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PALAEOENVIRONMENTAL SIGNIFICANCE OF HOLOCENE LAKE-LEVEL FLUCTUATIONS IN SHROPSHIRE

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RUTH MARY HOBBY

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ABSTRACT

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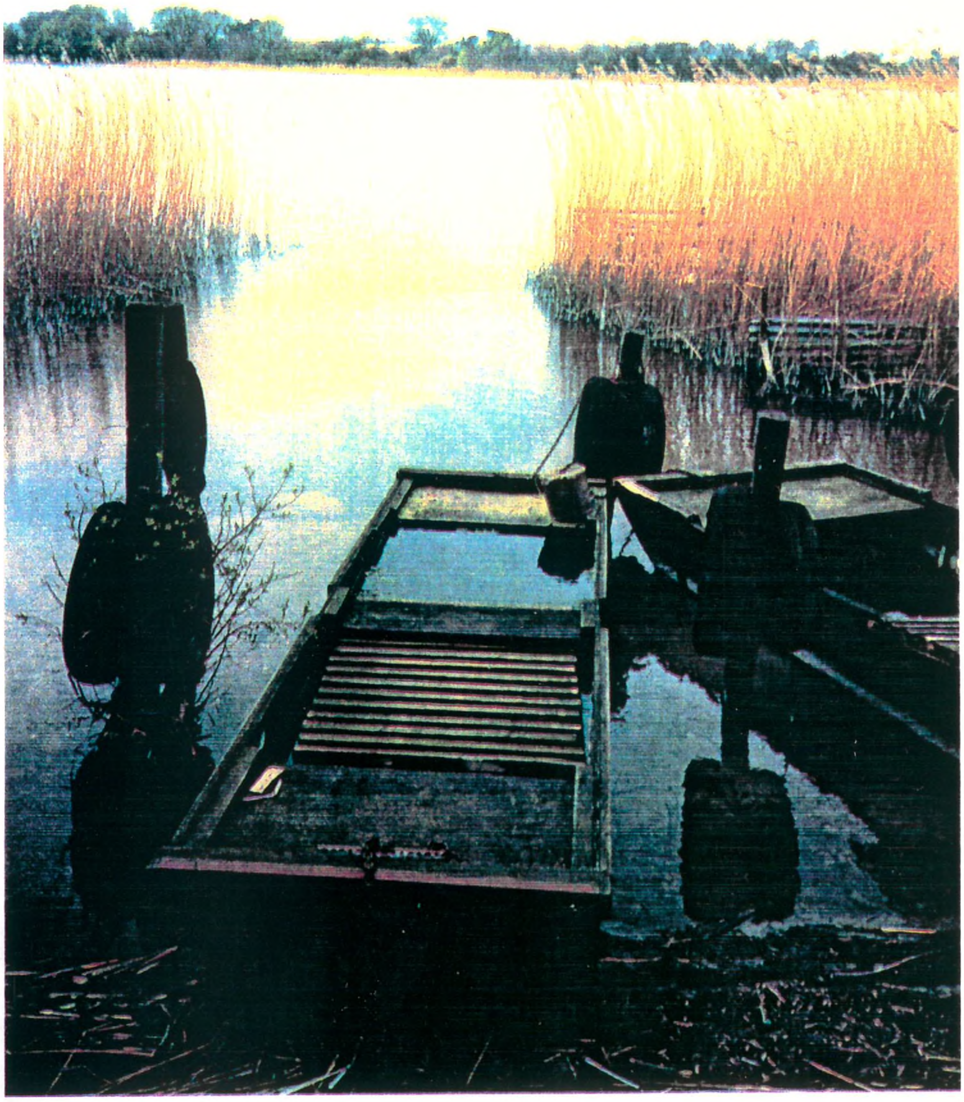
THE PALAEOENVIRONMENTAL SIGNIFICANCE OF HOLOCENE LAKE-LEVEL FLUCTUATIONS IN SHROPSHIRE

by Ruth Mary Hobby

Studies relating geomorphological features to lake level fluctuations reach back into the nineteenth century. It is only relatively recently, however, that sedimentary characteristics have been examined for indications of lake level changes. Temperate lakes have been studied for changes in water level as part of the IGCP Project 158, Palaeohydrology of the temperate zone, and climatic changes during the Holocene inferred from these results. Lake level fluctuation studies on lakes in southern Sweden indicate periods of lowered water level thought to be due to palaeoclimatic change around 9000BP and 500BP. These studies are based on results obtained from a combination of three major analyses, namely sediment limit reconstruction, particle size analysis and macrofossil analysis.

No lake level fluctuation studies have been done on lowland eutrophic lakes in Great Britain and it has been suggested that as Britain experiences greater oceanicity of climate than Sweden, any climatic changes would not be sufficient to be recorded in the sediment. This study aims to test this hypothesis by analysis of sediment from Crose Mere and Fenemere, two meres situated on the Shropshire Plain. The results obtained indicate that four periods of lowered water level have been recorded in the sediments of Crose Mere since the lateglacial, these occurring around 9100BP, 3700BP, 1800BP and 1800AD. The first two fluctuations correlate well with results from studies on lakes and mires in the Shropshire region suggesting that palaeoclimatic change was the primary factor involved.

The two later episodes appear to be more localised and are probably linked to anthropogenic disturbance. Such lake level lowerings are not, however, recorded in Fenemere and possible reasons for this difference between two sites only 10km apart are discussed together with alternative explanations for the fluctuation of lake levels.



"One may not doubt that somehow
good shall come of water and of mud"

Rupert Brooke

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Chapter 1 INTRODUCTION

Research into lake-level fluctuations really began towards the end of the last century (Forel 1885, 1892, Gilbert 1890, Nipkow 1920). Russell (1885) demonstrated two deep-lake periods with an intervening period of complete desiccation in Lake Lahontan, West Africa, using morphogeological and sedimentological features. This work has generally been proved correct by later studies (Morrison 1964).

Present day lake-level fluctuation studies have been based in Sweden, Poland, Switzerland, North America, and Africa (Ammann & Tobolski 1983, Ammann 1984, Ammann *et al* 1985, Digerfeldt 1971, 1972, 1974, 1975, 1977, 1986, 1988, Gaillard 1984a, 1984b, Hjelmroos-Ericsson 1981, Hjelmroos 1982, Street & Grove 1979, Street-Perrott & Harrison 1984, 1985, Harrison 1986, 1988a, 1988b, Harrison & Metcalfe 1985). There are two main approaches to the study of lake level changes, the first of these being the more theoretical approach of Street and Grove (1979).

Street and Grove (1979) produced world maps of lake-level fluctuations since 30,000BP based upon a literature survey of 141 lake basins with radiocarbon-dated chronologies. The resulting patterns were subcontinental in scale and showed orderly variations in space and time, reflecting substantial variations in continental precipitation, evaporation and runoff, due to glacial/interglacial fluctuations in atmospheric and oceanic circulations. These data were then coded at 1000 yr intervals in terms of lake status and lake-level trend (Street-Perrott and Harrison, 1984), showing that there was an important contrast in lake behaviour north and south of the Tropic of Cancer. This may reflect the different retreat histories of the Laurentide and Eurasian ice sheets (Denton & Hughes 1981). On the poleward side, phases of high lake level were a very prominent feature of the last 30,000 years compared with the intertropical belt and the

Southern Hemisphere.

Harrison and Metcalfe (1985) reconstructed lake-level changes in 67 lake basins in North America from a wide variety of geomorphological, stratigraphical and archaeological evidence. Geomorphic techniques include accurate surveying and description of landforms such as wavecut cliffs and platforms, shoreline caves, beaches, spits and deltas. Their preservation is related to their age and therefore the range of this approach tends to be limited to the upper Late Pleistocene and Holocene. Stratigraphic techniques provide better resolution in time, but frequently only yield curves of relative variations in depth or salinity, from which variations in relative extent must be deduced. Geomorphic techniques are also more likely to reveal serious changes in basic topography due to faulting or erosion. The conclusion, therefore was that a combination of geomorphological and stratigraphical techniques would provide the soundest and most rigorous method to achieve maximum precision in both space and time (Street Perrott and Harrison 1985). The total range of water depth registered within each of these 67 basins was divided into three status classes (low, intermediate and high) using an arbitrary, but consistent, set of rules. Four distinct regional patterns of lake behaviour through time emerged. Changes in lake status over North America were interpreted as indicating displacements in major features of the general circulation, specifically the zonal Westerlies and the Equatorial Trough, as reflected by changes in air mass trajectories and hence the position of air mass boundaries over the continent.

As a result of this research the Oxford Lake-Level data bank was created and the information from the 67 basins from the Americas north of the equator incorporated (Harrison and Metcalfe, 1985).

The second approach to the study of lake-level changes was adopted by the workers concerned with the International

Geological Correlation Programme Project 158 - Palaeohydrology of the temperate zone in the last 15000 years: Subproject B Lakes and Mires. It is based purely on stratigraphical and sedimentary evidence although geomorphological evidence such as old shorelines may play an important part in the initial choice of site. Three main analyses are involved; reconstruction of sediment limits, particle size analysis and reconstruction of the marginal reed vegetation. Taken separately each of these analyses could have an alternative explanation, but combined they indicate that a water level fluctuation has occurred.

Results obtained from previous lake-level fluctuation studies indicate that palaeoclimatic changes may have occurred more of less synchronously over Southern Scandinavia and Eastern Europe in the Preboreal (approx. 9500 BP) and in the Subboreal (approx 3700 - 3000 BP) periods. However, there are many "gaps" in the picture as this work has not yet been extended to include studies of lakes in the majority of Europe. It has been suggested that, unlike lakes in southern Sweden which experience a continental climate, climatic changes in central England were not of sufficient magnitude to be recorded in the sediment of lakes in this region (Dearing and Foster 1986).

The present study aims to investigate the applicability of the aforementioned methods to lowland eutrophic meres and to demonstrate whether lake-level fluctuations comparable to those found in Scandinavia have occurred in Central England. Results obtained from two Shropshire meres are presented and are supported by a variety of results from lake and mire studies in this region. These results are compared with the findings from Sweden and eastern Europe. Possible explanations for lake-level lowerings are discussed together with ideas for future research in the study of lake-level fluctuations.

Chapter 2 LITERATURE REVIEW

2.1 Introduction

There is extensive literature covering most aspects of palaeoecology including palaeoclimatology (Bradley 1985), palaeoenvironmental reconstruction (Lowe & Walker 1984), anthropogenic indicator species in palynology (Behre 1986) as well as more general palaeoecology texts (Birks & Birks 1980). The palaeolimnology of many lake basins has been studied and work of this nature can be found in nearly every edition of palaeoecological journals. This work, however, is usually confined to the general palaeoecology of the lake in question using a selection of diatoms, cladocera, pollen, macrofossils and chemical analysis of the sediments to give an indication of the environments in which the lake developed to its present day status. Little work has been done in the past to relate the results obtained from these analyses to fluctuating lake levels although the end of the last century saw the start of studies linking geomorphology to changing water levels (Forel 1885, 1892, Russell 1885, Gilbert 1890). It is only comparatively recently that the results from palaeolimnological studies have been interpreted in terms of lake level changes (Richardson 1969, Digerfeldt 1971, 1972, 1974, 1975,1976, 1977, 1978, 1982, 1986, 1988, Hjelmroos-Ericsson 1981, Hjelmroos 1982, Gaillard 1984b 1985). Consequently this has resulted in a paucity of literature concerned specifically with the subject of lake level fluctuations. It has been decided, therefore, to include only the literature relevant both to the analyses involved in the study of water level changes and to the type of lake involved *ie* temperate lakes of relatively small area (100 ha or less). The three main analyses used by Digerfeldt and other Swedish workers are sediment limit reconstruction, particle size analysis and macrofossil analysis and as this method for lake level fluctuation study has only been done for a few sites in Scandinavia and eastern Europe (figure 1) there is little literature

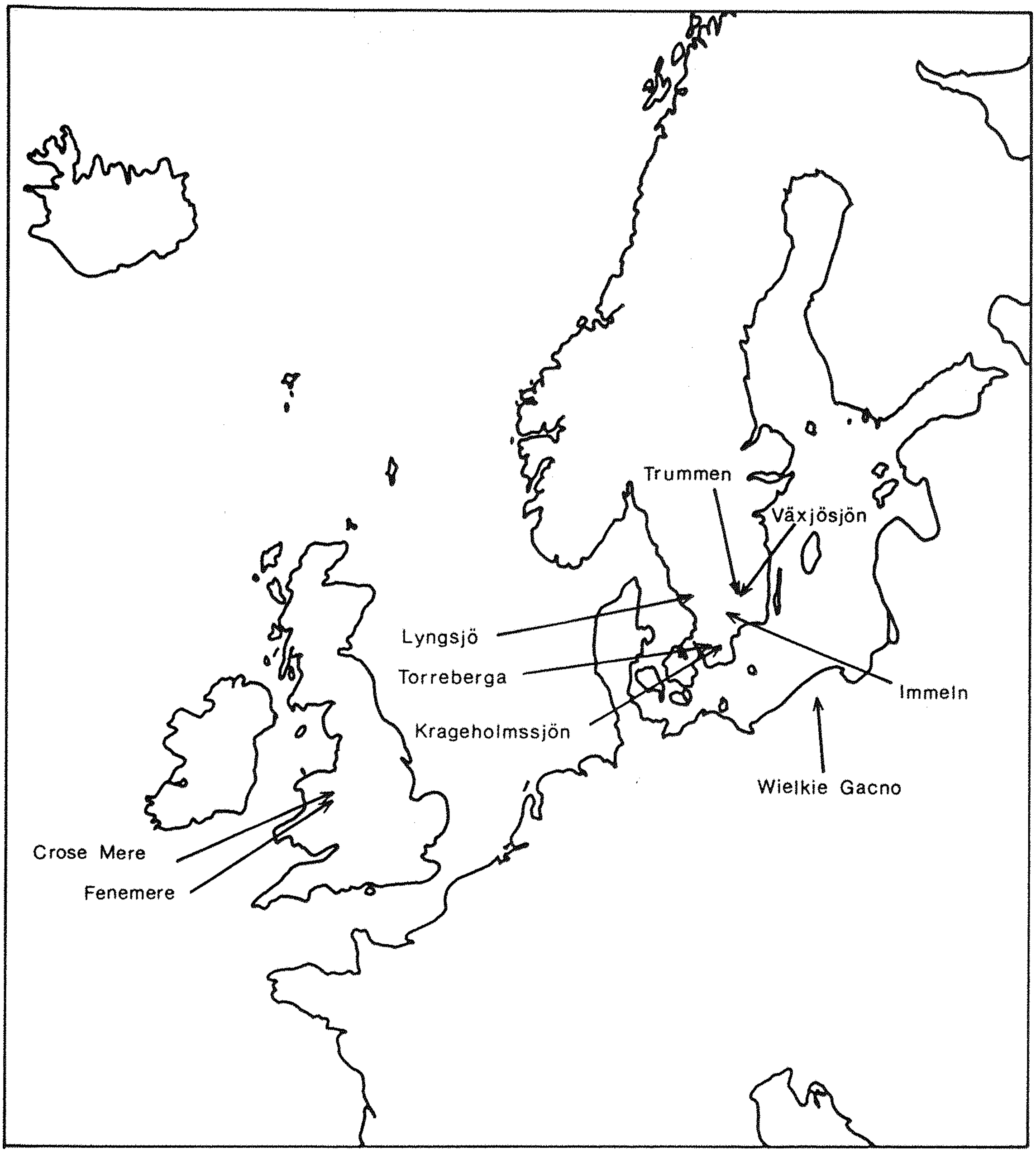


Figure 1 Previous lake-level fluctuation study sites

directly related to this subject.

2.2 Types of lake

There are many different types of lakes found throughout the world and almost as many different ways of classifiying these lakes. Lakes can be divided into two categories, temperate and tropical, depending on where they are situated. Temperate lakes can be subjectively subdivided according to their size, and as large lakes are not ideal for the study of lake-level fluctuations (Digerfeldt 1986), this chapter will concentrate on the sedimentary, physical and biological processes occurring within small, temperate lake basins only.

2.3 Sediments and lakes

Sedimentation in lakes is dependent on tectonic pattern, climatic conditions, lithology of the sediments in the drainage area, geological-geomorphological features of the lake basin and its hydrochemical conditions (Strakhov 1951). The matrix for all the fossil components preserved in lake sediment usually constitutes the bulk of the lake sediment and includes organic materials that cannot be recognised as specific fossils along with a fine-grained inorganic component that likewise cannot easily be distinguished as to mineral species. (Engstrom and Wright 1984). Sources of this particulate material constituting the majority of the matrix are not easily identified but the organic component includes both autochthonous algal production of lake water and the allochthonous detritus from terrestrial or littoral vegetation. The inorganic component includes mineral particles washed into the lake from the drainage basin by streams or hill wash, or blown into it from beyond as dust, as well as inorganic ions dissolved in the inflowing water of the regional precipitation (Engstrom and Wright 1984).

Oldfield (1977) says that

> "Sediment in its final form is a function of complex interactions between mechanisms of deposition, resuspension, chemical and biogenic transformation, exchange with water and organisms and longer-term diagenesis."

Therefore, before one can begin to reconstruct past lake level changes from sedimentary evidence it is necessary to have an understanding of the physical processes occurring in a lake, particularly those involving the movement of sediment.

2.3.1 Sediment accumulation

The first stage in the accumulation of sediment in a lake basin in a newly deglaciated area is the deposition of inorganic silts and sands over most of its area (Davis, Moeller & Ford 1984, Engstrom & Wright 1984). These sediments contain pollen and macrofossils from a tundra type vegetation and were deposited at a time when the export rate of particulate inorganics from the lake's watershed was more than thirty times higher than export from modern forested watersheds (Likens & Davis 1975, Davis & Ford 1982, 1984). Hakanson and Jansson (1983) describe three different areas of sedimentation within a lake. Accumulation areas are areas where fine materials can be deposited continuously. Fine particles of silt or mud are suspended in a lake for a relatively long period and are more likely to be resuspended than coarser particles. This means that the accumulation zone tends to occur in the deepest water near the centre of the lake where fine particles are often deposited (Davis 1968, Birks & Birks 1980). This differential deposition of particles is known as sediment focusing (Davis 1968, 1973, Likens & Davis 1975), and can become more intense as a lake becomes infilled, resulting in an increase in influx rates at the central coring site (Davis, Moeller and Ford 1984). The sediments deposited within the accumulation area have a high organic content and generally consist of loose muds.

Transport zones are characterised by periods of accumulation interrupted by periods of resuspension or transportation which are usually short lived (Hakanson & Jansson 1983). They can be connected to water turnover or to storms. There is, therefore, a discontinuous deposition of fine particles and aggregates and sediments range from sand to loose mud. The final zone described by Hakanson and Jansson (1983) is an erosion area where there is no deposition of fine materials. These areas are mostly found in shallow waters and are characterised by hard or consolidated deposits ranging from bare rocks, through gravels and sands, to glacial clays.

As a lake basin fills in, younger sediment may be spread over a larger area of the lake bottom than the older sediment. This results in the sediment accumulating in thinner layers and also means that the present lake bottom may give very little idea as to the past morphometry of the lake basin (Davis, Moeller & Ford 1984). Recent land clearances have been so extensive around many lakes that erosion has resulted in an increase in the deposition of mineral sediment detectable through a shift in the loss-on-ignition curve (Engstrom & Wright 1984).

Sediment accumulation is not quite as simple as the above account suggests. Dearing (1983) used magnetic susceptibility measurements to show that sediment accumulation patterns differ over a given time span. Accumulation rates in a small lake in southern Scania have decreased in more recent years and it was thought that this was due to the removal of hedges around the lake so that the water is now subjected to greater mixing by the wind. Focusing of sediment to the deepest or most central area of this lake does not strictly occur (Dearing 1983), and disturbance of the sediment to a decimetre or so by burrowing animals also disrupts the stratigraphy.

There is also evidence to indicate that wave activity in lakes significantly affects sedimentation processes. Influence of surface waves can be distinguished in distributions of sediment grain size, water content and chemical composition as well as in seismic reflection profiles, bottom and aerial photographs and sediment stratigraphy (Johnson 1980). Surface waves generated by winds can affect sedimentation in small depositional basins such as those of Crose Mere and Fenemere and can at times strongly influence sedimentation rates and stratigraphy (Johnson 1980). Vegetation surrounding the lake has a pronounced effect on the windflow patterns and, therefore, also affects sedimentation in a lake. A distance of approximately six times the height to the top of trees surrounding a lake will pass before the wind flow attaches itself to the lake surface (Etheridge and Kemp 1977). At the point of attachment the wind shear stress is zero and it takes a length of approximately seven times the height to the tree tops before shear stress attains its final value (figure 2)(Bradshaw and Wong 1972). Therefore, in a small lake a large part of the flow will be a boundary layer flow, resulting in a decreased rate of mixing compared with larger lakes (Ottesen-Hansen 1978). Apart from affecting the normal wind-driven circulation this will affect the mixing between the different layers in a stratified lake, which in areas with boundary layer flow will be substantially lower than in regions with fully developed turbulence (Ottesen-Hansen 1978).

Sedimentation patterns are also different in lakes that are ice-covered for part of the year. In Spring by the time the ice covering the lakes has melted the sun is high enough to start warming the epilimnion at once. At this time of year breezes are caused by the warming of the land and these are sufficient to mix the warmest water at the surface with the colder layers immediately below but not to mix the whole lake as often occurs in British lakes. A sharp thermocline is soon established and the difference in density between the epilimnion and hypolimnion is such that the occasional summer storm will not mix them (Macan

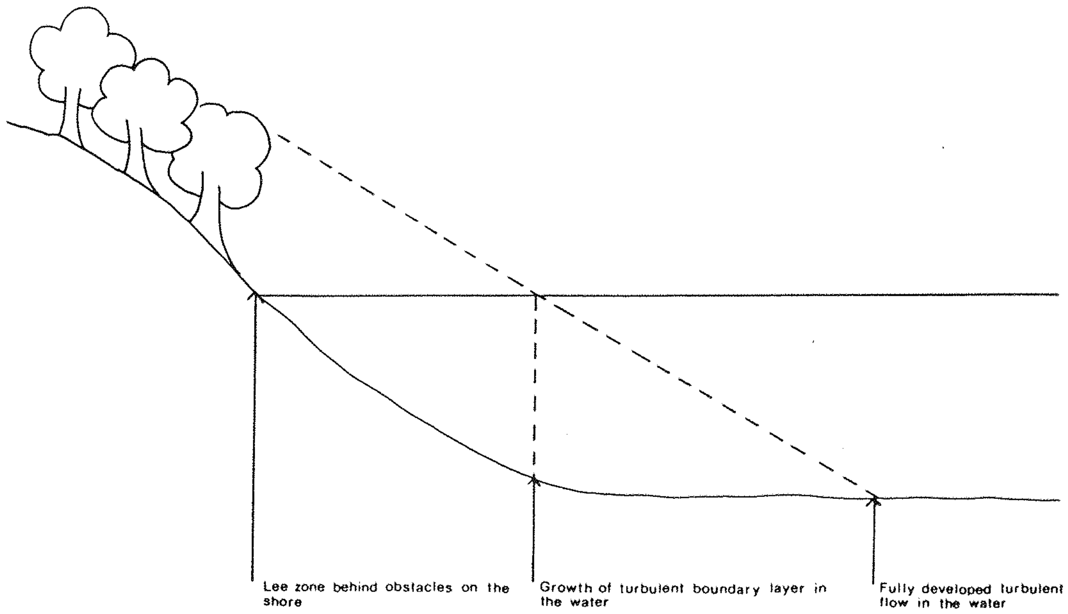


Figure 2 The effect of obstacles on the growth of the turbulent boundary layer in a lake (redrawn from Ottesen-Hansen 1978)

1970). The absence of strong winds also has the effect of producing a comparatively shallow epilimnion.

Autumn is a particularly windless time in the Carpathians and as the surface of the lake cools the water there becomes denser than it is lower down and the convection caused by its sinking brings about mixing. However, ice may form soon after the surface has reached 4^{o}C before this mixing is complete resulting in a hypolimnion which is permanently isolated from the surface waters. This could occur in Sweden where ice covered lakes are found but will not occur in English lakes where storms are the rule and ice-cover the exception (Macan 1970).

2.3.2 Sediment limit reconstruction

Recording changes in sediment limit is important in the study of lake level changes. The sediment limit is defined as being the highest limit at which predominantly organic sediment is deposited (Lundqvist 1925). Above the sediment limit fine detrital organic matter cannot permanently accumulate owing to the disturbing effect of waves and wind-induced water currents. In lakes characterised by predominantly minerogenic sedimentation, the sediment limit may be compared with the limit between erosion and transportation bottoms (Hakansson & Jansson 1983). Digerfeldt (1988) redefined the sediment limit as sediment whose organic content was greater than 50%. Determined on a dry weight basis, sediment accumulated at the sediment limit has an organic matter content of about 5% as measured by loss on ignition. The appropriateness of this limit is discussed in section 8.5 p205.

The reconstruction of past changes in sediment limit is usually complicated - often even made impossible - by the older sediments, which have accumulated at a higher lake level, being eroded and redeposited during a subsequent lowering. In some cases, all of the older sediment above the subsequent sediment limit may become eroded and removed. In other cases, depending on the character of the sediment, the erosion may be incomplete, raising the possibility that the earlier higher level of the sediment can only be determined in certain points in the lake.

Past fluctuations in lake level, particularly in shallow and moderately deep lakes may have resulted in extensive erosion and redeposition of sediment. If the landscape is not fully stabilised erosion may cut through the mantle of the soil and weathered rock and may bring to the lake unweathered minerals which are recorded in the lake sediments by a higher proportion of mineral to organic material and a higher content of potassium and sodium (Engstrom & Wright Jr 1984). This is more pronounced in oligotrophic lakes in which the content of mineral matter in post-glacial sediments averages about 70%, as measured by loss-on-ignition. Other features may suggest erosion and the possibility of redeposition such as an unconformity between two strata found in a line of borings, or a very sharp contact between two different sediments (West 1979). Information on such disturbances in sedimentation is certainly necessary if stratigraphical records are not to be misinterpreted.

2.4 Physical processes

2.4.1 Particle size analysis

Sediments are generally more coarse and better sorted in shallow high-energy environments exposed to waves than in deeper areas offshore (Solohub and Klovan 1970, Vernet *et al* 1972, Hakanson and Ahl 1975, Yuretich 1979). Sorting is not always better in the coarse nearshore sediments, however, than in finer offshore sediments (Graf 1976). The relatively coarse nearshore sediments often show positive skewness in grain size distribution, low porosity and low organic carbon content compared to the finer deposits in deep water (Johnson 1980).

Past lowerings of water level may be recorded by an increase in the amount of coarse material in the sediment because of associated outward displacement of the shore (Digerfeldt 1986). A rise in lake level and associated inward shore displacement may similarly be recorded by a decrease in this quantity. Coarse material was defined by Digerfeldt (1986) as that remaining in the 500 and 250um sieves after all the potentially identifiable macrofossils had been removed (Digerfeldt 1986). Loss on ignition was performed on these samples, possibly producing inaccuracies that would affect the final results as a proportion of the organic material had been lost at the start with the removal of plant macrofossils.

Littoral sediment normally contains a higher amount of coarse organic debris originating from the macrophyte vegetation growing along the shore, and also a higher amount of reworked coarse minerogenic matter. Displacement of the shore in connection with water level changes may result in changes in the amount of coarse organic and minerogenic matter in the sediment (Digerfeldt 1982). The amount of change in levels of coarse material depends on the exposure of the shore to wave action and wind induced water currents, and on the character of the shore deposits.

Digerfeldt (1986) suggests that there is normally a gradual decrease in the quantity and change in the particle size of the coarse material contained in the sediment from the shore outwards. However, work by Cahill (1981) on Lake Michigan shows that this is not always the case, and may be the exception rather than the rule. Hakanson and Jansson (1983) provide a good review of the principles of lake sedimentology, including grain size in relation to redistribution of sediment and the response of sediment to waves and currents.

This variation of coarse material is primarily recorded in oligotrophic lakes (Hjelmroos-Ericsson 1981, Digerfeldt 1971,1972,1973,1974,1975,1977) where it is a more important factor in the reconstruction of lake-level fluctuations than macrofossil analysis. In eutrophic lakes macrofossils can be more important than physical characteristics of the sediment as marginal macrophytes impede the flow of water and diminish the supply of silt to the lake (Macan 1970). Consequently plant remains accumulate and the sediment becomes more organic. However, vegetation can be very unpredictable and also varies in response to many different environmental factors and so may not be the most accurate way of determining lake-level fluctuations have occurred (chapter 9 p224).

2.5 Macrofossil analysis

2.5.1 Introduction

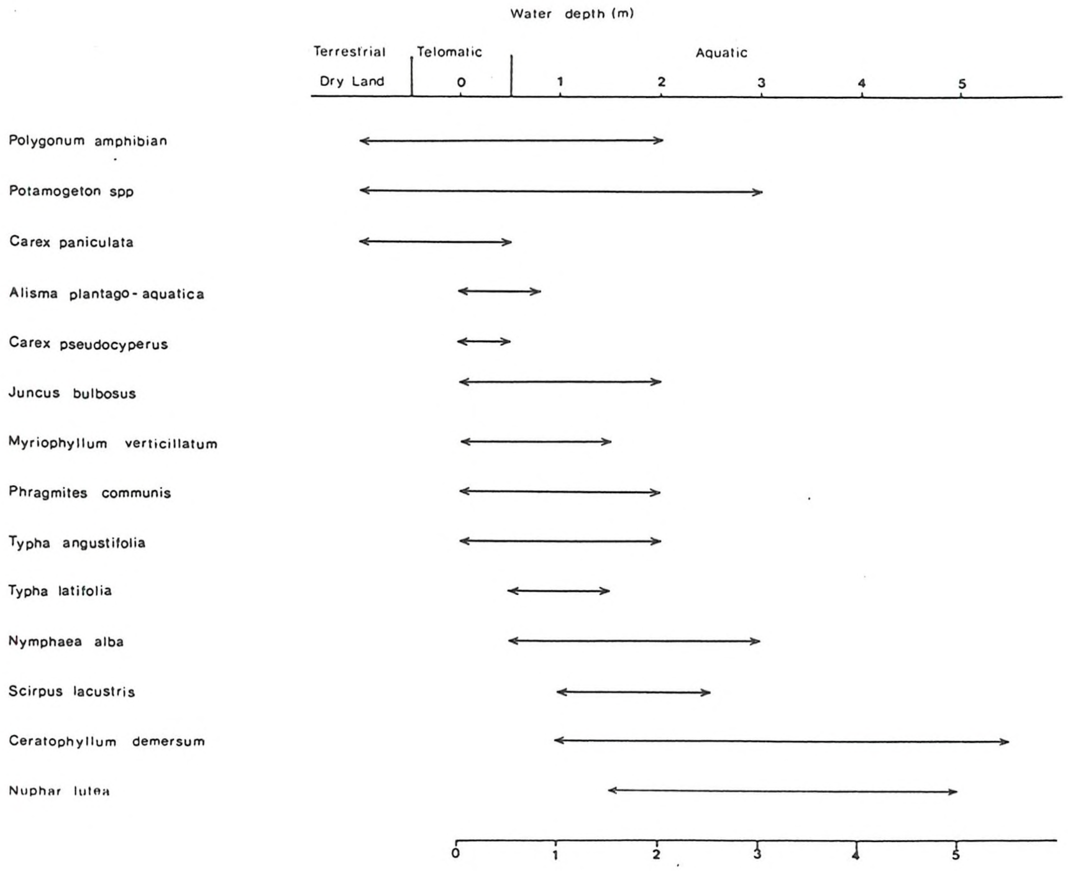
The term "macrofossil" describes any potentially identifiable plant and animal remains preserved in sediments, that are visible with the naked eye, although light microscopy is usually necessary for accurate identification. It is only recently that sufficient knowledge of habitats, chemistry, and ecology of present day species representative of the animal macrofossil groups encountered has enabled predictions as to the environment of the macrofossils to be made. As more knowledge is gained, the usefulness of these species as environmental indicators increases but as yet the knowledge and amount of reference material together with difficulties of identification excludes the majority of animal macrofossil analyses to all but the specialists in these subjects.

The quantity of animal macrofossils required coupled with the time it would take to produce results that could be interpreted in terms of lake-level changes and climatic change excludes their analysis from the present study although they have been used in previous lake-level fluctuation studies (Gaillard 1984b Ammann & Tobolski 1983). For these reasons it was decided that detailed plant macrofossil analysis would be preferable to the alternative macrofossil analyses such as Cladocera and Diatoms.

2.5.2 Plants and water depth

Plant macrofossil analysis is probably the most important analysis used in the study of water level changes occurring in eutrophic lakes, the aim being to reconstruct the marginal reed vegetation at various points in time. This is difficult in oligotrophic lakes because few species colonise such lakes and do not show hydroseral succession to the same extent as eutrophic lakes. As the marginal vegetation is dependent upon the depth of the lake it should reflect any changes of water level. A rise in water level would displace the reed vegetation outwards whilst a lowering of water level would result in the infilling of the lake by the spreading vegetation. However, interpretation of marginal vegetational changes is far from simple.

The growth of plants within a lake is very closely associated with water depth. In general, those plants which have most leaves above water show the greatest association with depth, usually growing in shallow places, while floating-leaved and submerged plants can be found in various depths of water (Sinker 1962). Very few floras give any precise indication as to the maximum depth of water in which a given species of plant is able to grow, the categories usually being limited to "shallow" and "deep". The few floras that give precise measurements (Clapham,Tutin and Warburg 1987, Haslam, Sinker and Wolseley 1982, Blamey and Grey-Wilson 1989, Spencer-Jones and Wade 1986, and Grime *et al* 1988) do not always agree on the precise measurements of minimum and maximum water depths but a general summary of plant species with their minimum and maximum water depths is given in table 1. This table shows that it could be possible to obtain a rough estimate of water depth from the macrofossil



Sources: Haslam, Sinker and Wolseley (1982)
Iremonger and Kelly (1988)
Grime, Hodgson and Hunt (1988)
Blamey and Grey-Wilson (1989)

Table 1

Maximum and minimum water depths for some of the marginal macrophytes recorded in Crose Mere and Fenemere.

assemblage preserved in a core at any one point. One factor which varies regularly with depth is light but in the English Lake District studies on several of the lakes show that no species occurs in a constant position in relation to light and sometimes the usual order of plants is reversed (Macan 1970). There does, however, appear to be some relationship between species and the composition of the sediments (figure 3)(Macan 1970).

2.5.3 Hydroseral succession

Natural succession of the hydrosere could account for the infilling of a lake basin by vegetation. Walker (1970) gives a good account of the possible hydroseral successions that may take place in lakes of different sizes and status. He divides the vegetation into twelve categories thus:

1. Biologically unproductive water
2. Micro-organisms in open water
3. Totally submerged macrophytes
4. Floating-leaved macrophytes
5. Reedswamp, rooted in the substratum and standing in more or less perennial water, with aerial shoots and leaves
6. Sedge tussock, rooted in the substratum and standing in more or less perennial water
7. Fen, dominated by grasses or sedges with a variety of acid-intolerant herbs all rooted in organic deposits which are waterlogged for the majority of the year
8. Swamp carr formed by trees growing on unstable sedge tussocks with some fen herbs, the intervening pools often harbouring thin reedswamp or floating-leaved macrophytes
9. Fen carr dominated by trees with an undergrowth rich in fen herbs and ferns all rooting in a physically stable peat mass
10. Aquatic Sphagna, floating very closely below, or on, the water surface
11. Bog, usually distinguished by a variety of *Sphagnum* species and acid-tolerant phanerogams

RAPID SILTING

Organic content 10% - 40%

Potamogeton spp
Typha latifolia

MODERATE SILTING

Organic content 20% - 60%

Nymphaea alba
Myriophyllum spp
Scirpus lacustris
Phragmites communis

SILTING NEARLY ABSENT

Organic content 60% - 95%

Potamogeton natans
Carex spp

Figure 3
Relationship between the degree of silting and plant species colonisation (from Macan 1970).

12.Marsh, composed of "fen" species growing on water-logged mineral soil

The most commonly found hydroseral successions found in small inland basins such as the kettlehole meres of Shropshire are shown in figure 4 (Walker 1970) and the approximate hydroseral successions found around the coring sites at Crose Mere and Fenemere are represented in figures 5 and 6 .

Environmental parameters affecting the seed production and dispersal of higher plants need to be known before any tentative suggestions can be made concerning lake level fluctuations. Some of the problems that need to be considered are outlined below.

2.5.4 Seed Production and Dispersal.

Birks (1972) has shown that it is possible for a macrofossil to occur in a lake but no plant of this species be recorded in the present day vegetation, and also that plants may occur in the lake but no macrofossils be recorded. From this it can be seen that knowledge of seed production and distribution from the vegetation growing in and around the lake is essential for correct interpretation of macrofossil diagrams. It also demonstrates the importance of comparing macrofossil assemblages with modern macrofossil assemblages rather than directly with the living plants.

Lake vegetation can be divided into three categories based upon their position in relation to the water level:

obligate aquatics	submerged or floating in the water
wetland plants	rooted in the lake margin and peatlands around the lake edge
dryland plants	found growing on dry land in the immediate vicinity of the lake

Obligate aquatics are generally perennial and they often

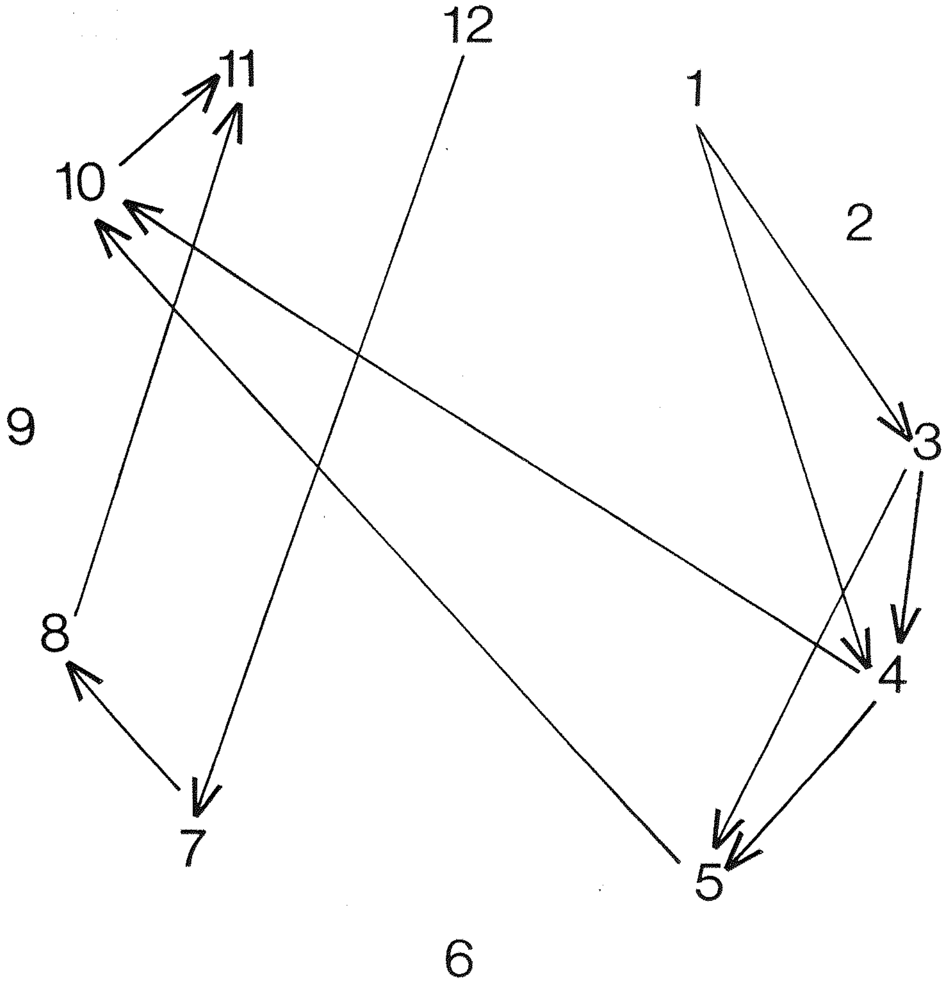


Figure 4

The most commonly found hydroseral succession in small inland lake basins (redrawn from Walker 1980). See text for explanation of the vegetational units represented by the numbers 1-12.

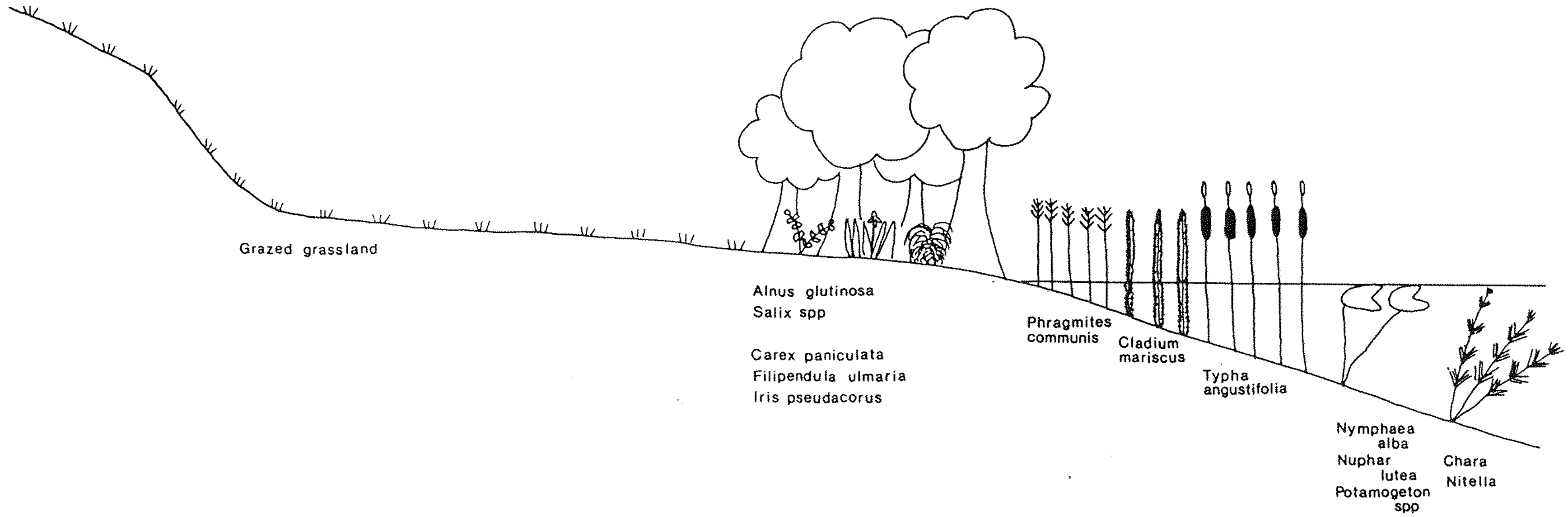


Figure 5 Approximate hydrosere found in the western bay at Crose Mere

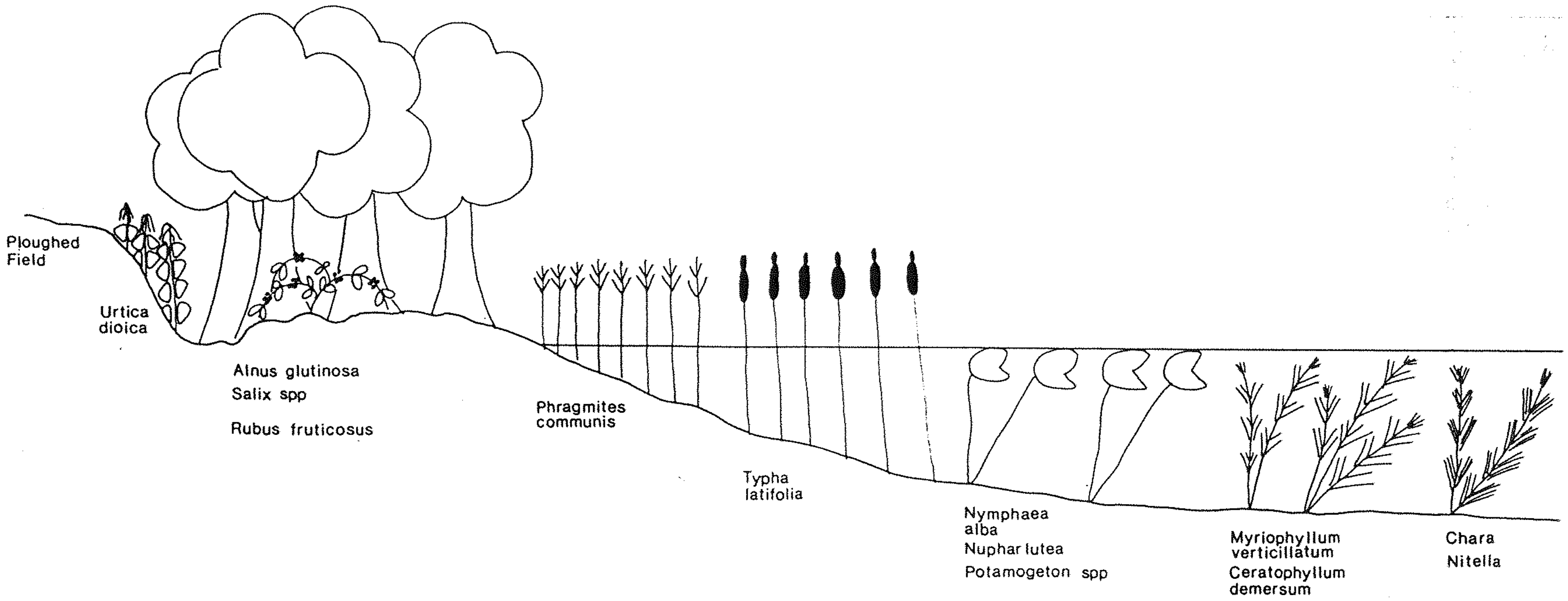


Figure 6 Approximate hydrosere found in the south east section of Fenemere

have very effective means of reproducing vegetatively. A good example of a plant that rarely fruits but relies on vegetative reproduction is *Ceratophyllum demersum.* The relationship between vegetative reproduction and the production of seeds is poorly understood, but there appears to be a connection between the amount of competition between species and the number of seeds they produce (Birks, 1980). Large numbers of seeds have been recorded from the period preceding the last glaciation in a number of sites (Birks 1984, Birks & Mathewes 1978, Watts & Winter 1966, Watts and Bright 1968) and in all these cases there is a subsequent decline in the numbers of seeds preserved in the sediment.

Studies of modern macrofossil assemblages and the present day flora (GreatRex, 1983) would appear to support Birks (1972) view that the absence of a macrofossil species does not necessarily mean that the species was not growing there at the time. So why would there be this decline in the number of seeds if approximately the same number of aquatics were colonising the lake? According to Birks (1980) one possible explanation for this would be that aquatic plants in a pioneer situation may reproduce sexually more frequently thus maintaining a variety of biotypes for maximum adaptability. However, in a closed situation, competition becomes more severe and vegetative reproduction of a successful biotype may be more effective. This view is supported by Grime (1979).

Obligate aquatic plants generally produce relatively few seeds which tend to sink rapidly and, therefore, are unlikely to be recorded in sediment more than a metre away from the parent plant (GreatRex 1983). There are several exceptions to this rule. *Chara* and *Nitella* oospores, *Lemna* seeds, *Utricularia* seeds and some *Potamogeton* fruits float well and as the *Chara* and *Nitella* oospores may be produced in considerable quantities they are often recorded in central deep water cores where very few seeds are found. Another exception to this rule is *Najas flexilis* which produces many seeds as an overwintering device. *Najas* seeds preserve well in lake sediments and can occur in high concentrations, usually as broken halves presumably as a result of embryonic germination (Birks 1980).

Because of their poor local dispersal macrofossils of aquatic plants in lake sediments provide positive evidence that the plant once grew in the lake or its catchment. Therefore, finds of macrofossils of aquatic plants beyond their present range of distribution clearly indicate that changes in distribution have taken place.

Many wetland plants utilise water dispersal and their seeds and fruits are often adapted for flotation. It has been found that in general wetland plants are represented in very similar ways to the obligate aquatics in that the number of seeds increases with increasing cover by that particular species of plant (Birks, 1972) and that the number of seeds recorded from more than a metre away from the parent plant is very few (GreatRex, 1983). Different organs of one plant species have different settling velocities and are, therefore, more likely to be differently deposited rather then found together (Wainman & Mathewes 1990) although Spicer & Wolfe (1987) have shown that several tree taxa such as *Abies, Pinus* and *Taxus* have a high probability of organ co-occurrence. Vegetative remains of *Phragmites communis* and *Typha* species are often preserved in situ but identification of such vegetative remains is dependent on the degree of decomposition and is not always possible. In contrast to this poor dispersal of wetland plants and obligate aquatics, the seeds and fruits of wind dispersed trees surrounding lakes are often recorded in considerable quantities over the majority of the lake. The most commonly recorded tree macrofossils are *Betula* species as these are produced in vast amounts and may float for a considerable time on the water surface before sinking. Because of this phenomenon, GreatRex (1983) has suggested that large numbers of *Betula* catkin scales and other *Betula* remains may be a more reliable indicator of the presence and abundance of *Betula* in the immediate vicinity than high frequencies of achenes alone.

2.5.5 Summary of macrofossil analysis

Fruits and seeds are the most commonly studied plant macrofossils in sediments as their thick exine means that they preserve well. Wood can be identified from thin sections and Weber (1980) isolated and identified leaf fragments from sediment collected from Vidy, France. Leaves such as *Dryas octopetala, Juniperus communis, Saxifraga aizoides* and *Pinus sylvestris* are very characteristic and can often be identified. However, in general, the large variability of age and condition of the material found together with the often insufficient quantity and problems in identification result in leaves being excluded from macrofossil analysis. There are, however, always exceptions to the general rule and work by Hill and Gibson (1986) on a lake in Tasmania has shown that it is possible for leaves to be found in greater abundance in a lake than reproductive structures and be more readily identified.

In the last century macrofossils were used as the only known means of reconstructing Quaternary vegetational communities (Reid 1899, Reid & Reid 1908) but as pollen analytical techniques became more sophisticated and their accuracy increased more people turned to pollen analysis as their tool in preference to macrofossil analysis. It is only recently that macrofossil analysis has been revived as its value in helping to reconstruct past communities is recognised. It is particularly valuable when used to support pollen diagrams as it has several advantages over pollen analysis and can be used to fill in the remaining gaps in the vegetational picture (Watts & Winter 1966, Watts & Bright 1968, Birks 1976, Birks & Mathewes 1978, Birks 1980, Wasylikowa 1986, Wainman & Mathewes 1987). Mannion (1986b, 1986c) presents a review of the applications in terms of reconstructing vegetational history from plant macrofossils preserved in deposits of varying ages. The possibility of using plant macrofossils as indicators of the status of the lake at a given point in time continues to increase as more knowledge is gained in this area (Seddon 1967, 1972, Kadono 1982, Jackson & Charles 1988).

It can be seen from this review that macrofossil analysis has an important part to play in the study of lake level changes as changes in the vegetation as a response to lake level fluctuations are recorded in the sediment. The approximate seral hydrosere is known and, therefore, changes in macrofossils appropriate to this can then be recognised and treated cautiously when drawing conclusions.

2.6 Pollen analysis

The principles of pollen analysis are presented by Faegri and Iversen (1975), Barber (1976), Moore and Webb (1978) and Birks and Birks (1980). Birks and Birks (1980) also provide a background to pollen production, dispersal and preservation. The data yielded from pollen analysis can provide direct information concerning the composition of the vegetational communities surrounding the lake or mire at any one point in time. These vegetational reflections have been utilised to yield information about many different environmental parameters (Huntley and Webb 1988). Pollen analysis has also been used in palaeoclimatic reconstructions (Delcourt, Delcourt & Davidson 1983, Bartlein, Webb & Fleuri 1984, Bartlein *et al* 1986, Gajewski 1988, Kershaw & Nix 1988) although this practice is generally restricted to large areas of almost homogenous plant cover such as America and parts of Scandinavia and is of little value in its present state to the British Isles. The primary function of pollen analysis in this study was to provide a chronological link between cores taken along a transect at a single site, and also between cores taken from adjacent sites. Therefore, only literature related to this aspect of pollen analysis is described below.

2.6.1 Pollen Analysis as a tool for dating sediments

Pollen analysis can be used both to date sediments and to provide a chronological link between several cores from one site, and also between cores of adjacent sites. Once a pollen diagram has been drawn, it may be divided into pollen assemblage zones based upon the percentages of species occurring at each level (Godwin 1940, 1975, Birks & Birks 1980).

Problems of hardwater error in several of the lakes studied in Southern Sweden have prevented accurate radiocarbon dates from being obtained (Digerfeldt 1988). Therefore, the cores have been divided into the Blytt-Sernander zones using pollen analysis. Blytt and Sernander analysed the stratigraphy of Scandinavian peat bogs and lakes and created a division of the postglacial period into five climatic periods. These were characterised as follows:

Sub-atlantic	Cold and wet	Oceanic
Sub-boreal	Warm and dry	Continental
Atlantic	Cold and wet	Oceanic
Boreal	Warm and dry	
Pre-boreal	Sub-arctic	

The five periods were later related to the results of pollen analysis and quickly became widely used (von Post 1916, Gams & Nordhagen 1923). Radiocarbon dates from Agerod's Mosse (Nilsson 1964a, 1964b, 1967) were then transferred to provide a dating system.

Godwin (1975) defined these zones in terms of vegetation in England and also provided an estimation of radiocarbon dates at their boundaries. These can then be used to correlate cores obtained from within this area.

There is further evidence to support the role of pollen analysis in the dating of sediments with Barber (1978, 1981) who demonstrated that sediments from Bolton Fell Moss were dated more accurately using pollen analysis than by radiocarbon dating.

2.6.2 Pollen recruitment to lakes

Most of the pollen collected by a lake has been shown to originate from trees more than 100m away, indicating that trunk space transport and direct deposition from overhanging trees are minor components of pollen transfer compared to atmospheric transport from above the canopy (Jackson 1990). Water circulation has been shown to affect the sedimentation of pollen grains in lakes sorting them according to morphological type (Davis and Brubaker 1973). Pollen grains with rapid sinking rates are deposited evenly onto the sediment throughout the lake. Those with slower sinking rates, due to small size or low density, are kept in suspension in the turbulent waters of the epilimnion. They are carried across the lake in wind-driven water currents and are deposited preferentially onto littoral sediment (Davis and Brubaker 1973). Pine pollen floats until water fills its air bladders increasing the density of the grains allowing them to settle rapidly (Brush and Brush 1972). This tendency for them to float initially keeps them high in the water where they can be moved against the shore and deposited onto the sediment. Birch pollen also shows a tendency to remain suspended in water (Brush and Brush 1972).

Uneven deposition may occur for pollen from any plant that flowers after lake waters have become stratified unless the pollen has a rapid sinking rate (Davis and Brubaker 1973). Before stratification mixing of the lake water will distribute the pollen throughout the water column (Davis 1973). After stratification sets in, however, currents in the epilimnion will carry the pollen horizontally unless it sinks rapidly enough to penetrate the thermocline before lateral transport occurs (Davis and Brubaker 1973).

In closed lakes with no inflow, the majority of pollen being recruited to the lake is airborne and is likely to have come from vegetation within a short distance of that lake (Bonny 1976). This could lead to underrepresentation of certain species in the pollen profile of a lake core. *Calluna* for example is poorly dispersed in air, but is often present in fairly large quantities in the pollen recruited to the lake by inflow from surrounding boggy land (Pennington 1964, Peck 1973, Bonny 1976). Variation in the ability of pollen to be dispersed by air also varies. *Betula* pollen appears to be dispersed with greater efficiency in air than *Alnus* pollen. *Compositae, Ranunculaceae* and *Cyperaceae* are all underrepresented in pollen diagrams from closed lakes because of the low efficiency of their pollen distribution by air but all are well represented in streamborne pollen components (Bonny 1978).

Davis, Brubaker and Beiswenger (1971) showed that the percentage pollen spectrum of surface sediments varies significantly from place to place within the shallower water near the lake margin, apparently as a result of high but localised pollen input from the nearest stands of emergent or terrestrial vegetation. Resuspension of pollen that has fallen to the bottom of the lake also occurs and the intensity of resuspension depends largely on the proportion of the mud surface subject to persistent disturbance by wind-generated water movements (Tutin 1955). Resuspension is, therefore, more intense in shallow lakes than in deep ones (Tutin 1955, Pennington 1974) and especially so in shallow lakes which do not stratify in summer due to strong winds (Davis 1973, Peck 1973).

2.6.3 Pollen as an anthropogenic indicator.

An increase in the amount of herb or non-arboreal pollen corresponding to a decrease in the amount of tree or arboreal pollen can be indicative of clearance of forest vegetation by man (Turner 1964). The species of non-arboreal pollen grains encountered can suggest the type of farming that was being practised in that particular area. Compositae, Cruciferae and Chenopodiaceae are arable weeds whereas the presence of *Plantago, Rumex* and Ranunculaceae in a pollen diagram indicate pastoral farming. This division of pollen into arable and pastoral weeds to reflect farming methods can be seen in Turner (1970) in East Anglia where a change from pastoral to arable farming was shown to coincide with the arrival of the Anglo-Saxons. Behre (1981, 1986) presents a good summary of anthropogenic indicators and their interpretation.

2.6.4 Summary of pollen analysis

Although pollen has many uses in the reconstruction of palaeoenvironments it is primarily used as a chronological tool in this study and also to provide some indication of the presence of man around the meres.

2.7 Summary of literature review

There have been numerous studies of lakes throughout this century but only a minute proportion of this work has concentrated on fluctuating lake levels. The majority of the work concerned with changes in water levels has involved tropical lakes which fluctuate dramatically with the changing seasons and there is very little literature on fluctuating water levels in temperate lakes except for literature relating to IGCP project 158. It is necessary to have an understanding of the sedimentary, physical and biological processes occurring within a lake before any interpretations concerning the fluctuation of water levels can be made.

Chapter 3 THE STUDY SITES

3.1 Topography of Shropshire

Shropshire is divided into two contrasting regions by the River Severn, these regions consisting of the Southern hills and dales, and the lower and more even Northern Plain (Chitty 1956). It is this Northern Plain which provides this opportunity for palaeoclimatic study of the sediments from the many meres and mosses found here. The Shropshire-Cheshire plain extends from the Mersey estuary to the South Shropshire hills and lies between the Welsh Massif in the West and the Pennines in the East. This gently undulating plain lies mostly below 100m OD but is interrupted by several low but prominent hill ridges. Ice sheets from the North and West met and mingled on the North Shropshire plain where they buried an older landscape under great thicknesses of boulder clay, morainic ridges and sheets of sand and gravel laid down by meltwater and cratered with kettle-holes where detached blocks of ice had been left (Sinker 1962, Worsley 1970, Shaw 1972). Such landforms resulted in the formation of the meres and mosses (Shaw 1972).

Several explanations for the origin of the meres have been forwarded but because of the range of morphometric variation of their basins, one single explanation is unlikely to be applicable. Four possible explanations are considered below:

a) Vestigial meltwater lakes
This theory expounds that the meres are the remains of what were once extensive meltwater lakes (Galliford 1960, Reynolds 1979)

b) Kettle holes
Ice blocks became detached from the stagnant ice front, slumped and were buried by ablation and outwash deposits. As these ice blocks melted, deep crater-like kettle holes

separated by hummocks of drift formed the distinctive topography of the moraine and marginal belts (Reynolds 1979). There are areas in Shropshire where this could have occurred and so it is reasonable, therefore, to expect at least some of the mere basins to be true kettle holes.

c) Moraine-dammed hollows
More linear basins in morainic drift that are not obviously kettle holes may have been enclosed by successive terminal moraine ridges (Reynolds 1979).

d) Post-glacial subsidence hollows
Natural subsidence of the drift surface occurs as a result of local "wet-head" solution of buried salt (Evans 1965, Taylor 1965, Reynolds 1979). This may have occurred where lake basins overlie saliferous bearing rock strata and can only be identified using boreholes (Taylor 1965). Coal mining in Flintshire and Staffordshire has also led to widespread subsidence of the ground surface (Wedd & King 1924, Reynolds 1979).

3.2 Geology of Shropshire

Shropshire has a remarkably varied geology for the size of the county; of the thirteen recognised geological periods, ten are represented in the rock sequences of this area (Toghill & Chell 1984). It has been affected by a number of periods of earth movements associated with orogenies whose centres have been some distance away, the last of these producing the Church Stretton fault during the Tertiary period (Toghill & Chell 1984).

The Plain is an elongated saucer-shaped depression of mainly carboniferous rocks; limestones, grits, shales and coal measures which outcrop round its perimeter, enclosing a broad basin of younger Triassic rocks of the New Red Sandstone series. The latter include mottled Bunter sandstones and pebble beds, and the overlying sandstones, marls and saliferous strata of the Keuper series (Pocock & Wray 1935). The solid rock mostly lies buried under a blanket of unconsolidated glacial drift deposited during the Pleistocene ice advances (figure 7)(Thomas 1989). Drift deposits vary in thickness from over 100m to only 10-20m (Beales 1980, Thomas 1989) and above 200m OD drift is thin or absent. The drift deposits are of two types;

1) Heavy unstratified boulder clay lodgement tills laid down at the base of the advancing ice sheet

2) Resorted silts, sands and gravels, carried out and redeposited by meltwater issuing from the decaying ice fronts, or in englacial channels beneath the ice sheet.

These resorted silts, sands and gravels have Triassic substrata covered by glacial drift. The undulating topography of low relief is broken by the sandstone ridges in the Eastern part of the plain. A pronounced belt of moraine runs through and south of Ellesmere and northwards to Whitchurch, dividing the North Shropshire Plain from Cheshire. North Shropshire is drained almost exclusively by southward flowing tributaries of the Severn (Reynolds 1979). The bedrock around Ellesmere is Triassic, with areas of Bunter and Keuper sandstones, Keuper waterstones and Keuper marl (Pocock & Wray 1925). Crose Mere and Fenemere are both situated well within the borders of glacial sand and gravel deposits and have marshy shores (Gorham 1957). The boulder clay in the substrata of Ellesmere Mere and White Mere may be more favourable for the maintenance of a deep steeply-sloping basin than the sands and gravels (Gorham 1957). The soils are predominantly brown earths of low base status, except in the vicinity of Ellesmere where gleys are found (Crompton & Osmond 1954, Burnham & Mackney 1964).

3.3 Present climate of Shropshire

The climate of the Plain is dominated by two factors:

1) The proximity of the Plain to the western seaboard

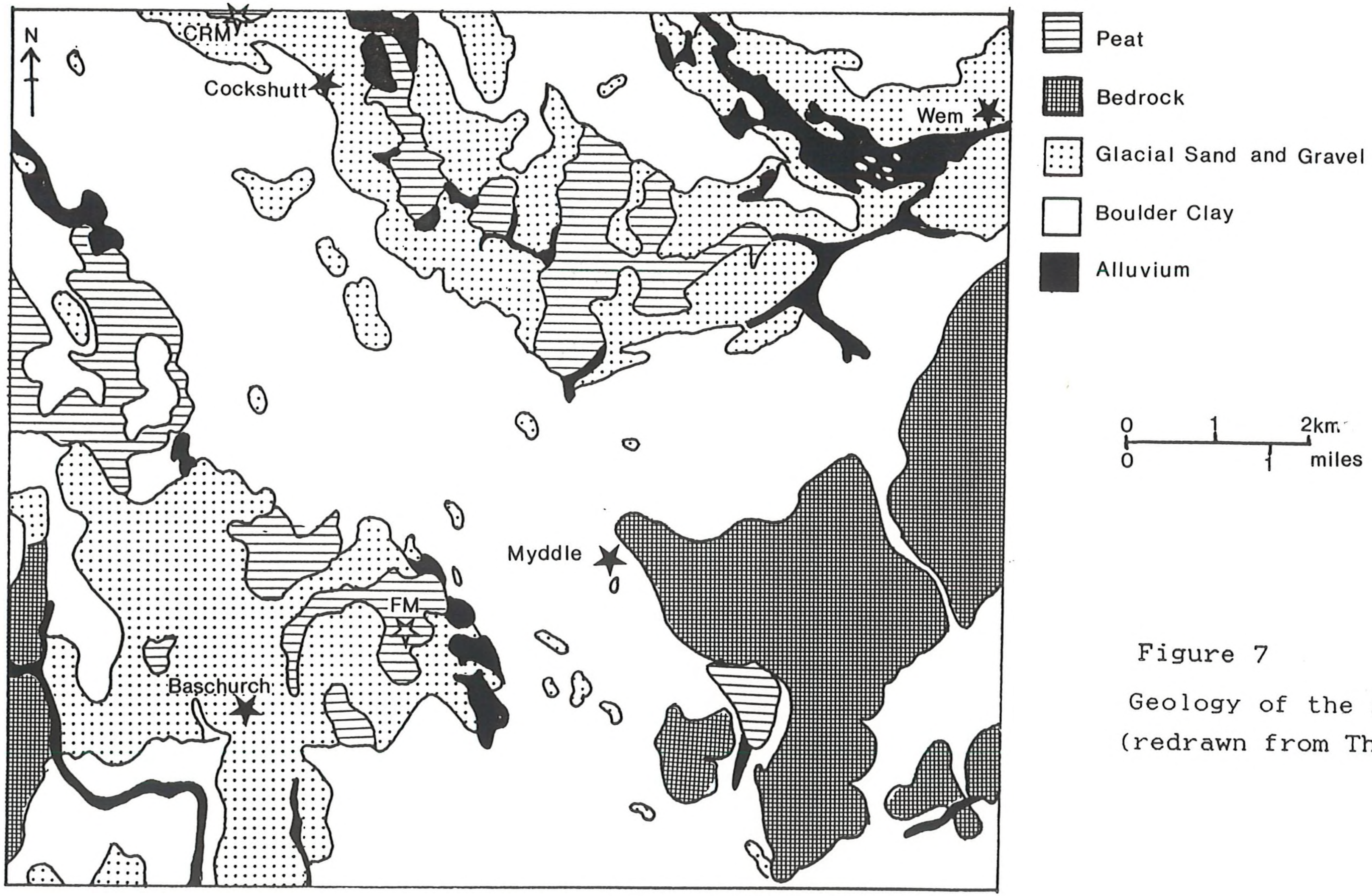


Figure 7

Geology of the study area
(redrawn from Thomas 1989)

ensures temperate, humid, sub-oceanic conditions throughout most of the year.

2) Its position in relation to the Welsh Massifs effectively provides a rain-shadow from westerly winds and eastward passing fronts. This results in the Northern Plain being one of the drier parts of the British Isles (Crompton & Osmond 1954, Reynolds 1979).

The meteorological station based at Shrewsbury gives a mean annual rainfall of 659mm (26")(Meteorological Office 1972) and estimated average evaporation at Shawbury, 13km southeast of Crose Mere, is 518mm (20.4")(Beales 1976). The mean annual temperature over the north Shropshire region is 9.5 ^{o}C (Haslam 1988), and accumulated temperature (day ^{o}C above 5.6) is between 1650 and 1925 (Bendelow & Hartnup 1980). Shropshire has a moisture deficit (Hodgson 1974) of 140-180mm and is unexposed, the approximate average windspeeds being less than 4.8m/s (Bendelow & Hartnup 1980). Both Crose Mere and Fenemere experience very little ice-cover at present although they may have been covered by fairly thick ice sheets for several months of the year in the past.

3.4 Anthropogenic influences on the Shropshire landscape

Shropshire is a landlocked region on the edge of the Welsh Mountains and does not appear to have been favoured by early settlement. Lower or Middle Palaeolithic tools have not been found in the Welsh Marches as during the last glaciation deposits were either scraped away or smothered by new layers of boulder clay and outwash gravels (Stanford 1980). The few Mesolithic type flint artifacts found in this area have not been sufficient to prove settlement in this period (Painter 1964, Stanford 1980), although there is evidence to suggest that the River Severn was used as a highway from Neolithic times onwards (Chitty 1949). Neither long barrows nor chambered cairns have been identified in Shropshire (Chitty 1956, Painter 1964). The nearest proven settlement dated by Neolithic pottery is at Ffridd Faldwyn near Montgomery, 30km southwest of Shrewsbury (Chitty 1956, Stanford 1980). Evidence for the lack of any real Neolithic impact comes not only from the paucity of archaeological evidence (Rowley 1972, Smith 1974) but also from pollen analysis (Beales 1980, Barber & Twigger 1987, Twigger 1988). The first major anthropogenic impact on this area appears to have occurred in the early Bronze Age (Barber & Twigger 1987).

