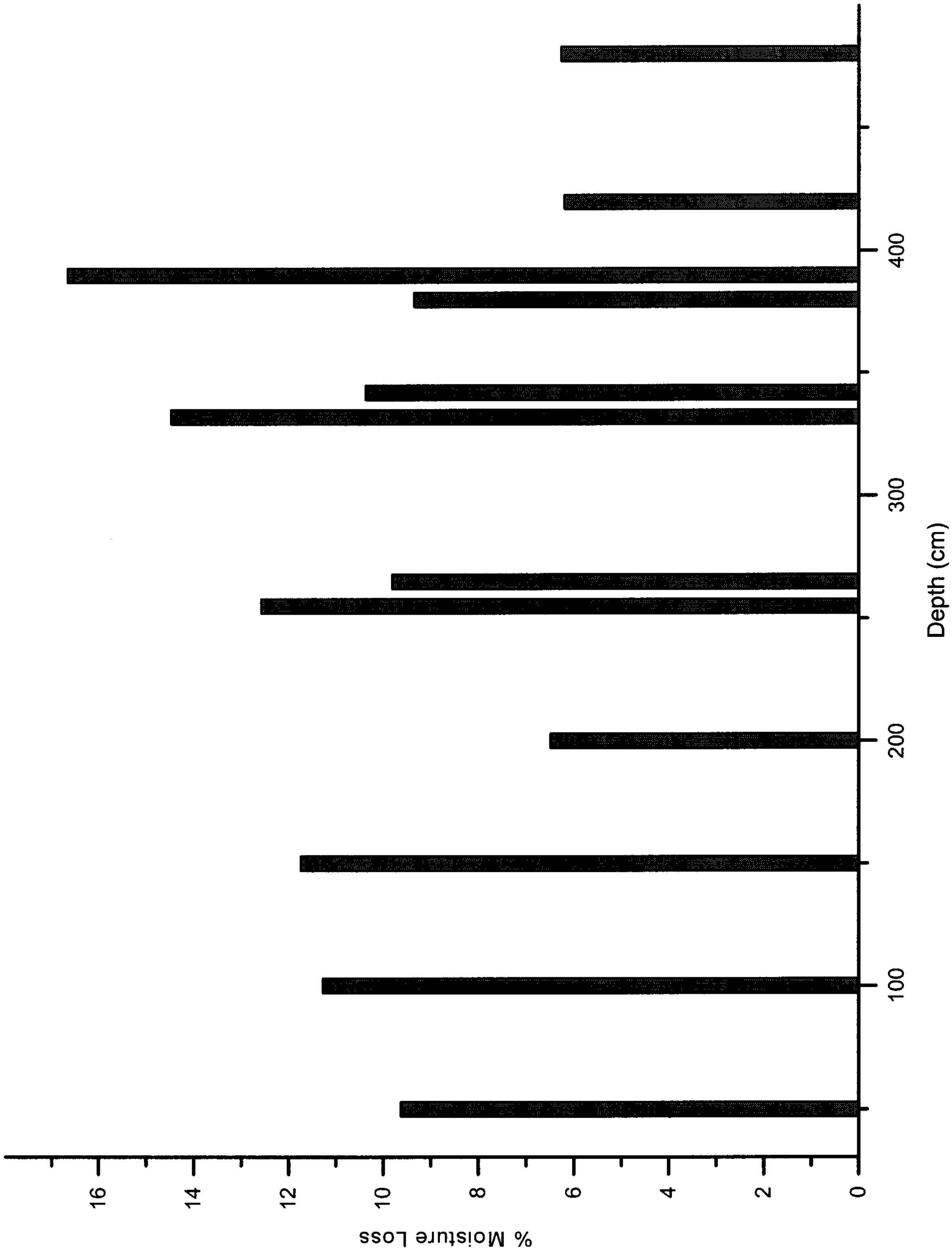


Figure 10- Moisture loss for LOW 0010



<u>Figure 11</u>- *The Lows* Pollen Assemblage using Cavalli-Sforza's chord distance cluster analysis. Trees, shrubs and herbs are expressed as % Total Land Pollen. Lithological symbols are after Troels-Smith (1955).

