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BLANKET MIRES AND CLIMATIC CHANGE; A PALAEOECOLOGICAL STUDY BASED ON PEAT HUMIFICATION AND MICROFOSSIL ANALYSES

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Thesis submitted for the degree of PhD

University of Keele

1990

ACKNOWLEDGEMENTS

I am indebted to many people for assistance in preparation of this thesis. Firstly, Dr. Frank Chambers, whose ideas and earlier work established the project. He has been an invaluable source of advice, information, and ideas ever since, and his suggestions have helped greatly improve on earlier drafts.

The Natural Environment Research Council provided a grant for three years, covered all fieldwork costs and additionally supplied 28 radiocarbon determinations free of charge. This support was generous and much appreciated. Dr. D.D. Harkness supplied the radiocarbon dates and comments about them.

Fieldwork assistance from Dr. Chambers, Dr. E. Cloutman, Lorne Elliott, Tim Mighall, Ian Wilshaw, Robert Maruziva, Simon Steel and Beverley Stirling is gratefully acknowledged. Beverley Stirling also contributed a series of humification analyses from the MIG 3 profile for which I am very grateful.

I would also like to thank Mr. H. Noble for access to the North York Moors site and routes to it. The National Trust (Llandudno) gave permission for work on the Migneint site. Access to the Irish sites was permitted by Letterfrack National Park, whose staff were very helpful.

Dr. Michael O'Connell, University College Galway, gave up valuable time to discuss the project and suggest possible sites in Galway and Mayo, and supplied pollen data and maps from the Letterfrack area.

Dr. Bas van Geel, Amsterdam also gave time and expertise in discussing the identification and meaning of various microfossils.

Many people within the department of Geography at Keele have provided assistance and technical help. Bryan Dawson has been very helpful in all matters of computing. Mal Beech patiently turned my drawings into respectable prints, and Andy Lawrence gave advice on drawing and produced figure 8.2. Mary Hamawi typed in the references.

Thank-you all.

ABSTRACT

The aim of this thesis is to evaluate the role of blanket peats as a source of proxy data by examining various properties of the peat and comparing the results with climatic changes known or inferred from other sources.

Blanket mires from the North York Moors, England, Connemara, Western Ireland and Snowdonia, North Wales, were chosen to cover a range of current climatic conditions.

The humification degree of peat was measured by a revised version of a previously used colorimetric technique. The method was reviewed and tested, showing that optical transmission values were indicative of, and proportional to, but not an exact measure of, the degree of humification.

Pollen and non-pollen microfossils, including previously unrecorded fungal, algal and unidentified remains, were counted and compared with the humification data. Horizons showing evidence of a change to wetter conditions were radiocarbon dated.

Detailed palaeoecological analysis across inferred wet-shifts demonstrate the nature of the changes and, in some cases, possible causes. In some examples the palaeoecology of blanket mires appears to have been dominated by the impact of man. However, synchronous increases in peat-surface humidity are recorded from all the areas studied, although not from every profile. Some microfossils show a different ecological preference from that found in previous studies. An attempt is made to model the response of blanket mire systems to different changing variables, and hydrological implications are discussed.

Coincident wet-shifts are inferred for the period around 1500 BC, between 1000 and 750 BC, between 400 and 200 BC, and around AD 650. Further periods of increased mire-surface wetness are recorded at AD 1150-1200, AD 1520-1600 and AD 1730-1800.

Blanket mires appear to have some of the properties required of a source of proxy climatic data.

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CHAPTER 1

INTRODUCTION

This introductory section argues the need for additional proxy climatic data, and explains that the aim of the project is to evaluate the role of blanket peats as a possible source.

1.1 Climatic change.

Climate, the long-term state of the atmosphere (Barry and Chorley 1982), is a controlling factor and important component of all environmental systems. Climatic change is therefore a cause of environmental change, which affects the study of changing climates in two ways. Firstly, it makes it necessary. Ecological and social systems all depend to some extent on climate. Secondly, the relationship between climate and environment makes its study possible. Reconstruction of past environments gives some indication of past climates.

Environmental conditions are perpetually changing on a range of scales from seconds to millions of years, influencing areas from microscopic to global in scale. The boundary that determines climate is the conventionally adopted 30-year element. Averages are determined within this span and include variation within the average which may be of critical biotic importance. Lamb (1984a) wrote;

> **"Climate, even under its natural development alone, varies continually. Each year, each decade, each century, each millenium.... has produced a somewhat different record."** (p24)

The impact of the man-made elements of climatic change are superimposed on a background of natural variability, and cannot be fully understood without an accurate background picture. Bradley (1985) stated that;

> **"Only when the causes of past climatic fluctuations are understood will it be possible to anticipate or forecast climatic variations in the future."** (p1)

Lamb (1984a) was more specific;

> **"The magnitude and extent of any changes attributable to man's activities.... cannot be determined without knowing the range, and the likely timing, of changes due to natural causes."** (p25)

Flohn and Fantechi (1984) pointed out that the aim of much recent scientific effort has been spent in trying to unravel the past history of world climate and the possible effects of future change. In suggesting where priority should be given, these authors stated;

> **"There is a need of** [sic] **careful and detailed reconstructions in space and time of past climates and time series analysis, based on meteorological observations and proxy data."** (Flohn and Fantechi 1984, p12.)

Past climates can be reconstructed from meteorological records only as far back as the early eighteenth century (Lamb 1977) and even then the spatial coverage of the records is minimal. Longer time spans can only be reconstructed through the use of proxy data. The term proxy is used to denote material that provides an indirect measure of climate, by measuring its effect on the environment. Components of environmental systems that have been preserved have also preserved a partial record of response to climatic signals. The components studied each have different response characteristics, allowing the measurement by proxy of a variety of elements of the climatic system. Adding to the sources of data, then, could be a valuable addition to understanding climatic variation in the past, and hence in the future.

1.2 Peat as a climatic record.

Peat accumulates when organic production is greater than removal and decomposition. An annual surplus of vegetative material steadily builds up to form mires of various types (cf Gore 1983). A factor influencing both the production and decomposition of a mire is prevailing climate, probably in terms of water balance. Ombrotrophic mires, those whose sole source of water and nutrients is precipitation, are by definition significantly influenced by climatic controls. The changing stratigraphy of peat bogs has been regarded as a potential source of proxy climatic data since the establishment of the Blytt-Sernander scheme (Sernander 1908) and the studies of Lewis (1905-1911). More recently, and with the benefit of radiocarbon dating, raised mires have yielded quite detailed proxy data, leading Barber (1985) to conclude;

> **"... that there is a close, if variable, relationship between climatic change and variations in peat stratigraphy."** (p183)

Properties of peat deposits including micro- and macro-fossils (van Geel 1978, Barber 1981), growth rate and the degree of decomposition (Aaby 1976), iodine content and oxygen isotope ratios (Dupont 1986, Brenninkmejer 1982), have been interpreted as being climatically controlled. Blanket peats, so called because of their landscape-cloaking distribution, are a complex of rheotrophic and ombrotrophic mire types (Moore, Merryfield and Price 1984), and have not been studied in the same depth as raised mires. Chambers (1984) suggested that blanket peats, apparently homogeneous and too well decomposed to be of value in this field, could in fact reflect past climates in their growth rate, surface vegetation and degree of humification. The potential of watershedding (ombrotrophic) blanket peats as a proxy climatic indicator has been suggested (Chambers 1990 in press).

Blanket peats cover a wide area of the British Isles (cf Taylor 1983, Lindsay et.al. 1988); they are thought to be the most extensive mire type (Goode and Ratcliffe 1977) and also have a wide global distribution, including Newfoundland, the Kamchatka peninsula, the Falkland Islands, southern Chile and New Zealand (see figure 1.1). If proxy climatic data can be found within these peats, they will provide a data source of great potential from both sides of the Atlantic and both hemispheres over approximately the same time period. The aim of this project is to determine whether, and how, blanket peat can be used as a source of proxy climatic data. This will be done by examining various properties of the peat and comparing the results with climatic changes known or inferred from other sources.

1.3 Proxy climatic data

Proxy data come from different sources, each with a different response rate and indicator value. Data sets tend to overlap with each other, and with instrumental records, allowing comparison and validation of the sources. Some authors (Ingram et.al. 1984, Lamb 1977) have separated documentary sources from the rest (environmental ones), but it could be argued that they are also proxy records. The use of weather maps constructed for the Spanish armada summer of 1588 (Douglas, Lamb and Loader 1978), and data from wine harvests in France (Le Roy Ladurie 1971) for instance, involve as many filter effects and interpretive problems as biological records. Most documentary sources are a record of man's response to climate, and not a direct measurement. They are therefore proxy data: the effect of a blurring "filter" caused by the response mechanism is no less complex in a human/social system than in a biological one.

A diagram presented by Birks (1981, p.112 figure 4.1) shows the overlapping nature of some biologically based proxy records. Birks points out the importance of the overlap. Each additional data source adds to the value of the others, and increases the value of any reconstruction. This was demonstrated by Flohn (1985) who compared the results of a number of overlapping sources. Lamb (1984b) tabulates the available sources of proxy data, pointing out the different resolution and climatic significance of each type. From these and other sources it is possible to pick out certain characteristics of proxy data sources which affect their usefulness.

(i) Resolution.

The resolution of a source of climatic data is of critical importance, as it determines the accuracy of any reconstruction. The resolution possible depends on the quality of data, sampling procedure in many cases, and the rate of response of the variable to a given climatic signal. The effect of climatic change is usually dulled by the inertia of the responding system, biological or economic. When comparing the results from different sources this is especially important. For example, tree-ring data sets show the most immediate response rate, delays being limited to a few years (Fritts 1976, Baillee 1988) but as is the case with many proxy records the exact facet of climate responsible is not clearly understood. At the other extreme the resolution of the latitudinal limits of tree assemblages reflects millenial changes, the response rate being complicated by succession, association, and competition (Wright 1984, Webb 1987).

(ii) Time span.

The value of any potential proxy record depends to some extent on the time interval covered. Climatic changes have a huge range in time scales (see figure 2.1). Data sources covering specific time periods should be selected in order to solve particular problems. Time scales that overlap with instrumental records or other proxy data are desirable.

(iii) Interference.

The response of a system to a climatic event may be similar to, or indistinguishable from, the response to another, non-climatic change. The value of a data source is therefore limited by the extent to which other factors may operate in the same way as climate. A source may be most useful when as many of the elements of the total system as possible can be investigated, allowing interference effects to be included in the interpretative stage.

(iv) Measurement.

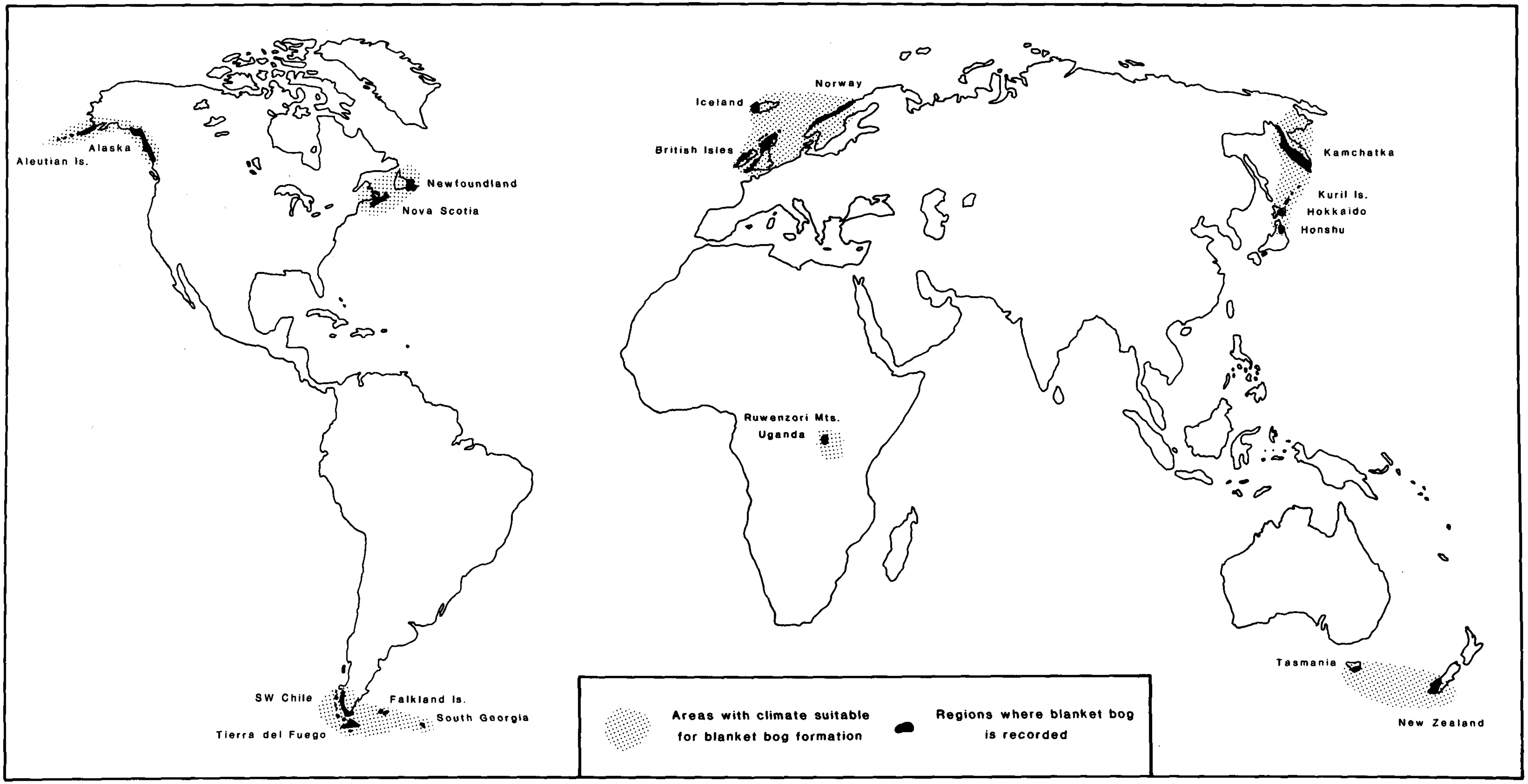
The link between the response of a variable and its measurement may also lead to a distancing of climatic change and final interpretation. The accuracy of results, and measuring the right variable in a climate-dependent system, are factors that the researcher can take into account. Other aspects, though, such as an incomplete record or the difference between life and death assemblages of biological records, are more difficult to compensate for.

(v) Areal extent.

Reconstruction of past climates and their meteorological interpretation depends on proxy data covering as wide a range as possible allowing comparison with other records and the inclusion of areas subjected to a variety of weather types.

Given careful analysis, correlation between proxy records is possible (Flohn 1985) allowing the extension of knowledge of climatic change to continue beyond the range of instrumental records. The following section reviews the use of peat deposits as climatic indicators, bearing in mind the properties discussed above. At the end of the review, conclusions are drawn as to the applicability and usefulness of the source.

Figure 1.1 World distribution of blanket peat (after Lindsay et.al. 1988)



ADAPTED FROM LINDSAY *et.al.* (1988) Fig. 10 p. 28

MOLLWEIDE'S INTERRUPTED HOMOLOGRAPHIC PROJECTION

CHAPTER 2

PEAT BOGS AS CLIMATIC INDICATORS - A REVIEW OF PAST INTERPRETATIONS.

2.1 The Blytt-Sernander sequence.

Towards the end of the last century, peat stratigraphy became the main source of evidence for past changes in the vegetation and climate of northern Europe (Birks and Birks 1980). In ombrotrophic mires, layers of relatively unhumified peat, often with *Sphagnum* as a major constituent, were interpreted as being indicative of wetter climatic conditions. Horizons of apparently slower growing peat, often with tree stump layers, were attributed to drier, warmer periods.

Such interpretations were widespread. Evidence from raised bogs in Scandinavia (Blytt 1876) was supported by the extensive observations of Lewis (1905-1911), whose "forest beds" were linked to the drier periods by Samuelsson (1910), giving a wider scale and greater credibility to the work of Sernander (1908). This was despite the reservations expressed by Lewis himself, who questioned the contemporaneity of the forest beds in different districts of Scotland, stating;

> **"This is really a most important problem, and upon it hangs the whole question of the stratification of the peat. If Blytt's conception of each forest bed as representing a dry period could be proved, then indeed we have a proof of the contemporaneity of these strata, but at any rate in the case of the lower forest, evidence from this country does not give any support to that theory."** (Lewis 1911, p824).

The Post-glacial period was divided on this basis into five phases, and although considerable opposition to the scheme was voiced (eg Andersson 1909) the scheme was generally adopted.

Period	Peat type	Climate inferred
Sub-Atlantic	Barely humified, *Sphagnum*	Oceanic
Sub-Boreal	Well humified, *Pinus* stumps	Continental
Atlantic	Barely humified, *Sphagnum*	Oceanic
Boreal	Well humified, *Pinus* stumps	Continental
Pre-Boreal	Hydroseral peat	Sub-arctic

Table 2.1; The Blytt-Sernander subdivision of the Post-glacial. After Turner (1981), Birks and Birks (1980).

The advent of pollen analysis led to a greater amount of evidence regarding past vegetation and as the Blytt-Sernander scheme was assumed to be correct, the changes in pollen diagrams were correlated with, and often attributed to, assumed climatic changes. The terms of the scheme were applied not only to peat stratigraphy, but to pollen zones and time periods. For example, the beginning of the Atlantic period was associated with the rise of *Alnus* in British pollen diagrams, thought to prefer wetter ground, and the decline of *Ulmus* appeared to reflect changing conditions at the Atlantic/Sub-Boreal transition.

Radiocarbon dates applied to peat stratigraphy and pollen diagrams have given rise to a more complicated picture of the pattern of post-glacial climate, and hence compromised the usefulness of the Blytt-Sernander scheme. The work of Birks (1975) is most pertinent, as it is a re-appraisal of the forest beds in Scottish peats, one of the original sources of evidence used to establish the scheme. Birks dated the stumps of pine and showed a considerable age range, not consistent with the Boreal and Sub-Boreal chronozones. Palaeoecological work indicated that there were a number of reasons for the growth and decline of the pine woods, including fire and local conditions. Although postulating that some increase in mire surface wetness killed the trees, Birks (1975) pointed out that a single wet season may be sufficient (McVean 1963). Birks concluded;

> **"Little evidence can be drawn from the palaeoecological studies for the hypothesis that large-scale climatic changes are reflected by the occurrence of forest beds."**
> (Birks 1975 p221).

Evidence from dated stratigraphic layers elsewhere has shown that the peat bands attributed to climatic change, especially the Sub-Boreal to Sub-Atlantic transition, are often asynchronous, as reviewed in more detail in section 2.2.

As well as the original evidence for the Blytt-Sernander scheme being questioned, some of the supporting evidence from palynology has since been reassessed. The representation of elm pollen declines in many diagrams at around 5000 years bp, and is apparently coincident with the end of the "Atlantic" chronozone. Determining the cause of the elm decline has become a matter of contention in palaeoecology, and has recently been reviewed by Molloy and O'Connell (1987). Iversen (1941) originally attributed the changes to climate, lending support to the Blytt-Sernander scheme. Further palynological evidence for a thermal deterioration at the beginning of the Sub-Boreal came from Iversen's (1944) study of the decline in mistletoe, ivy and holly, which suggested that these species are particularly susceptible to severe winter temperatures. Godwin (1975), however, points out that although the decline in these types and elm could be climatically caused, the persistence of the thermophilous lime over the same time period makes such an explanation unlikely. More recently, man and disease have been cited as possible causes of the elm decline.

The problem is reviewed by Smith (1981) who points out the difficulty in distinguishing between anthropogenic and climatic effects. What is clear is that the changes in tree pollen frequency at this time cannot be used as evidence supporting the climatic change suggested by the Blytt-Sernander sequence. The same may be said of the rise in alder pollen, a recent study of which has shown great asynchroneity in the British Isles (Chambers and Elliott 1990).

More detailed palaeoenvironmental work, associated with radiocarbon dates, has to some extent left the scheme behind. Smith (1981) concluded;

> **"The point has come when the simplistic concepts of the Blytt-Sernander scheme must surely be banished for ever."** (p143)

In the context of the current study the idea of the Blytt-Sernander model can be viewed as the first attempt to use peat deposits as a source of proxy data. The scheme attempted a broad approach in terms of time scale and areal extent, covering long-term changes over the whole of north-west Europe. Figure 2.1 attempts to represent the different approaches of peat-climate studies in terms of the space and time scales covered. The Blytt-Sernander model is shown by the "regional synthesis" block.

Interference effects were disregarded; only the nature and timing of the climatic changes were the subject of argument (Andersson 1909, pp Birks 1975). The technique of examining stratigraphy, with some macrofossil work, over a wide area produced what can now be regarded as relatively inaccurate results. The basic premise, however, of well humified peat corresponding to drier horizons and less humified peat to wetter periods, is one that continues into current research.

2.2 Recurrence Surfaces.

The premise of peat stratigraphic changes being related to climate was continued and refined in what Barber (1982) described as a **"search for fixed points"** (p108). Layers of less humified peat were again correlated with each other, although now more shifts were identified, the presence of wood layers being considered less important than changes to wetter, *Sphagnum*-rich peat. These so-called "Recurrence Surfaces" were first referred to by Weber (1900), and are associated with the general rejuvenation of the bog, caused by increased water availability at the bog surface (Walker and Walker 1961).

The history of recurrence surface studies has been eloquently reviewed by Barber (1982). A brief summary is presented here, followed by the implications of previous work for the problem of using peat as a proxy data source.

Weber originally suggested that the recurrence surface found in a number of north European bogs coincided with the Sub-Boreal to Sub-Atlantic transition, and named it the "Grenzhorizont". Granlund (1932) pointed out that there was more than one surface within the stratigraphy of any one bog and estimated the dates of five dark to light peat transitions by archaeological correlation (table 2.2).

Recurrence Surface	Years bp	Years BC/AD
RY I	750	1200 AD
RY II	1550	400 AD
RY III	2550	600 BC
RY IV	3150	1200 BC
RY V	4250	2300 BC

Table 2.2; Granlund's (1932) southern-Swedish recurrence surfaces.

Table 2.2 shows these changes, which as Barber (1981) notes reoccur on occasions in other studies (given the limits of radiocarbon dating). Nilsson (1935) proposed 9 recurrence surfaces, and Lundqvist (1962) seven. Godwin (1954) attributed the flooding horizons of the Somerset Levels to increasingly wet climatic conditions, finding a parallel in the fall of tree pollen frequencies (Godwin 1948). Whereas Granlund had hypothesised that rejuvenation may be linked to the shape of the bog and limits to bog growth, Godwin thought these effects negligible and instead preferred a directly climatic explanation.

The study of recurrence surfaces was radically altered by the advent of radiocarbon dating, although the new technique did not make anything much clearer. Palynological investigations of the Grenzhorizont in the raised bog complex near Emmen had already indicated that the age of the humification change differed (Frenzel 1966). Using the pollen zone marked by the arrival of *Fagus*, van Zeist (1954) concluded that local conditions greatly influenced the transition to younger *Sphagnum* peat (pp Tinsley 1981).

Dating recurrence surfaces radiometrically reaffirmed this conclusion. Age variations were found between and within mire systems. Schneekloth (1965) showed a range of 1100 years between dates from the Gifhorner Moor in Germany. Lundqvist (1962) found a 400-year difference in dates of what had appeared to be the same surface, and a long period between the end of the dry period before rejuvenation and the onset of new growth. Overbeck et.al. (1957) found a difference in dates for the main humification change, as well as discovering a recent age for the horizon- 100 BC rather than the 800 BC originally suggested by Weber (1900).

Mitchell (1956) also produced a spread of dates, and suggested times that produced concentrations of shifts to wetter conditions. These periods are 3450, 2750, and 1450 bp; only the youngest is close to those proposed by Granlund (1932). Godwin's (1966) average date of

2575 bp for the flooding horizon on the Somerset levels matches RY III (see table 2.2), though not the dates obtained by Mitchell. Subsequent dating of flooded trackways has provided a range of dates from 3460 ± 60 to 2470 ± 110 years bp (Tinsley 1981).

Dickinson (1975) looked at the stratigraphic changes at Rusland Moss in Cumbria and found shifts to wetter conditions that correlated with Granlund's RY I and RY II at 1200 AD and 400 AD. Dates of changes equivalent to RY II were also found by Mitchell (1956) at 1450 bp, by Overbeck (1957) at 1350 bp and possibly by Nilsson (1964) at 1300bp.

Svensson (1987, 1988) is one of the few more recent authors to provide dated evidence of recurrence surface features. A comprehensive stratigraphic survey of Store Mosse mire in southern Sweden revealed two recurrence surfaces formed at approximately 2,500 and 1,200 years bp.

A wide spread of dates for the so-called Grenzhorizont, or the Main Humification Change (MHC, after Haslam 1987), was confirmed by an extensive survey of the feature from Ireland to Poland (Haslam 1987). He identified a number of periods that favoured the formation of recurrence surfaces, due to the radiocarbon dates obtained varying over a wide time-span.

Explanations are required for the variation in the dates of surfaces if the overriding premise of peat stratigraphy being related to climatic change is not to be rejected. Two explanations are suggested by Barber (1982). Firstly, the use of bore-hole investigation and sampling, which could miss the small-scale variations found on peat surfaces past and present, and secondly, the different response rate of different mires. These are doubtless potential causes of asynchronous changes. In addition, however, it is worth noting the limitations of radiocarbon dating from peat profiles. Problems of natural contamination and calibration make accurate age resolution difficult, especially in the time period around 2,500 radiocarbon years bp.

Many mires produced proxy evidence in this way for a climatic shift somewhere in the period 2,200 - 2,800 bp. A concentration of dates around 1400 bp was also evident, and perhaps smaller changes at 3,950 - 3850 bp, at 3,500 bp and around 2050 bp (Barber 1982), although a lack of precision and consistency precluded detailed climatic reconstructions. Furthermore, the lingering theory of cyclic regeneration (Osvald 1949, Tansley 1968) contradicted the relationship between peat stratigraphy and climate.

In the period during which recurrence surfaces were most widely studied, the approach to peat stratigraphy as a proxy climatic record changed from a regional to a more local scale. Granlund's (1932) work referred to Sweden, and was a more localised model than the Blytt-Sernander sequence. Schneekloth (1965) and Overbeck et.al. (1957) examined individual mire systems, an approach followed by Dickinson (1975) and Svensson (1988a,b). Recurrence surface studies also became more concentrated in temporal scale, with little attention being paid to the early Holocene and much concentration on what appeared to be one event, the Grenzhorizont. This approach revealed the problems of mire hydrology and local effects, and showed the possibility of zero peat growth or erosion. Correlations between mires were more carefully judged. Along with the obvious advantage of dating techniques, more useful information was produced following a change to research in greater detail, and at a smaller scale, concentrating on local syntheses as illustrated by figure 2.1. Studies of recurrence surfaces did not, however, provide accurate proxy climatic data, being inaccurate in timescale and unspecific in meteorological implication.

2.3 The search for new methods.

A change towards a different approach was required, and later supplied. Barber (1982) describes the trend as one towards the reconstruction of climatic curves rather than the identification of fixed points, and dates the new approach to Nilsson's (1964) paper. The recognition of the secular nature of the climatic record in peat was important, and was made possible by the continuous and comprehensive nature of the data obtained. The new trend could be described as a search for new methods to determine a climatic signal from ombrotrophic mires.

An example of the detailed and multivariate approach is the work of Aaby and Tauber (1975), who studied the degree of humification, rhizopoda, pollen frequencies and *Sphagnum* remains from 13 profiles from 6 Danish raised mires. They found a clear relationship between the degree of humification as measured colorimetrically (after Overbeck 1947, Bahnson 1968) and surface wetness at the time of peat deposition. This provided evidence supporting the principal assumption of preceding stratigraphic work. The effects of autocompaction were also demonstrated. This work was supported by very extensive radiocarbon dating, with an unprecedented and subsequently unsurpassed 55 dates from a single profile. This detailed study enabled the reconstruction of surface conditions from undisturbed peat layers over a span of 5,800 years. Peaks of high humification and *Calluna* pollen percentages alternated with low humification and *Rynchospora* remains, while *Assulina* and *Amphitrema* spp. peaked in phases of relatively wet conditions. On the basis of this evidence, Aaby (1976) suggested a 260-year cycle in climate.

Another new method was used by Barber (1981). In testing the theory of cyclic regeneration, Barber (1981) found no evidence to support the theory. Instead, he demonstrated a close link between peat stratigraphy and climate. His study included macrofossil analysis, in particular the identification of *Sphagnum* remains, supplemented by careful stratigraphic observation over a wide area of Bolton Fell Moss, a raised bog in Cumbria, with pollen work to give a more regional perspective. By identifying "wet shifts" in former peat surfaces, Barber produced a curve that to some extent reflected the pattern of climatic change inferred for the region from other sources (Barber 1981 p.212). This study demonstrated the potential of detailed stratigraphic work on a mire where sections were exposed, and which may have been particularly sensitive to climatic change. Barber's (1981) careful comparison of palaeoecological data, local climatic records and regional data makes his work a valuable advance in the use of mires as a proxy record of climate, as usual requiring replication from elsewhere. This work is currently in progress (Stoneman 1990).

An approach to palaeoecology initially pursued by van Geel (1972, 1978) involves the recording and identification of all microfossils, as well as larger plant remains, at a contiguous 1 cm sample interval. The main characteristic of these studies is that they encompass a wide variety of ecological parameters, improving the overall picture of changing mire surface conditions. By reconstructing the surface conditions in such detail, the nature and causes of any changes can be more accurately assessed.

An even more detailed approach to deciphering a climatic signal from peat deposits is that of isotopic analysis. Following the work of Epstein et.al. (1977, 1978), Brenninkmeijer, van Geel and Mook (1982) reported techniques to determine Deuterium/Hydrogen and Oxygen $O^{18/16}$ ratios from cellulose. Applied to peat deposits of known or at least estimated age, this method has the potential to show not only climatic change, but also the nature of the change, as discussed by Dupont (1986). Initially, the effects of changing peat composition caused problems, although despite this a decline in both isotopic parameters was suggested for the period 3100 to 2400 years bp (Brenninkmeijer et.al. 1982). Samples from modern material illustrated the differences attributable to species changes (Brenninkmeijer et.al. 1982). Dupont and Brenninkmeijer (1984) used a correction technique based on the major component of the peat at a given level, and related their results to tree-ring densities, ice-core data and fluctuations in *Corylus* pollen influx. Dupont (1986) tentatively concluded that quantitative climatic information could be derived, and suggested that the area of study (Netherlands) was warmer (by 0.5 degrees C) and drier between 3500 and 4000 years ago, and was slightly colder (by 0.5° C) and becoming wetter around 3,000 bp. A further warm period (1.5° C above present mean annual temperatures) followed between 2,800 and 2,500 bp, during which conditions remained wet. The final change inferred was a shift to cooler (0.5 C below present) conditions after 2,000 bp, when humidity was similar to the present. This attempt is the most specific climatic information obtained from peat deposits. Its reliability can only be shown by replication from peat profiles elsewhere and from other sources.

Van Geel and Middledorp (1988) applied the technique of 2H/1H ratios to material from Carbury bog in Ireland, to test the experimental data against historical records. They too applied a species-correction technique, but noted problems of species dependence and growing season bias and found no correlation between reconstructed conditions and those proposed by Lamb (1977) for the same period. The potential of isotopic work depends on the interference effects of species composition being overcome, perhaps by using selected material (van Geel and Middledorp 1988).

Several of the studies outlined above have resulted in the production of curves of past surface wetness. Comparison has sometimes been made between these curves and other curves of climatic change for the same or overlapping time periods (Barber 1981, Dupont 1986). The production of a continuous climatic curve is hampered, however, by the inability of peat stratigraphic methods to determine shifts to drier conditions (Barber 1982, 1985). This is due to the belief that given stable conditions, continuing deposition of organic matter will raise the surface steadily above the water table. Aaby (1976) wrote;

> **"Shifts to drier bog conditions are therefore ignored as indicators of climatic changes"** (p.281).

Drier phases of climate can only be inferred from a lack of wet-shifts (cf Barber 1981). It appears, then, that continuous curves of climate cannot be produced from peat surface data.

The question remains then, as to how best to use the relatively accurate data recorded by the more recent peat-climate studies. The approach of Aaby (1976, 1978), Wijmstra et.al. (1984) and Dupont (1987) was to examine data sets for time-dependent variation. Aaby identified the points where changes to wetter conditions were first recorded, and compared the dates of these points from a number of profiles (cf Aaby 1978, figure 1). Given the concentration of dates from the section 1959 from Draved Mose, time-series analysis was distinctly possible, and Aaby (1976) reported a 260-year cycle in surface wetness. This was arrived at by firstly assuming that a cycle existed, and then testing which interval (250, 255, 260, 265 or 270 years) fitted the data most closely.

Wijmstra et.al. (1984) used the pollen density technique developed by Middeldorp (1982, 1986) to date a profile from the Netherlands as accurately as possible. Using data sets from consecutively sampled, multivariate palaeoecological analysis, they found cycles of various lengths in the pollen frequencies of *Corylus* and *Alnus*, and in the material characteristics of the peat. Some of the cycles suggested by time-series analysis corresponded with known cycles in sunspot activity, a periodicity of just over 200 years being the strongest signal. Dupont (1986) produced oxygen isotope data that appear to support this, with a cycle of 206 years being detected.

Although these studies are in their early stages, with many new and some persisting problems, attempts have been made to isolate particular elements of climate, and even possible causes of change. Specific temperatures have been inferred, and cyclic tendencies suggested, advances which have come from the reduction of the scale of observation (see figure 2.1). Following the approach of more recent authors, greater credence can be attached to the climatic implications of those observations.

The style of analysis that has led to the greatest reward was in fact suggested by Godwin (1954), who wrote;

"Bog stratigraphy ought to be approached from a knowledge of the ecology and hydrology of existing bogs, and the investigator should be broad enough in his interests to take account of the evidence from all relevant fields of science, whilst retaining his own cautious severity of judgement." (Godwin 1954, p.29)

2.4 Blanket Peats.

Blanket peats have been considered too well humified and slow growing to be used as climatic indicators (Chambers 1990 in press). These mires may also have been neglected due to their remote locations (Moore, Merryfield and Price 1984). Chambers (1982) noted apparently cyclic vegetation changes shown on pollen diagrams from high-altitude blanket mires, and subsequent humification determinations showed coinciding changes. Chambers (1984) suggested that that some deeper blanket mires may offer a similar climatic record to that claimed by Aaby (1976), while noting the possible effects of upland land use on the palaeoecological record. Rowell and Turner (1985) analysed a radiocarbon-dated core from blanket peat at Quick Moss, Northumberland for humification and pollen, although not in the detailed manner shown by Aaby (1976) or Chambers (1984). They showed increased variability in humification in the upper part of the profile, following a gradual decrease linked by the authors to the Sub-Boreal to Sub-Atlantic transition. These tentative studies show that there is potential for using peat from blanket mires, especially the ombrotrophic parts, as a source of proxy climatic data.

2.5 Peat deposits as proxy climatic records.

Having outlined the need for, and requirements of, proxy data sources, the potential of peat sources can now be summarised. In particular, the potential of blanket mires is assessed in terms of the characteristics outlined in section 1.3.

(i) Resolution.

The resolution possible depends on the growth rate of the bog and the sampling interval used. Barber (1985) notes an extreme example of 4 years per cm., a 2-year interval would be possible in this case. More typical are 1 cm reconstructions (eg van Geel 1978, Aaby and Tauber 1975, Dupont 1986) from raised mires growing at 5 to 6 cm per 100 years. If three consecutive readings are required to define a climatic event, this gives a resolution of around 50 years.

Growth rates of blanket mires are generally slower, and may themselves be linked to climatic change (Chambers 1984). An average of between 2 and 3 cm per 100 years can be compensated for, however, by using a close sampling interval. 0.5 cm thick samples are easily possible for pollen analysis (Chambers 1982). The potential of even closer samples has been demonstrated by Garbett (1981) and Simmons and Innes (1988), although Clymo and Mackay (1987) recorded some vertical movement of grains in the surface layers of peat. A detailed study should permit a sample interval of a decade.

(ii) Time span.

Peat suitable for climatic work can be found dating from the whole of the Holocene but particularly from the last 7000 years (Barber 1985). The range is limited in the later period by disturbance of the surface layers, for instance by cultivation, drainage, or removal for fuel. Blanket peats are prone to erosion (Tallis 1985), pollution (Chambers et.al. 1979) and afforestation (Lindsay et.al. 1988) reducing the time span available at certain locations. Although some blanket peats date from around 5,000 years bp (Moore 1975) the range possible is longer than this, as illustrated by Rowell and Turner's (1985) investigation at Quick Moss, dated at 8010 bp at the base.

(iii) Interference.

Interference effects in the peat record vary between different types of mires and locations. They include bog bursts, internal or surface drainage pattern changes, and the possibility of autogenic succession. Anthropogenic effects on the vegetation and hydrology are possibly the most important.

If peat deposits are to yield a proxy climatic record, non-climatic influences must firstly be minimised by careful site selection and then detected and taken into account. Pollen analysis has regularly been used to attempt the evaluation of human impact. Where cultivation has been practised the pollen record may include cereal types and various weed species, as well as disturbance of the peat profile. An example is the buckwheat cultivation on the widespread mires of the Netherlands (Casparie 1972, van Geel 1978). Less straightforward are the more subtle interference effects caused by burning or grazing, or by the alteration of the drainage characteristics of the surrounding area. It may be possible to detect burning of the mire surface due to residues of charcoal, in visible horizons or microscopically (Tolonen 1986). Furthermore, certain fungal types may be more common after burning, changes in their abundance possibly being used to infer local fire history (van Geel 1978, 1986).

Grazing by wild or domestic animals alters the composition of mire vegetation. The pollen record should contain these changes where present, although discriminating between changes caused by grazing and those forced by another mechanism may be more difficult (see section 6.1).

The hydrological regimes of coastal mires are to some extent regulated by changes in base level (Bakker and van Smeerdijk 1987, Denys and Verbruggen 1989). Raised bogs have a "perched" water table, sustained above that of the surrounding area by the water retention capacity of *Sphagnum* species. These mires must themselves be controlled to some degree by the surrounding base level. The mire sustains its water table to a height above the general level, the height being linked to the peripheral drainage characteristics, size and composition of the mire (cf Ivanov 1981, Ingram 1987). A rise or fall in the water table surrounding a raised mire could therefore alter surface conditions, and interfere with the stratigraphic record, reducing its efficacy as a proxy climatic record.

Blanket mires cover a variety of slope positions some of which may be more useful in this context than others. Interference effects are more likely where the mire is not ombrotrophic. Blanket mires tend to occur in areas where high rainfall and low evaporation sustain the high water table necessary for peat accumulation. They are likely to be less susceptible than raised mires to base level interference.

The interference effects applying to peat deposits are clearly numerous, and potentially overpowering. There may be clues within the palaeoecological record to deciphering some of them, but overall the need for careful site selection and overlapping sources of proxy data is re-emphasised.

(iv) Measurement.

Sections 2.1 to 2.3 showed how increasing the detail and variety of variables studied improved the proxy climatic record obtained from peat deposits. In particular, the multiple-profile studies of Barber (1981) and Aaby (1976), and the multi-variable approach of van Geel (1978), demonstrated the way forward. Blanket peats are slightly restricted in this sense, as the peat is often highly decomposed, preventing macrofossil analysis. The *Sphagnum* species used by Barber (1981) for instance may be completely absent from many blanket peat sections. Measurement errors caused by the differential preservation of *Sphagna* (Clymo 1965, 1984) should therefore be avoided. A range of variables are available, however, including the humification degree, growth rates and microfossil frequencies. All of these variables have been shown to be at least partly controlled by surface wetness.

(v) Areal extent.

Mires have a worldwide distribution, as shown by the map presented by Gore (1983). Ombrotrophic ones are restricted to areas where the balance between precipitation and evaporation is suitable. Blanket mires are similarly limited, although the conditions needed occur in many different places. Figure 1.1 illustrates the wide spread suggested by Lindsay et.al. (1988). The extent of blanket mires in Europe complements the ranges of other proxy records, allowing for comparison.

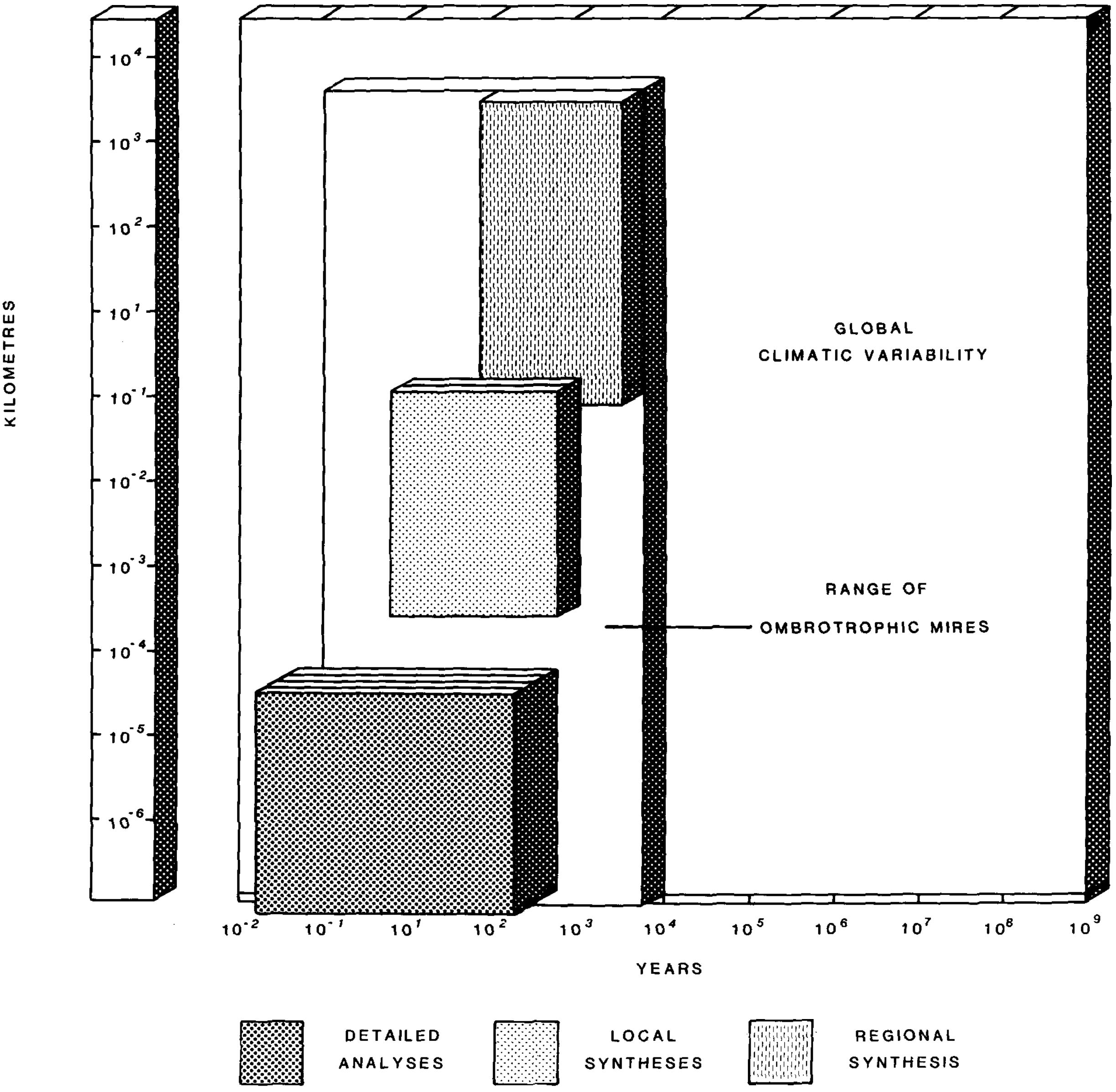
2.6 Summary.

It has been argued that there is a need for further sources of proxy climatic data, and the characteristics of such sources have been discussed. Stratigraphic studies from peat have been used in the past. These have been reviewed, and it was argued that climatic information was best obtained by high resolution, detailed, multi-variable studies.

Blanket peats have the potential to add to the proxy record. Their characteristics in terms of a data source were outlined. The importance of site selection was mentioned, and this is discussed further in chapter 3.

Figure 2.1 Time-space diagram showing the ranges covered by different approaches to the use of peat as a source of palaeoclimatic data.

TIME-SPACE RANGES OF DIFFERENT APPROACHES TO MIRE-BASED PALAEOCLIMATOLOGY



CHAPTER 3.

SITE SELECTION AND DESCRIPTION

3.1 Site selection.

Site selection has been regarded as a critical phase in palaeoecological research (West 1977). Projects aiming to reconstruct regional or local vegetational history may use the guidelines of Jacobson and Bradshaw (1981), who examined the usefulness and representation of different sediment types and positions. Peat hydrological studies need to take two aspects of site selection into account, especially when climatic inferences are sought. These are the regional aspect involving the spatial scale of the data required, and the local aspect that involves obtaining it accurately.