The major land use of the Plain today is for agriculture and there are many isolated farmsteads and small hamlets. Much of Shropshire is renowned for dairy farming with clay-derived soils given over to permanent pasture, the meres providing water for stock kept in surrounding fields. There has been an expansion of arable farming in the past 40 years especially on the well-drained sands and gravels (Rowley 1972). In both cases farmland extends to the edges of the meres. Inevitably, increased use of inorganic fertilisers influences chemical composition of natural drainage waters, but few meres can be described as being seriously polluted (Reynolds 1979).

3.5 The meres

There are more than sixty open water meres and pools greater than one hectare in area, and over two hundred peat-filled mosses occupying a crescent of hummocky morainic ground in the Western part of the Plain (Sinker *et al* 1985). The largest cluster of meres is situated immediately south of Ellesmere and Crose Mere is the most southerly of the group. The Baschurch Pools form another cluster of meres south of the Ellesmere group of meres (figure 8). These kettle holes and morained-dammed hollows have an almost total lack of natural surface drainage channels. The majority of the meres have been isolated from streams throughout most of their history and so have been neither naturally drained nor alluviated. (Reynolds 1979). Several meres have been continuously water-filled

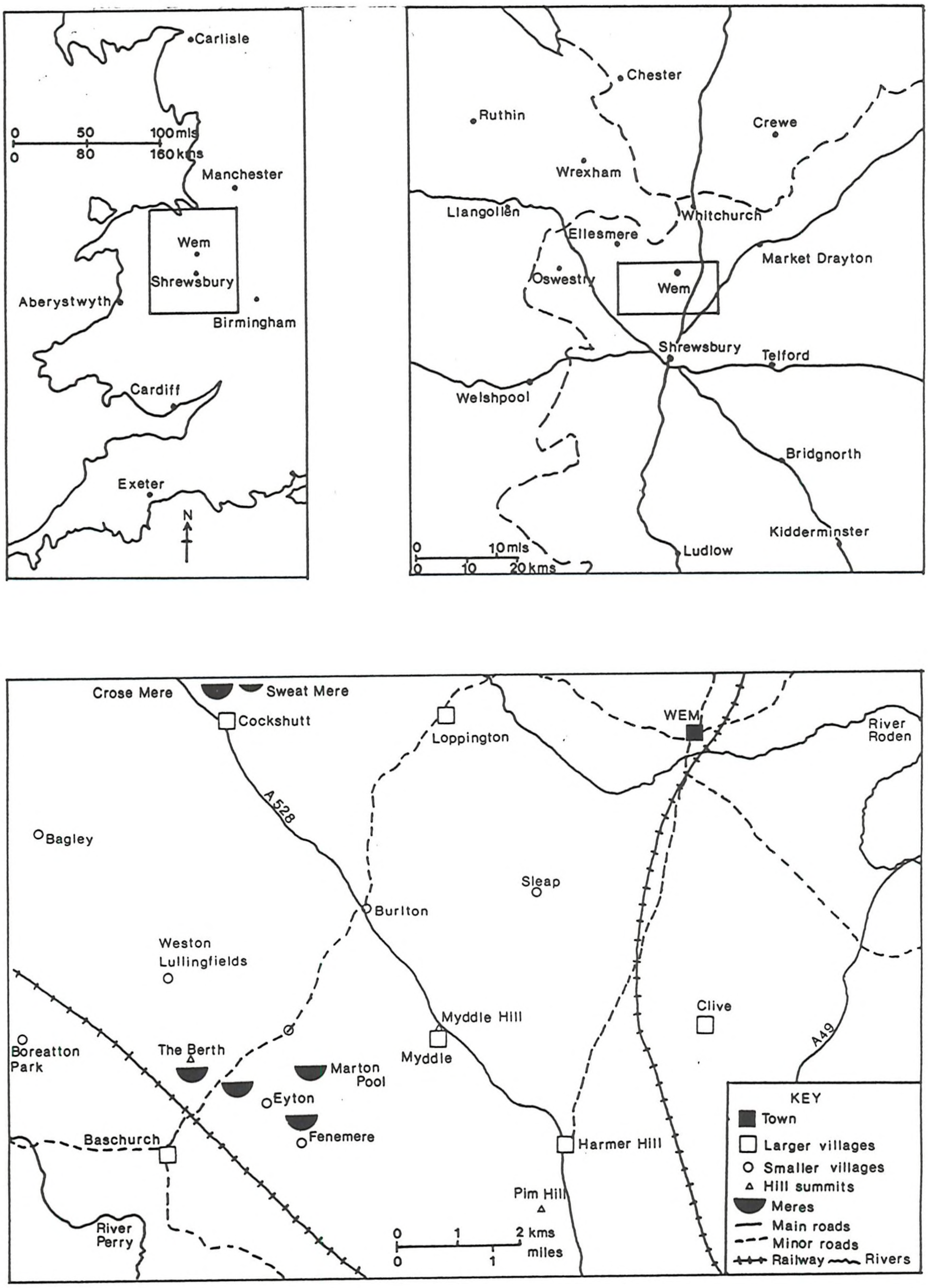


Figure 8 Position of the study sites

since 12,000 BP or earlier (Beales & Birks 1973, Beales 1976). Ridges of boulder clay, sands and gravels surrounding the meres and the meres themselves probably derive from a stagnating ice front during the latter part of the Devensian glaciation (figure 9). Imperfect and poorly drained soils (stagnogley soils) of the Salop and Clifton series are widespread and much of this area would have been thickly wooded (Twigger 1988).

In view of their rich nutrient supply, the macrophyte flora of the meres is surprisingly poor. These high nutrient levels are responsible for the large growth or bloom of phytoplankton which occurs when temperatures and light levels are favourable. In temperate lakes this usually happens twice a year and "the breaking of the meres" is a well documented occurrence in still weather during summer and autumn in Shropshire (Davies 1882, Galliford 1960, Reynolds 1979). It may be the shading effect of the dense surface blooms which keeps down variety of macrophytes.

A generalised flora of the higher plants found in these meres is described in Sinker *et al* (1985) as follows: *Ranunculus circinatus, Nymphaea alba, Nuphar lutea, Nuphar pumila, Elatine hexandra, Callitriche hermaphroditica, Littorella uniflora, Potamogeton obtusifolius, Zannichellia palustris*, and *Eleocharis acicularis*. The highly eutrophic meres have horned pondweed only or lack submerged macrophytes altogether. Where the shores are not too exposed to wave action, not heavily grazed, and not overhung by trees, the shallow margins of the meres are invaded by reedswamp.

3.6 Reasons for choice of study site

The abundance of closed basin lakes, or meres as they are known locally, located in the Shropshire Plain have given it the potential to be one of the best localities in the British Isles for palaeoenvironmental studies. It is thought that a large lake called Lake Lapworth, whose

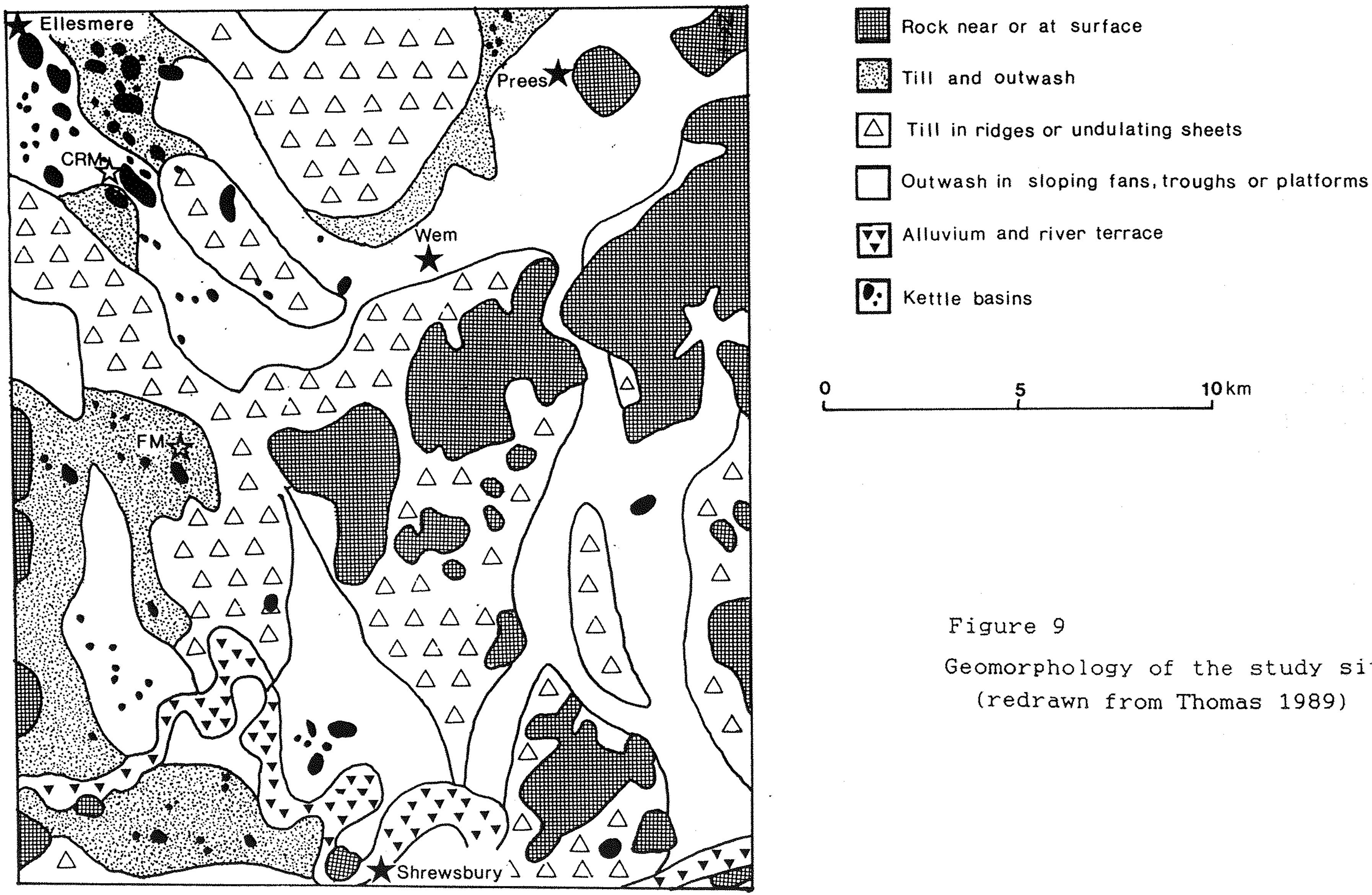


Figure 9

Geomorphology of the study sites
(redrawn from Thomas 1989)

shoreline roughly followed the present 300ft contour, occupied a great expanse of the Shropshire Plain once the glaciers had retreated at the termination of the Devensian glaciation (Pocock & Wray 1935, Sinker 1962, Painter 1964, Worsley 1970). The existence of old shore lines seen about the 90m contour line around several of the meres would appear to substantiate this hypothesis. According to Sinker *et al* (1985) "a typical mere does not have surface streams feeding it or draining it, but is maintained by the percolation of mineral-rich water from the permeable drift in which it lies". Because these meres have no inflow or outflow they have only groundwater seepage to affect their volume and are therefore most likely to be sensitive to climatic changes in the form of variation in precipitation levels and/or temperature.

Two contrasting meres were chosen as the study sites for this research. Crose Mere is a medium sized mere of 15.2ha situated about 6km south of Ellesmere. Old shorelines can be seen distinctly around the western margins of the lake and this was one of the deciding factors in the choice of Crose Mere as the primary study site. Crose Mere has probably been a closed mere for most of the Holocene and as Reynolds (1979) states:

> "Though evidently complex, the hydrology of Crose Mere and, perhaps, of many others with stable water levels is consistent with their maintenance primarily by ground water."

This stability of water level would suggest that Crose Mere is one of the most likely meres to exhibit lake-level fluctuations in which climatic change is the major controlling factor.

The Mere was artificially lowered in 1864 during extensive draining operations at Whattal Moss and Sweat Mere, an event that was said to lower Crose Mere by 2-3m (Hardy 1939, Sinker 1962, Beales 1976). This could provide a datum line against which to measure former fluctuations in water level. Primary investigations into the palaeolimnology of Crose Mere are available (Beales & Birks 1973) and Crose Mere was the study site of a doctoral study by Beales (1976, 1980). This study included a comprehensive pollen diagram from the deepest part of the lake and, most importantly, ten radiocarbon dates from a deep-water core. Hardy (1939) studied the anthropogenic influences on Whattal Moss which included the palaeoecology of this site bordering on Crose Mere. Pollen recruitment to Crose Mere has also been investigated (Bonny & Allen 1984).

Fenemere is the largest mere (9.4ha) in a complex of four meres known as the Baschurch Pools. Previous research on this mere includes its anthropological history (Twigger 1988) as well as its present day vegetation (GreatRex 1983) and vegetational history (Barber & Twigger 1987, Twigger 1988).

Both of these sites are easily accessible from roads, facilitating the transport of equipment down to the water's edge, and have locations for the launch of the two rubber dinghies used for taking cores from the lake bed.

One of the most important factors influencing the choice of study sites was the distance between them. Fenemere and Crose Mere are only 10km apart and, therefore, differences in climate will be negligible. Crose Mere and Fenemere are both situated on a similar geology of Triassic rocks with glacial sands and gravels (figure 10), and have marshy shores (Gorham 1957).

Neither lake appears to have been greatly affected as a result of anthropogenic disturbance until the drainage operations of the nineteenth century began. The nearest buildings to either mere are farm buildings and there is no evidence that either Fenemere or Crose Mere has been used for any purpose other than for fishing and provision of water for animals grazing in the surrounding fields.

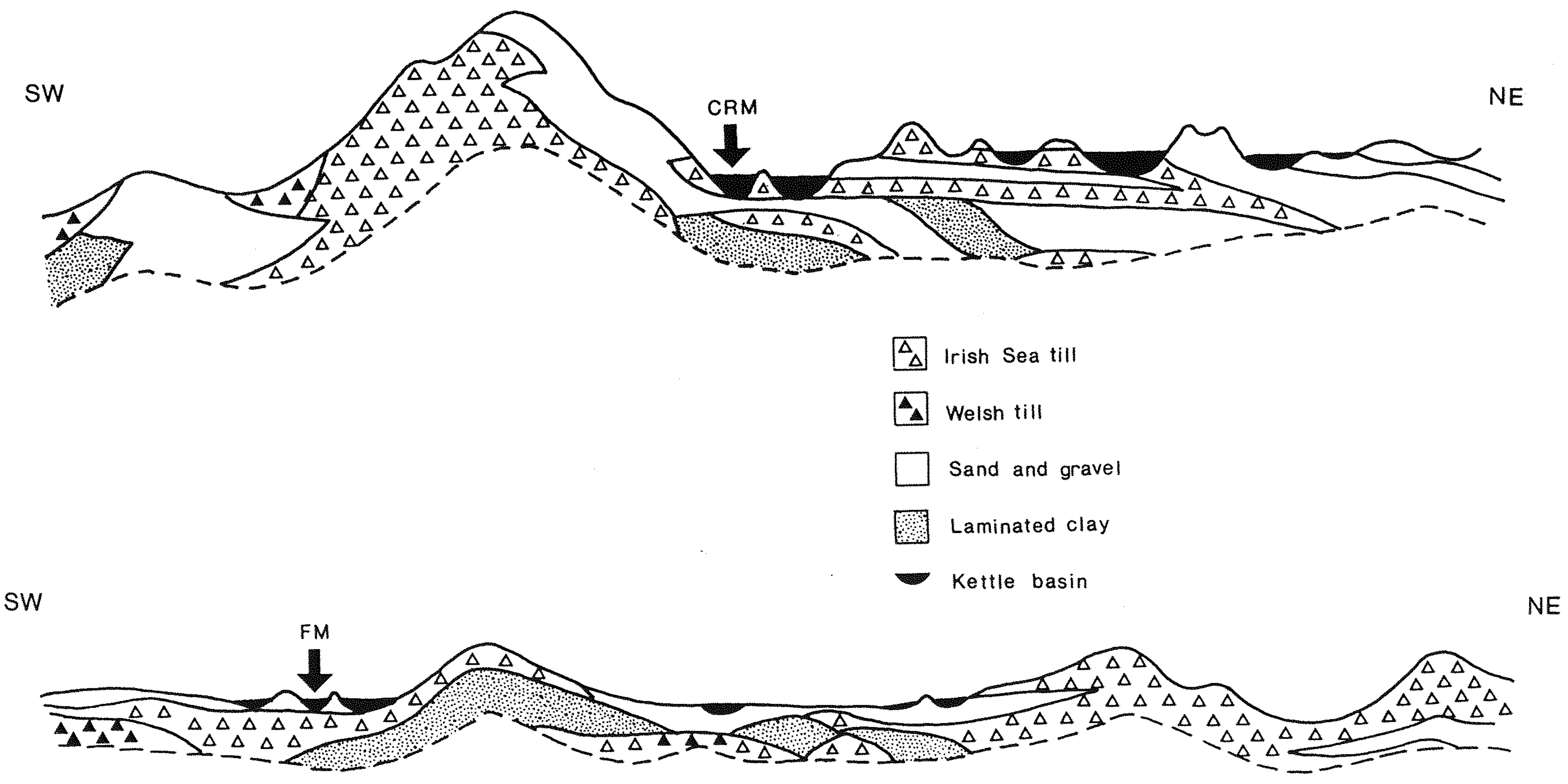


Figure 10 Geological cross sections of areas surrounding Crose Mere and Fenemere (redrawn from Thomas 1989)

3.7 Other sites considered for this study

Several other sites in Shropshire and central Wales were considered for lake-level fluctuation studies but were rejected for one reason or another. Two sites in Powys, mid-Wales were considered, these being Glaslyn (ref SN 826940) and Llyn Mawr (ref SO 008971). Glaslyn has a very stony substratum with very little, if any, organic sedimentation. It would, therefore, not provide any information of the lake's history. Llyn Mawr would be a possible site for the study of lake-level fluctuations but was rejected on grounds of its distance from Crose Mere and Fenemere and the fact that it experiences a different climatic regime from the meres situated in the Shropshire lowlands. A core taken from the western end of the lake showed about four metres of organics above the clay but there was no evidence of sandy bands in this core. Further research on Llyn Mawr may provide an interesting contrast to the Shropshire meres.

Shrawardine Pool (ref SJ 398160) is a small pool with good hydroseral succession but it occasionally dries out. This appears to have affected the stratigraphy (Twigger 1988) and may, therefore, give erroneous results for physical and sedimentary analyses. Isle Pool (ref SJ 461170) is situated within a loop of the River Severn and changes in the river would be likely to affect the water level of the pool. The sediments at Isle Pool appear to be more compacted than sediments occurring in other sites (Twigger 1988) and appear to have disturbed sediment stratigraphy. Neither of these pools was thought suitable for the study of lake level changes, therefore, even though they are both closed basin lakes.

Alkmund Park Pool (ref SJ 479163) is another possible site for lake-level fluctuation studies with approximately three to four metres of organic sediment overlying pink clay. This site was rejected in favour of Fenemere because of an artificial island situated in the middle of the lake, indicating a degree of anthropogenic disturbance, and the fact that Alkmund Park Pool is the only remaining pool in a complex of three, two of which have completely dried out. This suggests that the hydrology of this region is extremely complex and the pool may be subject to water loss by deep seepage as the upper two basins do not appear to have been artificially drained.

Other meres in the Ellesmere group were also considered. Ellesmere mere (ref SJ 407350) is the largest mere in this group and also one of the deepest (max depth 30m). It is now a nature reserve and has some concrete banks along the southwestern shore although varved sediments have been found in the lake (O'Sullivan pers. comm.). Blake Mere (ref SJ 415340) and Cole Mere (ref SJ 435333) are situated alongside the Shropshire Union Canal and may have disturbed stratigraphy resulting from the creation of the canal. Kettle Mere (ref SJ 418341) is a tiny deep lake with steeply sloping sides making coring difficult and increasing the probability of erosion. It also has a very limited distribution of marginal macrophytes reducing the variety of analyses available for the study of water level changes.

Two of the three remaining Baschurch Pools, Marton Pool (ref SJ 449234) and Birchgrove Pool (ref SJ 436232) were thought to be too closely linked to Fenemere to provide any extra information. In addition, Birchgrove Pool is small and deep (area 1.7 ha, maximum depth 4.8m) and has a disjunct marginal macrophyte zone. However, Berth Pool (ref SJ 430234) was shown to be a separate entity to the other three Baschurch Pools (Twigger 1988) and stratigraphic evidence from this site is discussed in section 8.2 p187.

3.8 Crose Mere

grid ref SJ 430305
area 15.2ha
max recorded depth 9.2m
estimated catchment area 340 ha

3.8.1 Topography

Crose Mere is situated about 6km south of Ellesmere in an area of boulder-clay moraine, known as the Ellesmere-Bar Hill moraine, and hummocky outwash gravels and sands which appear to represent a recessional or minor readvance stage during the Late Devensian glacial maximum along the Woverhampton-Bridgenorth line (Beales 1976). It is a shallow dimictic lake situated in glacial sands and gravels, overlying till and Keuper marl (Birks & Beales 1973, Beales 1976, 1980). Crose Mere has an eccentric basin, the deepest point (9m) being located in the NE region of the lake (Beales 1976, 1980)(figure 11).

The lake is one basin in a complex of three (figure 12). It is separated from Whattall Moss, a much modified raised bog with areas of Schwingmoore, to the north by a gravel ridge of maximum height 110m OD. Whattal Moss is composed of an understorey of *Myrica gale, Deschampsia flexuosa, Vaccinium oxycoccus, Dryopteris* spp and *Sphagnum* spp, and now supports areas of conifer plantations. Both Crose Mere and Whattal Moss join eastward with the third component, Sweat Mere, a shallow mere with a very rich hydrosere and the nearby Lloyds Wood, an open *Betula pubescens - Quercus robur* woodland growing on dry peat with a *Pteridium aquilinum* dominated field layer (Beales 1976). A small channel at the eastern end of Crose Mere conducts outflowing water approximately 500m to Sweat Mere which then drains via ditches to the River Roden.

Crose Mere appears to be fed primarily by subsurface flow through the gravels and clayey sands of the catchment

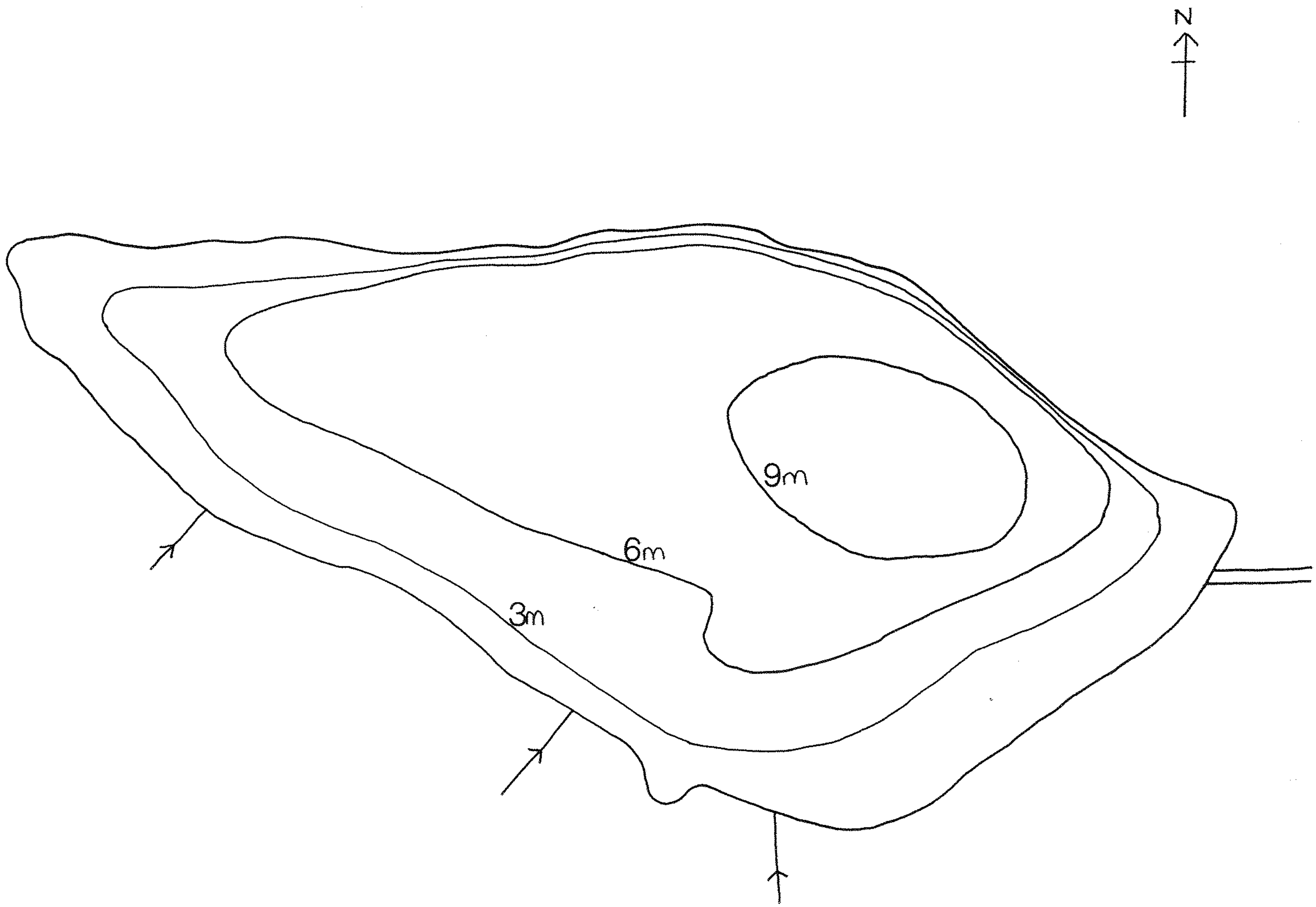


Figure 11 Bathymetry of Crose Mere

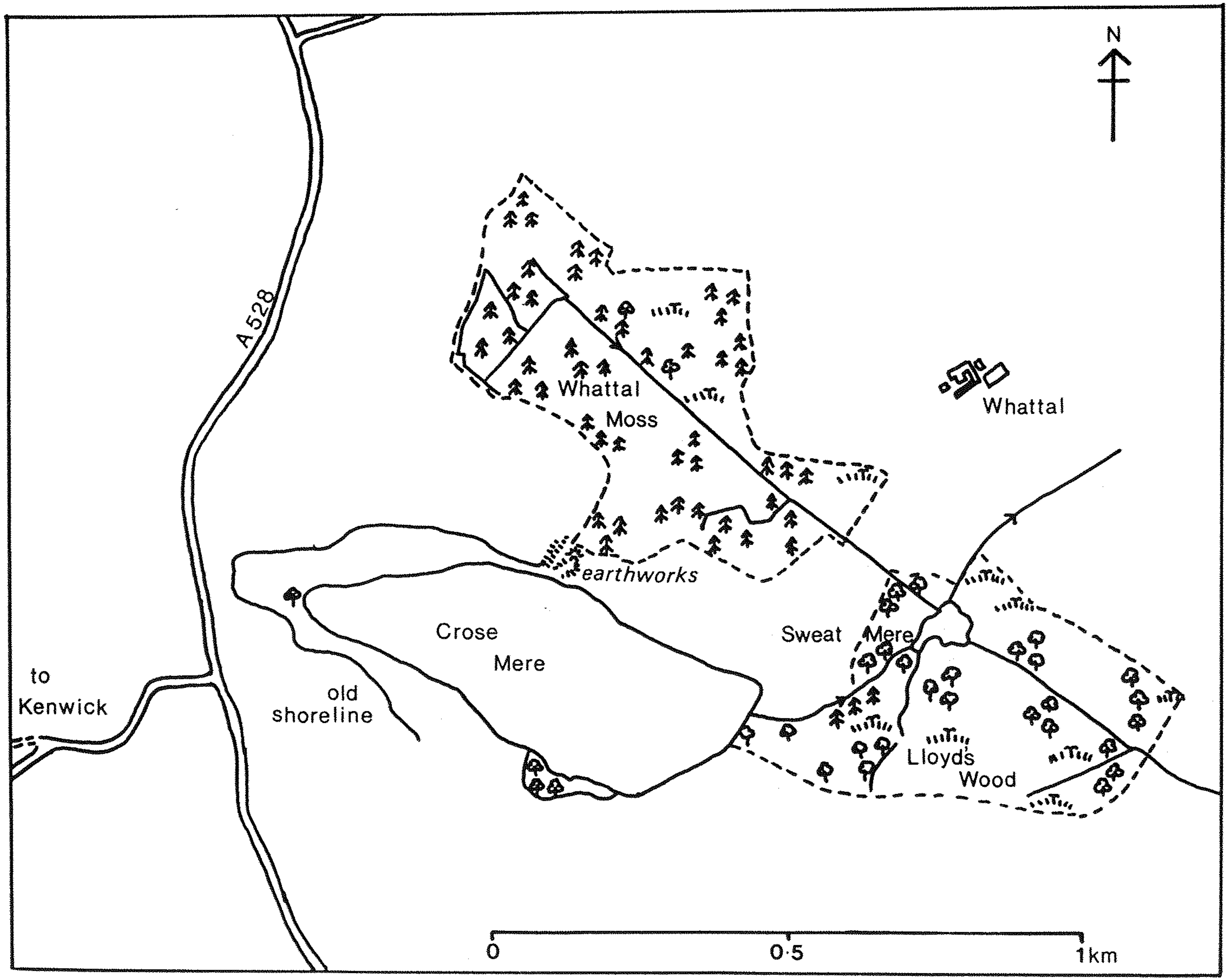


Figure 12   Present day map of the Crose Mere complex

which overlie impermeable till. Only small amounts of surface water are supplied in particularly wet weather via three ditches on the southern shore or by direct precipitation on the lake (Bonny and Allen 1984). These three ditches, shown in figure13 are artificial and have different characteristics. The main "inflow" nearest the eastern end of the mere had a sandy sediment deposited on its bottom. The 5cm or so of water in the ditch in early April 1990 was swiftly flowing suggesting that this could be an area of considerable inflow during wet weather. The second ditch was very silty and shallow (2cm compared to the previous 5cm). Neither of these ditches appeared to be heavily polluted. The third ditch, however, contained a large proportion of reducing bacteria, seen by the rusty-red marks along the banks and oily film on the almost stagnant water. These anaerobic bacteria indicate that this inflow ditch may discharge untreated animal sludge or fertiliser into the mere. However, the quantity discharged into the mere per annum would not be sufficient to cause pollution of the mere to any significant degree.

As Crose Mere is fed by groundwater rather than by surface drainage, there is no streamborne pollen component (Gorham 1957). It is probable that there is a steep gradient in the intensity of pollen input away from the shore of a lake (Bonny and Allen 1984). Reynolds (1979) attempted to quantify the hydrological input into Crose Mere from indirect observations and hypothesised that Crose Mere is isolated by an impervious seal over which ground water inspills into the mere. The largest change in water level of the mere during the year of 1974 was 13cm (maximum depth 9.21m, minimum depth 9.08m)(Reynolds 1979) but this cannot be directly related to the study of lake level fluctuations during the Holocene as the recent additions of inflow ditches and an outflow stream are likely to be playing a major role in the 1974 measurements.

An inflow once connected Crose Mere to Whattal Moss, flowing into Crose Mere half way along the northern shore. It is improbable that this inflow is natural given the

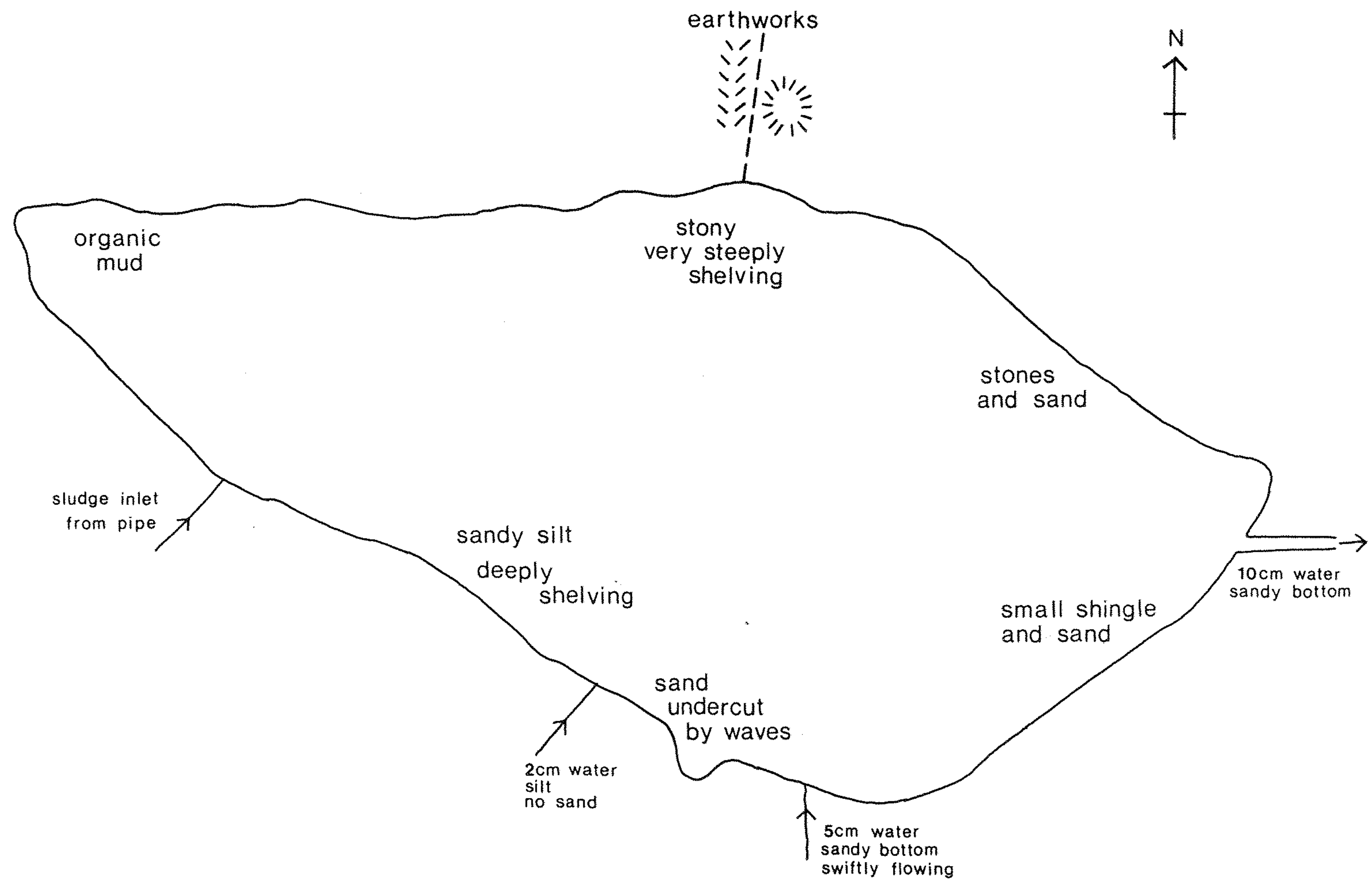


Figure 13 Description of superficial sediment in Crose Mere

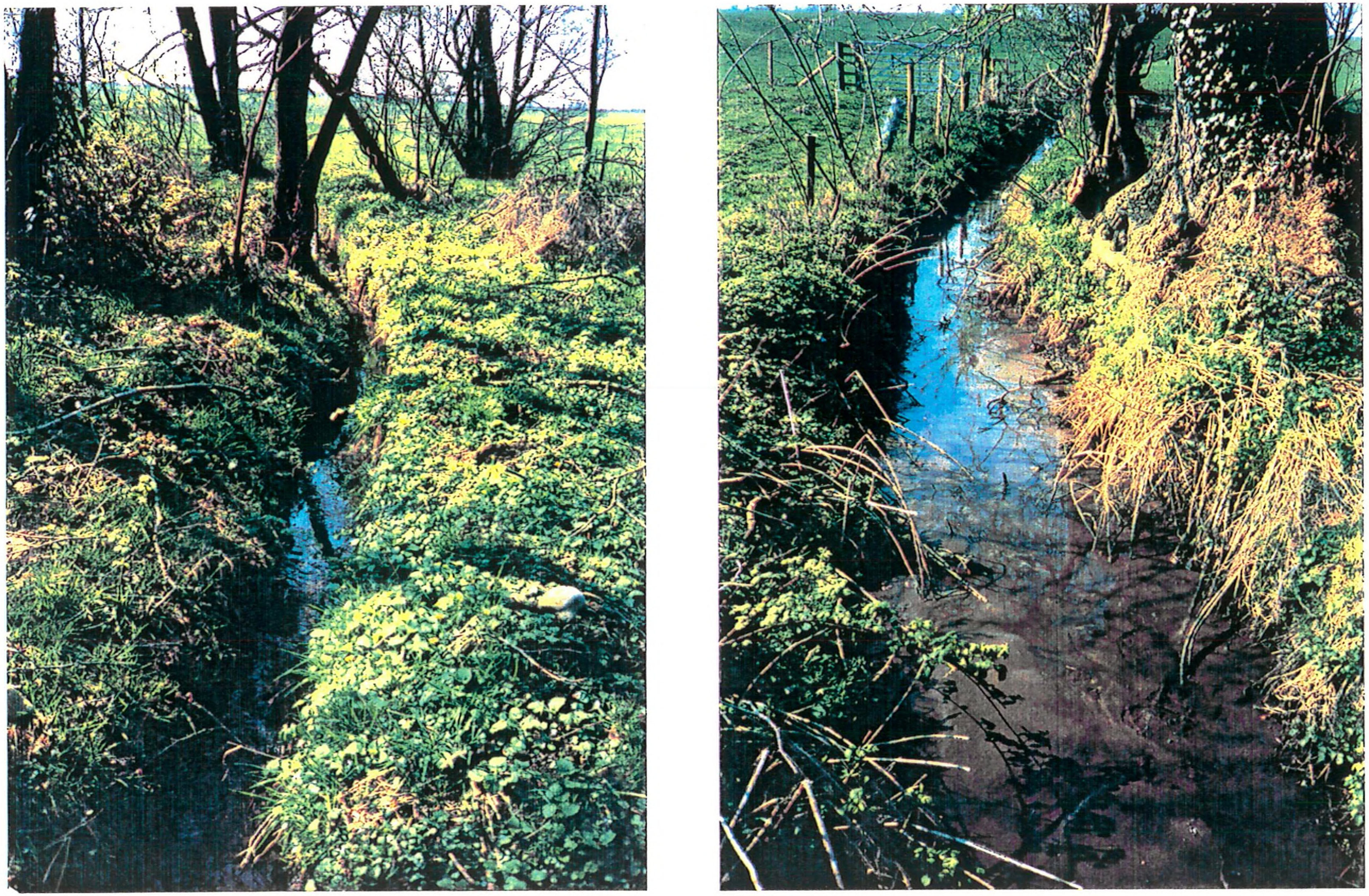


Plate 1 Two inflow ditches situated on the southern shore of Crose Mere

View of Crose Mere taken from the earthworks. hawthorn bushes indicate the site of the former inflow.

Site of outflow connecting Crose Mere to Sweat Mere (fence marks the position of the outflow)

Plate 2

Plate 3

Outflow ditch connecting Crose Mere to Sweat Mere

Earthworks seen from the south shore of Crose Mere geomorphology of the surrounding area and it was probably dug to drain Whattal Moss into Crose Mere so that the Moss could be used for cultivation or grazing purposes. The present day outflow connecting Crose Mere with Sweat Mere contained approximately 10cm of water in April 1990 but was quite capable of holding a much greater amount of water if necessary (plate 3). The sediment deposited in the outflow stream is sandy for approximately 20m from the mere and then graduates through sandy silt to an almost pure organic sediment as it enter Lloyd's wood. Extensive *Typha* rhizomes and dense stands of *Phragmites communis* extend for 10m or so along the outflow, which is lined along its banks by hawthorn and elderberry bushes.

The eastern end of the mere is most subject to disturbance by wave action (Bonny and Allen 1984) and the littoral sediments here include areas of sand, gravel and stones (figure 13). The stones decrease in size along the south-eastern shores, grading into a fine sand along the south shores of the mere. The only place where predominantly organic sediments accumulate is in the sheltered western bay, these organics giving way to stones and rocks on the northern shore, which shelves very steeply about 1.5m from the waters edge. This pattern of sedimentation greatly affects the distribution of reedswamp species as can be seen in the following section.

3.8.2 Present day vegetation

The lake is relatively well sheltered from wind action and the presence of alder carr along part of the shore will increase this shelter (figure 14). The tree cover around the mere is not continuous, the dense alder/willow scrub at the western end of the mere giving way to larger, more sparsely distributed alders which decrease in size and density going alond the northern shore. The trees cease before the earthworks and there is a treeless zone until a group of old mature alders with stilt roots and occasional hawthorn bushes and ash trees are recorded beyond the earthworks. An isolated patch of immature alders and

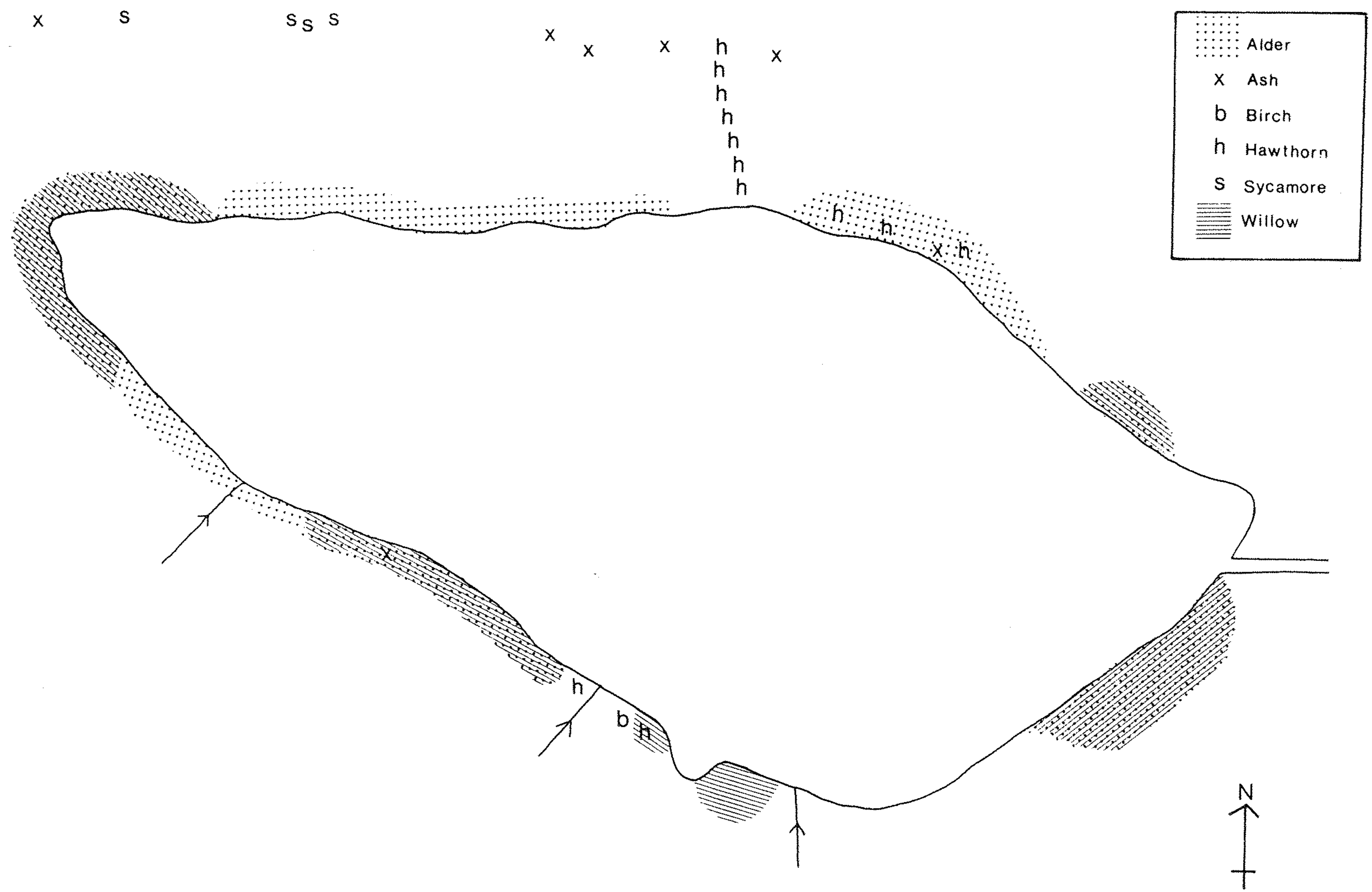


Figure 14 Distribution of trees around Crose Mere

willows occurs towards the northern end of the mere.

There is a cluster of dense, mixed age alders and willows situated around the outlet at the end of the mere. This is followed by another treeless stretch concluding with a dense alder/willow scrub around the boat house. This area contains the highest percentage of willow found around Crose Mere. The eastern shores are characterised by a belt of very large mature alders with stilt roots growing near the mere and some young alders growing on the landward side of the mature alders. The height of these stilt roots is about 1m as opposed to the stilt roots of approximately 30cm on the northern shores.

The predominantly minerogenic sediment suggests high rates of mineral sedimentation and/or low organic productivity. Organic compounds found in Crose Mere are derived mainly from algal diagenesis, while products from higher plants are relatively scarce (Cranwell 1977, 1978). The littoral of the sandy southeast shore of Crose Mere is bare as is the exposed stony northeast shore. The remainder of the lake shows varying amounts of reed swamp development. Limited areas of alder carr also occur.

On the northern shore of Crose Mere heavy cattle grazing has deflected the normal hydrosere from tall sedge fen to a rich fen-pasture (Sinker *et al.* 1985). The grazed fen found at the lake margin of Crose Mere (SJ 434304) consists of *Carex lepidocarpa, Epilobium parviflorum, Juncus subnodulosus, Parnassia palustris* and *Phragmites communis.* The tall fen on the lake margin of Crose Mere (SJ 434305) is composed of *Agrimonia eupatoria, Dactylorhiza majalis ssp praetermissa, Juncus subnodulosus, Phragmites communis, Sonchus arvensis, Stachys palustris* and *Vicia cracca* (Sinker *et al.* 1985). Leighton (1841) recorded the following species from Crose Mere lake itself; *Littorella lacustris, Cladium mariscus, Utricularia vulgaris, Phragmites communis, Calamagrostis lanceolata, Cuscuta epilinum, Parnassia palustris, Spergula nodosa, Carex paniculata* and *Cicuta virosa.*

Cladium mariscus was also recorded from the southwest margin of "Croesmere Mere" by J.E. Bowman Esq. (Leighton 1841). There was no mention of *Scirpus lacustris* at Crose Mere around this time.

Crose Mere has a very disjunct marginal macrophyte zone, this only occurring in any density at the sheltered western end of the lake. There are occasional patches of *Phragmites communis* along the northern shore, and tussocks of *Carex paniculata* at the eastern end of the lake but these patches would be insufficient to stabilise the margins. The presence of the isolated tussocks of *Carex paniculata* at the eastern end of the lake are interesting in that they suggest that the level of the lake was once lower than its present day level.

The three major reedswamp species; *Phragmites communis*, *Typha latifolia* and *Cladium mariscus* have a very distinctive distribution (figure 15). When this present day distribution is compared to the distribution of reedswamp species in 1971 and 1975 (Reynolds 1979) it can be seen that there has been considerable variation in the distribution of dominant reedswamp species during the past twenty years. This variation is probably a natural phenomenon and indicates how quickly vegetation responds to changes in lake status, exposure or degree of competition between neighbouring stands of differing species. The implications of this variation for macrofossil analysis will be discussed in section 8.6.5 p219 . *Cladium mariscus* has increased along the southwestern and northwestern shores and also in the western bay. *Phragmites communis* also appears to be on the increase at the western end of the mere, although it is diminishing along the southern shores where it is being replaced by fragmented patches of *Typha latifolia* and *Cladium mariscus*. There has been little change in the amount of *Typha latifolia* over the years except for a slight increase at the eastern edge of the mere. No *Scirpus lacustris* was recorded in April 1990 but judging from the macrofossil diagram this is likely to be as a direct

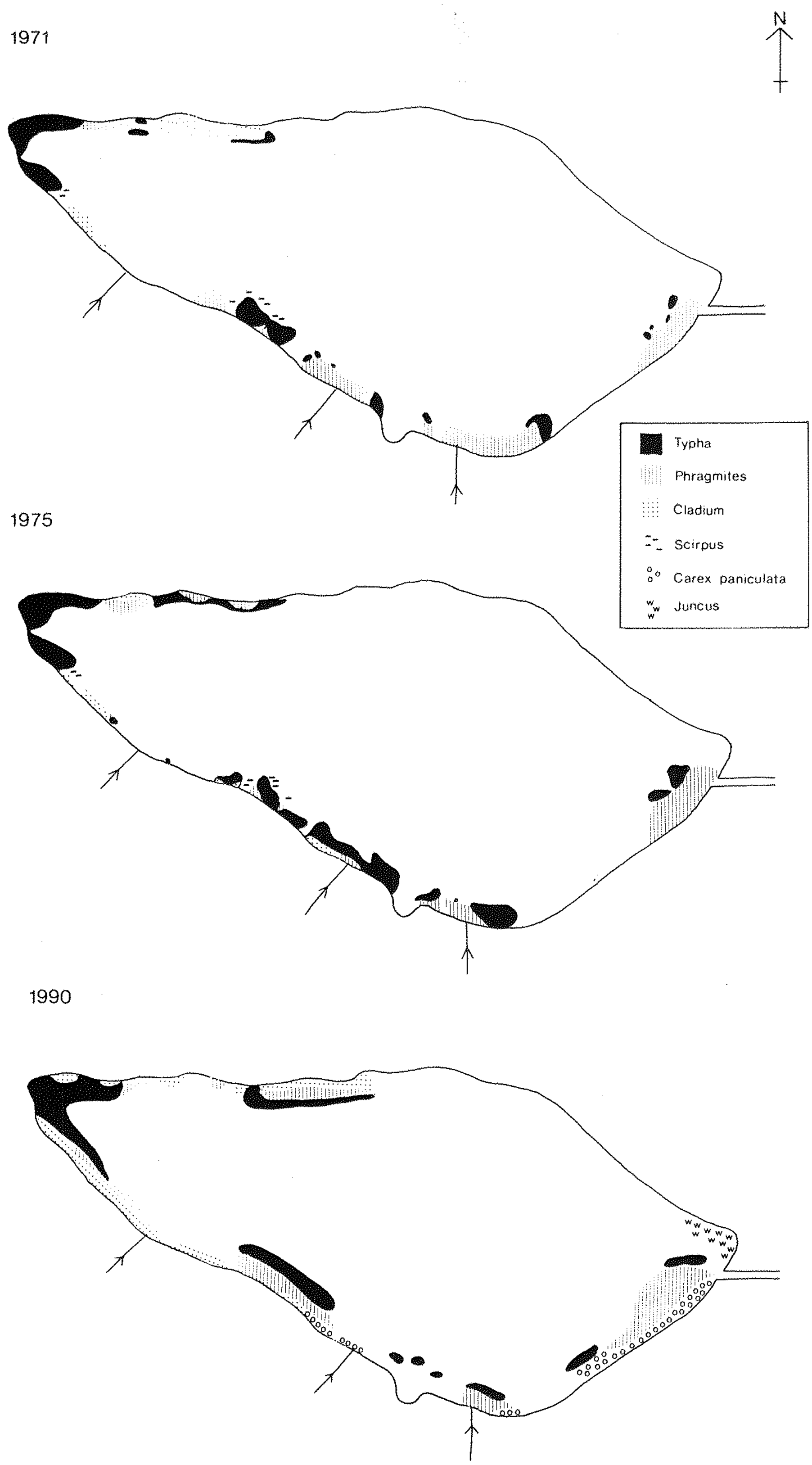


Figure 15

Distribution of marginal macrophytes in Crose Mere (a & b from Reynolds 1979).

result of the time of year at which the vegetation study was carried out rather than an indication that this species no longer colonises Crose Mere.

3.8.3 Present day use of land surrounding Crose Mere

Most of the fields around Crose Mere are under permanent pasture. Those to the south are grown chiefly for hay or silage and are usually cut in June before the meadow grasses are in full flower, so the grassland around the mere is relatively unproductive in terms of pollen (Bonny and Allen 1984). Arable land within 1km is used mainly for cereal crops.

3.8.4 History of Crose Mere and its surrounding land

There is a strip of peatland up to 150m wide around all the shores of Crose Mere, except the northeast shores, this attesting to the former extent of the lake. The earthworks on the northern shore of Crose Mere could have been built for the protection of prime fishing grounds in a time when Whattal Moss was still under water, but as no datable material was found during excavation of the earthworks (Peake 1909), there is no definite evidence as to the date of the structure. A dugout canoe was found during the drainage operations (Chitty 1927). Nothing was found with the canoe except a wooden baler and there was no evidence for dating them, although Fox (1926) suggests that they may have been Roman.

A road or track was once built from the "main" Shrewsbury Ellesmere road along the top of the gravel ridge to the earthworks at Stockett and then down to the edge of the lake. This can be seen on the first edition Ordnance Survey (1833) map of the area. It is unlikely that this road was built specifically to take boats down to the mere and may have been built for the frequent carting of something heavy either to or from the mere or the earthworks. This may have been gravel used in the building of the earthworks. Another possibility is that it was just a means of linking the earthworks to the main Ellesmere - Shrewsbury road and to the mere.

3.9 Fenemere

grid ref SJ 446229
area 9.4ha
max recorded depth 2.2m
estimated catchment area 940 ha

3.9.1 Topography

Fenemere is one mere in a group of four, collectively known as the Baschurch Pools (figure 16). Marton Pool is the closest mere to Fenemere being separated by approximately 100m at their closest points. Birchgrove Pool lies to the northwest of Fenemere and Marton, and Berth Pool, situated to the northwest of Birchgrove Pool, completes the foursome.

It is almost certain that during the late Devensian and early Holocene periods a single sheet of water existed in the basin now occupied by Marton Pool, Fenemere and Birchgrove Pool (Cannell and Harries 1981) and pollen analysis of the peat that has accumulated between Marton and Fenemere suggests that this peat began to accumulate from the early Boreal period (Godwin 1975) c.7000 BC (Twigger 1988). Below this peat a light yellowish brown calcareous mud occurs, overlying yellow sand. Several field drains flow into Marton Pool and Fenemere but the ditch linking Birchgrove and Marton to Fenemere is the only major stream flowing into the north end of Fenemere (figure 16). This inflow is fairly large, has a silty substrate and is overgrown, the dominant species being *Phragmites communis* (plate 4).

Fenemere is a slightly smaller lake than Crose Mere and has a very different basin shape, the deepest water (2.2m) being found in the centre of the basin. The mere lies in

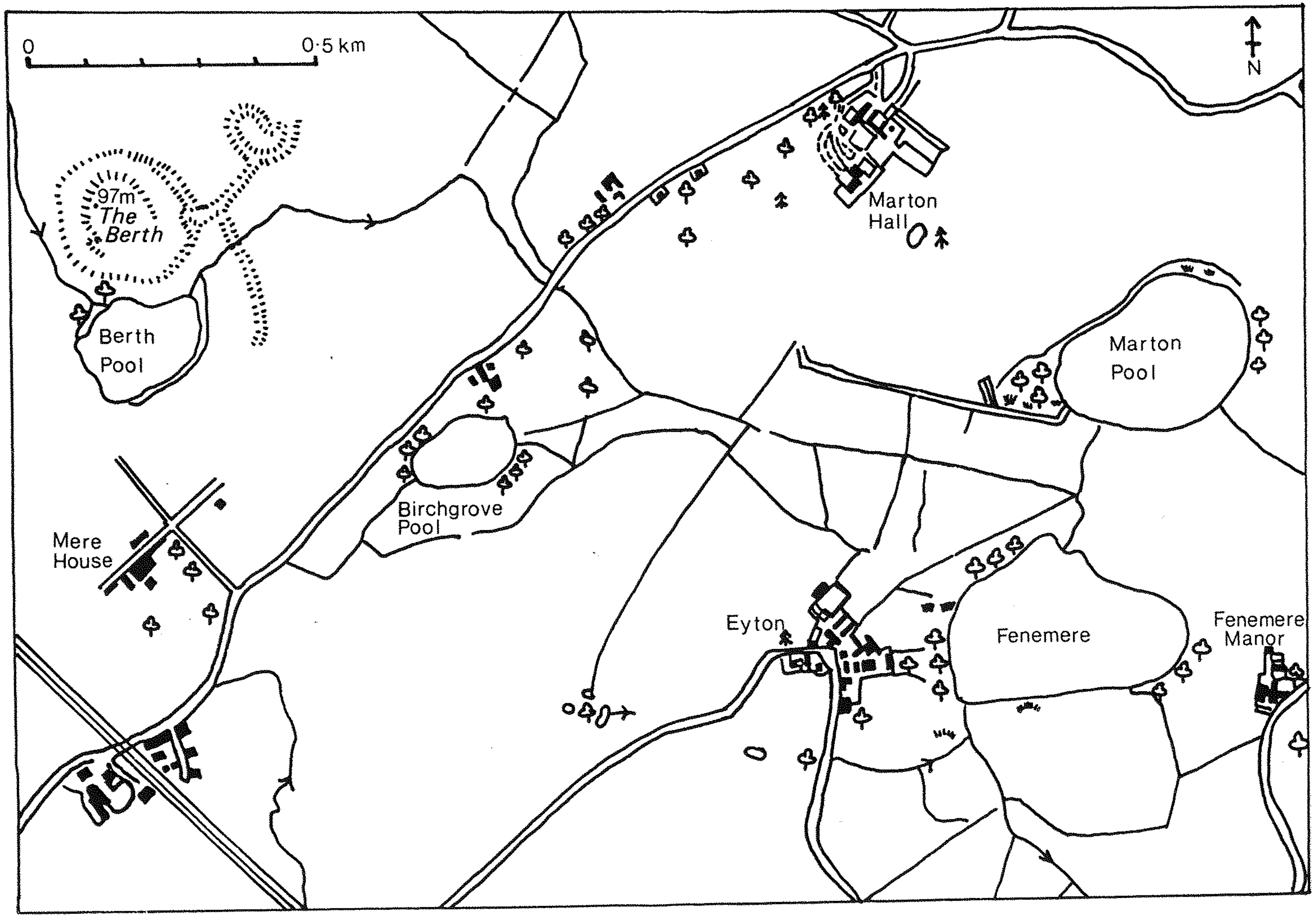


Figure 16   Present day map of the Baschurch Pools

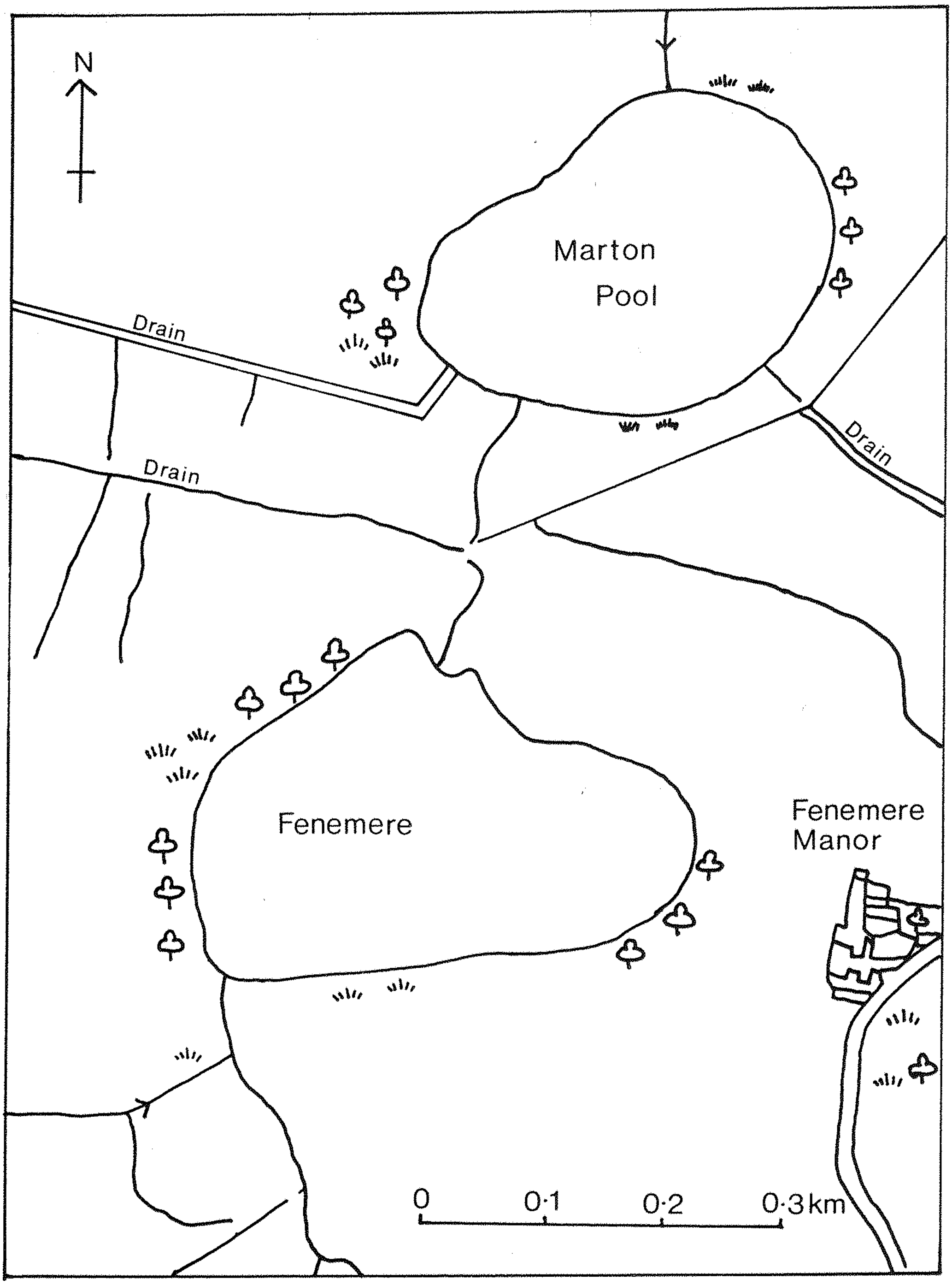


Figure 17 Map of Fenemere showing the present day drainage ditch system

Plate 4 Ditch linking Marton Pool to Fenmere

Plate 5 Outflow from Fenemere to War Brook

generally flat ground with very little slope or hills until the Berth, an iron age fort on the edge of Berth Pool, is reached. There is one outflow on the southwest side of the mere and it seems probable that this outflow is natural given the lie of the land and the appearance of the outflow channel (plate 5). Fenemere's drainage ditches have changed little since Domesday (Eyton 1860) as the maps of this area printed in Domesday time show little variation around Fenemere from those maps of today and it is possible that the outflow channel may have been in existence several thousand years before present day.

3.9.2 Present day vegetation

Most of the shoreline of Fenemere is colonised by a tree covered belt of vegetation up to 5m wide. The dominant tree species are *Alnus glutinosa, Salix fragilis* and *Salix cinerea* and their distribution is shown in figure 18. The western end of the mere is bordered by rich fenland characterised by hummocks of *Carex paniculata, Iris pseudocorus* and areas of stagnant water. The northern shores of Fenemere appear to have been grazed at the western end giving rise to telmatic species *eg Caltha palustris, Iris pseudocorus* and *Filipendula ulmaria* whilst the northeast and eastern fields are ploughed, leaving little of the natural vegetation intact. The southern fields are also ploughed but a greater belt of natural vegetation remains between the mere and the field (10m wide as against 2m on the northeastern side). This belt of vegetation consists chiefly of an understorey of brambles and nettles.

There is also an almost continuous zone of marginal macrophytes which will stabilize the sediments that have been deposited at the lake margins, therefore minimising erosion and redeposition of marginal sediments. The major reed species in these areas are *Typha angustifolia, Phragmites communis* and *Carex acutiformis*. *Nymphaea alba* and *Nuphar lutea* form extensive beds along the western and northern shores but are restricted in

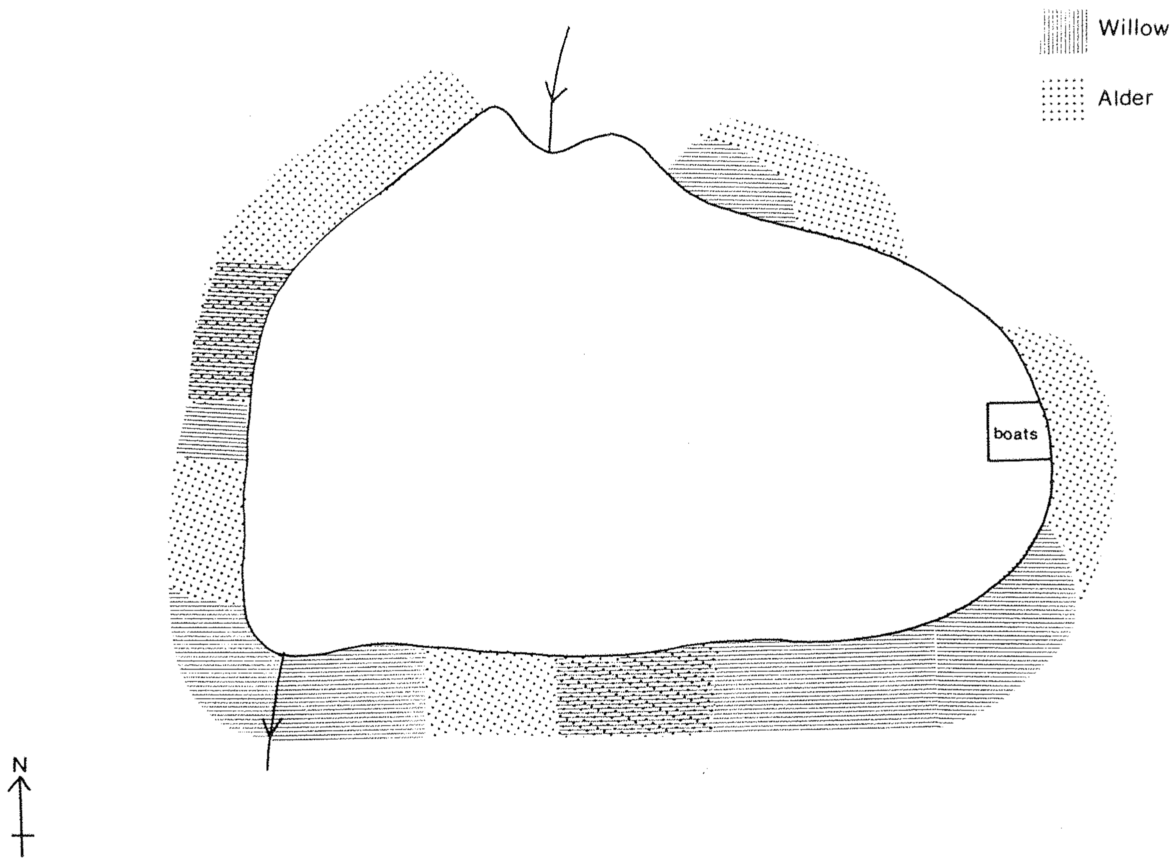


Figure 18 Distribution of trees around Fenemere

occurrence along the southern shores and are absent along the eastern edge of the mere. There is an area of the eastern shore that is completely bare, probably because of the stony sediments (figure 19). As the stones grade into sand, the area is colonised by *Epilobium hirsutum* and *Juncus species* before the reedswamp characteristic of the remainder of Fenemere reappears (figure 20).