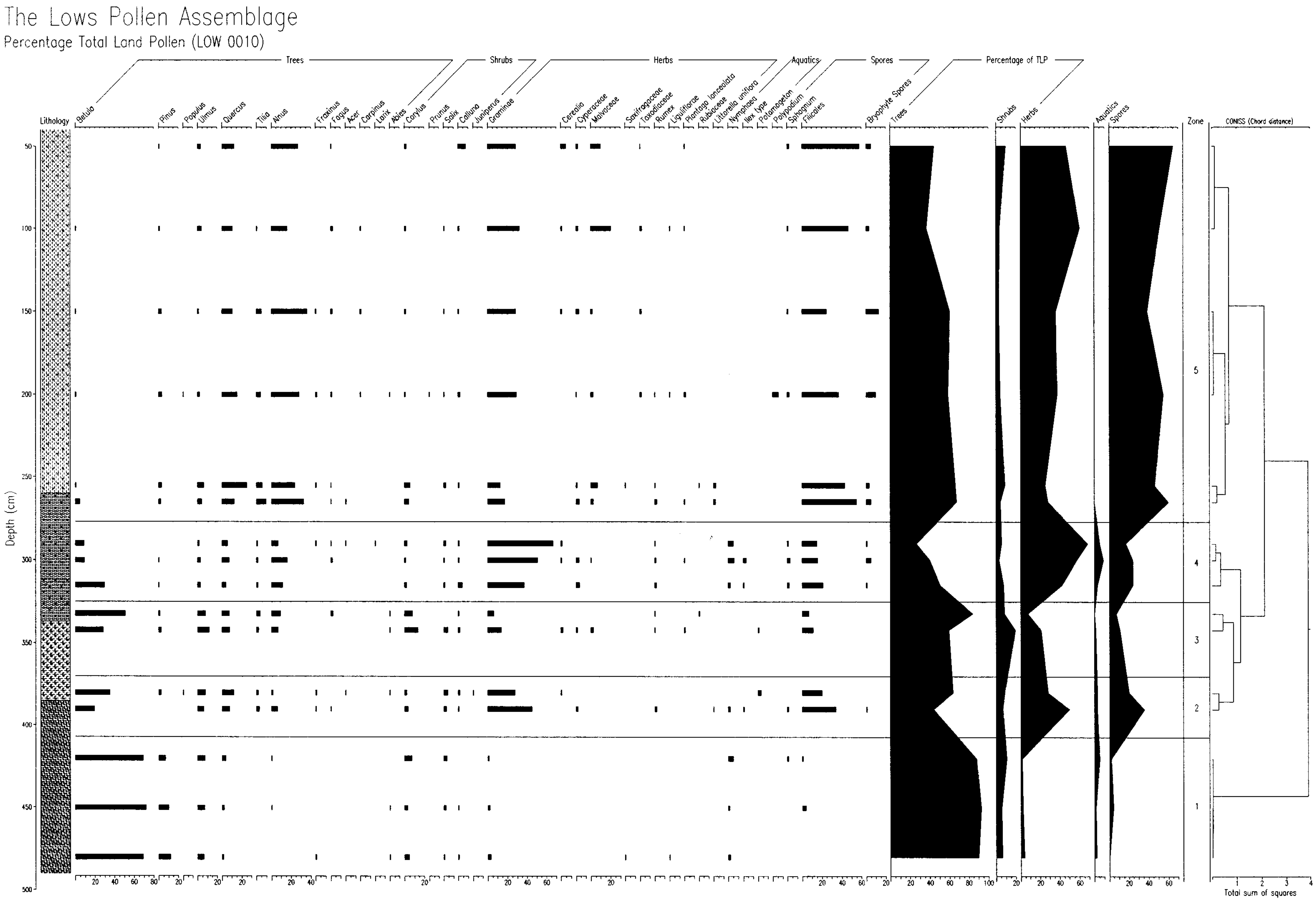


Figure 12-*The Lows* Pollen Assemblage using standardised Euclidian distance cluster analysis. Trees, shrubs and herbs are expressed as % Total Land Pollen. Lithological symbols are after Troels-Smith (1955).