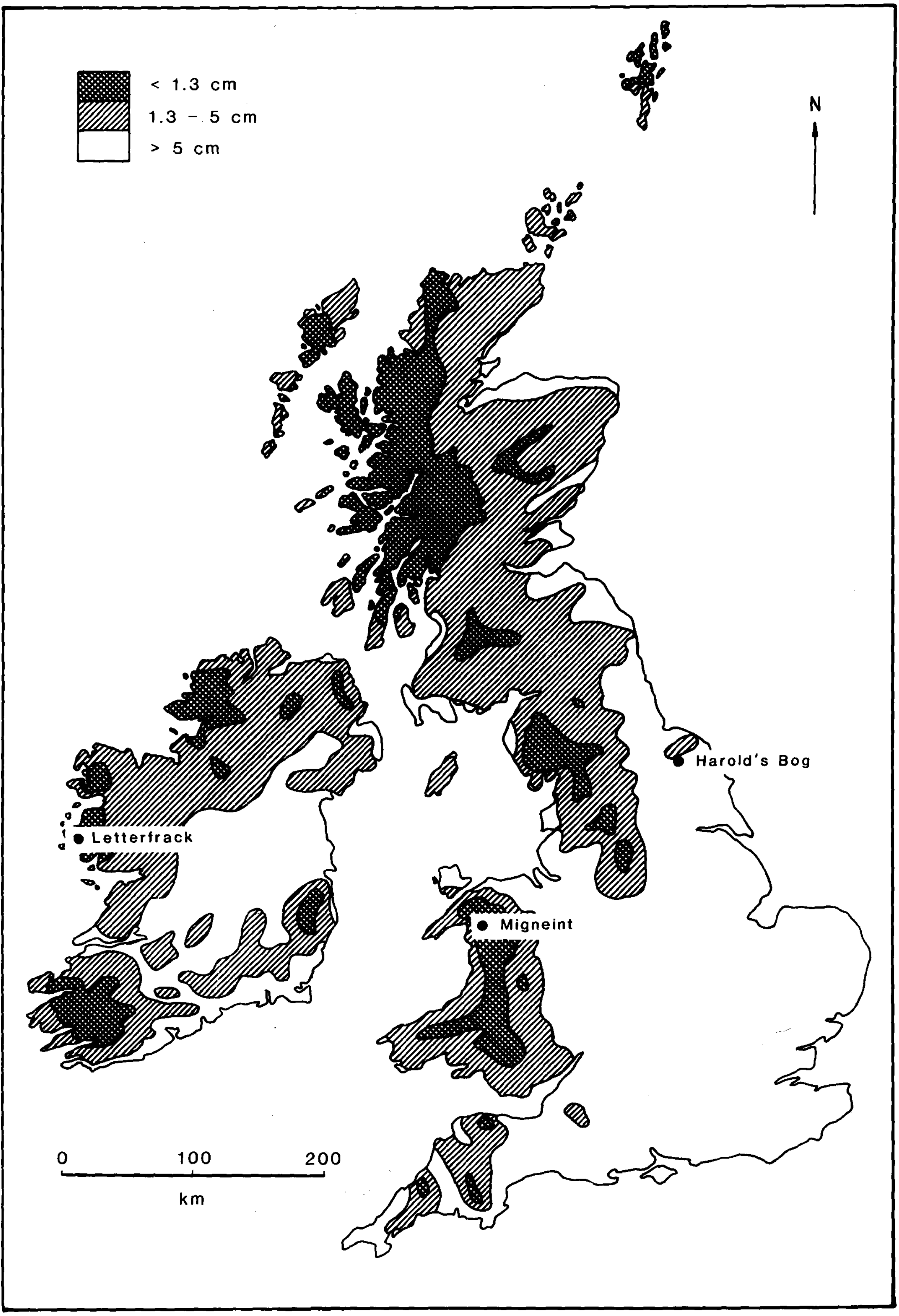
3.1.1 Regional site selection.

Geographical overlap with other proxy climatic data sources is desirable, making North West Europe a suitable area of study. The range of the current study is also limited by the overall extent of blanket peat in the region.

Barber (1985) suggested the possibility of a climatic "hinge line", to the west of which mire conditions may be too wet to respond to changes towards drier conditions, and east of which raised bogs may be relatively dry and unresponsive to climatic changes. This suggestion was to some extent supported by the results of Haslam (1988), whose most easterly sites did not show the pattern of wet-shifts found elsewhere. Although this idea was based on raised bogs, its applicability to blanket peats could be tested by an east-west transect approach.

Sites were selected to provide a range of present-day climatic conditions. Figure 3.1 shows the positions of the selected areas in relation to potential evapotranspiration, and table 3.1 shows the contrasting rainfall, raindays and evapotranspiration from the sites chosen. A range has been covered from the driest area of blanket peat in the UK to one of the wettest, and from the Easterly extreme almost to the Westerly.

Figure 3.1. Location of sites in relation to potential evapotranspiration (map adapted from Green 1964)


< 1.3 cm
1.3 - 5 cm
> 5 cm
N
Harold's Bog
Letterfrack
Migneint
0
100
200
km

Site	Harold's Bog	Migneint	Letterfrack
Abbreviation	HB	MIG	LET
Grid Reference	1,2. SE 584932	1. SH 765428 2. SH 766428 3. SH 765429	Irish Grid (1:100,000 ser.) L 76
Latitude	54° 19'35"N	1. 52° 58'13"N 2. 52° 58'12"N 3. 52° 58'16"N	1. 53° 31'28"N 2. 53° 32'02"N 3. 53° 32'03"N
Longitude	1° 6'02"W	1. 3° 50'26"W 2. 3° 50'25"W 3. 3° 50'22"W	1. 9° 55'26"W 2. 9° 56'36"W 3. 9° 56'38"W
Altitude (m)	302	1. 501 2. 503 3. 494	1. 287 2. 112 3. 80
Rainfall (mm)[1]	900-1000	2400-2800	1600
Rain Days[2]	175-200	>225	200-225
Daily Sunshine (h)[3]	3.5-4	<3.5	NA
Growing season days[4]	240	240-270	265
Potential evapotrans. (mm)[5]	25-75	<0.5	<0.5

Table 3.1; Site Data

Notes.
1. Source (HB and MIG); Met. Office, 1941-1970 Averages. LET; Haughton et al. (1979).
2. Source (HB and MIG); Coppock (1964). LET; Haughton et.al. (1979) Rain days defined as having > 3mm precipitation.
3. Source; Coppock (1964).
4. Sources; Coppock (1964), Haughton et.al. (1979).
5. Source; Green (1964).

3.1.2 Local site selection.

The second aspect of site selection is on a local, micro-relief scale. The importance of careful site selection at this scale from blanket peats has been discussed by Riezebos and Slotboom (1978) and Chambers (1982). By definition, blanket mires include components on a variety of slope positions. As some parts of the mire are not ombrotrophic, the changes in mire hydrology at these positions may not be closely linked to climate. Watershedding positions, however, whose only significant source of moisture is precipitation, would be more likely to provide an accurate reflection of past climatic changes. The resolution gained from water-receiving sites, however, may be expected to be greater, as peat is likely to accumulate faster. Sampling strategy, then, was designed to investigate the relationship between slope position and hydrological change further, by concentrating on watershedding sites but including downslope, though still convex, positions. At each site an investigaton was made of the pre-peat surface, resulting in a profile of peat depth and altitude. This allowed the precise position of the watershedding point of the pre-peat surface to be established and sampled.

3.1.3 Profile spacing.

If the changes in hydrological conditions of blanket mires are to be used as climatic indicators, some understanding of the spatial variability of the properties concerned is required. Built in to the sampling strategy is a range of distances between profiles, from 40 cm in the case of Harold's Bog to 1.6 km in the Letterfrack area. The degree of correlation or otherwise between data from these points should enable the degree of spatial dependance of each variable to be at least qualitatively assessed. The distances between the sites themselves are 250, 420 and 600 km, adding a much greater set of distances to the range covered. During the course of investigation samples from the same monolith spaced approximately 4 cm apart were measured for the degree of humification, adding another distance between profiles.

3.2 Harold's Bog, North York Moors, Northern England.

3.2.1 Site description.

Map reference, latitude, longitude and altitude information are presented in table 3.1. The position of the site is illustrated by figures 3.1 and 3.2.

The North York Moors represent one of the driest areas of blanket peat in the European region. Rainfall only exceeds 1000 mm per annum in the highest parts. Harold's Bog is at the southern extremity of a north-south sloping ridge, and represents a remnant of blanket peat in a distinctly marginal area for its growth. As such, it is hoped that it may be particularly sensitive to environmental, including climatic, changes.

The current vegetation is dominated almost exclusively by *Calluna vulgaris*. Bare patches of peat and ephemeral pools are present. Occasional examples of *Erica tetralix* and *E. cinerea* are the only other higher plants present. Lichens are present especially on older *Calluna* plants, including *Parmelia physodes* and *Cladonia portentosa*.

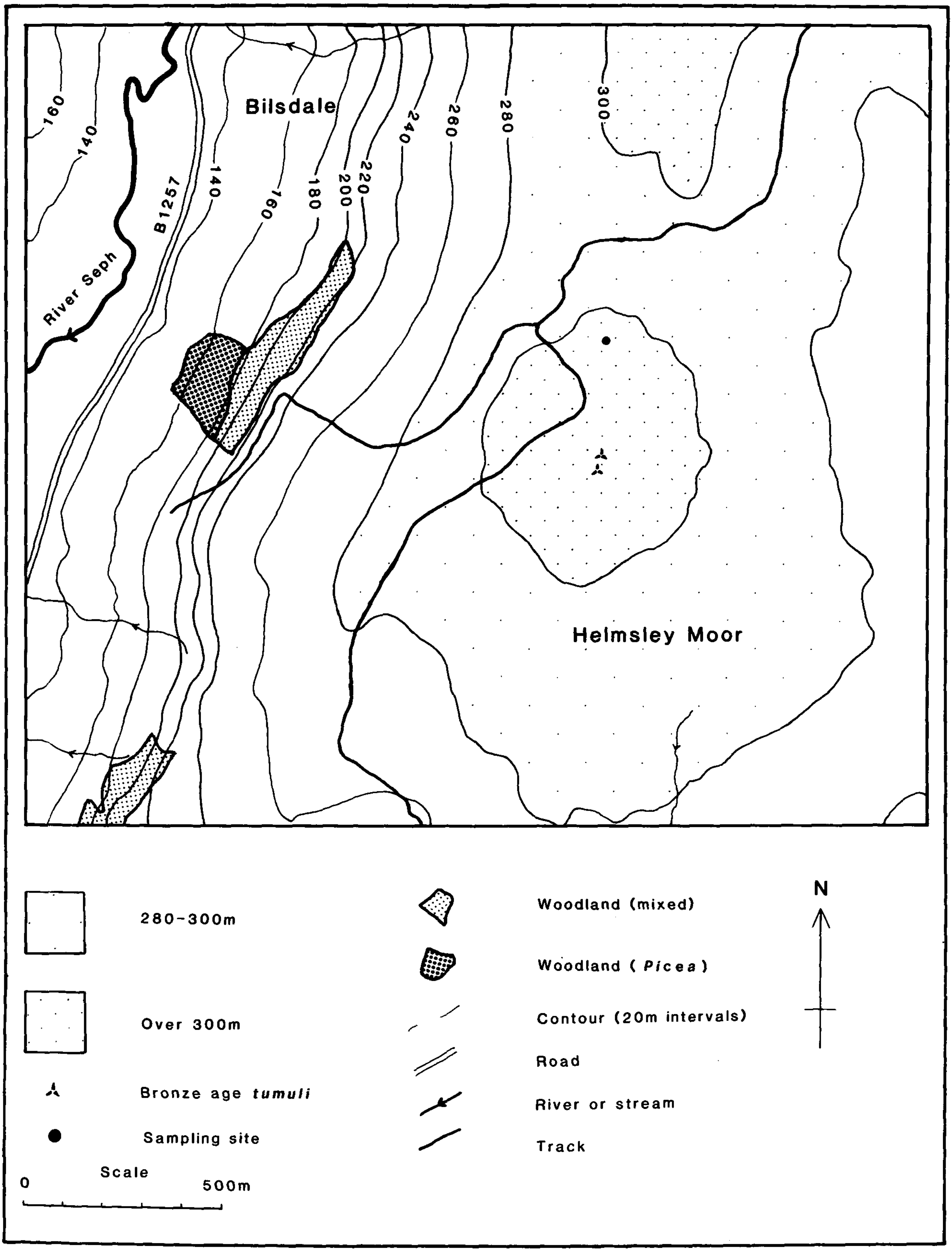
The valley-side slope to the west of the remnant peat deposit is markedly different. A transition downslope around 100 m from the profile position shows a change to a more varied vegetation cover, with *Vaccinium myrtillus*, *Pteridium aquilinum*, an increased abundance of *Erica tetralix* and various species of *Juncus* and Gramineae. Further down the slope, improved grassland and a small woodland area increase the variety of species possibly contributing to the pollen rain.

Current land-use practices include the frequent burning of the moor top and grazing by sheep and grouse. Evidence of former land use includes trackways across the moor top (400 m distant) and tumuli of Bronze Age origin (Elgee 1930, Spratt 1982) further south along the ridge (160 m distant). The peat deposit is currently being cut annually for domestic fuel by local farmers. The date of the beginning of this cutting, and inevitably drainage, is unknown, but before AD 1930 (H. Noble, pers. com.).

3.2.2 Fieldwork and sampling.

Earlier investigations had revealed the possibility of a channel in the pre-peat surface causing a disturbing effect on the lower organic horizons (Blackford 1986). Samples were taken from the exposed cut face avoiding this area, and avoiding those places where spoil was incorporated with the peat surface. A depth of 1.06 m of peat, overlying a sandy podsol with a thin iron pan, was sampled using 15cm x 15cm cross-section aluminium monolith tins cut to the required length. This constitutes monolith HB 1. A second monolith, HB 2, was extracted from immediately behind the first after cleaning the profile face. Samples were wrapped in thick polythene sheeting and later kept in a cool storage room. After sampling at 0.5 cm intervals for palynological and humification analysis, the monoliths were cut into 1 cm slices and stored until required for radiocarbon dating.

Figure 3.2. Location of Harold's Bog.



Bilsdale
Helmsley Moor
River Seph
B1257
160
140
140
160
180
200
220
240
260
280
300
280-300m
Over 300m
Bronze age *tumuli*
Sampling site
Scale
0
500m
Woodland (mixed)
Woodland (*Picea*)
Contour (20m intervals)
Road
River or stream
Track
N

3.3 Migneint Mountain, Snowdonia, North Wales.

3.3.1 Site description.

The Migneint area of blanket peat is a large plateau of bog at around 500 m above sea level (see table 3.1, figure 3.3). Owned by the National Trust, the area contains a more diverse flora than the North Yorkshire site. It is one of the wettest areas of the UK, rainfall around 2,500 mm annually, and a potential evapotranspiration figure of less than 1.5 cm (Green 1976, see figure 3.1). In some water-receiving parts the peat exceeds 5 m in depth, although on the watershedding hilltops this figure is much reduced.

The current vegetation cover includes the heather species *Calluna vulgaris* and *Erica tetralix*, with *Empetrum nigrum* on the drying out, eroding peat hags. Undisturbed areas on the summital plateau have a dense cover including *Molinia caerulea*, sedges including *Eriophorum* spp., and *Sphagnum* spp., as well as the heather species. Rarer but present are *Potentilla erecta* and *Plantago lanceolata*. Blanket bog vegetation of this nature extends for a large area around the sampling site. The nearest trees are in a *Picea* plantation 4 km distant.

The plateau is currently grazed by sheep, and some slopes in the vicinity have been drained. Erosion on the flatter hilltop parts is similar to that of other areas of blanket peat (Chambers 1982, Tallis 1987), and must have caused a lowering of the water table at some point in the past.

3.3.2 Fieldwork and sampling.

An extensive survey of the plateau resulted in one hilltop being preferred due to a large area of uneroded peat remaining (see figure 3.3). This site was then surveyed using an EDM to obtain relative height measurements of the current surface and a probe to provide peat depth data. This information was used to show where the top of the pre-peat surface was. Having located the general area, a more detailed transect was made across the slight rise, resulting in the location of core MIG 2 being chosen, exactly on the summit. A pit was dug to extract a monolith from a clean face, and samples were collected as at Harold's Bog. 70 cm of peat overlay rock, with only a 5 cm interface of organic material containing increasing amounts of

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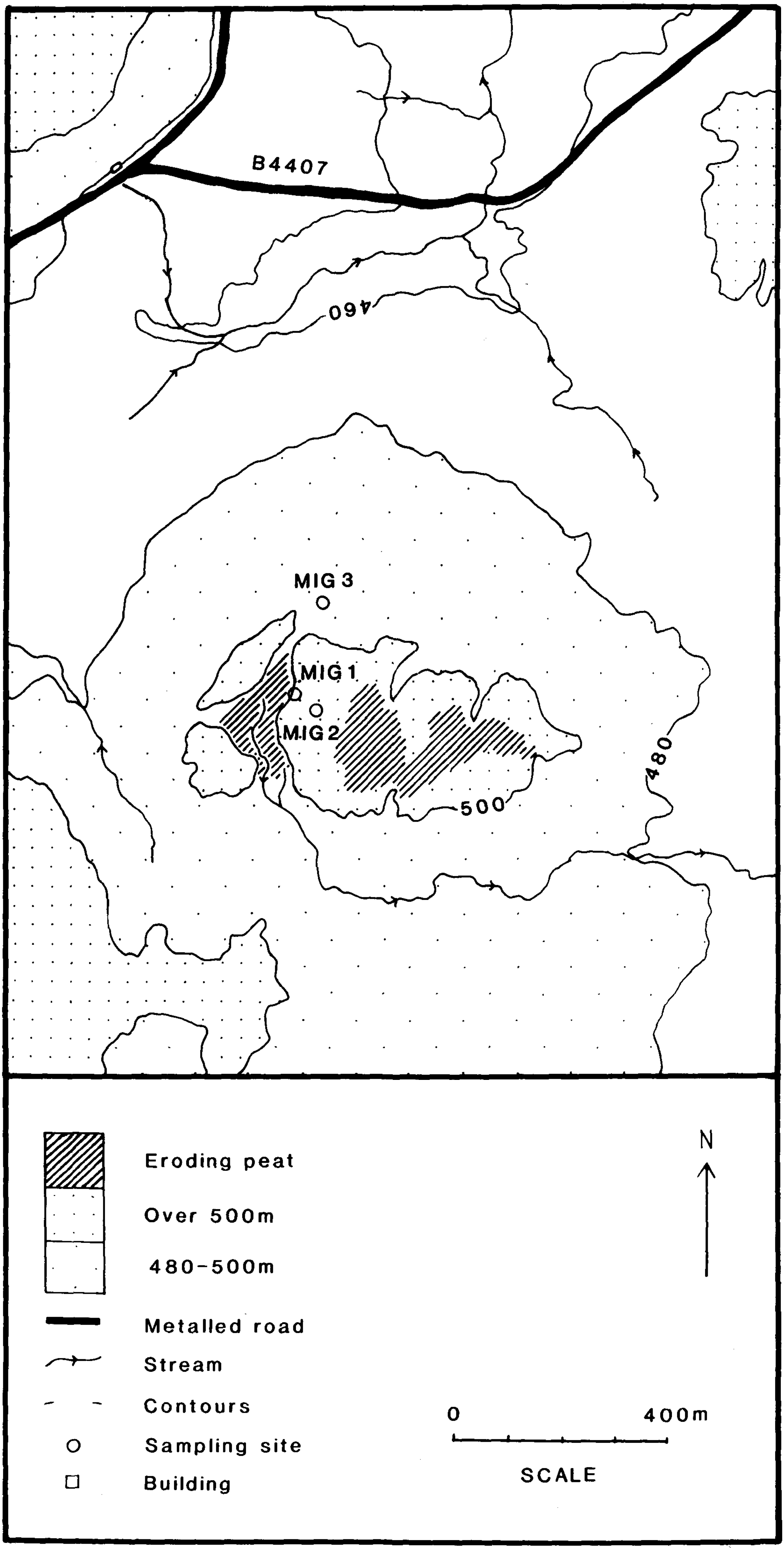
Figure 3.3. Location map of Migneint sites.


B4407
460
480
500
MIG 3
MIG 1
MIG 2
Eroding peat
Over 500m
480-500m
Metalled road
Stream
Contours
Sampling site
Building
N
0
400m
SCALE

weathered rock.

The survey revealed that a much greater depth of peat could be obtained less than 100 m distant, still on the watershedding convexity of the plateau. Monolith MIG 1 was removed from this position, where 2.23 m of peat had accumulated, again overlying a thin mineral soil and then quartz-rich metamorphic rock. Small samples of wood were removed from the lowest 10 cm. Larger wood samples were located and extracted from the eroding peat hags. In order to investigate hydrology/slope relationships a third monolith, MIG 3, was removed from a position 160 m distant (see figure 3.3). 70 cm of peat were removed from a pit dug through a sedge-rich local vegetation.

3.4 Letterfrack, Connemara, Co. Galway, Ireland.

3.4.1 Site description.

The blanket bogs of Western Ireland extend to sea level due to an excessive moisture surplus. Potential evapotranspiration is very low, while rain days and length of growing season are high, providing ideal conditions for peat growth. The Letterfrack National Park area of Western Connemara was suggested by Dr. Michael O'Connell, University College Galway, and was preferred to other investigated sites in Co. Mayo and Co. Wicklow due to the proximity of a previously studied site. Peat-covered watershedding ridges and hilltops abound in the area; the sites chosen for sampling had the added advantage of being undisturbed by peat cutters. Figure 3.4 shows the locations of the three Letterfrack samples.

The current vegetation is a floristically rich blanket bog type, variable as to slope position but generally composed of heather types *Erica cinerea* and *E. tetralix*, *Calluna vulgaris* and occasionally *Dabeocia cantabrica*. Sedges include *Eriophorum* species, *Rhynchospora alba*, and *Schoenus nigricans*. Grass species include *Molinia caerulea*. *Sphagnum* mosses are also common amid an assemblage characterised by a very high water table. *Narthecium ossifragum*, *Myrica gale*, *Pinguicula vulgaris* and *Potentilla erecta* are also present. The abundance of freshwater pools allows *Potamogeton* spp. to have a widespread distribution. A fuller account is provided by the National Park Notes, although two of the three sampling pits were dug just outside the

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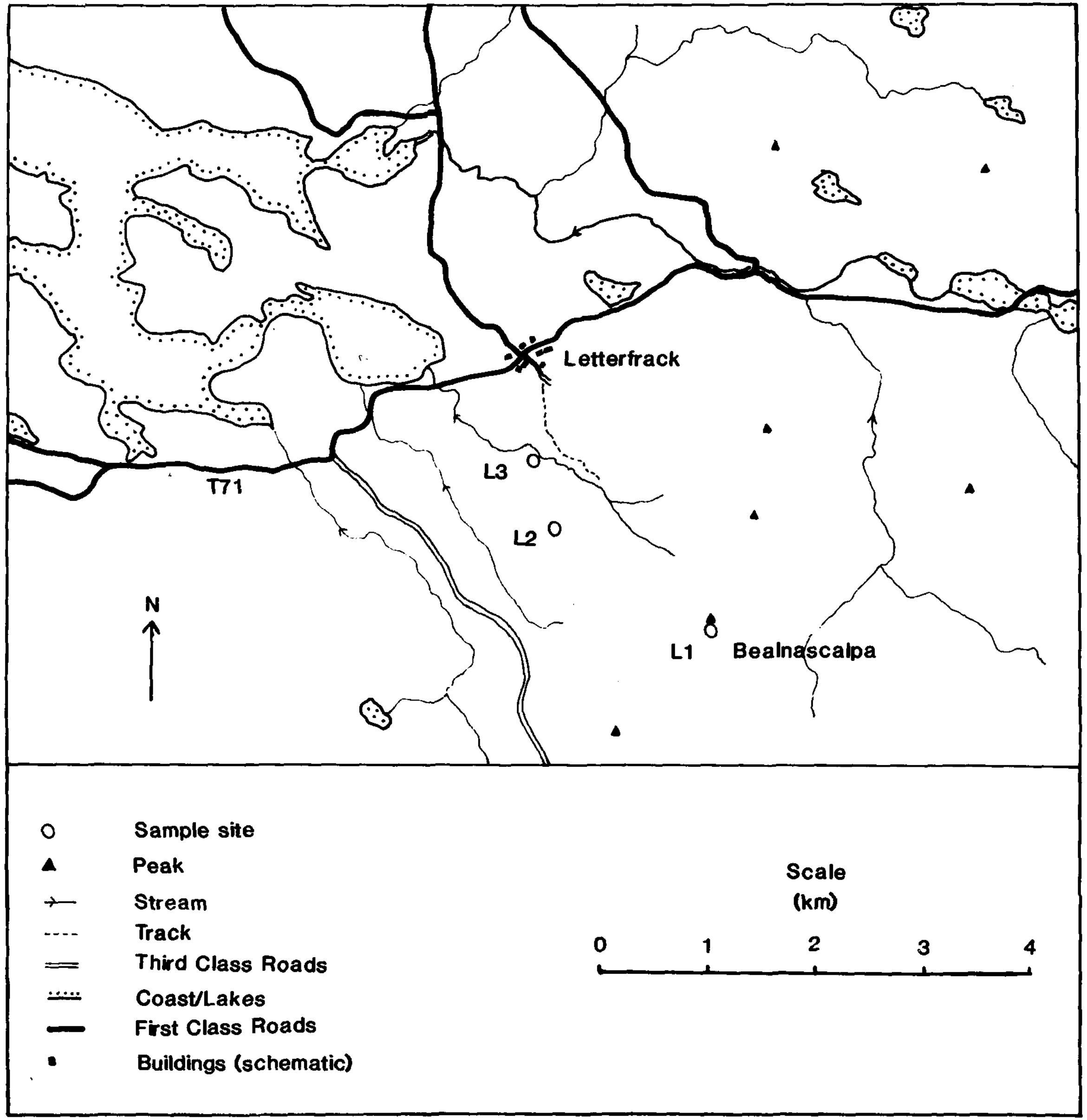
Figure 3.4. Location of Letterfrack sites.


Letterfrack
T71
L3
L2
L1
Bealnascalpa
N
Sample site
Peak
Stream
Track
Third Class Roads
Coast/Lakes
First Class Roads
Buildings (schematic)
Scale
(km)
0
1
2
3
4

park boundary. Current land-use practices allow sheep and sometimes cattle to graze the bog. Deer are also present in the area.

3.4.2 Fieldwork and sampling.

Investigation of the sub-peat relief allowed the precise watershedding points of the hill "Bealnascalpa" and the ridge "Weelkyle" to be located. Pits were again excavated to allow extraction of continuous monoliths from a clean face at the required locations. Monolith LET 1 from the summit of Bealnascalpa provided a metre of well decomposed peat, the base of which appeared to have no mineral soil interface, but was in contact with bedrock. Sample LET 2 was extracted from the summit of a raised part of Weelkyle ridge to the West-South-West of Bealnascalpa, 1.6 km distant. The peat had, as at LET 1, accumulated over rock. Monolith LET 3 was removed from near a river cutting to sample a downslope position and to allow direct comparison with the pollen record and radiocarbon dates kindly made available by Dr. O'Connell. The monolith came from the peat directly adjacent to where the earlier sample had been removed. 58 cm of peat grading into organic soil overlay a thickness of at least 3 m of glacial till, deeply incised by a stream. Samples were wrapped and stored as described in section 3.2.2.

CHAPTER 4

DETERMINING THE DEGREE OF PEAT HUMIFICATION.

It was argued in section 2.5 that the degree of peat humification might be a variable responsive to past environmental conditions. In particular, it might be a valuable source of data from well-decomposed blanket peats, and as such critical to the current study. The degree of humification of humic soil and peat has been estimated in many different ways. These can be grouped into four categories and are discussed below.

1. Visual examination and classification,
2. Measurement of physical properties,
3. Measurement of chemical properties,
4. Chemical extraction of soluble material.

4.1.1 Visual examination.

The earliest stratigraphic studies of peat humification changes led the way to theories regarding mire hydrology and ecology (Osvald 1923) as well as the regularly used climatic divisions of the Post-Glacial (see section 2.1). The data used were primarily based on the colour and content, in terms of plant material and its state of preservation, of obviously different peat horizons. Troels-Smith (1955) described how, by squeezing peat and examining the colour of the extracted water, humification degree can be estimated on a six-class scale. Von Post's (1924) 10-point scale is more effective, and uses the variables of texture and deterioration as well as colour. This classification is tabulated below (table 4.1).

The von Post humification scale has been widely used in recent studies alongside other measures of peat properties. For instance Haslam (1987) described vegetational changes across recurrence surfaces using both the 1-10 scale and plant macrofossil analysis. Tolonen et.al. (1985) used the technique with rhizopod counts.

In the case of the present study however, there are distinct disadvantages. One of these is that it is by nature a classification. Measurement on a continuous scale would be more accurate for the detection of small scale or cyclic changes. Additionally, although the guidelines

Type of peat, colour	Humification value
Yellow-light brown, often with undamaged *Sphagnum* leaves.	
Yellow, pale and whitish,	1
Yellow,	2
Light brown,	3
Brown, with *Sphagnum* leaves more or less damaged.	
Milk chocolate-brown,	4
Brown,	5
Dark chocolate brown,	6
Dark brown, *Sphagnum* leaves badly damaged.	
Dark brown, plant structures can still be observed in the matrix, wood remains, seeds etc. determinable,	7
Dark coffee-brown, macrofossils disintegrated and hard to determine,	8
Plant structures rarely observed and indeterminable,	9
Blackish-brown peat.	
Totally destroyed organic material,	10

Table 4.1. The 10-class scale of humification (after von Post 1924, Aaby 1986)

given as to what to look for are quite clear, the method is essentially subjective. The use of the state of *Sphagnum* remains as an important element of the classification makes its use difficult in peat where *Sphagna* are rare or absent. The most important problem in applying the scale to blanket peats is that only in the top sections of most profiles are classes 1 to 7 encountered. This leaves only a three-point scale to describe most of the peat profile.

All colour-based visual examination methods are beset by problems involving the condition of natural light and the effect of colour change through oxidation. Casparie (1972) developed an ingenious method of assessing humification by using the rapid colour change following exposure of fresh peat. The quicker the colour changed, the more humified the peat. This method is, however, unquantified, subjective and difficult to compare between different peat types. In a study of recurrence surfaces in a raised bog, Dickinson (1975) used a classification by colour, texture and degree of disintegration. She identified *Sphagnum* peat in which plants were in a whole state, consisting of stems, branches and leaves. This was distinguished from an intermediate stage where branches had become detached, and a more humified type in which leaves were separated from branches. When combined with colour observations this method worked well, except where *Sphagnum cuspidatum* was present which was always found with separated leaves. For the study of blanket peat this is again unsuitable as *Sphagna* are not frequent enough, the range of degrees of humification are not adequately covered and there are not enough groups to pick out smaller changes.

4.1.2 Physical properties.

As decomposition of plant matter proceeds, a number of quantifiable changes occur. Mineral matter (as a proportion of weight, see definition and determination in chapter 5) increases, as does bulk density (mass per unit volume). Large fibres are broken down, leading to an increase in fine material. Pore space between particles, and therefore water holding capacity, is progressively reduced. Measurement of these properties might directly or indirectly measure the degree of humification. Following the suggestions of Clymo (1984) and the success of the technique for Svensson (1988a), bulk density determinations were initially included in this project. Mineral content was assessed by combustion.

A comprehensive comparison of properties of peat materials has been carried out by Levesque and Mathur (1979) and Levesque et.al. (1980). Their experiments included water holding capacity which was found not to correlate significantly with those properties of peat that do change with decomposition. Fibre content was included in their tests and proved to have the highest number of significant correlations. Table 4.2 is adapted from Mathur and Farnham (1985) and Levesque et.al. (1980). The correlations with fibre content appear to make this the most suitable, if indirect, measure of humification in this group. Levesque and Mathur (1979) concluded that fibre content determination was the most suitable way of measuring the extent of humification in peats.

Properties	No. Correlations
Fibre content (rubbed)	13
% Mosses	13
Mineral Matter	12
Fibre content (unrubbed)	10
Bulk Density	10
Particles < 75 um	8
% Sedges	6
Particles < 1 mm	5
% Wood	4
Water holding capacity	4

Table 4.2. Significant Correlations of some Peat Properties. (After Mathur and Farnham 1985, p64)

There are distinct problems, however, with the way in which these authors assessed their data. Of the 13 correlations referred to, 3 are with other measures of the same property. Unrubbed fibre content, particles < 75 *u*m and particles < 1 mm are basically the same variable. A correlation with the pyrophosphate index is also included as being significant, despite their own findings that this index is not a reliable indicator of humification.

Sorting the percentage of mosses, sedges and wood in the tested peat (see above) would be hindered by differential preservation. It is also more an indication of parent material than of humification degree. Using mosses and sedges as correlates of fibre content is therefore of limited value. Additionally, no indication of the relative strength of correlations is given. Mathur and Farnham (1985) suggest that no single method of measuring the extent of humification should be used to the exclusion of all others. This is probably the most important conclusion reached.

4.1.3 Chemical properties.

The chemical transformations that occur as plant matter decomposes are extremely complex and are far from being fully understood. Certain chemical properties may be expected to increase and others to decrease, although the initial content will depend on plant type. Mathur (1982) found that accumulated and ephemeral enzymes, including abiotic ones, help determine the rate and course of decomposition. The presence of these and various other organisms complicates the picture, making chemical constituents less likely to be a reliable index of humification.

Humus has a higher cation exchange capacity, a higher nitrogen content and greater calorific value than undecomposed plant material (Mathur and Farnham 1985). These variables are very species dependent, though, and a changing vegetation cover prevents their use, especially where the surface assemblage cannot be reconstructed by macrofossil analysis.

Assessing the calorific content of peat deposits has been the subject of many studies concerned with finding mire horizons suitable for fuel. Tolonen (1982) found great difficulty in matching any easily measured property to calorific content or bulk density. The calorific content may be of use in this field when either a rapid and cheap means of measuring it is developed, or some reliable indirect measure is found. Even then, the effects of different parent material (plant matter) may be overwhelming.

The sugars contained in both living and dead plant material may be of use as indicators of decomposition. Hemicellulose and cellulose are decomposable fractions of living plant material. Microbial polysaccharides, rich in arabinose, are by-products of decomposition. Mathur and Farnham (1985) concluded, however, that these properties vary widely due to different botanical composition.

As biodegradation proceeds, the biodegradable proportion of the remaining peat decreases. Levesque and Mathur (1979) measured the rates of respiration of peats when allowed to decompose in ideal conditions. More humified peat would theoretically decompose less than fresh plant matter. Results from a variety of different samples correlated particularly well with fibre content data, adding more credibility to the use of particle size as a measure of the degree of peat humification.

4.1.4 Chemical extraction of soluble material.

Humic acids are a group of macromolecular compounds produced by the decomposition of organic material. They are dark brown in solution, giving humus its colour. Theoretically, as peat decomposes the proportion of humic acids increases, humification being the process of production of humic material.

Various attempts have been made to use extraction techniques to estimate the quantities of humic acids. The extractant most widely used in both palaeoecology and soil chemistry has been sodium hydroxide. Studies by Aaby (1976), Chambers (1984) and Rowell and Turner (1985) have assumed that the colour of NaOH extracts are indicative of humification degree.

Kaila (1956) noted that an NaOH solution of peat contains a high level of contaminant, non-humic material that is simultaneously extracted. Hayes (1985) noted that additional compounds may be produced by the extraction procedure. Kaila developed a "pyrophosphate index", whereby sodium pyrophosphate was used instead of alkali. Although this reduced the quantity of contaminants, it also reduced the amount of humic acids removed.

Hayes et.al. (1975) tested several different solvents in order to extract humic acids as efficiently as possible. The solvents used could be divided into two groups; those that did not alter the molecules but are relatively inefficient extractants, and those that extract efficiently but cause structural alterations.

Extractant	Humic acid yield (%)	Fulvic acid yield (%)
DMF	16	2.0
Sulpholane	10	12.0
DMSO	17	6.0
Pyridine	34	2.0
EDA-HCL	5	7.8
EDA (Anhydrous)	2	3.0
Sodium Pyrophosphate	13.7	1.6
Dowex A-1	17.8	1.6
EDTA	12.5	3.8
EDA	**49.0**	14.0
Sodium Hydroxide	**58.0**	2.0

Table 4.3. Yields of Humic and Fulvic fractions extracted with different solvent systems (after Hayes et.al. 1975, p236).

Table 4.3 above gives yields of humic and fulvic acids from the solvents tested. Of the reagents tested, significant yields were only obtained from the use of EDA and NaOH. These reagents extract the more complex and less water-soluble components of humus (Hayes et.al. 1975, p244). EDA appreciably alters the humic compounds extracted however, and so where reasonable yields are required, NaOH is more reliable.

Repeated extraction experiments, where a series of different reagents and processes were used successively showed that each step removed a little more humic acid until eventually higher yields were obtained. For close interval sampling as in the case of the present study however, such a procedure would be far too time consuming if a reasonable, and consistent extraction can be gained from a single process.

4.1.5 Conclusion.

From the physical properties group of measures of humification, fibre content appears to be the most reliable. Extracts of humic acids in sodium hydroxide should also provide a reliable, though impure, estimate of the degree of humification. After a review of the precise nature of the extraction technique, these two methods are compared in two profiles of apparently changing humification.

4.2 Testing the extraction procedure.

4.2.1 The standard method.

In palaeoecological studies an alkali extraction method has been used, with the resulting solution being optically measured for atomic absorption by means of a colorimeter. Methodology has followed that developed by Overbeck (1947), modified by Bahnson (1958) and translated by Aaby (1986, p151). This method is reproduced below, with insertions * to mark points which are discussed later.

> *"The peat sample is comminuted and dried in an open dish under an infra-red lamp.* ***Eriophorum vaginatum****, if present, is cut with a pair of scissors as this material may otherwise form a felty mass. The peat is then ground in a mill and dried in a drying cabinet at 105°C.*
>
> *0.2g of sample is placed in a 200ml volumetric flask and 100ml of 0.5 % NaOH is added with a pipette.* The flask is heated to boiling point on an electrical plate (24 flasks per batch). When the liquid begins to boil, foam is usually formed and this can overflow the neck of the flask. This can be prevented by rapidly removing the flask from the hot plate. After a few seconds, when the sample is thoroughly wetted, the flask can be replaced and boiled for one hour.* After cooling, distilled water is added to the mark and the suspension filtered through a medium filter. 50ml of the well shaken filtrate is added to a 100ml flask and diluted to the mark wih distilled water, after which the flask is thoroughly shaken. The absorbtion is then measured on an EEL colorimeter with a filter (540nm).*
>
> *The zero point of the instrument is determined with distilled water. If the colorimetric reading exceeds six, the sample is again diluted; in this way a uniform measuring accuracy is obtained.* In order to compare results from different series it is necessary to adhere to a strict time-schedule as some fading of intensities occurs with time.* The largest source of error in this method arise fom inadequate shaking of the flasks; this applies particularly to flasks with a high and thin neck. Repeated measurements, made on two or more portions of each sample, should be made in order to check the reproducibility of results. In each time series a pulverised humic acid standard (from Fluka Ltd. Switzerland), treated in the same way as the samples, is included.* Dilution experiments have shown that the humic acid standard forms an almost true soluion. The calibration curve for the humic acid standard may therefore be calculated. For the linear curve the equation $y=0.12x-0.1$ was found; $x=$ degree of humification, $y=$ colorimetric reading."**

Various tests have been conducted to determine the variability and tolerances of the above method. Firstly, a large portion of a relatively homogeneous horticultural peat type was dried and ground, then mixed for 20 minutes in an automatic homogenizer. This is the source of all the samples used below, to eliminate the effect of difference between samples as much as possible. A batch of 12 samples treated in the above way produced optical densities of a mean value 0.440, standard deviation 0.06. The range of these samples was within 1.3% of the mean. Any variability found in the following tests must therefore be greater than this to be relevant.

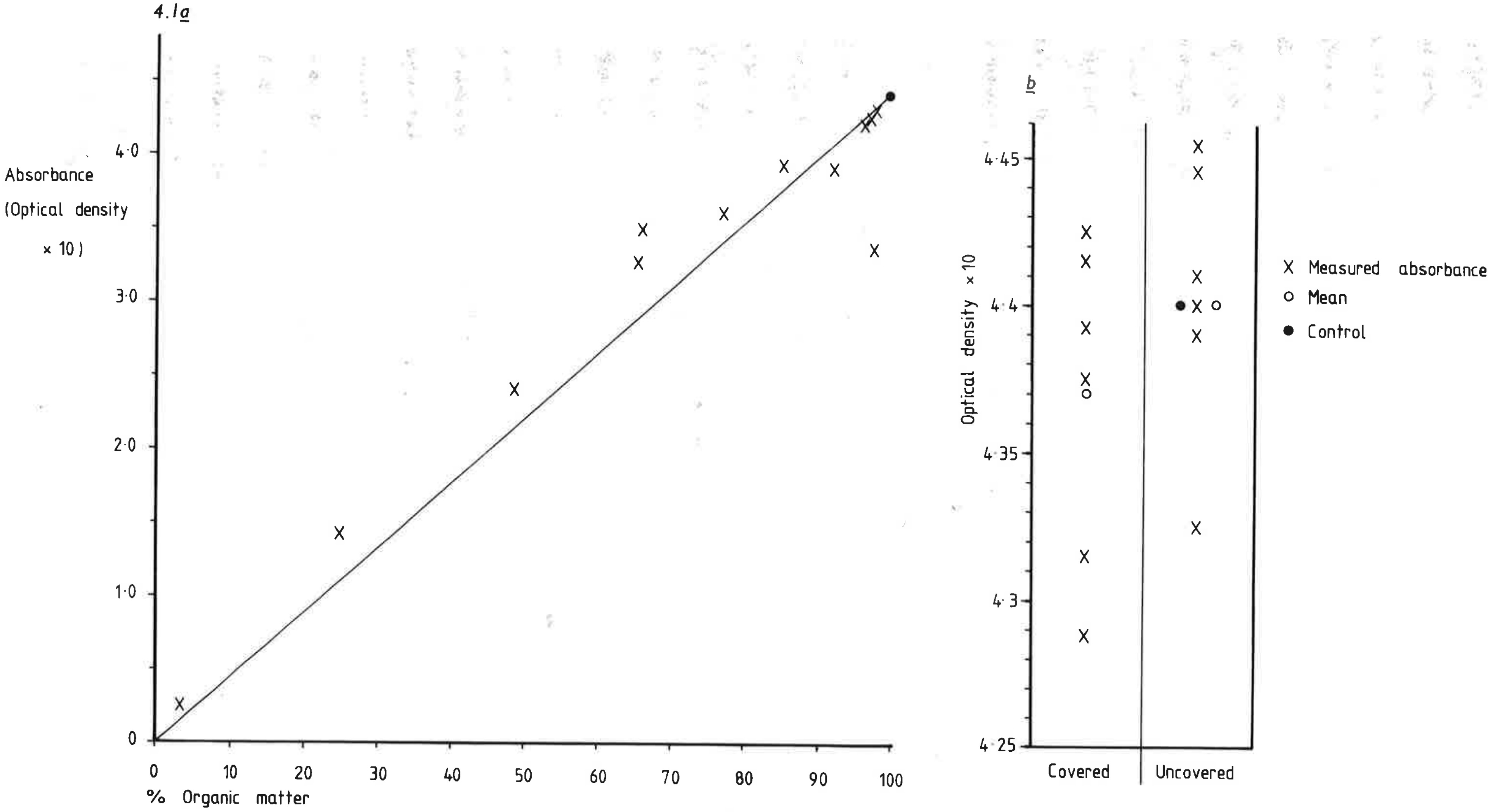
4.2.2 Mineral content.

Chambers (1984) referred to the possibility of inorganic material incorporated in the peat matrix causing a distorting effect on humification results. In order to test this effect a batch of samples were deliberately contaminated with varying quantities of clay. These samples (of the homogeneous mixture described above) were then remixed and divided, one part being tested for humification and the other being incinerated. Results were thus obtained for absorbance and loss on ignition, measuring respectively humification and inorganic fraction.

Figure 4.1a shows these results, demonstrating a linear relationship between the two variables. This is interpreted as being caused by the mineral matter causing the actual amount of organic matter in the original 0.2 g sample to be reduced. If loss on ignition were calculated for each sample, then, this effect could be corrected for. This was done in the present study, the transformation being carried out using spreadsheet equation 1 (see appendix 1).

It is possible that not all of the distorting effect of mineral material is accounted for in this way. Schnitzer (1967) suggested that clay particles in a humic soil can gather around humic molecules in such a way as to prevent their solubility in alkali. He found a considerably increased yield with a pre-wash treatment of HF-HCL, especially of fulvic, but also of humic acids. Inorganic content has been determined for each sample in this study, and most values are between 0 and 3 % by weight. Only in the case of monolith LET 3 do values become higher, and here the material is mostly of a large size class, and not of clay. Most of the effect of mineral material then can be accounted for.