3.9.3 Present day use of land surrounding Fenemere

The land surrounding Fenemere today is largely cultivated as pasture for cows and other livestock, although the field adjoining the southeast margin of the mere has been ploughed recently. The mere itself is very popular with fishermen and jetties have been built at various places along the margin of the mere to facilitate the launch of boats and ease of fishing.

3.9.4 History of Fenemere and its surrounding lands

Fenemere was saved the fate of so many similar shallow meres of Shropshire during the seventeenth Century as it bordered the estates of two of the land owners (Gough 1979). The boundary line actually runs through the middle of Marton Pool and it is probably Fenemere's position in relation to this boundary which prevented it from being drained to provide extra land for pasture or cultivation (Gough 1968, 1979, Eyton 1860). Other than this mention of landownership concerning Fenemere, the mere is rarely mentioned in old documents and, consequently, appears to have been considered of little importance to the economy and lifestyle of previous generations of owners.

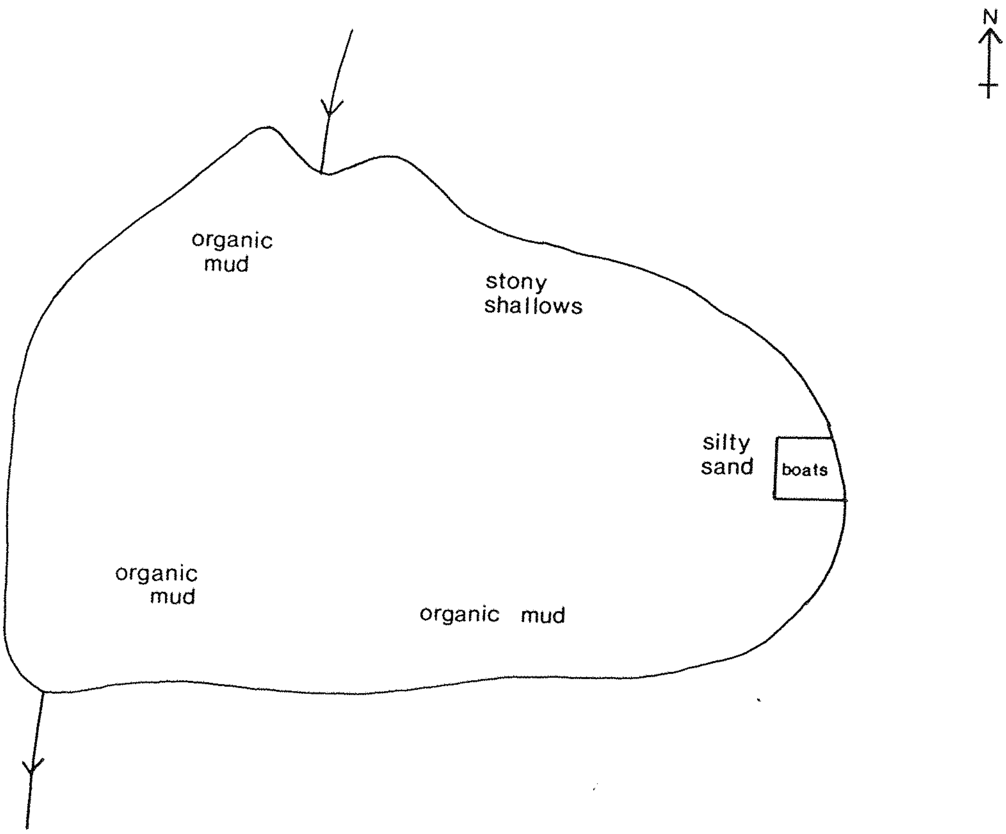


Figure 19 Description of superficial sediment in Fenemere

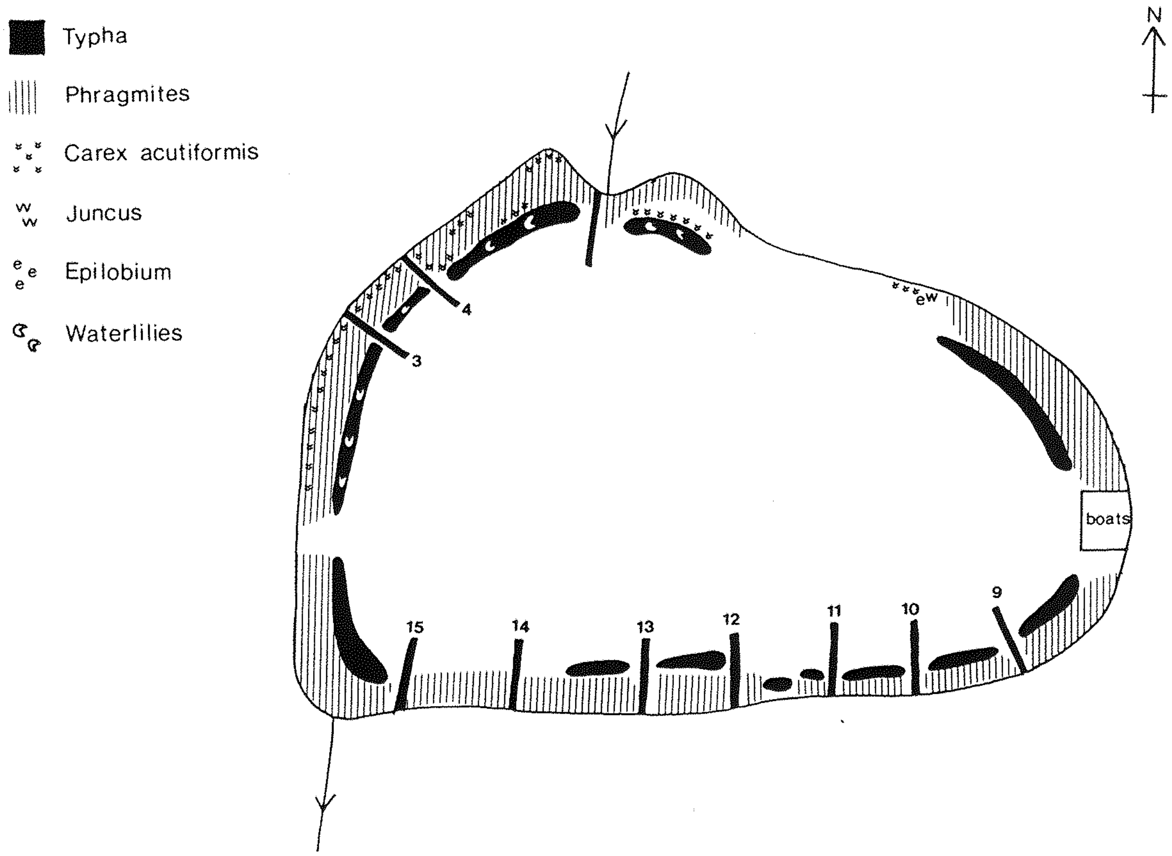


Figure 20

Distribution of marginal macrophytes in Fenemere

Chapter 4 METHODS

4.1 Introduction

There are many varied methods used in the reconstruction of palaeoclimatic changes and the majority of these are summarised in Bradley (1985). Several different methods utilised in the reconstruction of Quaternary environments are presented by Lowe and Walker (1984) and Birks and Birks (1980), and the reconstruction of past vegetational communities is outlined in Barber (1976). Therefore, only the methods relevant to the present study of lake level fluctuations in lowland Central England are described here.

4.2 Sampling procedures in the field

Lake sediment and peat cores for pollen, loss on ignition and magnetic mineral analyses were taken using a modified 50cm x 5cm Russian corer (Barber 1976). Samples for macrofossil analysis and radiocarbon dating were taken using a 30cm x 10cm large diameter Russian corer (Barber 1984). The stratigraphy of the cores was recorded in the field and any stratigraphic changes photographed before the cores were extruded into labelled plastic drainpipe sections of semi-circular cross section. The cores were then wrapped in aluminium foil and resealable polythene bags prior to relabelling. On return to the laboratory the stratigraphy and composition of the sediments were re-examined and then the cores stored in refrigerators at $4^{o}C$ to prevent microbial growth.

Contamination was removed in the field, particularly the removal of fresh plant material from the surface of the cores and from the lower end of the core sections where modern material dragged down by the corer can be incorporated in the sample when the core chamber is rotated.

The lake cores were collected using two rubber dinghies tied together at their sterns and secured to the land in two places. An anchor was used to provide a third anchorage point in the lake itself. The cores were then taken between the two boats using the modified 50cm x 5cm Russian corer previously mentioned.

At each site a coring transect was marked from the edge of the old lake basin, where visible, towards the centre of the mere, and cores taken at equally spaced intervals wherever possible although the density of *Phragmites* and presence of extensive root systems of *Alnus glutinosa* made coring in certain places impossible (figures 21 and 22). The positions of these cores were then recorded on maps, and their position in the field marked with small fluorescent posts. Cores for macrofossil analysis were taken at the mere margins as the displacement of reed vegetation occurring as a result of water level changes would most probably be recorded here. Cores were not taken for radiocarbon dating for the reasons stated in sections 5.1 and 5.4.

4.3 Laboratory procedures

4.3.1 Stratigraphy

The stratigraphy of the cores was recorded in the field and then supplemented by laboratory observations. Photographs were taken in the field of the major stratigraphical changes. General descriptions were given alongside the Troels-Smith (1955) comprehensive field description system, which describes the three major properties of the sediment; its physical properties, humification and composition (Birks & Birks 1980). For all three classes of parameters a five point scale (0-4) is used for characterisation, 0 implying absence of, and 4 the maximum presence of, or sole occurrence of, the element concerned (Aaby & Berglund 1986).

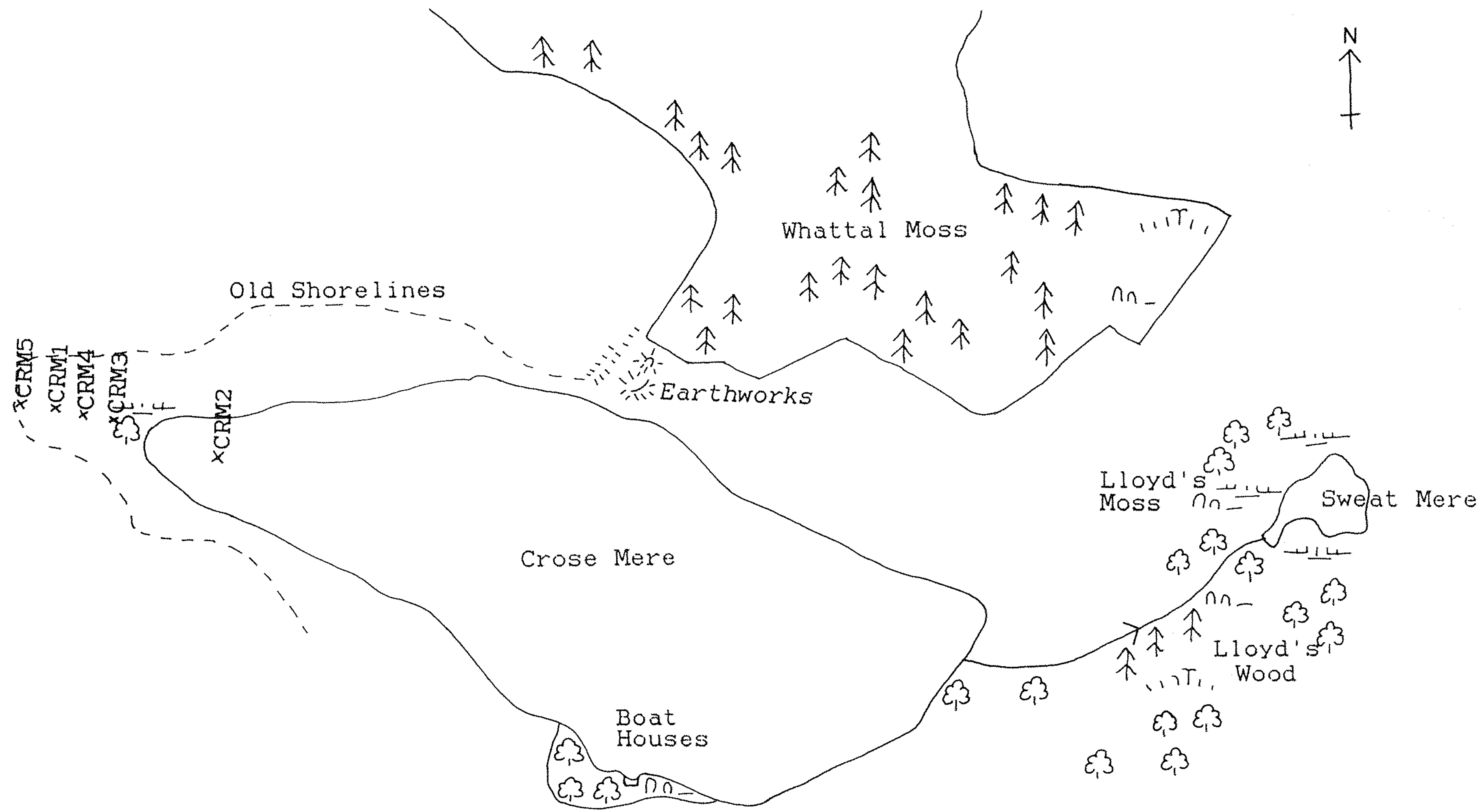


Figure 21 Position of the coring transect at Crose Mere

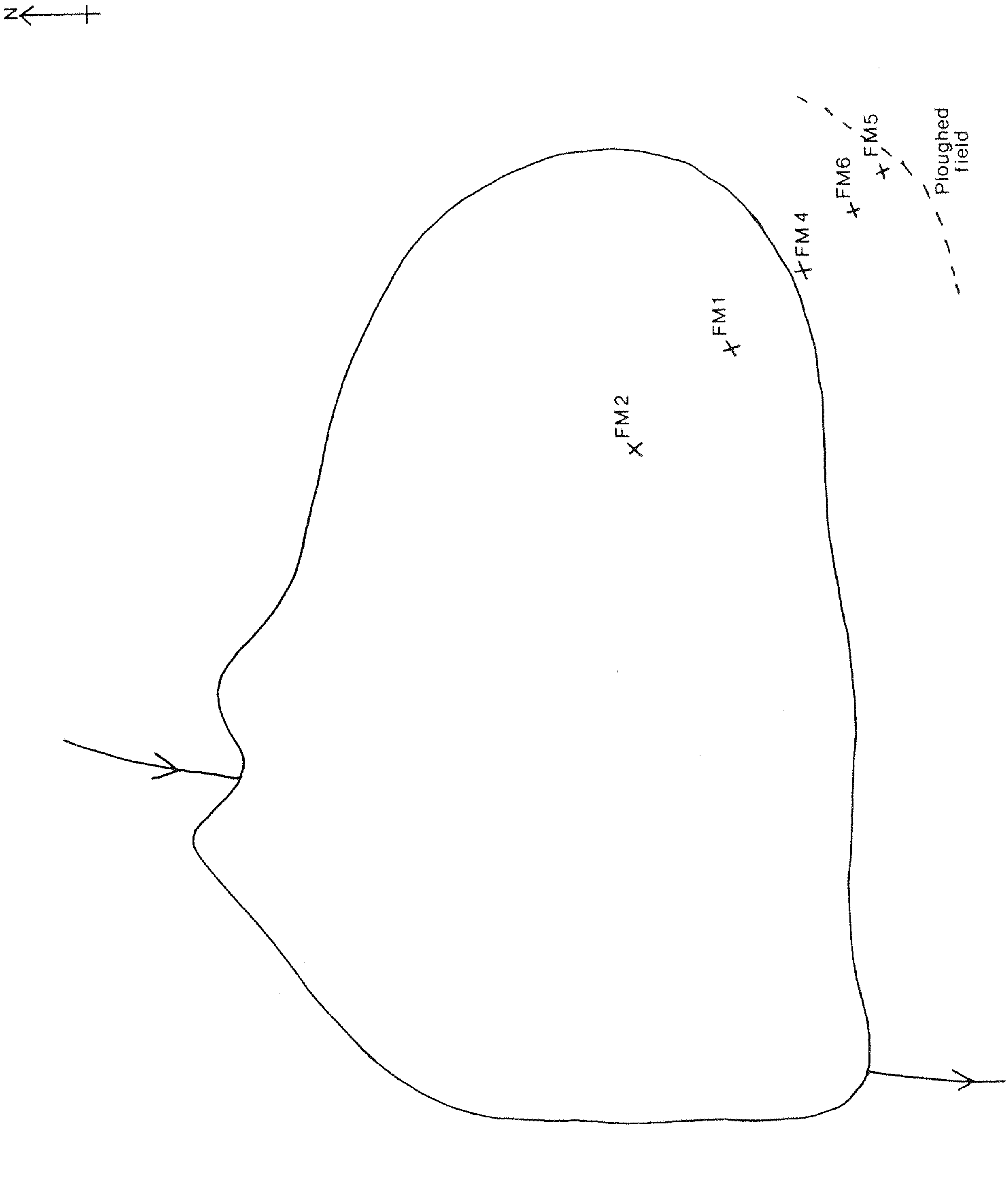


Figure 22 Position of the coring transect at Fenemere

COLOUR STRATIGRAPHY	TROELS-SMITH DESCRIPTION	GENERAL DESCRIPTION
	Nig3 Strf0 Elas1 Sicc2 Humo1 $Ld^{3}4$	Very dark and humic
	Nig2 Strf0 Elas2 Sicc2 Humo2 $Ld^{2}4$	Brown lake mud
	Nig1 Strf1 Elas3 Sicc2 Humo3 $Ld^{1}4$ Ag+	Yellow sandy band
	Nig2 Strf1 Elas0 Sicc2 As4	Clay
	Nig3 Strf2 Elas0 Sicc2 Ggmaj4 Ggmin+	Gravel

Figure 23

Comparison of colour stratigraphy with Troels-Smith descriptions

4.3.2 Loss on Ignition

The nickel crucibles used during the loss on ignition procedures were heated to 100 ^{o}C for thirty minutes, allowed to cool in a desiccator and then weighed prior to the addition of the sediment. Samples of wet sediment of approximately 10g were taken every four centimetres, weighed to find their fresh weight, and then oven dried for 12 hours at 100 +/- 5 ^{o}C. The samples were allowed to cool in a desiccator before being reweighed. They were then ignited in a muffle furnace for three hours at 550 +/- 50 ^{o}C, cooled in a desiccator and reweighed. The percentage weight lost on ignition was then calculated as a measure of organic content (Allen 1974), using the formula;

$$\%LOI = \frac{\text{dry weight} - \text{final weight}}{\text{dry weight}} \times 100$$

Oxidising agents such as hydrogen peroxide (Brown 1983, Birks & Birks 1980, Bengtsson 1982, Bengtsson & Enell 1986) were not needed as no organic material remained after three hours ignition. The loss on ignition values obtained using this method may be a little on the high side as they could include some water from clay minerals which will not evaporate until the temperature reaches 300 ^{o}C or more (Skempton & Petley 1970). Inspection of the residues from loss on ignition revealed the presence of mollusc remains in a few samples, giving a slightly increased estimation of the amount of minerogenic material in the samples. However, close examination of the stratigraphy and loss on ignition curves showed that molluscs were not present in the parts of the loss on ignition curve that were important in the reconstruction of sediment limit and so it was not thought necessary to analyse the samples for calcium carbonate content.

4.3.3 Particle Size Analysis

Approximately 5g of wet sediment was wet sieved using four nesting sieves of mesh sizes 1000, 500, 250 and 180um. The coarse fraction was taken to include the sediment retained by the 1000, 500 and 250um sieves whilst the remaining sediment was classified as "fine". The two fractions were oven dried at 40^{o}C to evaporate the water and then analysed for loss on ignition using the above procedure.

The results of this analysis indicated that the vast majority of the particles were less than 250um and so it was decided that an electrical sensing zone method would give more accurate results. A Coulter counter (model TAII) with a 280um aperture tube was used as this gave 13 operative channels with a 55um size range from 5.6-108um. This was calibrated at regular intervals as described by Whalley (1981). The Coulter Counter works on a principle where particles suspended in an electrolyte pass through a small aperture with electrodes on both sides. Passing particles displace their own volume of electrolyte whereby the resistance in the current is changed in proportion to the volumetric size of the particles. The number of changes per unit time reflect the number of particles per unit of volume in suspension (Hakanson and Jansson 1983).

4.3.4 Macrofossil Analysis

The size of the samples analysed varied from site to site depending both on the depth of the cores and on the size of corer used. Samples from Crose Mere consisted of contiguous 10cm sections of cores taken with the 50cm x 5cm modified Russian corer, whereas the Fenemere samples were composed of contiguous 5cm sections of cores taken with the 30 x 10cm large diameter Russian corer.

The volumes of these sections were measured in dilute nitric acid (8%) using a 500ml measuring cylinder. The samples did not disaggregate when left to stand in distilled water or when a strong jet of water was used during the sieving procedure. 10% sodium hydroxide solution left the fruits and seeds charred and mucilaginous and 8% potassium hydroxide had a similar effect when warmed. It was found that dilute nitric acid (8%) disaggregated the samples best and with least damage (Godwin 1975). Plant remains were a lighter brown colour at the end of the procedure but the condition of the fruits and seeds had not deteriorated. They also floated to the surface of the liquid so making the sieving process easier and less time consuming.

The samples were left overnight in dilute nitric acid and then washed through 500um and 250um sieves. A 125um sieve was also used initially but retained few identifiable plant remains and these were of little value in terms of reconstructing the marginal reed vegetation.

The sieve residues were scanned systematically under a Nikon stereozoom microscope (SMZ-10) and any identifiable plant remains picked out with a thinned sable hair paintbrush or watch maker's tweezers and placed in vials to await identification. A solution of 50:50 ethanol:distilled water was added to each of the specimens to prevent microbial attack and subsequent deterioration of the material. Fruits and seeds were identified from manuals and diagrams (Palmer 1916, Bertsch 1941, Beijerinck 1947, Jessen 1955, Martin & Barkley 1961, Berggren 1969, 1981, Swarbrick 1970, Godwin 1975, Weber 1978, 1979, 1980) using reference collections of both modern and subfossilised fruits and seeds. I started to build a modern seed reference collection at Southampton University in 1987 and this now contains seeds from all over the British Isles. This reference collection followed the guidelines laid down by Jensen (1979) for setting up reference collections and consists of approximately 500 species. *Potamogeton* leaves were identified using mounted specimens from the herbarium, Durham University.

Macrofossil diagrams were drawn up using a specially written computer program (J. Milne unpublished) with the number of seeds counted being adjusted to give the number of seeds per $100cm^3$ sediment. Unidentifiable plant remains were classified as monocotyledonous, dicotyledonous, wood or moss wherever possible but these results were not used in further analyses.

4.3.5 Pollen Analysis

Samples of sediment, $1cm^3$ were taken primarily at every 32cm and then this interval was reduced to 16cm,8cm and then 4cm where necessary. The length of the cores and the fact that the main purpose of pollen analysis in this study was to correlate the cores, not provide an accurate reconstruction of vegetational communities from each core, were the governing factors in the choice of coarse sampling intervals.

The preparation of the pollen followed the procedure set out by Barber (1976). It was found, however, that the standard procedure for the isolation of pollen grains from peat sediment resulted in thick, dark clumps of pollen and debris on the slide. The reason for this clumping is not known but the addition of a drop of detergent after acetylation did not alleviate this problem. The use of warm sodium pyrophosphate (Bates, Coxon & Gibbard 1978) had little effect on the preparation so it appeared that it was not clay that was causing the clumping. Samples still exhibited some clumping after the use of fine meshed sieves recommended in cases of very minerogenic sediment (Cwynar, Burden & McAndrews 1979) and the use of ultrasonics to disaggregate the clumps once they had formed was ineffective. Several washings with 60% hydrofluoric acid reduced the dirtiness of the slides but was considered too dangerous for use under normal laboratory conditions. Eventually, it was found that repetition of the potassium hydroxide stage up to ten times resulted in the most countable preparation, although the intensity of the chemical treatment resulted in slight corrosion of the pollen grains. Removal of the acetylation stage decreased the amount of clumping experienced and also reduced the blackness of the pollen clumps and made identification of the majority of the pollen grains in these clumps possible.

Pollen concentrations were calculated by the addition of three *Lycopodium* spore tablets to each sample (Stockmarr 1971). These spores were dissolved in dilute hydrochloric acid prior to the addition of the sediment sample to prevent further clumping of the pollen grains (Stockmarr 1971, Francis & Hall 1985, Tipping 1985, 1987).

The pollen grains were examined using a Nikon Optiphot microscope under x400 magnification, although x1000 magnification with oil was used for critical identifications. Unfamiliar pollen grains were identified using pollen identification guides (Erdtman 1954, Erdtman, Berglund & Praglowski 1961, Erdtman 1969, Faegri & Iversen 1975, Moore & Webb 1978) and pollen type slides. The slides were traversed at 1mm intervals. This meant that the majority of the slide had to be counted before the pollen sum was reached, thus counteracting the non-randomness of pollen grain types on a microscope slide (Brookes & Thomas 1967). The pollen sum was set at 500 total land pollen as this was considered to be most appropriate for tracing changes in regional pollen rain. Occasionally, the quality of the preparation, or the amount of pollen present in a sample made it necessary to stop counting short of the pollen sum, but this was avoided wherever possible. Relative frequencies of types within the sum were expressed as percentages of the sum, and those types outside the sum (spores, aquatics and unidentified/corroded) were expressed as a percentage of the sum plus their own sum.

Pollen concentrations were calculated using the following equation:

$$\frac{\text{Fossil pollen concentration}}{\text{Exotic pollen concentration}} = \frac{\text{Fossil pollen counted}}{\text{Exotic pollen counted}}$$

The concentration of total land pollen was calculated by multiplying the number of total land pollen grains counted by L/l where L = the number of Lycopodium spores added to the sample (approx 36,000) and l = the number of Lycopodium spores counted in the sample.

Pollen zones were zoned into pollen assemblages (Cushing 1964, Birks 1973) and named and described in accordance with Hedberg (1976). Local pollen assemblage zones were correlated with those described by Beales (1980).

Chapter 5 DATING AND CORRELATION OF CORES

5.1 Introduction

Beales (1976, 1980) obtained eleven radiocarbon dates on a central core taken from Crose Mere. Given the high mineral content of the cores taken from the edge of Crose Mere during this present study and the possibility of erosion and redeposition occurring at the margins of the lake, it was decided to correlate the five cores taken from the Western end of Crose Mere (figures 24 - 28) with the central core taken by Beales (1976, 1980) (figure 29) by pollen analysis and transfer the radiocarbon dates across.

5.2 Pollen Analysis from Crose Mere

The pollen diagram was zoned visually to correspond with the local pollen assemblage zones already obtained from Crose Mere (Beales 1980). The main pollen diagram was from CRM3 for which local pollen assemblage zones 1-4 were not represented in detail. The following local pollen assemblage zones were characterised thus:

CMCP-5 (bottom to 612cm) *Corylus avellana* LPAZ
Corylus avellana >30%
Quercus >10% in some samples
Contacts. Upper; *Pinus sylvestris* >10%
Quercus >10%
Lower; *Corylus* > *Betula*
Arboreal Pollen <50%
Age: 9136 +/- 210 to 8502 +/- 190 B.P.

CMCP-6 (612 to 548cm) *Pinus sylvestris-Quercus* LPAZ
Pinus 10-25%
Quercus >10%
Alnus present but <10%
Ulmus >5%
Tilia present

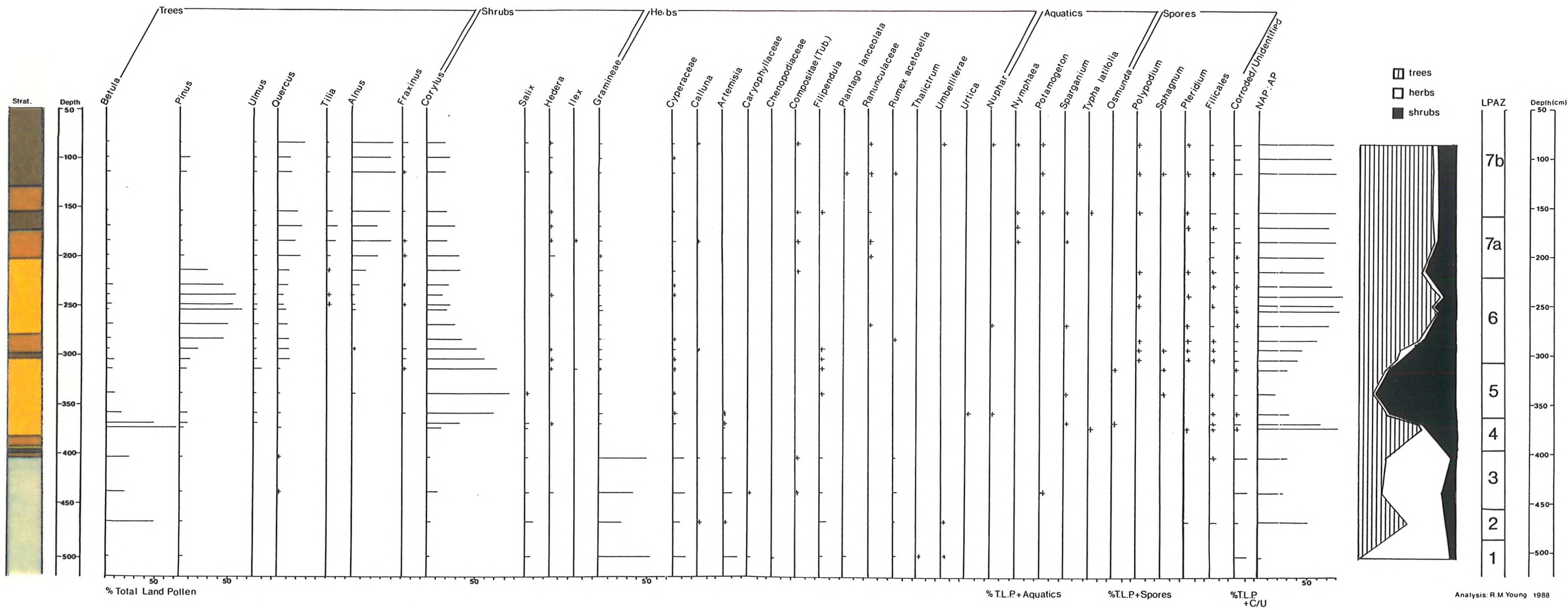


Figure 24 Pollen Diagram from Crose Mere (CRM1)

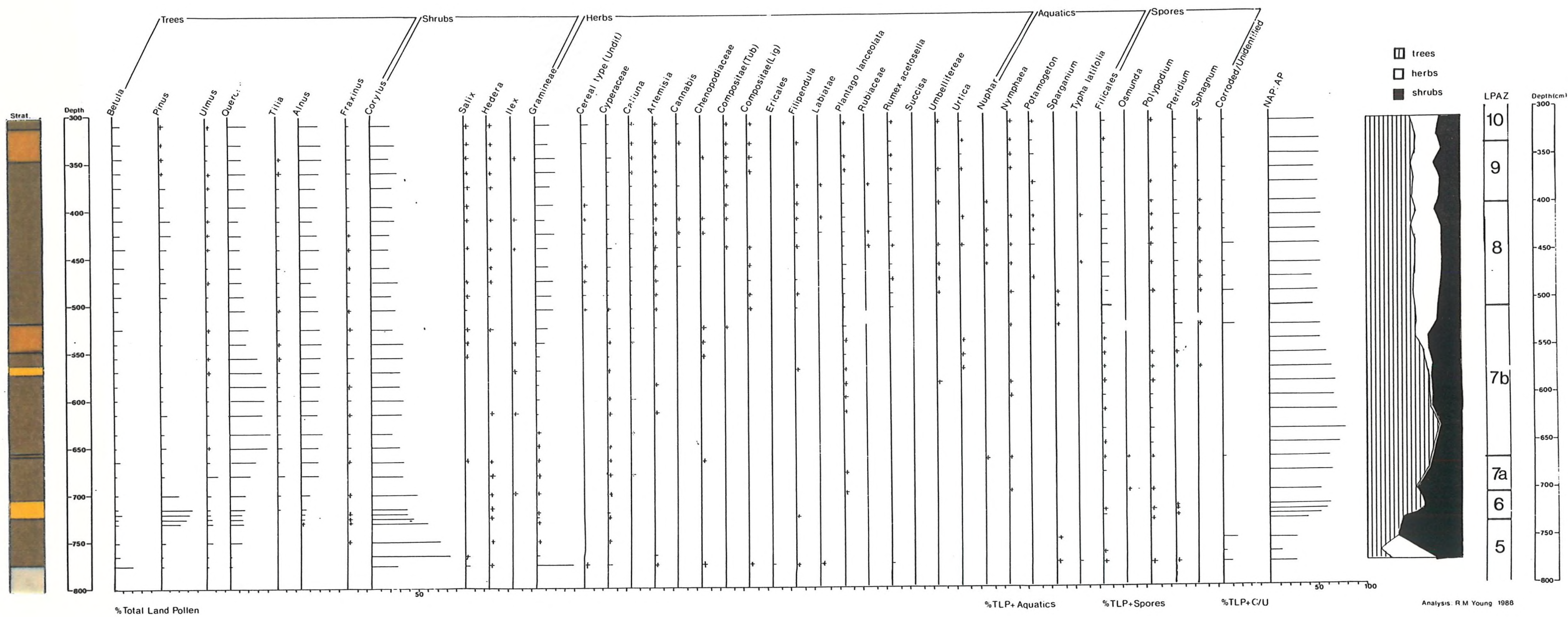


Figure 25 Pollen Diagram from Crose Mere (CRM2)

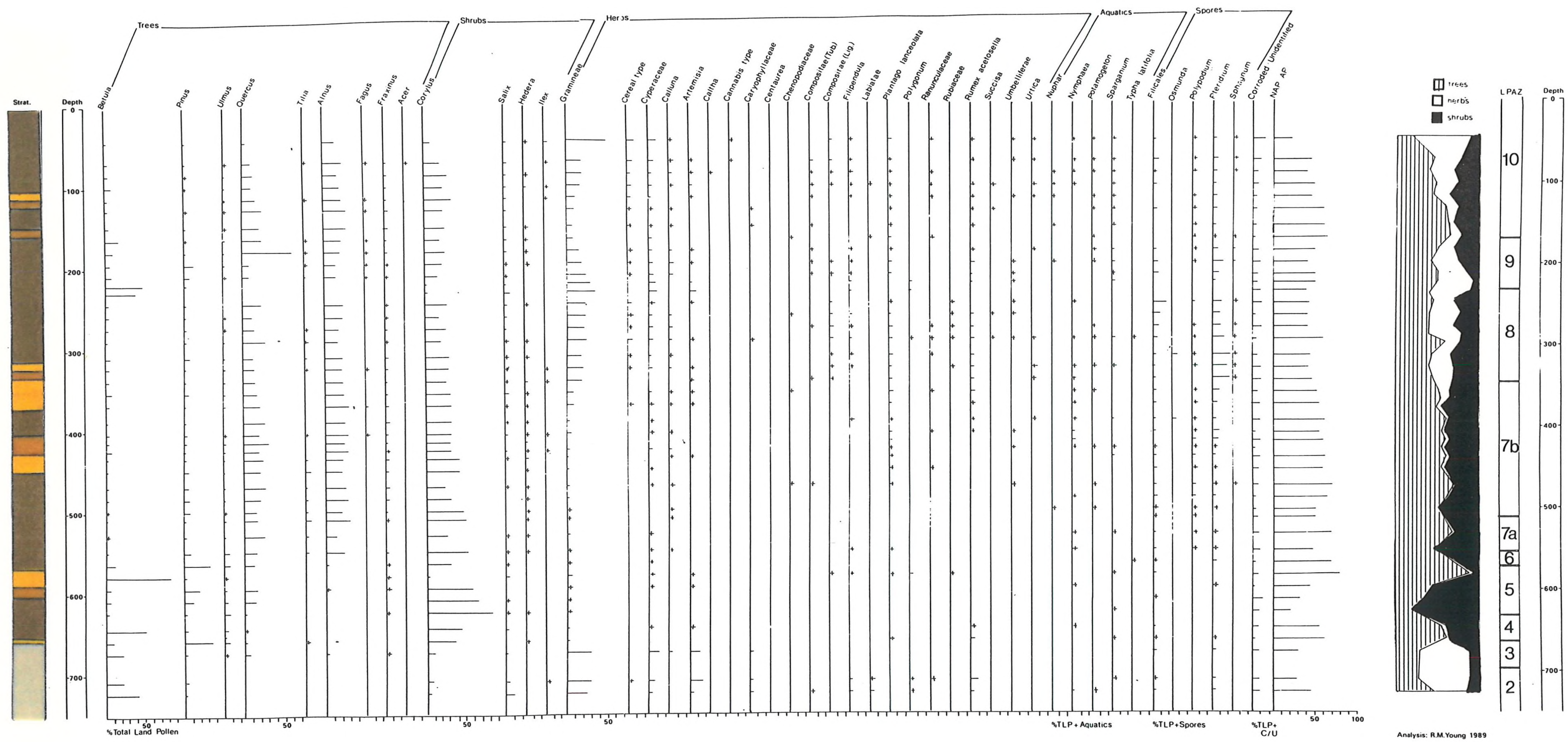


Figure 26 Pollen diagram from Crose Mere (CRM3)

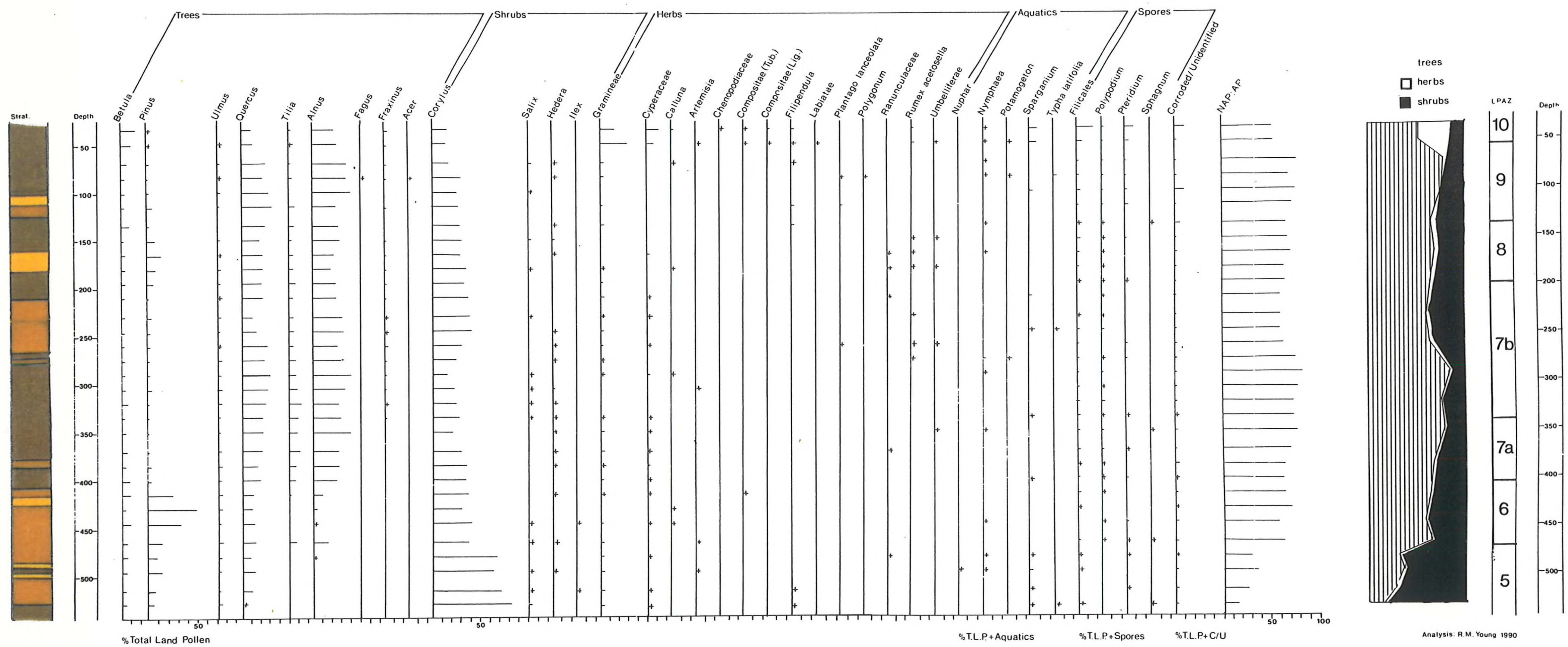


Figure 27 Pollen diagram from Crose Mere (CRM4)

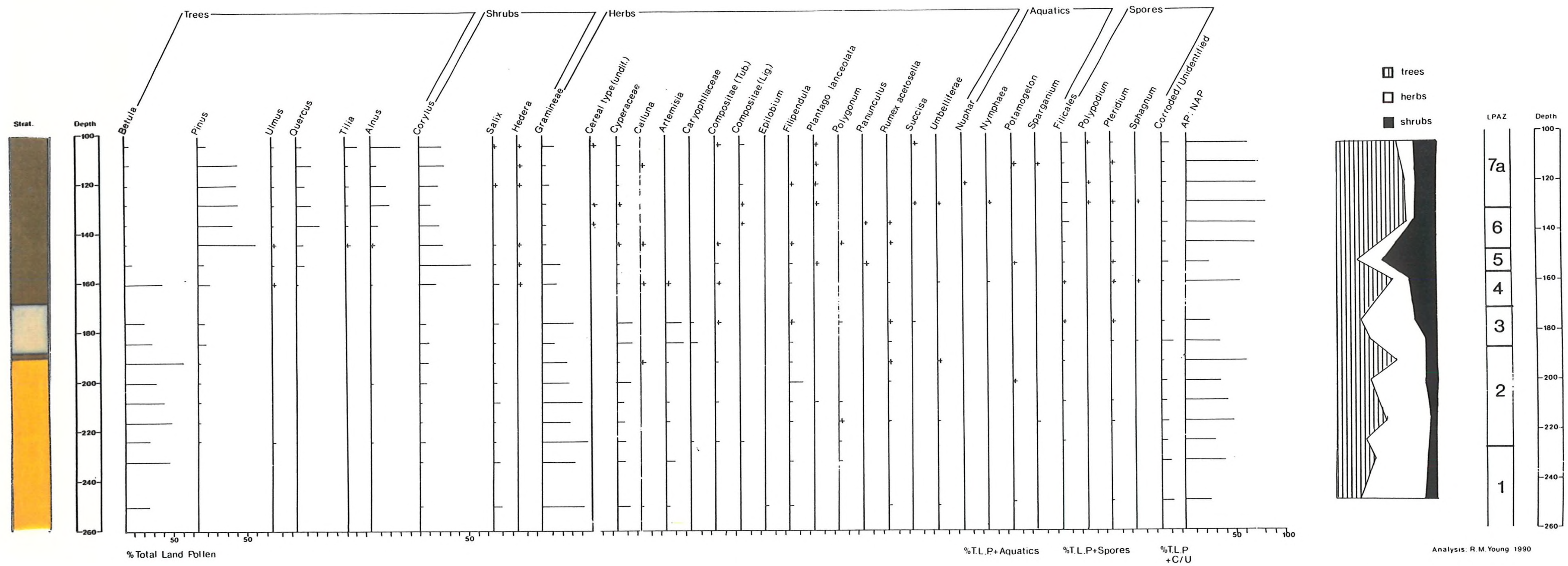


Figure 28 Pollen diagram from Crose Mere (CRM5)

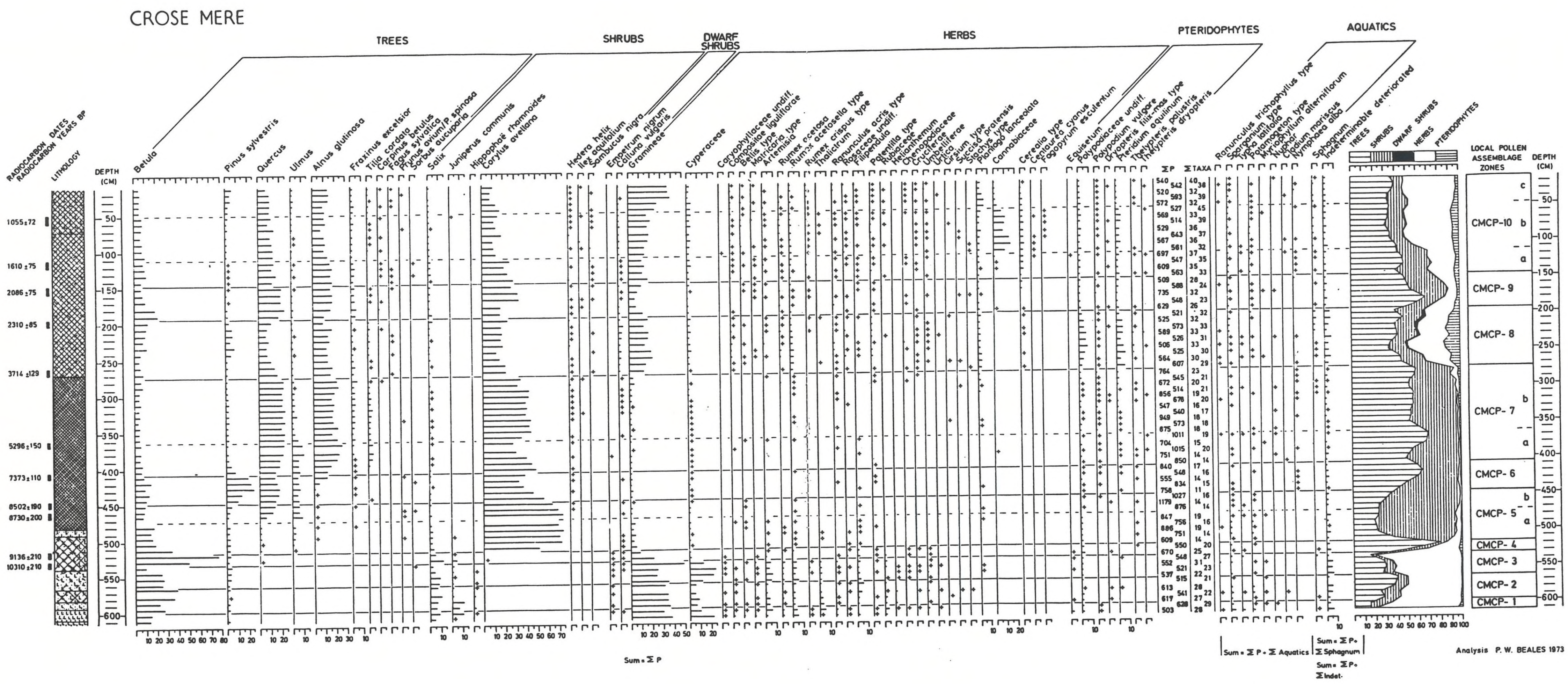


Figure 29 Pollen diagram from Crose Mere (reproduced from Beales 1980 with kind permission from the New Phytologist Trust).

Contacts. Upper; *Pinus sylvestris* <10%
Lower; *Pinus sylvestris* >10%
Quercus >10%
Age: 8502 +/- 190 to 7373 +/- 110 B.P.

CMCP-7 (548 to 340cm) *Quercus*-*Alnus glutinosa* LPAZ
Arboreal pollen >50%
Quercus >15%
Alnus between 15 and 25%
Pinus <5%
Betula <10%
Corylus >30%
Contacts. Upper; Arboreal pollen falls below 50%
Quercus and *Alnus* <20%
Herb pollen >20%
Gramineae >10%
Pteridium >5%
Lower; *Pinus* <10%
Quercus and *Alnus* >10%

Sub-divisions

CMCP-7a (548-470cm) *Ulmus* sub-zone
Ulmus >5%
Corylus <30%
Age: 7373 +/- 110 to 5296 +/- 150 B.P.

CMCP-7b (470-340cm) *Fraxinus excelsior* sub-zone
Fraxinus between 2 and 5%
Ulmus <5%
Corylus >30%
Age: 5296 +/- 150 to 3714 +/- 129 B.P.

CMCP-8 (340 to 148cm) Gramineae-*Pteridium* LPAZ
Herb pollen 20-35%
Gramineae >10%
Cerealia-type pollen present
Pteridophytes 5-15%
Arboreal pollen <50%
Contacts. Upper; Arboreal pollen >50%
Herb pollen <20%

Lower; *Quercus* and *Alnus* <20%
Arboreal pollen <50%
Herb pollen >20%
Gramineae >10%
Pteridium >5%

Age: 3714 +/- 129 to 2310 +/- 85 B.P.

CMCP-9 (148 to 80cm) *Quercus-Betula* LPAZ

Quercus >10%
Betula 5-25%
Alnus >15%
Fraxinus 2-5%
Herb pollen <20%
Gramineae <15%

Contacts. Upper; *Quercus* <15%
Herb pollen >20%

Lower; Arboreal pollen >50%
Herb pollen <20%

Age: 2310 +/- 85 to 2086 +/- 75 B.P.

CMCP-10 (80cm to top) Gramineae LPAZ

Herb pollen 20 to 50%
Gramineae 10 to 40%
Arboreal pollen <50%

Contacts. Upper; Defined arbitrarily as the top of the core

Lower; *Quercus* <20%
Herb pollen >20%

Section 5.3 Differences and similarities between the pollen diagrams obtained from Crose Mere.

The start of zone 8 in the master diagram from Crose Mere (Beales 1976, 1980) is indicated by a rapid increase in the amount of grass pollen recorded. This was not found at any other cores taken from Crose Mere nor in any of the cores taken from Fenemere. This could be because the majority of grass pollen counted could be *Phragmites* *communis* and therefore reflect a local expansion of marginal reed vegetation rather than a clearance of woodland which would be well documented in all the cores taken from Crose Mere and the surrounding area. This shows how pollen analysis of a single core from any one site may give a false impression of the vegetational history of the site in question. Because of this irregularity between zone8 on the master diagram and zone8 on the diagrams obtained as a result of this study, I have characterised zone8 according to the slight rise in *Pinus* pollen and the consistent presence of *Rumex acetosella, Plantago lanceolata* and *Pteridium aquilinum*.

Problems were also encountered in the correlation of subzones 10a, 10b and 10c as Cannabiaceae pollen was only recorded in very small quantities from the lake core (CRM2) and in insufficient quantities to differentiate zone10b from zone10a and zone10c. Beales (1980) was not certain whether this pollen was from hemp or hops but the weaving of hemp occurred in this area at this time (Hey 1974) so he took this to mean that the Cannabiaceae pollen recorded was in fact hemp. The fact that the Cannabiaceae peak was recorded from a core taken on the eastern edge of the lake and not in cores taken from the western side of Crose Mere suggests that the hemp was being cultivated on the eastern side of Crose Mere which is today the most probable site for cultivation of any crops as it is the least undulating. Cannabiaceae pollen does not appear to travel great distances (R. Scaife pers comm) and is therefore not represented in cores taken from the opposite side of the lake. It is also possible that the Cannabiaceae pollen recorded in CRM2 is hop pollen rather than hemp pollen as hops are occasionally found growing in association with alder carr and the western end of the lake is the only area to be colonised by dense *Alnus glutinosa*. This lack of Cannabiaceae pollen has meant that in this study zone10 is not subdivided into three subzones.

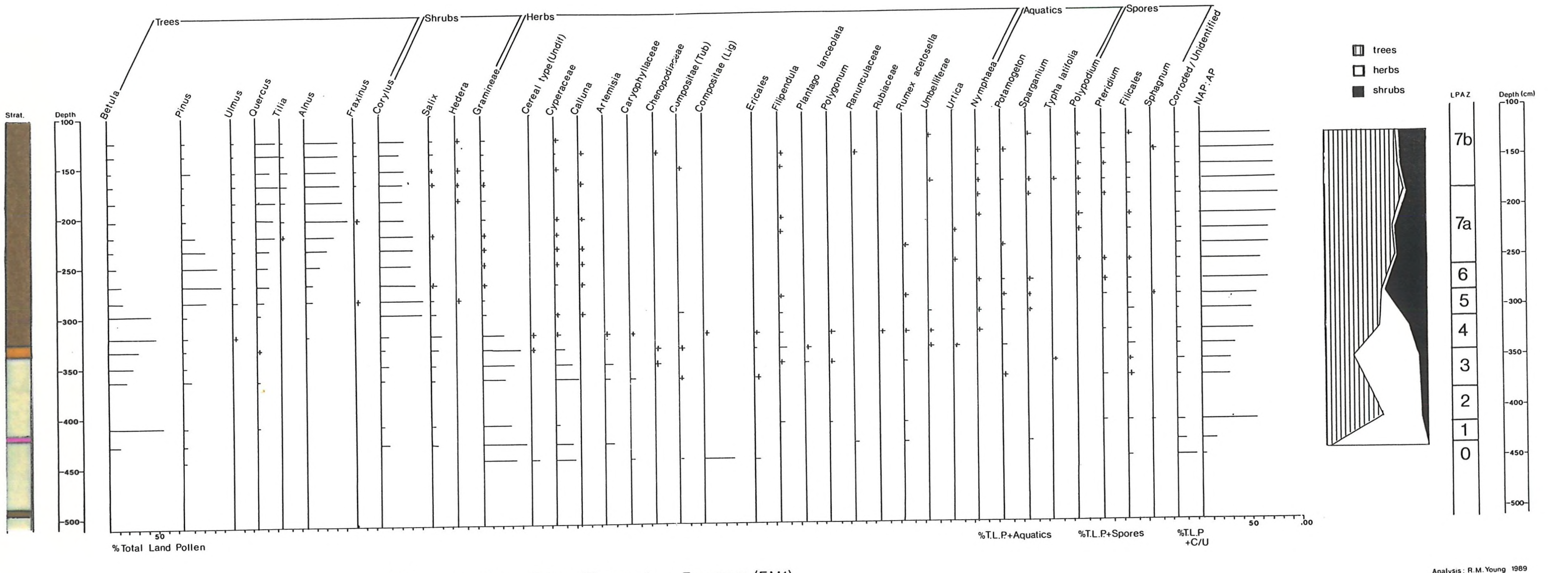


Figure 30 Pollen Diagram from Fenemere (FM1)

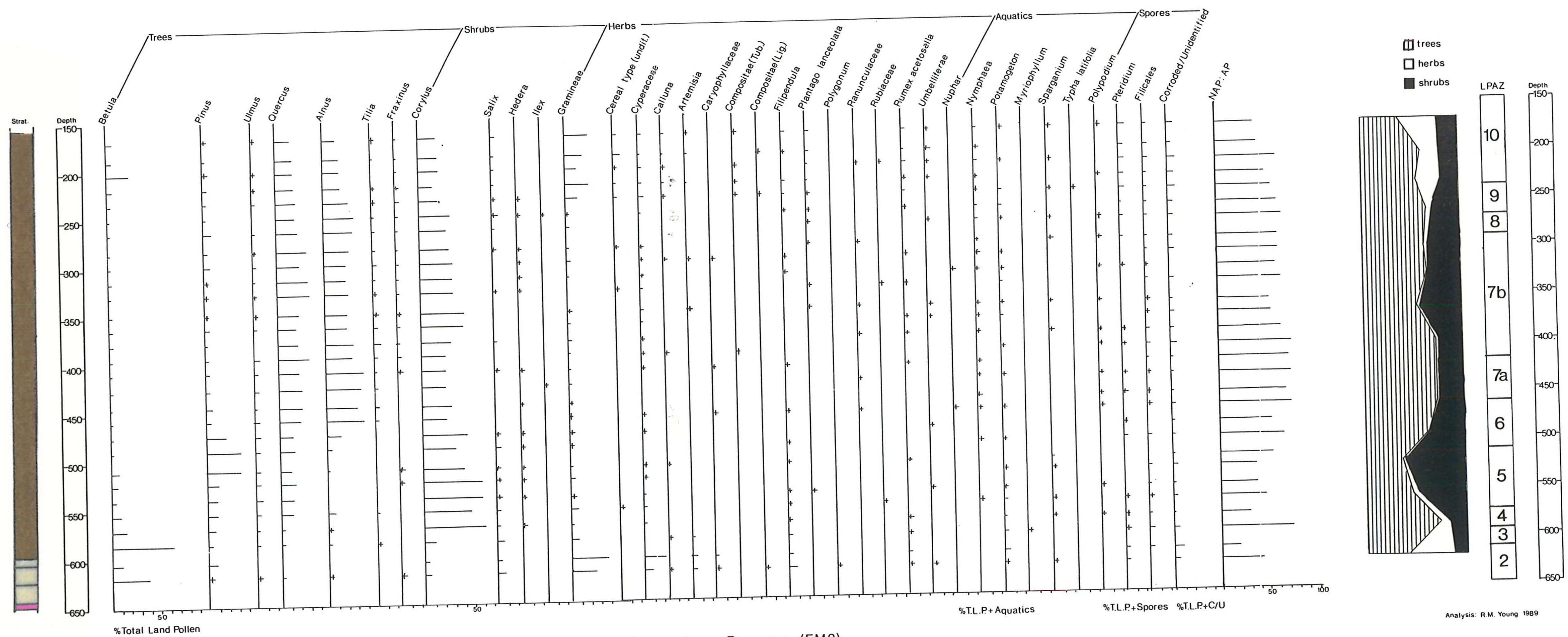


Figure 31 Pollen Diagram from Fenemere (FM2)

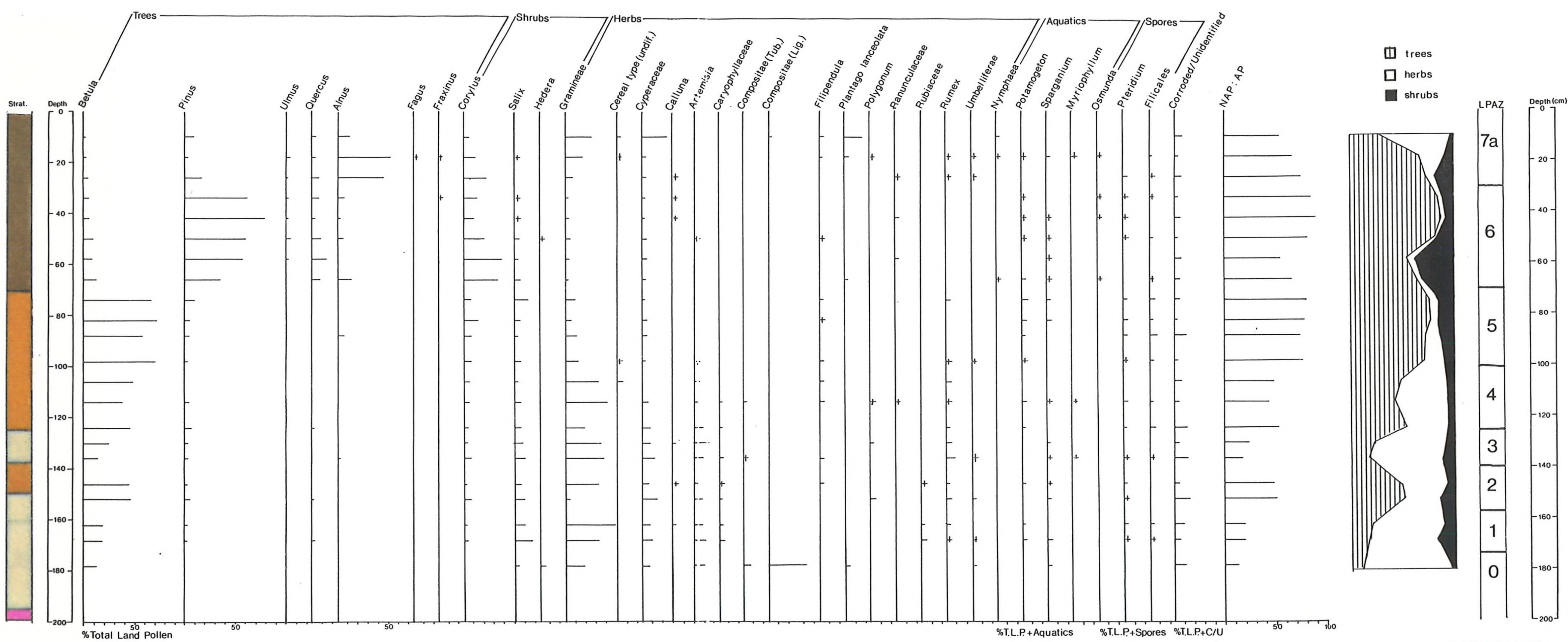


Figure 32 Pollen Diagram from Fenemere (FM4)

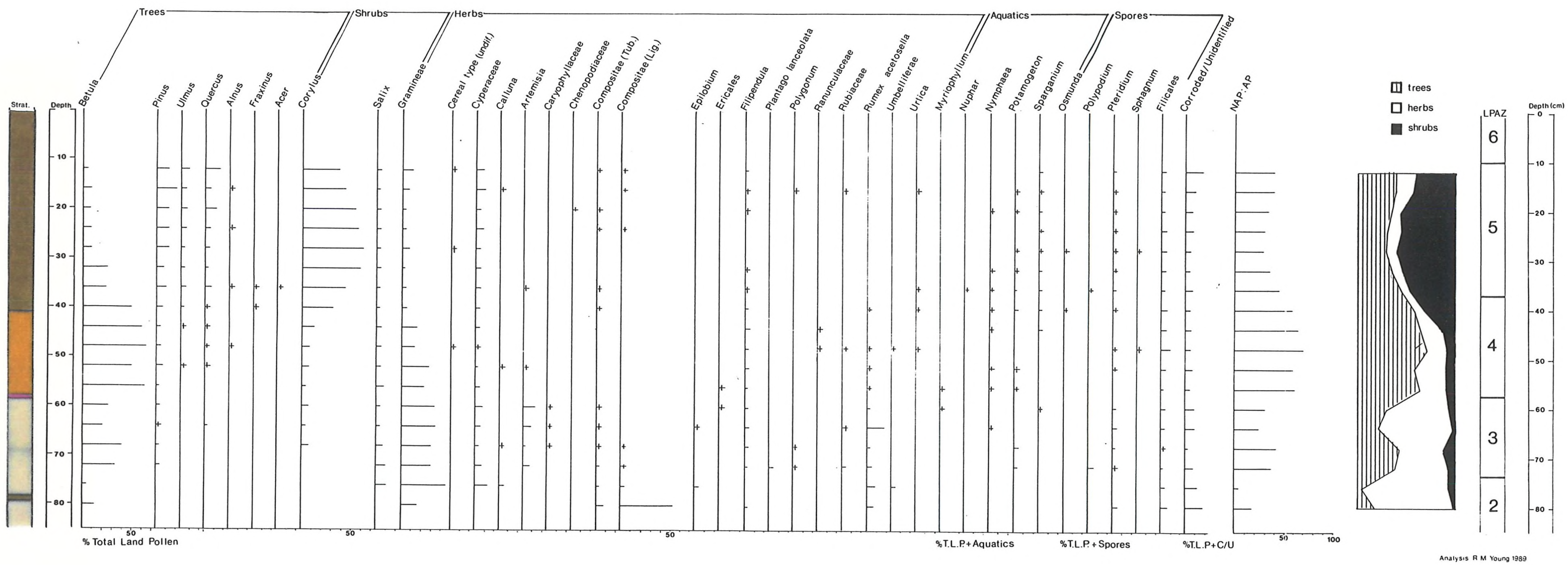


Figure 33 Pollen Diagram from Fenemere (FM6)

As the primary purpose of pollen analysis in this study was to provide a correlation of the cores and not to provide a detailed history of the local or regional vegetation, fewer levels were counted and to a lower pollen sum than seen in Beales' pollen diagram of Crose Mere (Beales 1976, 1980). This has inevitably led to the recording of fewer taxa but this is not thought to detract from the degree of correlation between the two sets of pollen diagrams.

5.4 Pollen Analysis from Fenemere

Twigger (1988) experienced problems with radiocarbon dates obtained from Fenemere due to inwashing of old carbon. This caused him to reject 50% of the number of radiocarbon dates received. In view of this experience, and the fact that the majority of sediments retrieved from Crose Mere and Fenemere had a high minerogenic content, it was thought best to transfer radiocarbon dates from Beales (1980) using pollen-analytical correlation (Digerfeldt 1982, 1988).

The pollen diagrams obtained from Fenemere were visually zoned to correspond to the local pollen assemblage zones from Crose Mere described in Section 5.6. The pollen diagram obtained from FM2 is described below as this core gave the greatest range of zones and hence ages.

FMCP-3 (bottom of core to 600cm) *Gramineae-Betula-Cyperaceae* LPAZ

Herb pollen 60-80%
Gramineae pollen >20%
Cyperaceae pollen 10-25%
Shrub pollen <10%
Some *Artemisia* and *Rumex acetosella* pollen >5%
Contacts. Upper; Arboreal pollen >50%
Lower; *Cyperaceae* pollen >10%

Artemisia pollen >5%
Betula <30%

Age: The upper boundary occurs immediately below 10310 +/- 210 B.P.

FMCP-4 (600 to 565cm) *Betula* LPAZ

Arboreal pollen 50-80%
Salix 5-15%
Herb pollen 10-30%
Filipendula >2%
Contacts. Upper; *Corylus avellana* pollen exceeds *Betula* pollen percentages
Arboreal pollen <50%
Lower; Arboreal pollen >50%
Betula pollen >40%
Age: Before 10310 +/-210 to 9136 +/- 210 B.P.

FMCP-5 (565 to 530cm) *Corylus avellana* LPAZ

Corylus avellana >30%
Quercus >10% in some samples
Contacts. Upper; *Pinus sylvestris* >10%
Quercus >10%
Lower; *Corylus* > *Betula*
Arboreal Pollen <50%
Age: 9136 +/- 210 to 8502 +/- 190 B.P.

FMCP-6 (530 to 465cm) *Pinus sylvestris-Quercus* LPAZ

Pinus 10-25%
Quercus >10%
Alnus present but <10%
Ulmus >5%
Tilia present
Contacts. Upper; *Pinus sylvestris* <10%
Lower; *Pinus sylvestris* >10%
Age: 8502 +/- 190 to 7373 +/- 110 B.P.

FMCP-7 (465 to 255cm) *Quercus-Alnus glutinosa* LPAZ

Arboreal pollen >50%

Quercus >15%

Alnus between 15 and 25%

Pinus <5%

Betula <10%

Corylus >30%

Contacts. Upper; Arboreal pollen falls below 50%

Quercus <20%

Alnus <25%

Herb pollen >20%

Gramineae >10%

Pteridium >5%

Lower; *Pinus* <10%

Quercus >20%

Alnus >10%

Sub-divisions

CMCP-7a (465-400cm) *Ulmus* sub-zone

Ulmus 5%

Corylus <30%

Age: 7373 +/- 110 to 5296 +/- 150 B.P.

CMCP-7b (400-255cm) *Fraxinus excelsior* sub-zone

Fraxinus between 2 and 5%

Ulmus <5%

Corylus >25%

Age: 5296 +/- 150 to 3714 +/- 129 B.P.

FMCP-8 (255 to 220cm) Gramineae-*Pteridium* LPAZ

Herb pollen 20-35%

Gramineae >10%

Cerealia-type pollen present

Pteridophytes 5-15%

Arboreal pollen <50%

Contacts. Upper; Arboreal pollen >50%

Herb pollen <20%

Lower; *Quercus* and *Alnus* <20%

Arboreal pollen <50%

Herb pollen >20%

Gramineae >10%
Pteridium >5%

Age: 3714 +/- 129 to 2310 +/- 85 B.P.

FMCP-9 (220 to 200cm) *Quercus-Betula* LPAZ

Quercus >10%
Betula 5-25%
Alnus >15%
Fraxinus 2-5%
Herb pollen <20%
Gramineae <15%
Contacts. Upper; *Quercus* <15%
Herb pollen >20%
Lower; Arboreal pollen >50%
Herb pollen <20%

Age: 2310 +/- 85 to 2086 +/- 75 B.P.

FMCP-10 (200cm to top) Gramineae LPAZ

Herb pollen 20 to 50%
Gramineae 10 to 40%
Arboreal pollen <50%
Contacts. Upper; Defined arbitrarily as the top of the core
Lower; *Quercus* <20%
Herb pollen >20%

Section 5.5 Correlation of the Fenemere diagrams with the master diagram.