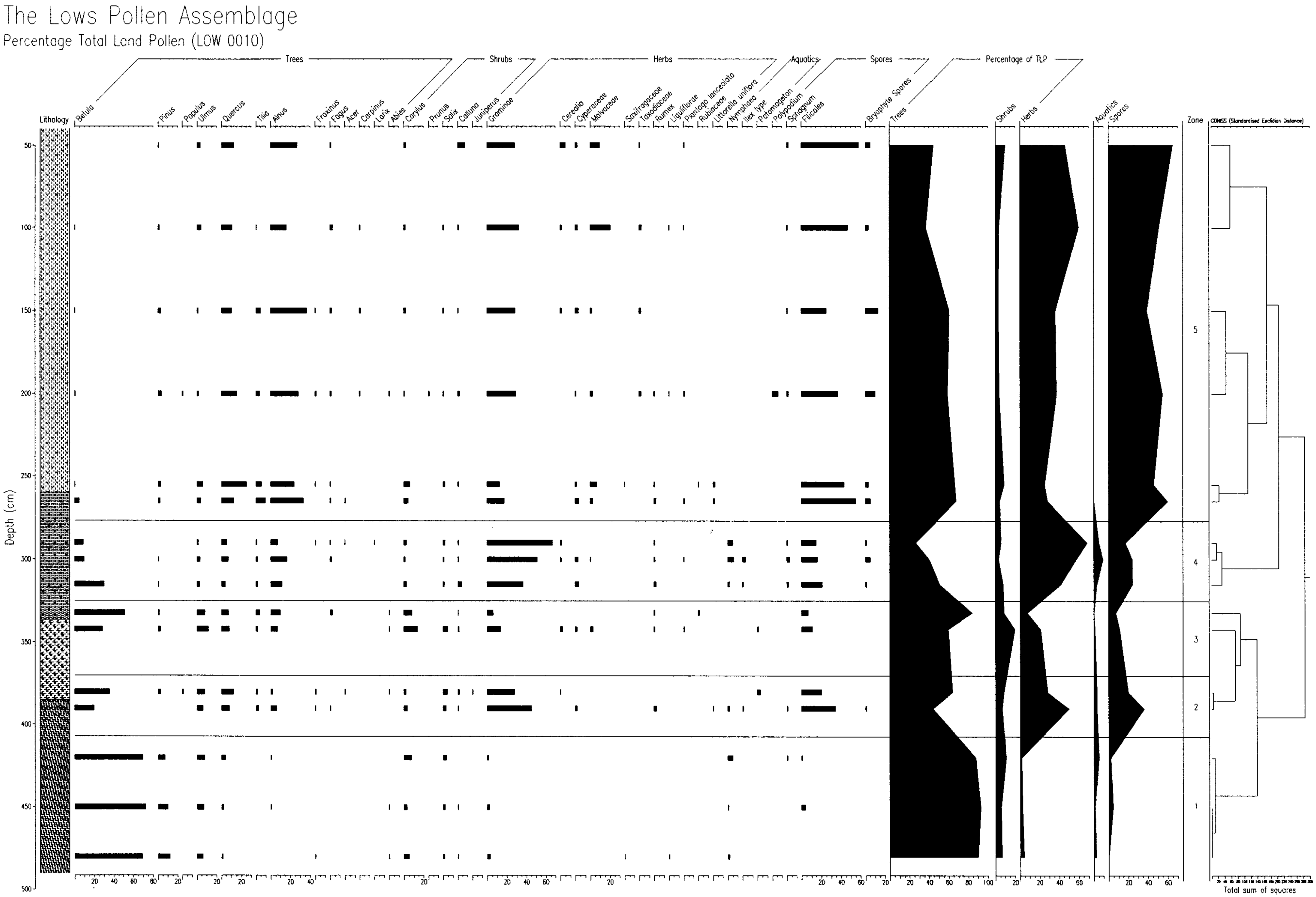


Figure 13- *The Lows* Diatom Assemblage. Diatoms are expressed as % Total Diatom Valves. Lithological symbols are after Troels-Smith (1955).