Figure 4.1. Graphs showing the effect of a. mineral material in the peat, and b. evaporation, on the optical density of alkali-soluble extracts.


4.1a
Absorbance
(Optical density
× 10)
0
1·0
2·0
3·0
4·0
0
10
20
30
40
50
60
70
80
90
100
% Organic matter
b
Optical density × 10
4·25
4·3
4·35
4·4
4·45
Covered
Uncovered
X Measured absorbance
○ Mean
● Control

4.2.2 Evaporation.

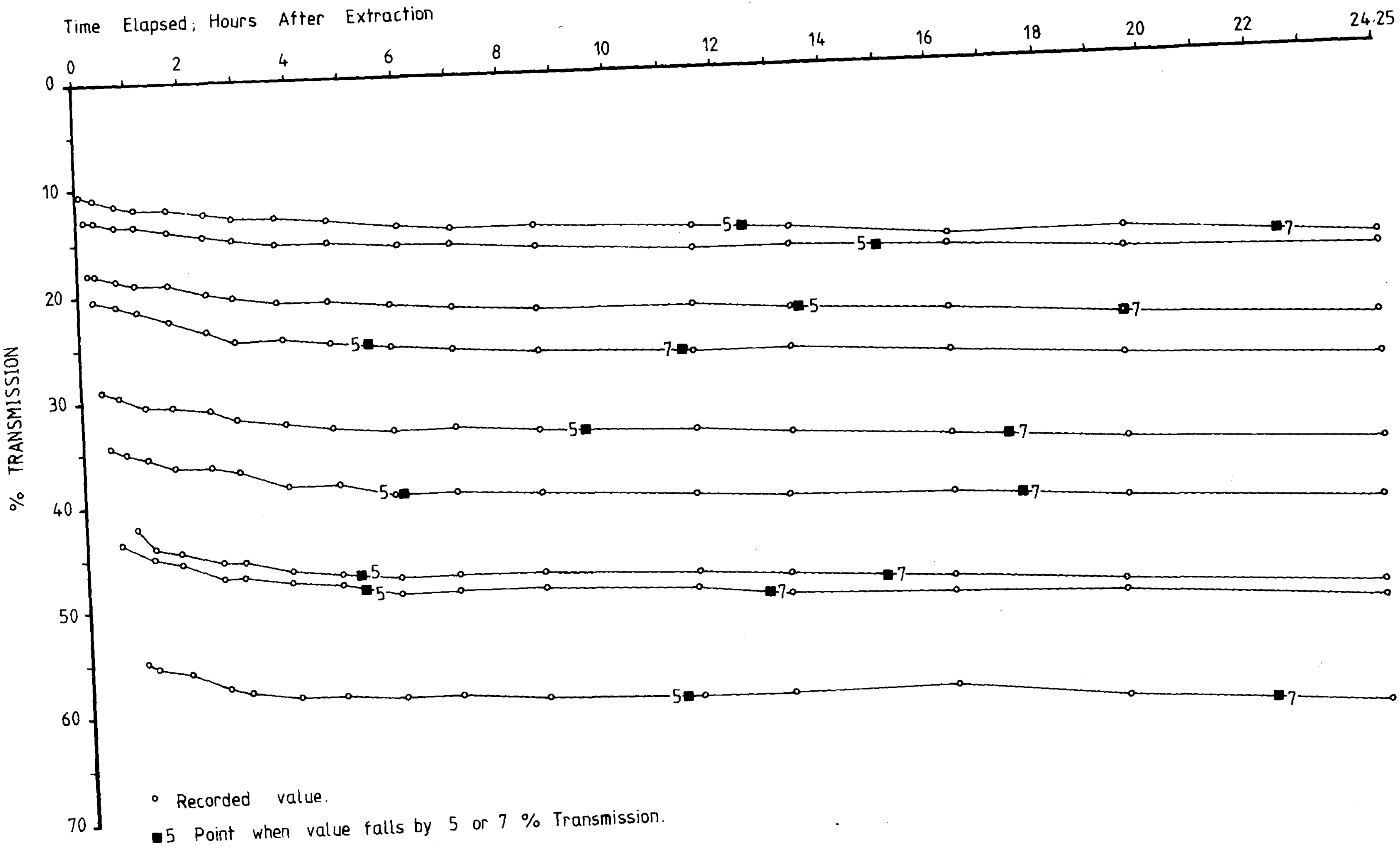
Haslam (1988) suggested that while boiling the samples a different amount of evaporation occurs from each one. He used flasks that reduced this risk. To quantify the effect of differential evaporation a batch of twelve similar samples were used, six being covered through the boiling time and six remaining uncovered. The data obtained from this experiment are illustrated on figure 4.1b. It appears that the uncovered samples have slightly higher values of humification than the others. This is possibly due to the effect of increasing concentration as water is lost. A t-test shows no significant difference between the means however (df=10, p=0.05, T[calc)=1.01, T[crit]=2.18). Evaporation can account for the loss of half of the original 100 ml solution. It appears that the loss must be just colourless steam, replaced in the subsequent dilution stage with no noticable change in the result obtained.

4.2.3 Fading.

Humic acid solutions obtained by alkali extraction in aerobic conditions fade in colour intensity. Aaby (1986, see above) recommended keeping to a strict time schedule. Quantification of this phenomenon would allow its effects on the humification test results to be better understood. To this effect, a batch of 9 samples was allowed to fade over a 48-hour period, transmission values being recorded at various intervals. The results of this for the first 24 hours are shown on figure 4.2. The plotted curves show an initial fall in the rate of fading, the fastest fading occurring over the first 3 hours. After around 8 hours the curves become virtually parallel, indicating that the rate of fade is not related to the absorbance. In the later section of the graphs the increase in transmission follows a linear pattern. This indicates that there are two elements to the fading process, one dependent on the amount of humic acid in the solution and the other more linear and roughly equal in magnitude whatever the starting point. This makes fitting an equation for correction purposes difficult. Transmission was therefore measured after 4 hours, any time elapsed after that was corrected for using a linear function applied through the spreadsheet (see appendix 1).

The nature of the fading effect is not understood, but is now to some extent described. Humification results can now be corrected for fading when necessary.

Figure 4.2. The effect of fading on the optical density of alkali-soluble extracts. p49


Time Elapsed; Hours After Extraction
0
2
4
6
8
10
12
14
16
18
20
22
24.25
% TRANSMISSION
0
10
20
30
40
50
60
70
5
7
○ Recorded value.
■ 5 Point when value falls by 5 or 7 % Transmission.

4.2.4 Alkali concentration.

The use of 5% solution NaOH is quoted in the literature as being the standard procedure. There are no reasons given for this, however, and it is possible that a stronger alkali might extract more dark substances. Tests were conducted on a series of homogeneous samples using a range of concentrations. The results are shown on figure 4.3a. Not all the possible extraction is achieved at 5% concentration. Figure 4.3a seems to indicate that a slightly higher (1.1%) absorbance is achieved with 8% NaOH. This is, however, within the limits set by the initial control experiment, and for repeated laboratory use 5% is notably less caustic. The pattern beyond 8% is interesting. Absorbance, and therefore extraction is reduced when 10% or 12% NaOH are used. This could be explained by the work of Gascho and Stevenson (1978) who found that a mild alkali was the best extractant, and that increasing salt content reduced yields of humic acids from histosols. As concentrations are increased, it is possible that after a certain level the presence of sodium compounds in some way inhibits extraction, or alternatively increases fading.

4.2.5 Extraction time.

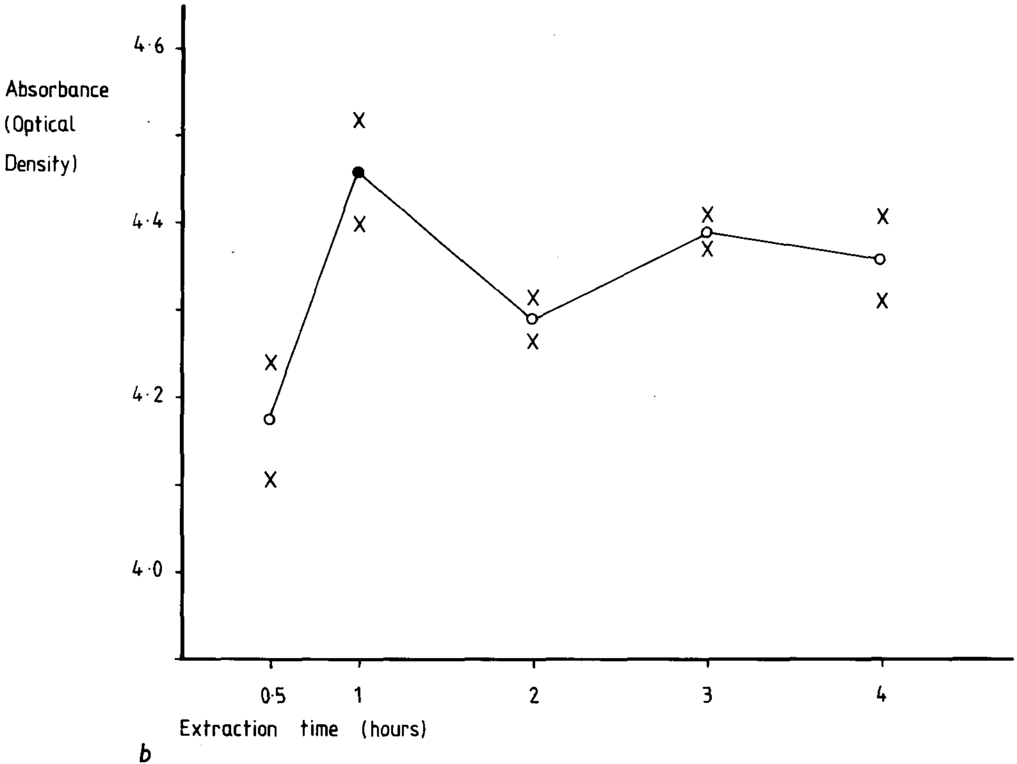
Referring again to the literature, no mention is given of the reason for allowing one hour extraction time. Samples were allowed to boil for different time periods, and the results are plotted on figure 4.3b. The results show that absorbance actually peaks at one hour; this is probably a feature of the sample intervals used. No further extraction is indicated by increasing the extraction time. Beyond one hour, the fading effect may explain the shape of figure 4.3b. One hour seems to be a sufficient but not critical period of extraction. Deviation by 10 minutes either way makes only 2% difference to the absorbance result.

4.2.6 Colorimeter wavelength.

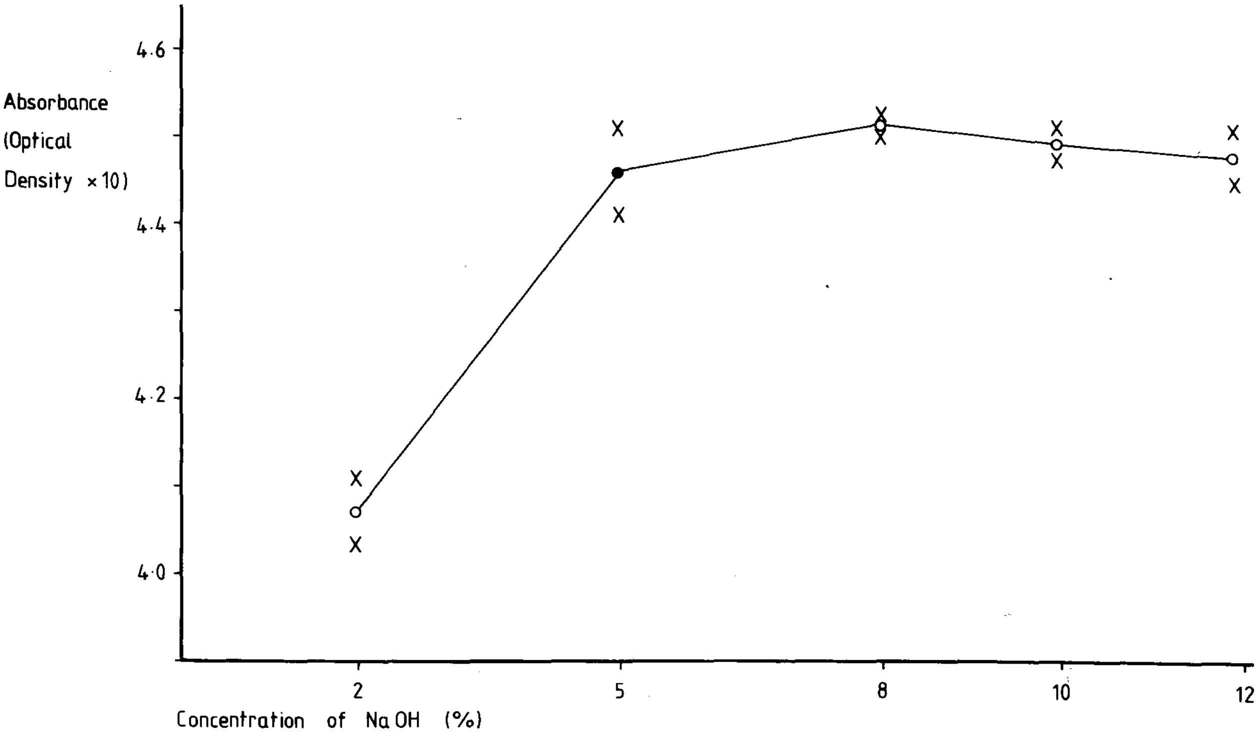
Standard procedure uses a colorimeter wavelength of 540 *n*m to test the transmission or absorbance of solute. A study by Sapek <u>et.al.</u> (1980) used wavelengths of A1, (280 *u*m), A2, (472 *n*m) and A3, (664 *n*m) where A is absorbance. The ratios of these values were then derived;

Figure 4.3. The effect of **a.** extraction time and **b.** NaOH concentration on the optical density of alkali-soluble extracts.

4.3 a


Absorbance (Optical Density)
4·6
4·4
4·2
4·0
0·5
1
2
3
4
Extraction time (hours)

b


Absorbance (Optical Density ×10)
4·6
4·4
4·2
4·0
2
5
8
10
12
Concentration of NaOH (%)

A1/A2, A1/A3, A2/A3. Sapek et.al. found a distinct effect on the optical properties of alkaline extract caused by iron content, an effect that did not diminish the usefulness of the measurement of optical density for the characterisation of humus (p691). Very high correlations between absorbance and iron, carbon and nitrogen content were found. These authors used the A1/A3 ratio as a measure of the "quality of humic substances". Their figure 1 shows, however, that the pattern of A1 and A3 are similar: the value of absorbance ratios is unclear. In the current study a wavelength of 540 *n*m was used throughout.

4.2.7 Summary.

The results of these tests allow a more accurate use of experimental data, especially where peats contain inorganic material. The tolerances of procedural elements have been quantified and their possible errors calculated. Given the inherent limitations of an extraction-colorimetric method, variations in experimental data can now be ascribed more safely to exogenous sources. The method described, if conducted accurately at every stage, appears to impose little error on results. The treatment of results is now discussed.

4.2.8 Determining percentage humification.

Values for optical density can be compared to a "humic acid standard" treated in the same way. Aaby (1986) recommends that percentage humification can then be calculated. However, there are distinct problems with this conversion, not least that the existence of a humic acid standard is dubious.

Humic substances are not fully understood. Techniques of electron spin resonance and NMR spectroscopy have still left gaps in the description and explanation of humus (Wershaw and Mikita 1987). What is clear is that each sample of humic acid is to some degree individual. Haworth and Atherton (1965) report chromatographic patterns characteristic of humic acids. Acid from the soil beneath a conifer plantation was of a different nature to that from a beech stand and a moss soil. These authors attributed the differences to the material from which the humic acids were derived: lignin, flavin or tannin (Haworth and Atherton 1965, p57-58). It is probable that humic acid is a variable and complex ....

> **"mixture of closely related macromolecules, and the composition is determined by the source of the acid and the method employed in its isolation."** (Haworth and Atherton 1965, p57).

A "standard" is inapplicable to any other material. This conclusion makes the calculation of "percentage humification" a meaningless transformation of the data. Absorbance was therefore not recorded, % transmission being preferred due to its regularity on the colorimeter scale. This means that the redilution stage mentioned by Aaby (1986) is not necessary.

Previously published humification curves calculated in the usual way are no less valid. The patterns or periodicities shown are a semi-quantitative measure of degree of humification; only the description of the x-axis on most curves is open to question. In the present study, data are presented as % transmission, higher transmission values being indicative of and proportional to, but not an exact measure of, lower degrees of humification.

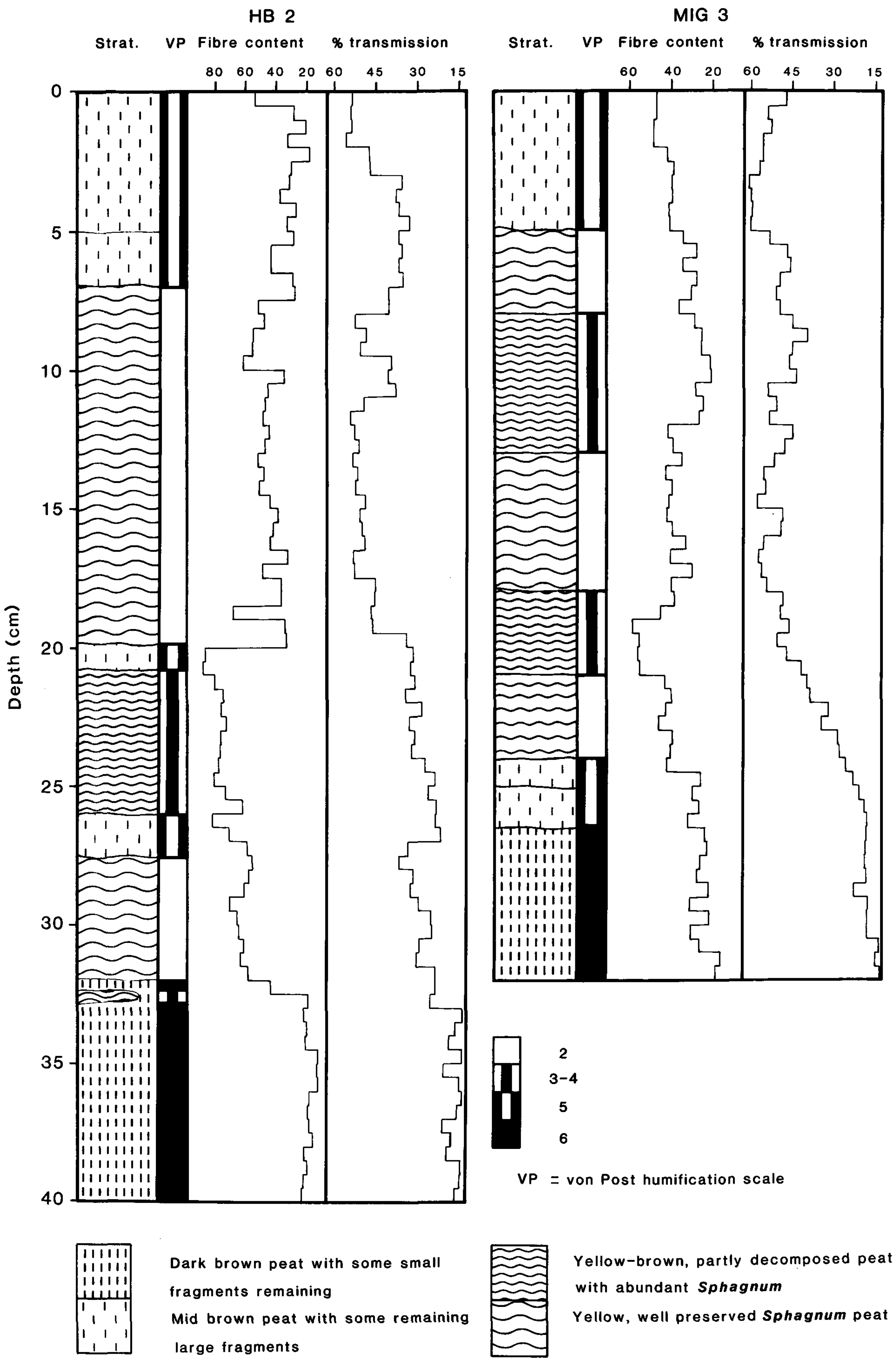
4.3 Fibre content and alkaline extraction as measures of the degree of humification.

The physical and chemical properties of decomposing peat have been reviewed as measures of the degree of humification. The NaOH extraction procedure has been discussed above, and is now compared to the fibre-content determination, arguably the most reliable physical measure of decomposition. The laboratory procedures used are described in sections 5.1 and 5.4.

The upper sections of monoliths HB 2 and MIG 3 were chosen due to the presence of visible changes in peat composition and humification. Half-centimetre samples were used. The results are shown by figure 4.4.

From profile HB 2, both variables show a high degree of humification for the lower section of the profile, recording changes at 32-33 cm, the exact position depending on the sampling across a thin lens of *Sphagnum* peat. At 27.5 cm depth, there is a stratigraphic change to slightly darker, more humified peat containing abundant Cyperaceae remains. This is reflected in the % transmission curve as a change to more humified peat. The fibre-content curve, however, increases, a pattern indicative of less humified peat. The end of this stratum at 20 cm

Figure 4.4. Comparison of fibre content and % transmission curves as measures of degree of humification.


HB 2
Strat.
VP
Fibre content
% transmission
80 60 40 20
60 45 30 15
MIG 3
Strat.
VP
Fibre content
% transmission
60 40 20
60 45 30 15
Depth (cm)
0
5
10
15
20
25
30
35
40
2
3-4
5
6
VP = von Post humification scale
Dark brown peat with some small fragments remaining
Mid brown peat with some remaining large fragments
Yellow-brown, partly decomposed peat with abundant *Sphagnum*
Yellow, well preserved *Sphagnum* peat

shows an increase in % transmission and a decrease in fibre content. The upper section of the short profile shows both variables recording more detail than the visible stratigraphy. Both show a decline coinciding with a visible stratigraphic change at a depth of 7 cm.

The general shape of the curves from profile MIG 3, rising between 32 and 21 cm and then falling to 10 cm demonstrates some agreement between these two measures of the same property. Differences are again noted, however, where a change in visible stratigraphy is observed. The fibre content curve rises abruptly, falling again at the change to *Sphagnum*-dominated peat at 12.5 cm. Humification as measured by % transmission shows a decrease at the beginning of the Cyperaceae band, and a subsequent fall at the end.

The % transmission curve increases in the uppermost 5 cm of the profile, despite the peat matrix consisting of darker, apparently more humified material. This could be caused by the presence of very recent root material; the curve might delimit the acrotelm/catotelm boundary (cf Ingram 1983). This observation has implications for interpreting the top horizons from other profiles.

These results show that the fibre content curves for both monoliths are closely related to the % transmission curves. Both methods appear to be an improvement on the visible stratigraphy. Other studies that have included both fibre content and humification determinations have shown a similar result. Tolonen (1982) compared results from humification degree (based on the von Post scale), to alkali-extract data and fibre content readings. Both curves showed a similar linear relationship (see Tolonen 1982, figs. 6 and 7), although with some deviation at the extremes. This was possibly due to the effect of very large particles on the fibre-content. Curves presented by Wijmstra et.al. (1971) and by van der Molen and Hoekstra (1988) both show a pattern of peaks of fibre content coinciding with troughs of humic extracts.

Where there are differences in the results from HB 2 and MIG 3, a visible stratigraphic change is usually noted, with changes from *Sphagnum* to sedge and to well decomposed, less identifiable peat types. It appears, then, that the two methods respond differently to changes in the source material.

Dickinson (1975) noted that *Sphagna* (with the exception of spp. *cymbifolium*) are prone to breakage on decomposition, but with leaves remaining intact and identifiable. *Eriophorum* remains preserved in a matrix of well decomposed peat often remain in a matted form, large particles surrounded by dark, amorphous material. Ericaceous remains, however, and the roots and leaves of Gramineae species, appear to decompose to smaller particles in the same conditions.

Fibre content determinations, then, appear to have problems in measuring humification consistently across changes in plant composition. This is caused by different plants, starting at different sizes, having different decompositional characteristics when subjected to the same decompositional environment.

Humification, as measured by alkali-extraction and atomic absorbtion, is also distorted by changes in the peat-forming plants. Different chemical and structural properties cause a different rate of humification, and a different end-product. However, the directional response of these changes makes this method preferable in the current study. For instance, if a "dry" assemblage dominated by *Calluna vulgaris* gives way to a *Sphagnum*-dominated "wetter" community, the degree of humification recorded would be reduced, as the *Sphagnum* decays at a lesser rate under the same conditions. Coulson and Butterfield (1978) present figures of weight loss during the first year of decomposition of 16.2% for *Sphagnum recurvum* and 25.6% for *Calluna vulgaris*. Heal et.al. (1978), showed a marked difference between the the decomposition of *Calluna* shoots and stems, and their results were appreciably lower than those of Coulson and Butterfield (1978). However, compared to the weight-loss data recorded for *Sphagna* by Clymo (1965, 1978), from similar sites, the *Calluna* decomposition rates appear fast. More humic material is produced from a "drier" assemblage over the same time period. A change to wetter conditions, then, as sought in the present study, should have an exaggerated effect on the extract colour when species composition changes. With fibre content percentages, the direction of response to a change in species composition may be opposite to that caused by a wet-shift.

The humic extract colorimetric method has been adopted for the rest of the profiles. The precise method used is given in section 5.1.

CHAPTER 5

METHODS

5.1 Humification degree; experimental procedure.

The previous section described the standard humification test and some of its problems. This section describes the procedure followed in the current study.

The peat was sampled carefully and dried under an infra-red lamp. Matted sedge peat was cut with scissors to prevent it forming a felty mass. The peat was then ground in a pestle and mortar and if necessary dried again until no further weight loss occurs. 0.2 g of peat was then placed in a 150 ml beaker and 100 ml of freshly mixed 5% NaOH added from a measuring cylinder. The remaining portion of each sample was used for loss-on-ignition determination (see later). Twelve samples were treated concurrently. After recording the time, the beaker was heated on a hot plate until the solution boiled The temperature of the plate was then lowered, and the samples were simmered very gently for 1 hour. After cooling, the contents of the beaker were transferred to a 200 ml flask, topped up to the mark, and thoroughly shaken. Samples were then filtered through Whatman "Qualitative 1" paper. 50 ml of solution was then diluted 2:1 in a 100 ml flask, which was again thoroughly shaken. Transmission was measured on a colorimeter at 540 *n*m wavelength, repeated samples being taken and ensuring that if different tubes were used in the colorimeter they all record zero when filled with distilled water. The time of each measurement was recorded. Results of % transmission, ash content/100, and time in excess of four hours elapsed between mixing and measurement, were recorded on a spreadsheet as shown in appendix 1.

5.2 Loss on Ignition.

Dried and ground material remaining after weighing 0.2 g for humification testing was burned in a crucible of known weight. Samples were left in a furnace for approximately 2 hours at 800-900 °C. Earlier tests had shown that no further weight loss occurred after this time. After cooling in a desiccator the crucibles were re-weighed, as was the empty crucible.

Percentage weight remaining after ignition (ash content) was then calculated by;

$$\frac{100(W3-W4)}{(W2-W1)} = A \quad \text{(Loss on Ignition)}$$

Organic content = 100-A

Where A = Ash content,
W1 = Weight of empty crucible,
W2 = Weight of crucible + dried material,
W3 = Weight of crucible + burned material,
W4 = Weight of empty crucible after burning.

5.3 Bulk Density

Bulk density was measured from the monolith as dissected in the laboratory rather than in the field. A small "mini-monolith cutter", a cruder version of that described by Cloutman (1987) was employed whenever the peat was suitable to cut a column of exactly 1 cm cross-section. This was divided into 1 cm cubes which were oven dried until no further weight loss occurred. Where the peat was matted and very fibrous, or so spongy that the cutting tool only pushed the material back, a knife was used to cut a less accurate, although usually larger, section of known volume. It now appears from results obtained that the sample size was too small throughout. Variation between samples was too great to detect meaningful variation between peat horizons. Larger samples were probably needed, being more representative of each peat type.

5.4 Fibre content

Determination of fibre content followed the method described by Sneddon et.al. (1971). Samples were soaked for at least 12 hours in sodium hexametaphosphate ("calgon") and thoroughly stirred at intervals while soaking. These were seived through a 0.25 mm mesh, using 30 L of water to wash each sample through. Remaining material was dried and weighed, the weights being compared to those from an unseived comparable sample. A future improvement of this technique may be to use a series of seives of decreasing mesh sizes, chosen to capture, for instance, *Sphagnum* leaves.

5.5 Microfossil Analyses.

5.5.1 Preparations.

Samples were prepared for pollen analysis following established techniques (eg. Moore and Webb, 1978). HF treatment was used where high mineral contents were a problem. Tablets containing *Lycopodium* spores in known quantities were added as marker grains to allow "absolute" calculations (Stockmarr 1971). Measured volumes of peat were prepared, either by using the mini-monolith cutter or by displacement in a 10 ml measuring cylinder.

5.5.2 Counting.

Prepared slides were traversed in such a way as to cover a representative sample of central and edge areas. This minimises the risk of bias due to the differential spread of grains across the slide (Brooke and Thomas 1968). This strategy is important especially where pollen concentration is high and less than one whole slide is covered. A pollen sum of 500 total land pollen was aimed at. Where pollen were particularly sparse, 250 was used. If a low pollen sum coincides with a high count of marker grains, the error in terms of pollen concentration estimation is no greater (Stockmarr 1971). Occasionally, where one type was dominant, higher counts were used (700+) to offset the effect of inaccurately recording less frequent taxa.

5.5.3 Non-pollen microfossils.

Definition.

Analysis of the remains of fungal, algal, animal and vegetative remains other than pollen and the spores of some mosses and ferns normally included in palynological recording, has led to the use of phrases such as "fungal, algal and other remains" (van Geel 1978) and "types of microfossil not normally recorded" (van Geel et.al. 1989). During this chapter the less cumbersome term Non-Pollen Microfossil, abbreviated to NPM, is used to denote these types. NPMs are all microfossils other than pollen grains and the spores of *Sphagnum* mosses and ferns.

In a review of the role of fungal spores in palynology, Graham (1962) pointed out that their distribution patterns change with environmental variations, allowing environmental conditions to be deduced from the presence of a given flora. Van Geel (1972, 1978) began cataloguing the spores and other microfossils in Holocene peat deposits and observing the distribution of morphologically distinguishable "types". Continuing work of this nature has led to a series of papers including microfossil analyses alongside other palaeoecological data (van Geel 1972, 1978, Pals et.al. 1980, van Geel et.al. 1981, 1983, van der Wiel 1982, Bakker and van Smeerdijk 1982, van Geel and Andersen 1989). By relating the frequency of such types with that of other macro- and microfossils, van Geel (1972) showed clear connections between spores, the peat-forming vegetation and the degree of humification of different peat layers. The information from curves of many fungal spores pertains to local conditions as most occur strictly *in situ* (van Geel 1986).

The distribution of certain morphologically characteristic types were found by van Geel (1978) to be consistently distributed according to peat characteristics, most noticably humidity and constituent plant material. Van Geel's work suggests that for the current study it might be valuable to count these types alongside pollen to reveal past wet or dry phases of peat growth.

As this line of investigation is very much in the developmental stage, especially where blanket peats are concerned, the current study will add as much to the knowledge of non-pollen microfossils as the non-pollen microfossils will add to the study.

Non-pollen microfossils including fungal spores and hyphae, rhizopoda, algal spores and animal remains were recorded when encountered on pollen slides. The effect of HF treatment on these microfossils is unknown, but van Geel (1972) noted that acetolysis did not affect the counts. Identification followed the various publications of van Geel and co-workers where possible, reference was also made to other mycological literature, especially Ellis (1971), Domsch and Gams (1972) and Ellis and Ellis (1985). Unidentified types were given temporary reference numbers prefixed by the code of the monolith from which they were first found. These were then changed to either codes allocated in previous literature or a new laboratory code (K). Rhizopoda were identified where possible according to Tolonen (1966), Corbett (1973) and van Geel (1978).

5.5.4 Diagrams.

A pollen sum of total land pollen has been used for the calculation of percentages and the plotting of results. This is linked to the research strategy being applied. It is changes in the local, mire surface vegetation that are of primary concern. An arboreal pollen sum would subject the percentages of the mire surface types to palynological changes often unconnected with their vegetative abundance.

Pollen diagrams are drawn so that the line thicknesses are equal to the sample thicknesses used, subject to the scale reduction. All horizontal bars are drawn to the same scale, a circle indicating that a taxon is present but represents less than 0.4% of TLP. Samples are referred to in the manner described in chapter 4, 6+ indicating the sample between depths of 6 and 6.5 cm. Where a whole-figure depth is given in the text (eg. 6 cm depth), this refers to sample 6+. Single or very rare occurrences are illustrated using letters on the diagram, with a key underneath in each case.

The pollen types encountered are presented in order of trees, shrubs, herbs and aquatics. NPM's are presented in the order of Bryophytes, Filicales, Rhizopoda, Copepoda, animal remains, algal spores and fungal microfossils.

The trees are in the established order of first appearance in the post-glacial. Shrubs are presented inclusive of *Salix*. Dwarf shrubs such as *Calluna* and *Myrica* are included under herbs. This is to keep the types most likely to constitute the mire vegetation together. This group is illustrated next, in the second part of the pollen diagrams.

Following the mire types, taxa most often associated with anthropogenic activity are drawn next. This grouping follows a review of Behre (1985), and is rather subjectively ordered, the types most frequently associated with man first. Rare herbaceous taxa follow the increasingly non-anthropogenic types at the far right-hand side of the diagram.

Aquatics are rare from watershedding blanket bog sites; those recorded are included in the final column of the pollen diagram.

The summary diagram illustrates the relative proportions of tree, shrub (shaded) and herb pollen. Charcoal counts are shown in terms of area (cm^2) per unit volume (cm^3).

The concentration curves are of total- and tree-pollen (shaded). The tree pollen curve is plotted on a different scale, half that of the total pollen curve. For instance, where the scale reads 100,000, this indicates a total pollen concentration of 100,000 grains per cubic centimetre. At the same point, however, the tree pollen concentration curve indicates a value of 50,000, or 100,000 grains per two cubic centimetre.

Non-pollen microfossils are plotted in the order of description (see appendix 2). Only a selection are graphed, the remaining NPM data are shown in tabular form in the appendix.

5.6 Microscopic Charcoal.

The use of microscopic charcoal as a record of fire history is reviewed by Patterson et.al. (1983). Problems in determining the frequency, duration and extent of former fire events make interpretation difficult. The studies of Simmons and Innes (1988), Winkler (1985b), Edwards and Hirons (1985) and Hatton (1990) are among those that interpret microscopic charcoal as a possible indicator of deliberate burning. An objective and quantitative technique is needed to make the interpretation of charcoal data, inherently difficult (Clark 1988), at least replicable and reliable. The methods previously employed can be grouped into two classes. Firstly, microscopically whereby charcoal density is estimated from pollen preparations, and secondly by treatments designed solely to determine carbon content. This latter group includes combustion techniques (Smith et.al. 1975), nitric acid digestion and combustion in combination (Winkler 1985a), and infra-red assays (Griffen and Goldberg 1983). To distinguish between organic and elemental carbon by combustion requires special equipment, as does the infra-red assay, which is also very time consuming. Winkler's (1985a) method is faster than these and apparently accurate (Winkler 1985b), but requires a larger quantity of sediment than microscopic techniques, perhaps losing some temporal resolution.

Results from microscopic techniqes of charcoal estimation have the advantage of being directly comparable to pollen data. Methods used have either counted the number of particles or estimated charcoal area. Estimating the number of particles does not take into account the effects of breakage and size differences between samples. Green (1981, 1988) used size-class analysis to estimate area deposited per year; a similar method was employed by Swain (1973). In intensive charcoal studies these methods work well, given the limitations of the data however gained. In this multi-variable study however, the rapid point-count method described by Clark

(1982) is preferred. If all samples are prepared in the same way and only large changes considered significant, this method should give a satisfactory estimate of relative charcoal quantities (Clark 1982). It does however assume that microscopic charcoal concentration is representative of total charcoal quantities, which are measured by chemical assay techniques. The method of Clark (1982, see page 534) has been employed in the current study.

5.7 Establishing a time-scale.

5.7.1 Radiocarbon dating.

Dating by radiocarbon is currently the best available method of determining the age of particular horizons from Holocene peat deposits. Samples were analysed by the SRRC research laboratory following pretreatment designed to give the most accurate estimate of the true radiocarbon age (Dresser 1970, Chambers 1980). The samples analysed consisted of the alkali-insoluble fine fraction. Age-estimates are based on the 5560-year half-life. Dates have been calibrated using the data and programme of Stuiver and Pearson (1986a,b) and Pearson and Stuiver (1986). Dates are referred to as bp for ^{14}C years, or BP/AD/BC when calibrated.

5.7.2 Interpolation.

For the purposes of interpreting the humification and microfossil data, correlation of cores and calculation of growth rates, the dating results need to be transformed into a time scale applicable to the whole profile. If time-series analysis is to be attempted, or response rates assessed, an estimated date in calendar years is required for each 0.5 cm humification sample.

Linear interpolation between the radiocarbon-dated samples makes the assumption that the growth rate was constant between the dated levels. Such an assumption is difficult to support given the probable drying out of the peat surface following a wet shift, and the variability found elsewhere (Chambers 1980, 1984, Pears 1976).

A possible solution to the interpolation problem is described by Middeldorp (1982, 1986) who utilised the relationship between pollen concentration and peat accumulation rate to estimate growth rates. This method, pollen density dating, involves calculating a cumulative pollen concentration curve for a profile between points of known age. This curve, plotted against depth, is then described as a polynomial, with depth as the independent and age as the dependent variables. Any given depth can then be applied to the equation to produce an estimated age. Middeldorp's technique has been applied by Wijmstra et.al. (1984), Dupont (1986), and van Geel and Middeldorp (1988) with some success.

This technique of assigning dates to samples also makes a number of assumptions. The most important of these is that the rate of pollen influx is more or less constant over the period in question. Selection of a largely regional, arboreal pollen sum by previous authors has minimised this problem.

Pollen density dating also assumes that the curve produced accurately describes the nature of growth-rate changes. The technique assumes that the changes in growth-rates occurred relatively smoothly, in the manner described by a polynomial best fit. Sudden changes or periods of zero or even negative growth would be smoothed out by a whole-profile curve. In addition, short time-scale variations would be lost. It may be more appropriate, despite being a less elegant technique, to plot the cumulative curve graphically, sample by sample, and estimate dates from this plot in an unsmoothed manner.

Thirdly, it must be assumed that the concentration of pollen is accurately calculated, and that no pollen destruction has occurred.

Finally, the end points of the cumulative curve are assumed to be accurately dated. In the past this has been achieved by radiocarbon dates, by showing the surface to be growing and therefore the top of the profile to be of zero age (in calendar years), or by linking pollen data to historical events.

The application of the pollen density technique in the current study involves two additional problems. Firstly, the estimate of pollen concentration is based on the exotic marker grain method of Stockmarr (1971), and is probably less accurate than the total retrieval method advocated by Middeldorp (1982). Secondly, the sampling interval is both variable and non-continuous, rather than at regular 1 cm intervals as in previous applications.

The first problem can be considered by referring to the accuracy measurements presented by Stockmarr (1971). For counts of 500 pollen grains and between 50 and 200 marker grains, an error of ± 3% is typical. This is comparable or slightly better than the quoted counting errors associated with radiocarbon determinations. The cumulative nature of the pollen density method may compound this error, however.

The problem of sampling interval can be solved by considering each sample as being representative of the horizon it bisects. For example, where the sampling interval is 4 cm, the pollen density estimate for the sample at 84 cm is treated as being representative of the interval between 82 and 86 cm. The cumulative pollen total is then reached by calculating the concentration in grains per cm^3 and multiplying by the interval covered. This inevitably makes the procedure less accurate than that used by Middeldorp (1982).

The series of dates obtained for the HB 1 profile (see table 6.1) can be used to cross-check the pollen density interpolation method. Using the fixed points of the basal date and the surface at AD 1986, a "run" of pollen densities for the whole profile, plotted alongside the radiocarbon dates and linear interpolations, provides an estimated date for all the intermediate points (see figure 5.1). Where these levels have been radiocarbon dated, direct comparison is possible. The results of this comparison of predicted and determined ages are shown on table 5.1.

Modern dates for the top two samples are possibly caused by contamination from recent root material. The youngest non-modern determination (900 ± 60 bp at 36-37 cm) was used as the uppermost fixed point in a second run. Additionally, problems of root accumulation may be problematic in determining the age of basal peat (Caseldine and Maguire 1983). The second oldest radiocarbon date has therefore been used in the second, mid-section run. Again the results are plotted on figure 5.1 and shown compared to the radiocarbon age estimates below.

Depth (cm)	^{14}C Date (yr. bp)	Poll. Density date full profile	Poll. Density date mid-section	Linear Interpolation
93-94	2790	2520	___	2780
83-84	1945	1540	1710	2290
55-56	1315	965	1005	1125
44-45	925	785	805	905
36-37	815	695	___	605

Table 5.1. Comparison of estimated ages by pollen density dating of the whole profile, of the mid-section, and by linear interpolation.

The differences between the radiocarbon dates and the pollen density age estimates are beyond the 95% level of confidence in the radiocarbon dates. This leads to two possible conclusions, either that the radiocarbon dates are inaccurate, or that the pollen accumulation curve is not representative of peat growth rate.

The assumptions referred to above regarding the pollen density method must be examined in the light of the non-coincidence of the estimates given above. Figure 5.2 shows four variables plotted against depth. These are total pollen concentration, tree pollen concentration, tree pollen percentage, and tree and shrub pollen percentage. The pattern of these curves is described below, and goes some way towards explaining the apparent failure of the pollen density technique at this site.

Between 104+ and 100+ concentrations fall dramatically. This may be explained by the extemely slow initial growth rate of so-called precursor peat (Taylor and Smith 1980) being replaced by increasingly waterlogged conditions.

From 100+ to 80+ all four variables fall erratically but significantly. Peaks and troughs in pollen concentrations, for example the samples at 94+ and 92+ are matched by similar changes in the % AP curve. This is possibly due to the changes in pollen concentration being caused by woodland clearance, the pollen produced by trees near the site not being replaced by that from non-arboreal types taking their place. There may or may not be a coincident change in growth rate, although the radiocarbon determinations indicate that this is not the case. For this section of the profile, then, it appears that pollen influx rather than peat growth rate determines the pollen concentration.

Between 80+ and 54+ pollen concentrations are very low. Within this section, however, there is a three-fold increase in tree pollen concentration between 68+ and 60+, reflected by a corresponding increase in arboreal pollen percentage. A regeneration phase is suggested, causing an increase in pollen influx. Growth rate changes are again concealed by pollen rain changes.