The difficulties with the grass peak in zone8 were also encountered here along with the lack of Cannabiaceae pollen from zone10. Both of these difficulties were resolved in the same way as they were for Crose Mere. One very interesting point to notice about the pollen diagrams from Fenemere is the peak in Compositae (Liguliflorae) at the base of the cores. This does not appear in any of the Crose Mere cores and so it was decided to call this zone FMCP-0 (figure 34) as it appears to be significantly

Radiocarbon Dates (years BP)	LPAZ	Species characterisation of zone
	10	Grass >10%, no Lime
2086+/-75		
	9	Birch zone, some Lime, end of Pine peak
2310+/-85		
	8	Pine peak, also see Rumex, Plantago and Bracken
3714+/-129		
	7b	Start of Ash curve
5296+/-150		
	7a	Start of Alder (<10%), no Ash
7373+/-110		
	6	Alder <10%, Pine zone
8502+/-190		
	5	Pine <10%, Hazel zone
9136+/-210		
	4	Start of Hazel, Birch >40%
10310+/-210		
	3	Low tree pollen, little Artemisia peak, Willow main shrub, sedges >10%
	2	Birch peak, sedges <10%
	1	Birch <10%, sedges >10%, high grass values
	0	"Dandelion-type" pollen >5%

Figure 34 Simplified summary of pollen zone characterization

different from CMCP-1. It is difficult to see why this should be a localised event as presumably it is a spread of "dandelion-type weeds" in the wake of the glaciers, so that it may be possible that the cores from Crose Mere do not go back as far in time as Fenemere, or that difficulties in preparing pollen samples from the lateglacial clays of Crose Mere were more problematical than those from Fenemere and so they have not either been sampled, or have not been as conducive to pollen preservation.

Section 5.6 Reliability of the radiocarbon dates obtained from Crose Mere

Beales (1980) obtained eleven radiocarbon dates calculated on a Libby half-life for radiocarbon 5568 +/- 30 years and these were expressed as radiocarbon years before present (BP) with the zero datum at 1950. No satisfactory straight lines could be fitted to the dates plotted against depth by linear regression analysis. These apparent uneven sedimentation rates could be due to three factors (Beales 1980):

1) The dates were taken at prominent biostratigraphical changes indicating that the environment had changed thus possibly influencing sedimentation.

2) Postdepositional redistribution of sediment is a common phenomenon in lakes (Davis 1973, Davis, Brubaker and Beiswenger 1971) and differences in effectiveness of this process will alter the sedimentation pattern.

3) Errors may have occurred in the radiocarbon dates due to inwashing of older organic carbon from terrestrial deposits (Pennington, Cambray, Eakins and Harkness 1976, Johansen 1977, O'Sullivan, Oldfield and Batterby 1973) or "hardwater error" resulting from the photosynthesis of bicarbonate (Deevey *et al* 1954, Broeker and Walton 1959, Olsson 1974, Oldfield 1977).

Possible dating errors have occurred in three of the eleven radiocarbon dates from Crose Mere. The date obtained for the decline in *Tilia* pollen (3714 +/- 129 BP) appears to be approximately 500 years too old when compared to other dates obtained from sites in the surrounding area (Turner 1962, 1964, 1965, Twigger 1988). This is probably due to an inwash of old carbon during clearance phases (Pennington *et al* 1976, Beales 1980). Two other dates (2085 +/75 and 1610 +/- 75) are also thought to be possibly too old, but these would be associated with "hardwater error" rather than periods of old carbon inwashing (Beales 1980).

These dating errors are probably due to the influence of man on the landscape surrounding the meres and there is evidence that the line of the Ellesmere - Shrewsbury road which runs less than 200m west of Crose Mere may have been used from the Neolithic period onwards (Chitty 1968) to support this interpretation.

5.7 Vegetational history of the study area

As the main aim of pollen analysis in this study is to correlate the cores and to enable the transfer of radiocarbon dates from Beales' (1980) pollen diagram from Crose Mere, only a brief history of the vegetation surrounding the two meres will be given here. A more detailed vegetational history from Crose Mere is given in Beales (1976, 1980) and a vegetational history of the surrounding area of neighbouring meres is discussed in detail by Barber and Twigger (1987) and Twigger (1988).

A dominance of grass and sedge pollen with a low tree pollen count in zone1 (figure34) indicates predominantly treeless conditions with diverse dry-land herb types. The presence of *Artemisia* and Chenopodiaceae suggest disturbed, well-drained soils and this is consistent with the high inorganic sediment values obtained throughout this zone. An expansion of birch in zone2 indicates a stabilisation of soils and this coincides with an decrease in the amount of minerogenic sedimentation. An increase in pollen concentrations during this time could be due to a decrease in sedimentation (see section 5.8 p103). The increase in the sedge pollen during zone3 together with the presence of *Artemisia* and *Rumex* pollen is suggestive of pollen changes which Walker (1966) attributed to changes in lower winter temperature which would bring about frozen ground. The resulting impeded drainage would then lead to an increase in wet soils.

Zone4 is typical of willow scrub. The replacement of willow pollen by birch pollen may indicate *Salix-Betula* carr as Salix is poorly represented by its pollen in such circumstances (Birks 1973). During zone 5 the more arctic flora of the lateglacial period is being replaced by the start of the postglacial forests with increasing amounts of *Quercus* and *Pinus* being recorded. Zone 6 is characterised by high levels of *Ulmus* pollen and by the beginning of the *Alnus* curve which marks the beginning of the Atlantic period (approximately 7000 years BP in Shropshire). The pattern of events at Crose Mere during this time is similar to events occurring in the north-west lowlands (Smith 1958, Birks 1964, Hibbert,Switsur and West 1971).

There is a decrease in the levels of *Pinus* and *Betula* in zone 7 as the forests of the Boreal period are replaced by forests of thermophilous trees such as *Quercus* and *Alnus*. *Corylus* levels are consistently high throughout the majority of the diagram. The elm decline occurs in zone 7b, about 5300 BP (Turner 1964, 1970, Garbett 1981). Evidence of anthropogenic activity is first indicated towards the end of zone 8 as the arboreal pollen sum declines and there is a corresponding increase in herb pollen, with several "weed" species such as *Rumex* and *Plantago* being well represented. The appearance of *Plantago* pollen and the expansion of herb pollen occurring around 3000 BP are attributed to forest clearance by Neolithic man (Beales & Birks 1973). Considerable erosion may have taken place in association with forest clearance. The percentage of organic sediment decreases to around 50% but the depression of the curve may not indicate the full extent of terrestrial inwash if erosion of organic forest soils was taking place (Beales 1980).

5.8 Pollen concentrations

Due to problems with clumping with early pollen preparations, pollen concentration values are only available for CRM3, CRM4 and CRM5. Pollen concentration values were low at the bottom of the core (zones4-0) and at the top of the core (zones8-10) indicating periods of rapid accumulation, the former due to the instability of the lateglacial landscape and the latter possibly due to man. High pollen concentrations were recorded at zone6/zone7a transition (Boreal/Atlantic transition), zone4/zone5 transition (Preboreal/Boreal transition) and during the Boreal period. However, this pattern of events is not found in CRM5. Pollen concentrations in this core were generally low with peaks occurring mid zone7a and at the transition between zone5 and zone6. A more rapid rate of accumulation of pollen would be expected for CRM5 as this core was on the edge of the old lake and, therefore, would receive the greatest amounts of inwashed sediments.

The concentration of pollen in all four cores from Fenemere followed a similar pattern to those described from Crose Mere. Zones8-10 and zones0-4 contained the low pollen values, characteristic of rapidly accumulating sediment. Pollen concentrations peaked at the following times (figure42).

These patterns of high pollen concentrations indicate that there have been several periods of low sediment accumulation in both Crose Mere and Fenemere. High pollen concentrations were recorded at both sites at the transition of zones 4 and 5 (Preboreal/Boreal) and at the transition of zones 6 and 7a (Boreal/Atlantic) possibly due to the changing climate characterising these

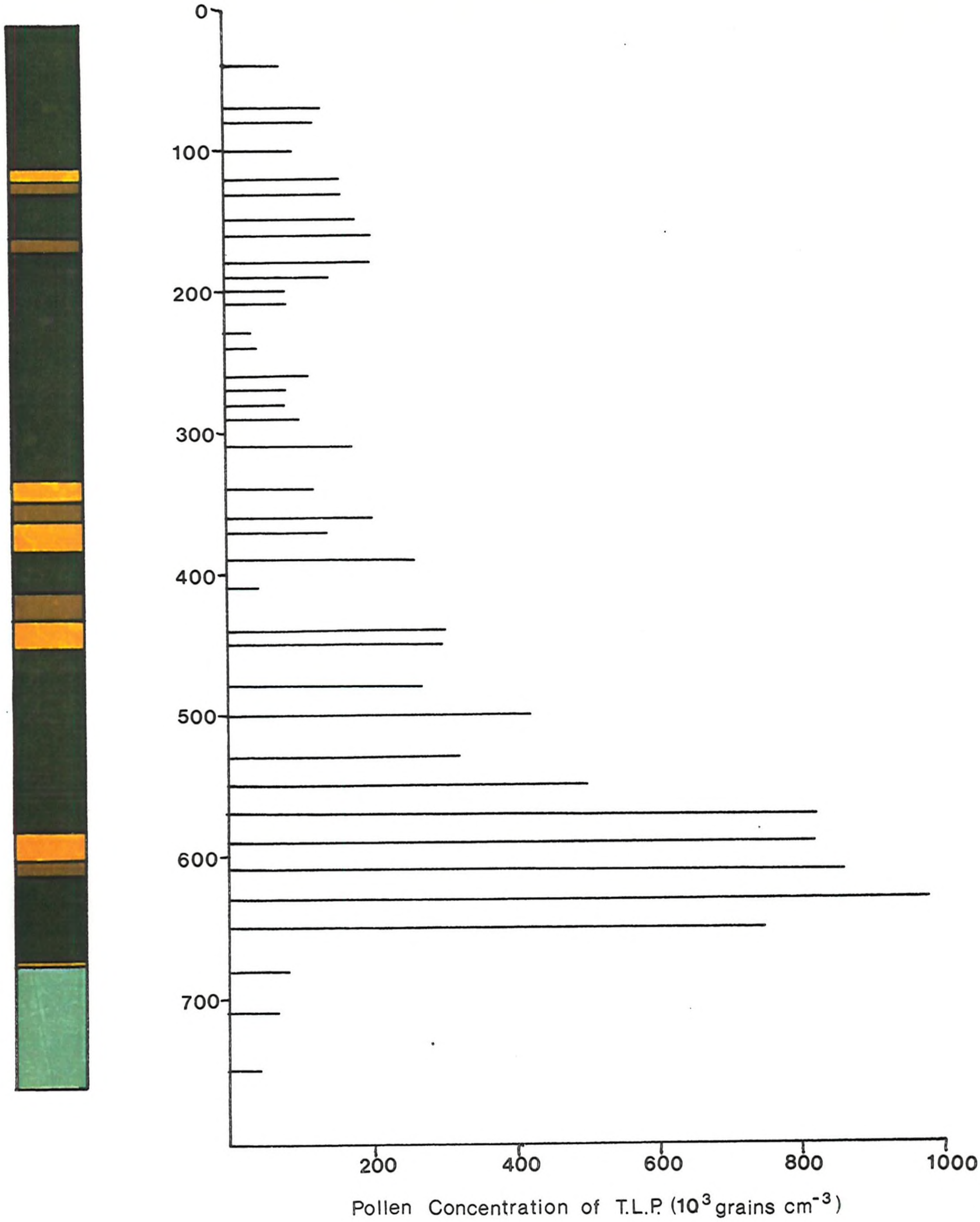


Figure 35 Pollen concentrations (CRM3)

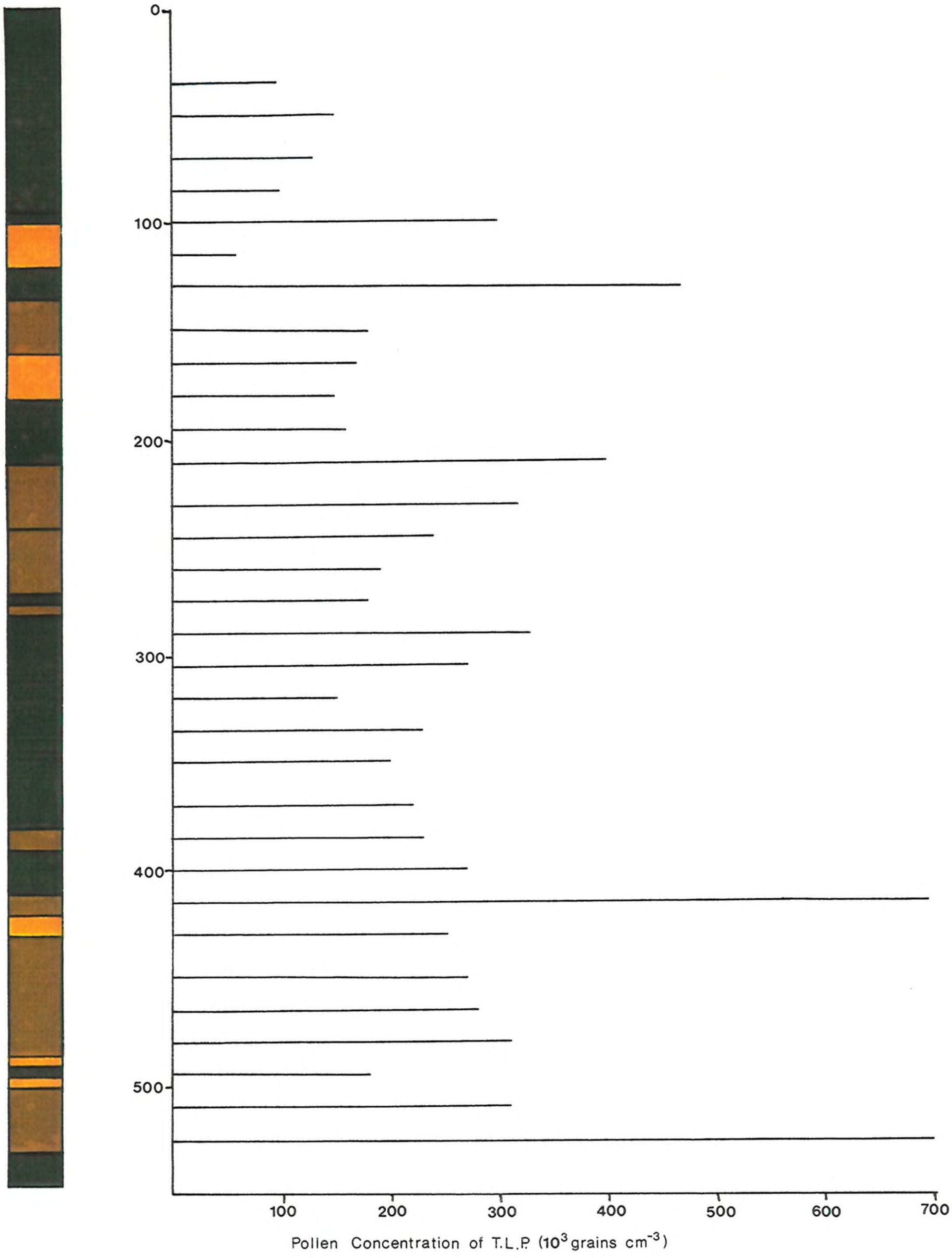


Figure 36 Pollen concentrations (CRM4)

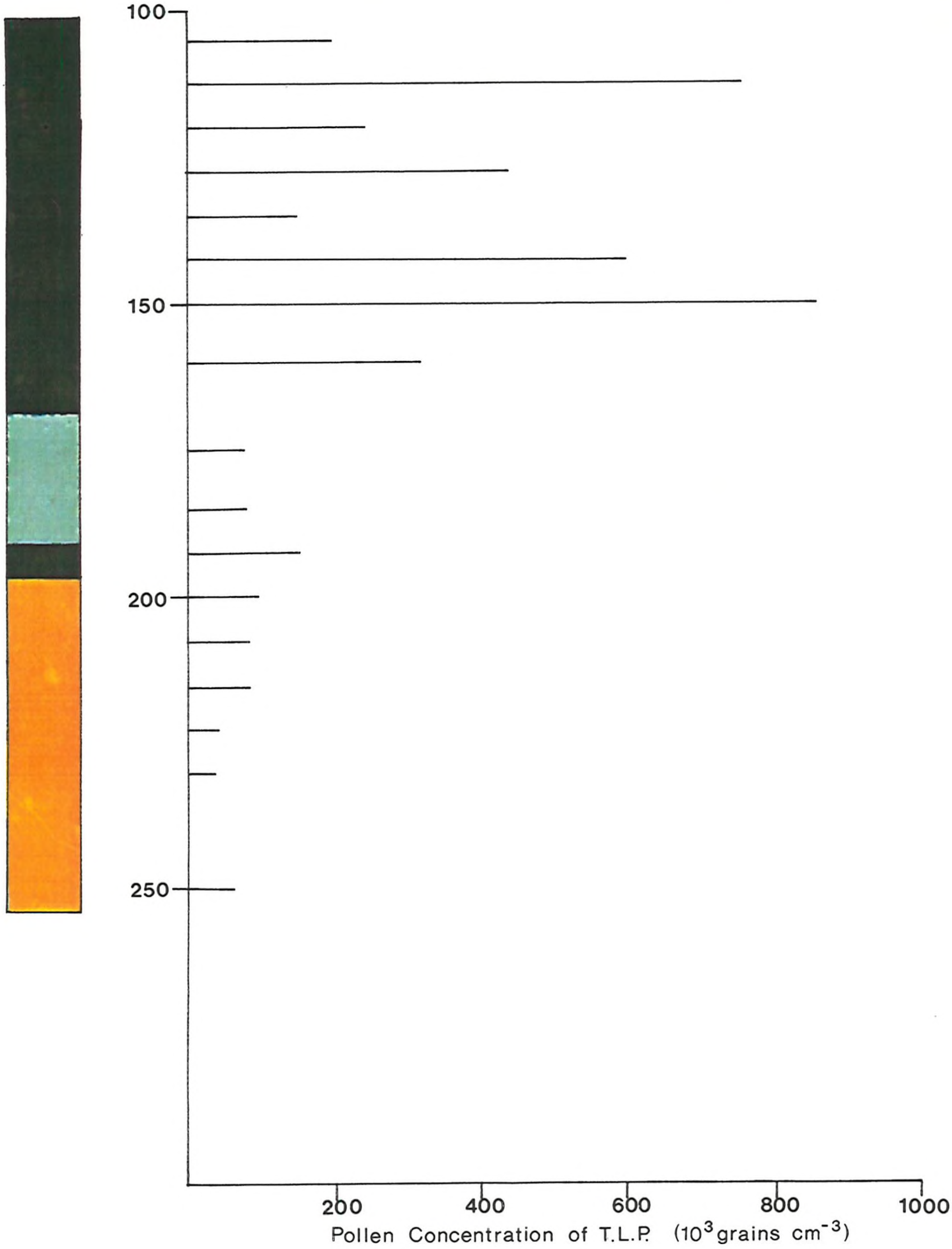


Figure 37 Pollen concentrations (CRM5)

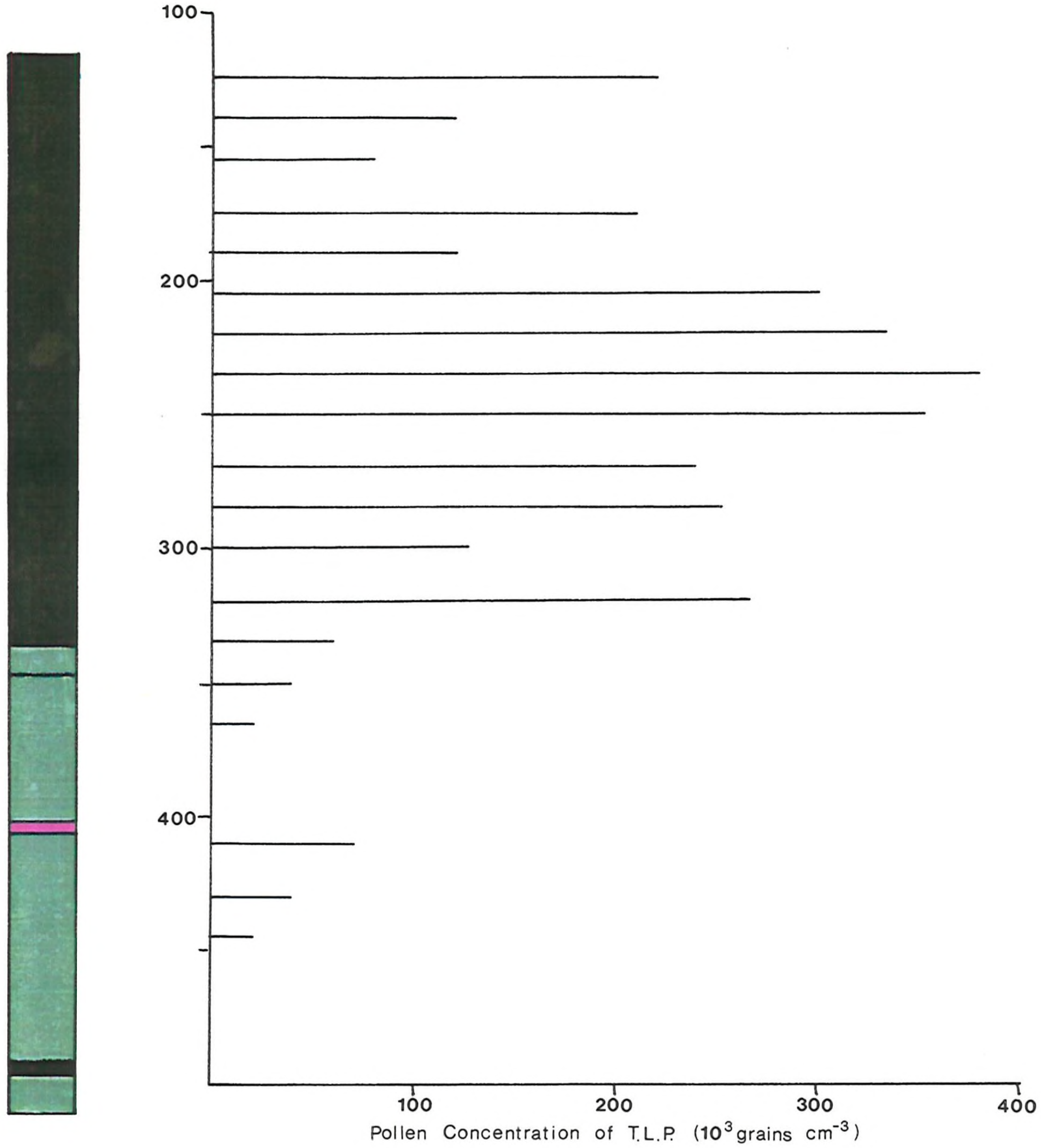


Figure 38 Pollen concentrations (FM1)

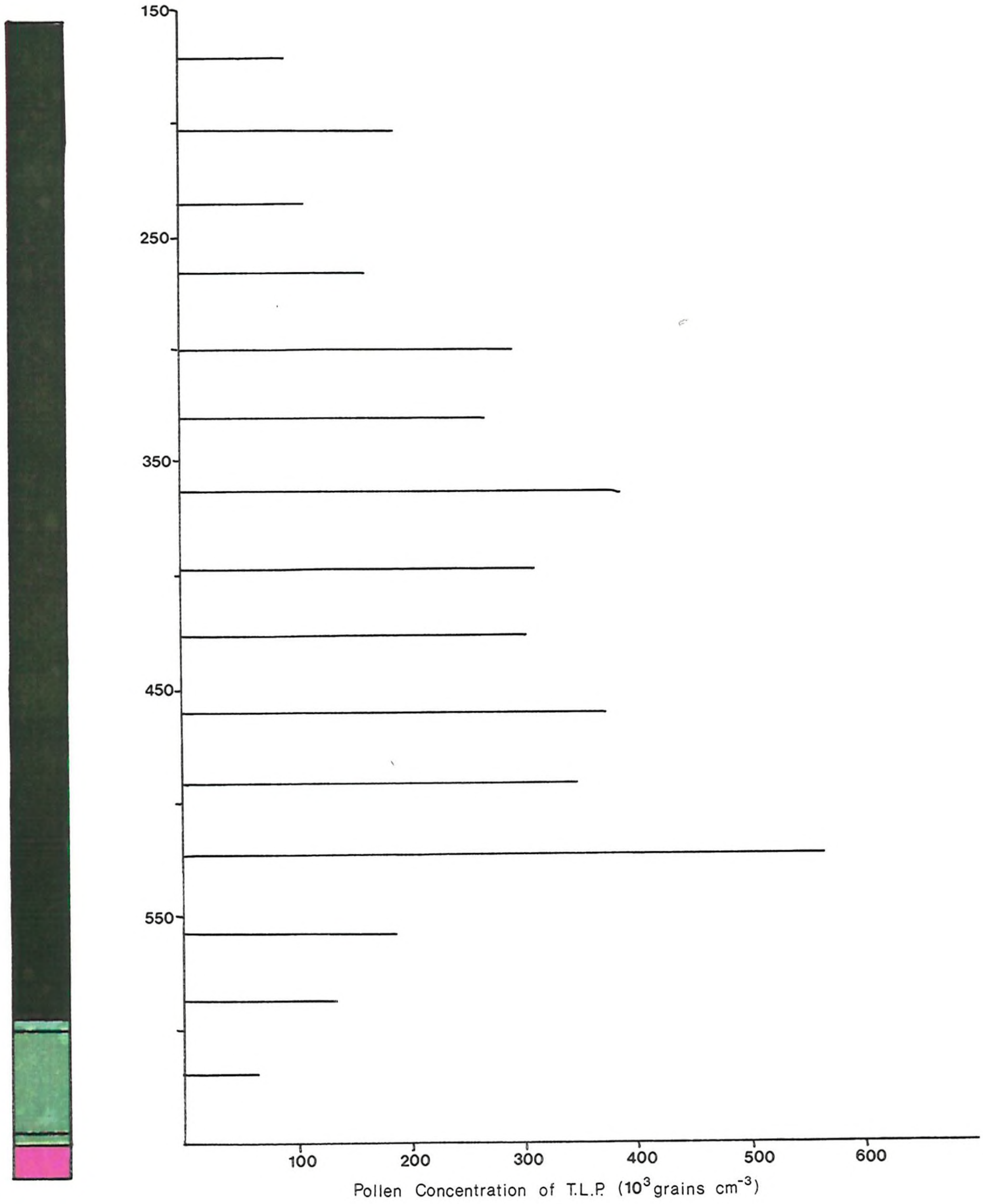


Figure 39 Pollen concentrations (FM2)

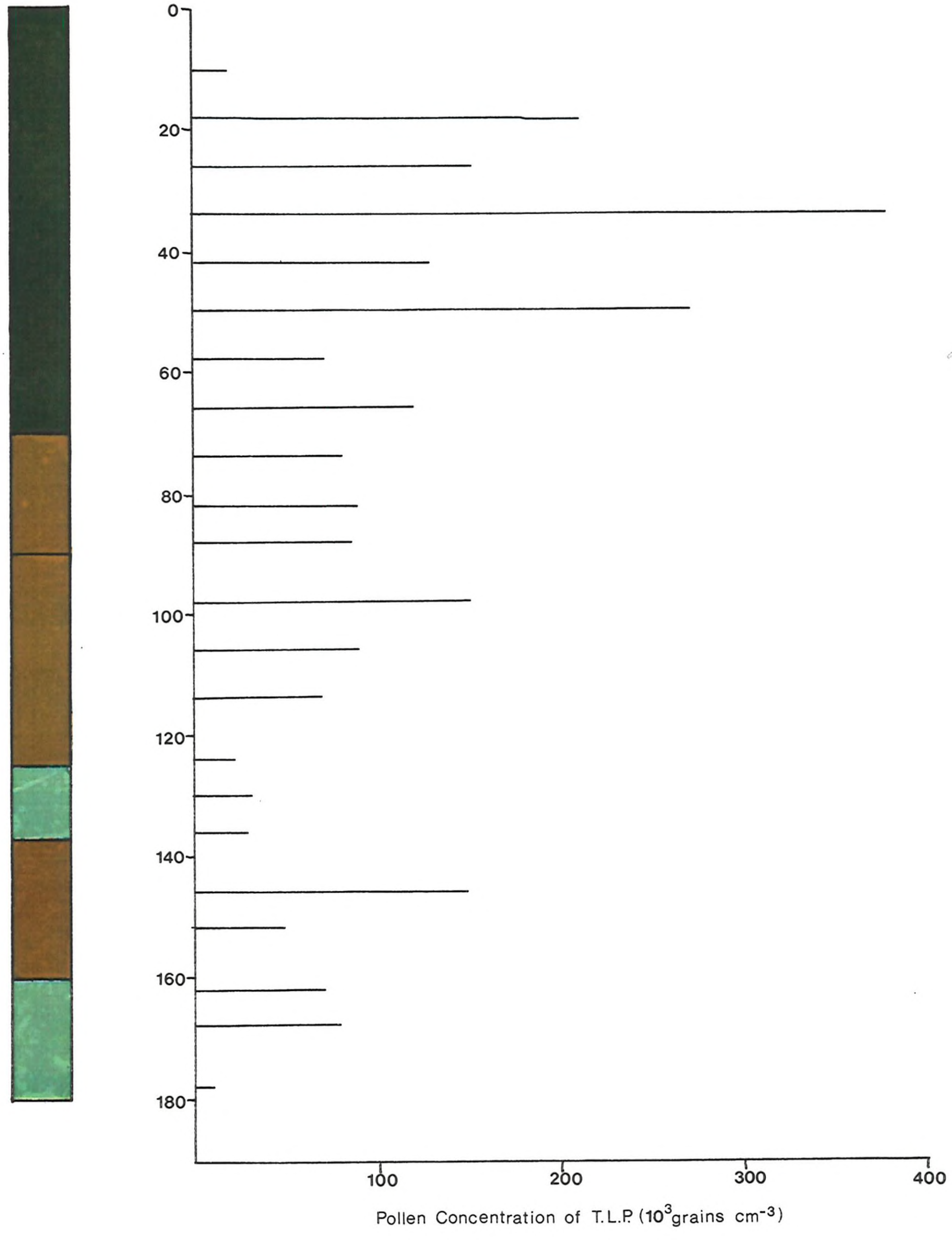


Figure 40 Pollen concentrations (FM4)

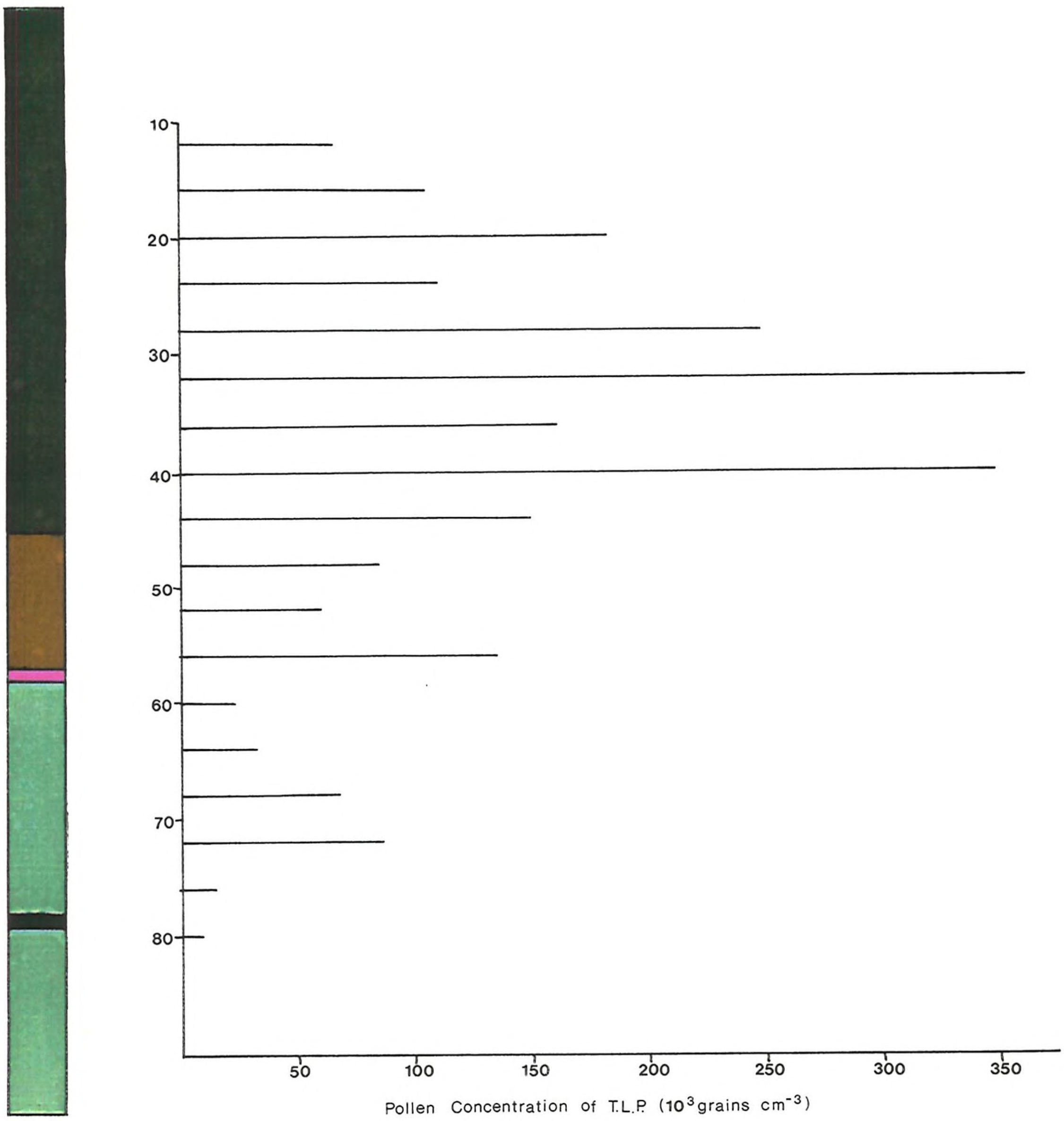


Figure 41 Pollen concentrations (FM6)

FM6	FM4	FM1	FM2
_	mid zone2	mid zone2	_
zone4/zone5 transition	_	zone4/zone5 transition	_
_	zone5/zone6 transition	zone5/zone6 transition	zone5/zone6 transition
_	zone6/zone7a transition	zone6/zone7a transition	zone6/zone7a transition
_	_	_	mid zone7b

CRM3	CRM4	CRM5
_	_	_
zone4/zone5 transition	zone4/zone5 transition	_
zone5/zone6 transition	_	zone5/zone6 transition
zone6/zone7a transition	zone6/zone7a transition	_
_	_	_

Figure 42 Periods of high pollen concentrations

transitions between zones. High pollen concentrations also occurred in Fenemere at the transition between zone5 and zone6 (Boreal period) but this was not seen in Crose Mere and so appears to have been a fairly localised event.

Chapter 6 RESULTS FROM CROSE MERE

6.1 Stratigraphy

Five cores were taken from Crose Mere (figure43). All of the cores showed characteristic banding of sediment represented in diagrams as yellow, light brown and dark brown colours. The shortest core (CRM5) was 250cm in depth and the longest core (CRM3) was 750cm.

The Troels-Smith notation for each of the five cores is given in tables 2 6 together with a general description. From this is can be seen that each core consists of three major sediment types - a dark organic sediment, light brown lake mud and yellow inorganic sediment.

CRM5 was the shortest core, being 250cm long, and was taken at the edge of the old lake bed. The top 100cm had to be removed before coring as the sediment consisted of rocks and top soil and was impossible to core through. The top 20cm of the sediment brought back to the laboratory for analysis consisted of wood peat suggesting that the lake level had been reduced sufficiently to allow colonisation of this area by woody shrubs and trees, probably *Alnus glutinosa*. This was dated to zone 7a. The sediment preceding this wood peat to a depth of 164cm contained large quantities of reed detritus suggesting that the level of the lake has been low enough to allow the growth of reedswamp species over this coring point since the Preboreal period (LPAZ zone4). Therefore, it is likely that the coring point has not been underwater since around 9000BP. The stratigraphy of CRM5 was very similar to that of FM4 (section 7.1 p151) in that it also contained a band of clay separated from the basal gravels and clays by a band of lake sediment or gyttja. This is possibly due to inwashing of sediment from erosion of the old shorelines. This would tend to suggest that this point was fairly close to the lake margin at this time.

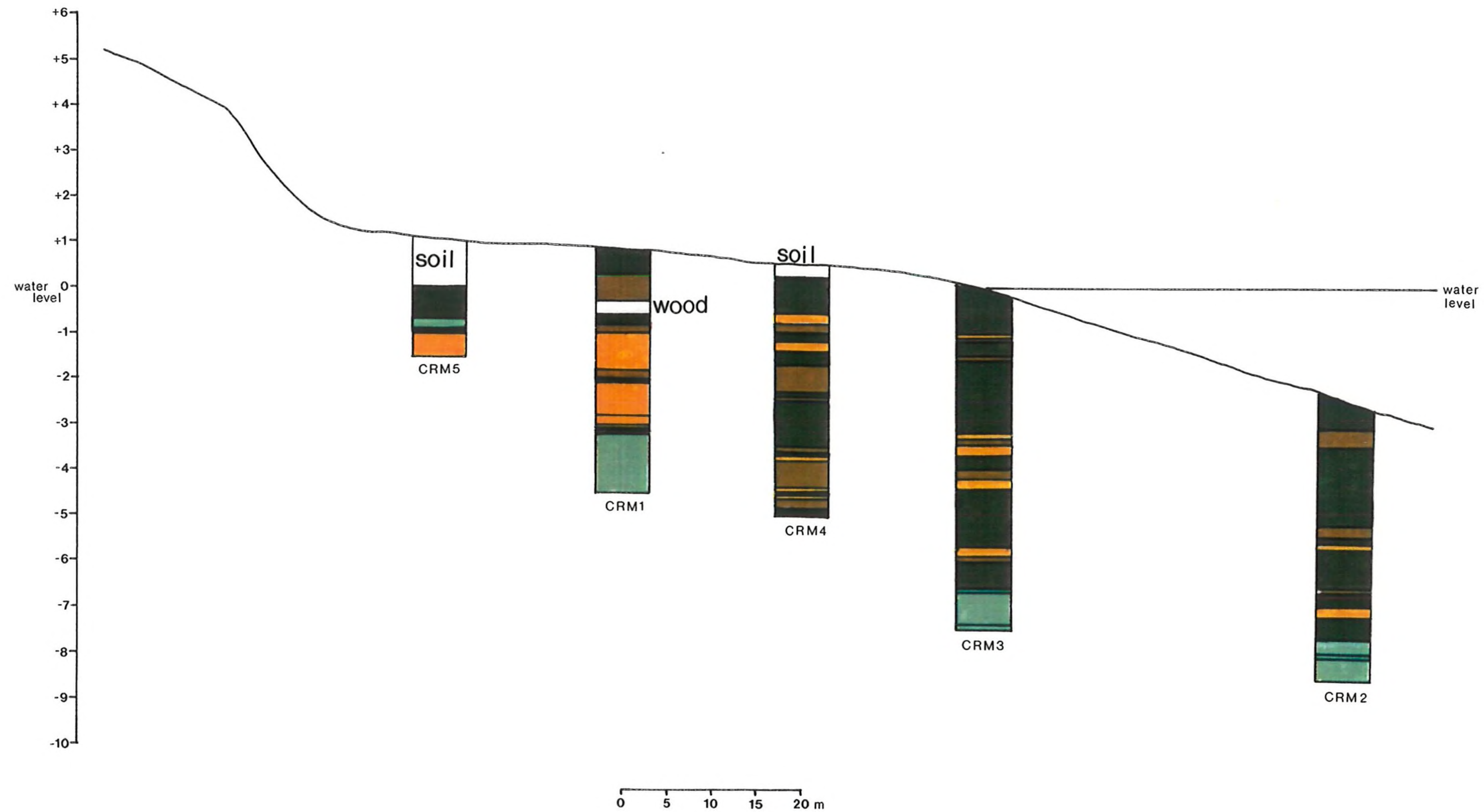


Figure 43 Stratigraphic diagram from Crose Mere

DEPTH	TROELS-SMITH NOTATION	GENERAL DESCRIPTION
70-132cm	Nig3 Strf0 Elas1 Sicc2 Humo1 $Ld^3$4	Very dark and humic
132-162cm	Nig2 Strf2 Elas2 Sicc3 Humo3 $Ld^2$4 Ag+	Light brown lake mud
162-165cm		Wood (Probably Alder)
165-170cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^3$4	Very dark and humic
170-187cm	Nig3 Strf1 Elas1 Sicc2 Humo2 $Ld^3$4 Test(moll)+ As+	Very dark, humic and shelly lake mud
187-208cm	Nig2 Strf1 Elas2 Sicc3 Humo3 $Ld^2$4 Test(moll)+	Light brown and shelly
208-285cm	Nig1 Strf0 Elas3 Sicc3 Humo3 $Ld^1$4 Ag+	Yellow sandy band
285-300cm	Nig2 Strf1 Elas2 Sicc3 Humo2 $Ld^2$4 Test (moll)+ Gs+	Light brown with shells and gravel
300-369cm	Nig1 Strf2 Elas3 Sicc3 Humo2 $Ld^1$4 Ag+	Yellow sandy band
369-392cm	Nig2 Strf2 Elas2 Sicc2 Humo2 $Ld^2$4	Light brown lake mud
392-395cm	Nig1 Strf1 Elas3 Sicc2 Humo3 $Ld^1$4 As+	Yellow sandy band
395-397cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^3$4	Very dark and humic
397-404cm	Nig2 Strf0 Elas2 Sicc2 Humo1 $Ld^2$4	Light brown lake mud
404-465cm	Nig2 Strf0 Elas0 Sicc2 As4	Grey clay
465-496cm	Nig1 Strf1 Elas0 Sicc2 As4	Lighter grey clay
496-530cm	Nig2 Strf0 Elas0 Sicc2 As4	Grey clay

Table **2** Sediment description of CRM1 ("Field Core")

DEPTH	TROELS-SMITH NOTATION	GENERAL DESCRIPTION
256-313cm	Nig3 Strf0 Elas2 Sicc2 Humo2 $Ld^{3}4$ Test(moll)+	Very dark, humic and shelly
313-348cm	Nig2 Strf1 Elas1 Sicc2 Humo2 $Ld^{2}4$	Light brown lake mud
348-531cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^{3}4$ Test(moll)+	Very dark, humic and shelly
526-547cm	Nig2 Strf1 Elas2 Sicc2 Humo2 $Ld^{2}4$ Ag+	Brown lake mud
547-566cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^{3}4$	Very dark and humic
566-578cm	Nig1 Strf1 Elas2 Sicc2 Humo3 $Ld^{1}4$	Yellow sandy band
578-661cm	Nig3 Strf0 Elas1 Sicc2 Humo3 $Ld^{3}4$	Very dark and humic
661-664cm	Nig2 Strf0 Elas2 Sicc2 Humo3 $Ld^{2}4$ Ag+	Brown lake mud
664-708cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^{3}4$	Very dark and humic
708-727cm	Nig1 Strf0 Elas3 Sicc2 Humo2 $Ld^{1}4$ Ag+	Yellow sandy band
727-772cm	Nig3 Strf0 Elas1 Sicc2 Humo3 $Ld^{3}4$	Very dark and humic
772-779cm	Nig2 Strf0 Elas2 Sicc2 Humo3 $Ld^{2}4$ Ga+	Brown lake mud
779-801cm	Nig1 Strf0 Elas0 Sicc2 As4	Grey clay
801-808cm	Nig3 Strf1 Elas2 Sicc2 $Ld^{3}2$ As2	Dark and humified clay
808-846cm	Nig2 Strf1 Elas0 Sicc2 As4 Ga+	Grey clay

Table 3 Sediment description of CRM2 ("Lake Core")

DEPTH	TROELS-SMITH NOTATION	GENERAL DESCRIPTION
0-95cm	Nig3 Strf0 Elas1 Sicc2 Humo1 Ld^{3}4	Very dark and humic
95-110cm	Nig1 Strf2 Elas3 Sicc2 Humo3 Ld^{1}4	Yellow sandy band
110-120cm	Nig2 Strf1 Elas2 Sicc2 Humo3 Ld^{2}4	Brown lake mud
120-145cm	Nig3 Strf2 Elas1 Sicc2 Humo2 Ld^{3}4	Very dark and humic
145-160cm	Nig2 Strf1 Elas2 Sicc2 Humo2 Ld^{2}4	Brown lake mud
160-320cm	Nig3 Strf0 Elas1 Sicc2 Humo2 Ld^{3}4	Very dark and humic
320-335cm	Nig1 Strf1 Elas3 Sicc2 Humo3 Ld^{1}4 Ag+	Yellow sandy band
335-350cm	Nig2 Strf3 Elas2 Sicc2 Humo4 Ld^{2}4	Brown lake mud
350-370cm	Nig1 Strf2 Elas3 Sicc2 Humo3 Ld^{1}4	Yellow sandy band
370-400cm	Nig3 Strf1 Elas1 Sicc2 Humo3 Ld^{3}4	Very dark and humic
400-420cm	Nig2 Strf1 Elas1 Sicc2 Humo3 Ld^{2}4	Brown lake mud
420-445cm	Nig1 Strf1 Elas3 Sicc2 Humo3 Ld^{1}4	Yellow sandy band
445-570cm	Nig3 Strf2 Elas1 Sicc2 Humo3 Ld^{3}4	Very dark and humic
570-590cm	Nig1 Strf2 Elas3 Sicc2 Humo4 Ld^{1}4	Yellow sandy band
590-600cm	Nig2 Strf1 Elas2 Sicc2 Humo3 Ld^{2}4	Brown lake mud
600-660cm	Nig3 Strf3 Elas1 Sicc2 Humo3 Ld^{3}4	Very dark and humic
660-665cm	Nig1 Strf0 Elas3 Sicc2 Humo4 Ld^{1}4	Yellow sandy band
665-750cm	Nig2 Strf1 Elas0 Sicc2 As4 Gs+	Grey clay

Table 4 Sediment description of CRM3 ("Alder Carr Core")

DEPTH	TROELS-SMITH NOTATION	GENERAL DESCRIPTION
0-96cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^{3}4$	Very dark and humic
96-102cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^{3}4$ Test(moll)+	Very dark and humic with shells present
102-123cm	Nig1 Strf0 Elas3 Sicc2 Humo2 $Ld^{1}4$ Test(moll)+	Sandy band
123-137cm	Nig2 Strf2 Elas2 Sicc2 Humo2 $Ld^{2}4$ Test(moll)+	Brown lake mud
137-163cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^{3}4$ Test(moll)+	Dark, humic and shelly
163-182cm	Nig1 Strf0 Elas3 Sicc3 Humo3 $Ld^{1}4$ Test(moll)+	Sandy band
182-208cm	Nig3 Strf0 Elas2 Sicc2 Humo2 $Ld^{3}4$ Test(moll)+	Very dark and humic
208-235cm	Nig2 Strf2 Elas2 Sicc2 Humo2 $Ld^{2}4$ Test(moll)+	Brown lake mud
235-238cm	Nig2 Strf2 Elas2 Sicc2 Humo2 $Ld^{2}1$ Test(moll)3	Brown lake mud with many shells
238-268cm	Nig2 Strf2 Elas2 Sicc2 Humo2 $Ld^{2}4$ Test(moll)+	Brown lake mud
268-273cm	Nig3 Strf1 Elas1 Sicc2 Humo2 $Ld^{3}4$ Test(moll)+	Very dark and humic
273-281cm	Nig2 Strf1 Elas2 Sicc2 Humo2 $Ld^{2}4$ Test(moll)+	Brown lake mud
281-379cm	Nig3 Strf3 Elas1 Sicc2 Humo2 $Ld^{3}4$ Test(moll)+	Very dark and humic
379-389cm	Nig2 Strf2 Elas2 Sicc2 Humo2 $Ld^{2}4$ Test(moll)+	Brown lake mud
389-408cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^{3}4$ Test(moll)+	Very dark and humic
408-420cm	Nig2 Strf3 Elas2 Sicc2 Humo2 $Ld^{2}4$ Test(moll)+	Brown lake mud
420-430cm	Nig1 Strf3 Elas3 Sicc2 Humo2 $Ld^{1}4$ Test(moll)+	Sandy band
430-486cm	Nig2 Strf3 Elas2 Sicc2 Humo2 $Ld^{2}4$ Test(moll)+	Brown lake mud
486-492cm	Nig1 Strf3 Elas3 Sicc2 Humo2 $Ld^{1}4$ Test(moll)+	Sandy band
492-497cm	Nig3 Strf2 Elas1 Sicc2 Humo2 $Ld^{3}4$ Test(moll)+	Very dark and humic
497-500cm	Nig1 Strf2 Elas3 Sicc2 Humo2 $Ld^{1}4$ Test(moll)+	Sandy band
500-531cm	Nig2 Strf3 Elas2 Sicc2 Humo2 $Ld^{2}4$ Test(moll)+	Brown lake mud
531-542cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^{3}4$ Test(moll)+	Very dark and humic

Table 5 Sediment description of CRM4

DEPTH	TROELS-SMITH NOTATION	GENERAL DESCRIPTION
100-164cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^3$4	Very dark and humic
164-189cm	Nig1 Strf1 Elas0 Sicc2 As4	Grey clay
189-192cm	Nig3 Strf1 Elas1 Sicc2 Humo2 $Ld^3$4	Very dark and humic
192-204cm	Nig1 Strf1 Elas3 Sicc2 Humo2 $Ld^1$4	Sandy band
204-250cm	Nig1 Strf3 Elas0 Sicc2 Humo4 $Ld^1$1 As3	Sandy Clay

Table 6 Sediment description of CRM5

CRM1 was the next core taken in the transect of cores from the edge of the old lake bed towards the centre of the lake itself. The top 70cm also had to be removed for the reasons mentioned above, but the top 170cm of this core contained reed detritus suggesting that the coring point was under less than a metre of water at this time (zone 7a). Sandy bands occur during the Lateglacial, Preboreal and Boreal periods in this core (table 2).

The top 96cm of sediment from CRM4 also contained a high proportion of detrital reed material suggesting that the lake level was little higher during LPAZ zone9 (approximately 2000 years BP) than it is today. Five sandy bands were recorded in this core, occurring in the Preboreal, late Boreal and Subboreal periods (table 5).

Six sandy bands were recorded in CRM3, the core taken right on the edge of the Alder carr. These occurred in the Lateglacial, Boreal, mid Atlantic, Subboreal and Subatlantic periods. The most recent of these sandy bands could possibly have been caused by the recent drainage of the land surrounding Crose Mere in 1864 as the sediment occurring above this sandy band consists of reed detritus rather then lake sediment suggesting a slight lowering of water level to its present day limit.

CRM2 has always been under fairly deep water (>1m) judging by the lack of reed detritus present in the core. Two sandy bands occur in this core, these being at the Boreal Atlantic transition and during the Atlantic period (table 3).

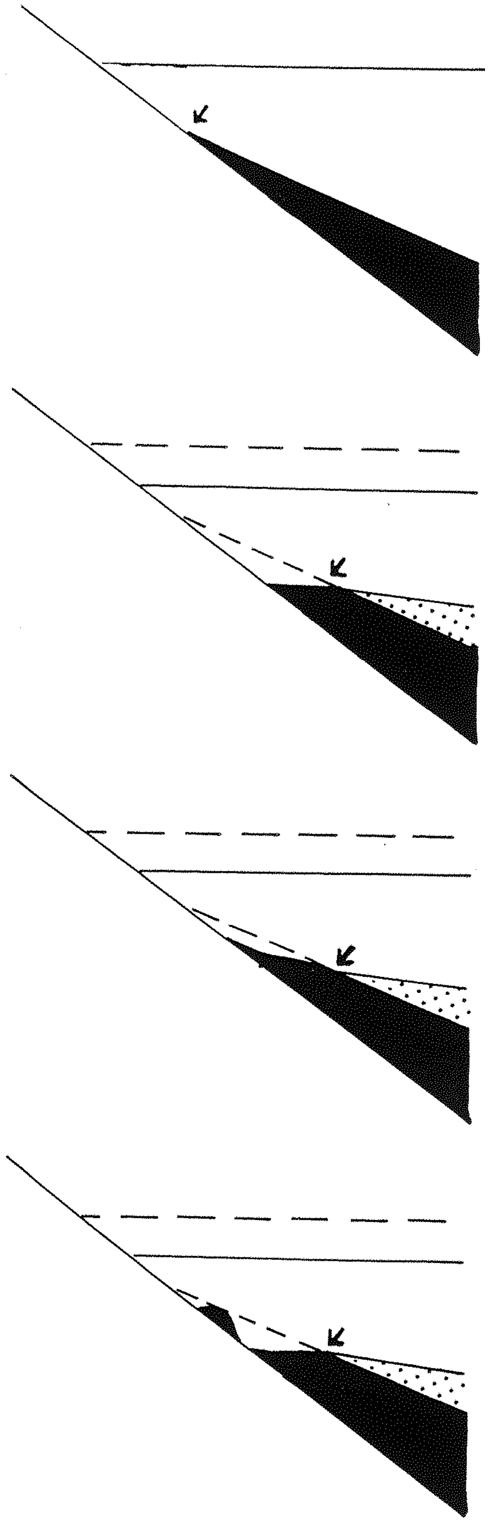
In a lake uncomplicated by redistribution of sediment it would be expected that these yellow sandy bands would occur at the same temporal intervals. However, when the five cores are correlated using pollen analysis and a stratigraphic diagram constructed, it can be seen that the picture is far from simple (figure 43). Some of the probable reasons for these complications are discussed in section 6.2 p121

A significant proportion of the organic content of Crose Mere is probably produced within the lake. In the Lake District, an area of high relief where many lakes are steep-sided valley lakes, it has been concluded that the majority of organic matter, as well as inorganic, is of allochthonous origin (Mackereth 1966, Pennington & Lishman 1971) but this is probably not the case in productive lowland lakes occupying closed basins (Gorham & Sanger 1967). Taking this into consideration, it seems probable that the sandy bands consist of inorganic matter inwashed from the lake margins which are composed chiefly of glacial till.

6.2 Sediment Limit Reconstruction

The sediment limit is defined as the limit above which organic material cannot accumulate owing to wind and wave action (section 2.3.2 p11). The reconstruction of past changes in sediment limit are usually complicated and often made impossible by the older sediments which have accumulated at a higher lake level being eroded and redeposited during a subsequent lowering. In some cases all of the older sediment above the subsequent sediment limit may become eroded and removed. In other cases, depending on character of sediment the erosion may be incomplete and raises the possibility of a minimum determination of the earlier higher level of the sediment limit. In some especially favourable cases, small patches or restricted layers of older sediment accumulated close to the earlier sediment limit may remain in less exposed positions. (figure44).

The sediment limit was reconstructed using loss on ignition procedures to give an estimate of the total amount of organic matter in the sediment. When the loss on ignition figures were compared to the stratigraphy the low levels of organic content correspond well to the sandy bands identified during the sediment description. The 5% limit (section 2.3.2 p11) was only crossed in two cores;



Sediment limit is defined as the highest limit for deposition of a predominantly organic sediment (indicated by arrow)

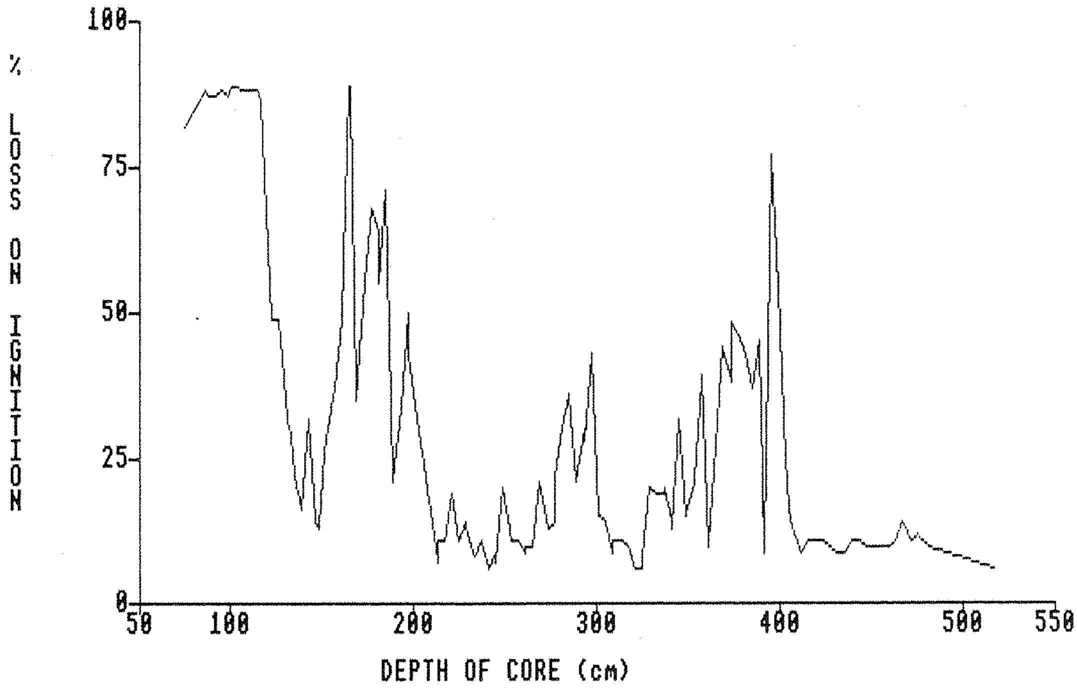
All of the older sediment above the new sediment limit has been eroded away

This erosion may be incomplete

Small patches of older sediment may remain in less exposed positions

Figure 44

Possible erosional effects of the sediment limit caused by a lowering of water level (redrawn from Digerfeldt 1988)



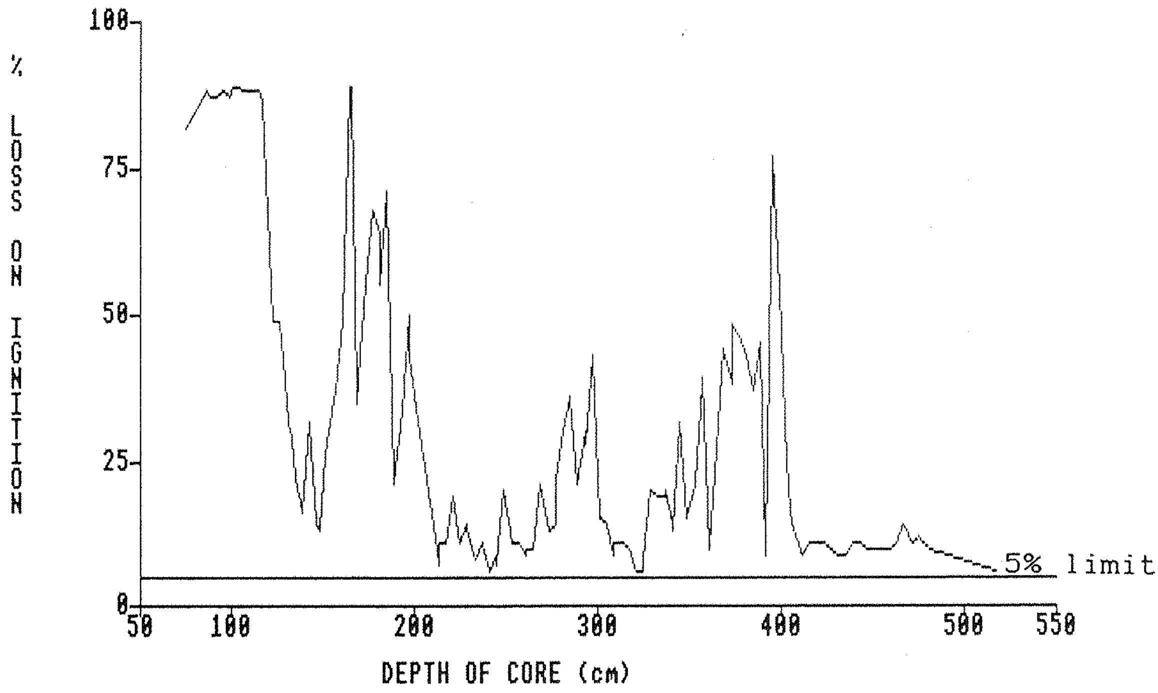
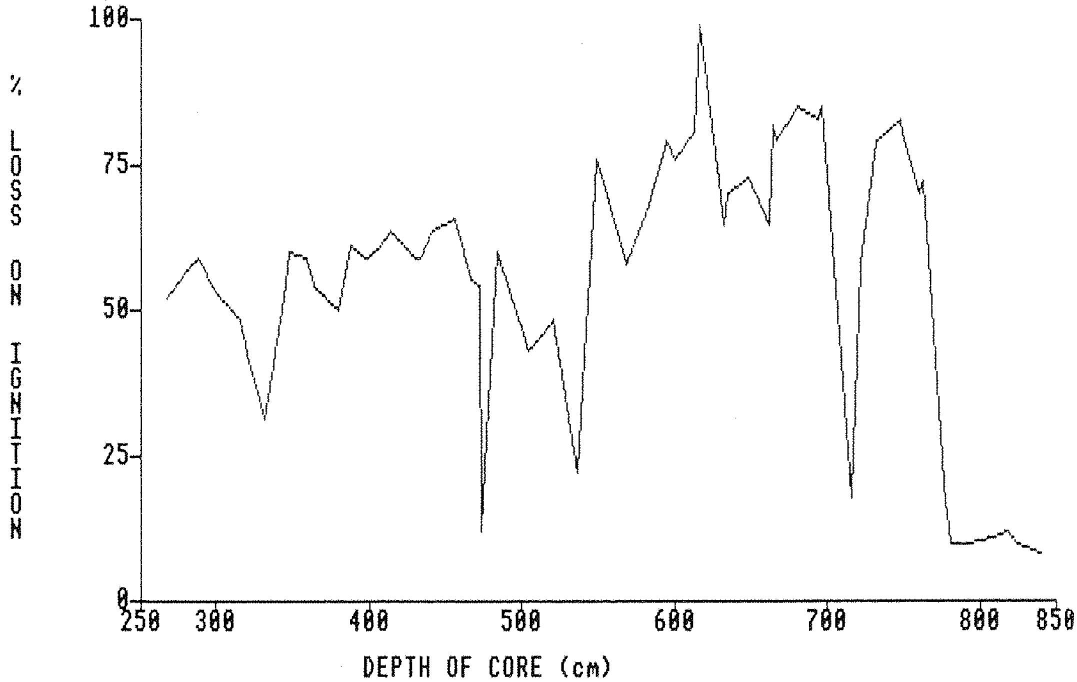


Figure 45 Organic content of CRM1 (see text for explanation of 5% limit)



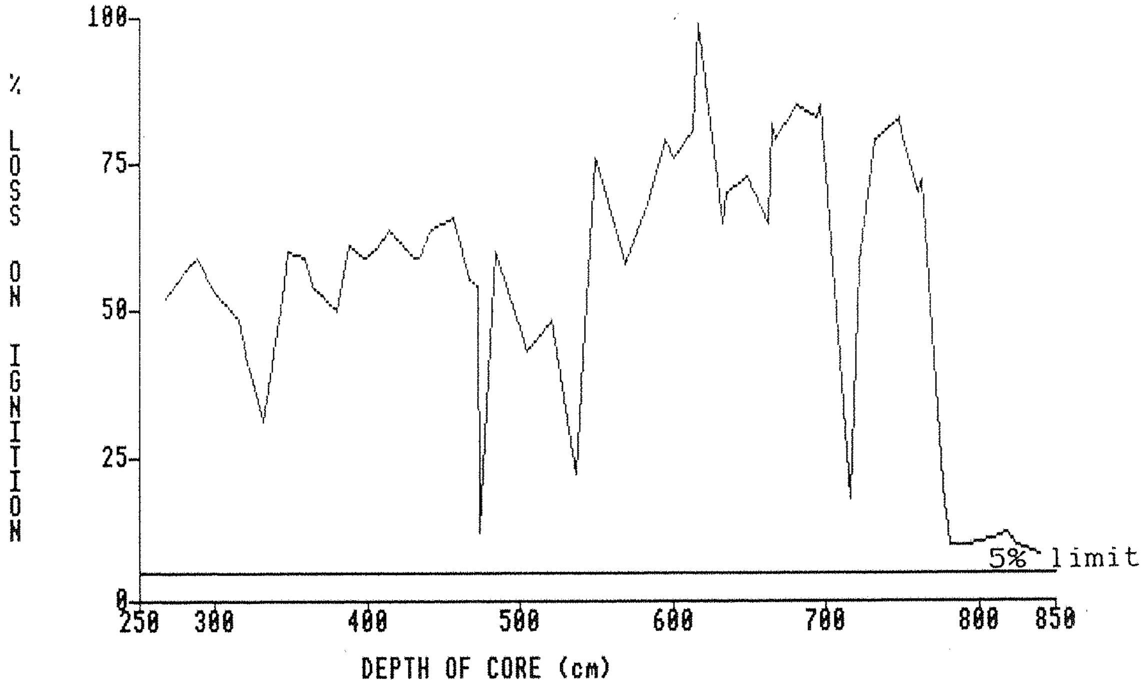
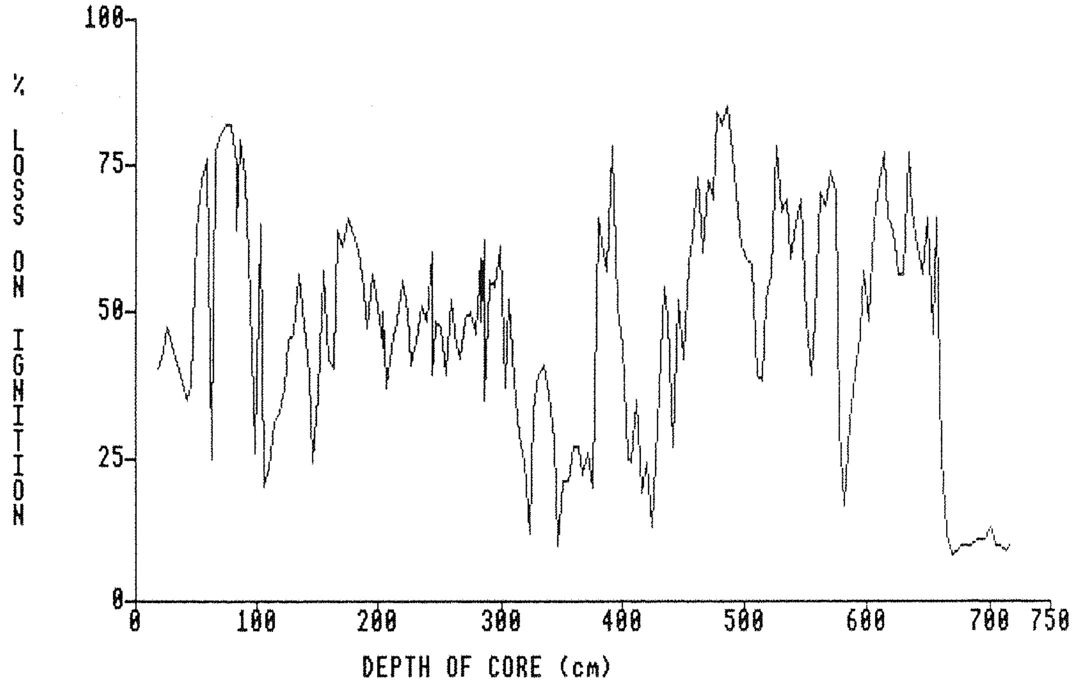


Figure 46 Organic content of CRM2 (see text for explanation of 5% limit)



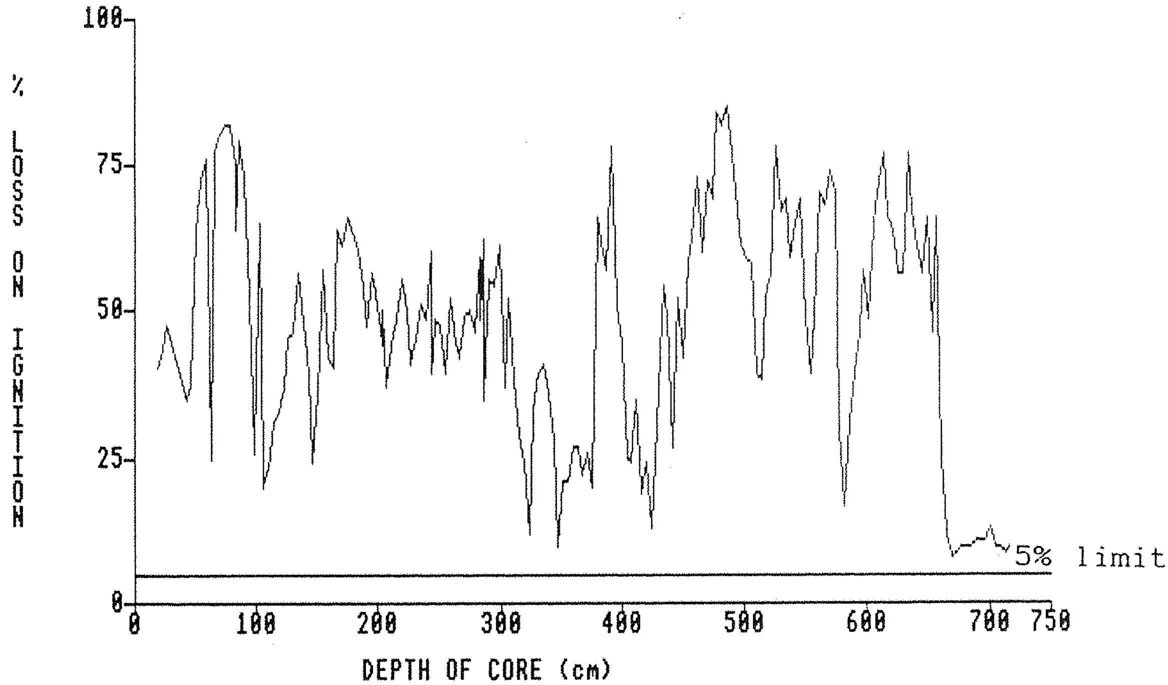
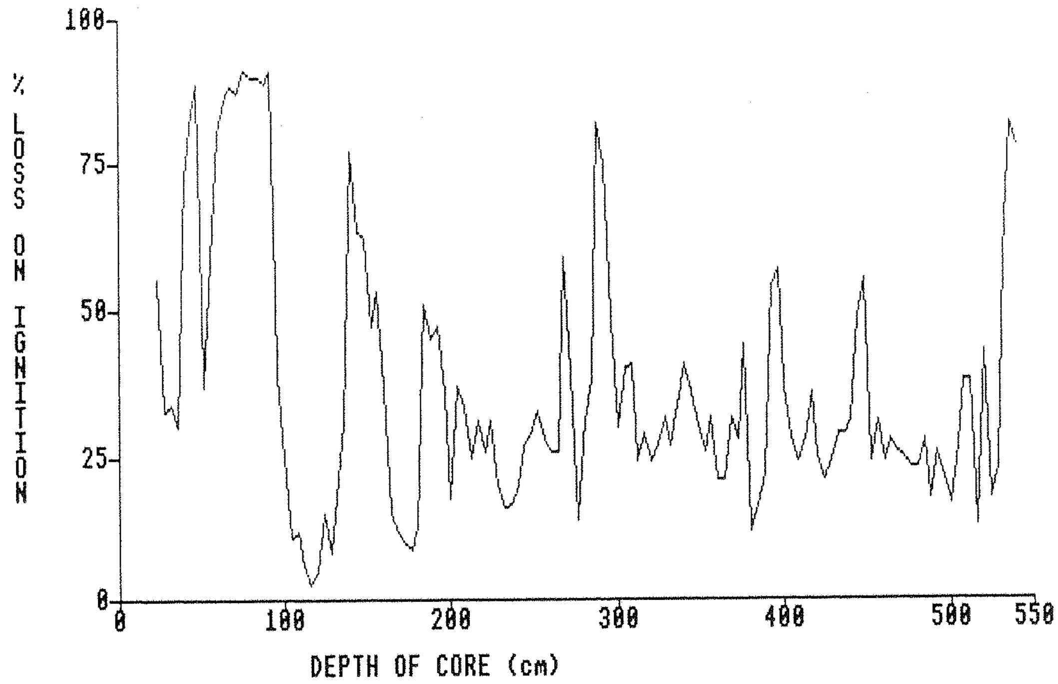


Figure 47 Organic content of CRM3 (see text for explanation of 5% limit)



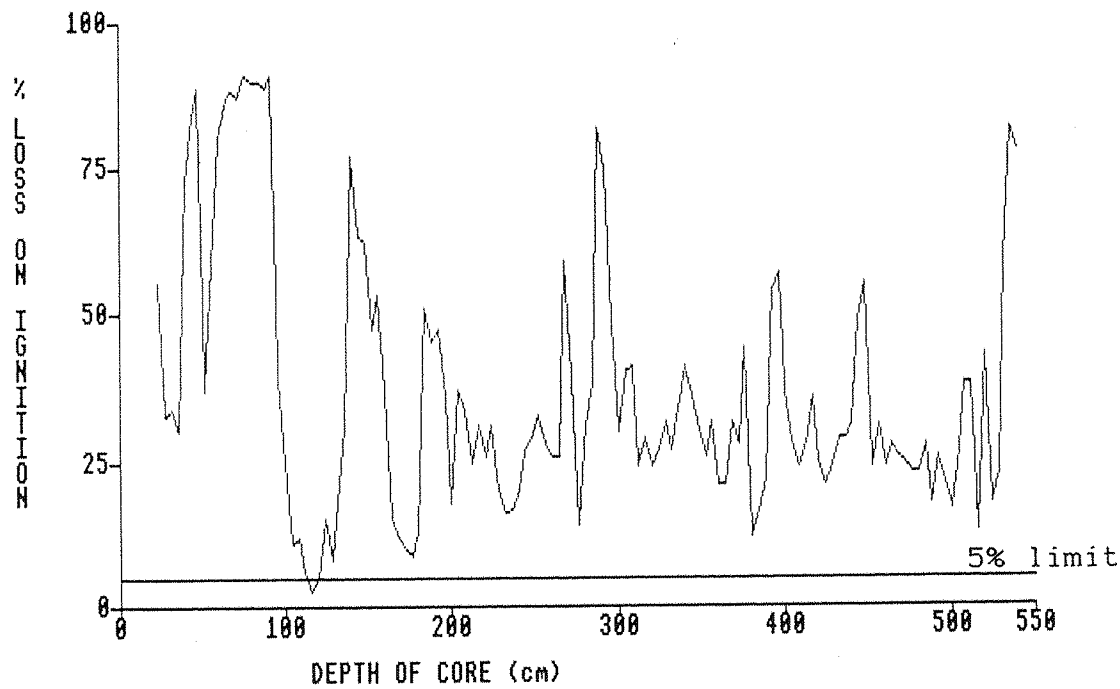
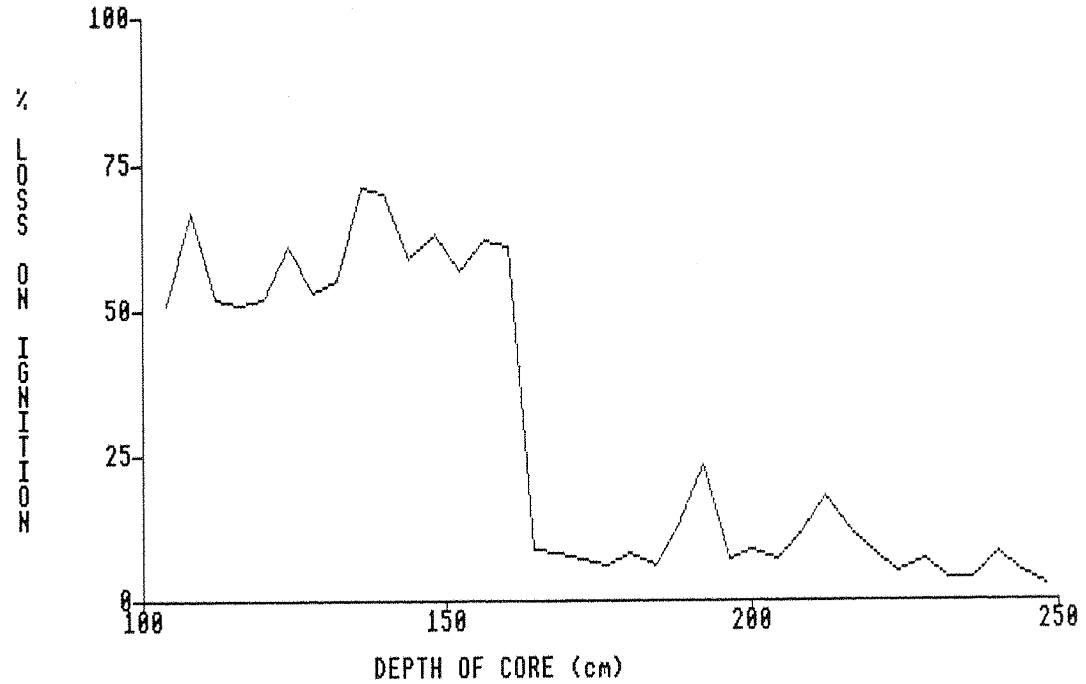


Figure 48 Organic content of CRM4 (see text for explanation of 5% limit)



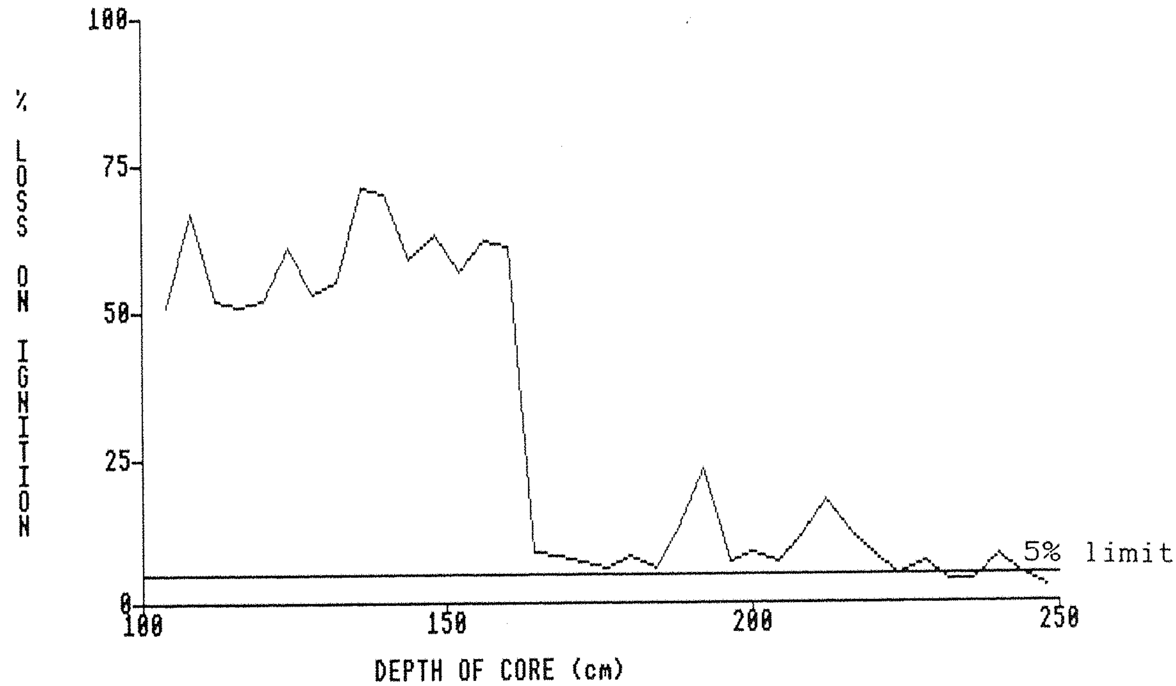


Figure 49 Organic content of CRM5 (see text for explanation of 5% limit)

CRM5 in zones1-2 and CRM4 in zone9. There is some question as to the relevance of this 5% organic sedimentation limit to British lakes and this is dicussed in section 8.4 p198 There were, however, periods of decreased organic content in the sediment which could be traced through some, if not all, of the cores. These could be followed from zone4 CRM5 to zone5 CRM2 (Preboreal/Boreal), mid zone7a CRM1 to early zone7b CRM2 (Atlantic), mid zone7b CRM1 to mid zone7b CRM2 (Atlantic), zone7b/zone8 CRM4 to zone7/zone8 CRM2 (Atlantic) and from early zone10 CRM3 to early zone10 CRM2 (Subatlantic). Other periods of decreased organic content occurred in various places in different cores (see table 7) but these were disjunct and no continuous pattern could be traced through the cores suggesting that they might have been subjected to erosional and redepositional processes. Therefore, although the sediment limit as defined by Digerfeldt (1986, 1988) cannot be traced through the transect of cores from the old lake bed at Crose Mere to the lake itself, it appears that five periods of lower organic sedimentation can be recognised, these occurring in the Preboreal/Boreal, Atlantic and Subatlantic periods.

6.3 Particle Size Analysis

Sorting occurs between the particles destined to make up the sediment at the bottom of the lake with the finer particles remaining in suspension longer than the heavier particles. It is thought that the lowering of a lake level will result in an increase in coarse minerogenic and organic matter at this spatial and temporal point in a core due to the inwashing of freshly isolated lake shores and the infilling of the basin by the marginal macrophyte vegetation. A rise in water level will cause a corresponding decrease in the amount of coarse material constituting the lake sediment at the same coring point (section 2.4.1 p 12).

This analysis was performed on CRM1 as this core was situated near the margin of the old

CRM5	CRM1	CRM4	CRM3	CRM2
Mid 1	-----	-----	-----	-----
1/2 transition	-----	-----	-----	-----
2/3 transition	-----	-----	-----	-----
-----	3/4 transition	-----	3/4 transition	-----
zone 4	4/5 transition	zone 5	zone 5	zone 5
-----	5/6 transition	mid 6	-----	mid 6
-----	6/7a transition	6/7a transition	6/7a transition	-----
-----	mid 7a	late 7a	7a/7b transition	early 7b
-----	mid 7b	mid 7b	mid 7b	mid 7b
-----	-----	7b/8 transition	7b/8 transition	7b/8 transition
-----	-----	mid 8	-----	mid 8
-----	-----	mid 9	-----	mid 9
-----	-----	-----	early 10	early 10

Table 7

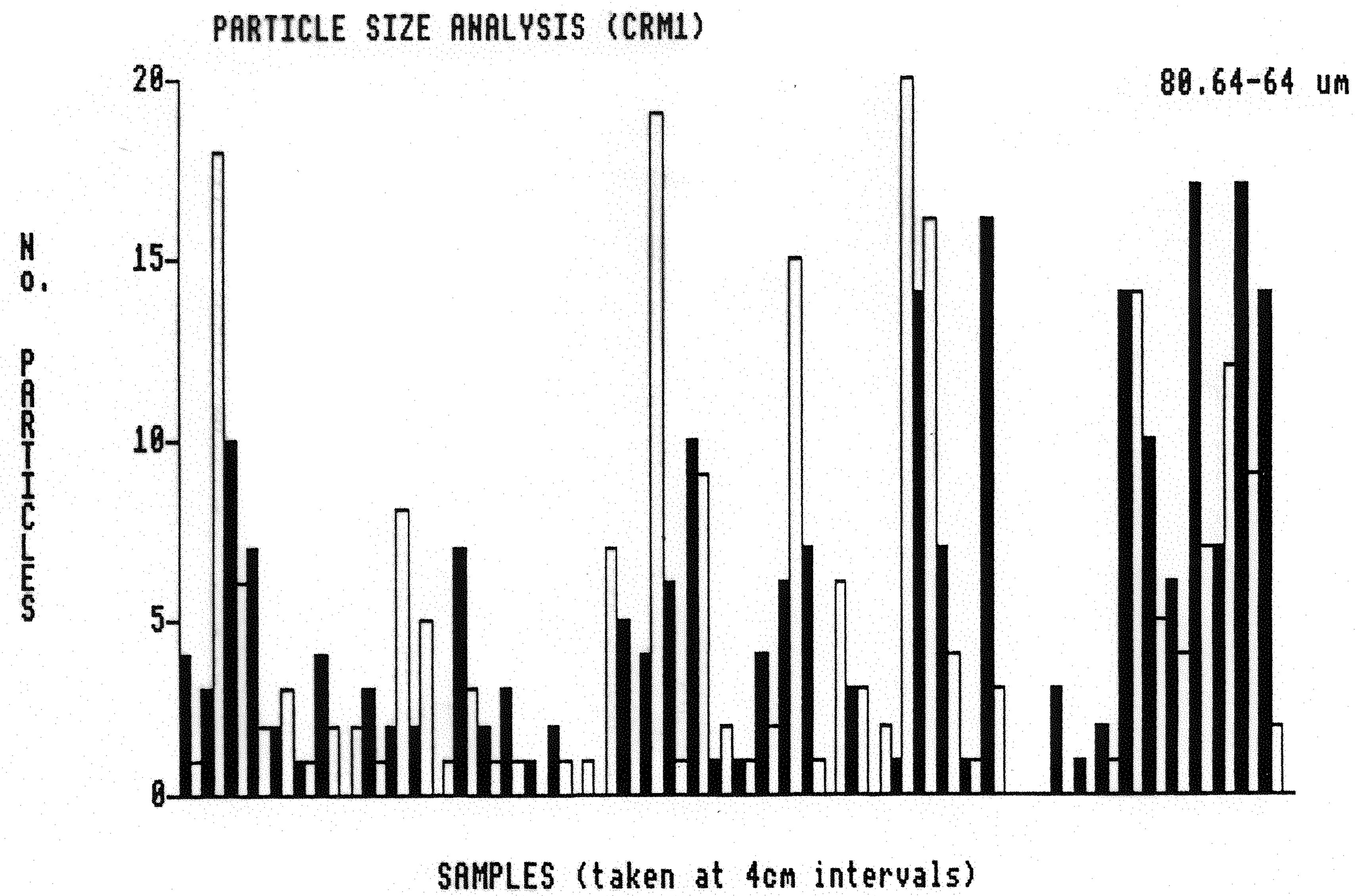
Decreases in organic sedimentation of Crose Mere lake. The results obtained indicated that there was little variation in particles less than 50um in diameter. The greatest variation occurred in particle sizes between 50um and 100um. Very few particles were recorded with a diameter greater then 100um. Peaks indicating an increase in particle size were recorded in two or more size classes at the depths shown in figure 50.

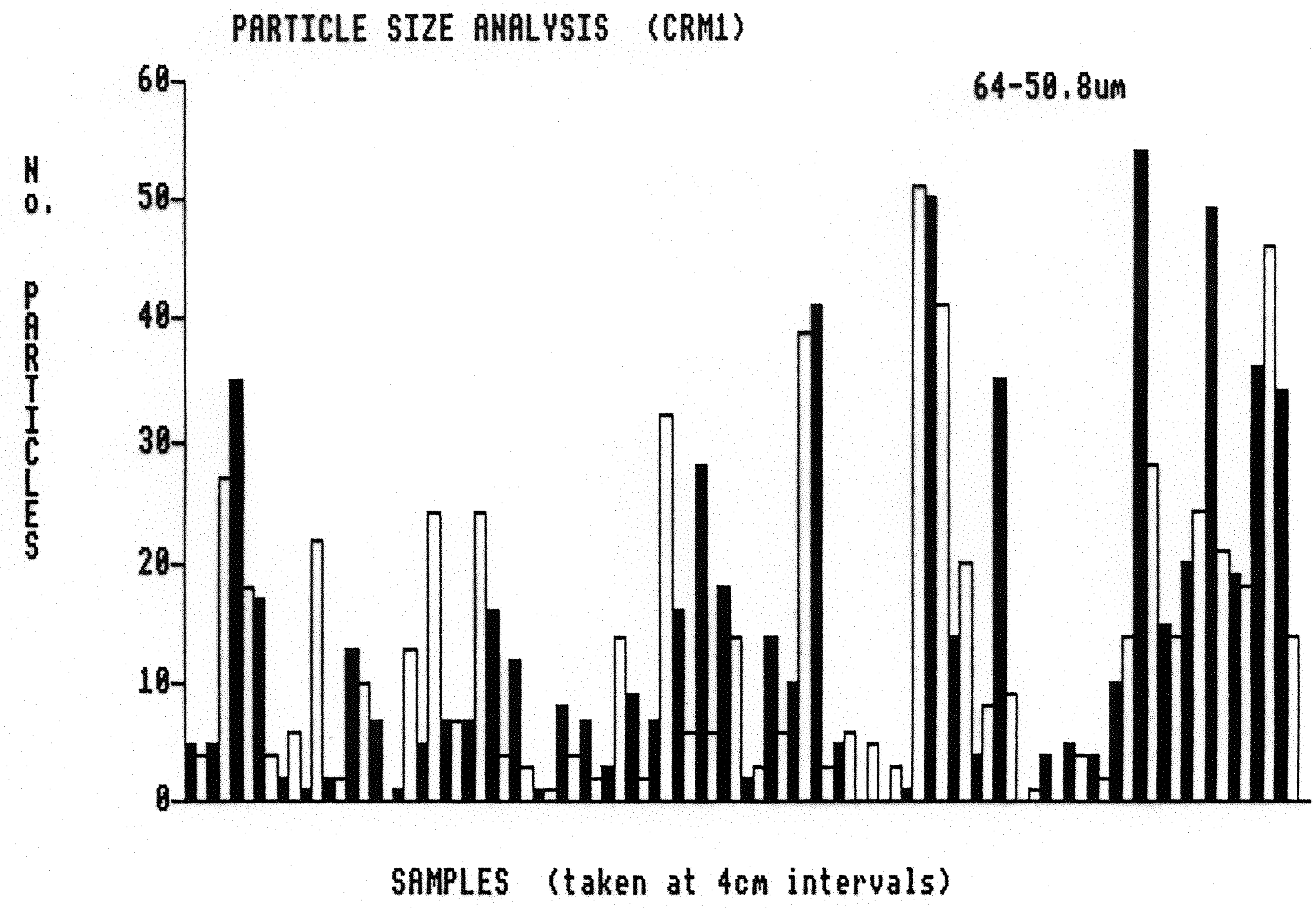
These results present a fairly complicated picture (figures 51.52). There would probably be a large amount of inwashing of exposed glacial till in the disturbed conditions of the lateglacial so several increases in particle size would have been expected during this time. The Boreal period also appears to have been a time of changes, as increases in particle size were recorded from both the upper and lower transition zones, as well as twice during the Boreal period itself.

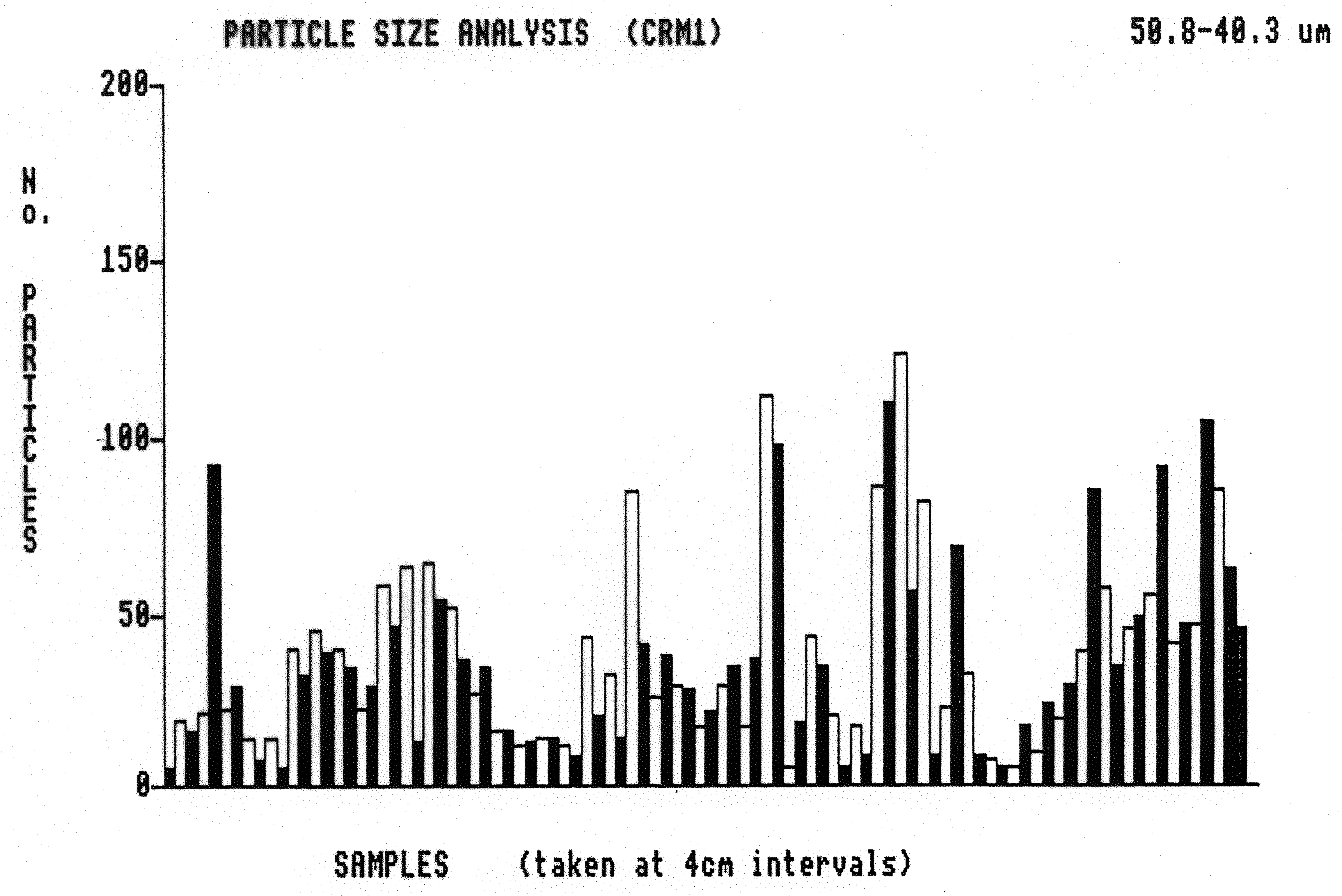
As CRM1 only represented zones 7 - 1 particle size analysis was also performed on CRM3 as this core is situated on the margin of the present day lake. Increases were recorded in CRM3 at the following depths;

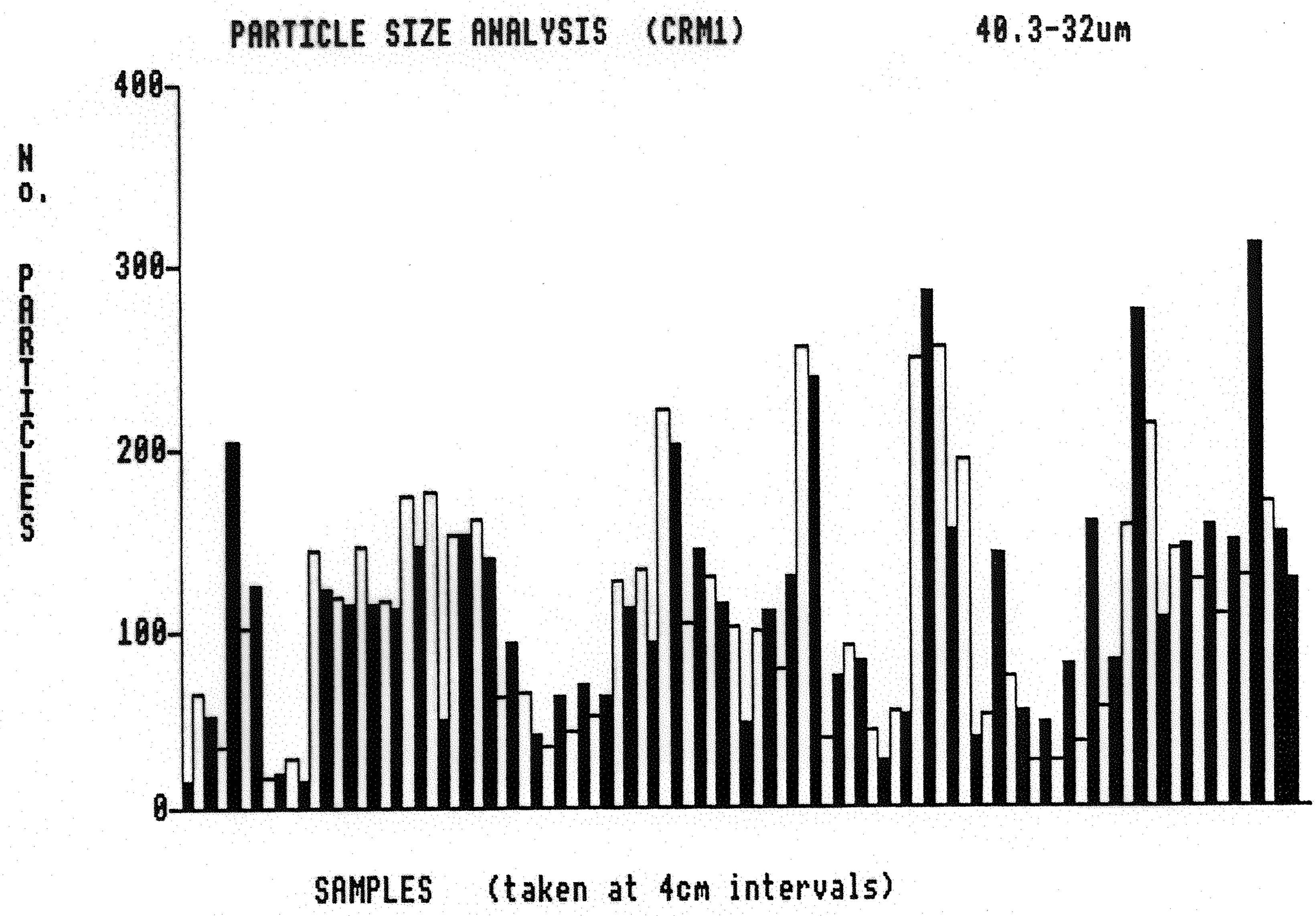
44cm	zone10	Subatlantic
140cm	zone10	Subatlantic
188cm	zone10	Subatlantic
300cm	mid zone8	Subboreal
344cm	zone7b/zone8 transition	Atlantic/Subboreal

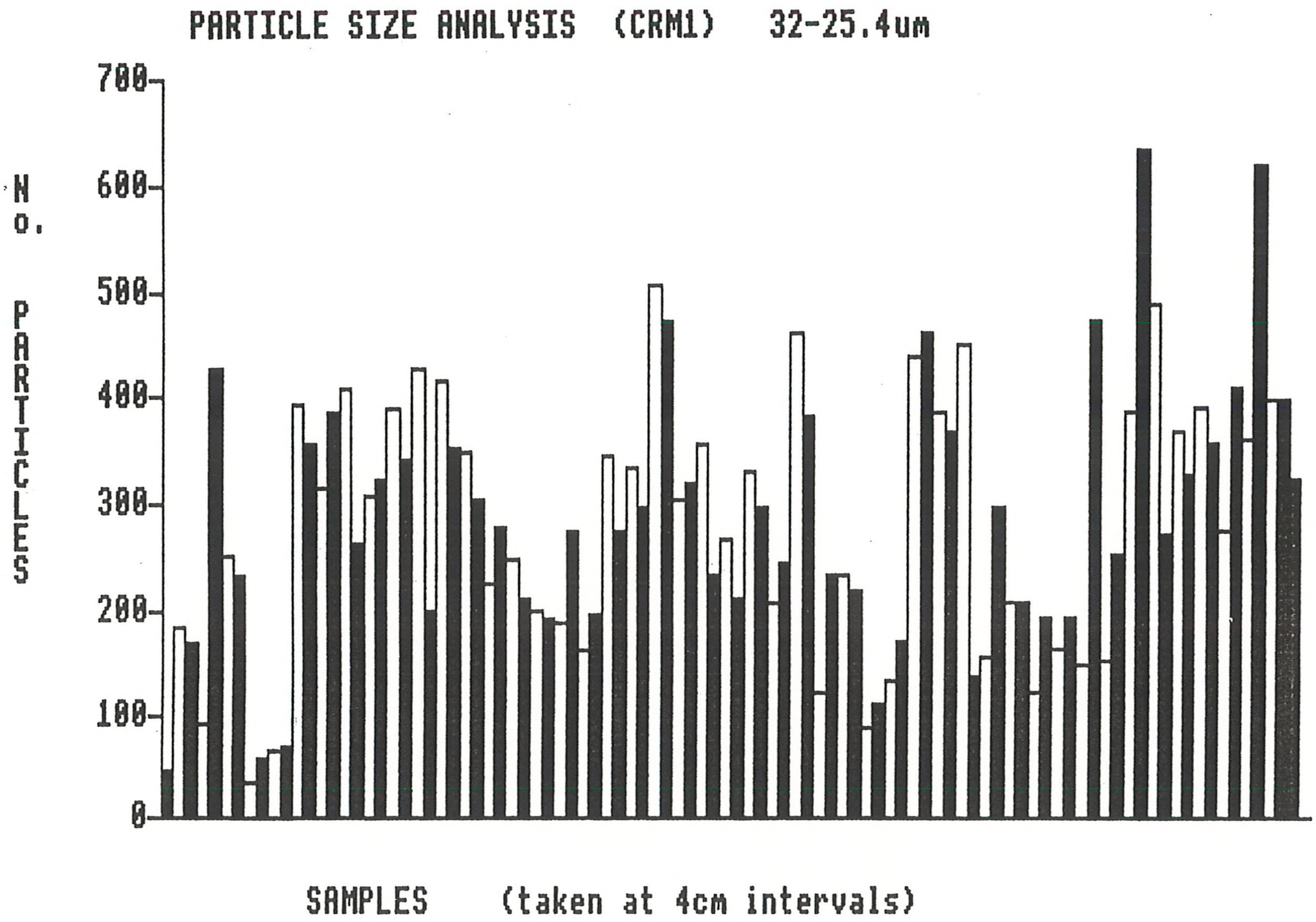
Two of these increases correspond well with decreases in organic sedimentation. These are the increases occurring at 188cm and 344cm (Subatlantic and Atlantic/Subboreal transition periods respectively). An increase in particle size coupled with a decrease of organic sedimentation may not be due to lowered water levels, however. Increased exposure of the lake, due to deforestation for example, would result in more movement of the water because of wind driven currents. This creates greater erosion of the lake margins decreasing the amount of organic sedimentation, and increases the probability of larger particles being


PARTICLE SIZE ANALYSIS (CRM1)
80.64-64 um
No. PARTICLES
20
15
10
5
0
SAMPLES (taken at 4cm intervals)

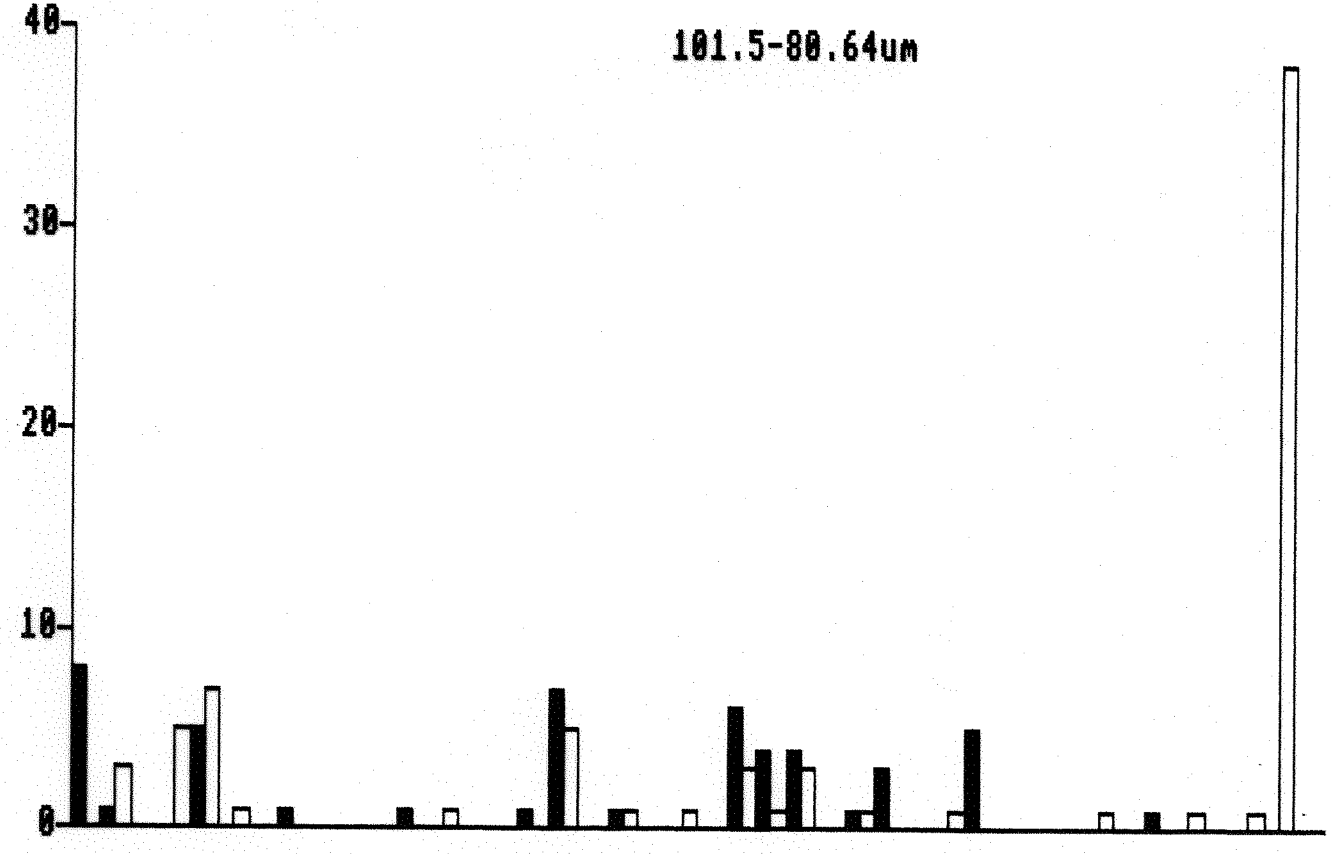

PARTICLE SIZE ANALYSIS (CRM1)
64-50.8um
No. PARTICLES
60
50
40
30
20
10
0
SAMPLES (taken at 4cm intervals)

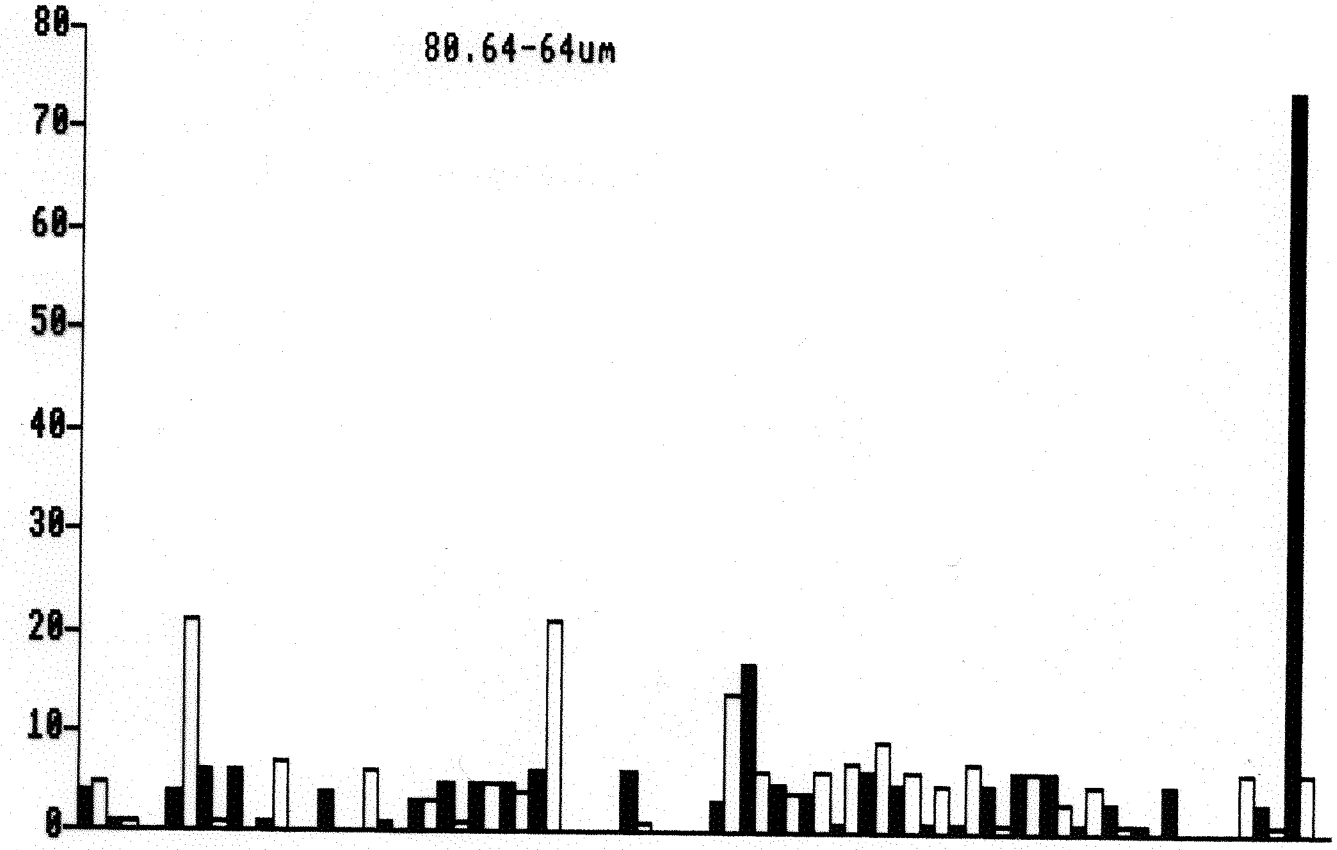

PARTICLE SIZE ANALYSIS (CRM1)
50.8-40.3 um
200
150
100
50
0
No. PARTICLES
SAMPLES (taken at 4cm intervals)

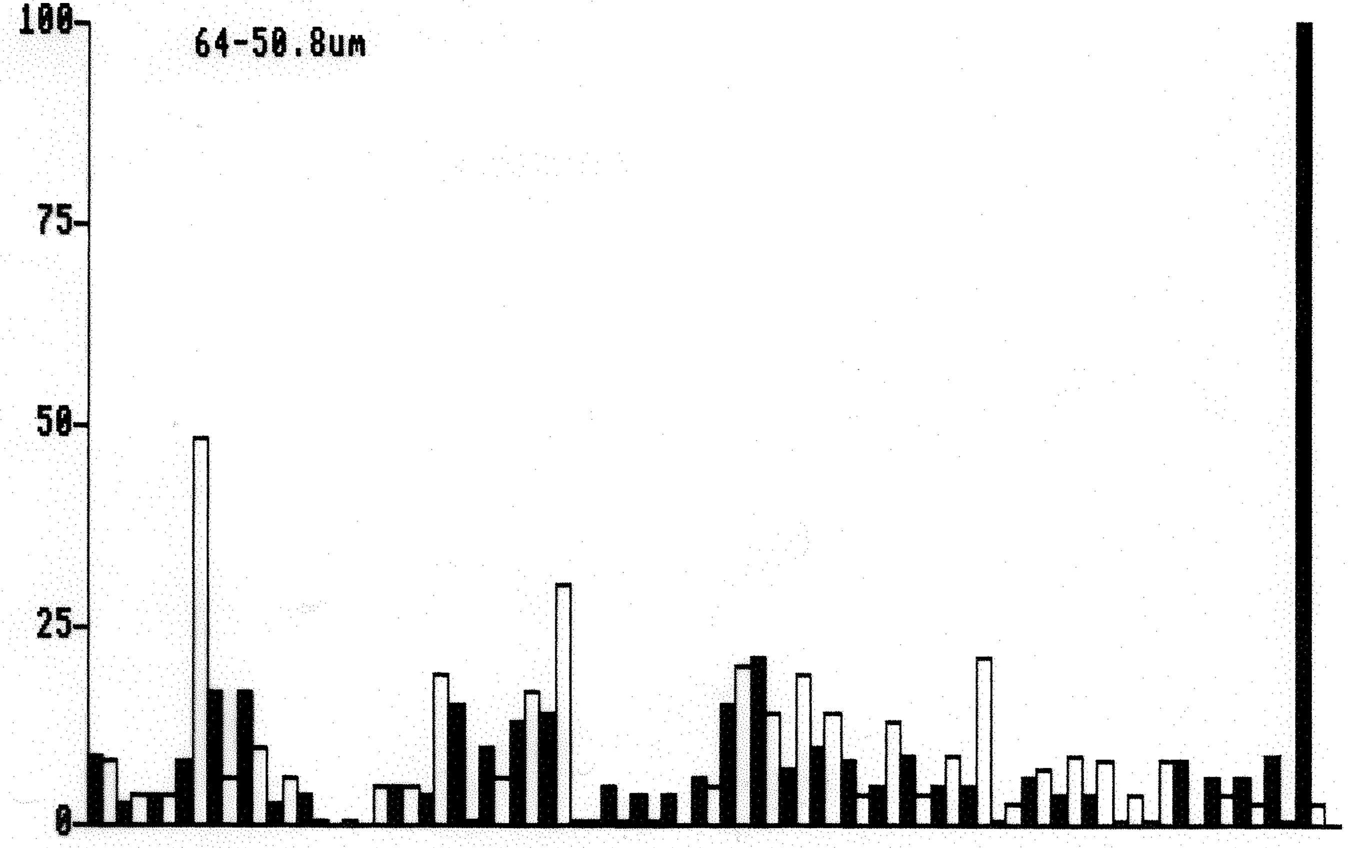

PARTICLE SIZE ANALYSIS (CRM1)
40.3-32um
No. PARTICLES
400
300
200
100
0
SAMPLES (taken at 4cm intervals)

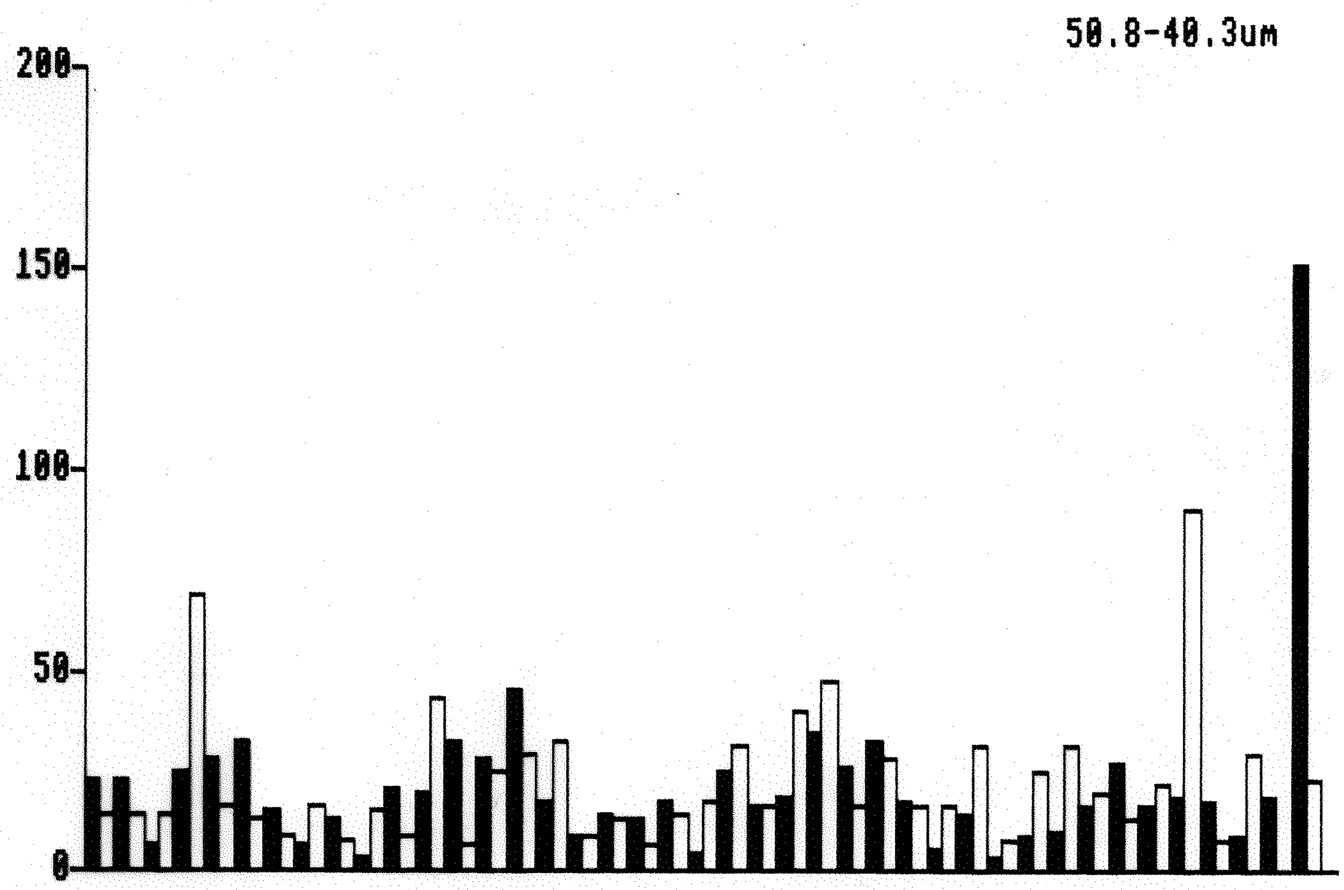


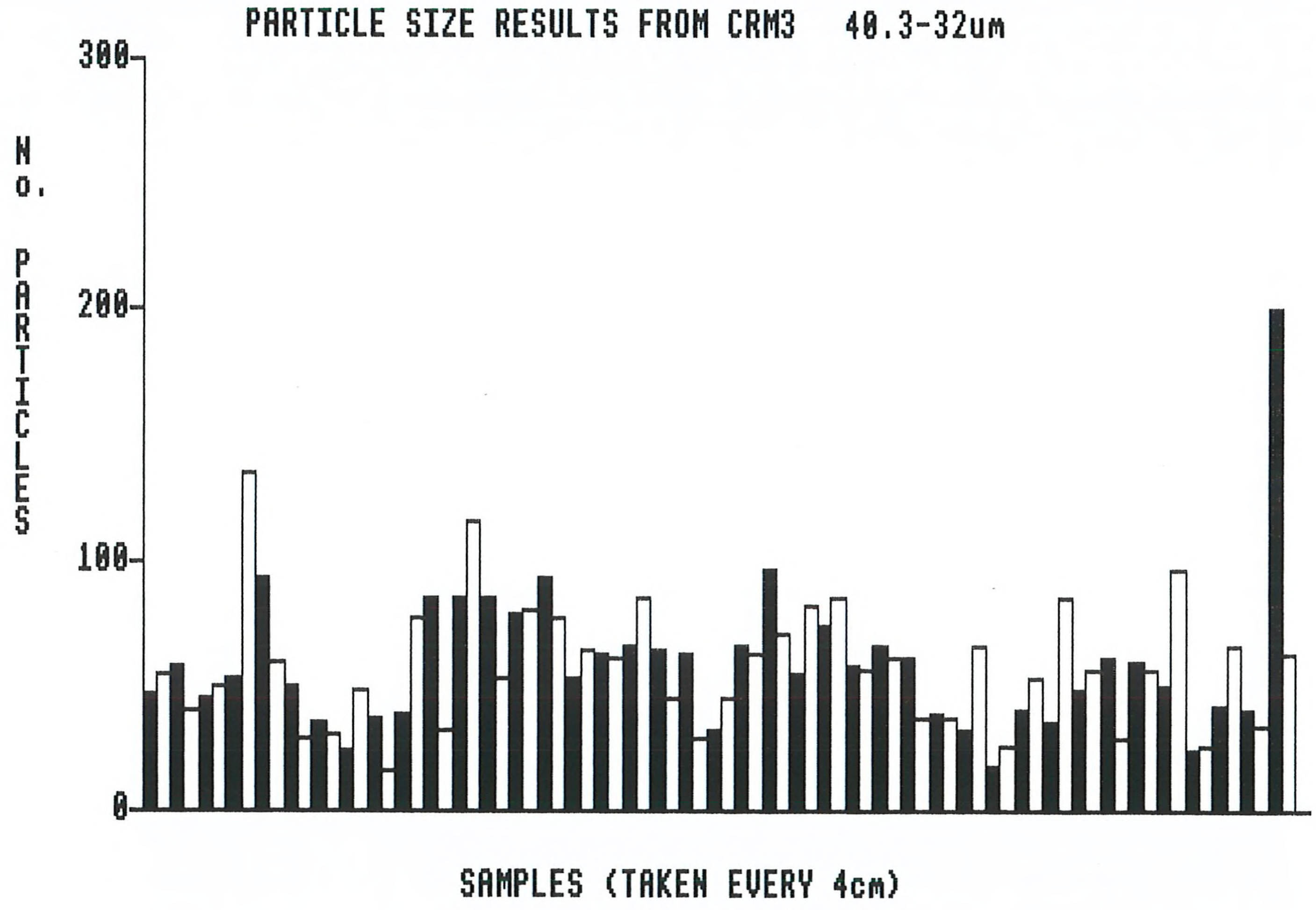
PARTICLE SIZE ANALYSIS (CRM1) 32-25.4um
No. PARTICLES
700
600
500
400
300
200
100
0
SAMPLES (taken at 4cm intervals)


101.5-80.64um
40
30
20
10
0


80.64-64um
80
70
60
50
40
30
20
10
0


64-50.8um
100
75
50
25
0


50.8-40.3um
200
150
100
50
0


PARTICLE SIZE RESULTS FROM CRM3 40.3-32um
300
200
100
0
No. PARTICLES
SAMPLES (TAKEN EVERY 4cm)

Depth	LPAZ	Blytt Sernander periods
76-77cm	late zone7b	Atlantic
238cm	zone6/zone7a transition	Boreal/Atlantic
282-290cm	early zone6	Boreal
326-334cm	zone5/zone6 transition	Boreal
354cm	zone4/zone5 transition	Preboreal/Boreal
402cm	zone3/zone4 transition	Lateglacial
426cm	mid zone3	Lateglacial
442-450cm	zone2/zone3 transition	Lateglacial

Figure 50 Increases in particle size recorded in two or more size classes (CRM1)

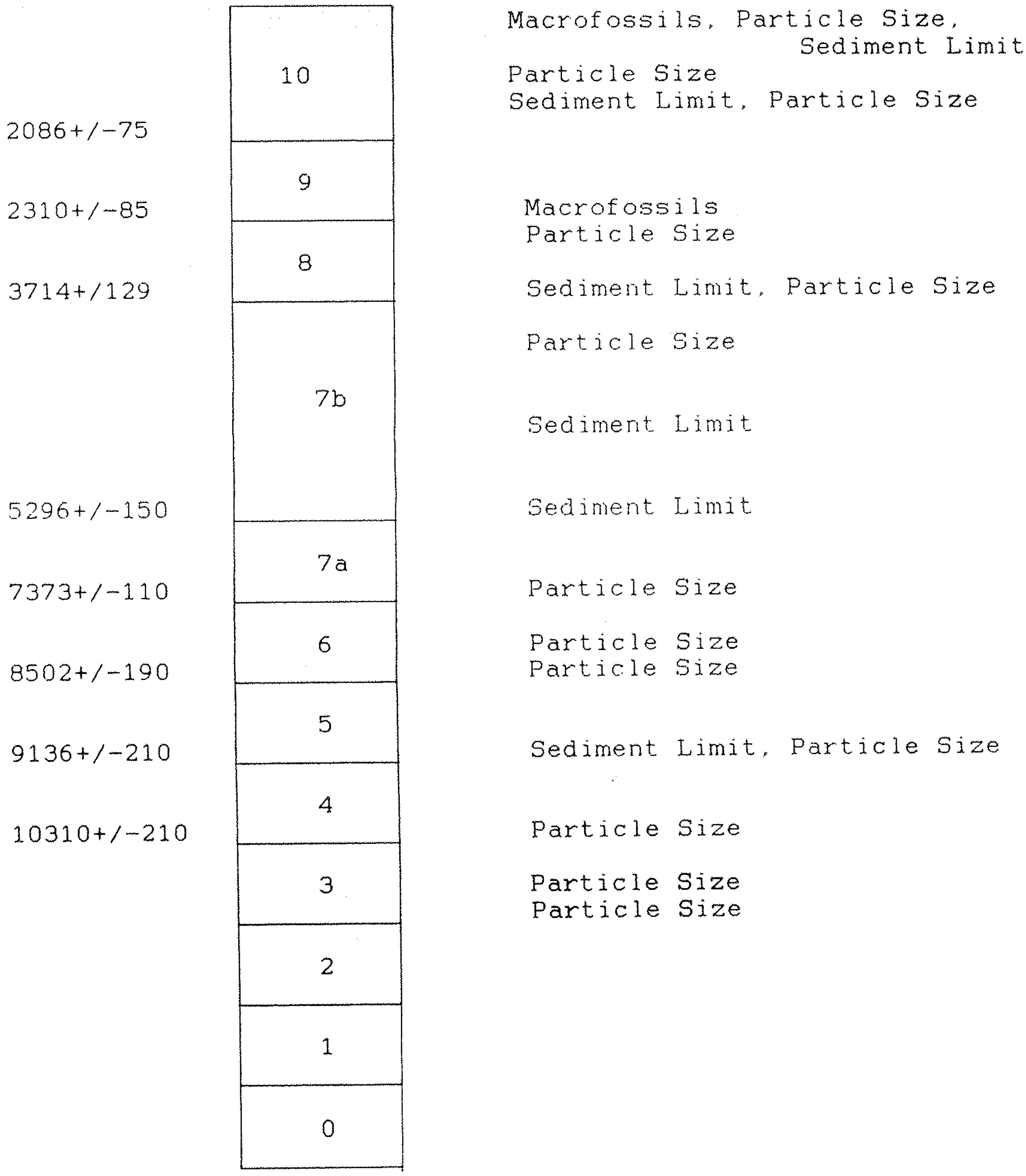


Figure 53 Positive results obtained from Crose Mere

deposited near the margins of the lake whilst smaller particles will remain in suspension longer, being carried out towards the centre of the lake before they are eventually deposited. Thus an increase in particle size together with a decrease in organic sedimentation would be recorded although no lowering of water levels of the lake had occurred.

To summarise, four increases in particle size correspond with decreases in organic sedimentation (figure53). The most recent increase in particle size corresponds well with rapid increases in *Alnus glutinosa* seeds preserved in the sediment. This almost certainly represents a decrease in lake level, probably connected with the drainage operations of 1864, as all three analyses have positive results at this point (figure 53).

6.4 Macrofossil Analysis

It was decided to represent only the numbers of fruits and seeds encountered in the macrofossil diagram, thus excluding the estimates of unidentified plant material which were thought to be too imprecise. Where remains other than fruits and seeds were included, these are clearly indicated on the diagram. The macrofossil diagram obtained from CRM3 was divided visually into the following macrofossil assemblage zones. Accurate dates were not possible as the local macrofossil assemblage zones do not correspond well with the local pollen assemblage zones. However, an indication of possible radiocarbon dates estimated from the pollen diagrams obtained from Crose Mere is given in the summary at the end of the section.

Zone1 (bottom to 660cm)

High *Chara* and *Nitella*

Juncus present

The abundance of Charaphytes in this zone is suggestive of fairly deep water. The presence of wetland marginal vegetation species such as *Juncus* would suggest that a certain amount of inwashing occurred during this zone. This is consistent with the unstable conditions of the lateglacial environment.

Zone2 (660 to 610cm)

Cladium mariscus generally consistently present

No *Najas flexilis*, *Alnus* or *Nymphaea*

High levels of *Betula*

The presence of *Cladium mariscus* is indicative of the appearance of marginal macrophytes maybe consisting of *Phragmites*, *Typha* and *Cladium* reedswamp. These species would indicate a general depth of approximately 1m of water over the coring point at this time although it is impossible to say whether *Cladium mariscus* was actually colonising the coring point or whether the seeds had been carried there by wind driven currents.

Zone3 (610 to 570cm)

Najas flexilis present

Betula levels decrease

The decrease in the amount of *Betula* macrofossils coupled with the appearance of *Najas flexilis* indicates that the lake level is gradually rising.

Zone4 (570 to 430cm)

High *Najas flexilis*

Low *Alnus*,*Betula* and *Nymphaea*

No *Nuphar*

Najas flexilis and *Nymphaea* have displaced the marginal *Cladium* reedswamp vegetation indicating that this was a period of higher water levels. The first occurrence of *Alnus* macrofossils in the sediment coincides well with the Boreal-Atlantic transition shown on the main pollen diagram at 565cm.

Zone5 (430 to 300cm)

Low *Alnus*, *Betula* and *Nymphaea*

A very low number of seeds was recorded for this zone suggesting that it was a stable period with few environmental changes (Grime 1979, Birks 1984) as plants often respond to a changing environment by producing an abundance of seeds, thus improving the probability of their survival against intruders in a very competitive habitat. This zone occurred around 3500 to 2700 BP.

Zone6 (300 to 200cm)

High *Betula* and *Alnus*

Carex pseudocyperus, Nymphaea and *Nuphar* present

Juncus and *Cladium mariscus* also present

This zone is characterised by large numbers of seeds and plant remains including many dry land and ruderal species. This is very important as the vegetation is clearly responding to some variation in the environment. However, there is no increase in particle size or decrease in sediment limit recorded at this point (approximately 3000 BP)(figure 54). This would suggest that the change in vegetation could be due to human interference, especially as it is coupled to the recording of anthropogenic indicators such as *Aphanes arvensis, Galeopsis tetrahit, Rubus fruticosa* and *Urtica dioica* in the macrofossil diagram.

Zone7 (200 to 50cm)

High *Chara*

Betula present

No *Alnus, Juncus* or *Nymphaea*

Dry land and ruderal species are no longer represented in this zone, and the sudden decline in *Alnus* and *Juncus* suggests that the lake levels had once more increased displacing the marginal macrophytes outwards.