The section from 54+ to 42+ is characterized by extremely low concentrations. The fall

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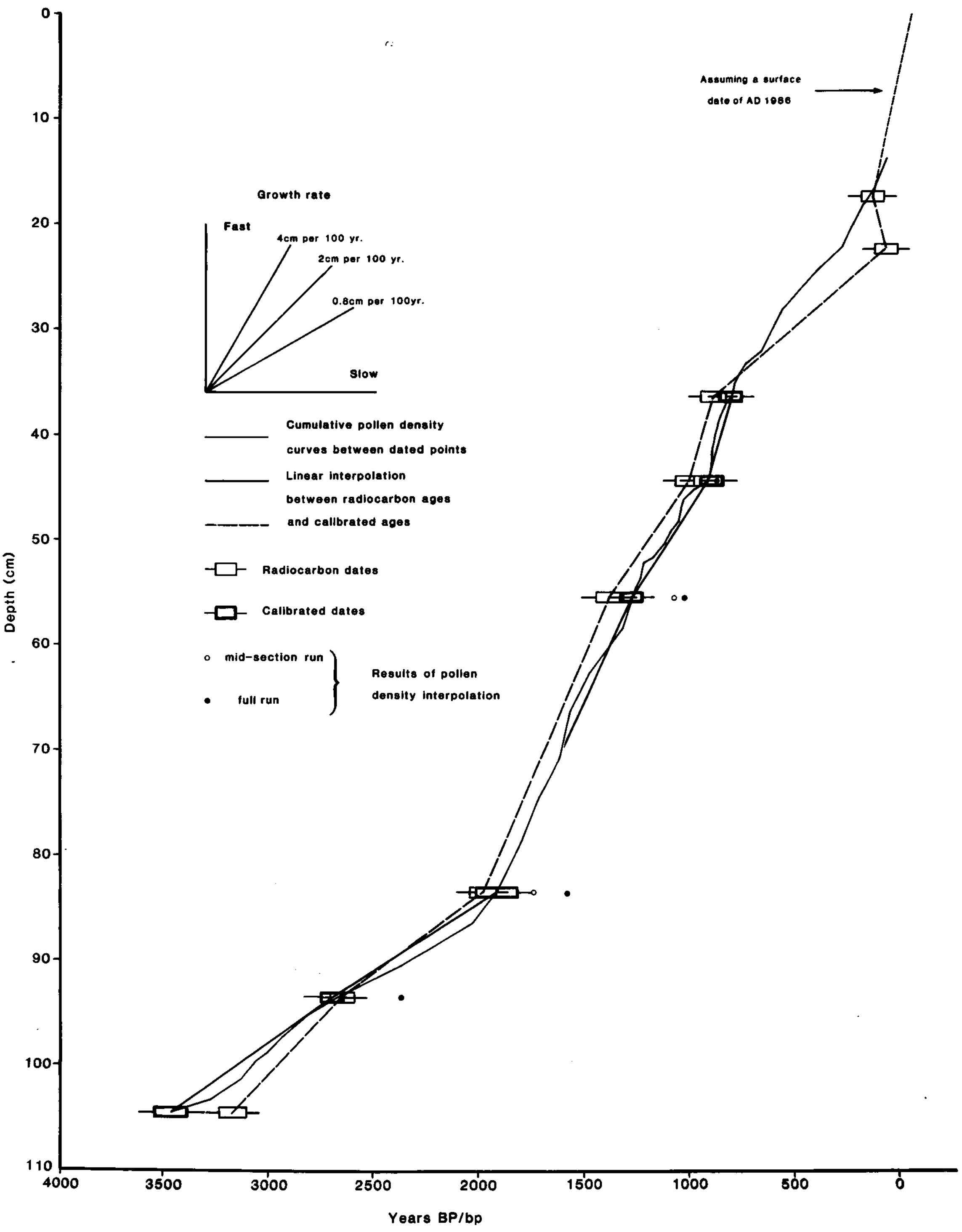
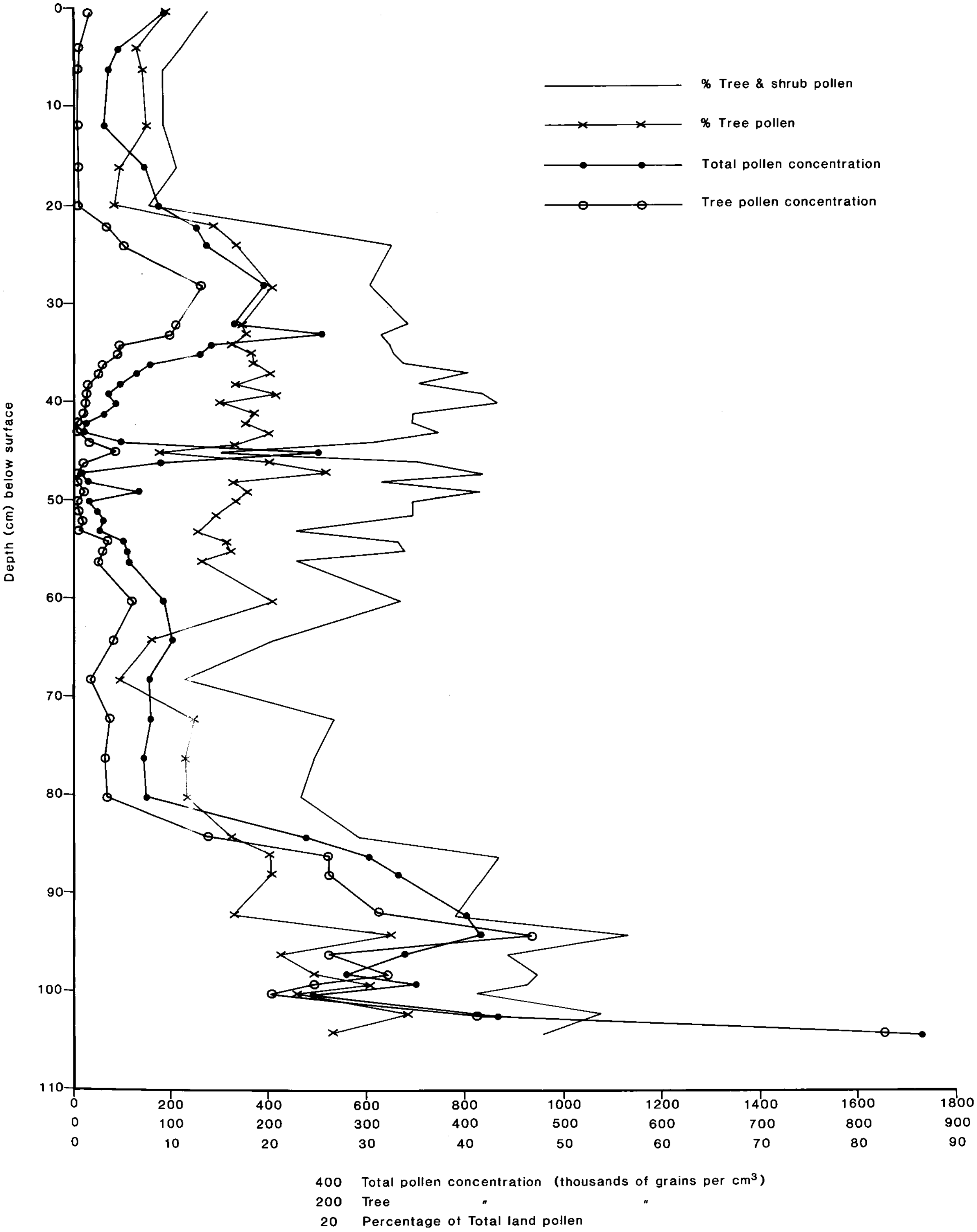
Figure 5.1. Age\depth profile from HB 1, showing calibrated and uncalibrated ages, growth-rate gradients, and the results of cumulative pollen density interpolation.

Figure 5.2. Pollen data from HB 1, showing tree pollen percentages and concentrations and total pollen concentrations.


Assuming a surface
date of AD 1986
Growth rate
Fast
4cm per 100 yr.
2cm per 100 yr.
0.8cm per 100yr.
Slow
Cumulative pollen density
curves between dated points
Linear interpolation
between radiocarbon ages
and calibrated ages
Radiocarbon dates
Calibrated dates
○ mid-section run
● full run
Results of pollen
density interpolation
Depth (cm)
0
10
20
30
40
50
60
70
80
90
100
110
4000
3500
3000
2500
2000
1500
1000
500
0
Years BP/bp

Pollen concentration and tree pollen percentages from Harold's Bog



between 54+ and 53+ is from 33,000 to 6,000 tree pollen grains per cubic centimetre. This is coincident with a fall in tree pollen percentages, but of a much smaller magnitude, from 15.8 to 13%. Subsequent rises and falls in tree pollen percentages are not reflected by changes in tree pollen densities, indicating that accumulation rate is the controlling factor in determining pollen concentration in this part of the profile, and possibly that the changes in tree pollen are not locally based. Relatively fast accumulation throughout this section is also suggested by the radiocarbon evidence, which suggests a rate of 3.9 cm 100 yr^{-1}.

An exceptional peak in the curve of Cyperaceae pollen at 45 cm appears to coincide with a change to wetter conditions at the sampling point. Tree pollen percentages plummet, while locally produced pollen increases in concentration, only to recede again by 43+. This feature could mark a peak in very local pollen production (see section 6.2.4) or a sudden slowing of growth rate. Stratigraphic consistency and the continuous nature of other microfossil curves make the former explanation the most likely.

The interval between 42+ and 28+ is one of gradually increasing pollen concentration. Tree pollen does not increase in proportion, indicating that the rise in density is due to a gradual deceleration of growth rate.

Between 28+ and 20+ a sharp drop in both pollen percentage and concentration implies that influx may again dominate the concentration curve. From 20+ to the surface, concentrations are very low, reflecting both low arboreal percentages and apparently rapid accumulation rates. The determinations supplied by Dr. D Harkness imply a very recent age for the whole top section of the profile.

The description above attempted to demonstrate that both peat accumulation rate and influx have, in varying proportions, determined the pollen density in each sample. The Middeldorp method assumes that changes in influx are negligible and is therefore inapplicable in the current study as an indirect estimator of growth rates. In circumstances where the assumptions can be met, and where accurate fixed points are available, pollen density dating should be an improvement over linear interpolation. In the current circumstances, however, it appears to be less accurate, possibly an over-elaboration; the quality of the original data is not high enough to allow such manipulation.

Dates have been assigned to each sample based on the mid-point of the calibrated range for each radiocarbon determination and linear interpolation between each dated sample. The success or otherwise of this could be tested by dating samples from interpolated levels.

CHAPTER 6

SITE ANALYSES

"If your ankles get wet, that's a Bog", said Eeyore.

"I see," said Pooh.

"Whereas," continued Eeyore, "if you sink in up to your *neck*, that's a swamp." *

6.1 Interpreting changes in vegetation in the context of changes in surface wetness.

6.1.1 Introduction.

The interpretation of humification changes may be aided by recording associated microfossil frequency changes. The analysis of vegetational change over a wider area than the columns of peat used for humification determination might allow the % transmission curves to be compared to changes over a wider locality. The tolerance or preference of certain taxa within the pollen flora is reasonably understood, providing a theoretical basis for interpreting the results obtained. This section aims to outline the possible indicator value of the most frequently recorded bog surface types in advance of the description of the changes actually recorded. In addition, the possibility of recording anthropogenic disturbance of the mire surface via the pollen record is discussed. It has been suggested that at sites away from human occupation the evidence is often weak and difficult to assess in a quantitative manner (Moore et.al. 1985), and may be indistinguishable from hydrological and floristic changes caused by other factors. The following section aims to pinpoint which taxa may be sensitive to hydrological changes, and which might record anthropogenically-induced alterations.

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* From Hoff (1982), p.105.

6.1.2 The effect of hydrological changes.

The most common blanket mire components over the area covered in the present study are the Ericales. At Harold's Bog the fossil pollen record is largely dominated by Ericaceous species, mainly *Calluna vulgaris*. In many peat stratigraphic studies, *Calluna* phases are regarded as being indicative of relatively dry conditions (van Geel 1978, Barber 1981, Svensson 1988).

Calluna vulgaris has a fairly wide ecological amplitude, including lowland and upland heaths, moors and bogs and a variety of open woodland types (Gimingham 1960). Within this range, however, it grows best where the substrate is at least moderately well drained (Gimingham 1960, 1964) and benefits from the drying out of "wetter" blanket bog communities (Gimingham 1964).

Within the range of mire vegetation types, *Calluna* prefers a drier habitat than, for instance, most bog sedges and species of *Sphagnum*. Communities dominated by *Calluna* can, however, contain certain *Sphagnum* species to a varying extent (Gimingham 1960).

Evans and Moore (1985) studied the distribution of *Calluna* pollen away from source, concluding that a reasonable measure of the former abundance of the plant may be inferred from its pollen record. It may be expected, then, that in an undisturbed community, changing frequencies of *Calluna* pollen may be used as an indicator of changing surface wetness. *Calluna* pollen curves may be expected to fall if the water table in the area of pollen recruitment rose in the past.

Other Ericaceous species common in blanket mire communities include *Erica tetralix* and *E. cinerea*. These are more common with wetter (*E. tetralix*) and drier (*E. cinerea*) surface conditions than those most favourable to *Calluna* (Bannister 1965, 1966), although *E. cinerea* has been reported from hummocks on an otherwise wet blanket bog (Tansley 1939). Bannister (1964) conducted germination experiments and suggested that the distribution of these three heath types can be explained by a consideration of their water relations. *Erica cinerea* and *E. tetralix* produce similar pollen grains and are not distinguished in the pollen analyses of the present study, and the distinctive epidermal cells of *E. tetralix* (van Geel 1978) were not encountered. Changes in the frequency of the Ericaceae undifferentiated pollen type are therefore difficult to interpret other than by a rather circular argument of association.

The pollen grains of *Empetrum* are distinguished in the pollen diagrams of this chapter, other than that from the first site analysed (Harold's Bog). They are almost certainly the grains of *Empetrum nigrum*, the only other candidate being *E. hermaphroditum* which is currently resticted to very high altitude sites in Scotland, the Lake District and North Wales (Bell and Tallis 1973).

Empetrum is currently growing on the driest peat hags of the Migneint area, and is suggested by Chambers (1982) and Moore et.al. (1985) to be indicative of dry conditions. Tansley (1939) describes the characteristics of drying peat and lists *Empetrum* and *Vaccinium* (the pollen of which was very rarely found in this study) along with *Calluna* as indicating drier areas. At Featherbed Moss, Derbyshire, a close positive correlation was noted between the presence of *Empetrum* and a lowered water table, and at Wybunbury Moss, Cheshire a decline in the abundance of *Empetrum* coincided with an increase in summer water-table levels (Bell 1969). This preference is not entirely clear cut, however, as Gimingham (1964) found that *Empetrum nigrum* reaches its maximum in two floristically and ecologically widely-separated communities. These were dry *Calluna-Empetrum* heaths and wet *Calluna-Erica tetralix* heaths, the role of this species in intermediate conditions being reduced. Across the range of ombrotrophic mire communities and conditions, though, *Empetrum* is generally favoured in the drier parts (cf Bell and Tallis 1973).

Although the pollen representation with distance has been shown to be to some extent non-linear (Evans and Moore 1985), fluctuations in the frequency of *Empetrum* pollen may be related to changes in surface moisture conditions.

The Cyperaceae are another important component of most blanket mire communities. *Eriophorum* spp. often dominate in wet areas of the Pennine mires (Tallis 1964). The pattern of distribution according to surface humidity is not clear cut, however, as *E. vaginatum* has the ability to grow over a range of moisture conditions, becoming dominant where the water table is at the surface in spring but is lower in summer (Wein 1973). This type of vegetation cover gives way to Ericaceous species on drainage (Tansley 1965), indicating a preference for relatively wet conditions. Gimingham (1964), however, suggested that due to deep roots and reduced competition from other blanket mire types, *E. vaginatum* can flourish for a time between drainage and *Calluna* invasion.

Other sedge species that could be present in the pollen rain are *Trichophorum caespitosum*, and *Carex* spp. some of which grow in open pools, the extreme of high water-table conditions.

Distinguishing the sedge species from pollen grains is difficult; only *Rhynchospora* has been distinguished in the current study. The ascospores of *Anthostomella fuegiana* have also been recorded, which may indicate the specific presence of *Eriophorum vaginatum* or *E. angustifolium*. *E. angustifolium* is associated with high water-table mire environments, more so than *E. vaginatum* (Summerfield 1974).

Other sedge species are currently found in the Connemara blanket mire assemblage. *Rhynchospora alba* is more abundant in wetter areas of the bog, possibly due to reduced competition from *Molinia* and *Schoenus* (Boatman 1961). While *Schoenus nigricans* is often more abundant where conditions are extremely wet, this could be a function of the availability of rainwater electrolytes in coastal regions rather than the water table level (Sparling 1968).

The wettest areas of blanket mires, especially where they tend towards ombrotrophic status, support *Sphagnum* mosses. *Sphagna* often occur in the wetter parts of a *Calluna* dominated assemblage (Gimingham 1972) and in the wettest parts, bogs can be entirely composed of the moss. This demonstrates the range of habitats covered by different *Sphagnum* species; for instance *S. cuspidatum* is common in pool environments with *S. rubellum* on hummocks. This pattern is further complicated by the way in which *Sphagnum* can raise the water table itself once established. On the whole scale of hydrological conditions found on ombrotrophic mires, *Sphagnum* mosses are generally less frequent on the drier areas. Previous stratigraphic studies have inferred wetter conditions from increases in *Sphagnum* as a component in layers of peat. If it is assumed that the proportion of *Sphagnum* spores in a pollen preparation is generally representative of its former abundance on the peat surface, then they can be of some use in reconstructing previous surface wetness.

The role of grass species in the communities found on blanket peats is not straightforward. Palynologically, differentiation between species is difficult and rarely attempted. Most of the peat analysed from the three sites covered contains little in the way of distinguishable macrofossil remains. The relative importance of local and regional *Gramineae* pollen sources, which could reflect entirely different environments, is impossible to determine from the pollen record.

Molinia caerulea is often associated with blanket peats (Moore et.al. 1984) and is generally considered to be abundant where the water table fluctuates widely (Gore and Urquhart 1966, Ingram 1967). When in competition with *Eriophorum vaginatum*, *Molinia* is reduced in abundance by increased waterlogging, although it can withstand extremely wet winter conditions. It occurs in a wide variety of associations, with *Sphagnum* in the wettest Connemara bogs and with *Calluna* in the drier "Stainmore" type (Pearsall 1950). Distinguishing the pollen of this species is impossible, and its indicator value as regards surface wetness is not entirely clear. Where *Molinia* fits in any hydrological scheme depends on local site factors, especially the range of competitors.

Nardus stricta and *Agrostis flexuosa* are more common in the driest extremes of peatland communities (Tansley 1939, Gimingham 1972). The effect of water-table, burning and grazing (Welch and Rawes 1964, Rawes 1983) on the relative abundance of these types is unfortunately of little relevance in the absence of specific identification.

The presence of up to 5% *Narthecium* pollen from the Irish sites suggests that this was a significant component of the blanket mire vegetation, especially as its pollen productivity is low (Moore et.al. 1985). *Narthecium* prefers "flushed" blanket mire locations, but is still a species of low nutrient requirement. The significance of the distribution of *Narthecium* regarding the water-table was suggested by Boatman (1957, 1961), who found a greater abundance in wetter areas. Summerfield (1973, 1974) was more specific, and demonstrated that extreme wet conditions rapidly eradicated *Narthecium*. Summerfield found that this species was best suited to conditions where the summer water table was not within 10 cm of the surface and where lateral or vertical water movements occur. Often associated with species of *Eriophorum*, *Narthecium* tends to occupy a niche between the water tolerances of *E. angustifolium* (wetter sites) and *E. vaginatum* (slightly drier in summer).

Boatman (1961) recorded *Myrica gale* more frequently from wetter mire habitats than from drier ones. Tansley (1939) described a *Rhynchospora alba* dominated blanket mire community from Connemara with frequent *Myrica* in the wetter areas. *Myrica* is similarly present in *Trichophorum caespitosum* dominated communities from the highlands, but absent, along with *Sphagnum*, *Eriophorum* and *Narthecium* from drier peat (Tansley 1939, Lindsay et.al. 1988).

Myrica pollen has been separated from that of *Corylus* from the later sites analysed, and could show wetter conditions. The structure of the small shrub above the rest of the blanket mire plants might cause its pollen to be less locally distributed than other types.

Potentilla-type pollen grains from the sites analysed most likely belong to the species *Potentilla erecta*, common on moorland and the drier areas of blanket mires (Moore et.al. 1985). The presence of *Potentilla* in the flora of the Connemara bog sampled, however, suggests that a wide range of hydrological conditions can be tolerated. Coupar (1984) found that *Potentilla erecta* was present in a wide range of communities, but absent from the four "wettest". The use of *Potentilla* pollen in detecting hydrological changes may be much less than the use of its response to grazing (see below).

6.1.3 The effects of human interference.

The direction and magnitude of vegetational change caused by climatically induced hydrological changes are likely to be difficult to distinguish from hydrological changes caused by other means. Various standard "anthropogenic indicators" may be used to suggest the occurrence of human-induced changes (cf. Behre ed. 1985), although the reliability of these is far from conclusive. In addition, changes may be brought about on the mire surface that have nothing to do with hydrological variation. The following section briefly outlines some of the possible effects of a change in management regime that would resemble, palynologically, vegetational changes caused by surface wetness factors. In particular, some effects of grazing, trampling and burning are discussed with reference to the main mire taxa relevant in the context of the current project.

6.1.3.1 Grazing.

The dominant blanket mire types are all grazed by a variety of animals and birds. *Calluna*, for instance, is grazed abundantly, and forms a substantial part of the diet of hill sheep (Gimingham 1960). This is especially so in winter, but also in the flowering season. The palynological effect of this might be to reduce the overall representation of the locally dominant pollen producer, causing a relative increase in the regional, often arboreal, pollen types. By this mechanism an increase in the intensity of the land use of an area might cause the apparently contradictory response of an increase in tree pollen proportions (Chambers pers. com.).

Ratcliffe (1964a) suggested that the *Eriophorum* dominated blanket mires studied were caused by the effects of grazing and burning a more varied *Callunetum*. Experiments involving the removal of sheep from high-altitude blanket bog showed an increase in *Calluna* within a *Calluneto-Eriophoretum*, indicating that grazing had favoured *Eriophorum* (Rawes and Hobbs 1979). Cody (1965), however, showed that persistent heavy grazing kills the plant, despite the tussocky growth form. Increases or decreases in *Eriophorum* could be attributed to grazing, then, depending on the intensity of grazing, the animals involved and the choice of plants available.

Grazing is apparently beneficial to the flowering of *Potentilla erecta* (Moore and Chater 1969), and peaks in the pollen representation of this type have been attributed to grazing pressure.

6.1.3.2 Trampling.

Trampling of the mire surface by animals could cause the surface to become more compacted, reducing the porosity and causing an increase in local surface wetness. The surface conditions could also be altered to improve the establishment chances of seeds of *Calluna* (Gimingham 1960).

6.1.3.3 Burning.

The effects of burning on a blanket mire community may be indistinguishable from changes brought about by other causes. Mallik and Gimingham (1984) reported charcoal causing a reduction in surface porosity, which could cause an increase in surface wetness. Burning is conducted to maintain a *Calluna* dominated assemblage in many areas, but the effect of fire is not consistent. The timing, intensity and duration of the fire and the original state of the vegetation cover alter the resulting changes.

An example of this particularly relevant to the current study is the effect of burning *Eriophorum* dominated moors. In the spring and early summer following a fire, *E. vaginatum* is often stimulated to profuse flowering (Ratcliffe 1964). This is possibly due to the release of nutrients (Wein 1973). Rawes and Welch (1969) noted that *E. vaginatum* became temporarily dominant after fire in *Calluneto-Eriophoretum* blanket bog in Westmorland, followed by *Calluna* regrowth. This effect is altered, however, by a regular burning regime which is accompanied by grazing, under which circumstances *Eriophorum* can retain dominance (Rawes and Hobbs 1979). If the grazing pressure is particularly intense, grazing without burning can reduce the cover of dwarf shrubs (Grant et.al. 1976). The effects of burning could appear in a pollen diagram, then, the same as a change to wetter conditions causing an increase in *Cyperaceae*.

The effects of fire on *Empetrum* are similarly inconsistent. Gimingham (1964) recorded a temporary abundance, Sinker (1962) classed *Empetrum* as fire sensitive and Dalby (1961) pointed out the importance of fire intensity and frequency on its ability to regenerate.

Potentilla erecta could also be favoured by less intense fires, as it is able to withstand fires by regrowing vegetatively from underground rhizomes and from a sub-surface seed store (Hobbs, Mallik and Gimingham 1984).

Another example of a complicated species in this context is *Narthecium* which does not regenerate well after burning and is subject to grazing (Summerfield 1974). It has been shown that it germinates more successfully on dry, bare areas of peat (Summerfield 1973b), a factor which Moore et.al. (1985) suggested could allow the frequency of *Narthecium* in pollen diagrams to be used as an indicator of anthropogenic disturbance. The abundance of *Narthecium* in many undisturbed bog communities makes this interpretation unreliable, however, as does its negative response to grazing and burning. The response of *Narthecium* to land-use pressures on the mire surface probably depends on the intensity and type of disturbance, being disadvantaged unless the effect is so extreme that the peat is laid bare.

Small quantities of *Melampyrum* pollen were recorded from the Welsh site, associated with temporary falls in tree pollen. Some *Melampyrum* species are found in open woodland, *M. pratense* can occur on mire surfaces especially after burning. *Melampyrum* pollen has been used as an anthropogenic indicator from a variety of sites, including the North York Moors (Simmons and Innes 1988). Under different circumstances Moore et.al. (1985) suggested that it might be indicative of fire. Hicks (1976) concluded that *Melampyrum* might spread into man-made habitats rather than being a direct cultural indicator.

Distinguishing the effects of burning a blanket mire vegetation from other causes of change is difficult from the pollen record. Firstly, the resolution is generally insufficient to record the early stages of post-fire succession, the samples from MIG 1, the fastest growing site used, represent a minimum of 11 years (approximately). Secondly, the effects of fires vary considerably, to such an extent that virtually any change in the relative abundance of pollen taxa could be attributed to this cause, depending on the properties of the fire event and the pre-fire conditions.

This problem could be resolved by the analysis of microscopic charcoal and by the identification of certain fungal remains. Species of *Neurospora* (van Geel 1986) and possibly *Gelasinospora* (van Geel 1978, O'Connell 1987) have been linked to burning.

6.1.4 Summary.

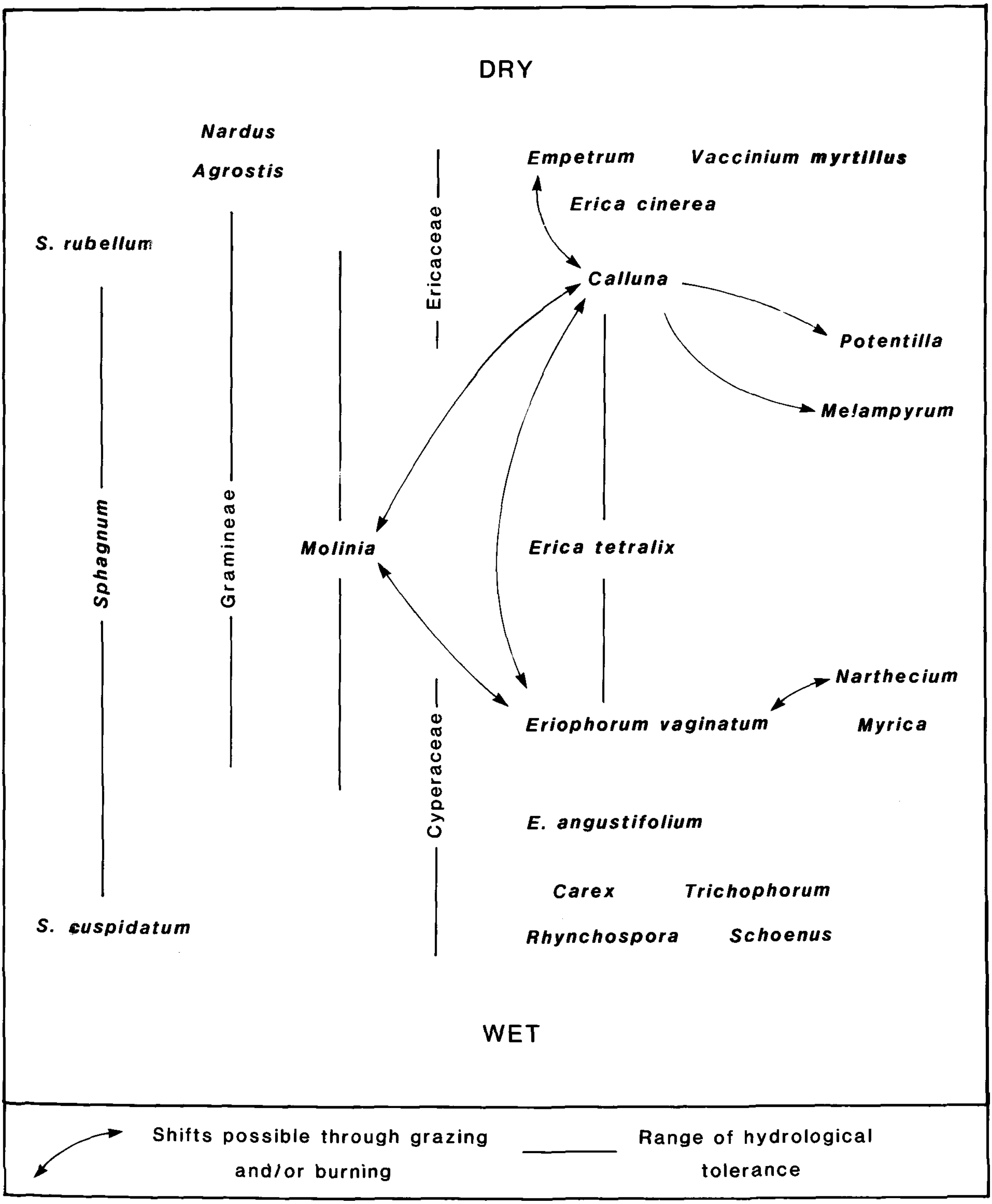
The sections above have demonstrated the problems involved in using palynological data to distinguish either climatically controlled or anthropogenic changes in mire surface vegetation. Only by the replication of similar directional humidity changes over a number of sites at the same time can a climatic signal be inferred. Similarly, more evidence than changes in the relative abundance of the dominant mire taxa are required to infer or reject the possibilty of human influence. Despite this apparent *impasse*, the effects of hydrological change must be somewhere in the record.

Figure 6.1 attempts to distinguish some kind of order in the hydrological preference of the main blanket mire pollen taxa recorded in the current study. The review above points out the problems of any such ordering, and highlights some of the difficulties involved in identifying the causes of change. As such, figure 6.1 also attempts to include indications of the changes that could be caused by factors other than changes in surface wetness.

Interpretation of the pollen diagrams, especially across humification changes, is based on the directional responses indicated by figure 6.1.

Figure 6.1. Relative hydrological preferences of blanket mire species. The vertical scale is of no importance, only the relative positions should be regarded. Similarly, the horizontal arrangement is arbitrary.

Relative hydrological preferences of blanket mire taxa



6.2 HAROLD'S BOG.

Results are presented in the following order;

- 6.2.1. Stratigraphy.
- 6.2.2. Humification analysis.
- 6.2.3. Radiocarbon dating.
- 6.2.4. Microfossil analysis.
  - 6.2.4.1. General vegetation pattern.
  - 6.2.4.2. Humification changes.
  - 6.2.4.3. Detailed section.
- 6.2.5. Summary.

6.2.1 Stratigraphy.

Changes visible in the field are illustrated by figure 6.2. (p76-77). The change to light-coloured *Sphagnum* peat in the upper part of the profile is visible all along the cut face (25 m long) at the site. Coring around the cut section revealed that the *Sphagnum* band was at least 500 m^2 in extent. A consistent but gradual change to increasingly homogenous, black peat occurs in the lower part of the profile. Identifiable remains were limited below 40 cm depth. *Calluna* stems and modern root material were present to 35 cm.

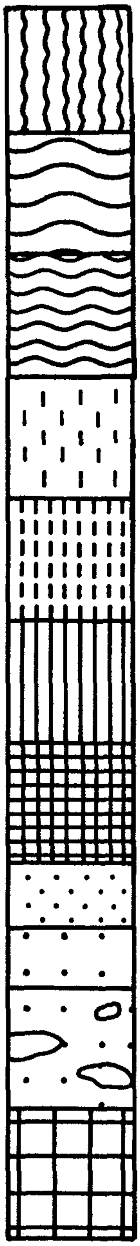
6.2.2 Humification.

Humification analysis from Harold's Bog was conducted at 0.5 cm intervals for the whole of one profile (HB 1) and a short section of another (HB 2). Interpretations are based on the full profile, with the added knowledge that the curve is to some extent representative of a 1 m^2 area. Figure 6.3 is the humification curve for HB 1, and includes corrected values of % transmission "smoothed" by a running mean of three consecutive samples. The curve demonstrates a number of characteristics common to the humification diagrams produced in this study. These are as follows;

Figure 6.2. Stratigraphy.

The classifications described by previously used stratigraphic symbols (cf Berglund 1986) are in general too broad for the current study. The profiles have been divided into a scheme explained below that covers the range of peat-types found.

Key to stratigraphy diagrams.



Undecomposed litter layer and root mat.

Yellow, well-preserved *Sphagnum* peat.

Yellow-brown, partly decomposed peat. Contains high proportion of *Sphagnum*.

Mid-brown peat with some remaining large fragments, can include *Sphagnum* remains.

Dark brown coloured peat with some small fragments remaining, no observable *Sphagnum* remains.

Very well humified deep brown peat containing very small, sparse fragments.

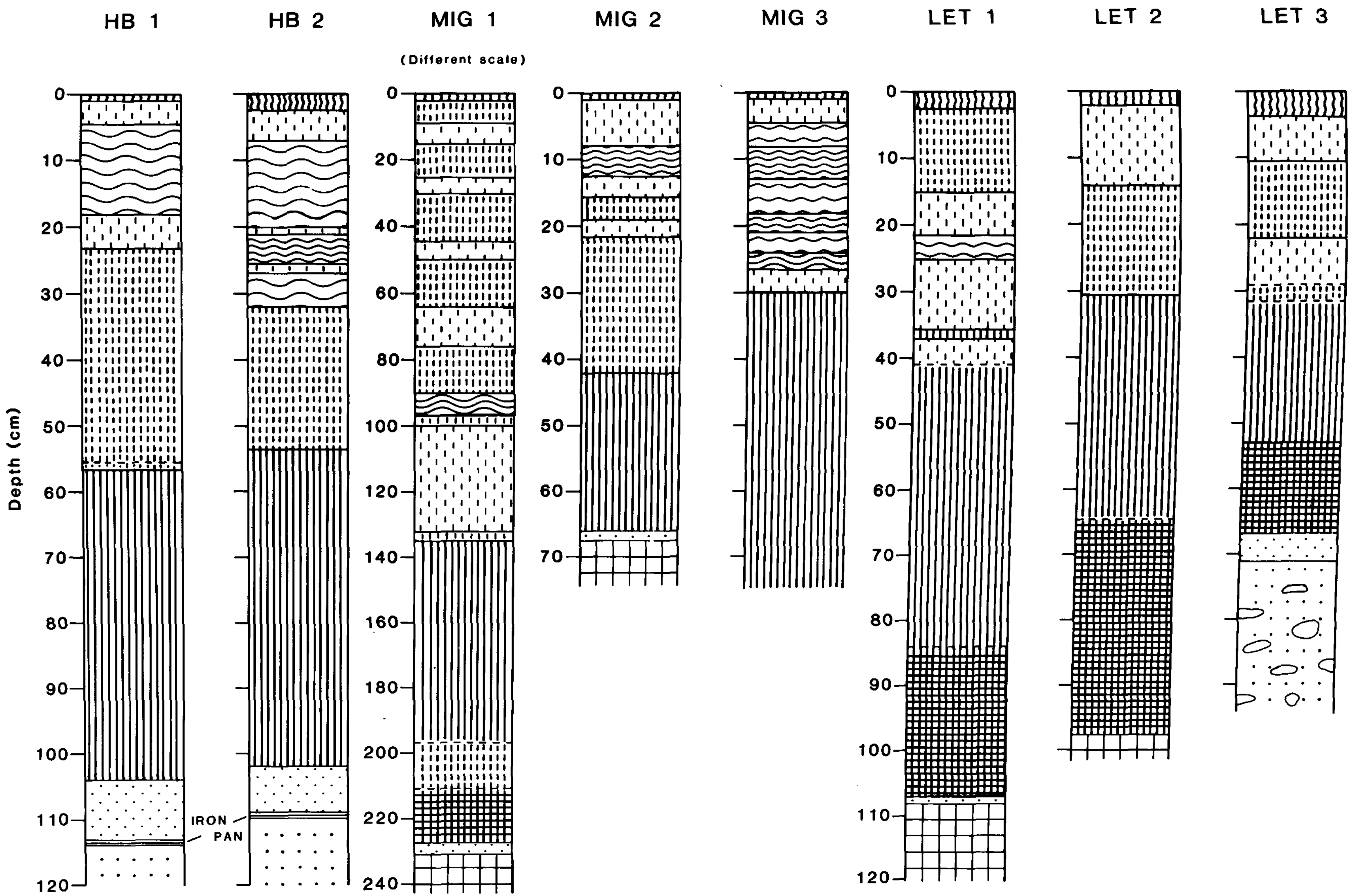
Blackish-brown, completely decomposed peat.

Mineral soil, containing predominantly sand (above) and clay (below) fractions.

Till.

Bedrock.

- - - - Gradual change.


HB 1
HB 2
MIG 1
(Different scale)
MIG 2
MIG 3
LET 1
LET 2
LET 3
Depth (cm)
0
10
20
30
40
50
60
70
80
90
100
110
120
140
160
180
200
220
240
IRON
PAN

(i). The gradual decline of % transmission values with increasing depth.

This is to be expected, as Clymo (1984) noted that decomposition continues throughout the time that material is in a mire, even when it has passed into the anaerobic zone. A time-derived function is therefore present in the data which needs to be taken into account when attempting to interpret humification curves. This function could be excluded from the data if an adequate time scale can be established (see section 5.7), allowing the time-depth relationship to be explained, and then detrending according to a decay curve.

(ii). "Major" changes.

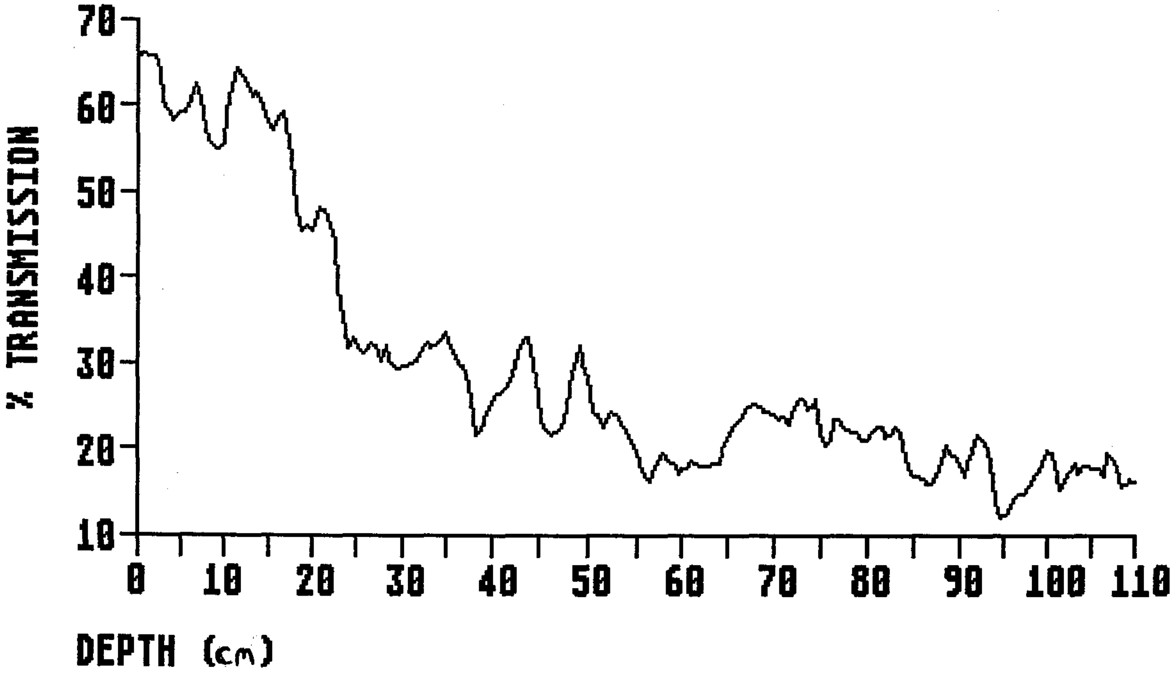
The humification curve shows variability over a wide range of scales. Major changes are defined as those that mark points beyond which the curve does not return. For example, at 93 - 94 cm the transmission curve rises from 12% to 20%. Despite continued variability above this point, the value never falls below 12% again. These major changes can be identified at depths (in cm below the surface) of 94, 84, 56, 45, 37, 23, 18, 10 and 4 and are the basis of sample selection for dating.

(iii). "Minor" changes.

Changes in the curve of a less prominent nature but still detected by three or more recordings (an arbitrary number that represents the variability remaining after smoothing), are described as minor changes, although it must be noted that this is a relative term, and cannot be applied to the possible factors causing the change. Minor changes can be detected at the depths listed below. Depths in cm; 100, 90, 78, 73, 69, 60, 51, 28, 26, 24, and 16. The change at 51 cm could be interpreted as a continuation of the larger rise initiated at 56 cm.

The interpretation of these changes is based on the discussions of chapter 4, and is simply that the depths listed above represent changes to conditions less suited to the decomposition of plant material into alkali-soluble humic substances. The most likely change is one to wetter surface conditions.

Figure 6.3 Humification curve from HB 1. Reading the graph from right to left (decreasing depth), a rise in the curve indicates a change to less decomposed peat.



HB 1; HUMIFICATION DIAGRAM (SMOOTHED)

6.2.3 Radiocarbon dating.

Samples were selected from the humification curve, the first 1 cm above the start of a "wet shift", dating the major shifts at each site. Samples were analysed by the SRRC research laboratory following pretreatment designed to give the most accurate estimate of the true radiocarbon age (Dresser 1970, Chambers 1980). Ages in column three are uncalibrated and are quoted in conventional radiocarbon years, based on the 5560-year half-life. An attempt at interpolation between these dates based on pollen concentrations is described in section 5.7.

Depth (cm)	Lab. Code	RC Age	Calibrated Age*
17-18	SRR-3487	Modern (135 ± 50)	-
22-23	SRR-3488	Modern (70 ± 55)	-
36-37	SRR-3489	900 ± 60	AD 1000-1260
44-45	SRR-3490	1020 ± 60	AD 890-1160
55-56	SRR-3491	1390 ± 65	AD 540-730
83-84	SRR-3492	1985 ± 60	168 BC-AD 130
93-94	SRR-3493	2630 ± 60	900-599 BC
104-105	SRR-3494	3170 ± 65	1600-1318 BC

Table 6.1. Radiocarbon dates from Harold's Bog.

Modern dates have been recorded for the upper two samples. The measured ^{14}C enrichments were such that a post-240 years bp date was allocated to both. Harkness (pers. com.) suggested that the samples would have been liable to contamination by fossil fuel emmissions and possibly by post-1954 bomb enrichment. A situation can be envisaged whereby the onset of peat cutting at the site was followed by a drop in the water table. This caused and allowed the previously shallow rooted mire plants to root more deeply. Relatively recent root material in various states of decay was then incorporated in the ^{14}C sample thus recording a date younger than the "host" horizon.

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* Calibration after Stuiver and Pearson 1986. See section 5.7.1.

6.2.4 Microfossil analysis.

6.2.4.1 General vegetation pattern.

The pollen diagram from HB 1 (figure 6.4) is divided into 6 phases. The diagram does not readily fall into conventional pollen assemblage zones, as the curves are constantly changing. The phases are not meant to delimit distictive vegetational episodes, but rather to pick out certain changes and allow comparison where possible with other work from the region. They are based on the "regional" pollen component where possible; the local changes in bog vegetation are discussed later. Dates quoted are approximate ages of the phase boundaries, calculated by linear interpolation of the mid-point of calibrated age-ranges.

Phase HBA. Base of profile - 85 cm. 1460 - 150 BC.

Phase A opens with the transition from humic mineral soil to peat. The predominant feature of the phase is a reduction in tree pollen percentages. In particular, *Tilia*, *Quercus*, and *Corylus* are affected. *Plantago lanceolata*, *Rumex*, Chenopodiaceae and *Artemisia*, along with some cereal-type Gramineae pollen grains, are present in small quantities throughout the phase. Heath-types increase in terms of pollen representation. The decline of *Tilia* from 3% TLP to virtually zero is possibly more significant than it appears, given the under-representation due to low pollen productivity of this tree. This feature is comparable to a marked decline in *Tilia* from Fen Bogs further west in the North York Moors area (Atherden 1975), which was dated at 3,400 ± 90 years. The decline could be caused by a variety of factors. Turner (1962) suggested that the fall found around 500 BC in many pollen diagrams was caused by man. *Tilia* could be affected by the increasing acidity of the mineral soil to bog transition if the source was reasonably local. Pollen representation could be another factor; Bellamy et.al. (1966) suggested that high *Tilia* pollen counts were caused by differential preservation. *Quercus* declines over the same levels, perhaps lending weight to an anthropogenic cause of the decline of lime over the approximate period 1450 to 1000 BC.

All tree pollen percentages, and the total concentration of tree pollen (see figure 6.1.4.2), fall during phase A. *Corylus* is also affected, and an interpretation based on woodland clearance

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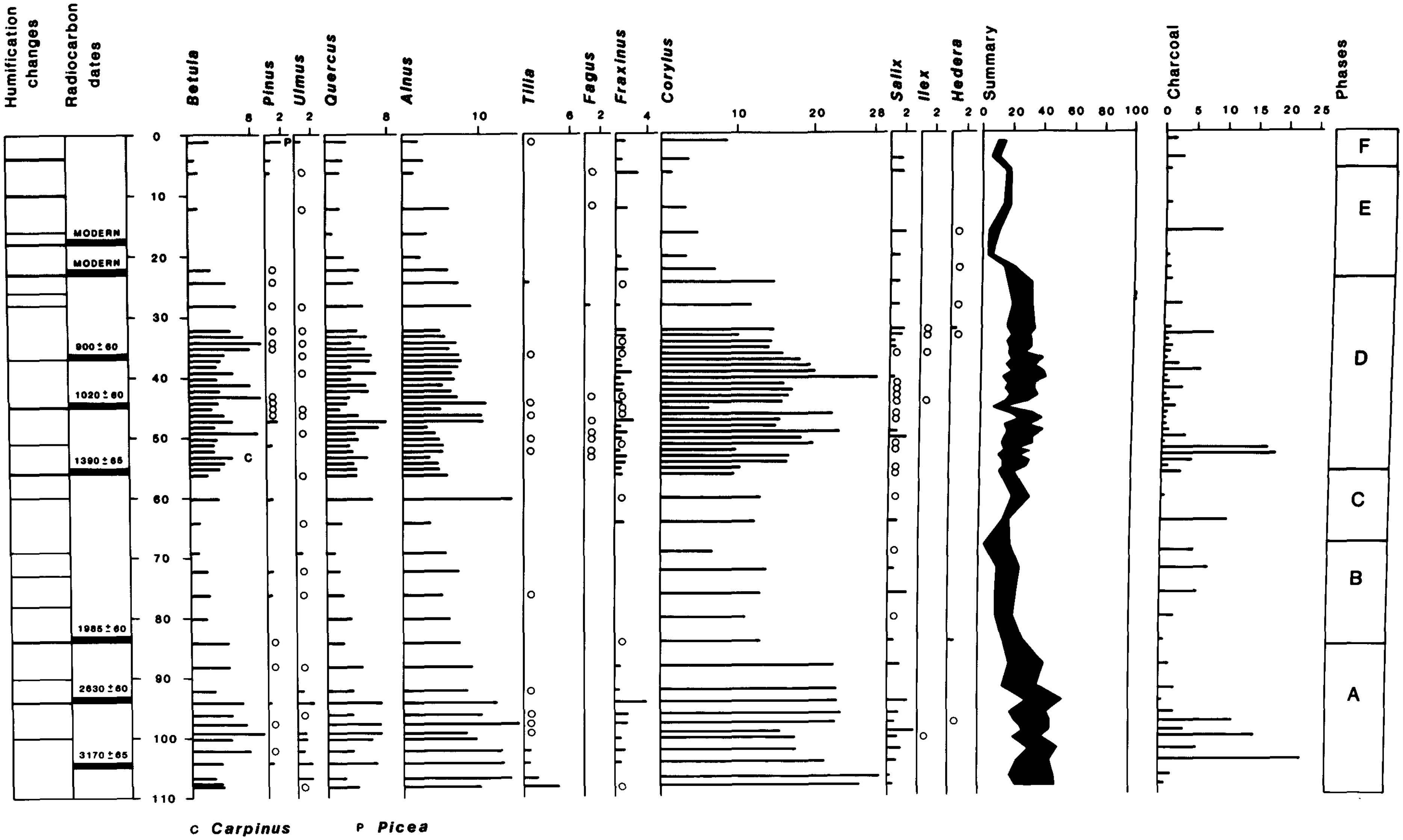
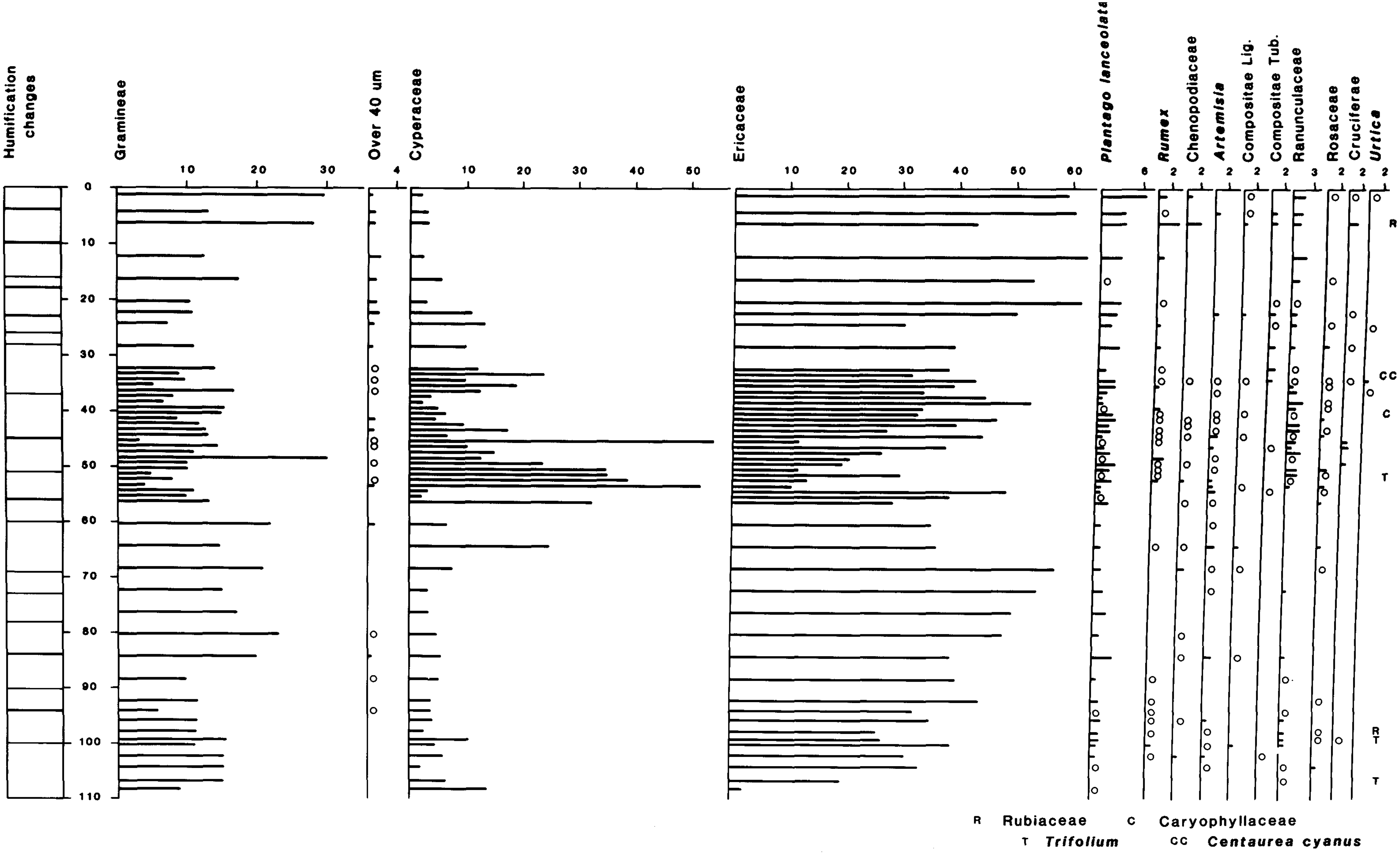
Figure 6.4. Microfossil diagrams from HB 1. a. Arboreal pollen, summary data, charcoal and concentration. b. Non-arboreal taxa. c. Selected non-pollen microfossils. Open circles represent less than 0.4 % of sum. Further explanation in section 5.5.4.

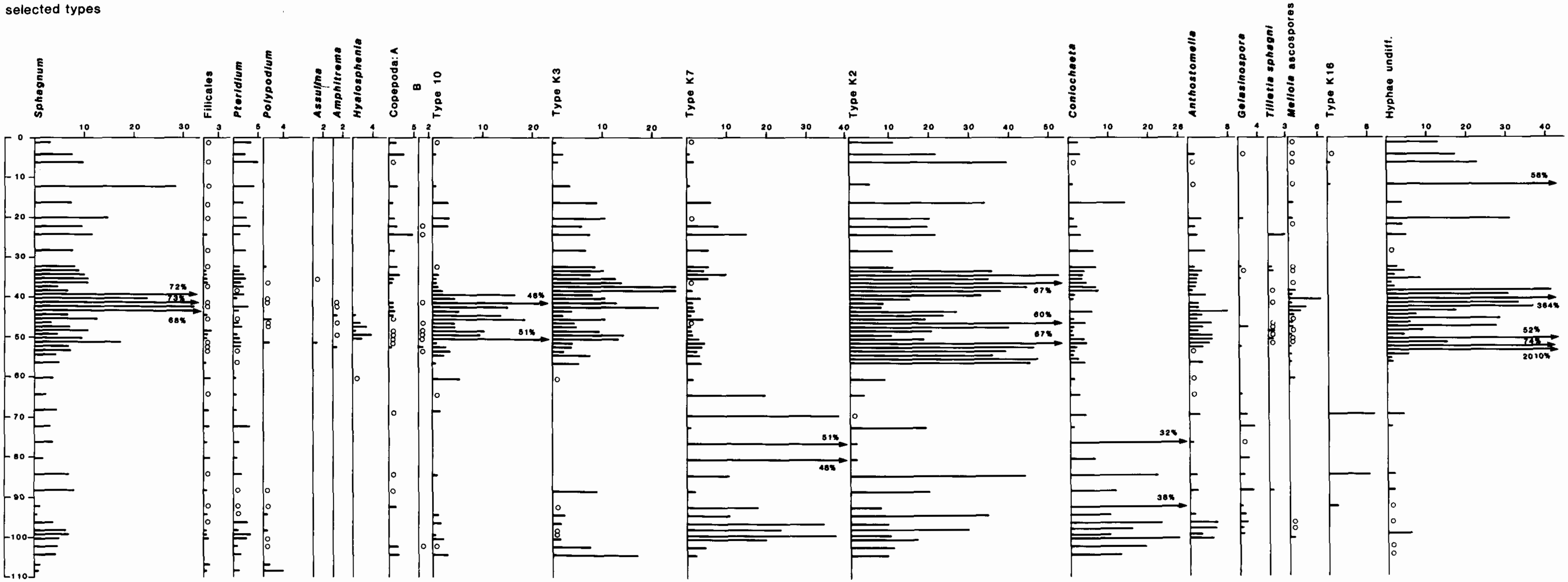
HB 1 Pollen diagram




Humification changes
Gramineae
Over 40 um
Cyperaceae
Ericaceae
Plantago lanceolata
Rumex
Chenopodiaceae
Artemisia
Compositae Lig.
Compositae Tub.
Ranunculaceae
Rosaceae
Cruciferae
Urtica
0
10
20
30
40
50
60
70
80
90
100
110
10
20
30
4
10
20
30
40
50
10
20
30
40
50
60
6
2
2
2
2
2
3
2
2
2
R
CC
C
T
R
T
T
R Rubiaceae
C Caryophyllaceae
T *Trifolium*
CC *Centaurea cyanus*

HB 1 Non-pollen microfossils:

selected types



by man is the most feasible. *Fraxinus* pollen becomes more frequent initially before declining again later in the phase. This could be explained by a temporary increase in ash, benefitting from the increased light available in partially cleared woodland, followed by a decline as clearance became more comprehensive.

A constant background of pollen types associated with open ground, pastoral and arable agriculture is shown throughout the phase. *Plantago lanceolata, Rumex,* Chenopodiaceae and *Artemisia*, along with some cereal-type Gramineae pollen grains, suggest that the valley sides and floor were used for agricultural purposes throughout the Bronze and Iron ages. (The beginning of the pollen record at Harold's Bog is not early enough to record the first exploitation of the area. Work by Simmons and Innes (1988) from a number of sites further north along the same ridge demonstrated the effect of Mesolithic land-use practices in the area. Phase HBA represents a compressed record of a long period of continuing or repeated woodland clearance and agriculture, beginning a long time after the Mesolithic). Early Bronze Age field systems have been recorded from the western side of Bilsdale (see figure 3.3) at Bumper Moor (Hayes 1963), and later Bronze Age barrows are common in the area. Spratt (1982) suggested that the hilltops were used for seasonal farming during this time. The palynological evidence supports the view of continued exploitation throughout phase A.

Regional syntheses by Jones et.al. (1979) and Simmons et.al. (1982) describes heathland increasing, with major deforestation, throughout the Bronze and Iron Ages. The results from HB 1 are entirely consistent with this.

The background of agriculture makes it more than likely that the hill tops would also have been subjected to some utilisation. The tree pollen percentages are not high enough to suggest on-site growth, as the lack of arboreal macrofossils suggests. The use of the land for grazing may well have affected the species balance at and around the sampling point, especially if burning was used to improve conditions.

Phase HB B. 85 - 68 cm. 300 - 635 AD

The opening of phase B is delimited by a repeated fall in the representation of *Corylus, Alnus, Quercus* and *Betula.* Charcoal values are slightly higher again. Cyperaceae and Gramineae increase in proportion and the Ericales pollen curve falls, although throughout the zone it is the most abundant type.

Phase B appears to show a second phase of tree clearance and the pollen taxa associated with anthropogenic activity are continuously present. Spratt (1982) stated that by the time of the Roman occupation the moors were as barren as today. The local pattern appears to be one of a dry surface vegetation assemblage, with Ericales pollen and fungal types K2, K7, *Gelasinospora* and *Coniochaeta.*

Phase HB C. 68 - 56 cm. 300 - 635 AD

Phase C is marked by a small increase in the representation of tree pollen, with increases in *Quercus* and *Fraxinus* for example. This increase is most notable at the end of the zone. When all tree species increase, it is possible that the change is due to a percentage effect rather than a vegetational change. A decline in the local pollen production of the bog plants could cause the rise in arboreal taxa shown in zone C. The changing concentration of tree pollen suggests, however, that although there is a notable change in the proportions of the major blanket mire types, at least part of the tree pollen percentage increase is attributable to increased pollen influx.

Cyperaceae become a major constituent of the apparently local vegetational assemblage in phase C, suggesting generally wetter conditions, or land use changes. *Anthostomella* ascospores increase and type K7 decreases, again indicating a slightly wetter surface environment.

Phase HB D. 56 - 24 cm. AD 635 - 1470.

Defining phase D is based on a regional approach. The bog types, which may have quite a wide pollen catchment, are dealt with in greater detail when the humification changes are discussed and their variations are profound.

A fairly constant pattern is shown by the tree pollen throughout phase D. The exceptions to this are the fall of *Corylus* between 40 cm and the upper limit of the phase, and a slight rise in the pollen percentages of *Salix*. *Corylus* is susceptible to both human and climatic pressures, and its fluctuations are difficult to interpret. The rise in *Salix* is only slight, but could be caused by the growth of willow species on the valley slope west of the sampling point, where small *Salix* trees are still growing.

The percentage variation shown by the other arboreal types can be explained to some extent by variations in local pollen productivity. The total tree and shrub percentage is generally between 30 and 40 %, indicating, according to the results of Tinsley and Smith (1974), the proximity of woodland. Again, the most likely source is the upwind, steep valley slope, where small patches of mixed woodland remain, and effective land improvement is very difficult.

Phase HB E. 24 - 6 cm. AD 1470 - 1850.

The boundary between phases D and E is a fall in tree pollen percentages to very low (<10%) levels. *Betula* and *Fraxinus* disappear from the pollen record completely and Quercus falls to 2%. *Alnus* is more variable but reaches a 2.2% minimum. *Corylus* declines to much lower levels, reaching 3.2% at 20 cm– the culmination of a decline from over 28% at 40 cm. The increase in Ericales pollen to 74% TLP could indicate that the low arboreal percentages are caused by swamping by local pollen production. Between 24 and 20 cm the frequencies of *Artemisia* and *Cerealia* type grains increases, along with a rise in the curve of *Plantago lanceolata.*

Atherden's (1975) zone G from Fen Bogs, zone WH 10 from West House Moss, 25 km north of Harold's Bog (Jones 1977) and the upper zones of the sites investigated by Simmons and Cundill (1974) all show a similar pattern of tree pollen below 10% and very high *Calluna* pollen frequencies. The overall pattern is comparable to that for the region as a whole by the eighteenth and nineteenth centuries AD.

The spores of *Pteridium* are increasingly abundant in phase E. This could be the beginning of the rise in this species that is now problematic to local farmers.

Phase HB F. 6 cm - surface, (Approx. 100 bp to present?)

Phase F is marked by a slight rise in tree and shrub pollen, notably *Betula, Pinus* and *Corylus*. *Pteridium* spores increase in abundance, reaching 10 % of the pollen sum.

The current mire surface around the point of sampling is extremely dry as a result of the drainage caused by peat cutting. Whether or not peat is still accumulating is debatable, the radiocarbon dates from the top 25 cm are questionable. A plantation of *Picea* 2 km distant could be the source of two *Picea* pollen grains recovered from the sample 2 cm below the surface.

6.2.5.2. Humification Changes.

This section examines the changes at each significant rise in the % transmission curve. If the curve reflects the local surface conditions then certain changes in the vegetation assemblage, and therefore in the pollen deposition pattern, would be expected (see section 6.1). In addition, changes in the importance of types perceived to be anthropogenically linked might shed light on any non-climatic causes of surface alterations.

The changes are numbered in order of decreasing depth, the depths given are the first samples to register the change, given in cm below the 1986 surface, and the dates are 2-sigma ranges estimated according to the method outlined above (chapter 5).

Humification change HB1.1, 93 - 94 cm. 900 - 600 BC.

The sharp rise in % transmission at 94 cm is marked by a fall in tree pollen across the change. In particular, the representation of *Betula, Alnus* and *Quercus* decreases. There is a rise in the proportion of heath and blanket bog types, especially Ericales pollen. *Sphagnum* spores are less frequent after the humification change.

This pattern appears to indicate a change to drier surface conditions. The interpretation of the changes is complicated, however, by the changing proportions and concentrations of arboreal pollen at this depth (see section 6.1.4). The rise in Ericales percentages could be caused by the fall in tree pollen influx rather than an increase in vegetative abundance. There is no palynological evidence, however, for an increase in surface wetness at this depth. The change in humification could be caused by a change in the vegetation at the precise sampling point, or a broader change could have occurred, but not shown up in the pollen record. Fungal types do show some change in the surface humidity, with types K2 and K7 declining in numbers along with T10 and *Coniochaeta* spores. It is possible that these variables respond to a change in the vegetation composition of the peat forming community exactly at the point of sampling.

The possibility of paludification caused by deforestation is unlikely due to the absence of evidence of the trees having been growing on the bog itself. There remains the possibility, though, that associated with what appears to have been the exploitation of the valley and/or valley sides, was increased usage and disturbance of the plateau.

The change falls into the pollen phase HBA, in which taxa linked to land use are present throughout. There are no notable changes in these curves at the 93 - 94 cm level.

Humification change HB1.2, 83 - 84cm, 170 BC - AD 130.

Taxa associated with anthropogenic activity are again present at the horizon of humification change HB1.2. *Plantago lanceolata* increases across the change as tree pollen frequencies continue to decline, especially that of *Betula*. Frequencies of Gramineae and Ericales pollen increase. The implications of the rise in Ericales were discussed above. A rise in grass pollen proportion could be caused by either a rise or a fall in the water table, or by an increase in the amplitude of fluctuation (see section 6.4). The results from the detailed section (see below) from this profile indicate that increases in the proportion of Gramineae pollen reflect a change to wetter local surface conditions. The evidence for this change from the microfossil assemblage is not conclusive, however. Type K2 and ascospores of *Coniochaeta* decline but K7 shows a slight increase in abundance.

Humification change HB1.3, 72 cm. AD 120 - 375.

The minor humification change at 72 cm is marked in the pollen record by a fall in tree pollen and also coincides with higher charcoal concentrations. Ericales pollen percentages are very high at this point, but immediately after the change, sharp rises in the curves of Cyperaceae and Gramineae could indicate a response to a higher water table. Types K2 and K7 decline across the humification change. K2 peaks at the point of change in direction of the humification curve, having a maximum value at the driest extreme before falling sharply as the mire surface appears to grow wetter.

Humification change HB1.4, 55 - 56 cm. AD 540 - 730.

The humification curve shows a major change to what can be interpreted as wetter local conditions at this point. Changes in the pollen and NPM curves also indicate that Harold's Bog became wetter around 1390 bp. Peaks in the representation of Cyperaceae pollen and *Anthostomella* spores at around this point and a rise in the pollen frequency of Gramineae coincide with an increase in the abundance of *Sphagnum* spores. Ericales pollen percentages rise temporarily, but then fall significantly. Type K2 again has its maximum value at the point of the graph, falling after the humification change. At or just above this level *Assulina* and *Amphitrema* tests are present for the first time and the curves of the spermatophores of Copepoda become constant. *Geoglossum* type spores increase as a proportion of non-pollen microfossils (NPMs). Types K3 and fungal hyphae increase dramatically in abundance.

Arboreal taxa do not show any significant change at this level and microscopic charcoal concentrations are low. The pollen of *Plantago lanceolata* and *Rumex* become less abundant. The possibility of the changes seen being caused by burning is not supported by the charcoal curve, although the relationship of microscopic charcoal to local fire history is dubious (Clark 1988). Other surface disturbances in the form of grazing, trampling or drainage are equally difficult to detect. In the absence of conclusive palynological evidence either way, the similarity between the timing of this change and that from the other sites indicates the possibility of a climatic cause for HB1.4.

Humification change HB1.5, 44 - 45 cm. AD 890 - 1160.

Changes in the pollen assemblage across the level of the humification change HB1.5 indicate that the change represents a change to wetter local surface conditions. The pollen percentages of Cyperaceae and Gramineae increase at the expense of Ericales. Representation of Copepoda increases and K7 frequencies fall shortly after the humification change. The spores of *Geoglossum*-type fungi increase just after the humification change. Possible indicators of anthropogenic activity do not on the whole increase, *Plantago lanceolata* decreases slightly and charcoal concentrations remain relatively low.

Humification change HB1.6, 36 - 37 cm. AD 1000 - 1260.

The rise in % transmission at 37 cm coincides with an overall fall in tree pollen, although *Betula* increases slightly. The pattern of HB1.4 and 1.5 is to some extent repeated, with Ericales being replaced by sedges and grasses in the pollen assemblage. Copepoda increase in abundance, as do *Geoglossum*-type fungal remains.

Again, HB1.6 can be interpreted as a change to wetter local conditions. There is no evidence of burning being the cause, unless the success of Cyperaceae can be interpreted as such (see section 6.4).

Humification change HB1.7, 22 - 23 cm, AD 1365 - 1530

The humification change at 23 cm coincides with a stratigraphic change to a *Sphagnum*-rich peat type. Ericales pollen increases in frequency, as do the spores of *Sphagnum*. This appears to show a contradiction in directional response. However, it is possible that a *Calluna*-*Sphagnum* assemblage replaced the more mixed blanket bog vegetation at the site, the pollen frequency of Cyperaceae declines markedly. Another possibility is that increased surface wetness caused the wetter locations within the pollen catchment to become overwhelmed with *Sphagnum*, causing a decline in sedges. The relative proportion of Ericales pollen would therefore increase if the heather species held their ground in the drier locations.

Fungal type K7 declines, while T10 and K3 rise in frequency indicating a local change to wetter conditions.

Humification curve HB1.8, 17 - 18 cm. AD 1500 - 1630.

The uppermost humification change that cannot be immediately attributable to undecomposed root material coincides with a slight increase in arboreal pollen percentages and an increase in Gramineae and Cyperaceae. The Ericales pollen curve falls temporarily. Types K7 and K2 decrease as proportion of NPMs as *Geoglossum* type, *Assulina* and *Amphitrema* increase. HB1.8 appears to be a change to wetter local surface conditions.

Summary of Humification changes

The pattern of the humification changes at HB1 indicate that out of the eight changes described, the lower two are not reflected by local vegetation changes. HB1.3 - HB1.6 and HB1.8 are paralleled by changes in the mire type pollen frequencies that seem to indicate wetter local conditions. HB1.7 shows a change in vegetation that may or may not be indicative of wetter conditions. There is no clear evidence as to the cause of the changes. The dates of the changes are compared to those from elsewhere in figure 8.1. which indicates that changes coinciding with HB1.3, HB1.4 and HB1.8 might also be recorded from the other sites.

6.2.5.3 Detailed Section, 56 - 34 cm depth. AD 635 - 1200.

For a section in the centre of the profile, pollen and NPMs were analysed every centimetre. This section is outlined in figure 6.4 and was selected to show a series of what appear to be wet-dry-wet phases in the humification curve. The results from this analysis allow the relationship between changing microfossil abundances and humification to be examined in detail.

The most important microfossil taxa are compared to each other and to the humification curve below. The patterns of changing pollen frequencies are inevitably linked, as they are calculated as percentages. Additional difficulties in interpretation are caused by the non-specific identification of the most abundant bog taxa.

Ericales pollen.

The Ericales curve generally records higher percentages when the % transmission is low. This trend is not consistent however, as the humification change at 45 cm is immediately followed by a rise in Ericales (see figure 6.4). This could be caused by the peak in Cyperaceae pollen at the 45 cm level, possibly caused by the presence at the sampling point of *Eriophorum* (see figure 6.2). A significant decline follows the change at 56 cm and a smaller one follows the wet shift at 38 cm. If the humification curve is a reliable indicator of surface wetness, then the Ericales pollen curve is an indicator, though not a constantly reliable one, of dry phases. This is consistent with the pattern expected from the discussion in section 6.4 with the added influence of the unreliable relationship between pollen representation and vegetative abundance.

Cyperaceae.

Sedge pollen shows great variability in frequency between consecutive samples. Despite the erratic peaks at 56, 53, 50 and especially 45 cm, the underlying trend appears to be one of concordance between % transmission and % Cyperaceae pollen. The pollen curve rises just after the humification change at 56 cm, but is more in step with the later changes. Possible reasons for the time-lag are discussed in section 8.5.

Gramineae.

The percentages of Gramineae pollen quite consistently rise at or just after points where the humification curve indicates a wetter local environment. Whether this is an effect of the percentage basis of the data or due to the vegetative response of grass species to changes in the water table is unclear.

Sphagnum.

Sphagnum spores increase dramatically at the level associated with a secondary wet shift at 50-51 cm. The *Sphagnum* data are not included in the pollen sum, and hence are independent of fluctuations in the taxa above. It appears that a wet shift results in a rise in the frequency of *Sphagnum* spores, and that the result of a wet-shift is an increase in the proportion of sedges and/or *Sphagna.*

Type 10

Type 10 fungal spores show an erratic distribution over the detailed section. If the evidence from the Ericales pollen data and the humification curve is accepted, a maximum at 41 cm depth of 45% of NPMs coincides with a period of apparent drying of the peat surface. T10 remains are also high at 50+, where a seemingly wet surface is indicated by high sedge pollen representation and a low degree of humification.

Type K2

Type K2 peaks at levels where the transmission values are low. Figure 6.1.6 demonstrates this, showing a near mirror-image relationship between the two variables.

Type K7

Type K7 is not as abundant through the detailed section as it is below it, its frequency is significantly reduced at the 56 cm humification change. A further reduction in the relative abundance of Type K2 occurs just after the 45 cm change. These microfossils appear to show a preference for drier conditions.

6.2.5 Summary.

It is difficult to avoid circular arguments in this type of comparative analysis. There is no one variable that can be independently, safely verified as an indicator of surface conditions. Aaby and Tauber (1975) verified the humification method for raised *Sphagnum* bogs by correlation with microfossils. The species used are too rare in the relatively dry blanket mires for this to be repeated in the current study. The best use of the data seems to involve using a suite of variables of at least partially understood ecology, and gradually increasing the number of useful data sources by correlation.

The examination of the detailed section above appears to indicate a pattern consistent with a series of changes from "wetter" to "drier" conditions, with sedges, grasses and *Sphagnum* gaining from the wet-shifts, and Ericales declining along with the spores of K2 and K7. If the interpretation of one or more key the variables is correct, then it is likely that all the interpretations are valid. If they are wrong, then the whole interpretation is incorrect.

It appears that this analysis has confirmed that the humification curve is related to changes in surface conditions, and that the direction of response is consistent with drier conditions producing lower % transmission.

6.3 MIGNEINT

Results are presented in the following order;

6.3.1. Stratigraphy.
6.3.2. Humification analysis.
    .1) MIG 1, .2) MIG 2, .3) MIG 3.
6.3.3. Radiocarbon dating.
6.3.4. Microfossil analysis.
    6.3.4.1. MIG 1
        i.) General vegetation pattern.
        ii.) Humification changes.
        iii.) Detailed section.
    6.3.4.2. MIG 2, (subdivided as above)
    6.3.2.3. MIG 3.
5. Summary.

6.3.1 Stratigraphy.

Figure 6.2 shows the stratigraphic divisions of the Migneint profiles. The divisions are in many cases less than definite, as the figure suggests, with a gradation rather than a clearly defined boundary.

6.3.2 Humification analysis.

6.3.2.1 Migneint 1.

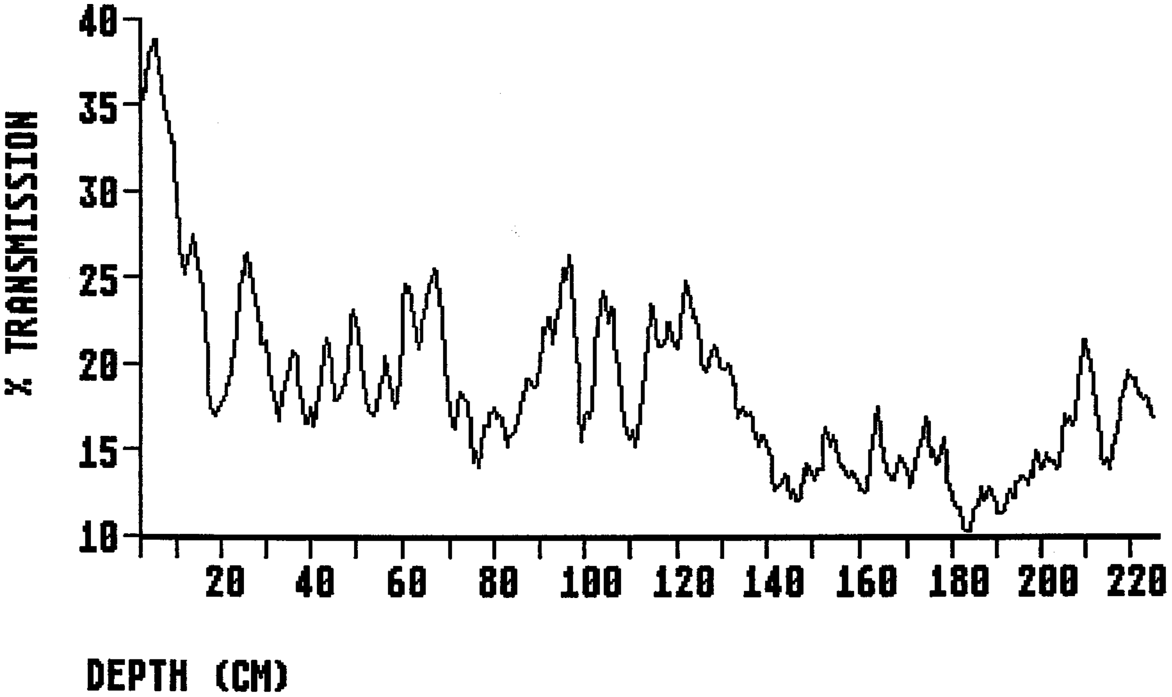
The humification curve from MIG 1 is shown in smoothed form in figure 6.7. Detailed sections of the curve are shown along with microfossil data in figure 6.11 and are discussed in section 6.3.2.4.

Major changes, as defined for Harold's Bog, are recorded at 213, 182, 141, 71 and 20 cm depth. Other changes in the direction indicating a wet-shift, are recorded first from depths of 188, 174, 170, 165, 160, 146, 125, 110, 97, 81, 75, 64, 59, 54, 45, 39, and 12 cm. These have been assigned approximate ages and plotted on figure 8.1.

The possibility of a cyclic element in the data is evident from the dates of these minor changes. A possible interpretation of the pattern as a whole is that a continuously variable, or even periodic, pattern of humification changes is superimposed on a pattern involving less frequent, irregular, higher amplitude changes.

Figure 6.7. Humification curve, MIG 1. Increased % transmission indicates less humified peat.

MIG 1; HUMIFICATION DIAGRAM (SMOOTHED)



6.3.2.2 Migneint 2.

Humification data from MIG 2 are presented in two diagrams. Figure 6.8 shows a smoothed (running mean of three consecutive samples) curve for the whole sampled profile. figure 6.8 also shows the lower 25 cm (representing half the time-span of the whole curve) against an expanded y-axis. This is justified by the inevitable loss of amplitude with age of the peat, as older samples will be more humified. The fluctuations in the lower part of the profile may be no less important as the more immediately noticeable ones at 42 and 23 cm.

The changes in humification within the MIG 2 profile can be described best as two types of features. These are major and minor, the definitions being those used in section 6.2.2 for the HB 1 profile. Major changes are first recorded at 42, 23 and 12 cm. These levels have been dated with mixed success, as shown above. Calibrated, interpolated dates for these changes are given in table 8.1 and figure 8.1, although the possibility of the dates being "too young" is again stressed. The change at 42 cm lasts for 14 samples (7 cm) and coincides with a change in stratigraphy. Minor changes in humification are shown on figure 6.8, and are first shown in the unsmoothed data by increases in % transmission at depths of 64, 61, 50, 43, 29 and 15 cm.

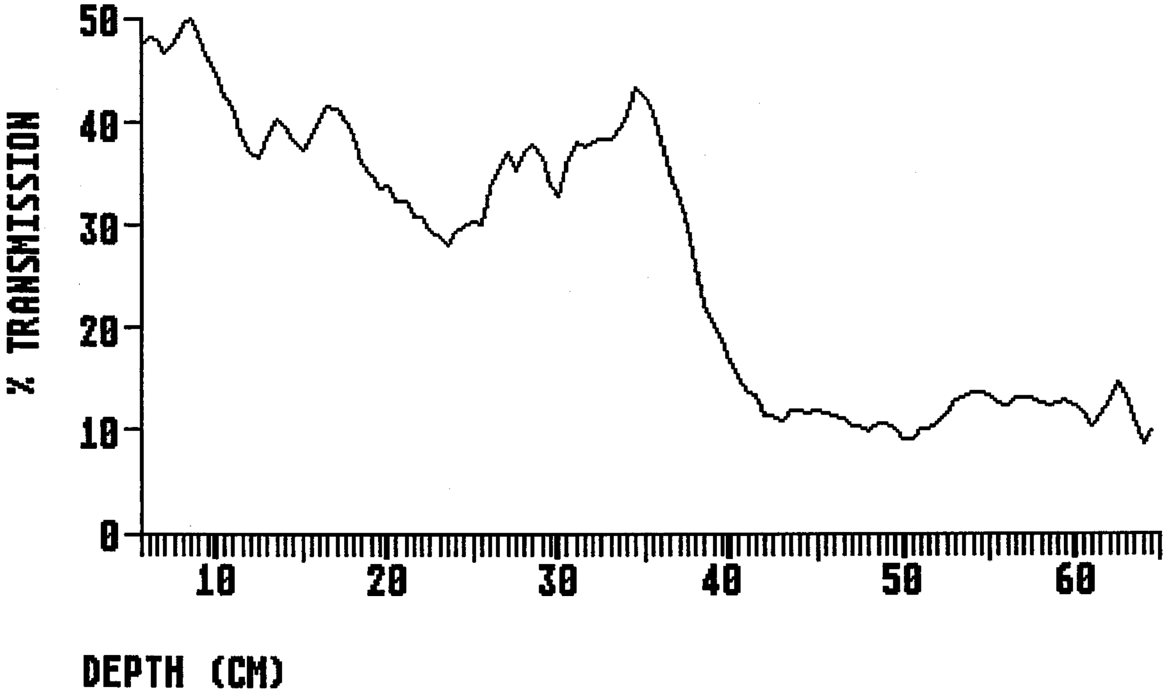
6.3.2.3 Migneint 3.

The MIG 3 humification curve is presented in the same way as that for MIG 2. Major changes (figure 6.9) are recorded at 26 cm and at 10 cm. The extreme rise in transmission between 26 and 21 cm depth is due to a change in the peat constituents, with *Sphagna* growing in importance.

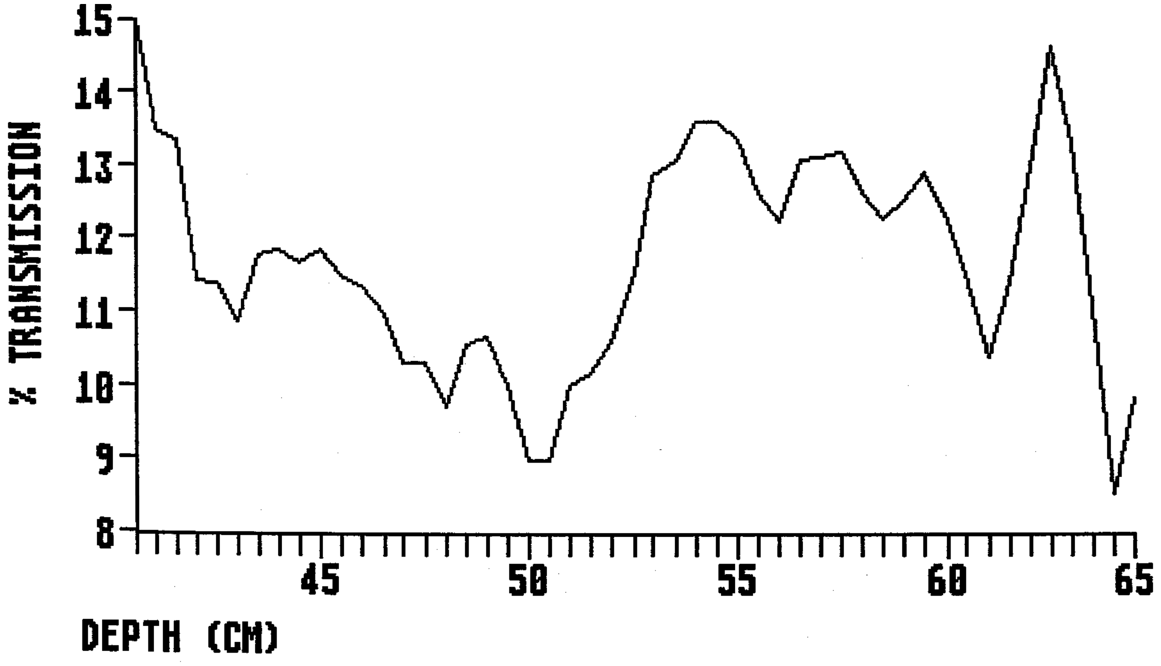
There are many smaller amplitude variations in the curve, however, and these are illustrated by expanding the y-axis for the lower part of the profile (figure 6.9, lower curve). Again, an apparently periodic sequence is recorded. Wet-shifts are recorded at depths of 70, 64.5, 53, 49.5, 43, 38.5, 33, and 12 cm. Unfortunately the radiocarbon determination for the most significant humification change returned a "modern" result; as such the dates for each sample are based on interpolation from the lowest date only and assume a linear growth rate and a present-day age for the surface. The tentatively assigned dates for the possible wet-shifts are recorded on figure 8.1.

Figures 6.8. and 6.9. Humification curves, MIG 2 and MIG 3. Whole profiles and lower sections.

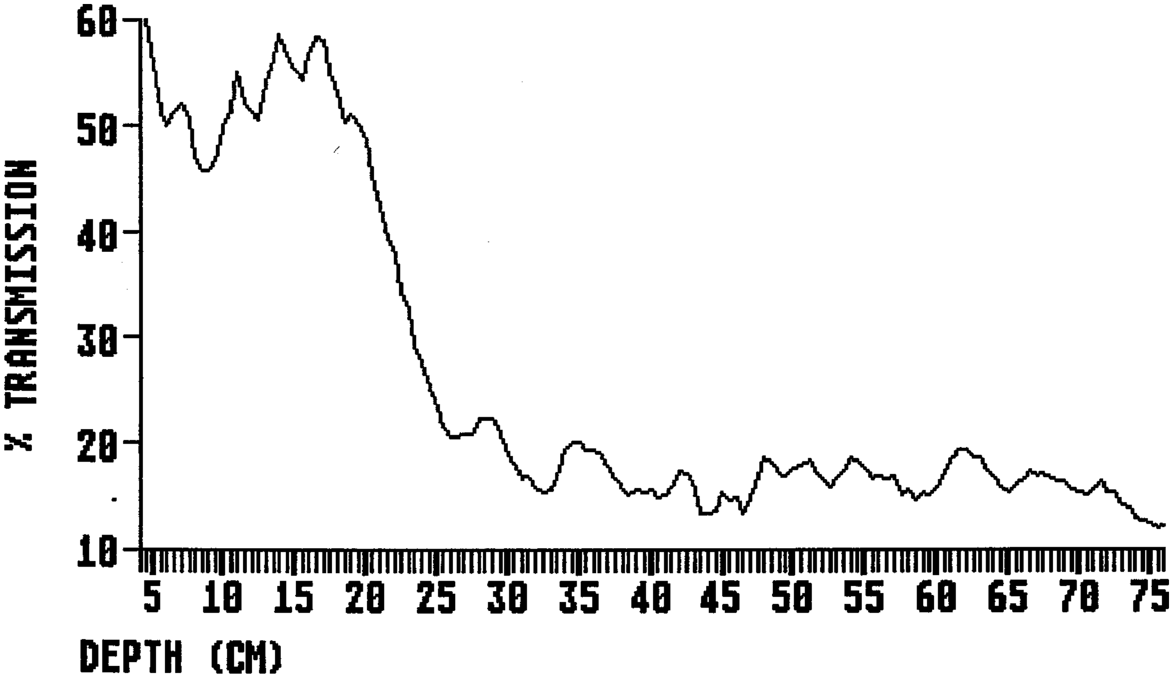
MIG 2; HUMIFICATION DIAGRAM (SMOOTHED)



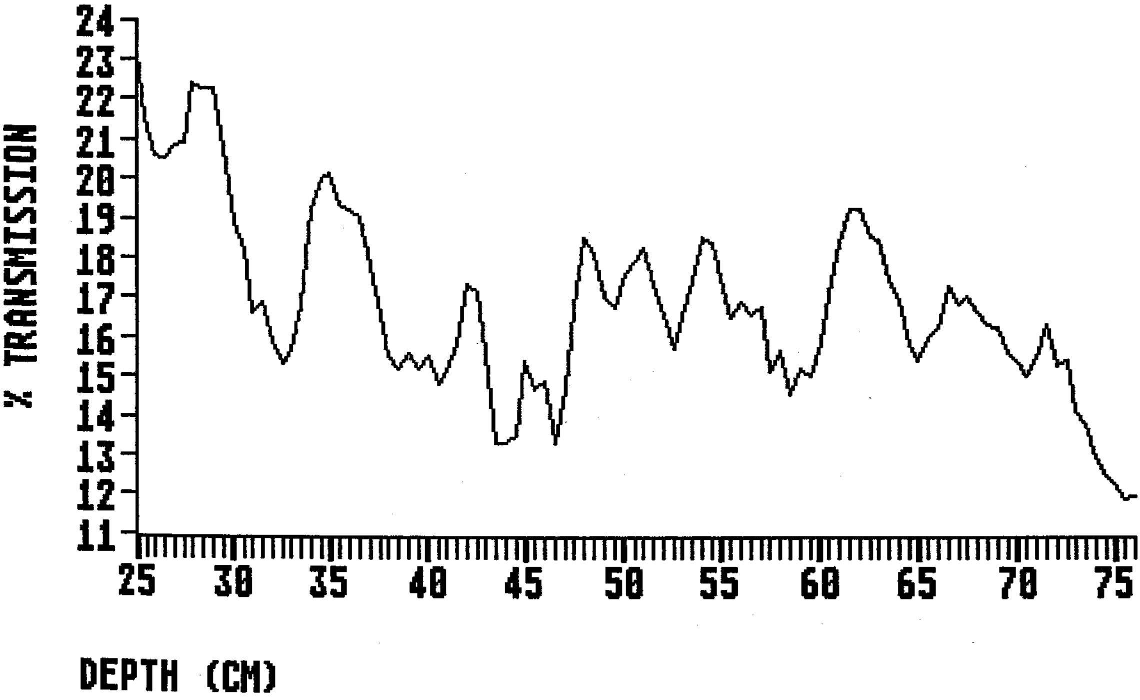
LOWER SECTION OF MIG 2, SMOOTHED HUMIFICATION DATA



MIG 3; HUMIFICATION DIAGRAM (SMOOTHED)



LOWER SECTION OF MIG 3; HUMIFICATION DATA



6.3.3 Radiocarbon dating.

Depth (cm)	Lab. Code	RC Age (Yr.bp)	Calibrated Age
MIG 1			
18-19	SRR-3519	370 ± 60	AD 1420-1650
69.5-70.5	SRR-3520	1400 ± 70	AD 530-771
139-140	SRR-3521	2290 ± 60	483-210 BC
181-182	SRR-3522	3195 ± 65	1681-1321 BC
221-222	SRR-3523	3625 ± 85	2275-1740 BC
MIG 2			
11-13	SRR-3524	Modern	-
23-24	SRR-3525	(150 ± 60)	-
41-42	SRR-3526	1695 ± 55	AD 220-430
64-65	SRR-3527	3480 ± 65	AD 1970-1680
MIG 3			
23-24	SRR-3528	Modern	-
78-79	SRR-3529	1860 ± 65	AD 20-260

Table 6.2. Radiocarbon dates from Migneint 1, 2 and 3.

The table above shows that some of the upper dates in the profiles have returned a "modern" date. In the case of the Harold's Bog samples these were attributed to contamination by modern root material. The same explanation can be given for the dates at MIG2 11-13 an 23-24 cm, and at 23-24 cm from MIG 3. The stratigraphy of this profile is also different, lacking a top section of uncompacted material found at MIG 2 and 3. This layer could have allowed penetration by modern roots in the post-industrial or even post-bomb time period. In interpreting the rest of the dates obtained, however, it must be assumed that part of the material sampled was derived from younger roots and that to some extent all the dates are "too young" (see also section 9.1.1).