Zone8 (50cm to top)

High *Alnus, Juncus* and *Stellaria*

Cladium mariscus present

No *Betula*

Extremely high levels of *Alnus* seeds were recorded in this zone, representing the Alder carr vegetation growing over the coring point today. There is a corresponding increase in the dry grassland species and ruderals, with high levels of *Stellaria* also being recorded. The

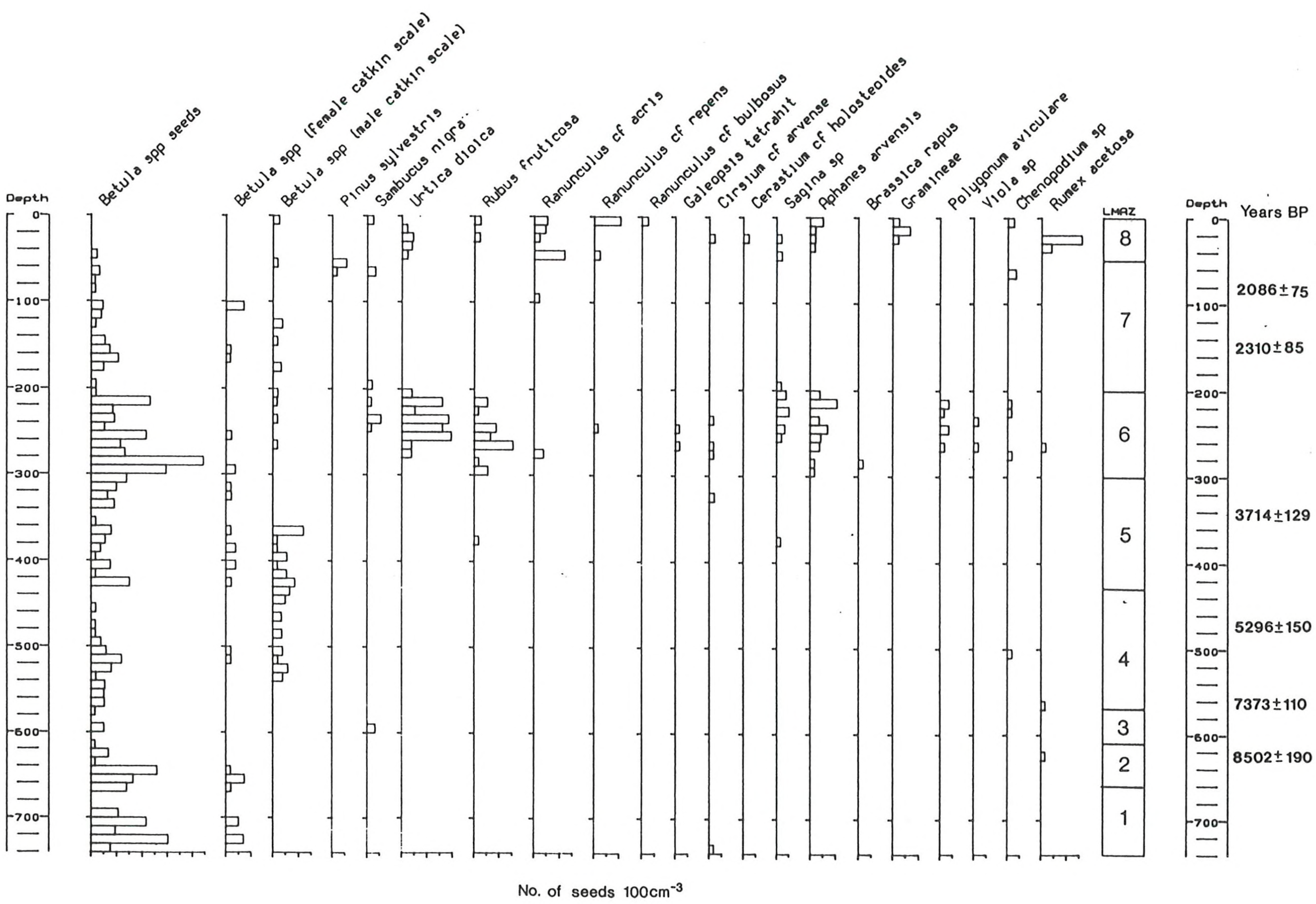


Figure 54 Terrestrial macrofossils (CRM3)

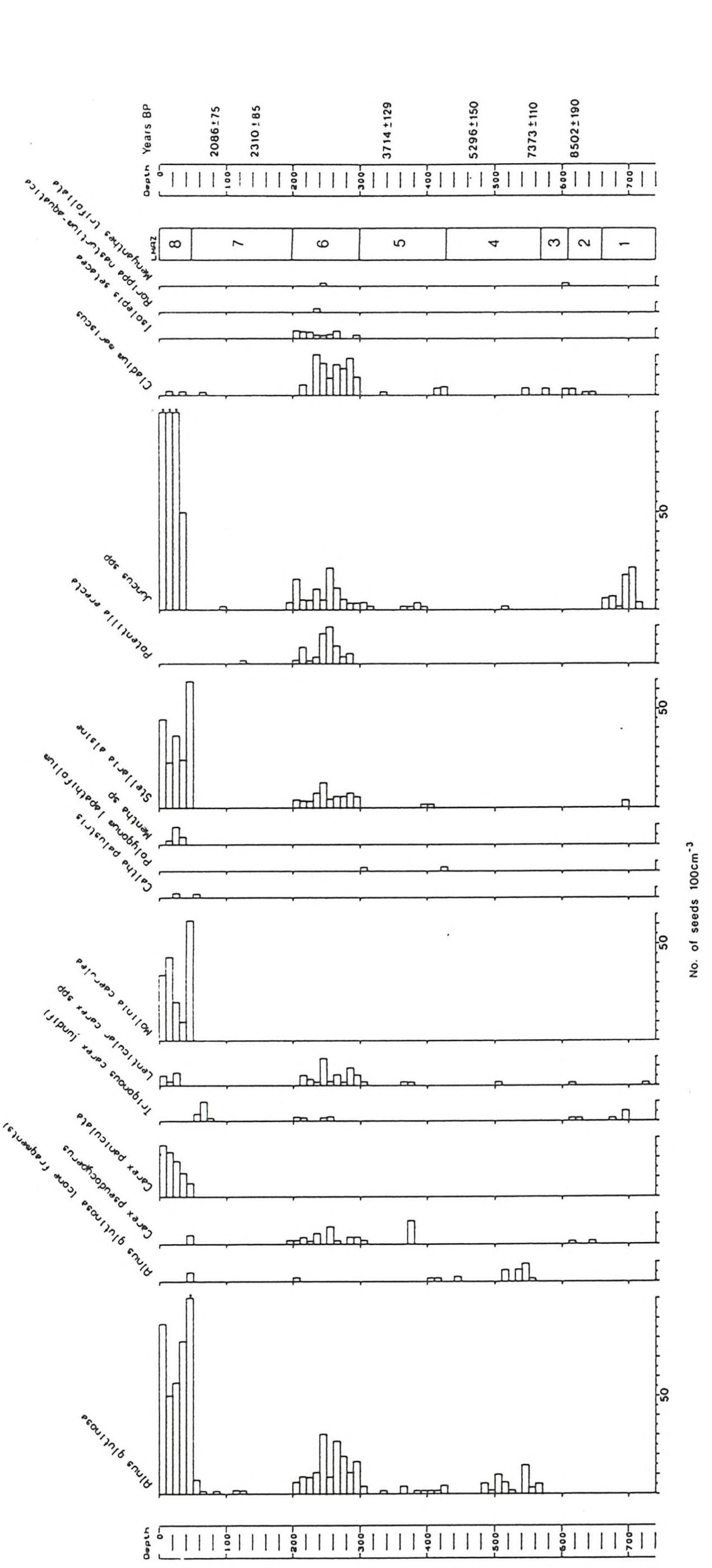


Figure 55 Telømatic macrofossils (CRM3)

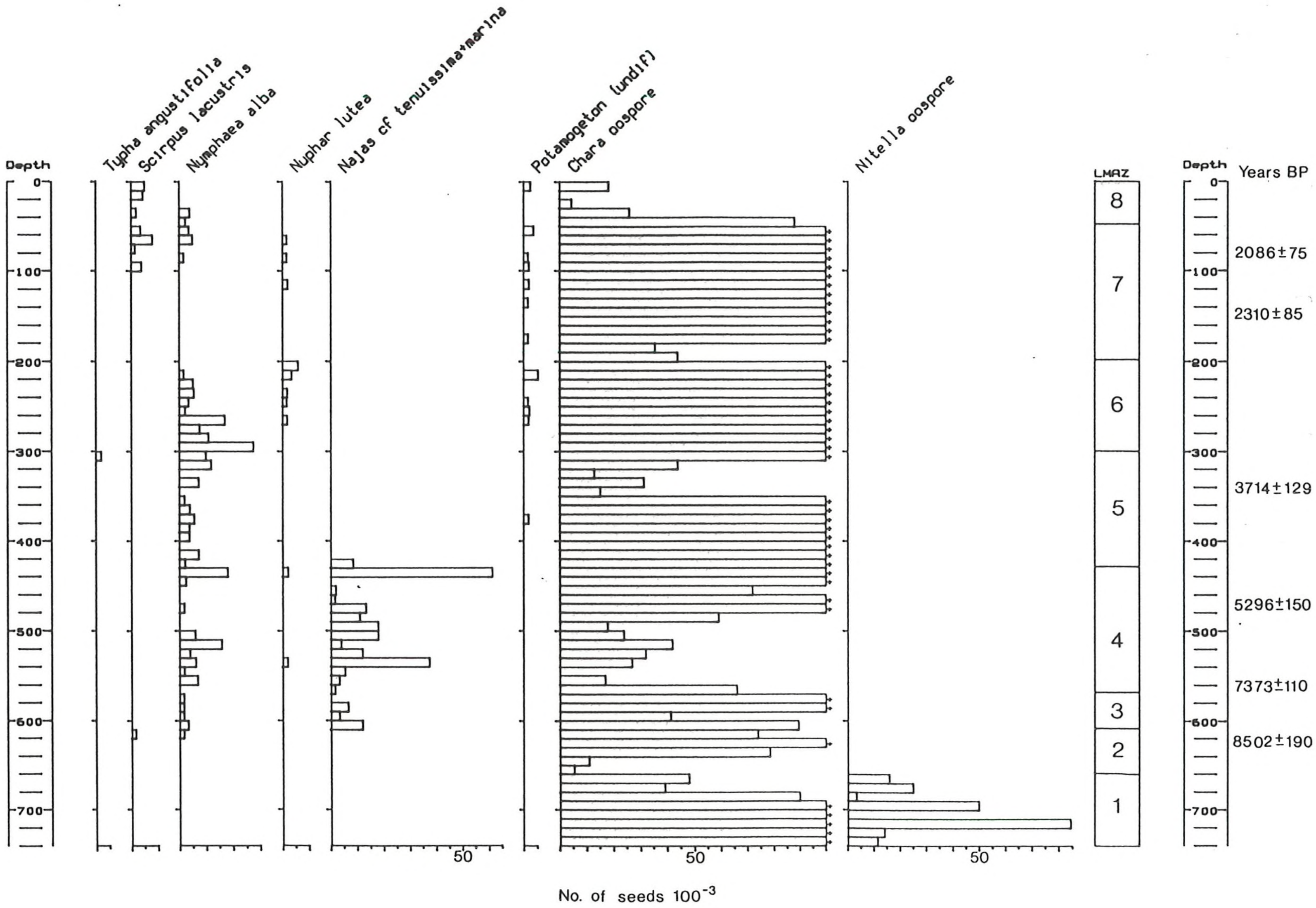


Figure 56 Aquatic macrofossils (CRM3)

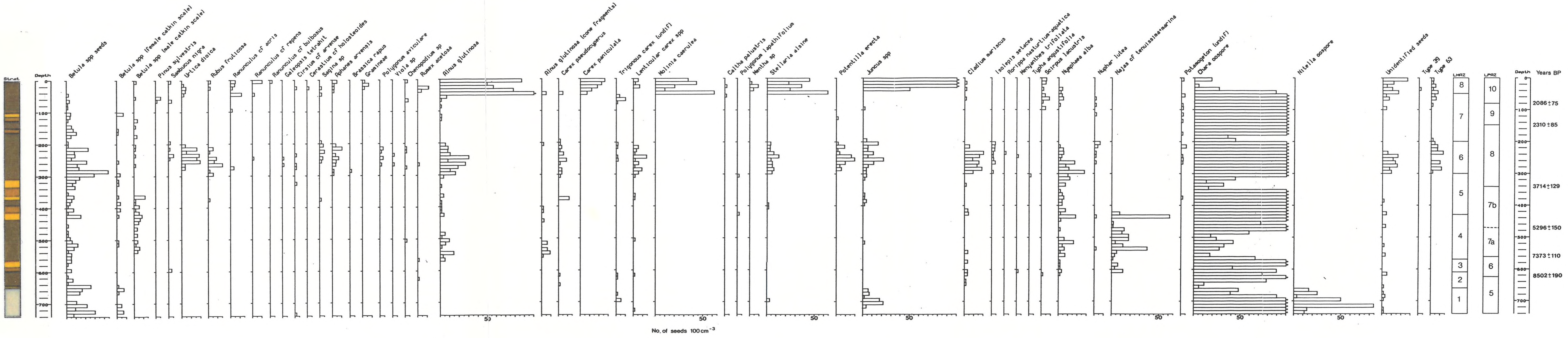


Figure 57 Macrofossil diagram from Crose Mere (CRM3)

Depth	LPAZ	Blytt Sernander periods	Description
730-640cm	zone2-zone4	Late Glacial	Disturbed
640-300cm	zone4-zone8	Preboreal-Subboreal	Fairly deep water
300-200cm	zone8-zone9	Subboreal	Lowered water level
200-100cm	zone9-zone10	Subboreal/Subatlantic	Rise in water level
100-40cm	zone10	Subatlantic	Recovery of marginal vegetation and shallow aquatics
40-0cm	late zone10	Subatlantic	Fall in water level to present status

Figure 58 Summary of results obtained from macrofossil analysis of Crose Mere

majority of the species recorded also appear in zone 5 suggesting that the lake status is similar in both zones.

Taking these results into consideration the pattern of lake development shown in figure58 is suggested.

These results seem to indicate two decreases in water level, these occurring in the Subboreal and Subatlantic periods. As these have occurred since the first recorded finds of anthropogenic activity in this area, it is possible that both these changes in lake status could be due to man's interference with the lake and its surroundings in the forms of drainage or land use changes. This is discussed in greater detail in section 8.6.6 p220 The most recent change in vegetation is probably due to the drainage operations of 1864 as decreases in the sediment limit and increases in particle size are also recorded at this point (figure53). The other period showing a change in vegetation occurred somewhere around 3000 to 2200 years BP and, as it is not reflected in any changes in the sediment, is probably due to land-use changes at this time. This hypothesis is supported by the large number of anthropogenic indicators recorded in the macrofossils during this period.

The data obtained as a result of macrofossil analysis were subjected to multivariate analysis using the computer program CANOCO (Ter Braak and Prentice 1988). CANOCO (CANOnical COordination analysis) is a multivariate direct gradient analysis which escapes the assumption of linearity, being able to detect unimodal relationships between species and external variables. One of the analyses included in this package is detrended correspondence analysis or DCA, and this analysis was thought to be the most appropriate to use as it assumes a unimodal relationship between the data and the external parameters and does not require the input of any environmental data which was not available, the macrofossil data set spanning over 10000 years. CANOCO is also particularly efficient at ordinating "sparse" data sets *ie* data containing many zero values compared to the number of non-zero values. It was, therefore, thought appropriate for use on the two macrofossil data sets obtained from this study as many of the samples had a large proportion of species not recorded in them.

The ordination of the results obtained from Crose Mere resulted in five clusters of samples, and one lone sample. Sample 55 was out on its own as it is the only sample (excluding surface samples) that contains no *Chara* oospores at all.

Cluster 1

This cluster contained samples 44,49,50,51,52,53,54,56, and 61. These samples were characterised by low *Chara* values and, possibly, by the presence of *Najas*. All the samples in this cluster contain *Najas* species but so do some of the samples in other clusters so this is not the only determining factor in the production of this cluster.

Cluster 2

This cluster contained by far the largest amount of samples as it grouped together all the samples that had few species recorded in them.

Cluster 3

Samples 20,21,22,23,24,25,26,27,28,29,30, and 71 were grouped together in this cluster and this is not surprising as this group of samples was also grouped together to make LMAZ zone 6 when the diagram was zoned visually. This is thought to indicate a lowering of water level around 3500 BP. Sample 71 is probably included in this group because of its high *Betula* values and lack of *Nitella*.

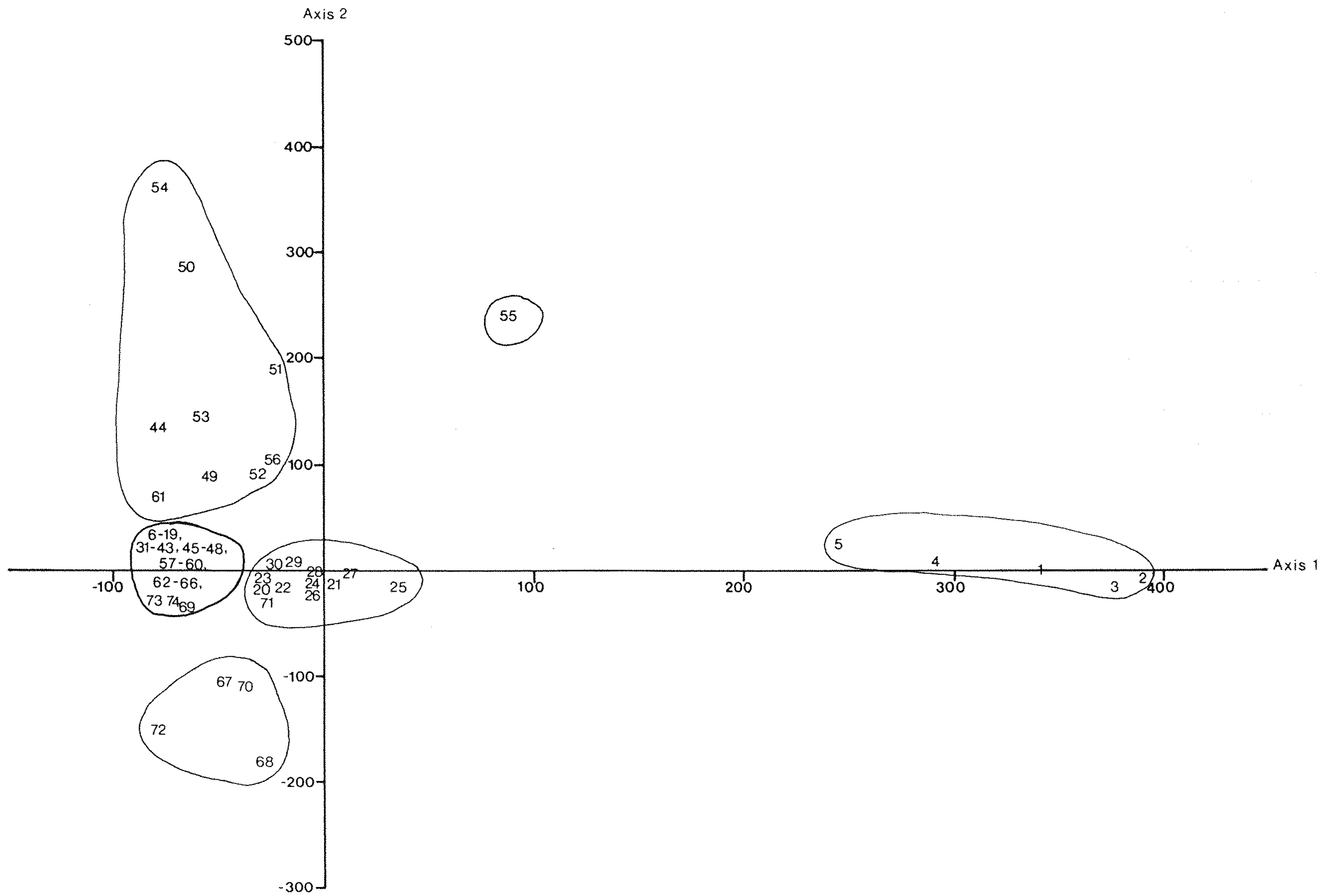


Figure 59 CANOCO Ordination of samples (CRM3)

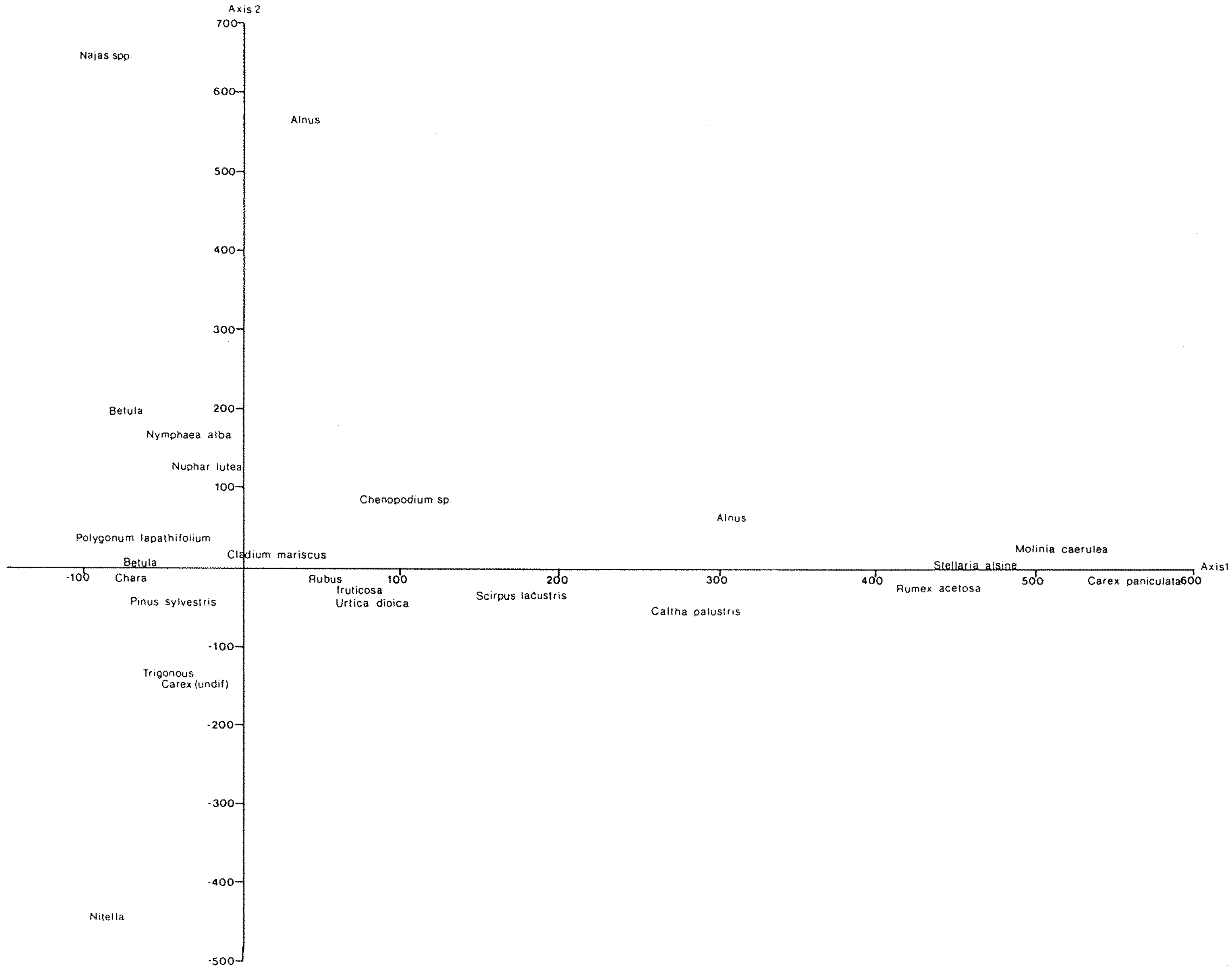


Figure 60 CANOCO Ordination of species (CRM3)

Cluster 4

This was the smallest cluster containing only four samples; 67,68,70 and 72. All of these samples have large amounts of *Nitella* oospores present.

Cluster 5

This final cluster contains the top five samples. These samples are characterised by high *Alnus* values and a large percentage of boggy plants such as *Stellaria alsine, Juncus spp., Molinia caerulea* and *Carex paniculata*.

The trends of the two axes appears to be as follows;

Axis1 Alder - Birch gradient

Axis2 *Chara* - *Nitella* gradient

Neither of these axes appears to show a wetness gradient as hoped. It is difficult to see what environmental parameter is being described by axis1 and this could be due to the large number of "empty" samples clustered at the negative side of the axis.

Axis2 may possibly be a function of water depth or of changing nutrient status of the lake. *Chara* spp are recorded more often from mesotrophic or eutrophic waters whereas *Nitella* is recorded from oligotrophic waters (BSBI handbook 5). On the whole, species of *Nitella* extend into deeper waters than species of *Chara* (BSBI handbook 5) but this is very dependent on species. As it is not possible to identify Charophyte species from subfossilised oospores alone a gradient of water depth cannot be confirmed for axis2.

6.5 Summary of results obtained from macrofossil analysis

Neither axis has produced an identifiable trend. Axis 1 describes a gradient from Alder to Birch but any trend being described here is probably being masked by the large numbers of "empty" samples included in the analysis. Axis

2 describes a gradient from *Chara* to *Nitella* and possibly indicates a change in nutrient status of the lake or a change in water depth. However, no definite conclusions can be drawn from the CANOCO diagrams for Crose Mere other than confirmation of the zones obtained visually.

6.6 Summary

The stratigraphic diagram of Crose Mere clearly shows that the cores consist of three major types of sediment, the most important of these in the study of lake-level fluctuations being the yellow sandy bands as they possibly indicate periods of lower water levels. However, when these sandy bands are traced throughout the sequence of cores from the field to the lake centre no recognisable pattern occurs (figure 43).

The reconstruction of the sediment limit was also complicated, probably by the redistribution of sediment several times during the lake's history. It did appear, however, that events had occurred in the Preboreal/Boreal, Atlantic and Subatlantic periods which resulted in a dramatic decrease in organic material.

Increases in particle size of the sediment were recorded during each of the Blytt-Sernander zones and indicate changes in the lake or its surroundings during these times. These increases are shown in figure 50. However, the only important increases in particle size are those that can be linked to positive results obtained from at least one of the other analyses and from figure 53 it can be seen that these increases occurred during the lateglacial, Preboreal/Boreal, Boreal, Atlantic/Subboreal and Subatlantic periods.

The results from macrofossil analysis present a fairly detailed picture of the lake's status throughout the past twelve thousand years or so including two periods of dramatic vegetational changes during the Atlantic/Subboreal and Subatlantic periods.

The combination of all these results is shown in Table 8. From this it can be seen that the only position in the Crose Mere cores where positive results from all three of the analyses were obtained simultaneously occurred fairly recently and was probably due to the drainage of land surrounding Crose Mere in 1864.

There are four periods where positive results from sediment limit reconstruction and particle size analysis coincide, these being at the Preboreal/Boreal transition (zone4/zone5), at the boundary of pollen zones7a and 7b in the Atlantic period, at the boundary of zone7b and zone8 (Atlantic/Subboreal period) and early zone10 (Subatlantic period). However, these results could be due to increased exposure of the mere to wind action, *eg* by deforestation, causing inwashing of the shore sediments into the lake rather then changes in lake level. As all of the results obtained prior to the known lake lowering of 1864 may have alternative explanations, cores from Fenemere, a neighbouring mere, were subjected to the same analyses as those from Crose Mere. It was hoped that the results obtained from the Fenemere cores would clarify whether the events recorded at Crose Mere were localised events or regional events. These results are discussed in the following chapter.

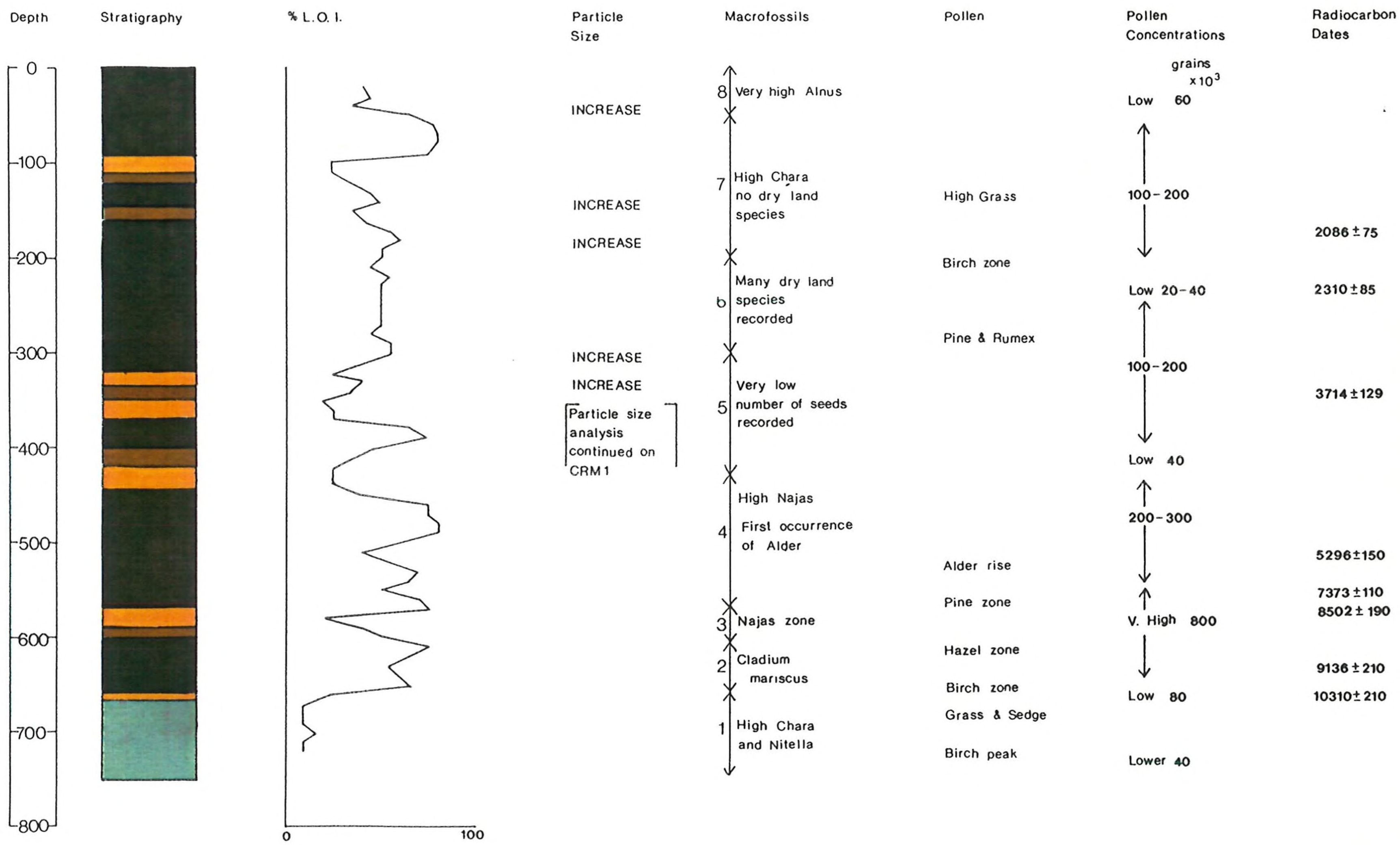


Table 8 Summary of the results obtained from CRM3

Chapter 7 RESULTS FROM FENEMERE

7.1 Stratigraphy

The cores obtained from Fenemere differed greatly in their stratigraphy from Crose Mere. The core depths were not as great (511cm as against 750cm) and no sandy bands were evident in any of the five cores collected (figure 61). The two lake cores (FM1 and FM2) were composed of dark brown lake mud overlying glacial silts and clays at their bases. FM2 had only 70cm of basal clays and gravels whereas the basal clays and gravels extended for 160cm in FM1. This could be because FM1 was nearer the shore than FM2 and therefore would receive greater amounts of inwashed clay at the end of the last glaciation.

The core taken at the lake margin (FM4) bore a greater resemblence to the cores taken at Crose Mere in that the majority of the core consisted of a yellow-brown sediment, probably deposited under shallow water. FM4 was also unusual in that a band of clay 10cm wide was separated from the basal glacial silts and clays by a band of shallow lake sediment 25cm thick (figure 61). This clay band dates back to the lateglacial (zone3). The sediment separating this band of clay from the basal clays was probably deposited during the Allerod period when conditions warmed slightly and vegetation expanded, leaving behind a more organic sediment than was previously deposited. This was replaced by very inorganic sediments when the temperature cooled and the vegetation disappeared (during zone3). The shallow lake sediments recorded at the top of FM4 end at the beginning of zone5 (around 9000BP) and are replaced by reed peat, suggesting that infilling of the lake is occurring. There is no evidence of deep water over this coring point at any time as there is no gyttja recorded in any of the sediments.

The top 20cm of sediment from FM4 have suffered from erosion and redeposition. Contiguous 1cm samples for

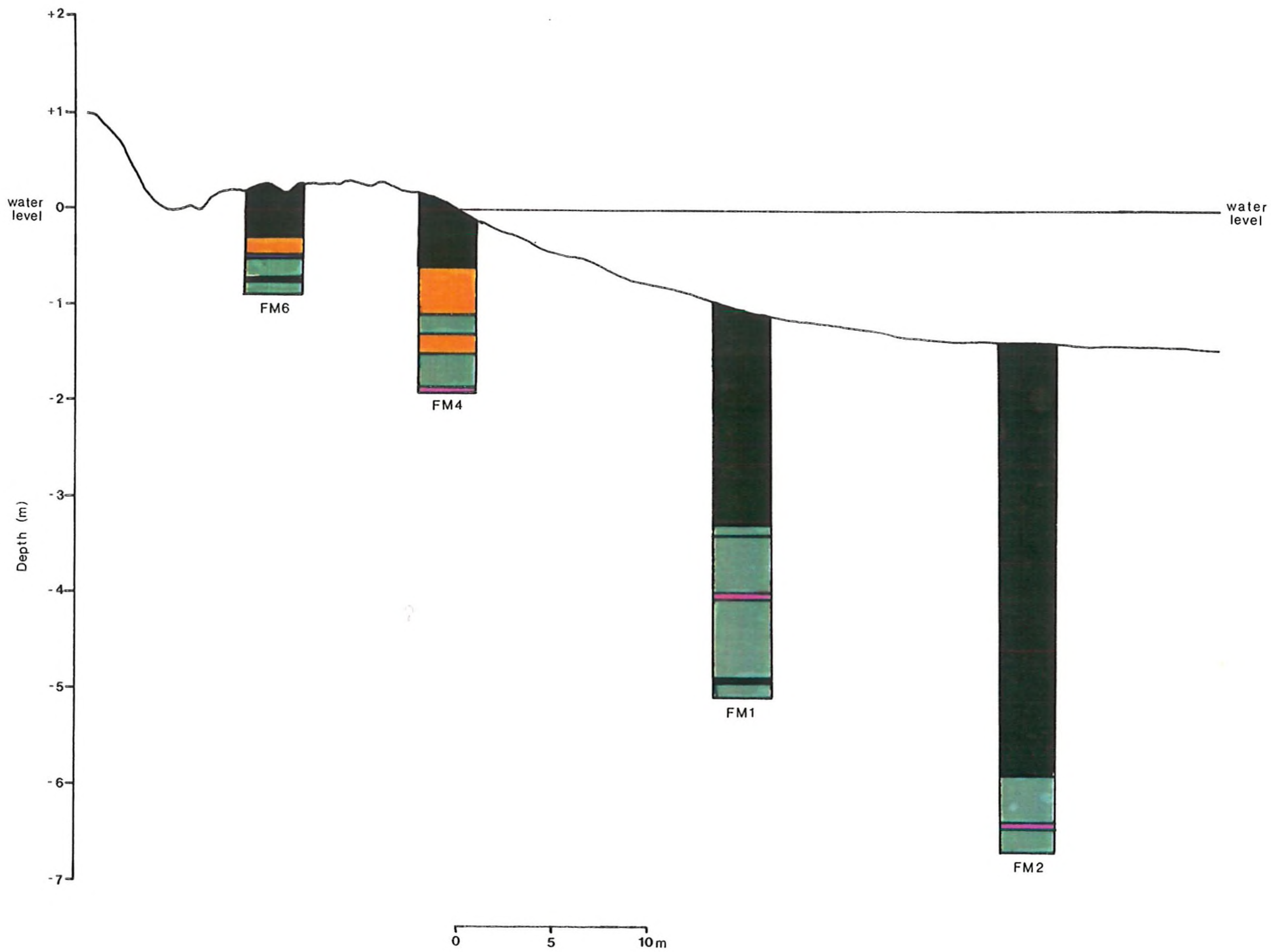


Figure 61 Stratigraphic diagram from Fenemere

DEPTH	TROELS-SMITH NOTATION	GENERAL DESCRIPTION
115-277cm	Nig3 Strf0 Elas1 Sicc2 Humo2 $Ld^{3}4$	Very dark and humic
277-336cm	Nig3 Strf0 Elas1 Sicc2 Humo1 $Ld^{3}4$	Dark, humic with plant fragments
336-346cm	Nig2 Strf1 Elas1 Sicc2 Humo4 $Ld^{2}4$ As+	Clayey lake mud
346-386cm	Nig1 Strf2 Elas0 Sicc2 As4	Clay
386-404cm	Nig1 Strf2 Elas0 Sicc2 Humo2 As4	Clay with moss fragments
404-407cm	Nig4 Strf1 Elas0 Sicc2 Ggmaj4 Ggmin+ As+	Gravel
407-441cm	Nig2 Strf1 Elas1 Sicc2 As4 $Ld^{2}+$	Organic Clay
441-443cm	Nig3 Strf0 Elas1 Sicc2 Humo3 $Ld^{3}4$	Organic band
443-460cm	Nig2 Strf1 Elas1 Sicc2 As4 $Ld^{2}+$	Organic Clay

Table 9 Sediment description of FM1 ("Reed Swamp Core")

DEPTH	TROELS-SMITH NOTATION	GENERAL DESCRIPTION
156-596cm	Nig3 Strf0 Elas1 Sicc2 Humo2 Ld[illegible]4	Very dark and humic
596-602cm	Nig2 Strf1 Elas1 Sicc2 Humo4 Ld[illegible]4 As+	Brown, clayey lake mud
602-606cm	Nig1 Strf3 Elas0 Sicc2 As4 Ga+	Clay
606-616cm	Nig1 Strf2 Elas0 Sicc2 As4	Clay
616-644cm	Nig2 Strf2 Elas1 Sicc2 As4	Organic Clay
644-647cm	Nig4 Strf1 Elas0 Sicc2 Ggmaj4 Ggmin+ As+	Gravel
647-656cm	Nig1 Strf1 Elas0 Sicc2 As4	Clay
656-667cm	Nig1 Strf2 Elas0 Sicc2 Ggmaj2 As2 Ggmin+	Clay/Gravel

Table 10 Sediment description of FM2 ("Open Water Core")

DEPTH	TROELS-SMITH NOTATION	GENERAL DESCRIPTION
0-60cm	Nig3 Strf0 Elas1 Sicc2 Humo1 $Ld^{3}4$	Very dark and humic
60-111cm	Nig2 Strf1 Elas2 Sicc2 Humo2 $Ld^{2}4$	Yellow/Brown lake mud
111-129cm	Nig2 Strf0 Elas0 Sicc2 As4	Clay
129-150cm	Nig2 Strf1 Elas2 Sicc2 Humo2 $Ld^{2}4$	Yellow/Brown lake mud
150-183cm	Nig2 Strf1 Elas0 Sicc2 As2 Gg2	Clay and Stones fragments
183-193cm	Nig2 Strf0 Elas0 Sicc2 Ggmaj4 Ggmin+ As+	Gravel

Table11 Sediment description of FM4 ("Marginal Core")

DEPTH	GENERAL DESCRIPTION
0-7cm	Missing
7-31cm	Top Soil
31-44cm	Iron-Rich Gravel
44-46cm	Organic band
46-50cm	Clay

Table12 Sediment description of FM5 ("Field Core")

DEPTH	TROELS-SMITH NOTATION	GENERAL DESCRIPTION
0-44cm	Nig3 Strf0 Elas1 Sicc2 Humo1 Ld^{3}4	Very dark and humic
44-57cm	Nig2 Strf2 Elas2 Sicc2 Humo1 Ld^{2}4	Brown humic lake mud
57-58cm	Nig4 Strf0 Elas0 Sicc2 Gg4	Gravel
58-69cm	Nig1 Strf0 Elas0 Sicc2 As4	Clay
69-77cm	Nig2 Strf0 Elas0 Sicc2 As3 Ggmin1	Sandy clay
77-78cm	Nig3 Strf0 Elas1 Sicc2 Humo2 Ld^{3}4	Organic band
78-93cm	Nig2 Strf2 Elas0 Sicc2 As3 Ggmin1	Sandy clay

Table13 Sediment description of FM6 ("Old Lake Core")

pollen analysis indicate a high percentage of Gramineae, Cyperaceae and *Alnus* with very little presence of other taxa . The grass and sedges represent the marginal vegetation growing on the coring site at the moment and could, therefore, give an indication of the time of colonisation of the margins with *Phragmites* and Carices. *Alnus* was probably growing locally too. The presence of *Artemisia* throughout the top 20cm could indicate redeposition of lateglacial sediment in this area and could explain the lack of lake sediment in FM5, 30m away from FM4.

A great increase in Cerealia pollen was expected in the surficial sediments as Fenemere is surrounded by fairly level farmland, but few grains were recorded. This could be explained if the farmland was used for pasture or for hay as the majority of the grasses would have been cut before they flowered. An alternative explanation would be that as this area is in the erosion zone (Hakanson and Jansson 1983) pollen deposited here is eroded and redeposited in deeper water towards the centre of the mere. Very low pollen concentration ($29x10^3$ - $163x10^3$ pollen grains cm^3) and a high level of corroded pollen grains would tend to support this erosion hypothesis.

Due to these problems it has been impossible to define local pollen assemblage zones 7b to 10 from FM4.

FM3 was a duplicate core taken from the same position on the lake margin as FM4. This core provided confirmation of the stratigraphy of FM4 and would have provided extra sediment for macrofossil analysis had FM4 been insufficient.

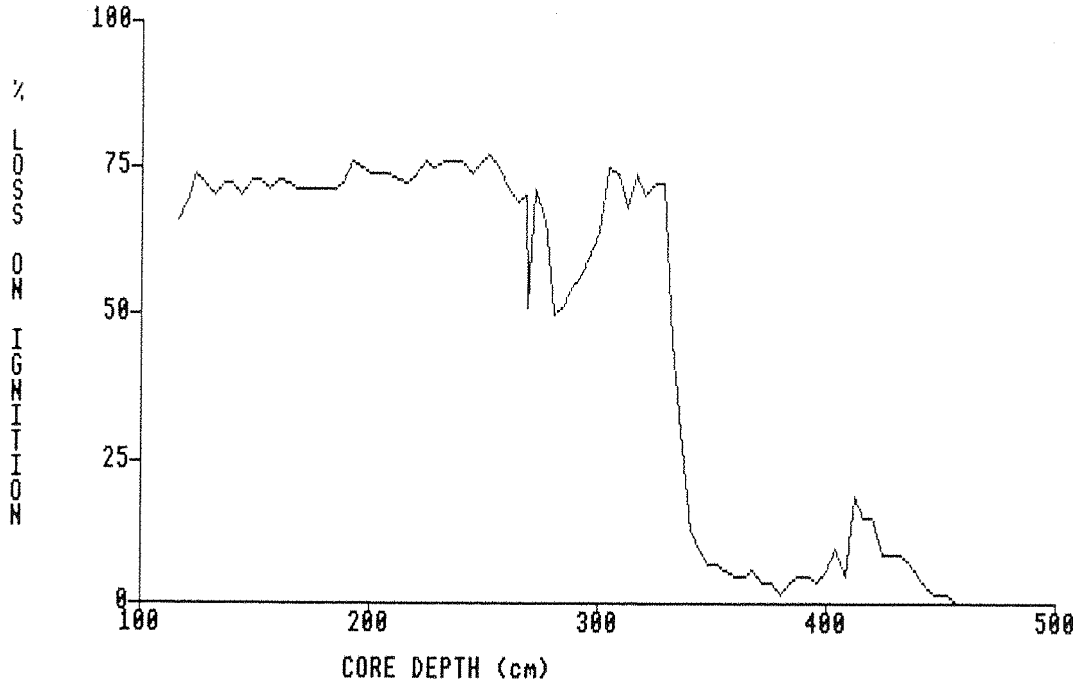
The core taken in the old lake bed (FM6) showed reed peat overlying the basal glacial till. There was no indication of lake mud in the sediments of this core and it appears that this area has been covered by reed swamp since 10,000BP.

FM5 was taken on the field boundary (figure 22) and consisted chiefly of soil overlying a very gravelly, iron-rich clay. It would appear from this core that either the lake had not extended to this distance for a considerable period of time, if ever, or the core has suffered badly from erosion. This core was not used in any further analyses due to its short length and poor sediment quality which probably resulted from disturbance due to the cultivation of adjacent land.

7.2 Sediment Limit Reconstruction

The organic content of the cores falls below the 5% line marking the sediment limit (section 2.3.2 p11) in all four cores as seen in figure 67. This is to be expected given the rapidly changing environmental conditions of the lateglacial periods. The sediment limit curve does not go below the 5% line once zone 4 is reached and environmental conditions have stabilised. However, decreases in organic sedimentation have occurred in several places in the cores since 10,000 years BP (bottom of figure 66). No importance is attached to a decrease in organic sedimentation which occurs in one core only as this could be accounted for by a localised event rather than by an event which would affect the mere as a whole. The decrease in organic sedimentation recorded in the top 20cm of FM4 cannot be taken into consideration when looking at the results of sediment limit reconstruction due to the erosion and redeposition of the sediment which was shown by pollen analysis to have occurred here.

It can be seen from the bottom of figure 66 that decreases in organic sedimentation were recorded in FM6, FM4 and FM2 around 9000BP but that all other decreases in organic content were isolated, or could be tentatively linked to a decrease in organic content around the same time in one other core only. Therefore, the only possible water level change as indicated by the sediment limit occurring since the lateglacial was recorded in the Preboreal period around the transition of LPAZ zones 3 and 4.



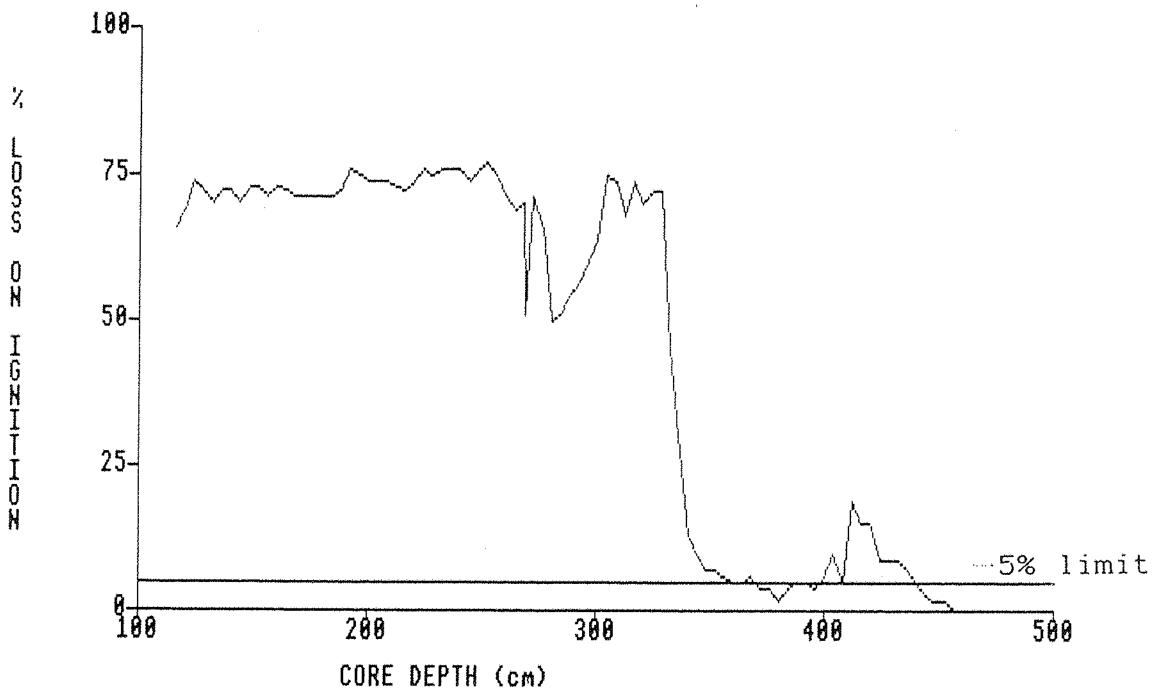
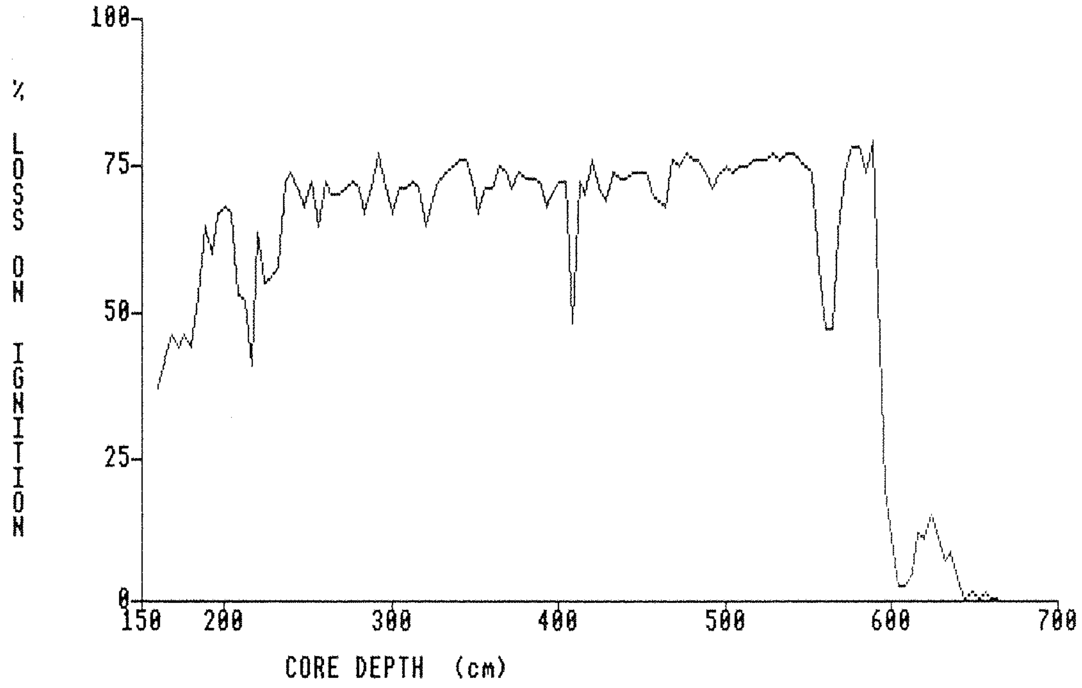


Figure 62 Organic content of FM1 (see text for explanation of 5% limit)



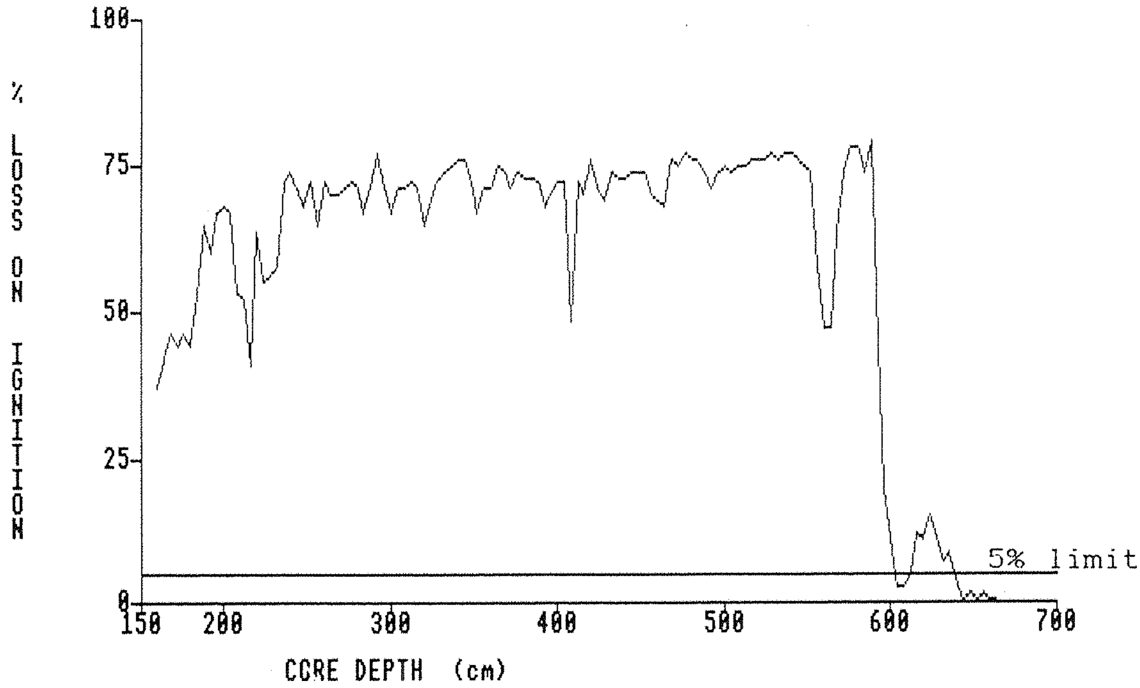
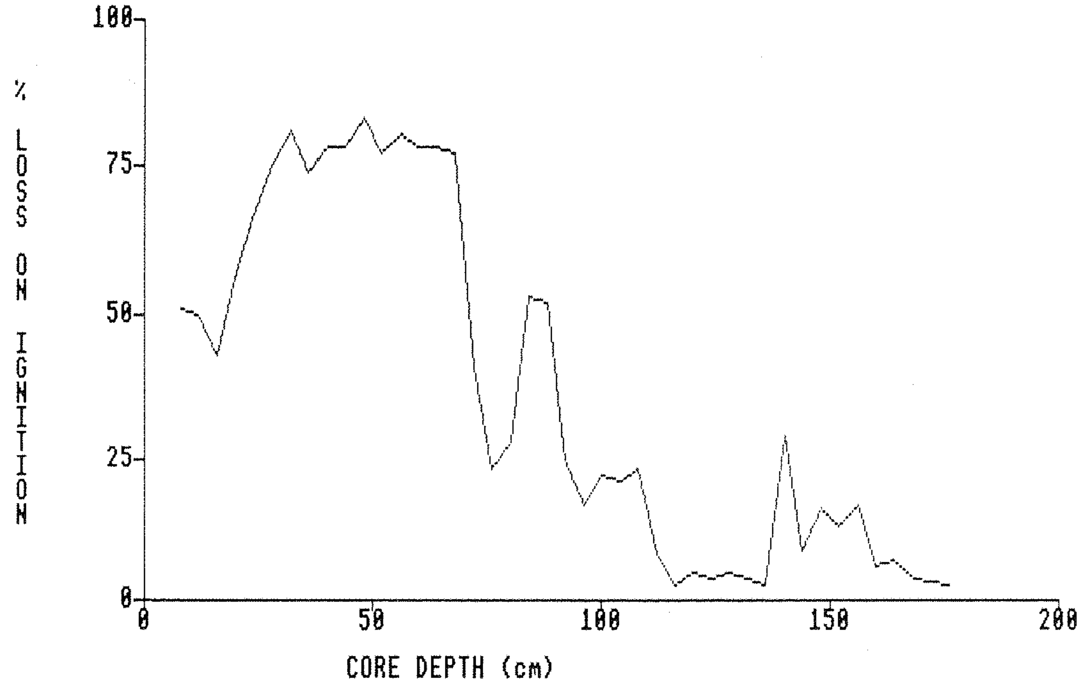


Figure 63 Organic content of FM2 (see text for explanation of 5% limit)



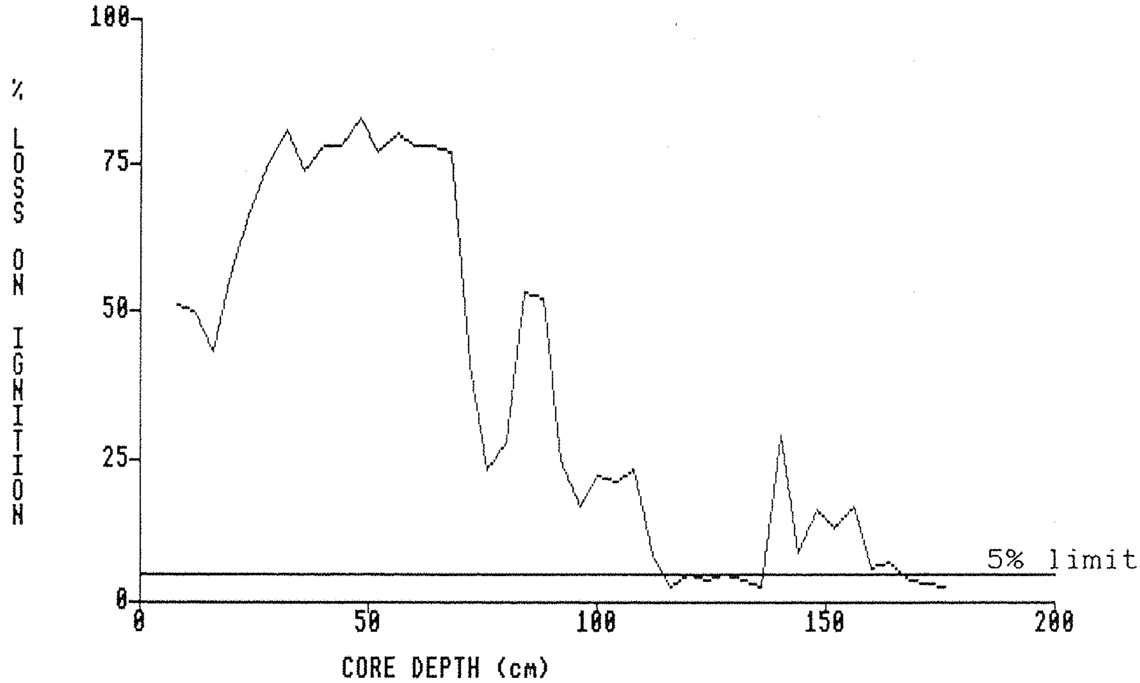
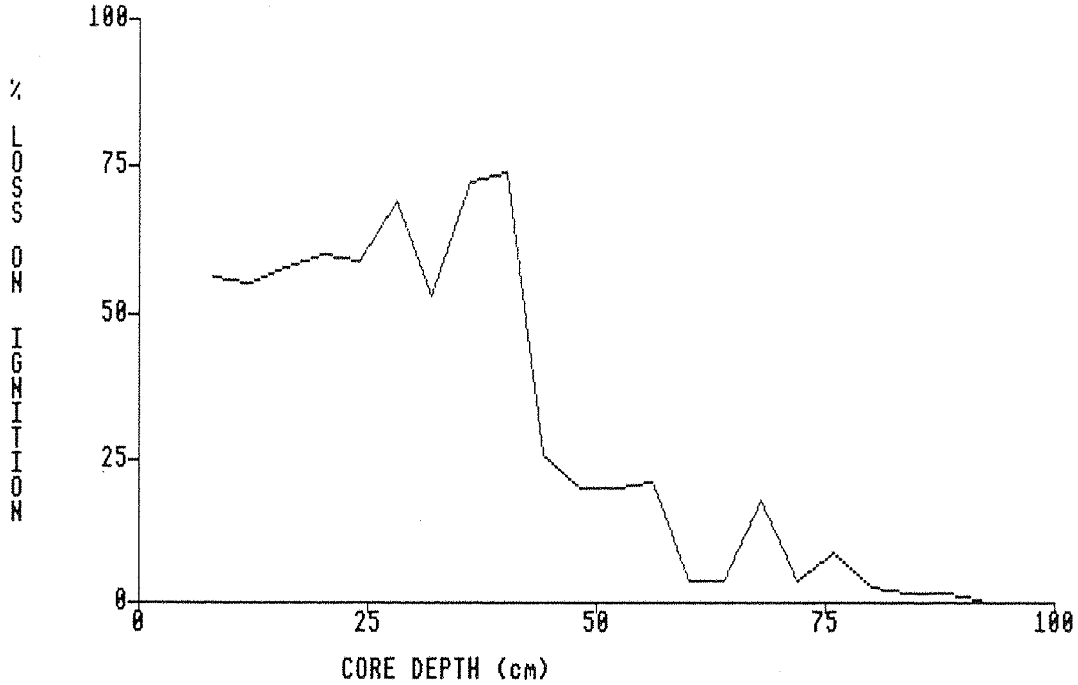


Figure 64 Organic content of FM4 (see text for explanation of 5% limit)



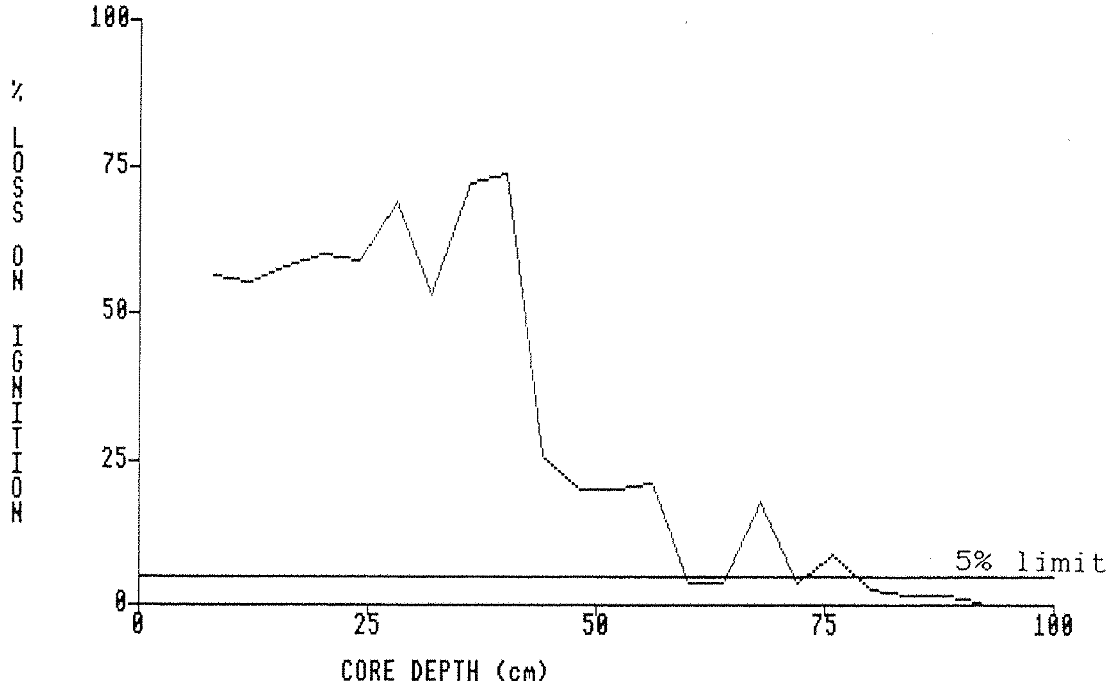


Figure 65 Organic content of FM6 (see text for explanation of 5% limit)

FM6	FM4	FM1	FM2
Mid 0	zone 0 - mid 1	0/1 transition	-----
mid 2	-----	-----	mid 2
mid 3	zone 3 - 3/4 transition	zone 3	3/4 transition
-----	zone 4	-----	-----
4/5 transition	4/5 transition	-----	mid 5
mid 5	-----	early 6	-----
-----	-----	mid 6	-----
-----	7a/7b transition	-----	early 7b
-----	-----	-----	zone10

Figure 66

Decreases in organic sedimentation of Fenemere

dry land	———————————		water
FM6	FM4	FM1	FM2
mid zone0	zone0 - mid zone1	zone0/zone1 transition	Absent
mid zone2	Absent	Absent	mid zone2
mid zone3	zone3 - zone3/zone4 transition	zone3	zone3/zone4 transition

Figure 67

Periods of organic sedimentation less than 5% in Fenemere

These results confirm the lack of sandy bands in the stratigraphy and indicate that the sediment limit does not appear to have changed drastically since the rapid accumulation of clays and gravels during the late glacial period. Once environmental conditions had stabilised and vegetation colonised the area surrounding the lake, the amount of exposure the lake was subjected to would decrease, organic matter could be deposited over the majority of the lake and the minerogenic sediment limit would disappear, being replaced by an organic sediment limit (section 8.4 p198).

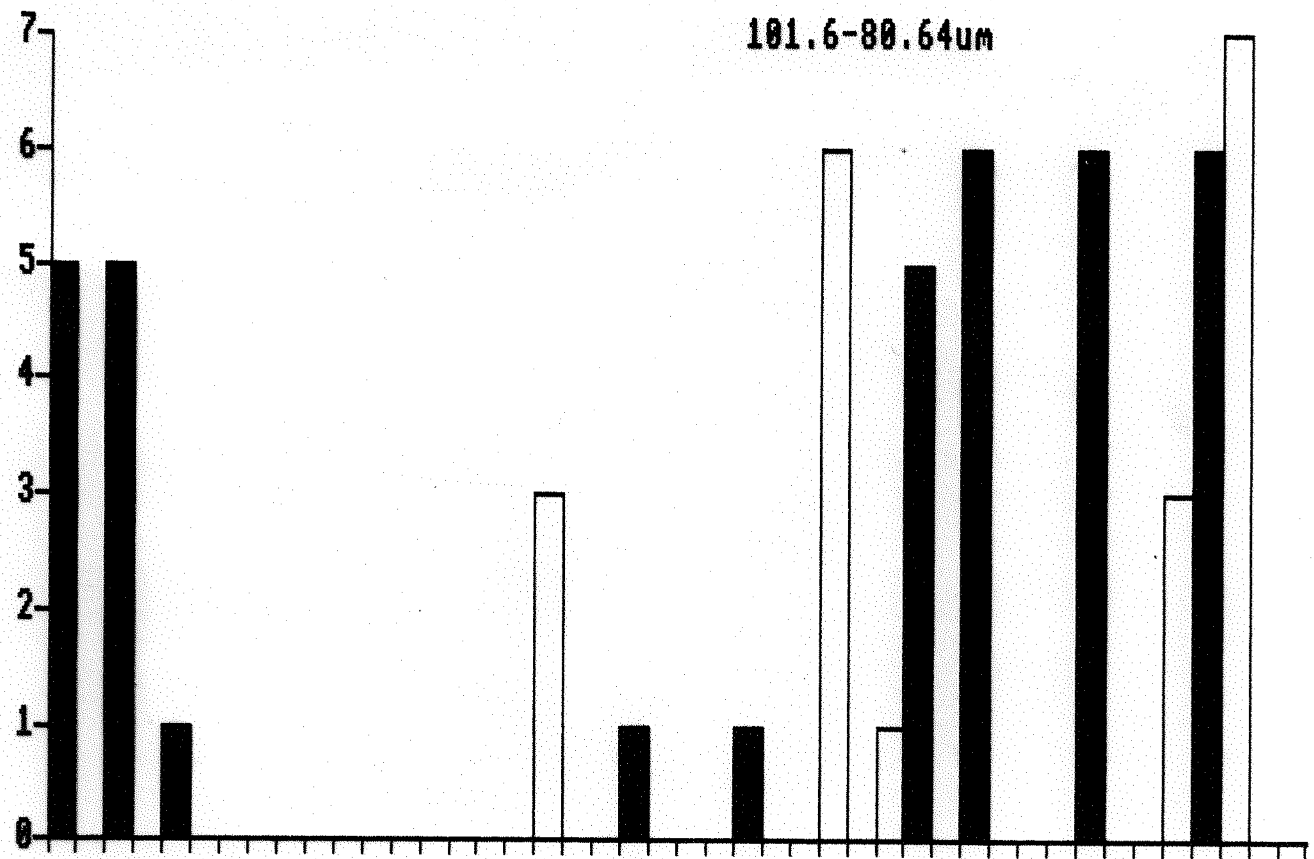
7.3 Particle Size Analysis

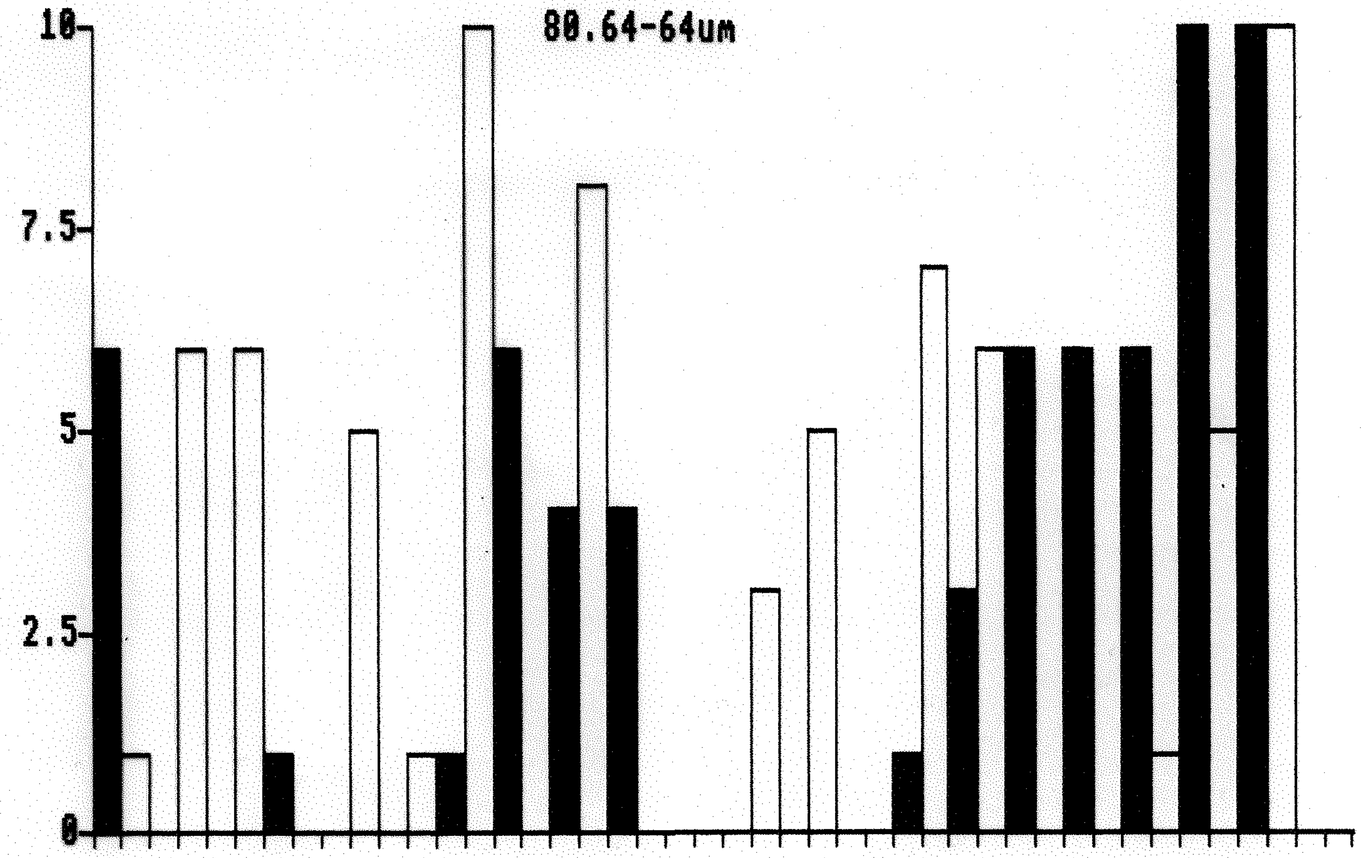
Particle size analysis was carried out on the core taken from the present lake margin (FM4) as it would appear from the shallow lake sediment lying directly over the glacial till that this point has probably always been fairly close to the lake margin and, therefore, would be most likely to record any changes in the particle size occurring as a result of changes in the lake level. This analysis was performed using a Coulter Counter as, with the exception of the basal gravels, the sediment consisted chiefly of very fine particles (100um and less).