6.3.4 Microfossil analysis.

6.3.4.1 MIG 1

i). General vegetation pattern.

The pollen diagram from MIG 1 (figure 6.10), is divided into 5 phases. As in the case of the Harold's Bog profile they are based on the "regional" pollen component where possible. Their purpose is to clarify the overall context of the changes in local bog vegetation and to allow comparison with the other Migneint profiles and with other studies from the region.

Phase MIG1 A. 227-208 cm. 2,000 - 1800 BC.

Phase A is marked by fluctuating tree pollen percentages and concentration, in particular showing a sharp fall at 212+. The values of tree pollen are between 30 and 40 %.

This appears to indicate either open woodland around the site or a source forest some distance away. Indications of a variety of tree pollen types and the preserved macro-remains of tree stumps and roots suggest an open, mixed woodland during phase A. There is some evidence in the pollen record for disturbance, with reasonably high charcoal concentrations and rapid fluctuations in the tree pollen curve. Records of *Melampyrum* pollen have been associated with the human disturbance of similar ecosystems (Simmons and Innes 1988, Moore et.al. 1985, Hicks 1976), either as indicating openings in woodland or burning. The small representation of *Melampyrum* at 213, 214 and 215 cm, coinciding with the temporary decline in tree pollen percentage could be interpreted as evidence of temporary human influence on the vegetation cover. Other so-called anthropogenic indicators (*Rumex, Plantago lanceolata*) are very rare at these levels.

Phase MIG1 B. 208-152 cm. 1800 - 720 BC.

The boundary between phases A and B is marked by the decline of *Corylus*, and also of *Tilia*, which is no longer consistently represented above 208 cm. Phase B is a period of declining tree pollen, with *Corylus* remaining steady after the initial decline. *Quercus* remains

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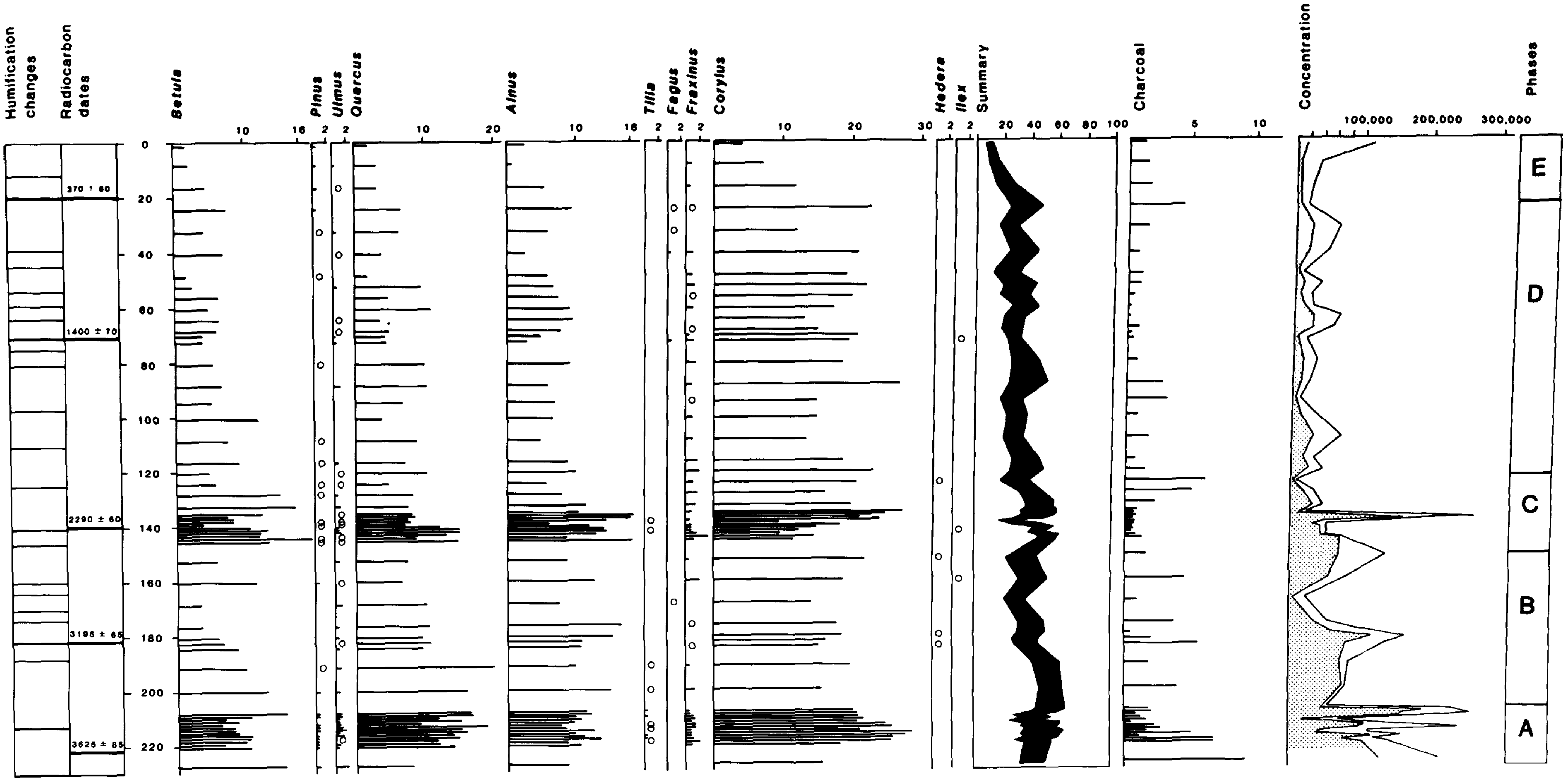
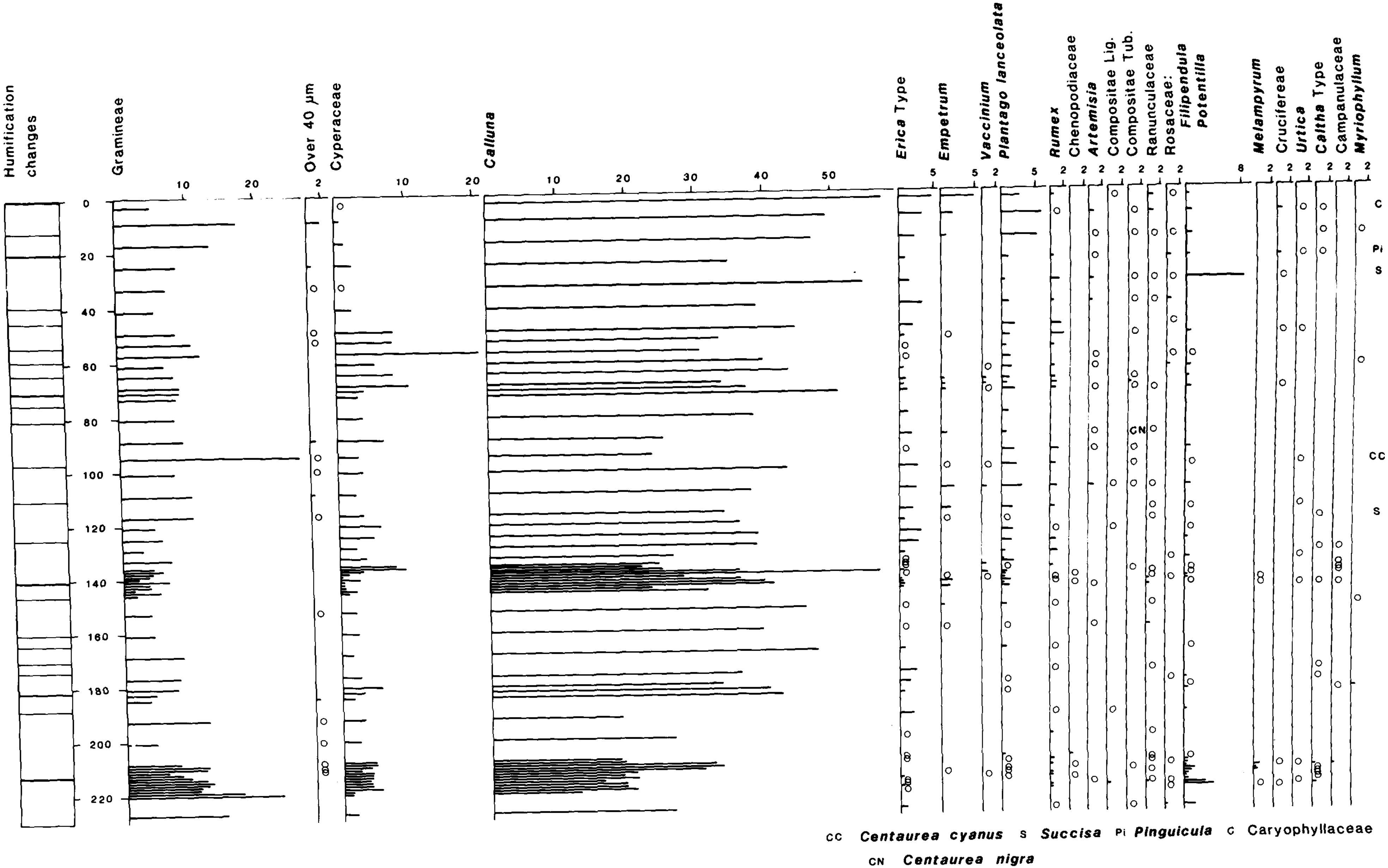
Figure 6.10. Pollen diagram, MIG 1. a. Arboreal taxa, summary, charcoal, concentration b. Non-arboreal taxa, c. Non-pollen microfossils.

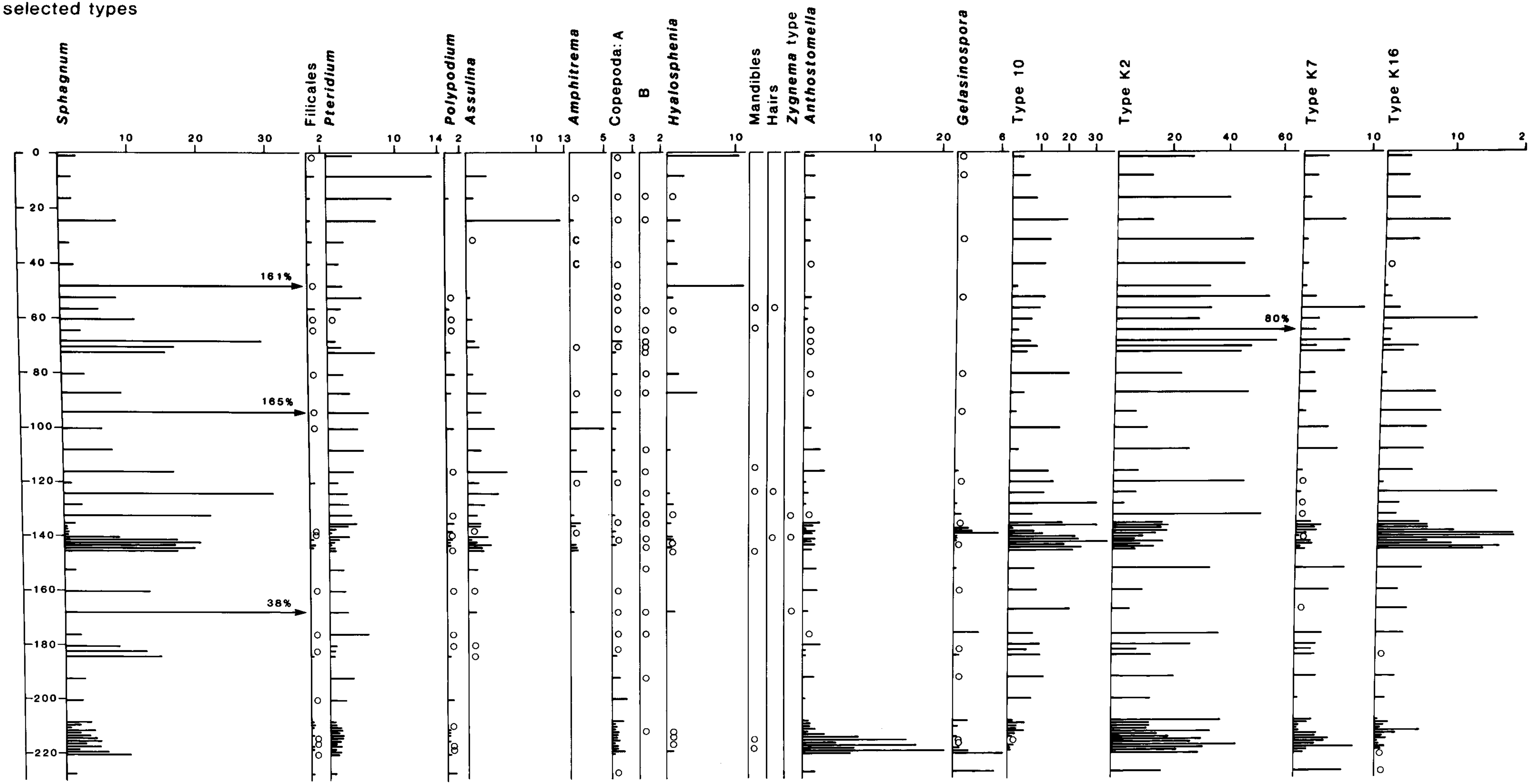
MIG 1 Pollen diagram




Humification changes
Gramineae
Over 40 µm
Cyperaceae
Calluna
Erica Type
Empetrum
Vaccinium
Plantago lanceolata
Rumex
Chenopodiaceae
Artemisia
Compositae Lig.
Compositae Tub.
Ranunculaceae
Rosaceae: *Filipendula*
Potentilla
Melampyrum
Cruciferae
Urtica
Caltha Type
Campanulaceae
Myriophyllum
0
20
40
60
80
100
120
140
160
180
200
220
10
20
2
10
20
10
20
30
40
50
5
5
2
5
2
2
2
2
2
2
2
8
2
2
2
2
2
2
CN
C
Pi
S
CC
S
CC Centaurea cyanus
S Succisa
Pi Pinguicula
C Caryophyllaceae
CN Centaurea nigra

MIG 1 Non-pollen microfossils:

selected types



c *Callidina angusticollis?*

at or around 10 % of TLP, *Betula* in particular falls other than at the exceptional 160 cm level. This may indicate that the trees declining where those growing on the mire. The concentration curve shows total trees and total pollen rising and then falling to a minimum at 168 cm. As tree pollen percentages and concentrations move in different directions, this possibly reflects changes in peat accumulation rate over the phase.

Heath types increase in phase B, including the *Erica tetralix/cinerea* type and in particular *Calluna.* Cyperaceae percentages are generally low, with *Gramineae* pollen and *Sphagnum* spores fluctuating considerably. The overall pattern appears to be one of heath-dominated blanket bog vegetation expanding at the expense of tree types. Frequencies of *Plantago lanceolata, Rumex* and *Potentilla* are all increased in phase B, indicating more open habitats and possibly grazing (see section 6.1).

Phase MIG1 C, 152-123 cm. 720 - 150 BC.

Phase C is delimited by increased total tree pollen, less *Corylus* and at the outset by a reduction in *Calluna* percentages. The generally increased arboreal pollen frequencies are, however, interrupted by a sharp decline at the 140 cm level, the events of which are described and discussed as humification change MIG1.3. There is some evidence of a repeat of the pattern in Phase A, as increases in the pollen frequencies of *Plantago lanceolata* and *Melampyrum* precede the drop in tree pollen.

The later part of Phase C is marked by a change in the bog flora to a community including more Cyperaceae and less *Calluna.* Non-pollen indicators of relatively wet conditions also increase in Phase C. Phase C appears, then, to have been a period of change in the peat growth characteristics, including a dramatic event at around 140 cm.

Phase MIG1 D, 123-24 cm. 150 BC - AD 1450.

This rather broad phase is delimited on the basis of fairly constant arboreal pollen frequencies (20-24 % of TLP). The percentages of *Plantago* and of *Rumex* are higher throughout the phase, while charcoal concentrations are generally low.

The relative frequencies of the principal blanket bog taxa vary considerably throughout the period, with occasional peaks in Gramineae types, a notable decline in *Calluna* at 88-94 cm, and a period of abundant Cyperaceae between 48 cm and 68 cm.

The overall pattern of phase D could be one of reduced trees, no longer growing on the bog-covered plateau area. Mighall and Chambers (1989) noted the role of man on deforestation at Bryn y Castell, 8 km West of the Migneint site. Further work has shown the localised nature of this feature (Mighall, pers. com.), which is apparently confirmed by the lack of a notable clearance phase within phase MIG1D, although the sampling interval is broad.

The bog vegetation may have been used for grazing, peaks in the frequency of *Potentilla*, especially at the 68 cm level, could indicate periods of grazing pressure, with a series of hydrological changes reflected by the changing abundance of *Calluna*, *Empetrum*, Gramineae and Cyperaceae.

Phase MIG1 E, 24-0 cm. AD 1450 - 1830?

Phase E is marked b a decline in AP percentages to less than 10 %. *Corylus* declines dramatically, along with *Alnus* and *Betula*. Frequencies of Cyperaceae are very low in phase E, while *Calluna* and *Empetrum* increase, along with *Erica tetralix/cinerea* type and *Plantago lanceolata*.

The fall in representation of arboreal taxa is indicative of clearance of the landscape to a totally open plateau similar to the current scene without coniferous plantations. The phase can be correlated with the later part of phase A of Mighall and Chambers (1989), indicating regional deforestation. The changes in the mire-type frequencies are indicative of a change to drier local conditions which could have been caused by the onset of erosion of the peat allowing freer drainage. The phase covers a final decline in the native trees of the region, corresponding to the present treeless landscape other than plantations. The lack of a *Pinus* rise shown from MIG 2 may indicate that the top part of the MIG 1 profile has been truncated, possibly by drying due to erosion.

(ii) Humification changes.

This section describes some of the vegetational changes inferred from microfossil data that coincide with the major humification changes.

Humification change MIG1.1. 213 cm. 2150 - 1650 BC.

Humification change MIG1.1 is part of the detail section discussed below. The microfossil changes can be summarized as follows. A fall in arboreal pollen, accompanied by an expansion of *Calluna*, appears to precede the rise in % transmission. The arboreal pollen percentage recovers after the 213 cm humification change, followed by a return to more humified peat.

The change could have been caused a temporary removal of trees (see discussion in section 6.3.4.1, iii). The expansion of heath types shows the change to a more open environment.

Humification change MIG1.2. 182 cm. 1680 - 1320 BC.

The humification change towards apparently wetter conditions at a depth of 182 cm is marked by an increase in the representation of Gramineae and Cyperaceae and a temporary decline in *Calluna*. *Erica tetralix/cinerea* type increases slightly. *Betula* pollen becomes less frequent across the change while *Alnus* increases. Tree pollen in general remains fairly constant. *Sphagnum* spores become slightly less abundant between 184 and 180 cm, but remain well represented (8-12% of TLP).

The implications of these changes are that conditions became wetter in the vicinity of the site as well as at the sampling point. The sharp fall in pollen concentrations at this depth implies a faster growth rate following a change to wetter surface conditions. The cause of the change cannot be explained by changing tree abundance, but high charcoal values around this level may imply local burning, the possible effects of which include a change in vegetation and degree of humification as implied by the microfossil data.

Humification change MIG1.3. 141 cm. 525 - 250 BC.

The first sample to record this humification event is at 141 cm depth. The sequence of events is again the best guide to the possible cause of the change, and is discussed in detail in section 6.3.4.1, iii.

The conclusion of the discussion is that a change to wetter surface conditions took place, but that the relationship between degree of humification and changing vegetation at this depth is unclear.

Humification change MIG1.4. 110 cm. 90 BC - AD 210.

The humification change MIG1.4 has not been examined in detail, but pollen and spore counts from above and below can be used to give some idea of the coincident vegetation changes. *Calluna* appears to increase in abundance, remaining at high levels after the humification change. *Plantago lanceolata* and *Rumex* are relatively frequent, which with a small decrease in the already low proportion of arboreal pollen perhaps implies an increase in anthropogenic activity within the pollen catchment. The frequency of *Sphagnum* spores decreases slightly, while that of *Pteridium* increases. Type 10 and *Assulina* decline, while K2 increases in abundance. Pollen concentration decreases following the rise in % transmission, indicating a faster growth rate.

The seemingly contradictory evidence of humification and microfossil curves can be reconciled if the change to surface wetness is considered a very local event. The local indicators of NPM types show supposed wet and dry indicators providing contradictory information. There is no evidence of a wider scale change.

Humification change MIG1.5. 97 cm. AD 140 - 370.

The opposite can be said of the change 13 cm higher in the profile. *Calluna* pollen becomes much less frequent, being replaced by Gramineae. *Sphagnum* frequencies reach very high values just after the humification change, possibly indicating relatively wet local conditions. Rhizopoda are well represented, but show a slight decline. Copepoda remains increase in abundance. There is no significant change in the tree pollen curve.

This wet-shift appears to have been reflected in the vegetation composition of the pollen catchment, and cannot be attributed to tree clearance or any detected land-use change.

Humification change MIG1.6. 71 cm. AD 530 - 770.

The most significant microfossil change at this level is a significant increase in the representation of Cyperaceae. The *Calluna* curve shows a temporary decline. Arboreal pollen and types associated with the impact of man show no significant changes. *Sphagnum* spores are well represented, along with Rhizopoda and Copepoda remains.

This can be interpreted as demonstrating a change to wetter surface conditions in the vicinity of the site. The humification change and rise in Cyperaceae is followed by a peak in frequency of *Potentilla* pollen. This could be caused by an increase in grazing or burning, or by an increase in abundance allowed by the reduction of *Calluna*.

Humification change MIG1.7. 32 cm. AD 1200 - 1435.

The humification change at 32 cm is marked by a subsequent increase in the representation of Cyperaceae. Following a peak at the point of inflection of the humification curve, the frequency of *Calluna* pollen decreases. The *Potentilla* pollen curve again peaks after the humification change at 32 cm. *Assulina* tests represent a maximum of 12% of NPMs at the subsequent level.

The humification change appears to be matched by a small change to wetter mire conditions in the pollen catchment, although the rhizopod tests may indicate a more significant change at the sampling point. There are no obvious signs of the cause of the change; tree pollen is so low as to preclude a clearance explanation.

Humification change MIG1.8. 20 cm. AD 1420 - 1650.

The rise in % transmission at 20 cm depth is accompanied by changes in the microfossil assemblages above and below. Tree pollen and *Corylus* decrease significantly, to be replaced in the pollen sum by heath types, *Calluna*, *Erica tetralix/cinerea* type and *Empetrum*. The Cyperaceae are barely represented. The Gramineae pollen curve begins to increase, while *Plantago lanceolata* reaches a peak of 6% immediately after the humification change.

There is no evidence from the pollen diagram of a change to wetter conditions in the vicinity of the sampling point. There is a significant humification change, however, and a reduction in pollen concentration implying faster peat accumulation growth rates after the change. It is possible that the change was very localised. It is also possible that the effect of reduced trees and shrubs, and the expansion of heath types caused the record to be obscured. It is also possible that the expansion of *Calluna* and *Empetrum* marks the beginning of the drying out of the surface at the MIG 1 site due to erosion, and that the humification change has no local or regional significance.

This range of possibilities emphasises the importance of inter- and intra-site correlation in detecting climatically controlled wet-shift features.

(iii) Detailed sections.

Two sections of the MIG 1 profile have been analysed in greater detail than the rest of the core to investigate the changes across humification boundaries. They are selected to include or coincide with features that the % transmission curve suggests are wet-shifts.

The first of these is the section illustrated by figure 6.11. This is the interval between 220 and 208 cm, dated at between 1970 BC and 1840 BC. The humification feature selected is a fall and rise in % transmission, i.e. a temporary period of well-humified peat terminating around 212 cm with an inferred wet-shift.

Figure 6.11 shows the relative changes of % tree pollen, % *Calluna*, % Gramineae and the degree of humification in terms of % transmission (%T). Each variable is plotted on a different horizontal scale to show the full range in each case, and the shading is for ease of visual appraisal.

A relationship between the relative changes of arboreal pollen frequency and degree of humification is indicated by the rising values of AP between 219 and 213 cm, coinciding with a general fall in the % transmission curve. This relationship is further shown between 213 and 212 cm, where tree pollen falls, and % transmission rises indicating an increase in surface wetness. The fall in tree pollen coincides with a rise in the representation of *Calluna*. A possible explanation of the pattern here is that a decline in trees allowed the expansion of heath vegetation, or at least increased the pollen proportion of local types. A fall in trees could also have caused a rise in the water table, and if the trees were growing close enough to the sampled site, this could be reflected in the humification diagram. This is discussed further below.

The percentages of arboreal pollen between 220 and 208 cm do not reach levels conclusively indicative of local tree cover. Arboreal pollen percentages of 70% are quoted by Caseldine and Maguire (1983) as indicative of close woodland from a similar environment, although published estimates vary. Smith (1981) suggested that arboreal pollen percentages of less than 50% indicate an open landscape, such is the relative over-representation of trees in the pollen rain. Caseldine (1981) recorded 75% *Betula* pollen from within a birch forest. Tinsley

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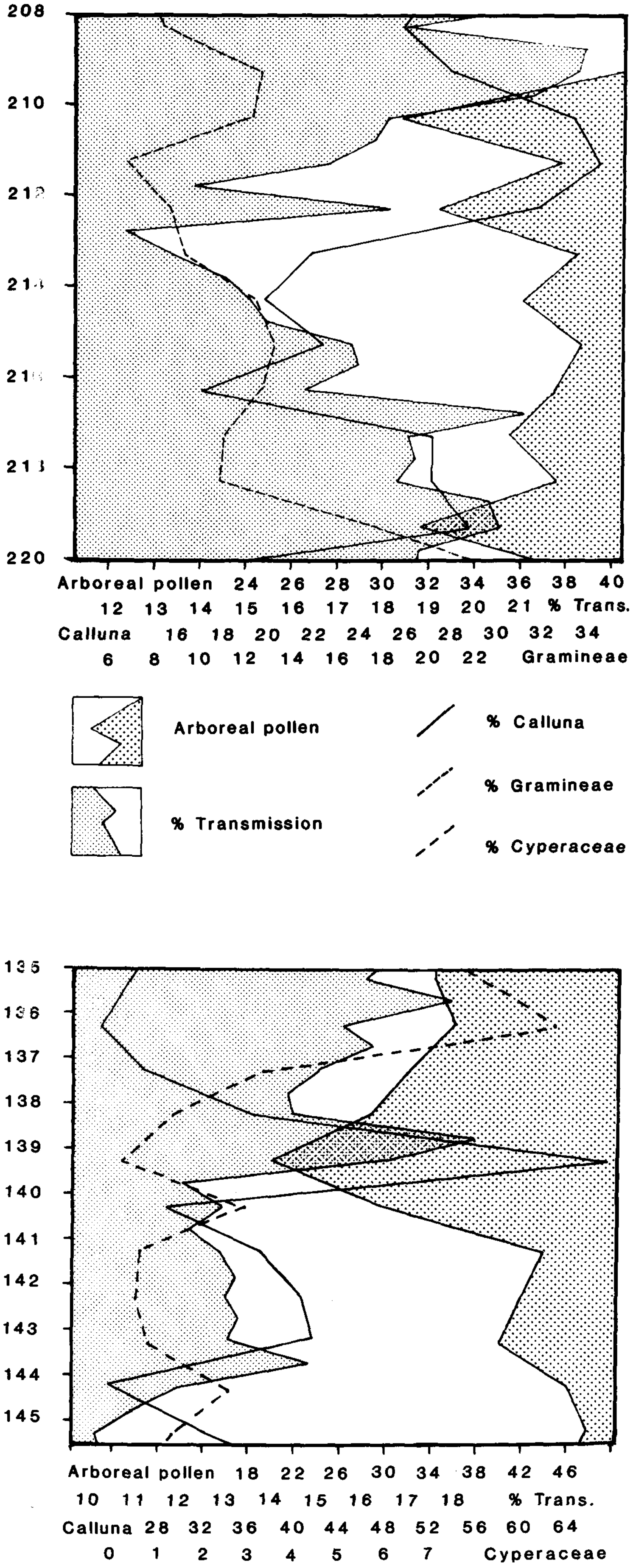
Figure 6.11. Detailed sections from MIG 1.

Migneint 1 Detail sections



and Smith (1974) produced curves that indicate a rapid distance-decay of arboreal pollen away from a woodland edge, which suggests that trees could be near enough to the MIG 1 profile to affect the hydrological regime at the sampling point without reaching high pollen percentages.

Macrofossil finds of wood at 216 cm depth from the profile, and from the bottom 15 cm of eroding peat indicate the local presence of trees; the pollen record indicates that it may have been an open woodland environment by the time peat growth began. Close examination of the results suggests that removal or death of even open woodland may have caused a hydrological response. The first change to lower tree pollen percentages is recorded at sample 213+. This is followed by a further decline to sample 212+ (see figure 6.11), when the humification curve shows a slight change to apparently wetter conditions. A more consistent change is recorded after 211+, which is two centimetres and, very approximately, 25 years after the initial decline in tree pollen. *Calluna* pollen falls at the 210+ level, possibly due to the spread of Gramineae species preferring wetter surface conditions or a more variable water table.

Charcoal values are relatively high at the beginning of the section but are actually lower at the time of tree pollen and % transmission change. *Potentilla* type, a possible indicator of grazing and/or burning, and *Plantago lanceolata* are also poorly represented at the critical levels. Only the occurrence of *Melampyrum* suggests an anthropogenic cause of the tree pollen decline and apparently consequent hydrological change.

The frequencies of non-pollen types over the detailed section are quite erratic. Some trends can be identified, however. *Sphagnum* spores gradually fall in abundance over the section, increasing again between 210 and 208. The same pattern, although more erratic, appears to be shown by fungal type K2. *Anthostomella* ascospores decline from very high percentages to very low, without a subsequent recovery. These possibly indicate a drying out of the precise point of sampling followed by a partial return to wet conditions after about 211 cm. Sedges do not return to the sampling point, however, if the interpretation of *Anthostomella* is correct (see chapter 7 and appendix 2).

The second section analysed in extra detail is the section between 135 and 145 cm depth, approximately 500-310 BC. This section includes two humification "events", one at 143.5 cm depth to 145.5 (see figure 6.11) and another apparent wet-shift first recorded at a depth of 139.75 cm. The microfossil changes recorded are discussed below, along with possible interpretations. The first change is associated with a temporary drop in *Calluna* pollen percentage and a rise in the representation of Gramineae and Cyperaceae. This pattern is consistent with a change to wetter mire conditions at the time of the humification change. A slight fall in the proportion of arboreal pollen **follows** this change, which precludes tree removal as a cause of the initial humification event. The *Calluna* pollen curve rises again at the expense of Cyperaceae, perhaps suggesting that, with the humification curve returning to levels indicative of relatively dry conditions, the mire surface dried quite quickly (1 cm representing, very approximately, 20-25 years).

Tree pollen percentages show a considerable decrease from 42% of TLP at 141+ to 19% at 139+. *Calluna* reaches a very high value at the 139+ level, sedge pollen in particular is greatly reduced in proportion. This pattern could be a result of a super-local effect of an anther from *Calluna* being incorporated in the sediment. However, the suppression of Cyperaceae in particular rather than all other types equally, and the coincident sharp change in pollen concentrations (see figure 6.10), suggest that this explanation is unlikely.

Very high pollen concentration and seemingly dry surface conditions (shown by low % transmission, suddenly low *Sphagnum*, *Assulina* and *Amphitrema* frequencies and abundant *Calluna* and *Gelasinospora*), make a hiatus in peat growth between 140 and 139 cm a possibility. The change to less humified peat and far lower pollen concentration (and therefore probably faster growth rate) that follows can be seen as a pronounced wet-shift, exaggerated by the apparent extremity of the preceding dry conditions.

The nature and cause of the change to wetter conditions can again be investigated by examining figure 6.12 and considering the order of events. Increased indicators of land-use, in particular *Potentilla* type, coincide with an increase in tree pollen percentages, possibly together indicating high grazing levels, **before** the humification change. The first change is a sharp fall in the tree pollen curve recorded at 140+ cm. At this point the humification curve still records relatively dry conditions. The first level where an increase in % transmission is recorded is at 139+. Cyperaceae thereafter increases at the expense of *Calluna*, indicating an increase in the relative wetness of the "local" pollen catchment.

This sequence can be explained by a decline in trees causing a higher water table in the manner described for the lower detailed section. Humification and then ground-level vegetation changes follow, possibly causing secondary effects as Cyperaceae increase and % transmission rises again around 137 cm. This could be due to the effect on the humification curve of a change in vegetation cover at the sampling point.

This explanation depends, however, on the arboreal pollen values of 42-46 % being sufficient to be interpreted as enough to show local growth of trees. It was argued above that 70% was required on the basis of studies of modern pollen rain. There are no wood macrofossil remains in the peat at this level at the sampling site or anywhere in the eroding region; roots and stumps appear restricted entirely to the bottom thirty centimetres of peat. There remains the possibility that an environmental change caused both the decline in tree pollen and the change to wetter conditions, the cause of the change being outside the studied system. There also remains the possibility that regional tree pollen percentages were inflated by grazing of the local mire plants.

The study of detailed sections in this way has demonstrated the relationship between the pollen representation of mire types and the degree of humification. It has also allowed some degree of explanation of the cause of changes in mire surface conditions although the evidence at the 135-145 level is inconclusive.

6.3.4.2 MIG 2.

i). General vegetation pattern.

The results of microfossil analyses from MIG 2 are shown in *figure 6.12*. The diagram is divided into three phases on the basis of the "regional" pollen component.

Phase MIG2 A. Base - 44cm. 1800 - 440 BC.

Phase A is marked by tree pollen of 20 - 24%, consisting of *Betula*, *Quercus* and *Alnus*. *Corylus* values are around 12% (but fluctuating) through the phase. Arboreal pollen concentrations show that the peat was probably slow growing at first, increasing growth rate

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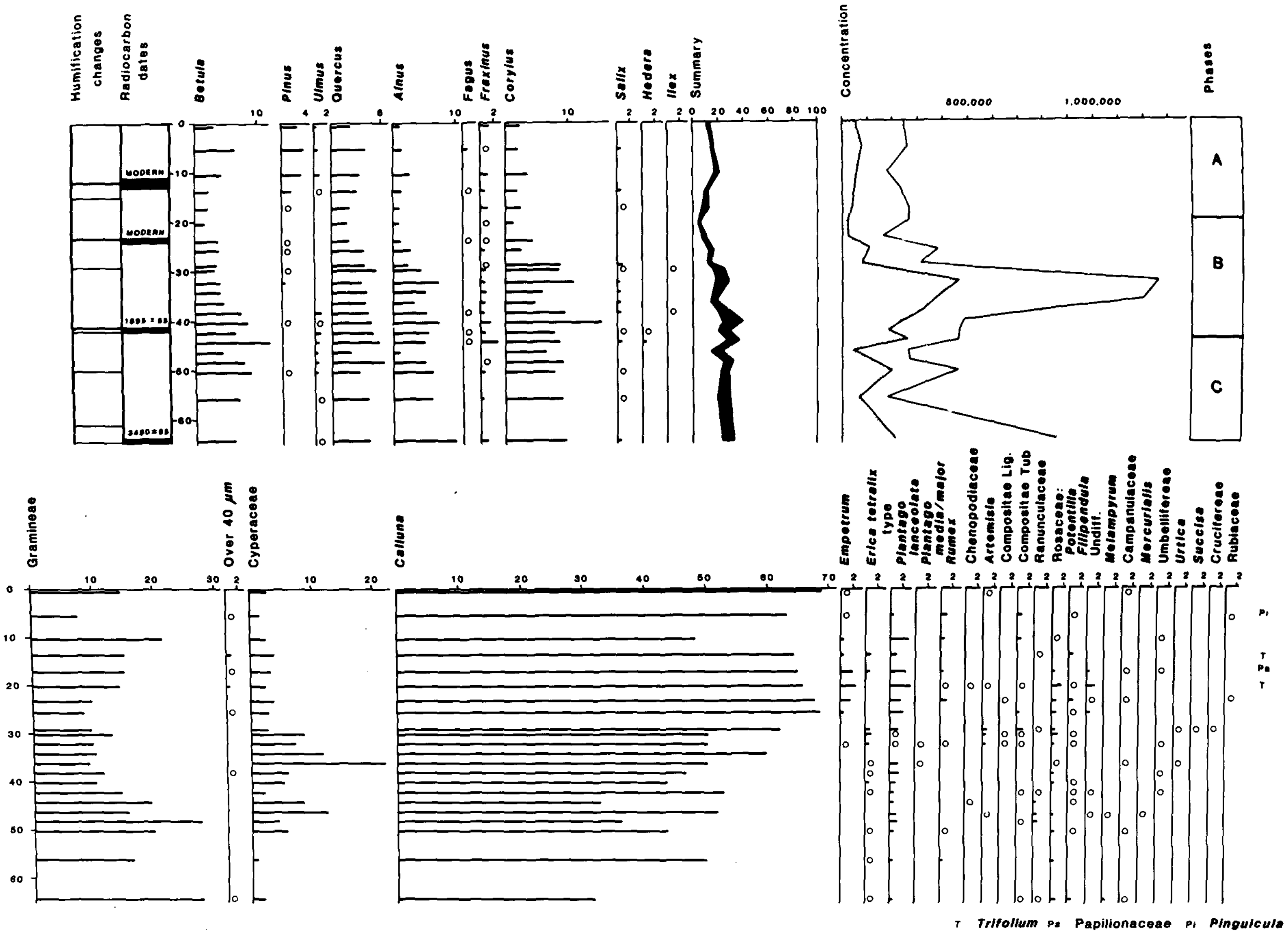
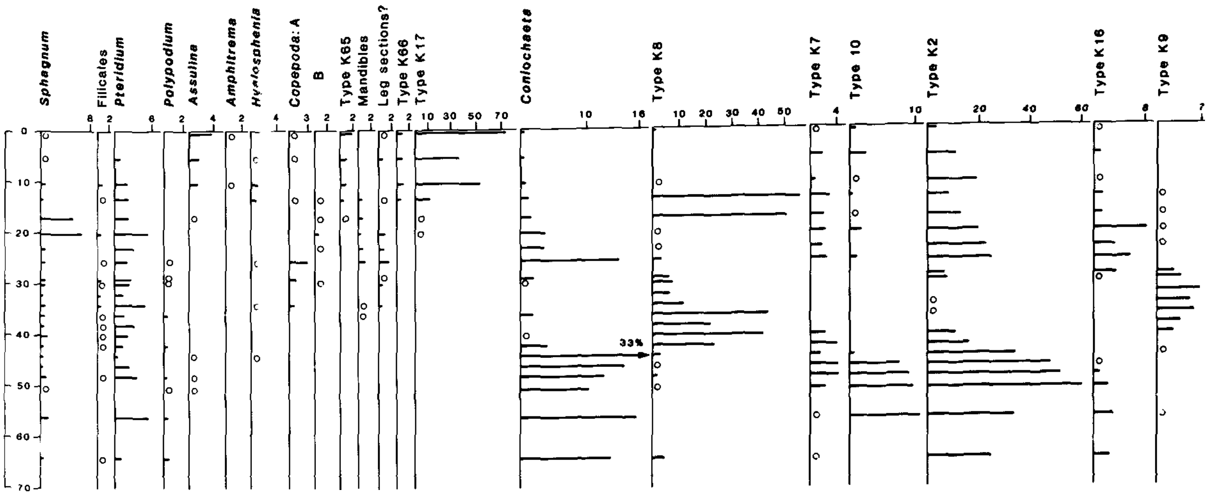
Figure 6.12. Pollen diagram, MIG 2. **a.** Arboreal taxa, summary, charcoal, concentration **b.** Non-arboreal taxa, **c.** Non-pollen microfossils, MIG 2 and 3.

MIG 2 Pollen diagram

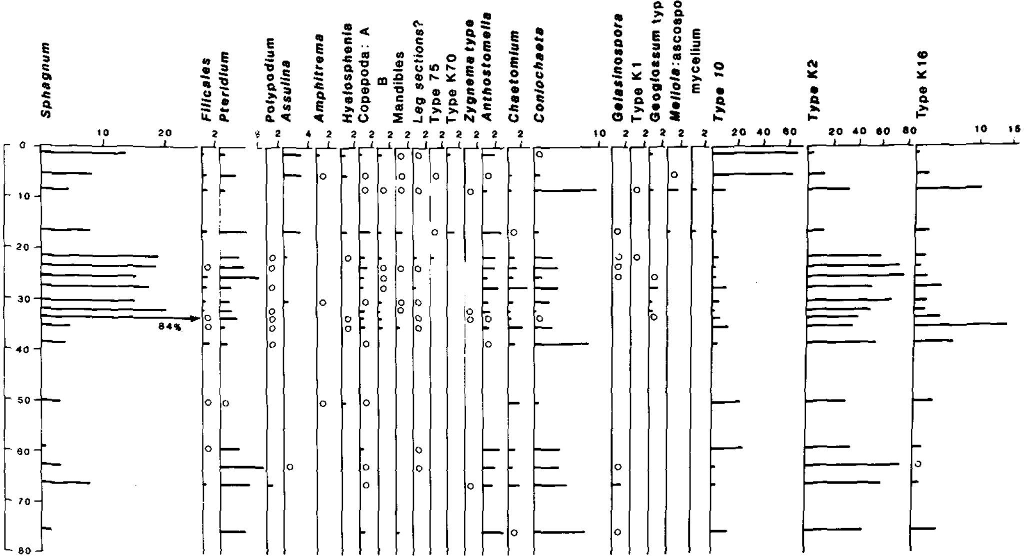


MIG 2 Non-pollen microfossils:

Selected types



MIG 3 Non-pollen microfos.ils:
Selected types



reflected by declining concentration towards the end of phase A. Gramineae pollen are frequent in the lower horizons, being gradually replaced by *Calluna* and increasing Cyperaceae, especially for a section between 50 and 30 cm deep. *Plantago lanceolata* and *Potentilla* pollen types are present throughout the phase.

The assemblage is similar to that of Phase MIG1 D, without the apparently localised extreme peaks in the frequency of *Potentilla*. The end of the phase is marked by the beginning of a decline in tree pollen, by a switch from Gramineae to Ericaceae (*Calluna* increasing from 32 to 53 %) and by a temporary rise in the abundance of Cyperaceae pollen.

Phase MIG2 B. 44 - 20cm. 440 BC - AD 1830.

Phase B is one of declining proportions of tree pollen. In particular, *Betula* and *Alnus* fall in percentage, but all types decline to some extent. The sum of the pollen percentage of trees plus *Corylus* falls from a maximum of 40% to a minimum of less than 10%. *Corylus* declines sharply, particularly at the end of the phase.

Fluctuations in the relative proportions of the main mire taxa show a possibility of a particular drying episode around 26 cm depth with *Empetrum* peaking and Cyperaceae falling. This could be associated with the onset of erosion of the peat a short distance away, causing a lowering of the water table.

Correlation with Phase MIG1 E seems secure on the basis of the regional pollen component. The apparent rise in species favoured by a lower water table is possibly later than that demonstrated at MIG 1. This could be due to the greater distance from the area of peat erosion.

Phase MIG2 C. 20 - 0cm. AD 1830 - 1987.

The boundary between phases B and C is marked by an upturn in arboreal pollen percentages, mainly *Betula, Pinus* and *Ulmus*. The rise is from just 5% at 20 cm to around 15 - 20% at 6 cm. Gramineae pollen are more abundant at the beginning of the phase, accompanied by the highest values of *Sphagnum* anywhere in the profile. *Plantago lanceolata* increases in abundance, as do grass grains greater than 40 *u*m in diameter, tentatively identified as cereals. *Potentilla* declines in frequency, as does *Empetrum*. *Calluna* regains its dominance in the later part of the phase as Gramineae declines once more.

The specific nature of the rise in AP percentages precludes the explanation that it is *caused by a reduction in the pollen productivity* of the local elements in the pollen sum. Phase C appears to have been one of initially wetter conditions at the MIG 2 site, the boundary between B and C being a wet-shift. A more rapid growth rate is suggested by the concentration curves, although this could be a product of increased arboreal representation. The phase is apparently missing completely from MIG 1, possibly due to the proximity of the erosion gullies causing a severe drying of the surface and a cessation of peat accumulation. There is some evidence for an increase in the activities of man, although the lack of a positive response from *Potentilla* suggests a regional rather than a local effect.

Microfossil analyses have been conducted across the main humification change and at certain other levels in the profile. The biggest change is at around 40-41 cm, although the first sample to show a rise in the running mean sequence is that at 43.25. The humification curve shows a dramatic increase over 16 samples (8 cm), and there are associated changes in the pollen and NPM curves. The beginning of this "event" is difficult to distinguish.

ii). Humification changes.

Some of the humification changes can be further investigated by reference to the pollen diagram, figure 6.12. The use of a more regular sample interval is tested here, covering more of the humification changes than would have been possible by close-interval sampling but in less detail.

Humification change MIG2.1. 50 cm. 1000 - 760 BC.

The % transmission increase first recorded at 50 cm can be investigated by referring to the pollen sample either side. Firstly, figure 6.12 shows that Gramineae increase in proportion, coinciding with a slight decline in the abundance of Cyperaceae and *Calluna*. The curve representing *Plantago lanceolata* rises slightly, as does that of Ranunculaceae. Tree pollen remains equal in total, but with an increase in the proportion of *Quercus*.

A possible interpretation of these changes is that a slight shift in the balance of blanket mire types, involving less *Calluna* and more Gramineae, coincided with the humification change. The origin of the Gramineae pollen is unknown, however, and likely to be a number of different geographical and ecological sources. Another complicating factor is that the precise depth of the vegetation change is unknown. In addition, vegetation changes of much greater magnitude may have been missed by spacing of the pollen samples. There does not appear to be sufficient evidence to support the idea that this humification change had a more widespread representation in the surrounding flora.

Humification change MIG2.2. 42 cm. 430 - 220 BC.

A large rise in the % transmission curve (see figure 6.8) starts at a depth of 42 cm and continues to 35 cm. A fall in arboreal pollen is recorded around the phase A/B boundary above (firstly at 46.5 cm, then at 44 cm), along with an increase in open-ground indicators. This could be interpreted as the first phase of a sequence including the humification change. The humification curve first changes at 42 cm. Changes in the pollen proportions at this depth are illustrated in figure 6.12. The frequency of Gramineae falls initially and then remains constant. Cyperaceae values increase to a maximum of 22% of TLP by 36 cm, and *Calluna* pollen increases in proportion initially before falling slightly, although remaining dominant; in excess of 40% of the pollen sum. The peat becomes more humified above a depth of 36 cm, associated with a decline in the abundance of Cyperaceae pollen and a rise in *Calluna*. All these changes are against a background of declining tree pollen percentage, although the initial frequency is low. *Coniochaeta* ascospores decline in frequency along with Types 10 and K2. Type K8 increases in abundance to 40% of the non-pollen microfossil sum and Type K9 increases in frequency.

The humification shift, spore evidence and rise in the proportion of sedges suggests an increase to wetter mire conditions. The evidence of *Calluna* and Gramineae curves do not, however, suggest that the magnitude of the change was reflected on the surrounding bog.

Interpreting some parts of the pollen diagram, non-pollen microfossils and humification diagrams suggests the occurrence of a change to wetter conditions at the site. However, the evidence for a palynologically recorded change in the surrounding mire vegetation is inconclusive. It is possible that the change was very localised. The cause of the change cannot be determined, although the low arboreal representation suggests that trees were not in the local abundance required for a paludification effect.

Humification change MIG2.3. 29 cm. AD 1140 - 1280.

The first record of a shift towards wetter conditions at the sampling point is the humification curve rising at 29.25 cm. Palynological analyses have been conducted from just above (centre of sample 28.75) and just below (30.25).

Tree pollen percentages decline slightly, particularly *Quercus* and *Alnus*. The mire taxa show a significant switch to higher *Calluna* percentages, at the expense of Gramineae and Cyperaceae. *Plantago lanceolata* and Compositae Tubuliflorae type also increase in proportion.

Assessing this evidence according to the conclusions of section 6.1 suggests that the mire vegetation surrounding the sampling site changed towards an assemblage indicative of a lower water table. This is supported by the change in relative abundance of non-pollen microfossils, with Types K8 and K9 declining as "drier" indicators return. This suggests that the humification change was either of a small magnitude, or not related to surface wetness.

Humification change MIG2.4. 23 cm. AD 1740 - 1860.

The humification curve shows a significant and permanent change to less humified peat beginning with the recordings between 22 and 23 cm. Arboreal pollen continues to fall to 10% or less, and Gramineae increases in abundance. *Potentilla* and *Plantago lanceolata* are well represented at this time, in numbers that suggest the possibility of local occurrence in association with Gramineae on the blanket bog. *Pteridium* increases in relative value. There is little change in the representation of the main mire constituents, other than a sharp rise in the frequency of *Sphagnum* spores. Type K8 increases in abundance after the humification event, possibly indicating wetter conditions.

The pattern shown by the humification change MIG2.2 is one of a local increase in surface wetness, associated with a pattern that could be interpreted as an increase in anthropogenic activity. This appears to be in the form of regional woodland clearance and possibly an impact on the mire vegetation.

Humification change MIG2.5. 15 cm. AD 1825 - 1905.

A small increase in % transmission is recorded by three consecutive samples beginning at a depth of 15 cm. Pollen samples above and below show an increase in the representation of arboreal taxa, as discussed in the phase descriptions. Mire types remain unchanged, with the exception of *Empetrum*, which declines from 2.2% to 0.4% of TLP. The representation of *Sphagnum* falls from 5.5 to less than 1% of TLP between the samples above and below the humification change.

Vegetation changes recorded by the pollen diagram are not indicative of a widespread change to a higher water table. This indicates a small-scale or localised change.

Humification change MIG2.6. 12 cm. AD 1860 - 1920.

Pollen samples either side of the 12 cm level suggest that Gramineae, *Plantago lanceolata*, *Rumex* and Compositae Tubuliflorae increase in abundance. *Calluna* declines, accompanied to a lesser extent by *Erica tetralix* type and Cyperaceae. Arboreal taxa generally increase in frequency. *Assulina* and Type K17 increase in abundance, the former indicative of increased surface humidity, the latter of unknown ecological significance.

A possible interpretation of the pollen diagram at this point is that an increase in grazing pressure and deliberate management temporarily reduced the dominance of the *Calluna*. An alternative interpretation is that a change to a higher water table supressed the *Calluna*, allowing Gramineae, possibly *Molinia*, and associated types to increase in abundance. The decline in the percentage of Cyperaceae suggests that a widespread wet-shift did not occur. A decline in *Potentilla* frequency suggests that the influence of land use on the mire vegetation was not the cause.

A third alternative is that the root matter from current vegetation, barely decomposed, has altered the humification result. The modern radiocarbon date reported from the 12 cm level to some extent supports this hypothesis. To summarize; there is no definite evidence to suggest a climatically induced, widespread wet-shift at the 12 cm level, although some data suggest a local effect.

6.3.4.3 MIG 3

The MIG 3 diagram has been divided into phases in the same way as the previous pollen profiles (see figure 6.13) Phases A to C described below are similar in content but not in depth to the phases described for MIG 2.

Phase MIG3 A. 76-30 cm. AD 80 - 1280.

The apparently regional component of the pollen diagram is again used to divide and compare the phases. Tree pollen is around 20 % of TLP for phase A; *Betula, Alnus* and *Quercus* are the major arboreal taxa. In addition, *Corylus* is well represented.

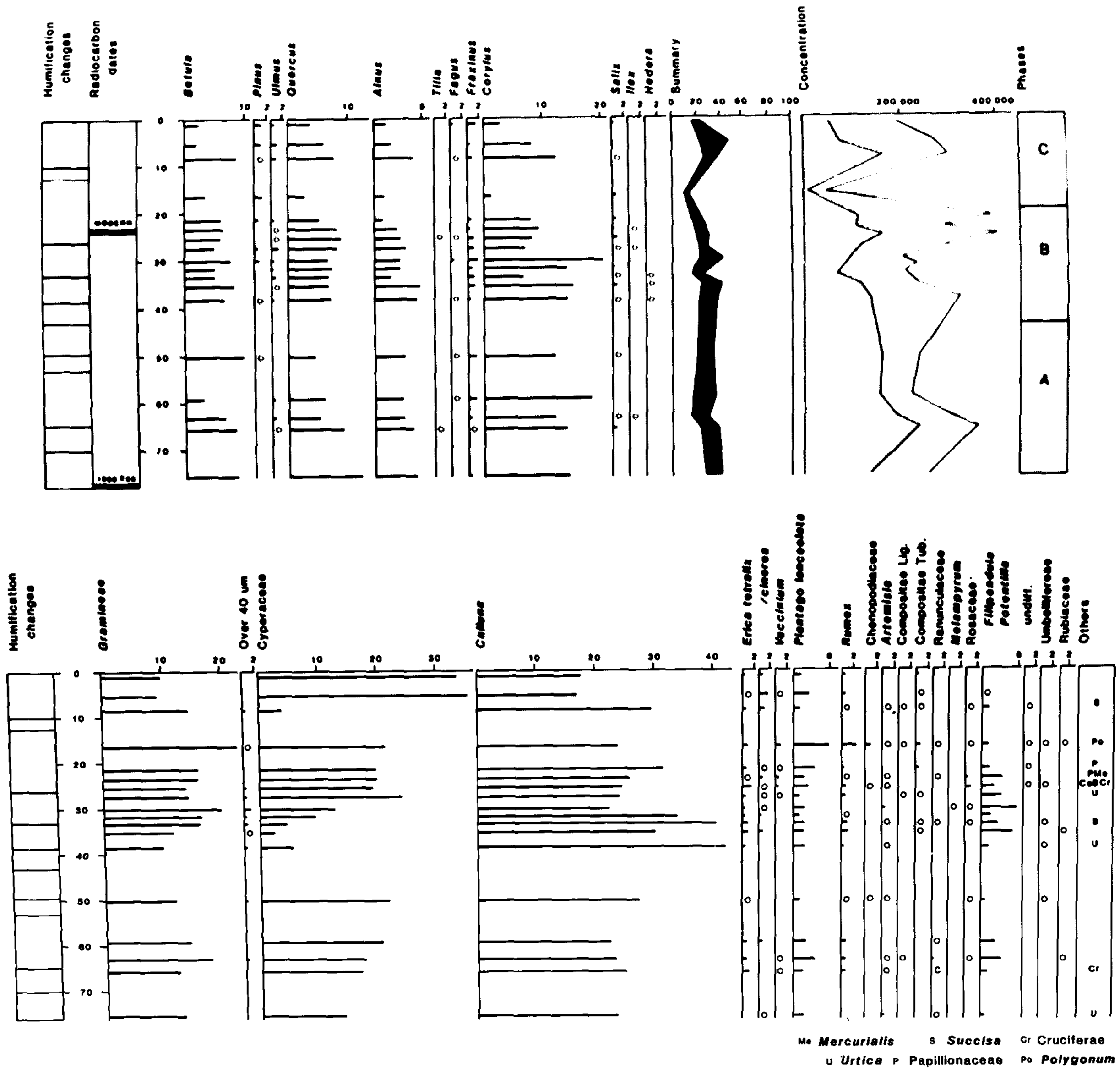
More local types fluctuate throughout the phase, some of the changes coinciding with those in the arboreal taxa. Relatively abundant Cyperaceae between the base of the profile and a depth of 50 cm could be indicative of relatively wet local conditions. The interval between 50 cm and 30 cm is very much dominated by *Calluna* pollen, with Cyperaceae declining. This could be due to a change to relatively dry conditions on the mire surface within the local pollen catchment. *Plantago lanceolata* and *Potentilla* type pollen curves are consistent throughout phase A. Both taxa were perhaps a natural constituent of the mixed blanket mire vegetation by this time in the areas vegetational development.

Phase MIG3 B. 30-16 cm. AD 1280 - 1610.

The boundary between phase A and phase B is marked by the beginning of a decline in arboreal pollen percentages. Tree pollen falls to less than 10% during the phase. A coincident change in the mire surface taxa is indicated by a change in the pollen curves of *Calluna,* which falls and Cyperaceae which appears to replace it to some extent. *Anthostomella* ascospores are more frequent in this section, indicating the immediate presence of sedges. *Sphagnum* and Copepoda curves increase, again indicating a change to locally wetter surface conditions.

Figure 6.13. Pollen diagram, MIG 3. a. Arboreal taxa, summary, concentration, b. Non-arboreal taxa, see **Figure 6.12c** for Non-pollen microfossils.

MIG 3 Pollen diagram



Phase MIG3 C. 16-0 cm. AD 1610 - 1987.

Phase C is characterized by the recovery of tree pollen percentages. All types increase slightly, *Pinus* and *Ulmus* in particular. Cyperaceae increase to very high percentages, and *Empetrum* is also represented more frequently in the pollen record in phase C.

The rise in *Empetrum* could indicate an increase in drier environments, whereas the Cyperaceae curve seems to show the opposite. An explanation of this apparent contradiction is that the *Empetrum* grew on the driest parts of eroding peat hags (Chambers 1982), while the uneroded MIG 3 site experienced a period of relatively fast growth and wetter conditions. This is consistent with the absence of the final phase from MIG 1 (closest to the area of present-day erosion), with the curves of pollen concentration, and with the indicators of local relative wetness.

ii). Humification changes.

The humification changes from MIG 3 have been analysed in two ways. Firstly, samples from the peaks and troughs in the fluctuating lower part of the humification curve have been compared. Secondly, the most prominent change, starting around 34 cm below the current surface, has been investigated by a series of palynological analyses.

Samples were analysed from peaks and troughs of the humification curve below the 34 cm change. If the peaks represent wetter conditions and the troughs relatively dry phases, a difference in the pollen spectra would be expected. Figure 6.13 shows the pollen spectra used in this comparison, and also shows the lack of convincing results.

The apparently dry phases do not register higher frequencies of *Calluna* pollen or that of Ericaceous taxa, as might be expected given their general water-table preferences. The mean percentage of *Calluna* pollen recorded from all the 6 samples was 28.9, the mean from transmission peaks being 30.4, and in troughs 27.4. Other mire types show a similarly random spread of values regardless of sample position.

There are a number of explanations of these observations. Firstly, it is possible that there was no link between peat humification and the surrounding flora. Alternatively, the magnitude of the change in surface wetness may not have been sufficient to cause a vegetational response of a detectable size within the pollen catchment. Thirdly, as an apparent time lag has been demonstrated between the humification curve and associated vegetational response, the pollen analyses may have been in the wrong place. Sampling just after the peaks and troughs may have shown the vegetation changes. The recording of a vegetational response after a time lag at 34 cm suggests that the magnitude of the change may be the most likely explanation.

The most dramatic element of the microfossil curves from this profile coincides with a humification and stratigraphic change at the 34-30 cm level. Arboreal pollen declines from already low levels, while open-ground but non-mire types increase in abundance, including *Plantago lanceolata*, *Rumex* and Chenopodiaceae. *Calluna* pollen falls in frequency from 40 to 23% of TLP, being replaced by increased Gramineae and *Potentilla*. Cyperaceae increase from 12.5 to 25%, and *Sphagnum* spores increase in abundance markedly to their highest percentage at the 33 cm level. *Anthostomella* increases at the same level, suggesting the local abundance of Cyperaceae. *Assulina* is recorded at the 30 cm horizon. Fungal types 10 and K16 decline between 35 and 30 cm, while K2 increases in abundance. *Coniochaeta* ascospores become less frequent between 38 and 33 cm, but then recover slightly over the next 8 cm.

There seems little doubt that the site was affected by an important change to wetter conditions. The change began at a depth of 34 cm, and continued for up to 7 cm thereafter.

Interpreting these changes involves considering the relative stratigraphic position of the response of each variable. The drop in tree pollen is first recorded at the 34 cm level, coinciding with the turning point of the humification curve. Humification changes from MIG 1 have been explained by the death or removal of locally growing trees. In this instance, however, an arboreal pollen sum of only 20% does not seem enough to represent local growth. The pattern of reduced tree-pollen and increased herb taxa may represent a regional component. The coincidence between the degree of humification and the arboreal pollen curves could be a result of each being influenced by the same environmental factor.

Variation and timing of the changes in the apparently local taxa suggests that Gramineae and *Potentilla* increased in abundance before the stratigraphic change and the rapid increase in the representation of Cyperaceae. This could be interpreted as showing an increase in grazing of the bog vegetation at this time. In section 6.1 the possible consequences of grazing were mentioned, which include causing wetter surface conditions. This is especially possible if burning was used to improve grazing conditions.

Humification change MIG3.1 is reflected in the surrounding vegetation and marks the beginning of a long period of wetter conditions. It can be attributed to a number of possible causes, inseparable on the basis of the evidence available.

6.3.5 Summary.

A variety of sampling intervals and variables have been compared between and within the three Migneint profiles. Some of the humification changes recorded by the % transmission curves have been shown to be associated with more widespread vegetation change. Others, however, have not, and in some instances different variables provide apparently contradictory information. In some of the situations where surface wetness increases can be identified, possible causes involving tree-removal or land-use have been suggested.

Two conclusions from these discussions are that the relationships between the variables studied and the water-table are not clearly understood, and that a climatic cause can only be attributed to a particular feature if the date coincides with that from other sites.

6.4 LETTERFRACK.

Results are presented in the following order;

- 6.4.1. Stratigraphy.
- 6.4.2. Humification analysis.
  - .1) LET 1, .2) LET 2 .3) LET 3.
- 6.4.3. Radiocarbon dating.
- 6.4.4. Microfossil analysis.
  - 6.4.4.1. LET 1
    - i.) General vegetation pattern.
    - ii.) Humification changes.
  - 6.4.4.2. LET 2, (subdivided as above)
  - 6.4.4.3. LET 3.
- 6.4.5. Summary.

6.4.1. Stratigraphy.

The visible stratigraphy of the three Letterfrack cores are shown on figure 6.2. The changes are in the main transitional, only the uppermost horizons being distinct. The peat profile LET 2 was removed from a peat/rock interface with no intervening mineral soil horizon. LET 1 showed only a very thin semi-organic layer before very humified, black peat.

6.4.2. Humification analysis.

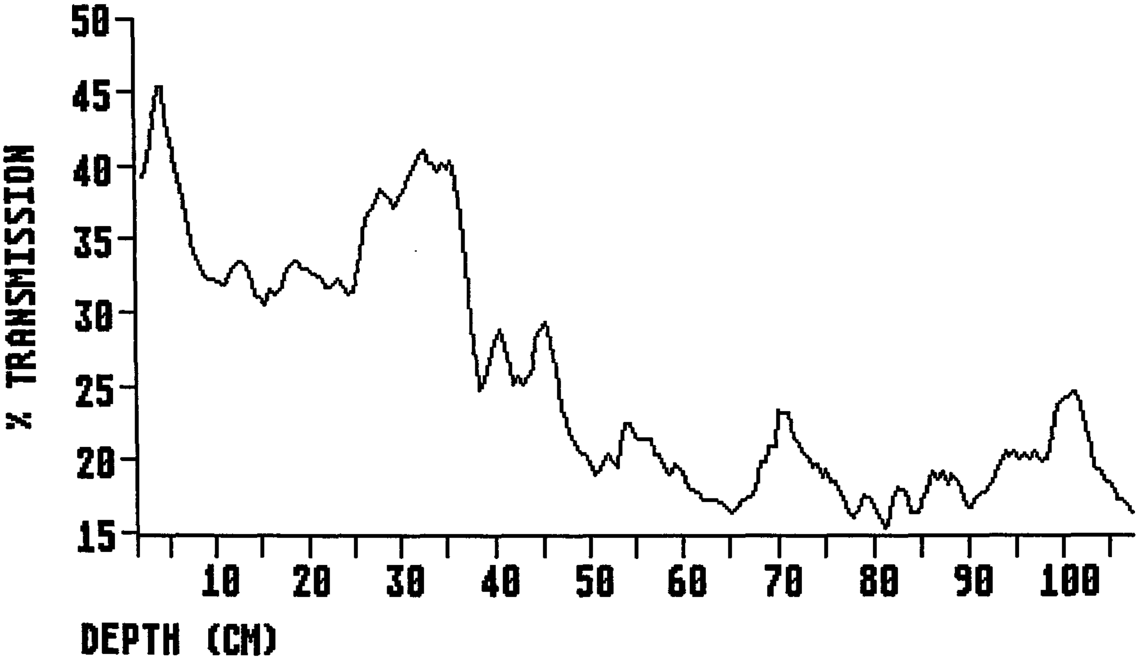
6.4.2.1 Letterfrack 1 (LET 1) Humification curve.

Figure 6.14 shows the corrected and smoothed humification curve for the LET 1 profile. Major changes were recorded starting at depths of 80-77 (the exact beginning is unclear), 64, 49.5, 37 and 16.5 cm below the peat surface. The change at 80 cm is not recorded by three consecutive readings, but could be subjectively considered to be the first movement towards less humified peat that is more pronounced by the change at 77 cm.

Minor changes are recorded at 89, 82.5, 56.5, 49.5, 41, 29, 22, 16.5 and 11 cm. Dates were obtained from 5 points where significant wet-shifts were first recorded. The calibrated and interpolated dates of these changes are shown by figure 8.1.

Figure 6.14. Humification curve from LET 1. Smoothed (running mean of three consecutive samples) data.

LET 1; HUMIFICATION DIAGRAM (SMOOTHED DATA)



6.4.2.2 Letterfrack 2 (LET 2) Humification curve.

The corrected and smoothed humification curve for the whole LET 1 profile is shown by figure 6.15a. Major changes to apparently wetter conditions are recorded at 90, 65, 33 and 21 cm depths. The lower part of the profile is shown in more detail on a stretched y-axis as figure 6.15b. Other changes of a similar direction are detectable at depths of 84, 77, 70, 60, 54, 51.5, 44, 42, 36 and 24 cm. Dates were obtained from stratigraphic changes rather than humification changes for the LET 2 profile due to the stage of analysis reached at the time of submission of samples for dating. As such, the dated horizons are not always in exact correspondence with the humification changes, which tend to pre-date the visible stratigraphic response.

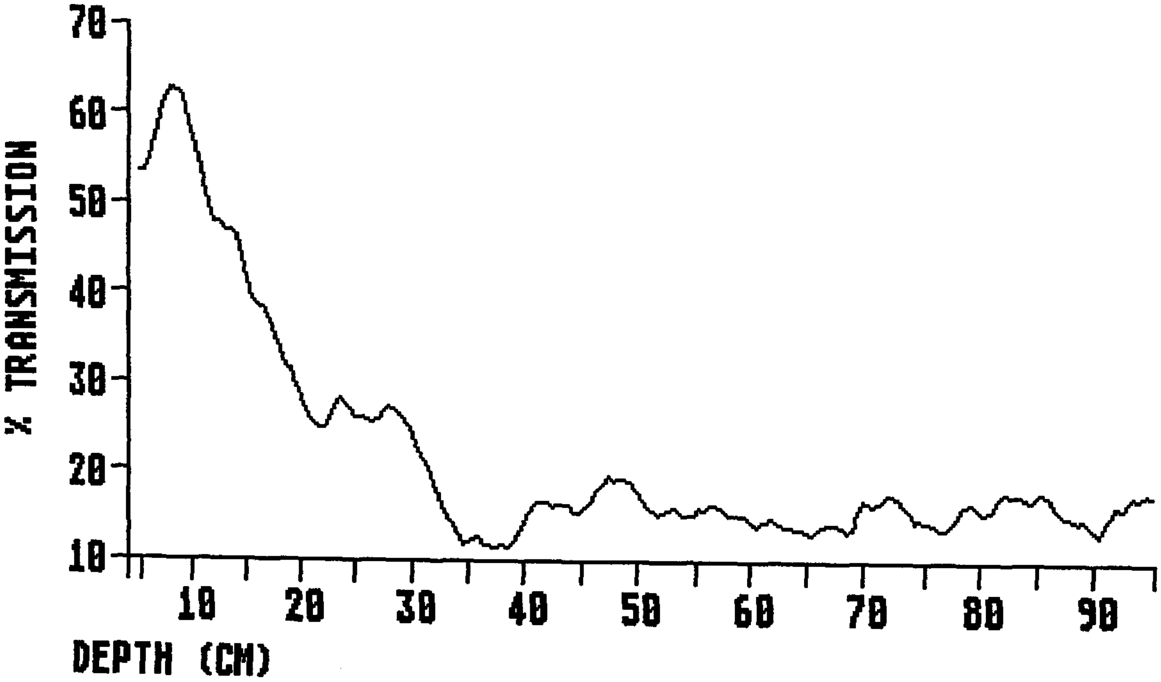
6.4.2.3 Letterfrack 3 (LET 3) Humification curve.

The humification data from LET 3 is illustrated by figure 6.16a and b. The smoothed curve shows a general decline in % transmission values until a depth of 32 cm. Extracted data from the lower section of the curve in terms of running-mean extracts (figure 6.16b) demonstrate the variations within this gradual increase in the degree of humification. A smooth increase is shown between 32 and 18 cm, interrupted only by "kinks" caused by single samples. Major changes towards less humified peat are recorded at 32 and 10 cm. Smaller changes occur at 50, 45, 40, 36, 17, 14 and 7.5 cm, excluding those shown by only one or two samples. Calibrated and interpolated dates, based on the assumptions and correlations described below, are used to plot figure 8.1. The correlation with core FRK IV below suggests that the depths of the smaller humification changes should coincide with depths of 39, 35.5, 32, 29.5, 15, 12.5, and 6 cm.

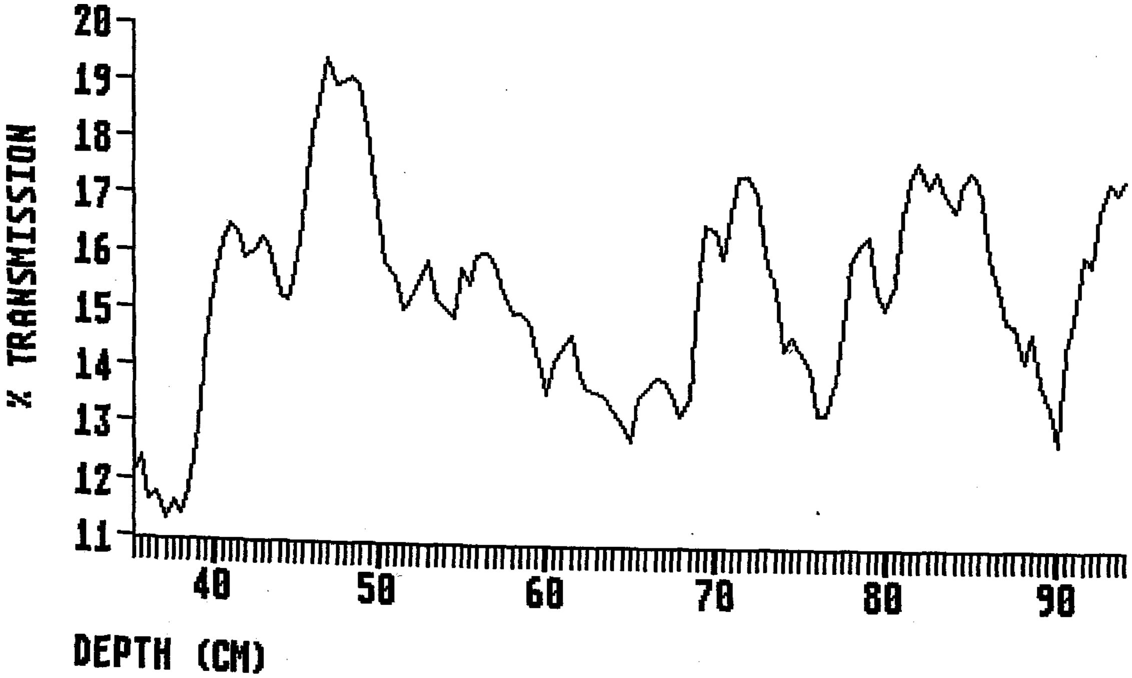
Figure 6.15. Humification curve from LET 2. **a.** Whole profile, **b.** Lower section.

Figure 6.16. Humification curve from LET 3. **a.** Whole profile, **b.** Lower section.

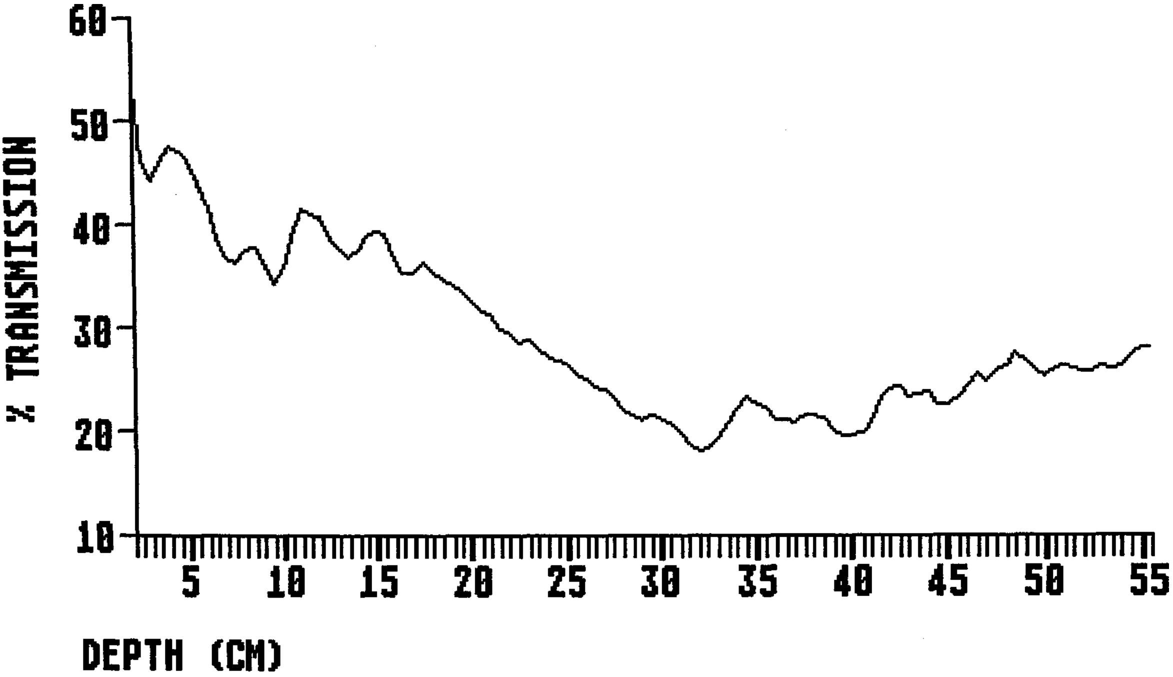
LET 2; HUMIFICATION DIAGRAM (SMOOTHED)



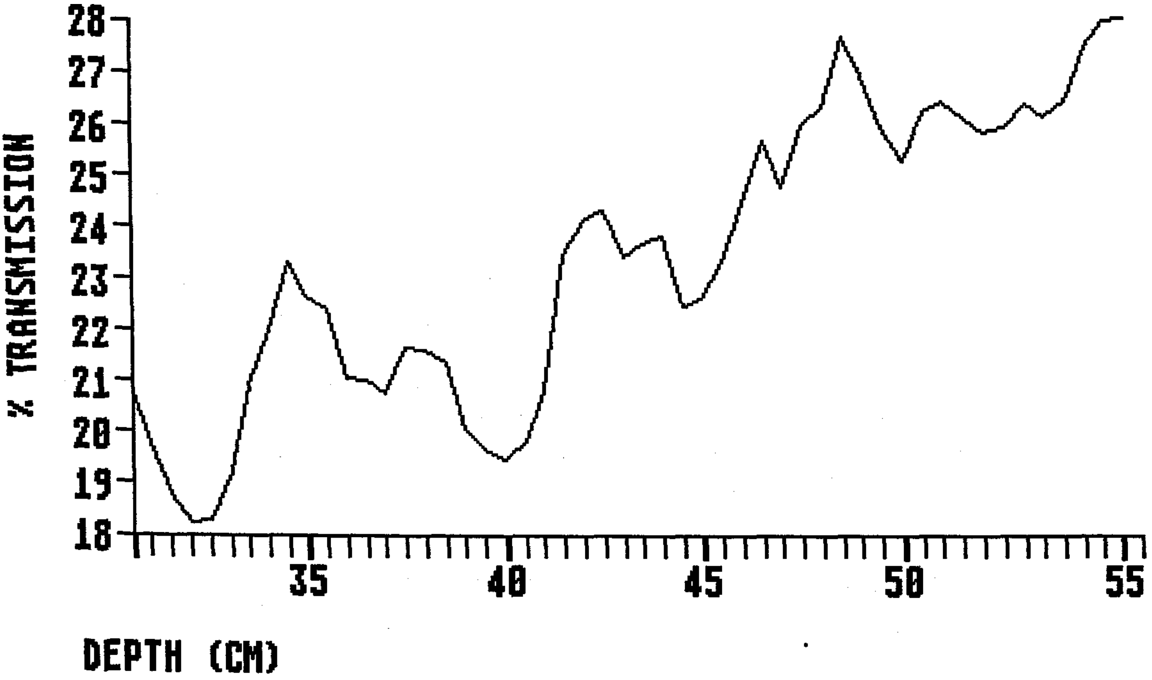
LOWER SECTION OF LET 2, SMOOTHED HUMIFICATION DATA



LET 3; HUMIFICATION DIAGRAM (SMOOTHED)



LOWER SECTION OF LET 3; SMOOTHED HUMIFICATION DATA



6.4.3 Radiocarbon dating.

	Depth (cm)	Lab. Code	RC Age (yr.bp)	Calibrated Age
LET 1				
	15-16	SRR-3531	Modern	-
	36-37	SRR-3532	490 ± 65	AD 1306-1490
	49-50	SRR-3533	1390 ± 70	AD 540-770
	76-77	SRR-3534	2750 ± 65	1187-800 BC
	106-107.5	SRR-3535	5040 ± 60	3990-3700 BC
LET 2				
	13-14	SRR-3536	630 ± 80	AD 1260-1430
	29-31	SRR-3537	530 ± 75	AD 1280-1480
	64-65	SRR-3538	1390 ± 80	AD 436-797
	96.5-98	SRR-3539	2535 ± 70	830-410 BC

LET 3 Dates not obtained; see discussion below.

Table 6.3. Radiocarbon dates from Letterfrack.

Radiocarbon dates have not been obtained from the LET 3 profile, although by correlation, determinations from a profile FRK IV (O'Connell 1989) can be used. The monolith LET 3 was extracted from the peat face directly adjacent to the sampling site of LFK IV. As well as radiocarbon dates, the results of pollen analyses were made available by Dr. O'Connell. Pollen work from LET 3 was aimed at correlating the two cores, in order that the information supplied could be compared to the humification curve. Samples from the base of the peat at the interface with minerogenic soil are compared in figure 6.17 to the data from the same stratigraphic position on core FRK IV. The pollen spectrum from the 55+ horizon of LET 1 fits most closely to the -2 to -3 horizon, that is 2-3 cm above the soil\peat boundary. A selection of both sets of pollen percentages are presented in figure 6.17 for comparison. Exceptionally high levels of *Betula, Pinus, Quercus, Hedera* and *Ilex* are shown by both samples. *Ilex* is particularly useful in this context because of its low pollen productivity and poor dispersal. Concentrations of Ilex

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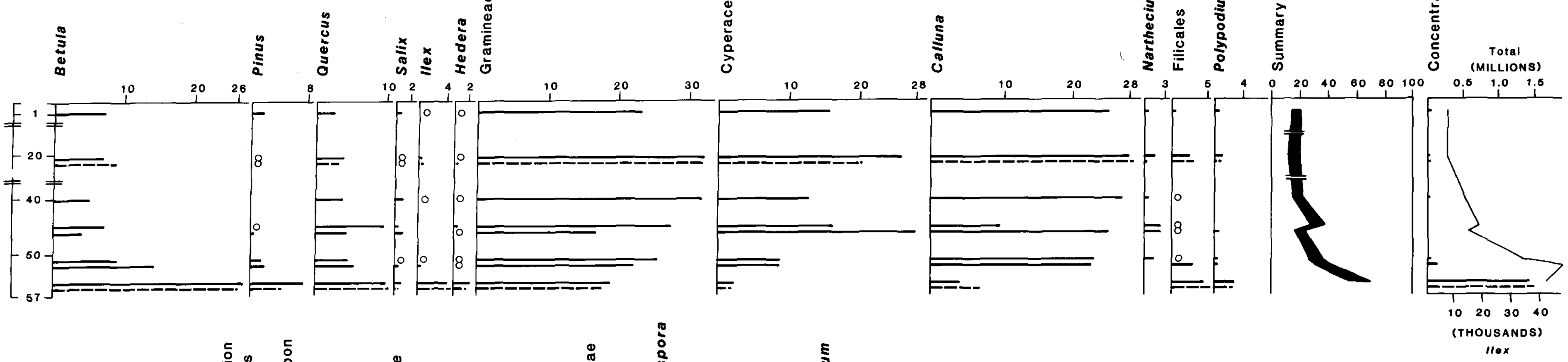
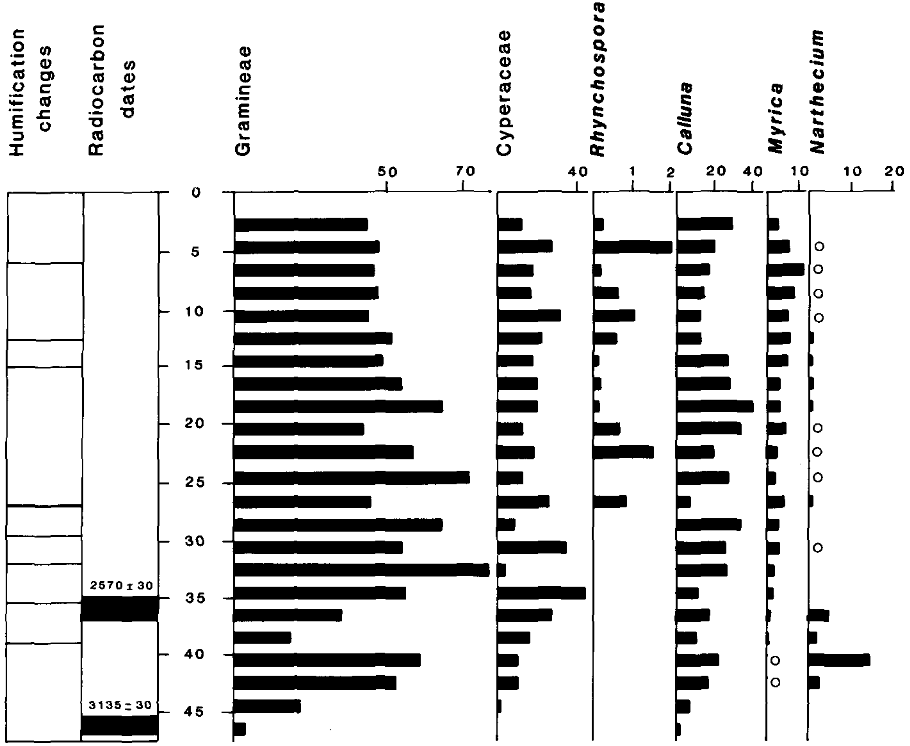
Figure 6.17. Pollen diagram from LET 3, compared to data from FRK IV, and depth correlations. Mire types from FRK IV (after O'Connell).

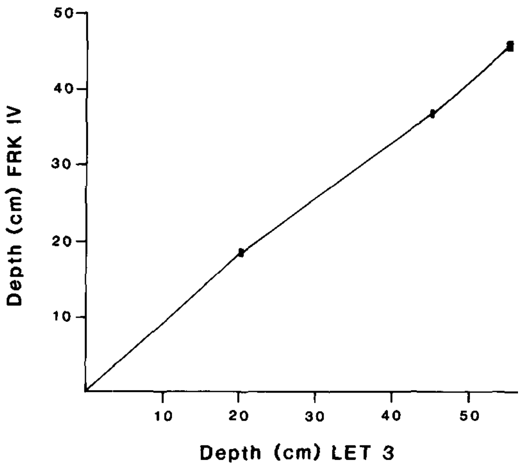
LET 3 Pollen diagram



FRK IV
Pollen diagram



Depth correlation



pollen are plotted on figure 6.17 and show almost the same levels for both samples. The figures are well within the single standard error margin for pollen concentration calculations as described by Stockmarr (1971). Low frequencies of blanket bog types are also shown by both data sets. These include *Narthecium*, unusually absent from both. *Polypodium* and Filicales values are almost identical.

Samples from LET 3 at 52+ and 51+ show a decline of arboreal taxa and the expansion of the bog types. This is comparable to the pattern from FRK IV. The samples at 46+ and 45+ show an increase in the abundance of *Betula* and *Quercus* as *Salix* declines. This shows the possibility of LET 3 45+ being comparable to FRK IV at a depth of 36 cm (sample -11), although the preceding horizon, dominated by *Plantago lanceolata* and other herbs, has not been recorded. *Narthecium* values are comparable at this level. A tentative correlation may be made between the levels LET 3 45+ and FRK IV depth 36 cm.

A pattern of low tree pollen percentages, high Gramineae and *Calluna* values and very little *Pinus* suggests that the LET 3 sample from 20+ is comparable to the FRK IV profile somewhere between 16 and 22 cm depth. The correspondance of Filicales and *Polypodium* frequencies makes the sample numbered -29 (at a depth of 18 cm) the most likely. These two levels are compared on figure 6.17.

The 0-1 cm sample from LET 3 shows an increase in *Pinus* and *Salix* comparable to the upper layers of FRK IV although the surface was not sampled in this case.

There is sufficient evidence to support an assumption that the cores are comparable. There are also grounds for assuming that the sample at 55+ from LET 3 is equivalent to that at 44-45 cm depth from FRK IV. It is also possible that synchronous horizons, at least within the limits of the dating techniques available, have been detected at two lower levels.

If the correlations described above are correct, then a different growth rate is inferred for the two profiles. The depths that appear to coincide are tabulated below (table 6.4).

The relevant radiocarbon determinations from FRK IV are:

Sample No.	Lab. code	Depth	Determination	Calibrated age
FRK IV-1	GrN-14095	-12--10	2570 ± 30	806-595 BC
FRK IV-2	GrN-14096	-2 - 0	3135 ± 30	1494-1322 BC

Table 6.4, Radiocarbon determinations from FRK IV relevant to the current study (kindly made available by Dr. M. O'Connell).

The date of 3135 ± 30 bp for the 45-47 depth range can be used to estimate an age for the 55-55.5 cm sample from LET 3. Pollen concentration curves suggest a very slow growth rate in the lowest few centimetres of the peat, slower than the mean rate of 56.5 years per centimetre between the two radiocarbon determinations. A date of around 3,200 calendar years before present (1250 BC), is suggested for the mid-point of the sample. The 2570 ± 30 bp date is from the level correlated with 45-45.5 cm. This calibrates to 790 BC. A third age estimate can be obtained if the surface is considered contemporary. Additional correlation at the 20 cm level allows an interpolated date of unknown accuracy of approximately AD 810. A fifth approximation can be taken from the pollen record. *Pinus* rises at a depth of 8 cm below the current surface of FRK IV, suggesting a date of around 250 calender years before present, (AD 1700). The precise point of the *Pinus* return from LET 3 is not recorded.

Depth LET 3	Depth FRK IV	Approximate Age
Surface	Surface	AD 1987
Unknown	8-9 (*Pinus* rise)	AD 1700
20-20.5	18-19	AD 810
45-45.5	36-37	790 BC
55-55.5	44-45	1250 BC

Table 6.5. Depth comparison and age estimates for LET 3 and FRK IV.

6.4.4 Microfossil analysis.

6.4.4.1 Letterfrack LET 1.

i.) General vegetation pattern.

The pollen diagram from profile LET 1 (figure 6.18) is divided into 5 phases, based where possible on the regional pattern. This is intended to allow the three cores to be compared with each other, and with changes recorded by previous studies. The hill top position of the sampling point is of particular interest when interpreting the regional pollen component. The site is exposed to all wind directions and is likely to record the changing vegetational pattern from a broad area. The later phases are based on mire-type pollen frequencies due to the lack of variation within the arboreal pollen record.

Phase LET1 A, 108-72cm. 3960 - 750 BC.

Phase A is characterised by arboreal pollen percentages of 20-30%, with *Pinus* constituting 10-12% of TLP; up to 40% of AP. *Ulmus* is also present in phase A, although only between 1 and 2% and rather inconsistent. The mire-type pollen component is very variable, with *Calluna* ranging from 10 to 62% of TLP and Cyperaceae from 1 to 20%. The peat in the lower part of the column is very well decomposed and apparently slow growing.

Phase A appears to be a period of moderate afforestation within a regional context. The occurrence of *Pinus* in the diagram coincides with the dates obtained by O'Connell et.al. (1988) for the pine stump horizons lower in the valley at site LFK II. *Pinus* reached maximum abundance growing on the peat at LFK II at around 4,000 ^{14}C years bp, declining substantially at 3700 bp (O'Connell et.al. 1988). Bennett (1984) suggested that the decline of *Pinus* might be related to increasingly wet soil conditions, an idea supported by the work of M^{c}Nally and Doyle (1984). Teunissen and Teunissen-van Oorschot (1980) investigated and reviewed the vegetational history of Connemara, and dated the regional decline of Pine at around 4200 bp. Evidence from LFK II suggests a local date of around 2150 bp for the final extinction.

The mire taxa recorded show a variety of surface environments within a short depth interval. The radiocarbon dates suggest, however, a long time period between samples. It appears that variations between dry and wet phases may well have occurred, but that the sequence is not clearly demonstrated by the microfossil analysis.

Phase LET1 B, 72-52 cm. 750 BC - AD 490.