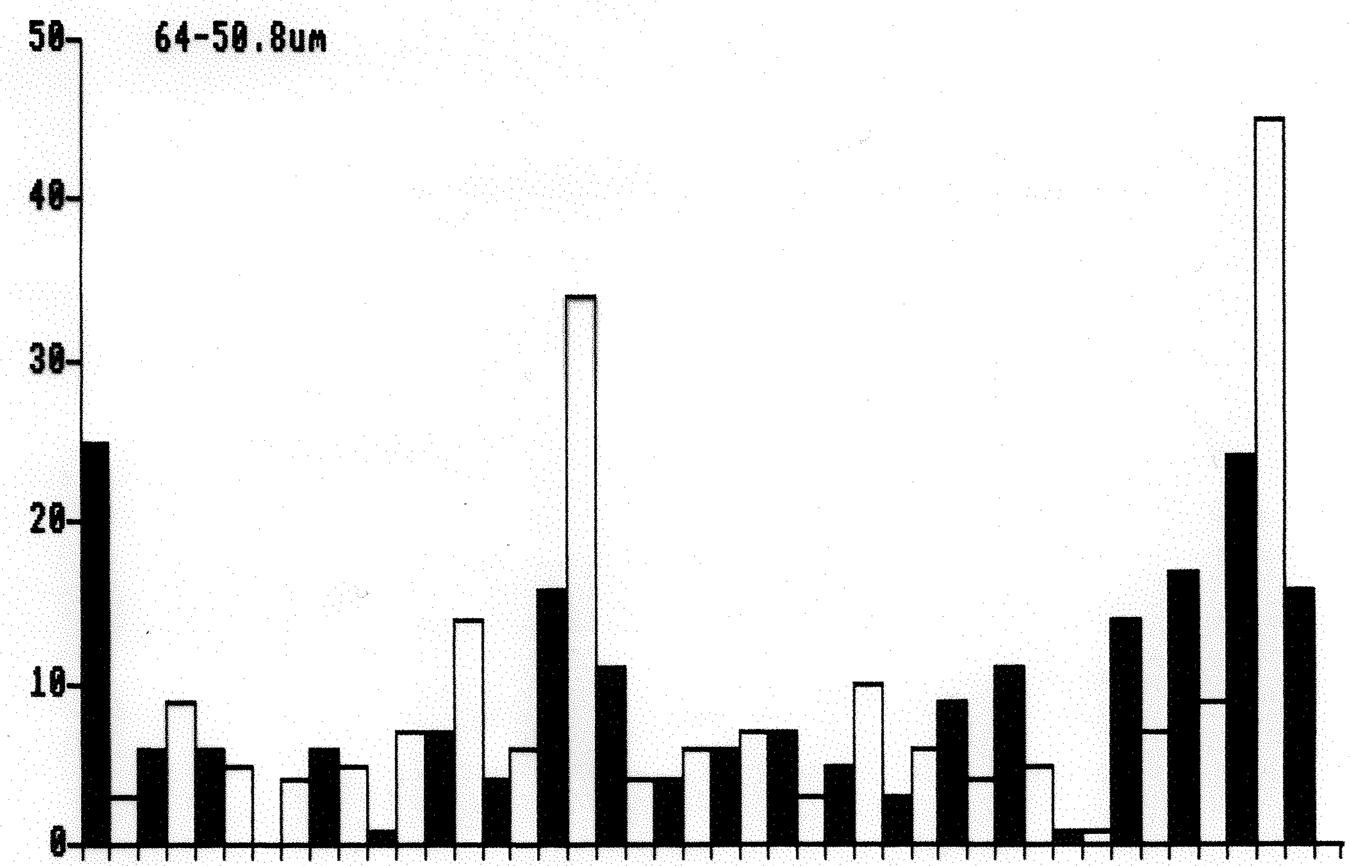
Increases in particle size occurred in more than one size range at the following points:

Depth	LPAZ	Blytt Sernander Periods
4cm	muddled	
15-16cm	zone7a	Atlantic
68-72cm	zone5	Boreal (approx. 8500BP)
120-132cm	zone3	Lateglacial
148cm	mid zone2	Lateglacial
164-168cm	late zone1	Lateglacial

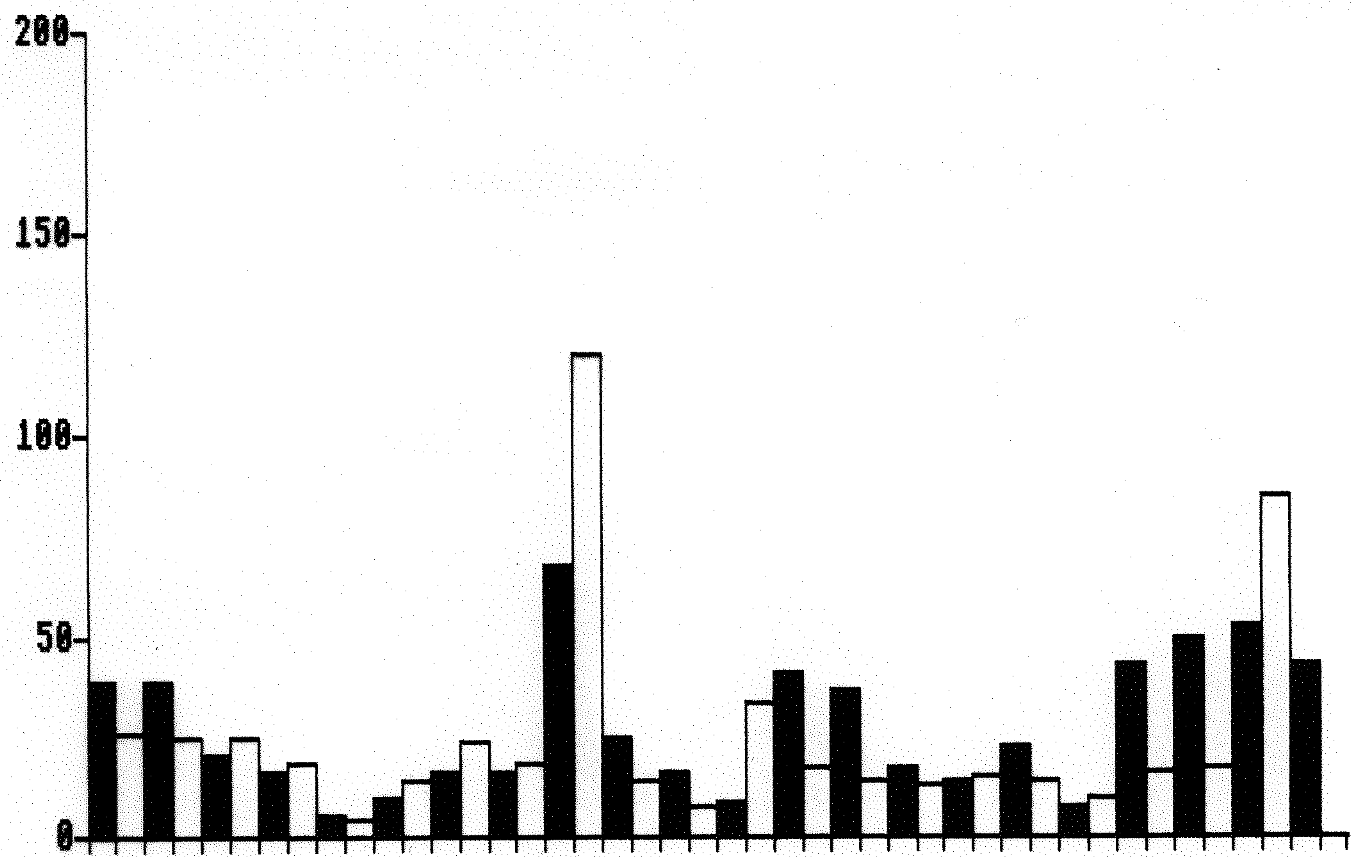
The most significant increase in particle size occurred at 68-72cm (approx. 8500 BP) and consisted of an increase in particles from five of the six size classes. It would

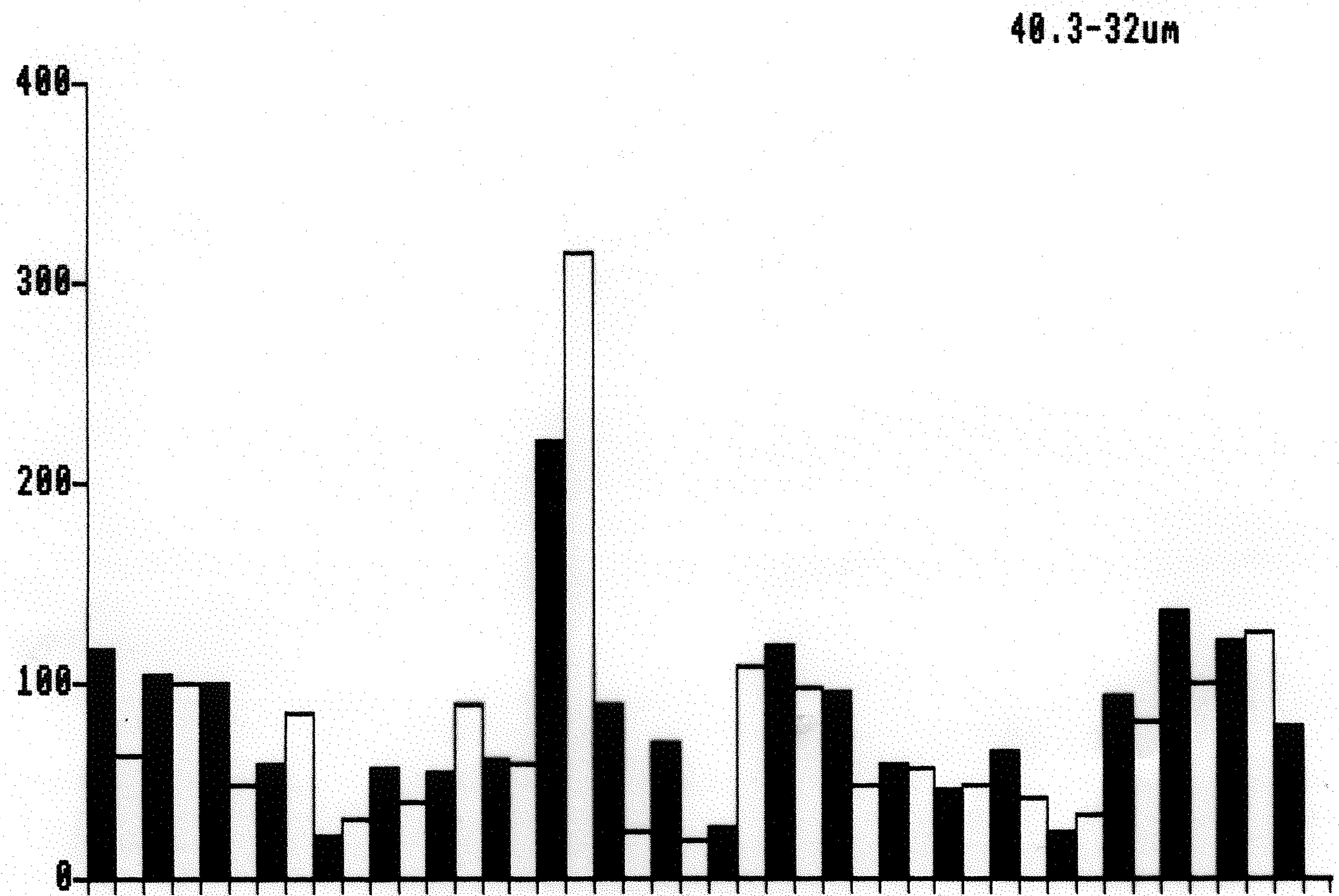

101.6-80.64um
7
6
5
4
3
2
1
0

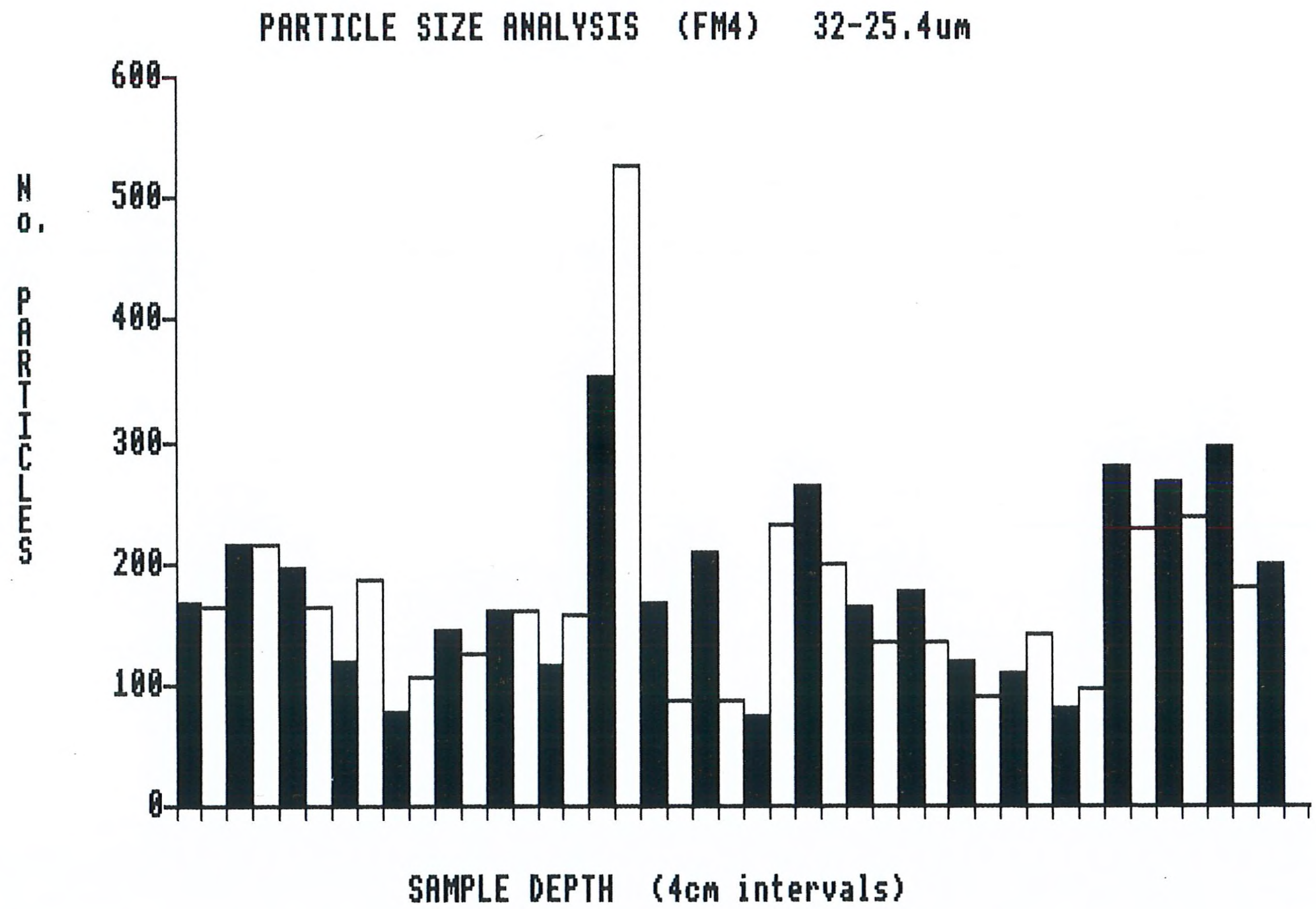

80.64-64um
10
7.5
5
2.5
0


64-50.8um
50
40
30
20
10
0

50.0-40.3um




40.3-32um
400
300
200
100
0


PARTICLE SIZE ANALYSIS (FM4) 32-25.4um
No. PARTICLES
600
500
400
300
200
100
0
SAMPLE DEPTH (4cm intervals)

also appear from the above results that increases in particle size occurred both during the lateglacial, probably as a result of rapid inwashing, and in the top 20cm of the core. Unfortunately this last result had to be disregarded due to the probability of erosion and redeposition of the sediments in this area (section 7.1 p 151).

Increases in particle sizes were expected during the lateglacial period as unsorted mineral matter would have been brought down even the gentlest of slopes by alternate freezing and thawing and ultimately deposited in the lake basin. However, this explanation cannot hold true for the increase in particle size which occurred in the Boreal period around 8500BP as a much more stable environment existed at this time. There were, however, vegetational changes taking place at this time with a decline in pine occurring together with an increase in hazel (section 5.4 p 95) and it would be possible that these changes were affecting the degree of exposure the lake was receiving. This in turn could affect the amount of sediment washed into the lake through runoff or increased wave action.

7.4 Macrofossil Analysis

FM4 was also used for macrofossil analysis as changes in the marginal reed vegetation would be most likely to be recorded in this core with its situation on the present day margins of Fenemere. The results obtained from this analysis were zoned visually, but the local macrofossil assemblage zones obtained did not correlate well to the local pollen assemblage zones, thus not allowing the transfer of radiocarbon dates to the boundaries of the local macrofossil assemblage zones. However, the addition of the local pollen assemblage zones together with radiocarbon dates to the macrofossil diagrams (figures 69 71) gives an indication as to the age of each of the zones described below.

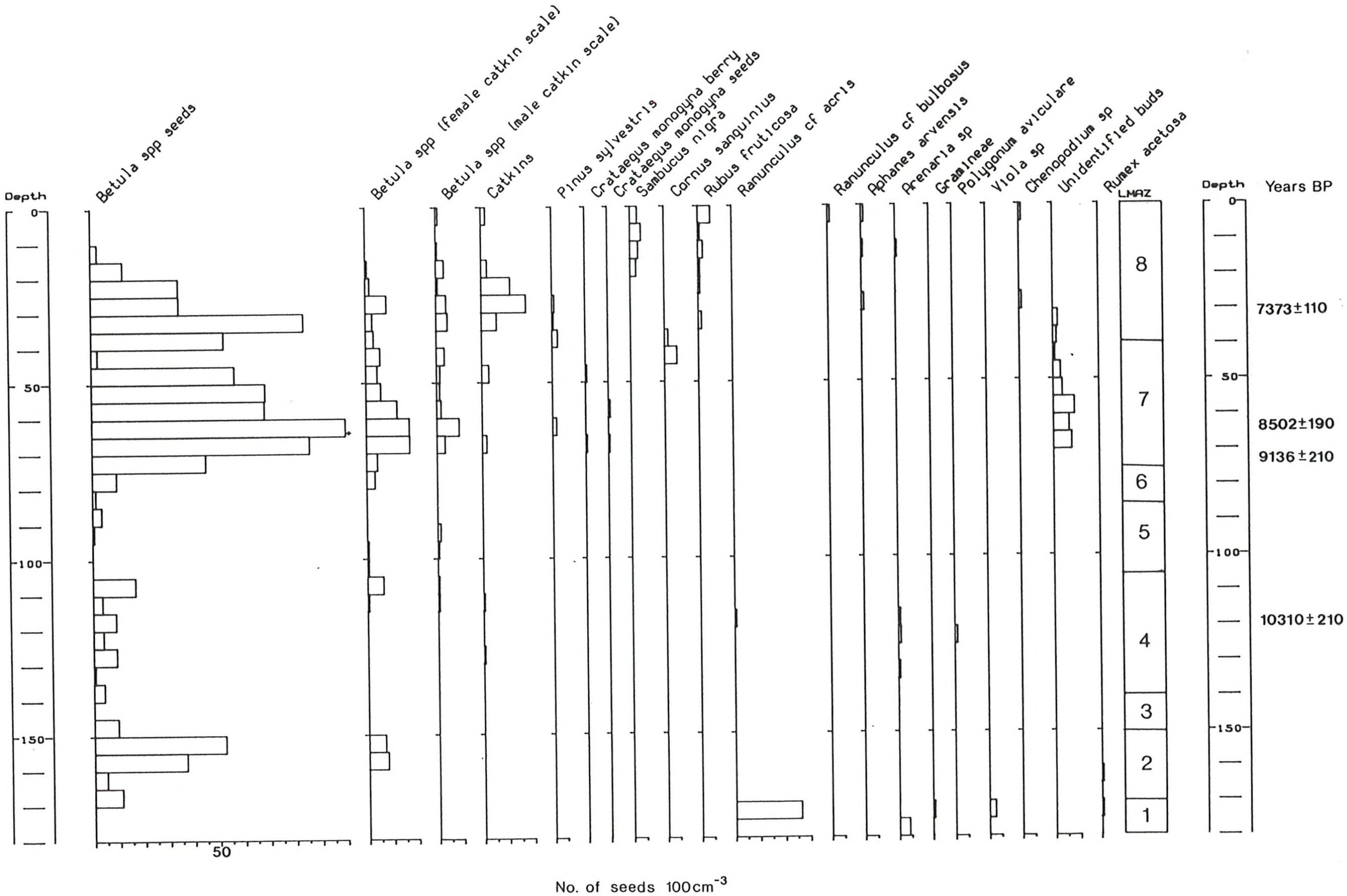


Figure 69 Terrestrial macrofossils (FM4)

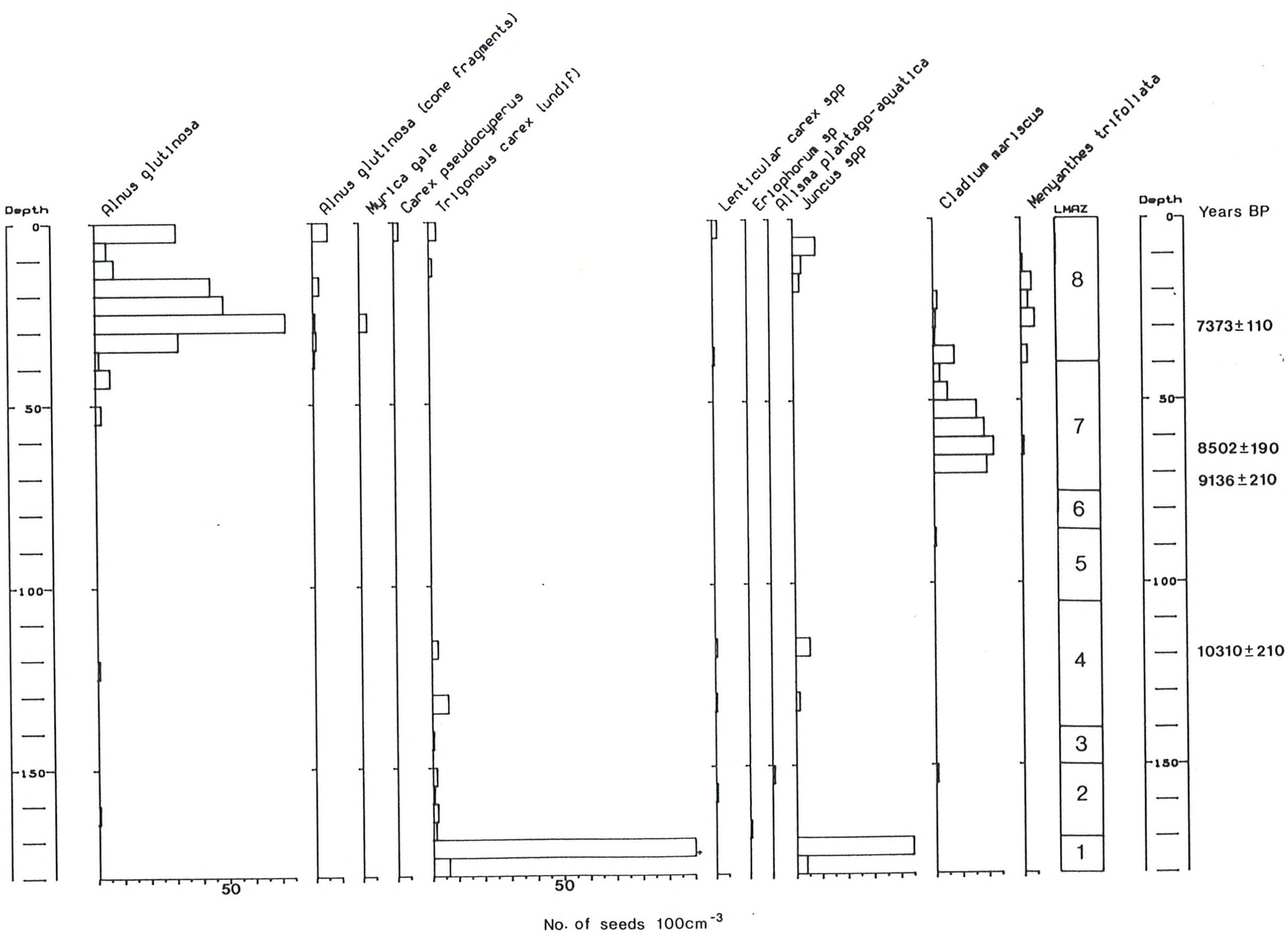


Figure 70 Telomatic macrofossils (FM4)

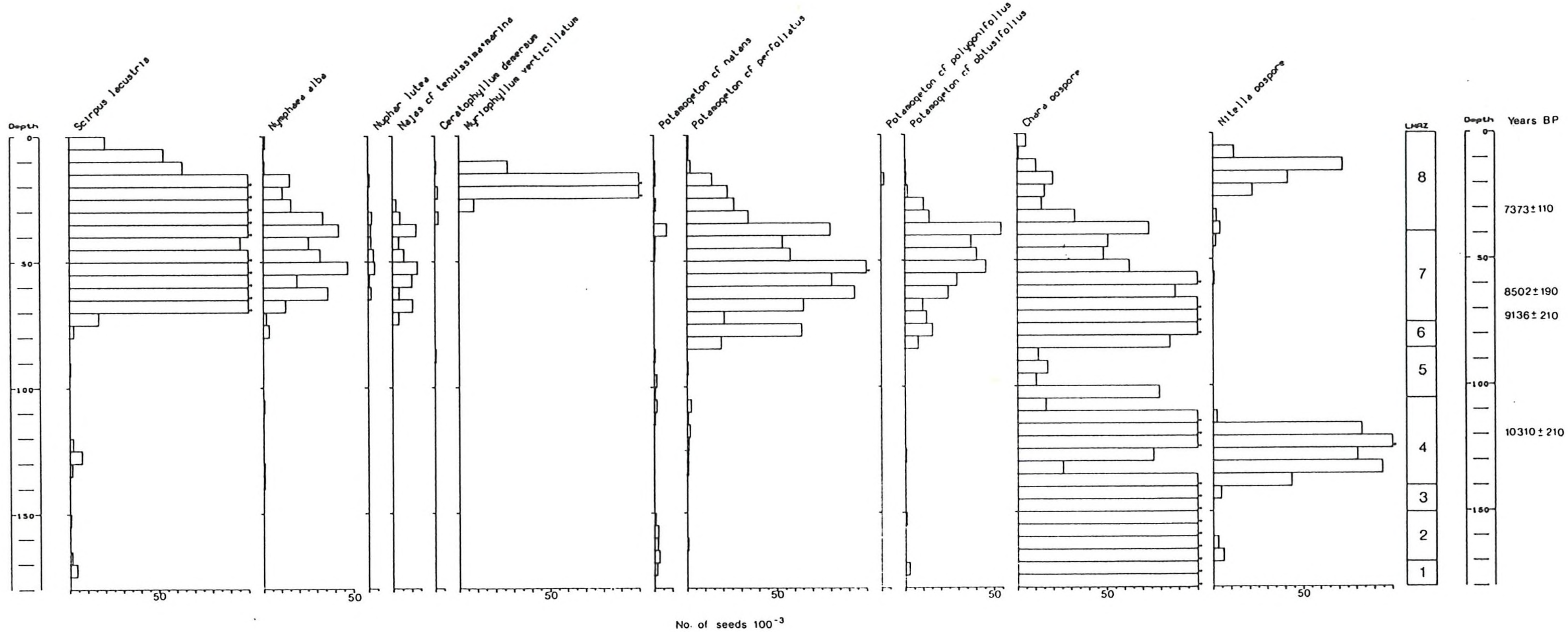


Figure 71 Aquatic macrofossils (FM4)

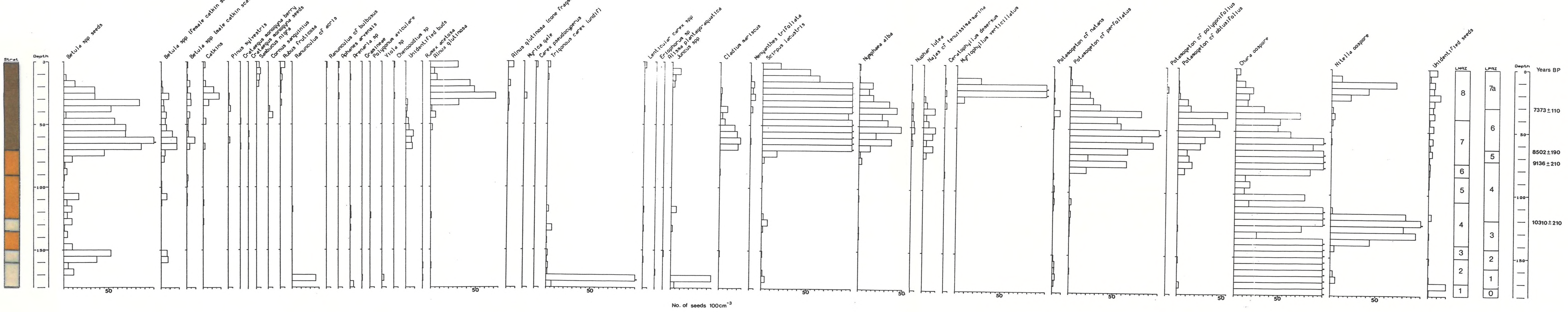


Figure 72 Macrofossil diagram from Fenemere (FM4)

Zone1 (arbitrarily defined as bottom of core to 170cm)

High *Juncus* and *Chara*

High levels of unidentifiable trigonous *Cyperaceae*

Presence of *Potamogeton natans, Scirpus lacustris, Rumex acetosa, Viola, Gypsophila* and *Ranunculus*

The presence of several dry grassland species in this zone could be an indication of the instability of the environment surrounding the lake at this time (>10,000 BP). Periods of inwashing could account for their preservation underwater. Low pollen concentration rates indicate high accumulation rates of sediment throughout this zone.

Zone2 (170 to 150cm)

High *Betula* and *Chara*

Presence of *Alnus glutinosa, Scirpus lacustris, Cladium mariscus, Ceratophyllum demersum, Potamogeton natans* and *Nitella*

The marginal macrophyte vegetation is well represented in this zone together with species more indicative of a deep water environment. Pollen concentrations are low during this zone indicating a period of increased sedimentary accumulation rates.

Zone3 (150 to 140cm)

Presence of *Nitella*

Few seeds present

The presence of *Nitella* in this zone is suggestive of deep water. A peak in the pollen concentrations during this zone indicates less rapid accumulation of sediment so it appears that the lack of seeds preserved in the sediment at this level could either be a result of poor preservation or could indicate sparse vegetation cover both in and around the mere during this part of the lateglacial period.

Zone4 (140 to 105cm)

High *Nitella*

Low *Betula* and *Nymphaea*

No *Nuphar*

High values of *Nitella* suggest deep water although some *Nymphaea* was recorded in this zone which could indicate that there was some colonisation of the more shallow water towards the edge of the mere. Birch macrofossils were consistently present throughout this zone but only in small quantities.

Zone5 (105 to 85cm)

Low *Chara*

No *Nitella*

Very low *Betula* levels

The low values of *Chara* and lack of *Nitella* in this zone suggests that a lowering of water level has occurred with the result that the mere is too shallow for the growth of *Nitella*. *Potamogeton* fruits were also recorded from this zone and are indicative of a disturbed environment supporting this hypothesis. High *Betula* pollen levels were recorded throughout this zone. Pollen concentrations were high and there was an increase in the amount of organic sedimentation during this period (approx 10,000 - 9700 BP).

Zone6 (85 to 75cm)

High *Chara* levels

Presence of *Potamogeton, Scirpus lacustris* and *Betula*

The appearance of marginal macrophytes could indicate that the vegetation is recovering after the fall in water level (approx 9700 - 9300BP).

Zone7 (75 to 40cm)

High *Chara, Betula, Scirpus lacustris, Cladium mariscus, Potamogeton, Nymphaea, Nuphar* and *Najas flexilis*

The lake may be showing signs of hydroseral succession as gradually more plants colonise Fenemere. This zone is characterised by a sudden increase in organic sedimentation and is dated around 9300 - 8000BP.

Zone8 (40cm to top)

High *Betula* and *Alnus*

Presence of *Scirpus lacustris, Nymphaea, Menyanthes trifoliata and Myriophyllum verticatum*

Little *Cladium mariscus*

Decreasing *Potamogeton* levels

Little *Nuphar*

Sub-divisions:

Zone8a (40 to 25cm)

High *Nuphar, Nymphaea, Betula, Alnus, Scirpus lacustris and Potamogeton*

Presence of *Najas flexilis*

Little *Nitella*

Some *Cladium mariscus*

No *Myriophyllum* and *Menyanthes*

Zone 8b (25 to 10cm)

High *Nitella, Myriophyllum, Menyanthes, Scirpus lacustris* and *Alnus*

Presence of *Sambucus nigra, Juncus* and *Nuphar*

Decreasing levels of *Potamogeton* and *Betula*

No *Najas flexilis*

Zone 8c (10cm to top)

High *Juncus, Type 12*

Presence of *Sambucus nigra, Cyperaceae, Potamogeton*

Nymphaea and *Chara*

Decreasing *Scirpus lacustris* and *Alnus*

No *Betula, Menyanthes, Myriophyllum, Potamogeton natans* and *Nuphar*

This zone appears to be recording a succession of species from open water, through a semiaquatic environment to the present day environment in which the core was taken.

The general trend of the lake suggested by these results is shown in figure73. One thing seems apparent from these results: there is no indication that the marginal vegetation has ever come forward or retreated and, therefore, no changes in the water level of Fenemere can be suggested except for a gradual decrease in water level

Depth	LPAZ	Description
180-150cm	zone0 - mid zone2	Disturbed environment affecting lake
150-80cm	mid zone2 - mid zone5	Poor seed preservation or lack of higher plants. High *Chara* and *Nitella* indicate a deep aquatic environment
80-20cm	mid zone5 - mid zone7a	Shallow aquatic environment
20cm to top	mid zone7a - present day	Dry land with occasional flooding

Figure 73

Summary of the results obtained from macrofossil analysis of Fenemere over thousands of years, probably due to natural succession of vegetation and infilling.

The macrosfossil data from Fenemere were also ordinated using CANOCO (section 6.4 p143) and the results can be seen in figures 74 and 75. This analysis gave a better spread of samples than than was obtained from Crose Mere and this was to be expected as the results obtained from macrofossil analysis on FM4 were very difficult to zone visually. A variety of species was present in most samples from the Fenemere data whereas in the data obtained from Crose Mere there were a few species recorded in most samples and only a concentrated band of 100cm sediment that contained any amount of a variety of species.

Five clusters of samples were obtained using DCA on the Fenemere data.

Cluster 1

This cluster contained samples 24,25,26,27, and 28. All these samples had high values of *Nitella*.

Cluster2

Samples 21,23,29,30,31,32,33,34,35 and 36 were grouped together in cluster2. They all contain high percentages of *Chara* oospores but few other species were present except for a low level of *Betula* and occasional appearances of species such as *Ranunculus* and *Arenaria*.

Cluster3

Cluster3 consisted of samples which had low *Chara* values and had very few seeds recorded in them. These samples were 15,16,17,18,19,20 and 22.

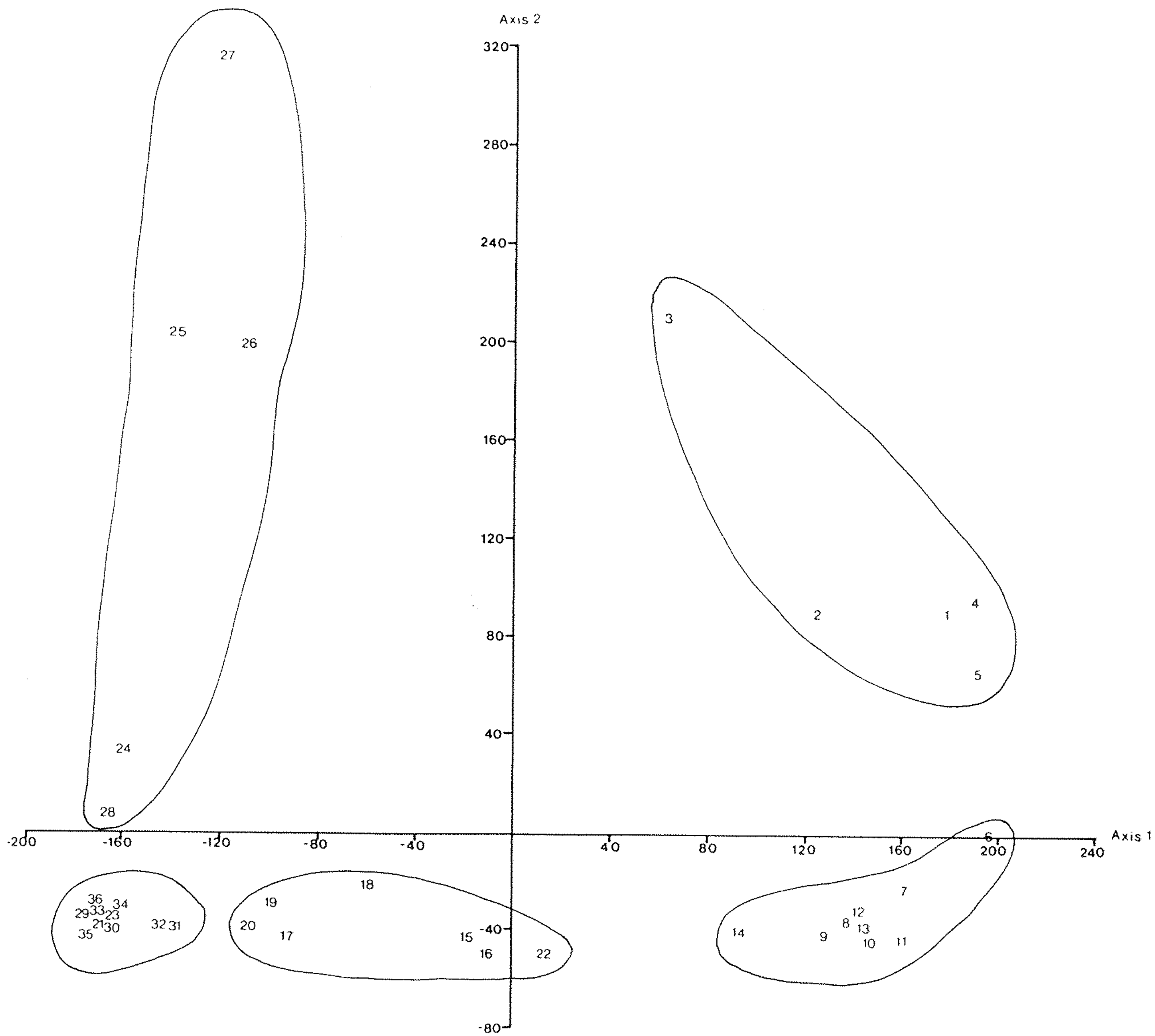


Figure 74 CANOCO Ordination of samples (FM4)

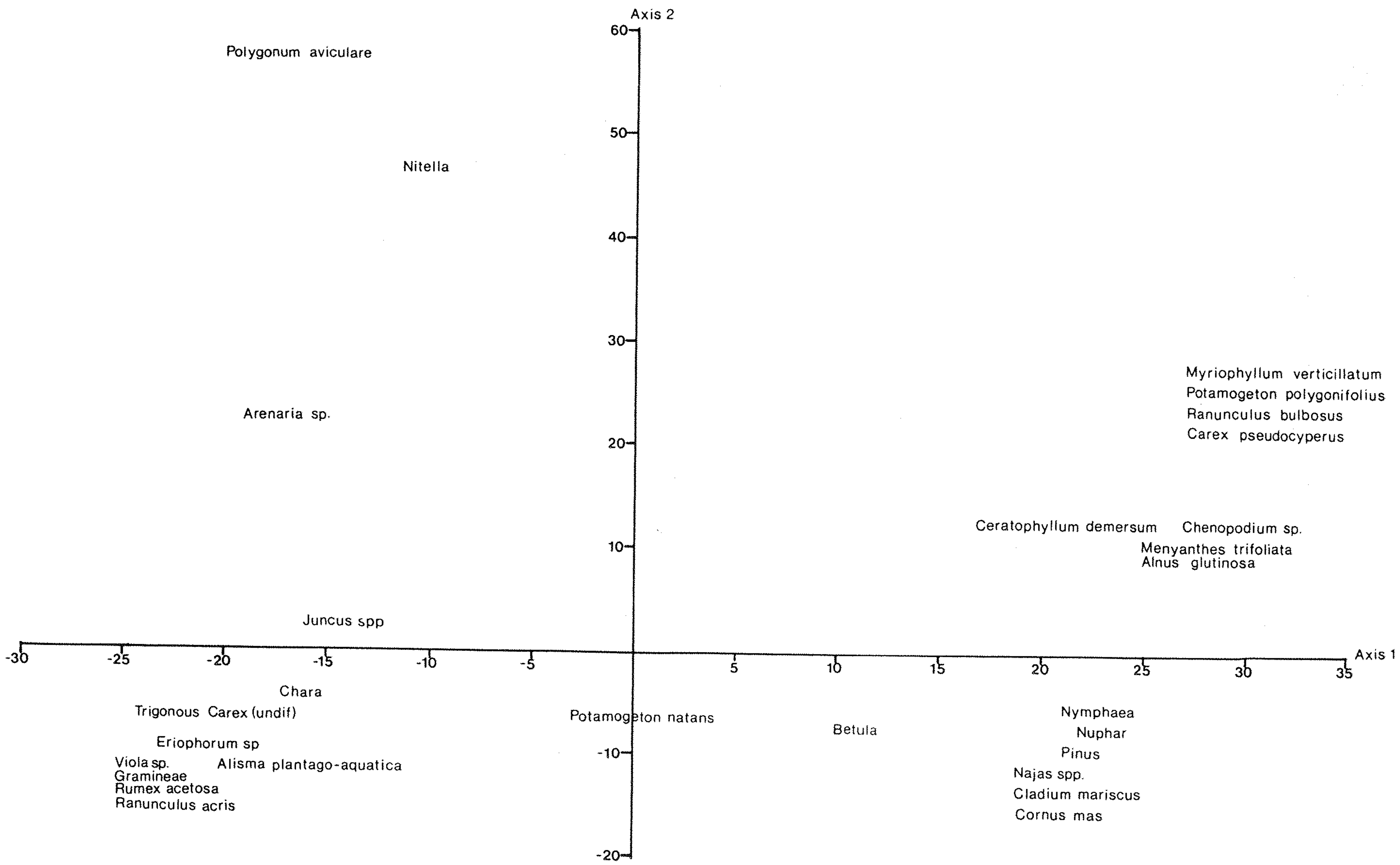


Figure 75 CANOCO Ordination of species (FM4)

Cluster4

This included samples 6,7,8,9,10,11,12,13, and 14. These samples were characterised by high *Scirpus* values and a consistent presence of *Nymphaea, Najas* and *Potamogeton* spp.

Cluster5

This cluster contained the top five samples characterised by a large variety of dry land species including *Sambucus, Rubus, Aphanes, Arenaria, Chenopodium* and *Ranunculus*.

The trend of axis1 appears to be from *Chara* to *Scirpus* and is difficult to interpret this trend in terms of environmental parameters. Axis2 appears to be dependent on *Chara* and *Nitella* and thus could represent a gradient of water depth or nutrient status (section 6.4 p 143). Although neither of these trends appears to be dependent on water depth, the multivariate analysis has been useful in the zonation of the macrofossil data and has also indicated that water depth may not be the primary factor controlling the distribution of vegetation within and around the mere.

7.5 Summary

A summary of all the results obtained from analyses on FM4 are shown in figure76 whilst positive results obtained from Fenemere are summarised in figure77. The latter figure shows that no major changes have occurred in sediment limit or particle size since the beginning of the Boreal period. The macrofossils indicate only a gradual infilling of the lake over time and are, therefore, of little use in reconstructing former lake levels. Positive results from sediment limit reconstruction and particle size analysis combined could indicate a lake level fluctuation has occurred but as positive results from these two analyses have only been obtained simultaneously

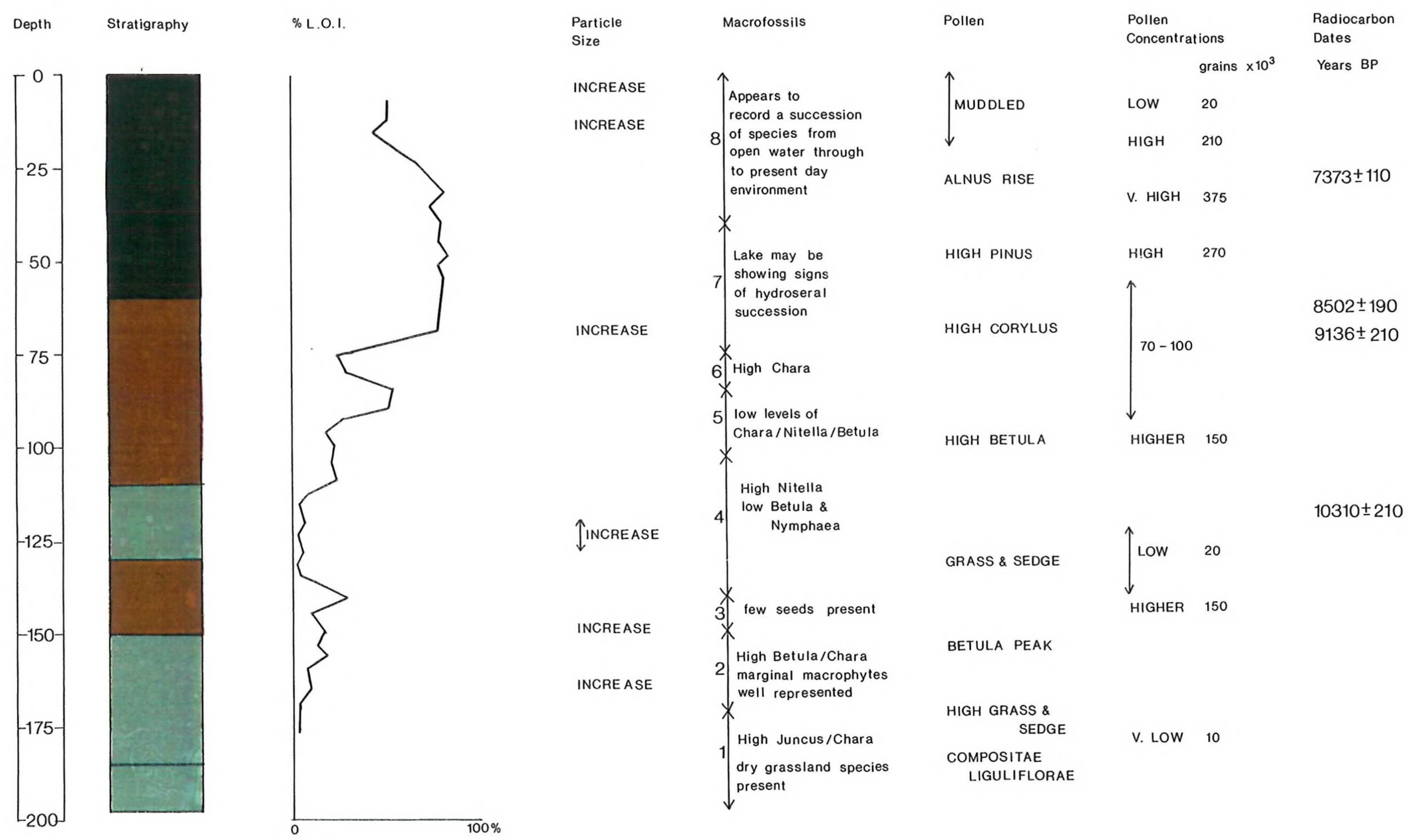


Figure 76 Summary of the results obtained from FM4

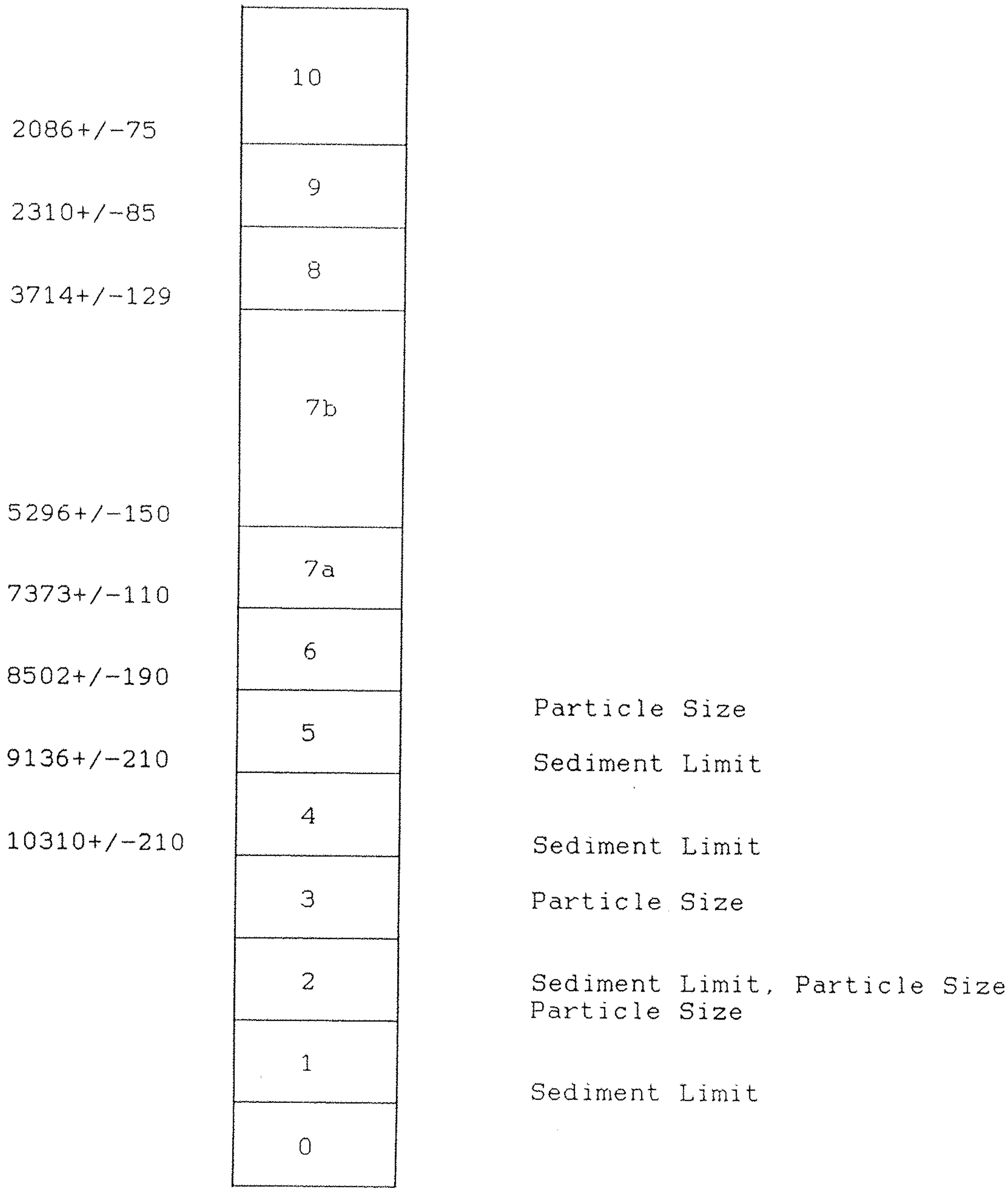


Figure 77 Summary of positive results obtained from Fenemere

in the late glacial period, it is unlikely that the water level of Fenemere has ever changed dramatically from that of its present position.

Chapter 8 DISCUSSION

8.1 Summary of results obtained from this study

The results obtained from Crose Mere and Fenemere are summarised in table 14. From this it can be seen that the sedimentation patterns occurring within each lake have been significantly different throughout the past 12,000 years or so since the meres were created. Crose Mere appears to have been a very complex mere, recording changes in its surroundings and in the mere itself in the sediments accumulated in the western bay. Cores taken along this transect show complexity in the pattern of sediment bands of yellow, light brown and dark brown colour. This was expected as positive results obtained from physical sedimentary analysis are more likely to be reflected in Crose Mere with its patchy distribution of reed vegetation than in Fenemere which has an almost continuous band of marginal macrophyte vegetation.

Four periods of positive results indicative of water level fluctuations have been recorded from Crose Mere. These are as follows:

LPAZ	Approximate date	Analyses yielding positive results
late 10	1864AD?	macrofossils, particle size, sediment limit
early 10	1700BP	particle size, sediment limit
7b/8 transition	3714+/-129BP	particle size, sediment limit
4/5 transition	9136+/-210BP	particle size, sediment limit

Crose Mere

LPAZ	Date	Positive results
10	2086+/-75	Macrofossils, Particle Size, Sediment Limit; Particle Size; Sediment Limit, Particle Size
9	2310+/-85	Macrofossils; Particle Size
8	3714+/129	Sediment Limit, Particle Size
7b	5296+/-150	Particle Size; Sediment Limit; Sediment Limit
7a	7373+/-110	Particle Size
6	8502+/-190	Particle Size; Particle Size
5	9136+/-210	Sediment Limit, Particle Size
4	10310+/-210	Particle Size
3		Particle Size; Particle Size
2		
1		
0		

Fenemere

LPAZ	Date	Positive results
10	2086+/-75	
9	2310+/-85	
8	3714+/-129	
7b	5296+/-150	
7a	7373+/-110	
6	8502+/-190	
5	9136+/-210	Particle Size; Sediment Limit
4	10310+/-210	Sediment Limit
3		Particle Size
2		Sediment Limit, Particle Size; Particle Size
1		Sediment Limit
0		

Table 14 Positive results obtained from Crose Mere and Fenemere

As mentioned previously (section 6.3 p128) an increase in particle size combined with a decreased sediment limit or a decrease in organic sedimentation could be due to increased exposure of the lake to wind action, maybe because of changes in the vegetation of the catchment area, rather than a lowering in water level. This hypothesis is supported by Beales (1980) who showed that the first major human impact to be recorded at Crose Mere occurred around 3700BP and, therefore, vegetational and land-use changes could be responsible for the sedimentary changes recorded in Crose Mere since this time.

Fenemere has a different catchment area and so it was hoped that results obtained from the four cores from Fenemere would support the results from Crose Mere showing that the events recorded in Crose Mere were regional rather than local. However, Fenemere does not appear to have undergone any significant changes that have been recorded in the sediment since 8500BP. Positive results recorded before this time were due to the enormous environmental upheavals that occurred in the early postglacial period (Simmons & Tooley 1981). The only point in the Fenemere cores where positive results from two different analyses were recorded contemporaneously was in the middle of local pollen assemblage zone 2, *ie* during the early lateglacial period.

Therefore, four events have occurred during the history of Crose Mere that were not recorded in Fenemere, a lake only 10km away. The latest of these events occurred in the latter part of zone 10 and is probably due to the extensive drainage operations that altered the catchment area of Crose Mere in 1864. It will not, therefore, be recorded in any other site as it is a local, not regional event. The three other events could be localised or regional events and so preliminary results from Berth Pool, another of the Baschurch Pools, are considered to see whether the results from Crose Mere or those from Fenemere are supported.

8.2 Preliminary results from Berth Pool

Berth Pool is smaller than Crose Mere and Fenemere and is deeper than Fenemere (area 2.9 ha, maximum depth 3.8m). It lies at a slightly higher elevation than the other Baschurch Pools although this is minimal (Twigger 1988). Two cores were taken from the southwestern shore of Berth Pool (figure 78) and contained approximately four metres of organic sediment overlying glacial clays (figure 79). Sandy bands were not recorded throughout the cores as found at Crose Mere, but there was some evidence of sandy bands near the base of the cores (tables 15 & 16). Pollen analysis showed that these sandy bands were deposited during the rapidly changing environments between the lateglacial and early Boreal periods. No stratigraphical changes have occurred since the stabilisation of the environment around 9000 BP, (the Preboreal/Boreal transition), apart from a change in humicity shown by loss on ignition (Twigger 1988)(figure 80). This occurred c.800-900ad (Twigger 1988) and is attributed to inorganic inwashing which seems to have increased whilst rye and hemp were being grown (Twigger 1988). Sediment deposited in Berth Pool is more minerogenic than sediment deposited in Fenemere and in this aspect, the Berth Pool cores are more similar to the Crose Mere cores. However, preliminary findings suggest that the 9100BP and 3700bp episodes have not been recorded in sediment deposited in Berth Pool although this sediment provides an excellent picture of anthropogenic disturbance since the Neolithic period (Twigger 1988).

Since these results are inconclusive, the Crose Mere results were compared with stratigraphic changes in sites distributed throughout the study area and the rest of England. A few sites from Wales, Scotland and Northern Ireland are also considered.

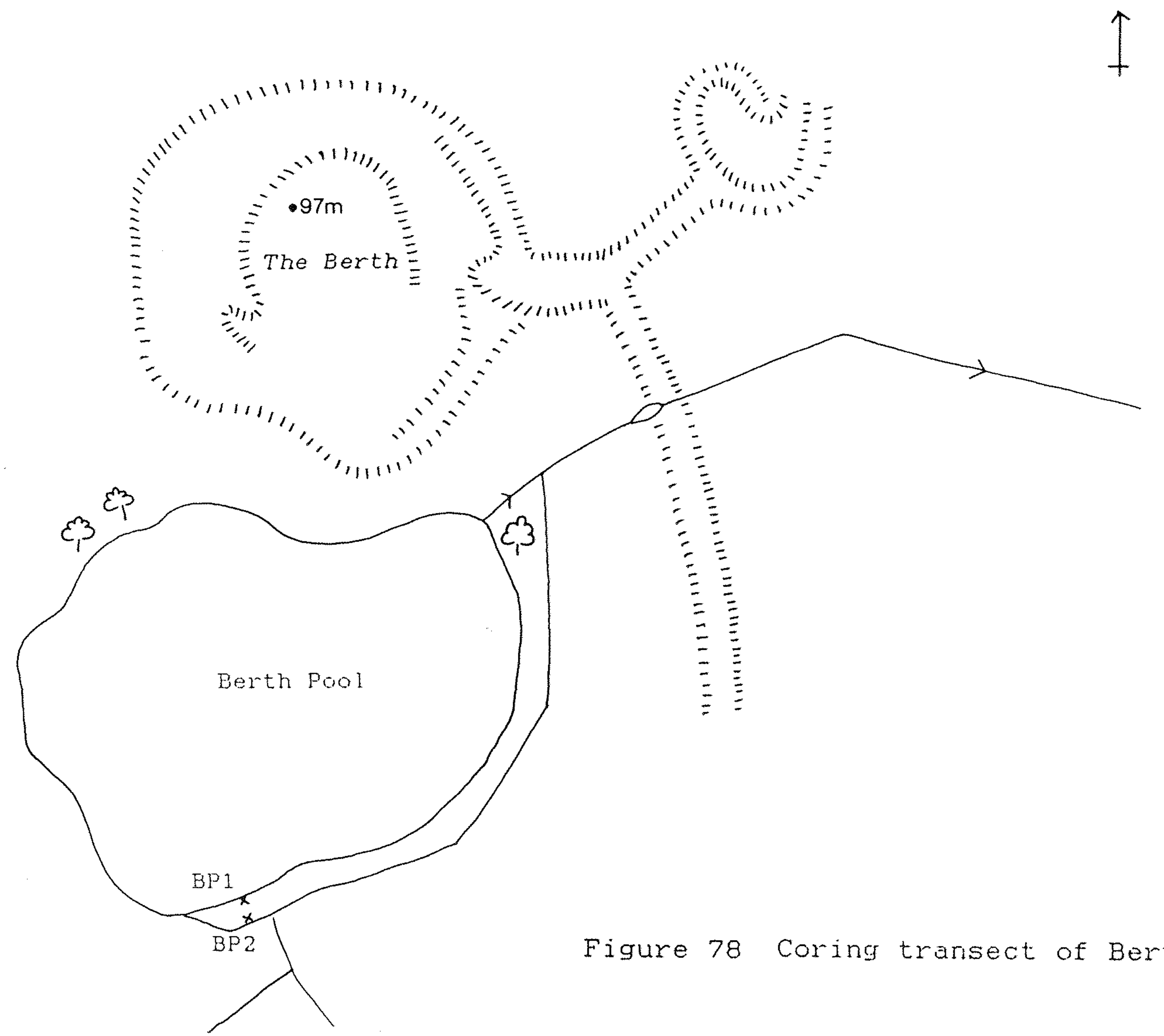


Figure 78 Coring transect of Berth Pool

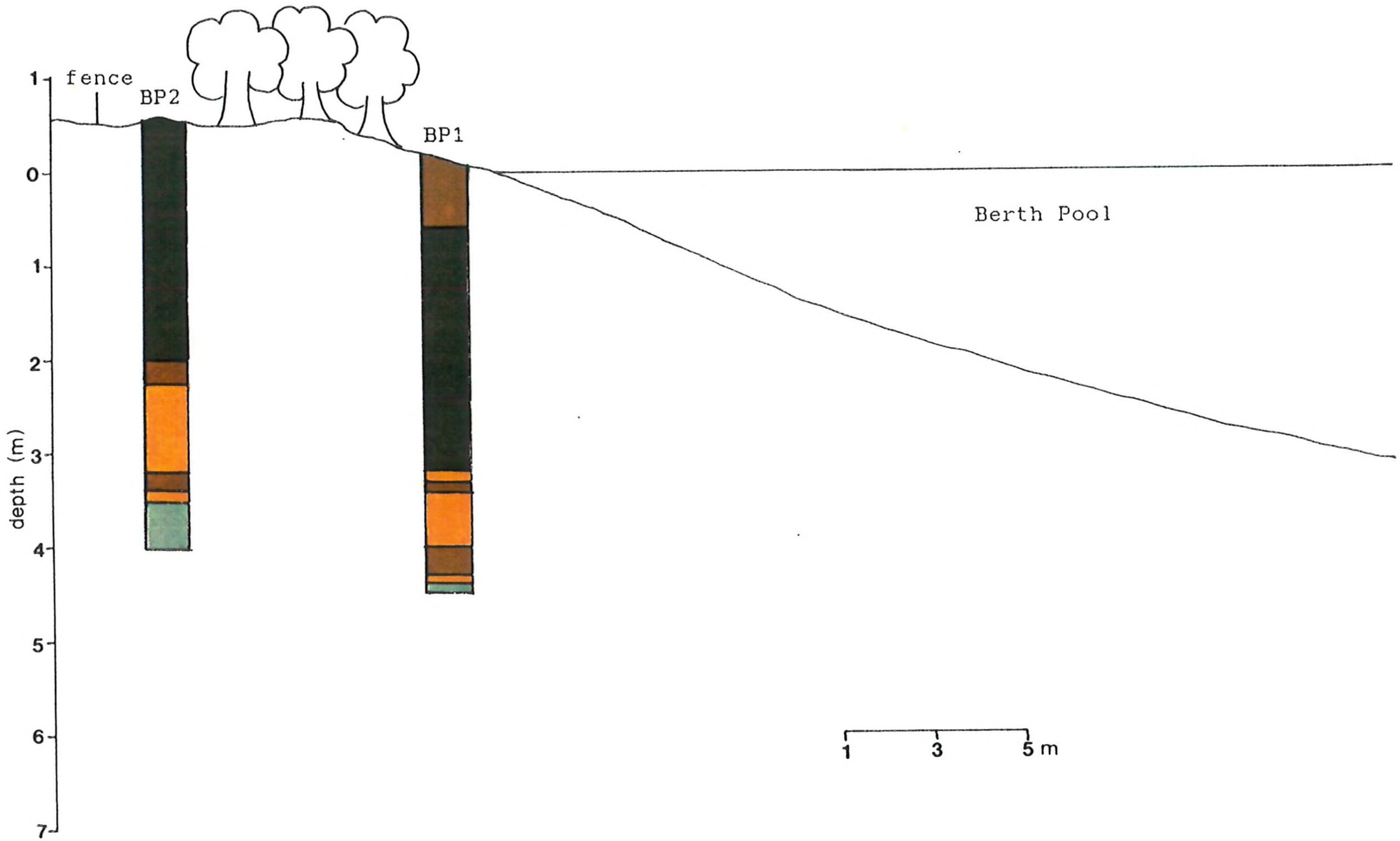


Figure 79 Stratigraphic diagram from Berth Pool

DEPTH	TROELS-SMITH NOTATION	GENERAL DESCRIPTION
0-62cm	Nig2 Strf2 Elas2 Sicc2 Humo2 Ld^{2}4	Brown lake mud
62-316cm	Nig3 Strf0 Elas1 Sicc2 Humo2 Ld^{3}4	Very dark and humic
316-323cm	Nig3 Strf0 Elas1 Sicc2 Humo2 Ld^{3}4 Test(moll)+	Very dark and humic
323-328cm	Nig1 Strf1 Elas3 Sicc2 Humo4 Ld^{1}4 Test(moll)+	Sandy band
328-335cm	Nig2 Strf1 Elas2 Sicc2 Humo4 Ld^{2}4 Test(moll)+	Brown lake mud
335-400cm	Nig1 Strf2 Elas3 Sicc2 Humo4 Ld^{1}4 Test(moll)+	Sandy band
400-427cm	Nig2 Strf2 Elas2 Sicc2 Humo3 Ld^{2}4	Brown lake mud
427-437cm	Nig1 Strf1 Elas3 Sicc2 Humo3 Ld^{1}4 As+	Sandy band
437-450cm	Nig1 Strf1 Elas0 Sicc2 Humo3 As4	Grey clay

Table15 Sediment description of BP1

DEPTH	TROELS-SMITH NOTATION	GENERAL DESCRIPTION
35-248cm	Nig3 Strf0 Elas1 Sicc2 Humo2 Ld^{3}4	Very dark and humic
248-250cm	Nig3 Strf0 Elas1 Sicc2 Humo2 Ld^{3}4 Test(moll)+	Very dark, humic and shelly
250-275cm	Nig2 Strf1 Elas2 Sicc2 Humo4 Ld^{2}4 Test(moll)+	Brown lake mud
275-364cm	Nig1 Strf2 Elas3 Sicc2 Humo3 Ld^{1}4 Test(moll)+	Sandy band
364-380cm	Nig2 Strf1 Elas2 Sicc2 Humo3 Ld^{2}4	Brown lake mud
380-392cm	Nig1 Strf2 Elas3 Sicc2 Humo3 Ld^{1}4	Sandy band
392-450cm	Nig1 Strf1 Elas0 Sicc2 Humo3 As4	Grey clay

Table16 Sediment description of BP2

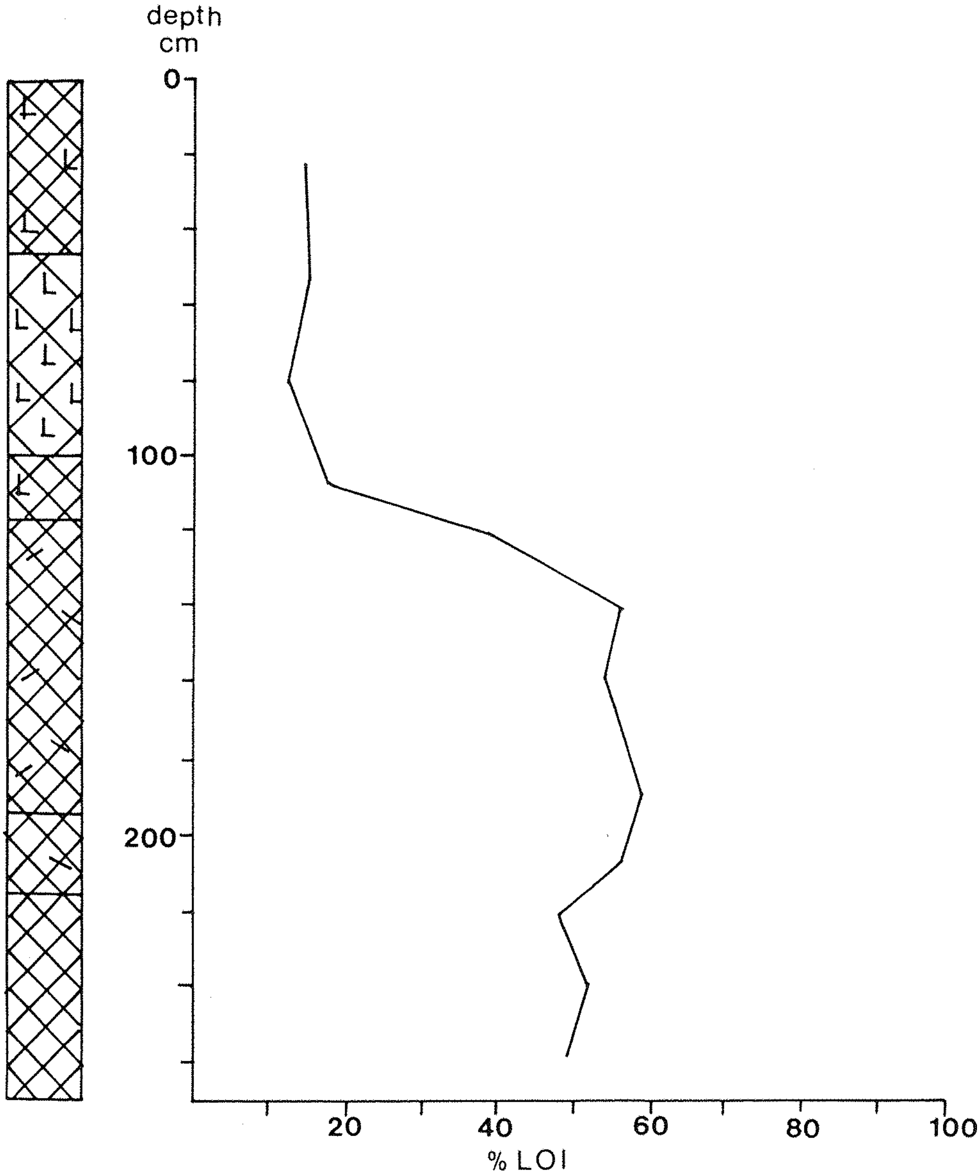


Figure 80

Percentage loss on ignition figures for Berth Pool (redrawn from Twigger 1988)

8.3 Correlation of the Crose Mere results with stratigraphy from other sites in the British Isles.

The sites are categorised into the following areas:

Scotland	North England
Ireland	Midlands
Wales	East Anglia

These results are summarised in tables17-20. There were several problems encountered in this collection of data. In some diagrams the stratigraphy was curtailed at the top or bottom of the core and so the wrong time span was represented on the diagram. Other diagrams had no indication of depths or pollen assemblage zones and, therefore, had to be eliminated from the investigation. Where only the local pollen assemblage zones were shown on a diagram it was not always possible to link the local pollen assemblage zones to the dates in question. However, it was possible to use the data from 22 sites situated around the six areas of the British Isles.

The only evidence supporting the events occurring around 1700BP in Crose Mere occurs in neighbouring Whixall Moss where an increased wetness was recorded by Haslam (1988). This would tend to suggest that in Crose Mere this was a fairly localised event, and, given its timing, is probably due to anthropogenic interference. However, changes in stratigraphy have been recorded at both the boundary between zones 7b and 8, and the boundary between zones 4 and 5 in several sites (Table 17). These generally reflect a trend from wet conditions to drier conditions which would be reflected in a lowered water level in sensitive lakes.

This indicates that the events occurring in Crose Mere at the 4/5 transition and the 7b/8 transition were widespread, not just confined to the Midlands, and were probably due to climatic changes, especially at the transition between zones 7b and 8 where the lowering of

AREA	SITE	AUTHOR	SEDIMENTARY CHANGES		
			c. 9000BP	c. 3700BP	c. 1800BP
MIDLANDS	Whattal Moss	Hardy 1939	change in humicity	lake mud -> Moss peat	no change
	Whixall Moss	Hardy 1939	—	Carex/Sphagnum peat -> Sphagnum peat	no change
	Whixall Moss	Haslam 1988	—	—	humification change 1700BP
	Bettisfield	Hardy 1939	—	change in humicity	no change
	Tregaron	Turner 1964	—	—	no change
	Tregaron	Godwin & Mitchell 1938	lake mud -> Carex peat	no change	possible humification change:dates not accurate
	Wilden Marsh	Brown 1988	clay -> detritus	sedimentary change	change to reedpeat
	Birchgrove	Twigger 1988	—	no change	change in humicity
	New Pool	Twigger 1988	—	no change	—
	Boreatton Moss	Twigger 1988	—	moderately humified Sphagnum -> dark herbaceous peat	no change
	Berth Pool	Twigger 1988	—	no change	no change

Table 17 Stratigraphical changes in the Midlands

AREA	SITE	AUTHOR	SEDIMENTARY CHANGES		
			c. 9000BP	c. 3700BP	c. 1800BP
NORTH WEST ENGLAND	Moorthwaite Moss	Walker 1966	no change	no change	no change
	Abbot Moss	Walker 1966	no change	no change	no change
	Oulton Moss	Walker 1966	no change	no change	no change
	Scaleby Moss	Walker 1966	reed -> moss peat	no change	no change
	Glasson Shore	Walker 1966	reed -> moss peat	no change	no change
	Windermere (1-7)	Pennington 1947	no change	no change	no change
	Windermere core8	Pennington 1947	clay gyttja -> brown mud	—	—
	Moorthwaite	Pennington 1970	gyttja -> lake mud	—	—
	Blea Tarn	Pennington 1970	no change	no change	—
	Barfield Tarn	Pennington 1970	—	no change	—
	Burnmoor Tarn	Pennington 1970	no change	—	—

Table 18 Stratigraphical changes in North West England

AREA	SITE	AUTHOR	SEDIMENTARY CHANGES		
			c. 9000BP	c. 3700BP	c. 1800BP
NORTH WEST ENGLAND	Moss Lake	Godwin 1958	no change	—	—
	Haweswater	Oldfield 1960	no change	no change	—
	Silverdale Moss	Oldfield 1960	no change	no change	—
	Devoke water	Pennington 1964	no change	light brown silty band	—
	Seathwaite	Pennington 1964	no change	organic band & sandy layer	—
	Goatswater	Pennington 1964	no change	—	—
	Blind Tarn	Pennington 1964	—	coarse detritus band	—
	Blea Tarn	Pennington 1964	clay -> detritus mud	—	—
	Red Tarn	Pennington 1964	clay -> detritus mud	—	—
EAST ANGLIA	Saham Mere	Bennett 1988	no change	—	—
	Hockham Mere DB5	Godwin & Tallantire 1951	no change	changes in organic content of Carex peat	—
	Hockham Mere DB6	Godwin & Tallantire 1951	organic layer	no change	—

Table 19 Stratigraphical changes in North West England and East Anglia

AREA	SITE	AUTHOR	SEDIMENTARY CHANGES		
			c. 9000BP	c. 3700BP	c. 1800BP
WALES	Cefn Ffordd	Chambers 1982	—	mineral/peat transition	—
	Cefn Gwernffrwd	Chambers 1982	no change	no change	no change
	Coed Taf	Chambers 1983	—	—	mineral/peat transition
	Cwm Idwal	Godwin 1955	no change	—	—
	Llangorse Lake	Jones, Benson-Evans & Chambers 1985	silty clay -> lake mud	no change	change from lake mud
	Llyn Dwythwch	Seddon 1962	no change	increase of clay in detritus mud	—
	Nant Ffrancon	Seddon 1962	no change	no change	—
SCOTLAND	Linton Loch	Mannion 1978	coarse mud -> marl	coarse mud/fine mud/ fen peat	—
IRELAND	Lough Neagh	O'Sullivan et al 1973	no change	no change	no change
	Lough Beg	O'Sullivan et al 1973	no change	—	—
	Coolteen	Craig 1978	—	—	—
	Belle Lake	Craig 1978	brown gyttja -> brown detritus gyttja	—	—

Table 20 Stratigraphical changes in Wales, Scotland and Ireland

lake level in Crose Mere coincides with the appearance of a recurrence surface in neighbouring Whattal Moss, Whixall Moss and Bettisfield (Hardy 1939, Turner 1962, 1964, Haslam 1988).

These results then pose one question - why are these climatic changes recorded in Crose Mere but not in Fenemere?

8.4 Comparison of characteristics of Crose Mere and Fenemere

Because of the closeness of the two meres to each other both Crose Mere and Fenemere are likely to experience very similar climatic conditions. They are also both situated on very similar geological substrata. This means that the major factors that could account for the magnitude of variation between the results obtained from the two meres are topography, basin morphology, vegetation and anthropogenic influences.

Crose Mere is situated in an area of hummocky moraine so the surrounding land undulates quite extensively (figure 81). Fenemere, however, lies in generally flat ground with very little slope or hills other than the Berth, an iron age fort on the edge of Berth Pool (figure82). Crose Mere and Fenemere also have different sizes of catchment. Crose Mere has a very small catchment area (340 ha) because of the hummocky morainic landscape surrounding the mere. Fenemere however, has a much greater catchment area (940 ha), especially as it is linked to the other three of the Baschurch Pools. These differences in topography will affect the quantity of groundwater, both surface and subsurface, flowing into the lakes from the immediate area and also from the catchment area.

Fenemere's drainage ditches have not apparently changed since Domesday whereas this is not the case with Crose Mere. The inflow marked on the first edition Ordnance

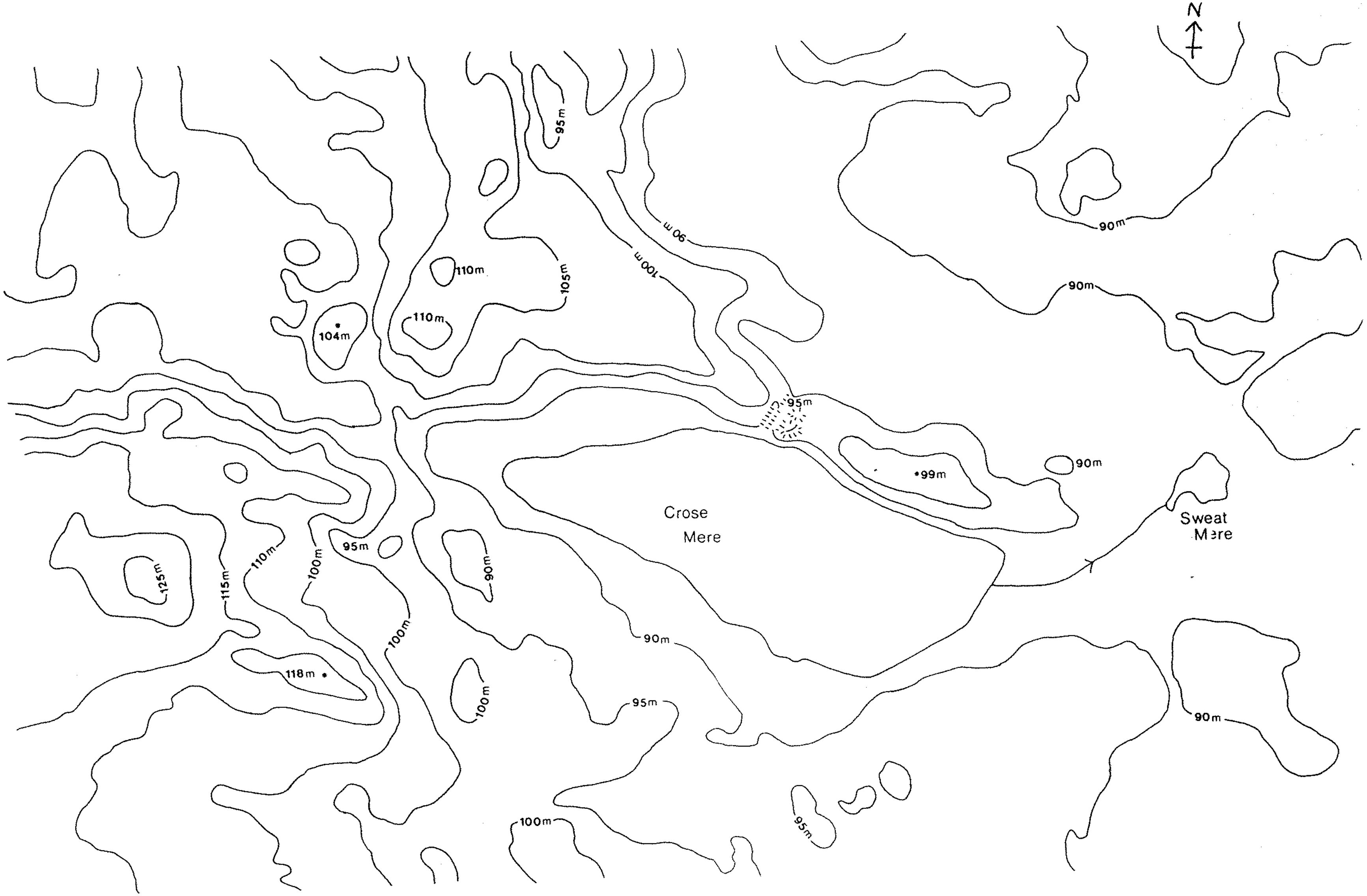


Figure 81 Contour map of Crose Mere

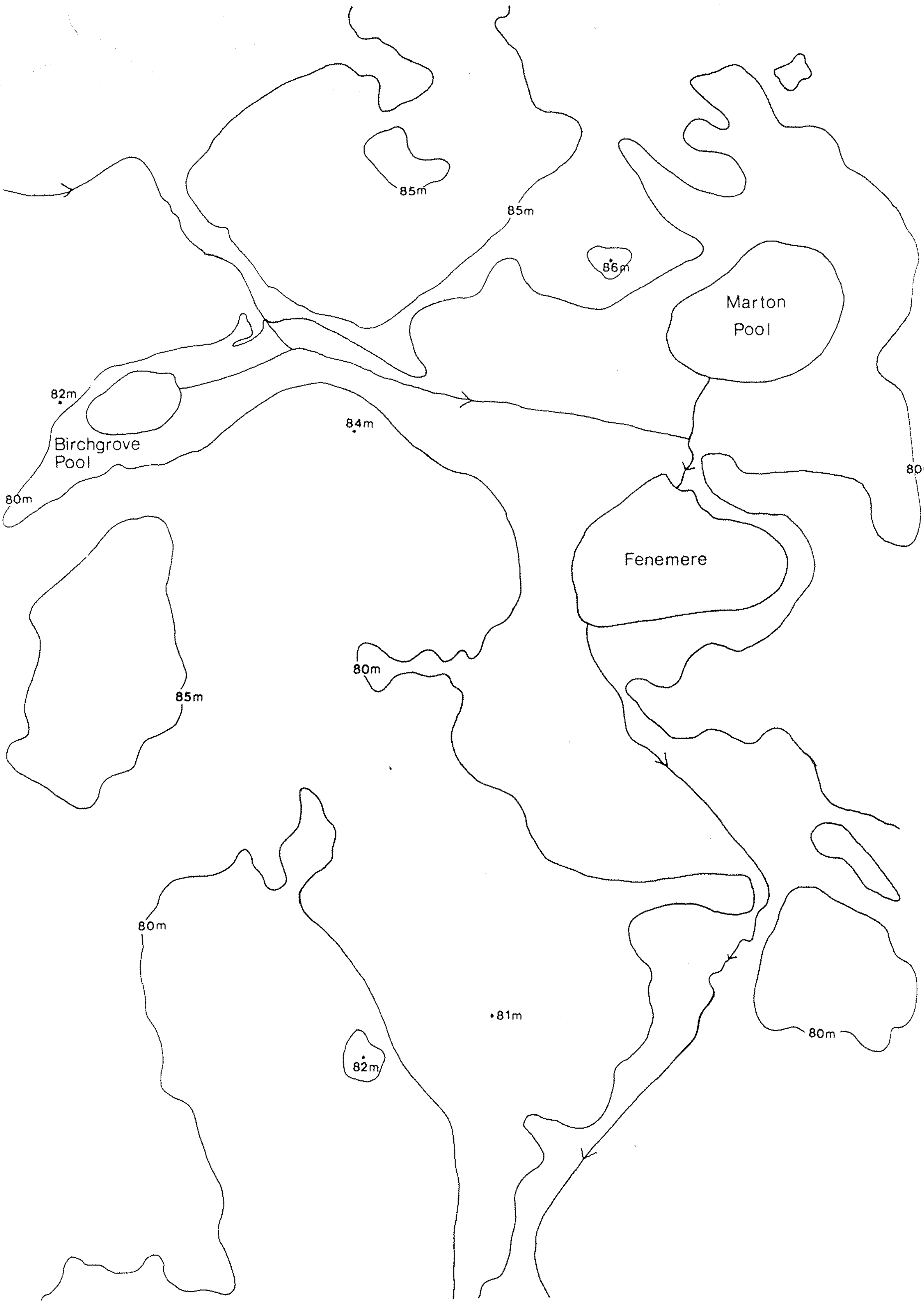
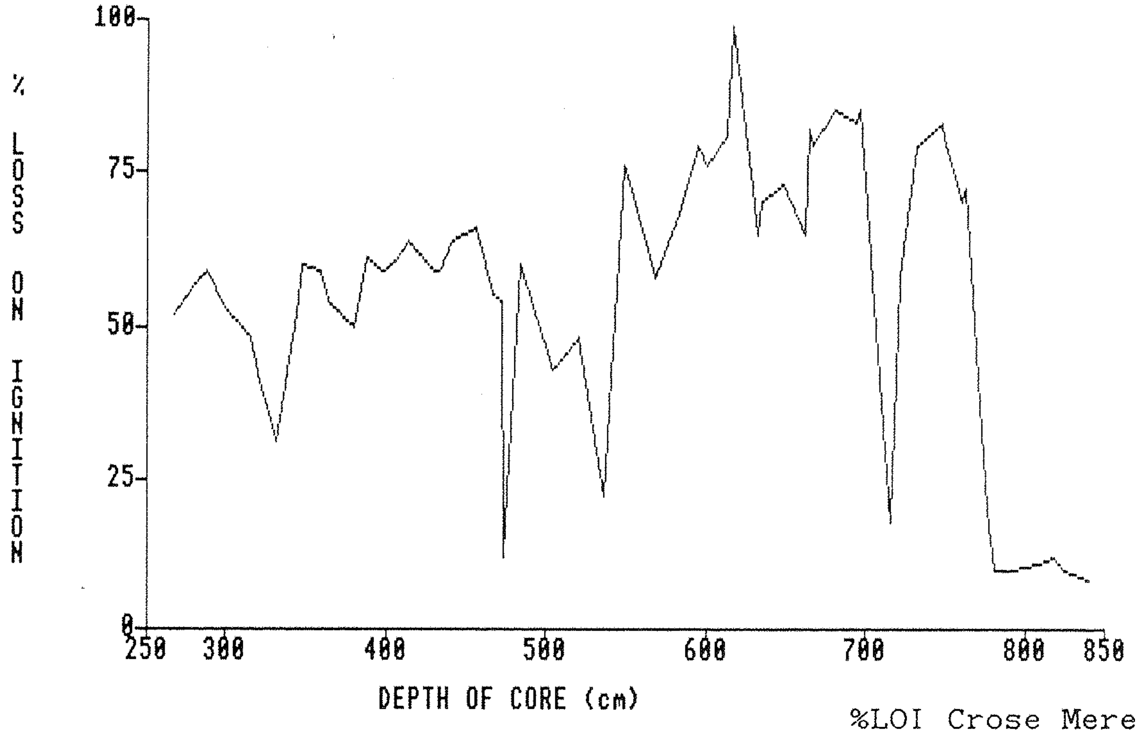


Figure 82 Contour map of Fenemere

Survey map no longer exists and an outflow channel now joins Crose Mere to Sweat Mere. This outflow channel is not marked on early maps of the Crose Mere area (figure 87) and so presumably is only a fairly recent addition to the complex. There is the possibility that the outflow from Fenemere is natural and has been there for a considerable amount of time, but it is improbable that the inflow into Crose Mere was natural because of the gravel ridge running parallel to the lake, between Crose Mere and Whattal Moss. It was probably dug to drain Whattal Moss into Crose Mere so that the Moss could be used for cultivation or grazing purposes (plates 1 - 3). The outflow may be natural but it is doubtful and would only have affected the water level of the mere in the last hundred years or so.

Fenemere is a slightly smaller lake than Crose Mere and has a very different basin shape, the deepest water (2.2m) being found in the centre of the basin. Crose Mere, on the other hand, has an eccentric basin, the deepest point (9m) being located in the north eastern region of the lake. This will result in a variation of sedimentation patterns between the two lakes with sediment in Fenemere being deposited more evenly over all of the lake bottom where as sediment focussing will occur in the deepest part of the basin of Crose Mere.

Sedimentation in Fenmere is largely organic (approx. 70%) whereas Crose Mere has a higher inorganic sedimentation (approx 50%)(figure 83). This will affect the amount of vegetation colonising the margins of the mere and ultimately affect the degree of exposure to which the mere is subject. At the present Fenemere is surrounded by a dense band of willow scrub with a nettle/bramble understorey. This is likely to stabilize the sediments surrounding the lake and prevent its inwash. There is also an almost continuous zone of marginal macrophytes which will again stabilize the sediments that have been deposited at the lake margins, and therefore minimise erosion and redeposition of these marginal sediments.



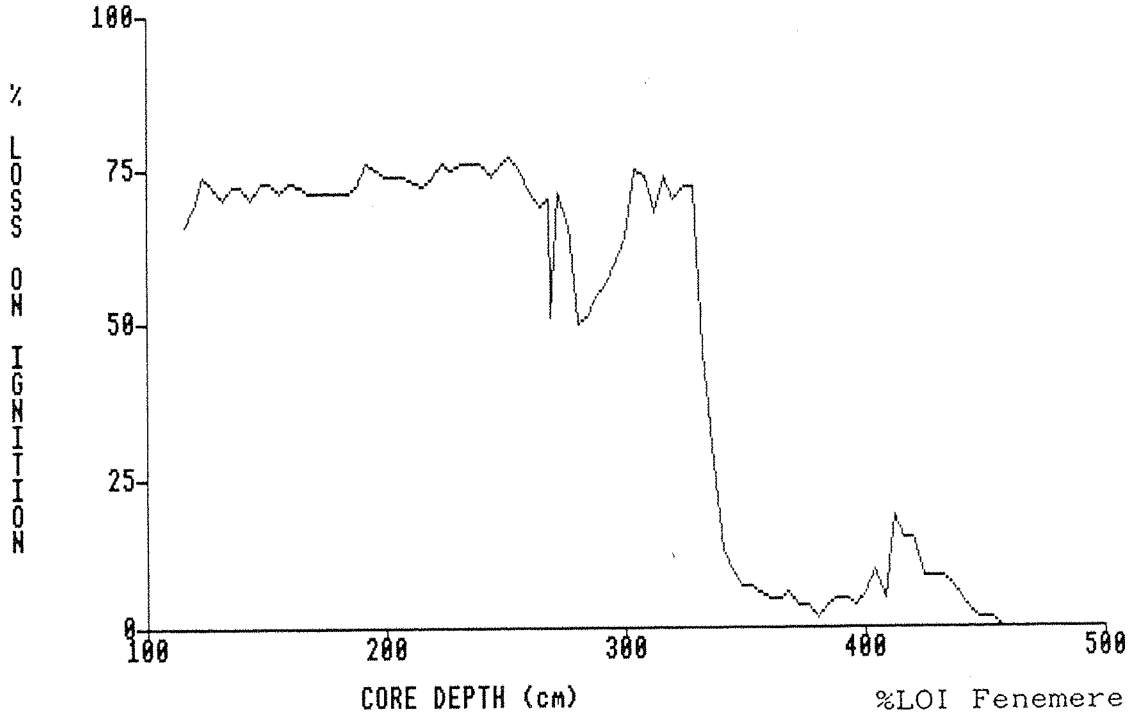


Figure 83 Comparison of loss on ignition figures for Crose Mere and Fenemere

Crose Mere today has a very disjunct marginal macrofossil zone, this only occurring in any density at the sheltered western end of the lake. There are occasional patches of *Phragmites communis* along the northern shore, and tussocks of *Carex paniculata* at the eastern end of the lake but these patches would be insufficient to stabilise the margins. It is probable that this has always been the case with Crose Mere given the general paucity of macrofossils recorded in the cores.

It is probable that no single one of these variables can account for the difference in results obtained from Crose Mere and Fenemere but that a combination of all of these factors was responsible for the variation in sedimentation patterns. If a difference in the age of the outflows can be assumed it is likely that this could account for the variation in sedimentation between the two meres as lakes that have always had an outlet may provide the least satisfactory record of palaeoclimatic change.

8.5 Comparison of the Shropshire results with those obtained previously from other studies.

The results from studies of lakes, bogs and glaciers situated in Europe and Scandinavia are shown in figure 84 together with results from Crose Mere and Fenemere. From this summary figure it can be seen that a water level lowering has been recorded from at least one site at every temporal position from 10000BP to 1000BP. There is even little correlation between the eight sites situated in South Sweden although water level lowerings occurred in all the lakes around 9500BP and around 3500BP . Given the radiocarbon dating errors it is possible that these coincide with the water level lowerings recorded at 9136+/-210BP and at 3714 +/- 129BP at Crose Mere *ie* at the transition between Preboreal and Boreal periods and at the transition between the Atlantic and Subboreal periods. The remainder of water level lowerings appear to be of regional significance and pose several questions. Are the lakes really experiencing fluctuations in water level or

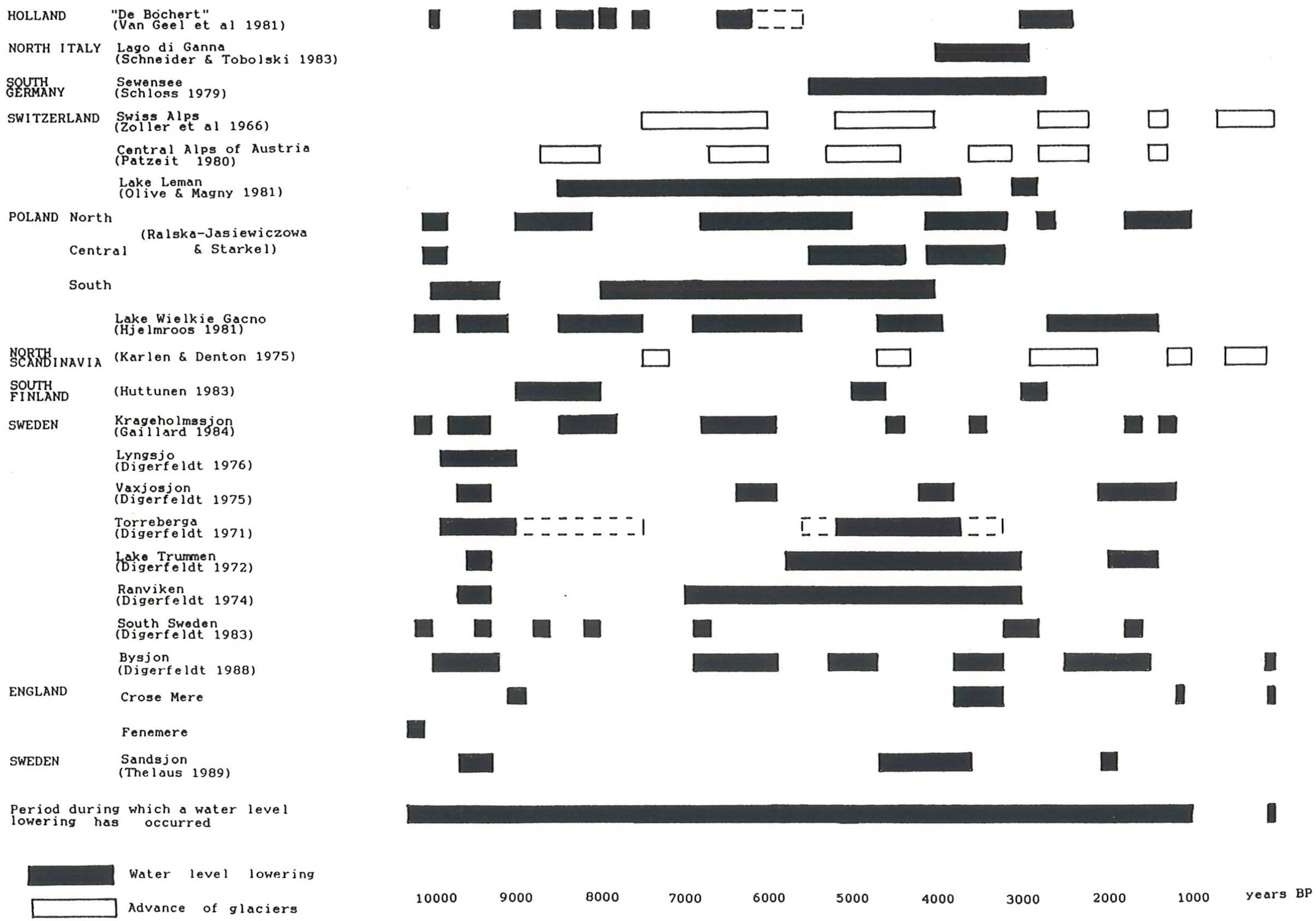


Figure 84 Summary of results obtained from lake level fluctuation studies

are other factors being recorded? Are the lakes responding to localised climatic changes, or indeed is climatic change the governing factor in the fluctuation of lake levels?

Digerfeldt based his method for the study of lake level fluctuations on the fact that, although each one of the three methods may produce positive results without a water level lowering occurring, when positive results are obtained for all three analyses simultaneously the lake in question has undergone a decrease in water level (Digerfeldt 1986). This is very rarely, if ever the case (table 21). In the majority of cases positive results are obtained in particle size analysis and sediment limit reconstruction only and these could be as a direct result of increased exposure of the lake. More vigorous wave action will produce a greater sorting of sedimentary particles near the shore giving an increase in particle size, and will also erode and redistribute more of the fine organic particles resulting in a decrease of the sediment limit as organic sediment is unable to remain near the shore. This results in an increase in particle size and a decrease in the sediment limit without any change in the lake level occurring.

Macrofossil analysis can only really be useful in eutrophic lakes which usually show a succession of marginal macrophytes. These lakes have a high organic sedimentation and often do not have sufficient mineral input to give a sediment limit of 5% as defined by Digerfeldt (1988). This results in an organic sediment limit described by Thelaus (1989) as the limit between the erosion and transportation bottoms (Hakansson and Jansson 1983). This is not easy to define either in the field or in the laboratory. As the 5% limit was set by Digerfeldt (1986, 1988) it may have a limited application to lakes outside South Sweden as it is dependent on basin morphology, underlying geological strata and the sedimentary composition of lake shores. It may, therefore, be preferable to have a decrease of organic

Lake	9000BP			3700-3500BP		
	Particle size	Sediment limit	Macro fossils	Particle size	Sediment limit	Macro fossils
Vaxjosjon	X	✓	X	X	✓	X
Krageholmssjon	X	✓	X	X	✓	✓
Lyngsjo	X	✓	X	—	—	—
Torreberga	X	✓	✓	X	X	✓
Lake Trummen	✓	✓	X	✓	✓	X
Ranviken	✓	✓	X	✓	✓	X
Bysjon	X	✓	X	X	✓	X
Sandsjon	✓	✓	X	✓	X	✓
Wielkie Gacno	✓	X	X	✓	X	X
Crose Mere	✓	✓	X	✓	✓	✓
Fenemere	X	✓	X	X	X	X

Table 21
Summary of results obtained from the three major analyses involved in the study of lake level fluctuations

sedimentation of maybe 20-30% as an indication of sediment limit change. This would be applicable to both lakes with high organic sedimentation and lakes with high mineral deposition and would indicate a change in sediment limit when recorded contemporaneously in two or more cores from a transect.

It is almost impossible to find the perfect lake for lake level fluctuation studies - a small ellipsoidal basin with no inflow or outflow - and all the lakes summarised in table 21 fail in some aspect. Lake Torreberga has been repeatedly drained with shrinkage of underlying dead ice causing a progressive lowering of ground level as well as draining the lake (Berglund and Digerfeldt 1970). The Ranviken bay is a tiny shallow area of a large lake system on the vegetational limits of *Picea, Narthecium* and *Erica*. Vaxjosjon has both an inflow and an outflow as does Krageholmssjon. Sandsjon is a small lake in a complex of lakes and peatlands and is situated in a boundary region between the Nemoral and Boreo-nemoral vegetation zones described by Sjors (1963, 1967) (Thelaus 1989). Both Crose Mere and Fenemere have outflows at the present and there is the possibility that the outflow at Fenemere is long established.

The majority of lake level lowerings are thought to have a palaeoclimatic explanation, although the influence of man cannot be ruled out in more recent lowerings (since approximately 3000BP in most areas). This has led to the adaptation of the Blytt Sernander zones to include short periods of varying climate in the larger named periods (Gaillard 1985). However, alternative explanations for a fluctuation in lake level have to be considered before any conclusions concerning lake levels and palaeoclimates can be reached.

8.6 Alternative explanations for lake-level fluctuations

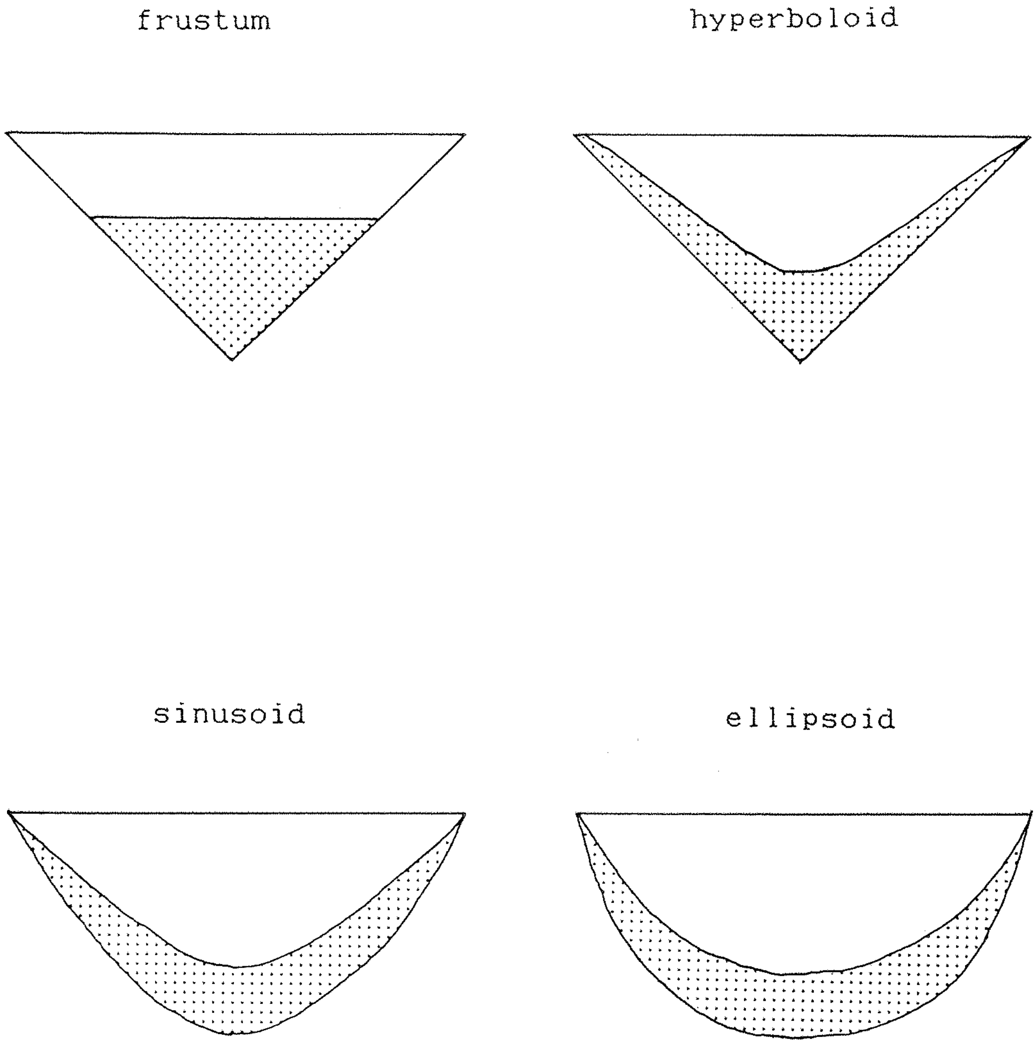
8.6.1 Morphometry of lake and positioning of cores.

Results obtained from the study of lake-level changes are dependent on the size and shape of the lake basin. There are a great many basin shapes but these can be split into two categories depending on whether the deepest part of the lake is in the middle or not. If the greatest depth of water is found in the centre of the lake, the lake can be one of four approximate shapes (figure 85)(Lehman 1975).

Each shape of basin has different sedimentary processes, thus directly affecting sediment limit reconstruction and particle size analysis, and indirectly affecting the vegetation. In a frustum shaped basin sedimentation occurs primarily at the centre of the lake with little sediment being deposited at the lake margins. As any sediment deposited here will be quickly eroded and redeposited in the centre of the lake, there will be no rooting substrate to enable marginal macrophytes to colonise the lake and vegetation will be restricted to floating aquatics such as *Lemna* and possibly *Potamogeton* species and deep water aquatics (*Ceratophyllum, Chara* and *Nitella*).

A hyperboloid basin is more likely to have colonisation of its shores by marginal macrophytes than a frustum basin but still is not ideal for the study of lake-level fluctuations because of the steeply sloping sides and restricted sediment accumulation at the lake edge. A sinusoid basin also suffers from these restrictions and so should not be used for research into changes of water level if possible.

An ellipsoidal basin is probably the best shape of lake basin for lake-level fluctuation studies as sediment is deposited almost uniformly over the majority of the lake



stippled area   sediment deposited

white area   present day basin

Figure 85 Four sediment accumulation models (redrawn from Lehman 1975) enabling a variety of plants to colonise the lake at different depths creating a hydroseral succession of species from dry land through to deep water. Erosional and redepositional processes will be minimal in this lake so providing as accurate a picture of lake level changes as possible in a concentric lake basin (Digerfeldt 1982). Fenemere appears to be ellipsoidal in shape, the maximum water depth (2.2m) being situated near the centre of the mere and sediment thicknesses reaching around 4m near the shore and increasing slightly towards the centre of the mere.

Not all lake basins are concentric, however, often having their greatest water depth off-centre creating an eccentic basin shape. Crose Mere is an eccentric basin with the greatest water depth being located near the north-eastern end of the lake. This results in the steep north eastern shores being subjected to a large amount of erosion and redeposition creating the sandy, stony shores with little vegetation seen at the eastern end of the lake, whilst organic sediment accumulates in the more gently sloping western shores of the lake. Marginal macrophytes quickly colonise these organic sediments creating a sheltered bay.

The size of the lake basin is also very important as large basins may have their lake sediment deposition largely influenced by currents resulting in deltas, sandbars and various irregularities of the bottom (Gould and Budinger 1958, Lehman 1975). Crose Mere is larger than Fenemere (15.2 ha as against 9.4 ha) but they are both classified as small lakes (Hakanson and Jansson 1983). This difference between Crose Mere and Fenemere, however, is unlikely to account for the difference in results obtained.

The position of the coring transect is also important as in the case of minor lake level changes, the local conditions *eg* the character of the shore region, water depth and vegetation decide whether or not such minor changes will be registered in the sediment. Due to changes in these local conditions which take place during the lake development it seems unlikely that more than a few such minor water level changes will be found registered in one lake, or at least in the same part of a lake (Digerfeldt 1975).

The site from which a core was obtained may not always have been exposed to equivalent degrees of water movement. For example, the entrance point of a stream may have changed with reference to the core site. Old maps show that this has indeed been the case with Crose Mere during the last 200 years at least. In a shrinking lake the core site may have been transformed from a region of turbulent open water to a quiet bay or lagoon, which though closer to the shore would have received a smaller proportion of coarse detrital sediment then before, thus confusing the results obtained from a study of lake level changes (Richardson 1969).

8.6.2 Tectonic processes

Crustal movements can dramatically affect the level of lakes particularly in areas of isostatic uplift which can cause the lake and its catchment to tilt (Kukkonen 1973, Dearing and Foster 1986). This is unlikely to have occurred in Shropshire, however, and can thus be excluded from this investigation.

Lakes situated in areas where the crust is unstable or whose basins comprise weakly jointed strata such as limestone will be particularly susceptible to deep seepage (Dearing and Foster 1986) but this is unlikely to represent a major pathway of water loss from a lake that is well established. Both Crose Mere and Fenemere lie in an area of glacial till overlying sandstones (section 3.2 p33) and are, therefore, unlikely to have experienced great water loss by deep seepage or, indeed, little change in seepage rates during the past 10,000 years at least.

8.6.3 Hydrology of lakes and their catchments

Lake levels are intrinsically linked to the hydrology of both the immediate area surrounding the lake and its catchment area. As the hydrology of lakes and their catchments is so complicated, only the hydrological processes which may affect the Shropshire meres will be considered here.

Figure 86 shows a very simplified hydrological model of how Crose Mere might have been before man dug drainage ditches and altered the amount of water entering and leaving the lake. Water lost by deep seepage would be negligible once the lake had become established (section 8.5.2). Similarly groundwater inflow and outflow will be restricted by the impermeability of the glacial clays around the meres and, therefore, can only be considered to have an effect in the top 40cm or so of peat deposits surrounding the meres. As this component is primarily dependent on the amount of rain falling on land surrounding the meres it will reflect changing climate rather than other factors affecting water levels.

This leaves just four major factors governing the water level of a closed lake: precipitation, evaporation, surface runoff and evapotranspiration. The first two factors are entirely climatic and any changes either in the amount of rainfall the lake receives or in temperature will affect the level of water in the lake. Evaporation is the only mechanism of discharge in a closed basin, but could be very variable if the lake is in a shallow basin as any change of volume involves a proportionally large increase in area and consequently in total evaporation which is a function of area (Richardson 1969).

The final two factors are largely governed by vegetation. Replacement of deciduous broadleaved forest by coniferous trees, such as might have occurred when *Pinus* replaced *Betula* and *Corylus* around 9000BP in Shropshire (section 5.7) would increase the amount of water lost from

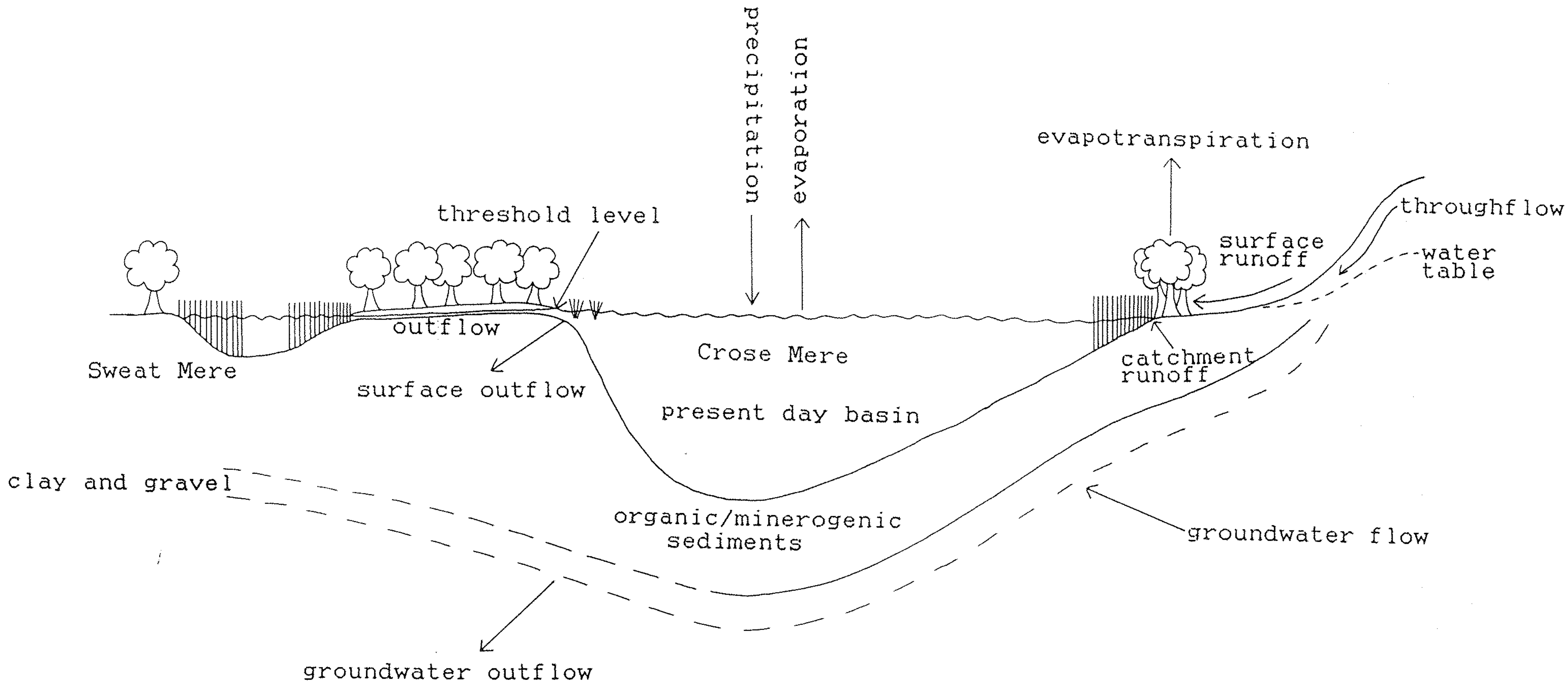


Figure 86 Hypothetical hydrological model of Crose Mere (adapted from Dearing and Foster 1986)

the ground by evapotranspiration so probably reducing throughflow. Similarly deforestation, either natural clearance due to fire or as a result of anthropogenic activity would reduce the amount of water lost by evapotranspiration thus increasing throughflow and also increasing surface runoff from surrounding land. The complexity of hydrological processes and vegetational changes is largely unknown at the moment although there have been some attempts to predict such effects (Penman 1948, 1963, Lockwood 1979, Gurnell 1981) and so it is impossible to say precisely what effect such changes in vegetation will have on lake levels.

So far, only the hydrological processes occurring in a closed basin have been considered but as closed lakes are few and far between the lake being studied in terms of lake level changes will probably have an inflow stream, an outflow stream or a combination of both. A large percentage of these open basins would always have had inflow and/or outflow streams since the lakes were created causing an added "hydrological complication". Inflow streams bring mineral and organic particles from the lake catchment area and deposit them into the lake disrupting the sedimentary processes around the area of the inflow. Changes occurring in the catchment will be recorded, therefore, in the sediment of the lake (Oldfield 1977). This can confuse and even distort the sedimentary evidence for lake level changes. Creation of a dam upstream could dramatically reduce lake levels throughout time as can diversion of inflow and increase in inflow size.

Outflows are less of a problem in terms of sediment disruption but can have a pronounced effect on a lake level particularly with respect to the enlargement of an outflow channel by downcutting. Only where an outlet stream has drained continuously over solid bedrock can it be assumed to have little effect on past water levels (Dearing and Foster 1986). In drift covered areas it can be supposed that threshold adjustment was originally rapid and perhaps pulsed during the time taken for the erosion of unconsolidated deposits overlying the bedrock (Dearing and Foster 1986).

On the whole, lakes which have always had an outlet provide the least satisfactory record of palaeoclimates. There often exists the interpretive complication of erosional downcutting at the outlet and for many such lakes, variations in volume of inflow or outflow streams may have left more dramatic records of past climatic change than have variations in the level of the lake (Richardson 1969).

The inflow from Crose Mere was probably manmade as it is situated through a gravel ridge (110m OD) separating Whattal Moss from Crose Mere (section 8.3). The present day outflow connects Crose Mere to Sweat Mere which drains into the River Roden by drainage ditches but did not exist originally (figure 88).

Fenemere, on the other hand, has an outflow called War Brook on its southeastern shore and it is possible that this outflow channel was created soon after the lake formed when the glacier retreated. All the ditches connecting Fenemere to the three remaining Baschurch Pools are probably artificial and so are likely not to have affected sedimentation in Fenemere until comparatively recently. Fenemere lies only 3km from the Perry floodplain and floodplain clearance of the River Perry has been shown to have occurred around 1300BP (Brown 1990). This may have had an effect on the water level of the Baschurch Pools and almost certainly was a complicating factor in the hydrological processes occurring in Fenemere, assuming that War Brook drained Fenemere at this time.

8.6.4 Stratification of lakes.

Stratification of lake water may occur resulting in the separation of the water into a warm, upper layer (epilimnion) and a cold, lower layer (hypolimnion). These

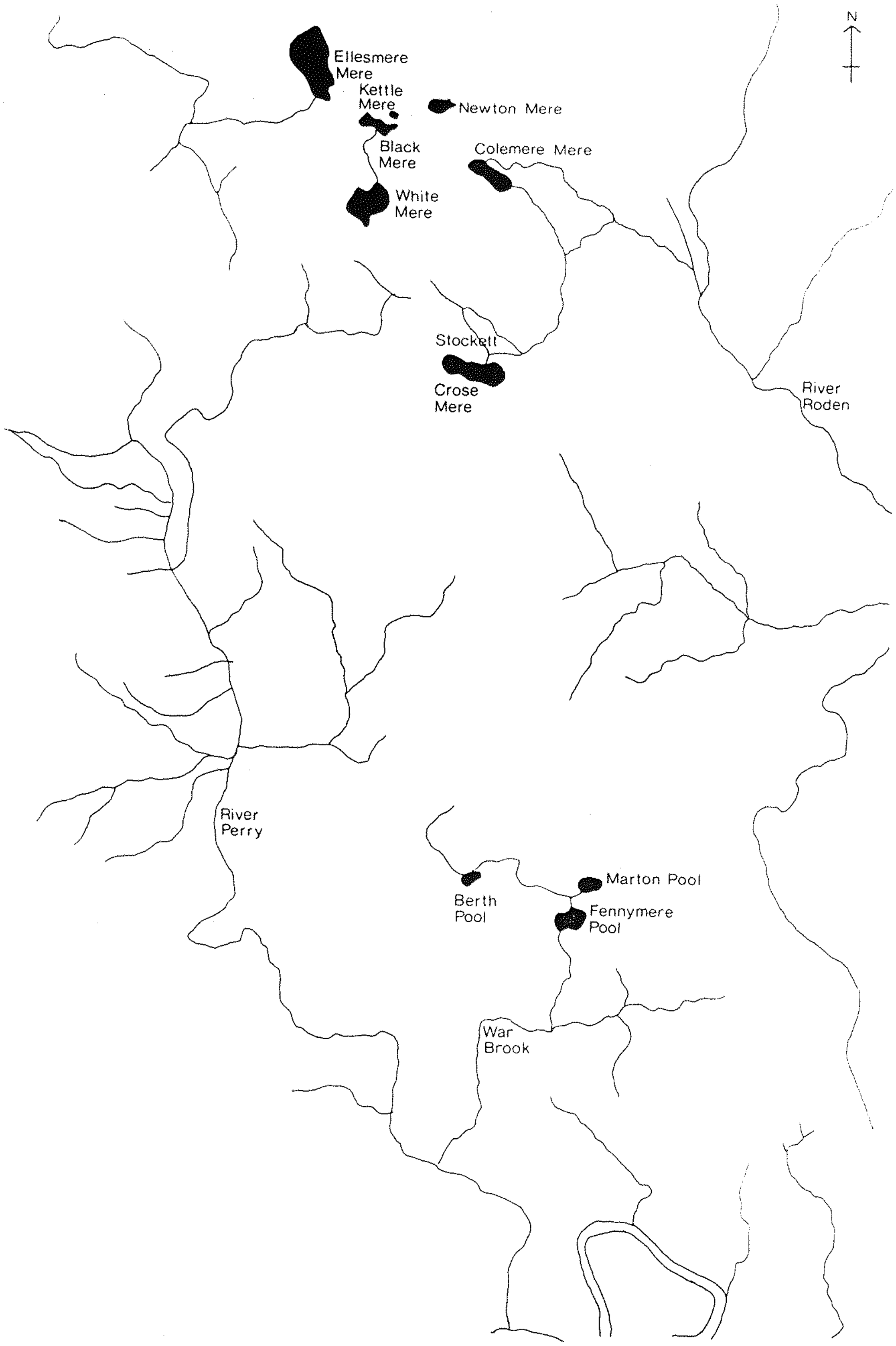


Figure 87

Map of the study area around Domesday time (Eyton 1860)

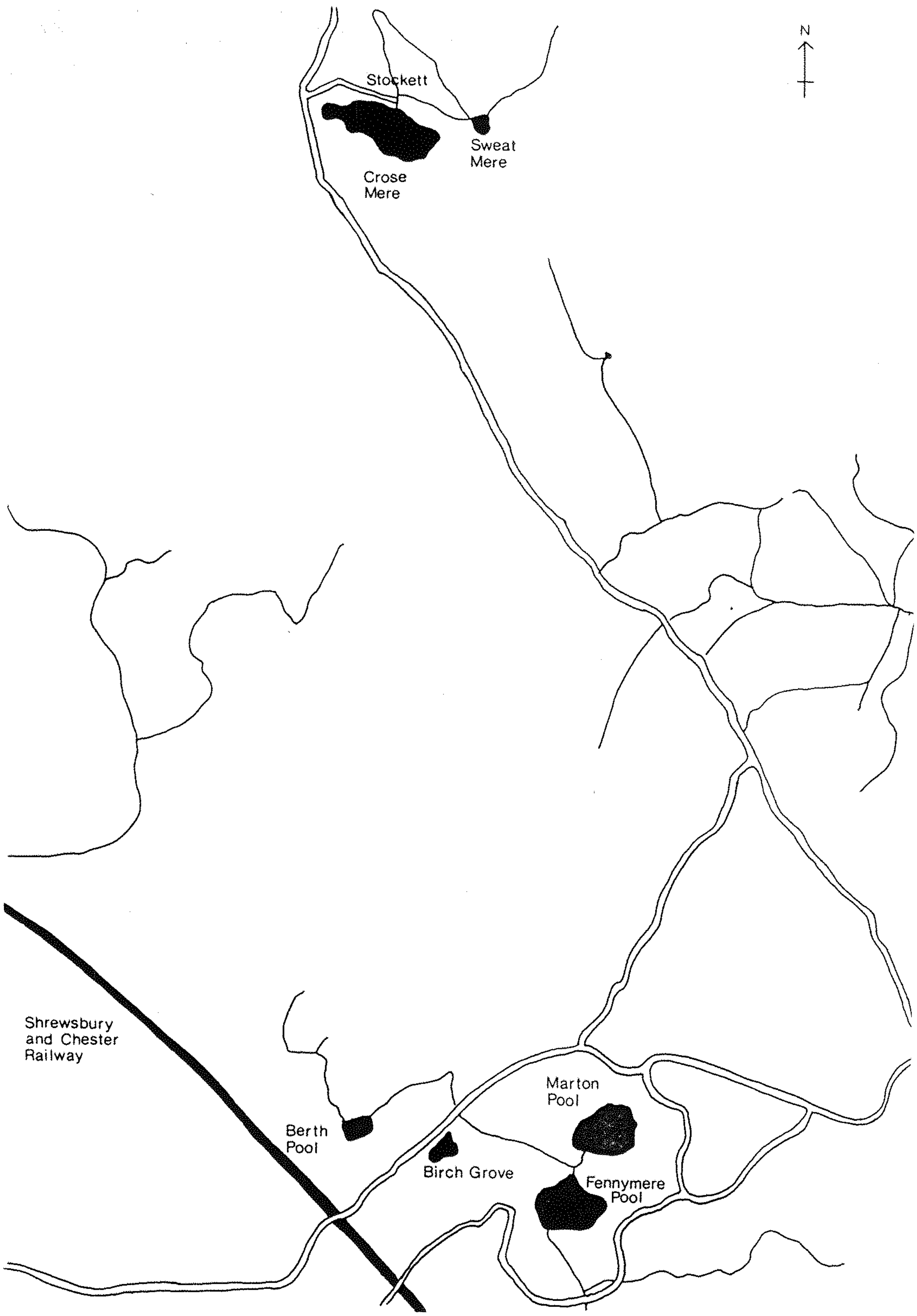


Figure 88

Map of the study area redrawn from the first edition Ordnance Survey map (1833) two layers are separated by a more or less narrow layer known as the metalimnion or thermocline. The majority of the Shropshire meres exceeding 5-8m in depth become thermally stratified in spring (Reynolds 1979). Crose Mere is amongst these meres but Fenemere is too shallow to exhibit stratification. These meres showing stratification remain stratified until late summer or late autumn depending on their depth and wind exposure. The deeper meres appear to have only one period stretching from mid autumn to mid spring of complete mixing per year but the shallower meres, including Crose Mere, may experience several such mixings each year (Reynolds 1979). This will affect the deposition of fine silt particles and pollen grains in particular as they tend to stay in suspension in the lake water for longer periods than heavier particles which rapidly sink to the lake floor. Thermal stratification has been shown to effect a movement of sediment from littoral to profundal zones as a consequence of overturn following the breakdown of the thermocline (Davis 1976).

A rise in lake level may also raise the thermocline as demonstrated in Mirror Lake, New Hampshire (Davis, Moeller and Ford 1984). This rise enabled organic gyttja to accumulate at depths where gyttja had not accumulated before, and in some areas this was the first episode of net accumulation of sediment since the lateglacial period. Consequently, post-settlement sediment in these areas directly overlies lateglacial silt.

Lakes which do not exhibit thermoclines today may have done so in earlier stages of development when water depths were greater (Dearing and Foster 1986). A combination of increased wind exposure, the former existence of a thermocline and steeper underwater slopes could have caused sediment to focus into the deepest zones and set the sedimentation limit in relatively deep water.

Thermoclines are also affected by the amount of time the lake experiences ice-cover. This is discussed in greater detail in section 2.3.1 p9 .

8.6.5 Vegetational changes

One of the three major analyses involved in the study of lake-level changes is macrofossil analysis. By recording the quantity and species of fruits and seeds preserved in lake sediment, extrapolation of changes in water levels may be possible. However, vegetational changes are difficult to predict as they are influenced by such an intrinsic complexity of factors.

Normal hydroseral succession or infilling of the lake, recognisable from a shift in aquatic seeds preserved in the sediment through boggy or fen land species to more dry land or terrestrial species, has to be identified before any interpretations of former lake levels can be suggested. Changes in climate which may affect water levels will undoubtedly affect vegetation maybe increasing or decreasing the amount of tree cover around the lake. This in turn will affect groundwater levels, the amount of runoff flowing into the lake and the amount of water lost from the ground surrounding the lake by evapotranspiration (Penman 1948, 1963, Gurnell 1981). The amount of exposure the lake is subjected to would also change affecting the sedimentary processes in the lake. This series of events would also occur during deforestation of the land, or by clearance of vegetation by fire.

Vegetation is not static from year to year. Competition between species may result in the spread of one dominant species with a detrimental effect to all other species in the vicinity. Such changes can occur within ten years as shown in chapter 3.8.2 p54 and will be reflected in macrofossil analysis of sediment taken from the lake margin. Thus, care must be taken when interpreting macrofossil diagrams as a decrease in number of seeds of one species may indicate a change in its distribution rather then a variation in quantity of the species (GreatRex 1983). Similarly, wind currents may carry seeds to areas of the lake where certain species may not be able to grow because the water is too deep or too shallow so giving a distorted picture of the distribution of vegetation in the lake.

Species also change with changing nutrient status of the lake. *Nitella* is found in more eutrophic lakes than *Chara* and so a shift from *Nitella* oospores in sediment to *Chara* oospores could indicate a change in trophic status of the lake rather than a change in water depth, even though *Nitella* is generally found in deeper water than *Chara* (BSBI handbook 5).

The presence of *Phragmites* around a lake shore is known to be associated with the deposition of silt (Lind 1949) and the inwash of such silt could result in the replacement of *Typha* and *Sparganium*, plants of organic mud, by *Phragmites*. This could explain the distribution of *Phragmites* in Crose Mere (section 3.7.2).

8.6.6 Anthropogenic interference

Man has probably had the greatest influence over the water level of lakes in recent time. Drainage of land surrounding lakes, building of dams, channelling ditches into or out of lakes, cultivation of land adjacent to lakes and afforestation/deforestation can all affect the water level of the lakes in question to a greater or lesser degree. The start of this anthropogenic effect varies in time from place to place. In Shropshire the earliest evidence of man is confined to hill ridges such as the Long Mynd, south-central Shropshire (Rowley 1972). These hill-crest tracks are thought to be important in the Bronze Age (Chitty 1963, Rowley 1972). The most pronounced traces of prehistoric man to be found in Shropshire, however, are the hillforts of the late Bronze Age and Iron Age (Brown & Barber 1985), Barber & Twigger 1987, Limbrey 1987) and evidence from the Welsh Marches supports the later Bronze Age origin for the hillfort building tradition (Megaw & Simpson 1979). It is possible that the early population at this time was of a similar magnitude as that of Domesday time (ca. 1.5 million inhabitants) (Stanford 1982), although this estimate may be erroneous as it is based on the assumption that everyone lived in the hillforts.

Barber and Twigger (1987) identified two cycles of woodland interference and regeneration, one around 3700 - 3500BP and the other around 3200BP. However, they believe that total tree cover was little affected, favouring small-scale clearances and an alteration of forest structure as an explanation for changes in tree pollen observed in diagrams. More extensive clearance is believed to have occurred from 2750BP onward with regeneration in some localities but not in others.

Arable expansion during Anglo-Saxon/Medieval times may have been responsible for increased alluviation seen in middle Perry reaches around 1400 years ago (Brown 1990) and Beales (1980) shows a partially cleared landscape from early to mid-Bronze Age onwards and an associated expansion of agriculture during Anglo-Saxon/ Medieval times. Thus, anthropogenic interference with the Shropshire meres before the late Bronze Age (ca. 3000BP) is unlikely.

In Sweden, human interference cannot be ruled out from any lake-level changes that have occurred from the Subboreal period to present day (Gaillard 1985) and so care needs to be taken in the interpretation of the causal factors of lake-level fluctuations occurring since the Subboreal period in most areas of Europe and Scandinavia.

As Gaillard (1985) writes;

> "Whether lake level fluctuations should be interpreted in terms of climate is still a question that remains open in many cases. Regional events such as river activity, lowering of riverbeds by down-cutting or deforestation by man may be at the origin of water level changes. Only by further investigations concerning the relations between human activity and palaeohydrological changes, thanks to different kinds of palaeoecological evidence and by comparison with fluvial environments will we be able to understand the causes of lake level fluctuations with certainty."

8.6.7 Temporal resolution

> "An absolute sediment chronology of the highest resolution is a prerequisite to an accurate assessment of the timing and longevity of lake level, and hence palaeohydrological changes"
>
> Dearing and Foster 1986

The final factor to be considered in the interpretation of lake level fluctuations is the temporal resolution of the results obtained. Without the temporal accuracy of annually laminated sediments, dating of lake sediments by most commonly used dating methods is subject at best to a resolution of tens of years, and at worst to hundreds of years. Radiocarbon dating is perhaps the most common means of dating sediments but has been shown to be particularly ineffective in the dating of various lake sediments. Errors can be due to old carbon inwashing (Pennington *et al* 1976, Twigger 1988), photosynthesis of bicarbonates (Olsson 1974) or even erosion and redeposition of older sediment on top of sediment that was more recently deposited. Mineral magnetism can give a more accurate temporal resolution on sediment from carbonate rich waters and can also detect periods of inwashing from the lake catchment but is limited in its use where erosion and redeposition has occurred. Hiatuses are also common in a magnetic curve (Oldfield 1983, Thompson & Oldfield 1988) and there can be problems involved in the interpretation of the magnetic curve obtained from a lake core in terms of temporal resolution, particularly if there are no other magnetic curves from the area in question. Dating lake sediments in terms of isotopes is expensive, particularly when a transect of cores is involved, and can be beyond the means of the research budget involved in the study.

For these reasons, pollen analysis has become the chief dating tool in the study of lake level fluctuations and the Blytt and Sernander zones used to date the changes occurring over Scandinavia and Europe. This has worked well in the correlation of cores both intra- and inter-sites but lacks the fine resolution required for absolute chronology.

8.7 Summary

Only in areas where all other factors are considered unlikely can it be hypothesised that any fluctuations in water level may be due to climatic change. Evidence for the climatic theory needs to be supported by evidence from several other lakes in the same region. The size of the region required for study purposes is dependent on the type of climate the area experiences. Sweden has greater continentality of climate than the British Isles and so a fairly large area experiences similar weather conditions. England, however, has a more oceanic climate which may vary over tens of kilometers. This means that the lakes being studied for lake level fluctuations and palaeoclimates need to be closer together in Britain than those in Sweden to experience similar weather conditions. Therefore, identification of synchronous changes in lake levels within a region may be the best means for isolating the effects of climate, but true synchroneity will frequently be difficult to achieve given typical dating errors.

Chapter 9 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The results obtained from the study of Crose Mere and Fenemere are significantly different. Four water level changes were recorded in the sediment of Crose Mere, the first two episodes occurring around 9100BP and 3700BP, and the second two since 2000BP. However, no changes in lake level have been recorded in Fenemere since the lateglacial period. As these two sets of results do not correspond well it is not possible to extend regional palaeoclimatic change as the primary cause of lake level changes in Shropshire on the basis of this study alone. The results obtained from Berth Pool did not correspond well to either the Crose Mere results or the Fenemere results, but were more similar to the results obtained from Fenemere in that no sedimentary changes had been recorded in the sediment from the beginning of the Boreal period until the appearance of anthropogenic disturbance on the landscape. Thus, the only conclusions that can be reached from studies on the three Shropshire meres is that all three meres underwent sedimentary changes during the lateglacial period but once the forest cover of the Boreal period had stabilised the surrounding soils no further changes were recorded in Fenemere and Berth Pool until the appearance of man around 3000BP. This would seem to suggest that the water level lowerings recorded around 3700BP and 2000BP in Crose Mere were localised events.

However, when these results are compared to the results obtained on other lake and mire studies in England (p193) there is evidence that the 9000BP and 3700BP changes were palaeoclimatically induced. The two episodes which occurred after 2000BP appear to be more localised phenomena and are, maybe, more a reflection of anthropogenic influences on the landscape rather than climatic change.

When compared to results obtained from previous studies of lake level lowerings in central Europe and Scandinavia it can be seen that the results from Crose Mere correspond well to the lowerings recorded around 9000BP and 3500BP suggesting that climatic changes were widespread at these times. However, the complete picture is still far from simple and it is likely that the addition of results from similar studies will add further complications to the general scene, although they may clarify the events which occurred around 9000BP and 3500BP.

It has been argued by Dearing (pers. comm.) that in order to interpret results obtained using these methods in terms of lake level fluctuations, one will first have to study a controlled environment in which lake level fluctuations occur. At first glance this would seem very feasible given the number of reservoirs and man-made lakes with records of water management going back more than a hundred years, but it may be very difficult to detect sudden lowerings of water level in sediments from the lake especially when the methods involved are largely based on vegetational changes. Bare, rocky scoured shores surrounding Thirlmere and Hawes Water in the Lake District, Northern England, both of which are reservoirs for Manchester, show the extent to which the constant changes in water level affect both sedimentary processes and vegetational succession of such a controlled lake. It ceases to be a natural lake and becomes an artificial anthropogenically controlled basin of water.

Lake levels that fluctuate due to climatic changes may do so gradually over a period of maybe a hundred years. There is not yet any controlled study of a lake that has been relatively unaffected by man that goes back this far. It is impossible to artificially control climate affecting a lake and its existing ecosystem to provide a yardstick for lake level fluctuations. Reservoirs and recorded sudden changes of water level in a lake due to drainage for example can only give us a brief unsatisfactory glimpse into what could be recorded in a natural lakes sediment throughout a long temporal phase of gradually deteriorating or ameliorating climates.

Ideally, an alternative, more refined, method for the study of lake level fluctuations could be constructed which would be less site specific. This would probably be based on fine resolution physical and chemical analyses of lake sediment and would include particle size analysis on all the cores across a transect of the lake, mineral magnetism and isotope studies to determine the source of particulate material in the sediment and chemical analysis of the sediment. A combination of several of these analyses would then be applied depending on the type of lake under investigation. The biological element of such a study would be largely eliminated as vegetation is very unpredictable and each lake has different vegetation assemblages. These assemblages not only vary from lake to lake but they also vary from one part of the lake to another. They are very sensitive to any changes in their surrounding environment but also respond to competition and change within an assemblage thus complicating the results.

This present study has shown the many different explanations that could apply to positive results obtained from sediment limit reconstruction, particle size analysis and macrofossil analysis and also goes part way to identifying some of the problems connected with the study of lake level fluctuations. This type of study could, however, play a very important part in palaeoecological studies as more and more information about lake level changes is discovered, particularly if the effects changing water levels have on lakes with varying sediment types is quantified to some extent and more information is obtained from lakes in the temperate zone.

To conclude, further research needs to be done on the meres and mosses of Shropshire concentrating on the four time periods 9000BP, 3700BP, 1800BP and 1800AD to confirm palaeoclimatic changes in the first two cases, and the presence of anthropogenic interference during the latter two temporal periods as indicated by the results from Crose Mere, and to present a more detailed account of anthropogenic activity in the Shropshire area so that this can be taken into consideration when interpreting the results obtained from lake level fluctuation studies in this area. The ultimate goal for such studies must be the elucidation of palaeoclimatic changes affecting Great Britain during the Holocene and how such changes have shaped the landscape into that which we find around us today.

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