The boundary between phases A and B is marked by a decline in tree pollen. The disappearance of *Ulmus* and *Pinus* from the pollen spectra between the samples at 75 cm and 68 cm coincides with a less catastrophic decline in the representation of *Betula, Quercus* and *Alnus*. Total tree pollen declines to between 10 and 15% of TLP by the 52 cm sample, while

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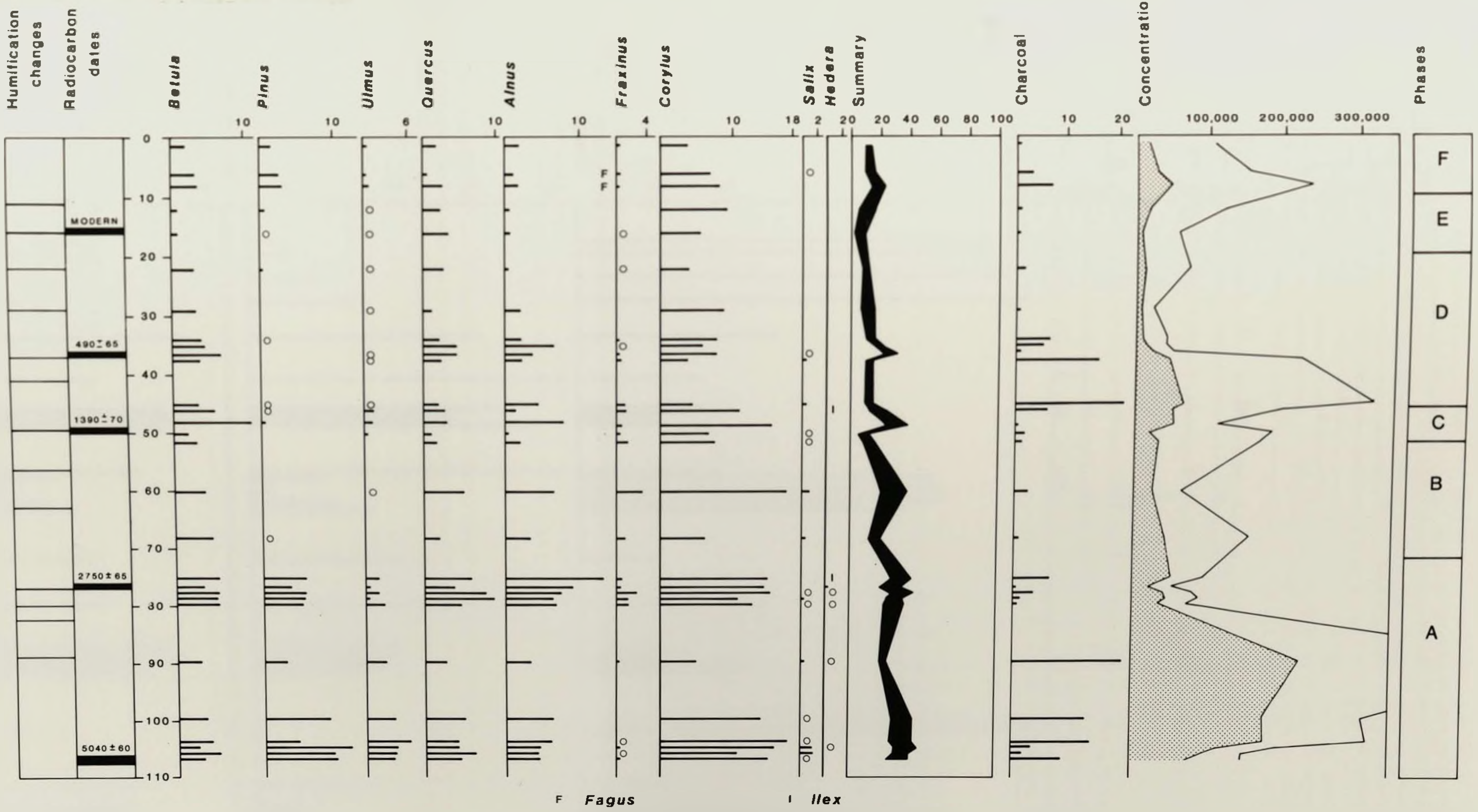
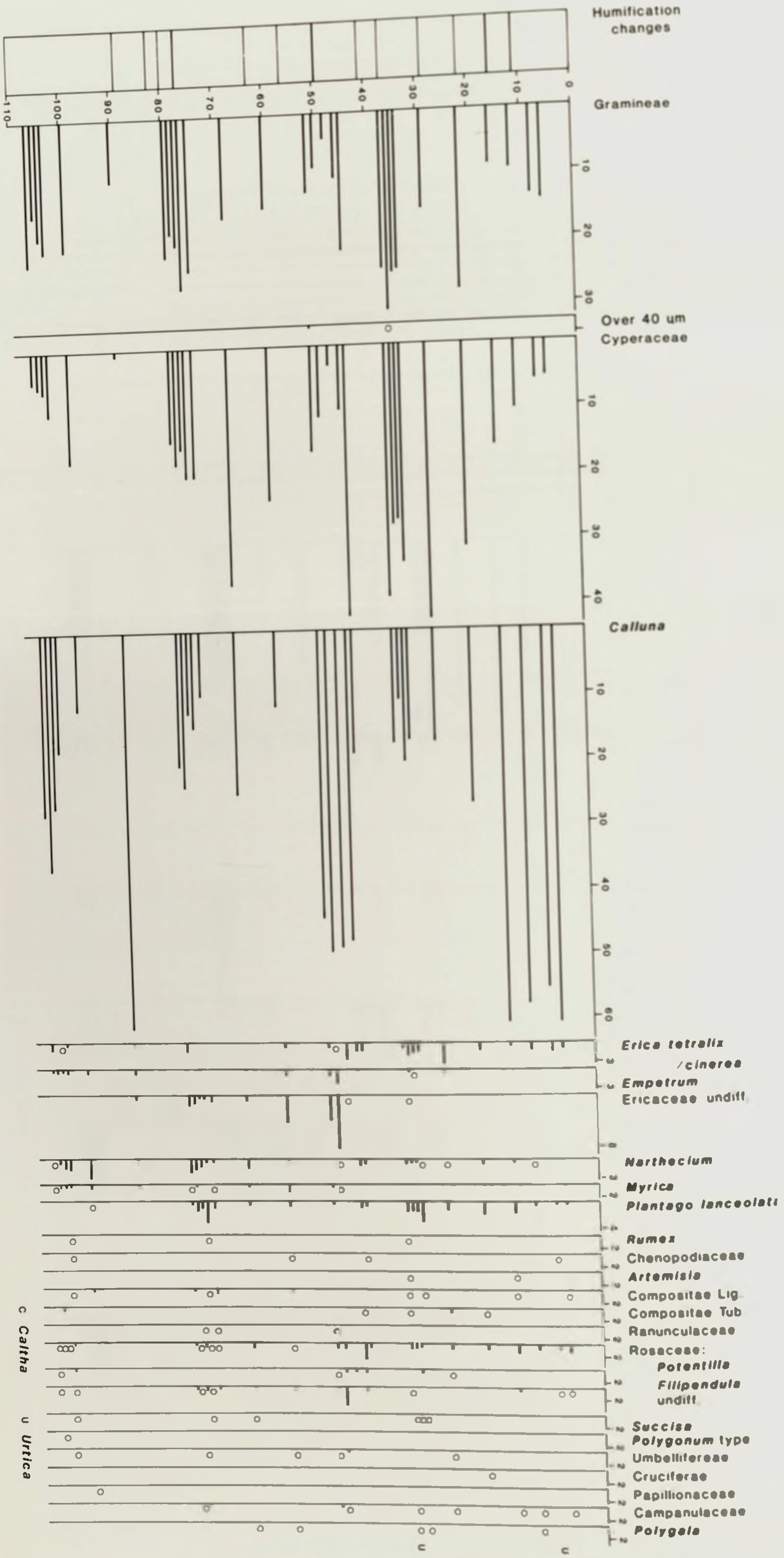
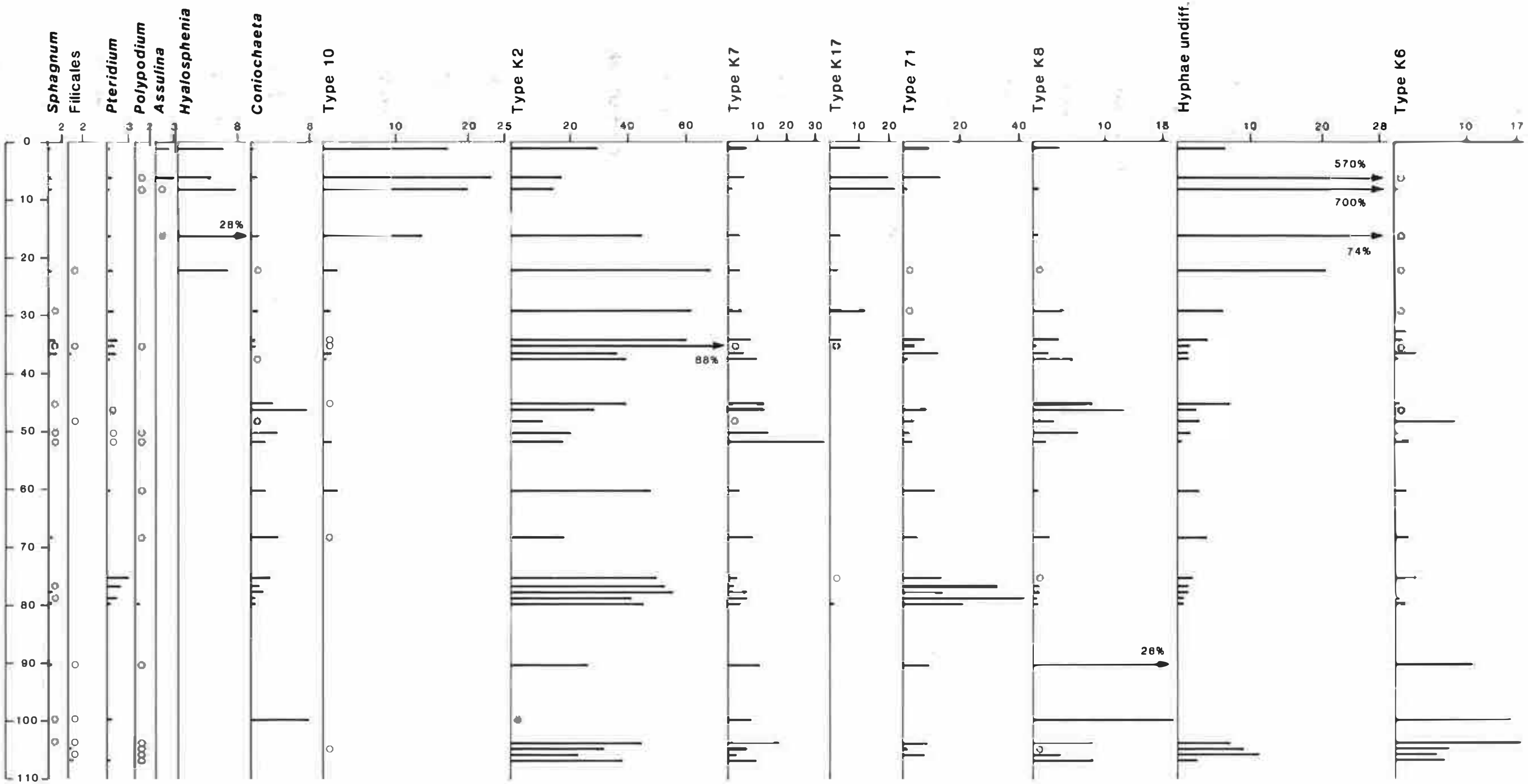
Figure 6.18. Pollen diagram from LET 1; a. Arboreal taxa, summary, charcoal, concentration b. Non-arboreal taxa, c. Non-pollen microfossils.

LET 1 Pollen diagram




Humification changes
Gramineae
Over 40 um Cyperaceae
Calluna
Erica tetralix
/cinerea
Empetrum
Ericaceae undiff
Narthecium
Myrica
Plantago lanceolati
Rumex
Chenopodiaceae
Artemisia
Compositae Lig
Compositae Tub
Ranunculaceae
Rosaceae:
Potentilla
Filipendula
undiff
Succisa
Polygonum type
Umbelliferae
Cruciferae
Papillionaceae
Campanulaceae
Polygala
0
10
20
30
40
50
60
70
80
90
100
110
c Caltha
u Urtica

LET 1 Non-pollen microfossils:
selected types



Cyperaceae and Ericaceae undifferentiated pollen increase in abundance. The *Erica* type involved is not distinguished, although the correspondance with what appears to have been a change to wetter mire conditions may indicate *E. tetralix* as a likely candidate.

The disappearance of *Pinus* and *Ulmus* is dated at approximately 2,300 bp (calibrated to 900-500 BC) not far removed from the approximation of O'Connell et.al. (1988) given the proximity of their sampling site to the source.

Phase LET1 C, 52-46 cm. AD 490 - 560.

The boundary between phases B and C is marked by a sharp rise and fall in tree pollen percentages and a change to lower frequencies of Gramineae and Cyperaceae. *Calluna* increases in abundance for the duration of phase C. The former feature includes all tree types and *Corylus*.

The change in arboreal percentages could be caused by dispersal effects, by grazing reducing the productivity of local pollen producers, or by the temporary revival of trees in the pollen catchment area. The fact that **all** tree pollen curves increase suggests that a pollen percentage effect may be the cause. This is because it is more likely that one local producer (in this case *Calluna*) is over-represented at this level,than that all tree and shrub types increased by the same proportion. Possible indicators of pastoral land-use (*Potentilla*, *Plantago lanceolata*, *Rumex*) do not show any increase, therefore not suggesting a grazing cause.

The change to a consistently high *Calluna* percentage at the expense of local types more suited to wetter conditions suggests drier conditions throughout the phase.

Phase LET1 D, 46-20 cm. AD 850 - 1710.

Tree pollen percentages remain low throughout the upper half of the profile. Phase D is defined by the switch from *Calluna* dominated pollen spectra to higher values of Gramineae and Cyperaceae. Cyperaceae represent between 25% and 45% of TLP, with *Calluna* dropping from over 45% to less than 20%. *Plantago* and *Potentilla* are quite well represented, and the curve of *Erica tetralix/cinerea* type remains relatively high.

The changes indicate a shift to wetter local conditions. Pollen concentrations show a faster growth rate for phase D than for B and C. Although the so-called anthropogenic indicators are present throughout the phase, as they are in the next one, they do not show any pattern that might be used in explanation of the surface wetness changes recorded.

Phase LET1 E, 20-10 cm. AD 1710 - 1850.

The definition of phase E is based on the results from only two levels. However, the difference in mire-type representation warrants the delimitation of a phase. *Calluna* increases in abundance sharply, at the expense of Gramineae and Cyperaceae, and then falls again at the boundary with phase F. The humification curve appears to support the inference that this represents a phase of dry local conditions, with a relatively flat curve at a point in the curve where the time-decay element in humification variability should be quite strong (see section 8.3).

Phase LET1 F, 10-0 cm. AD 1850 - 1987.

Phase F is marked by the regional components of the pollen diagram. An increase in arboreal taxa, in particular *Betula* and *Pinus*, occurs at around 10 cm depth. *Calluna* remains the dominant mire species, with other Ericaceae also increasing in abundance.

Reforestation around the Connemara region began in the last 250 years (Teunissen and Teunissen-van Oorschot 1980) and included *Pinus sylvestris*. Phase F appears to represent this time period, demonstrating the intact nature of the surface layers. A rough date of AD 1700 may be tentatively assigned to the opening of phase F.

ii). Humification changes.

This section examines the microfossil changes at a selection of significant rises in the % transmission curve.

Humification change LET1.1. 107-100 cm. 4015 - 3625 BC.

The definition of a specific starting point for the increase in % transmission between 107 and 100 cm is difficult. From the base of the profile the peat becomes progressively less humified. Pollen and spores have been analysed at 1 cm intervals for the beginning of this rise and then at the peak of surface wetness as inferred from the humification curve.

The arboreal pollen remains at levels as described in the phase description, other than a temporary fall in the representation of *Pinus* at 104 cm. The mire types show a progressive change, Cyperaceae increase in proportion from 5% to 16% of TLP. The *Narthecium* curve rises smoothly, while Ericaceae, including *Calluna,* decline. The Gramineae curve shows an initial decline before increasing again. This could be due to different species contributing to the Gramineae pollen total. NPM types show a significant difference in the surface conditions between the sample 104 cm and that at 100 cm, the point of least humified peat. K2, K71 and undifferentiated hyphae are reduced in proportion, while *Coniochaeta* and K8 increase.

The evidence suggests that as well as the decompositional environment at the sampling point becoming wetter, the surrounding vegetation changed to an assemblage characteristic of a high water table.

There is no evidence of those types used as anthropogenic indicators increasing, or of the removal of trees causing a rise in water table. Possible causes of the humification change include a climatic change and the impedance of drainage around the hill-top causing wetter conditions. As this section is at the base of the profile it is also possible that as the peat developed, increased acidity and reduced microbial activity caused reduced humification.

Humification change LET1.2. 80 cm. 1430 - 1135 BC.

The humification change at 80 cm is characterised by a fall in the curve of *Calluna.* Gramineae and Cyperaceae increase, especially the latter. *Narthecium* frequencies fall at this time, demonstrating the unusual nature of the response of this species to what appear to be changing hydrological conditions. *Plantago lanceolata* and *Potentilla,* are present but not in significant frequencies. Non-pollen types show no particular trends, other than a slight rise in the relative numbers of *Coniochaeta* spores.

The interpretation of these changes suggest a change to wetter conditions in the area of the LET 1 site. No causes are suggested by the microfossil data, but it can be noted that the wet-shift quickly gives way to a return to relatively dry conditions as indicated by the humification curve.

Humification change LET1.3. 49.5 cm. AD 540 - 770.

The change at and around 50 cm has been examined palynologically by samples just below, at and following the trough in the humification curve. Cyperaceae pollen percentages decline to a low point just after what can be considered the driest sample at the point of inflection in the % transmission curve. The representation of this group then increases rapidly from 3%, then 10% and up to 42%. Gramineae are also better represented in the sampled levels above the humification change. The *Calluna* curve responds at the same time as the Cyperaceae, but in the opposite direction. Other Ericaceae are also reduced in frequency, falling catastrophically after the Cyperaceae dominate the pollen spectra. Types K2 and K7 are reduced in frequency, while K8 increases.

The pattern described above appears to show a switch to a different balance in the blanket bog community following a change in the humification record. Humification change LET1.3 appears to be reflected in the vegetation of the surrounding area as a wet-shift.

Humification change LET1.4. 37 cm. AD 1300 - 1490.

The change to less humified peat at and after 37 cm has been investigated by four microfossil analyses; one from apparently well-humified peat, one at the point of change, one as % transmission increases and one after the curve has levelled. *Calluna* values remain low through this short sequence. Arboreal pollen frequencies increase slightly, though hardly significantly. The variation in the mire taxa pollen records is very low compared to the magnitude of variation elsewhere in the profile. *Calluna* shows a temporary decrease from an already low percentage, and Gramineae show a small increase. *Narthecium* shows a slight decline in frequency. K2 increases in abundance as the % transmission curve rises. Type K7 declines initially before returning as the humification curve levels.

There is slight but inconclusive evidence of the change to wetter conditions having a wider impact away from the sampling point. It could well be a very localised feature.

The increase in arboreal taxa and Gramineae, against a background presence of species associated with human activity, could lead to the conclusion that increased grazing of the mire surface caused a repression of pollination of the local taxa and hence a percentage rise in trees. If this was the case, it is possible that grazing caused the humification change, although this is unlikely as the humification evidence precedes the pollen change. A stratigraphic change is recorded between 37 and 35.5 cm. A change in surface vegetation could have caused the humification change (see section 4.3), although it is impossible to show causality either way as both humic and visible stratigraphies change at the same level.

6.4.4.2 Letterfrack LET 2.

Pollen and spore diagrams are presented as figure 6.16, the key and explanation of them as in chapter 5.

i). General vegetation pattern.

The following section describes the general vegetational sequence as recorded palynologically. Phases are determined on the whole by the "local", mire-type component of the pollen spectra due to the uniformity of the arboreal taxa.

The site of LET 2 is the most floristically rich in current vegetation of the sites analysed and this is reflected in the pollen record. *Rhynchospora*, *Narthecium*, *Pedicularis* and *Myrica* are added to the list of the types likely to be a constituent of the bog flora. The *Pedicularis* grains probably represent *P. palustris*.

Phase LET2 A, 97-71 cm. 620 BC - AD 440.

Arboreal pollen represents around 20-24% of total land pollen during phase A. The tree pollen consists mainly of a mixture of *Betula*, *Quercus*, and *Alnus*, with *Ulmus* and *Fraxinus* present in quantities up to 1-2% of TLP. The mire types are dominated by Cyperaceae, with Ericaceae and Gramineae being less important. Towards the end of the phase *Rhynchospora* becomes significant and the presence of *Myrica* and *Narthecium* may also indicate a relatively high water table. The sample counted from the 81cm level shows a reversal of this pattern. Ericaceae are temporarily better represented than Cyperaceae, while *Betula* peaks at 10% of TLP. A possible explanation of this is a temporary dry period or an expansion of *Betula*-heathland in

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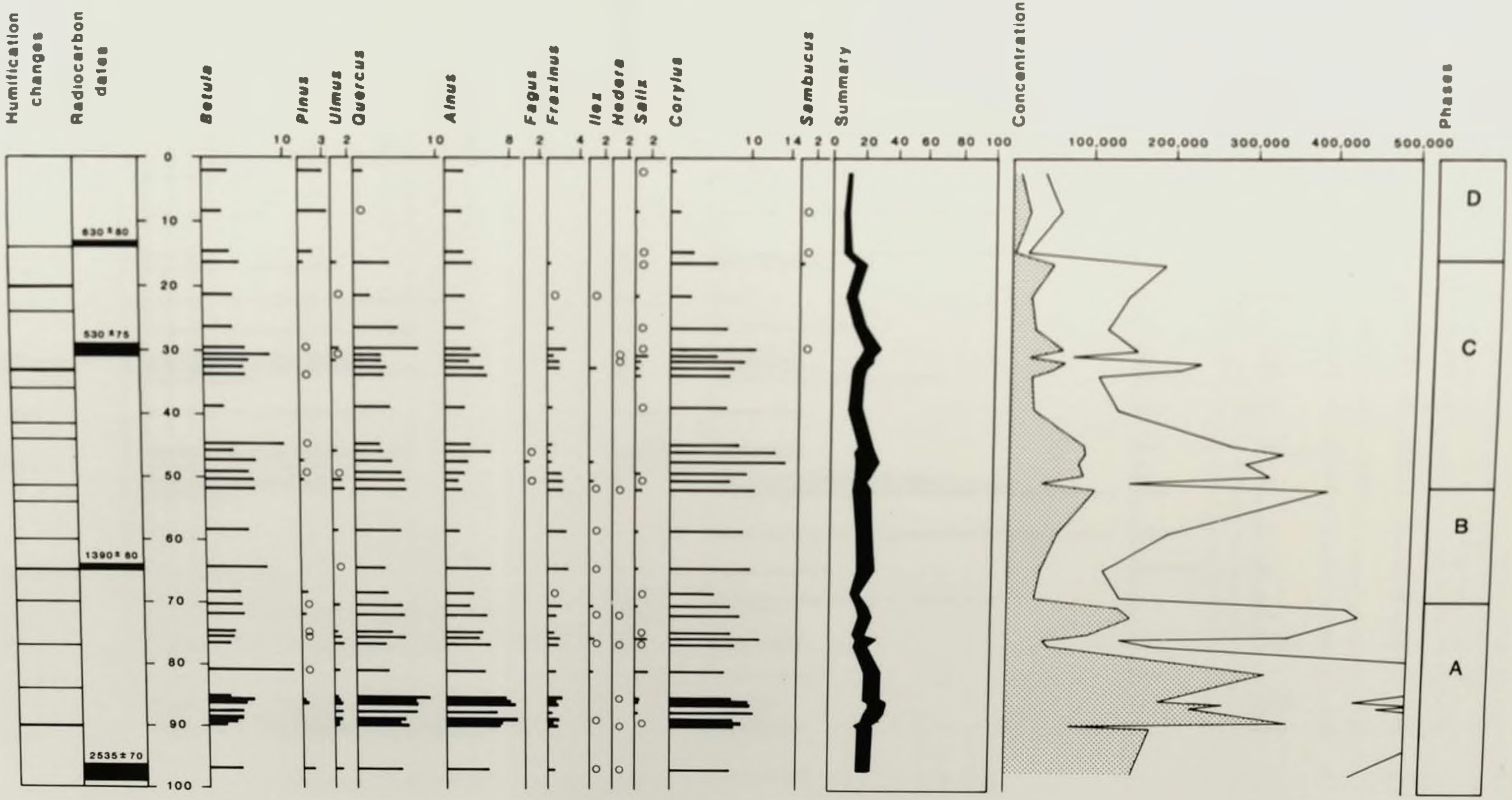
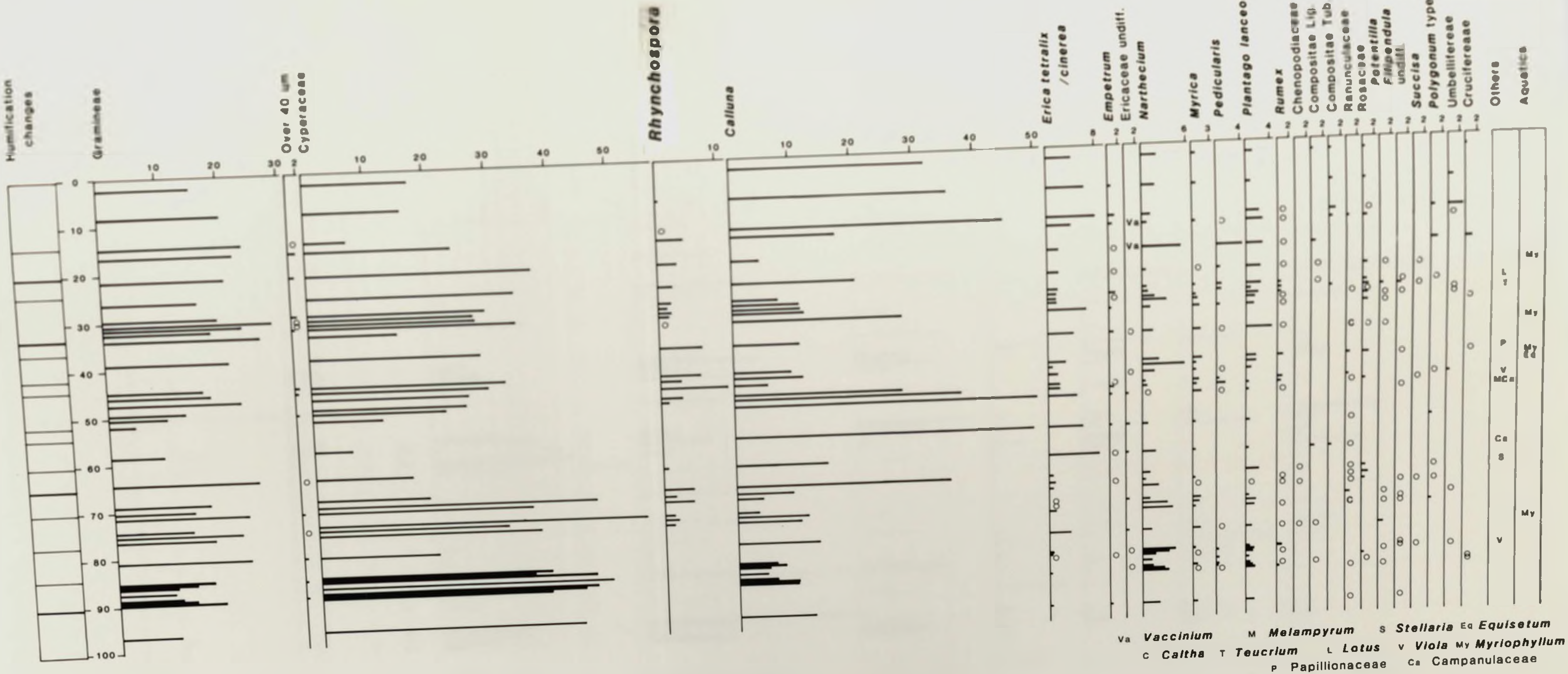
Figure 6.19. Pollen diagram from LET 2. **a.** Arboreal taxa, summary, concentration. **b.** Non-arboreal taxa, **c.** Non-pollen microfossils.

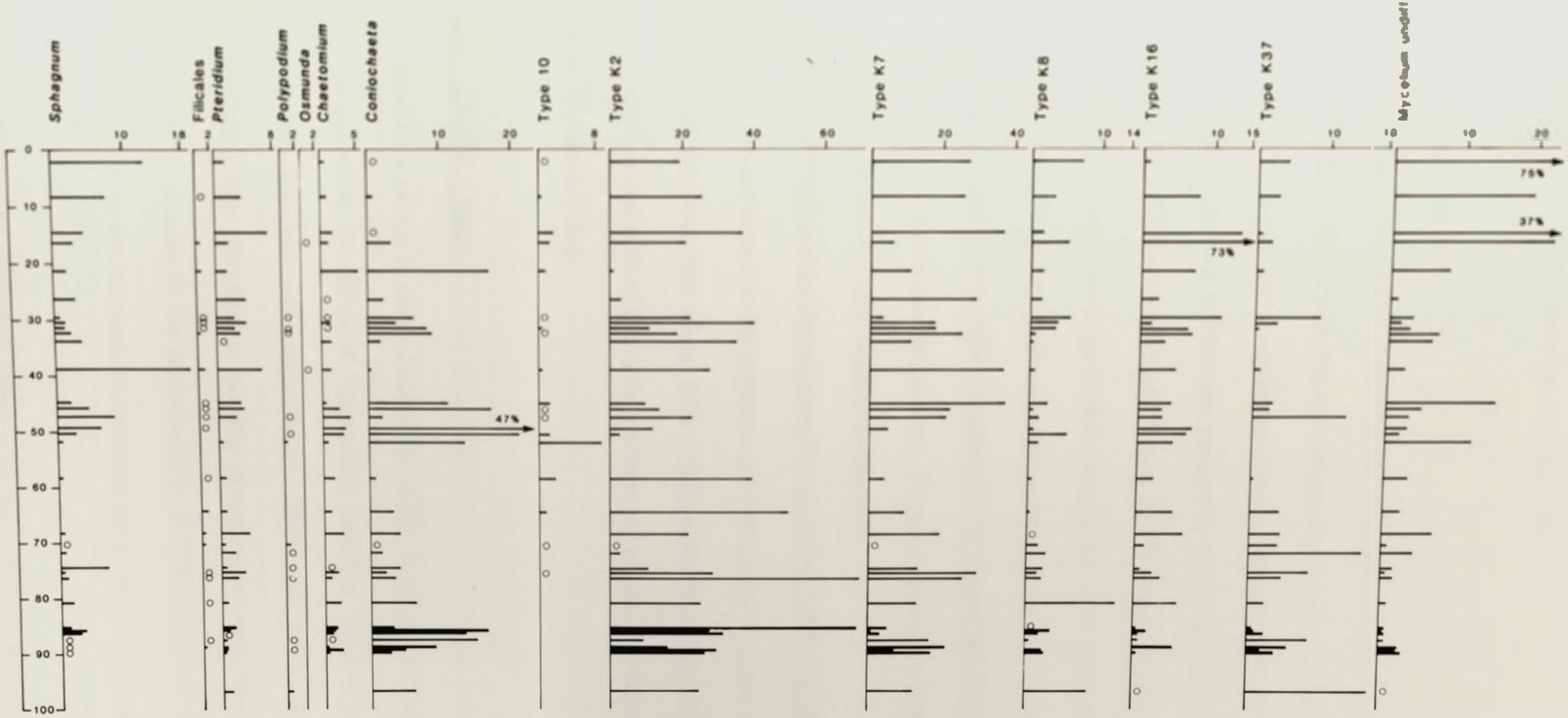
LET 2 Pollen diagram




Humification changes
Graminae
Over 40 um Cyperaceae
Rhynchospora
Calluna
Erica tetralix /cinerea
Empetrum
Ericaceae undiff.
Narthecium
Myrica
Pedicularis
Plantago lanceolata
Rumex
Chenopodiaceae
Compositae Lig.
Compositae Tub
Ranunculaceae
Rosaceae
Potentilla
Filipendula
undiff.
Succisa
Polygonum type
Umbelliferae
Cruciferae
Others
Aquatics
0
10
20
30
40
50
60
70
80
90
100
Va
My
L
T
P
V
MCa
Ca
S
C
Va Vaccinium
C Caltha
M Melampyrum
T Teucrium
P Papillionaceae
L Lotus
S Stellaria
V Viola
Ca Campanulaceae
Eq Equisetum
My Myriophyllum

LET 2 Non-pollen microfossils

selected types



the area.

The overall pattern during phase A is one of a generally wet blanket mire community within an area of some, although either quite sparse or distant, tree cover.

Phase LET2 B, 71-51 cm. AD 440 - 920.

The boundary between phase A and phase B is marked by a sharp increase in *Calluna* percentages, coinciding with a decline in the Cyperaceae and Gramineae curves. This is followed by a temporary rise in the Gramineae curve and a significant drop in pollen concentration. The types most likely to respond to anthropogenic activity are present at this stage, as "trace" taxa but also more frequently in the case of Rosaceae *Potentilla* type and *Plantago lanceolata.*

Phase B appears to have opened with a change to drier conditions, although a temporary reversal of this could be inferred from the fall in *Calluna* pollen percentages at the 64 cm sample depth. As there is no coincident fall in the tree pollen percentage, the concentration curve can be attributed to an acceleration of the peat accumulation rate. It seems, therefore, that a faster growth rate can occur despite an apparently "dry" surface community.

Potentilla shows a temporary increase across the phase boundary, possibly suggesting that grazing and/or burning may have contributed to the expansion of *Calluna* on the mire. *Plantago lanceolata* values rise just after the boundary, along with a temporary and slight fall in tree pollen percentages. One possible explanation of this is an increase in pastoral agriculture in the area, with increased use of the blanket bog.

Phase LET2 C, 51-15 cm. AD 920 - 1680.

Phase C is characterised by a return to sedge domination of the blanket mire community. A change in conditions is suggested by the curves of Cyperaceae, including *Rhynchospora*, and *Narthecium*. Ericaceous species are less well represented. *Myrica* is more consistently represented than in the previous phase. Gramineae, possibly *Molinia*, are more frequent than in the *Calluna* dominated phase B. A peak in the representation of *Pedicularis* (4% of TLP at the 22cm level) coincides with a peak in the *Narthecium* curve and a low point in the percentage of *Calluna*.

Arboreal pollen percentages decline further in phase C to below 10% of TLP for the first time. Open-ground indicators other than blanket bog species are present throughout the zone, and *Plantago* is particularly common.

A pattern of further regional deforestation with a relatively wet local environment is envisaged for phase C. A wet mire surface coincides with increasingly rapid growth rates according to the concentration curves, although the effects of decomposition time and variable pollen influx must be considered.

Phase LET2 D, 15-0 cm. AD 1680 - 1987.

Phase D is marked by changes in both the regional pattern in terms of tree pollen and in terms of changes on the mire. The tree pollen total shows a further decline, also described by the arboreal pollen concentration curve. *Corylus* shows a sharp fall to less than 2% of TLP, and *Quercus* disappears from the record completely for one level and is very rare thereafter. Against this background the *Pinus* curve moves from zero to around 3% of TLP at the 8 cm level.

The mire taxa show a switch back to a *Calluna* dominated assemblage, with *Erica tetralix/cinerea* type increasing to nearly 8% along with a temporary increase in *Empetrum*. Compositae Tubulifloreae and Umbelliferae also seem favoured by conditions in phase D. Cyperaceous species are less well represented.

The phase seems to have been one of continued tree removal. While natural woodland was reduced, it appears that planted *Pinus* was reintroduced to the area. This allows some correlation with the upper phase of profile LET 1. The frequencies of open-ground indicators, in particular Gramineae, *Plantago lanceolata* and *Rumex*, are reduced, as are the percentages of large grass grains. This suggests that heathland and bog replaced the arboreal types rather than arable or pastoral agriculture.

Interpretation of the the local changes is more straightforward; a drying out of the blanket bog can be inferred at around the 15 cm level.

ii). Humification changes.

Humification change LET2.1, beginning at 90 cm. 550 - 135 BC.

Humification change LET2.1 is an uneven increase in % transmission between 90 and 85.5 cm below the peat surface (see figure 6.15). The initial rise is analysed by three consecutive half-centimetre samples, the later, more gentle rise by another three. One sample was analysed between the two at a point where the % transmission dips slightly.

The pollen record shows an initial change to increased Cyperaceae at the expense of Gramineae and Ericaceae. *Narthecium* and *Plantago* also decline in proportion, while *Myrica* appears to show an increase although at very low frequencies. Frequencies of *Coniochaeta* rise until the last sample of the sequence. Type K2 declines and then rises indicating a preference for drier surface conditions. Type K37 shows the opposite tendency, being most abundant in what appear to have been wet horizons.

Gramineae and *Narthecium* appear to vary in their response to apparent hydrological changes depending on the initial state of the assemblage. The interpretation of the other two main components of the pollen diagram is clearer, however, demonstrating a change to generally wetter conditions.

The second series of three consecutive samples shows almost a mirror image of the first set. Cyperaceae decrease in abundance again, to be replaced by Gramineae and *Calluna*. A possible interpretation is that as surface wetness increased the vegetation changed towards species preferring a higher water table. As the change to wetter conditions slowed, the former vegetation cover recovered quickly. The initial change in the % transmission curve can be interpreted as a wet shift, shown by the humification and pollen evidence. Thereafter, however, either the sampling point became unrepresentative of the surrounding area, or the accumulation of vegetative matter brought the surrounding area to a relatively dry state.

Humification change LET2.2, 77 cm. 50 BC - AD 350.

The second humification change examined in detail from the LET 2 profile is characterised by a rise in Cyperaceae. This category includes the separately identified *Rhynchospora*, thought to prefer very wet surface conditions (see section 6.1). The percentages of *Calluna* and

Narthecium decline, while *Myrica* increases slightly. Types K2 and K7 decline relative to other NPMs, with *Sphagnum* spores and K37 increasing in abundance.

Pollen samples were also analysed for the period after the rise in % transmission, showing the vegetation patterns coinciding with what may be a drying of the peat surface, at least at the LET 2 site. Three samples show that *Calluna* increases in abundance rapidly, with Cyperaceae declining. K2 and K7 return to dominate the NPM assemblage.

These results appear to show that the humification curve reflects changes in surface wetness over the surrounding bog. The possible causes of the change are not clear; there are no patterns in the arboreal or anthropogenically-related taxa to suggest human activity.

Humification change LET2.3, 52 cm, AD 780 - 1060.

Six samples have been analysed across an inferred wet-shift at the 52 cm level. The samples cover a rise and fall in the humification curve (see figure 6.19).

The first 0.5 cm sample to record an upturn in % transmission records the highest value for *Calluna* of just over 50 % of TLP. Cyperaceae and Gramineae are poorly represented at this point. A rapid change occurs, however, with increasing % transmission between 49 and 52 cm. The *Calluna* pollen curve plummets to 6%; replaced by Cyperaceae including *Rhynchospora*, and Gramineae. NPM types also record a dramatic change. "Dry" indicators K2 and K7 are completely absent from the 52 cm horizon, *Coniochaeta* and Type 10 and Type K8 increase in abundance. Mycelium fragments of unclassified form (Mycelium undiff. on figure 6.19c) show a general increase in fungal remains.

This pattern demonstrates that the point of upturn in the humification curve, as well as being the first recording of a possible wet-shift, is also, paradoxically, the driest extreme. High *Calluna* values at the beginning of this sequence suggest dry conditions. The humification curve and fungal spores show a change to wetter conditions first. There is a detectable time-lag between the first humification record, NPM frequency changes and vegetation response.

The samples from the period of declining % transmission show that the vegetation change has some inertia, or that the LET 2 curve is unrepresentative of the surrounding area at this time. Cyperaceae continue to increase in frequency, along with *Narthecium*, in the 45-47 cm section. *Calluna* and other Ericaceae increase only in the last sample of the series.

The humification change analysed as LET2.3 appears to have been a significant wet-shift, both at the point of sampling and in the catchment area for mire-type pollen producers. After 50 cm, the pollen concentration curves indicate a change to faster growing peat. Again there are no palynological clues as to the causes of the pattern recorded; types associated with anthropogenic activity appear to benefit from the changes but do not precede or coincide with the onset of the inferred hydrological change.

Humification change LET2.4, 33 cm. AD 1210 - 1430.

The most prominent humification change begins at a depth of 33 cm. A series of pollen and spore analyses from just below the change, through it, and then above it, describe the vegetation changes at the time. *Calluna* and other Ericaceae decrease in abundance. Cyperaceae and *Narthecium* become more frequent, a trend that continues as the peat becomes less humified. Types K8 and K37, microfossils possibly linked to wet surface conditions, increase in abundance over the humification change. This evidence suggests that a change to wetter conditions took place both at the point of investigation and on the surrounding bog. A change in the visible stratigraphy to lighter coloured, less-decomposed peat is recorded at around 30 cm depth. An alternative hypothesis might be that the changing vegetation caused the humification change by altering the composition of the peat-forming vegetation. However, the humification change precedes the stratigraphic change at this point by what may be 50 years, suggesting that the conditions changed first, forcing the vegetation change later as a secondary effect.

Humification change LET2.5, 16 cm. AD 1610 -1690.

Humification and stratigraphy change at a depth of 16 cm down the LET 2 profile. *Calluna* dominates the blanket mire vegetation at this point (see phase D description above). Samples above and below the inferred change show a slight drop in the dominance of *Calluna* with a corresponding increase in Cyperaceae and *Narthecium*. Increases in the abundance of K2, K7, with an associated fall in Types K8 and K37 suggest a change to drier, immediately local conditions.

LET2.5 presents contradictory evidence from different variables. The humification curve appears to represent a wet-shift. It is possibly only detectable in the palynological record because of the preceding dry-phase. The kink in the humification curve and temporary decreases in the representation of *Calluna* and *Erica tetralix/cinerea* type indicate a minor change to wetter conditions, unsupported by NPM evidence.

6.4.4.3. Letterfrack LET 3.

i). General vegetation pattern.

Pollen data have been provided by Dr. M. O'Connell for this site and discussions of the zonation and regional vegetational history are published by him (O'Connell 1989). No further attempt is made here. Non-pollen microfossil data are not available for this site.

ii). Humification changes.

Humification change LET3.1, 50 cm. 1150 - 805 BC.

The change in humification towards apparently wetter conditions at 50 cm can be tentatively correlated with the 39 cm level of FRK IV. The associated palynological changes summarized by figure 6.17 show an increase in the frequencies of Gramineae and Cyperaceae pollen. The direction of these changes are dictated, however, by an exceptional level below the change in humification, which was dominated by *Plantago lanceolata* and other herbaceous types.

There is a possibility of increasing surface wetness in the area, and a strong possibility of anthropogenic influence on the local bog (Phase C of LET 2 showed a relatively high proportion of some of the same types, although not to the same degree).

Humification change LET3.2, 44.5 cm. 900 - 600 BC.

The second small humification change in the direction indicating wetter conditions falls between the pollen horizons at 36 cm and 34 cm. The differences between these two include a rise in the representation of Gramineae and Cyperaceae, while the *Calluna* and *Narthecium* curves fall.

This could indicate a minor change to wetter conditions in the pollen catchment, but the magnitude of the changes in pollen percentages are unconvincing.

Humification change LET3.3, 40 cm. 575 - 300 BC.

The pollen samples from FRK IV at depths of 32 and 30 cm are the best approximation to the depth of this humification change in the curve from LET 3. Cyperaceae increase in abundance from 5% of TLP to 36%. Gramineae decline in abundance over the same interval, while the representation of other types remains roughly the same.

Gramineae pollen appears to vary in its response to inferred changes in surface wetness depending on its status before the change. In this instance, a decline from high values could indicate a negative response to a wet-shift. An alternative interpretation, given the sharp increase in the frequency of Cyperaceae pollen coinciding with a change in degree of decomposition, is that the sedges began growing at the sample site. This change in peat source material would cause a change in the humification curve (see chapter 4).

Humification change LET3.4, 36 cm. 315 - 60 BC.

The change in humification recorded first at a depth of 36 cm from LET 3 can be tentatively correlated with the a level of 29 cm from FRK IV. Pollen data from FRK IV show a sharp fall in the percentage of Cyperaceae. Gramineae, dominant at this time, increase in abundance along with *Calluna*, which increase in terms of TLP from 12% to 28%.

There is no evidence, then, of a widespread surface wetness change. The shift must either be a local feature or be incorrectly correlated between profiles.

Humification change LET3.5, 32 cm. 55 BC - AD 185.

The biggest change in the humification curve from LET 3 is recorded between the depths of 32 cm and 18 cm. A gradual change in visible stratigraphy occurs between 31 and 22 cm. Assuming the correlations summarized in table 6.5 are correct, the beginning of the humification change coincides with a depth of 27 cm on the FRK IV pollen diagram. Extracted data from Dr. O'Connell's analysis are shown on figure 6.17. *Calluna* and Gramineae can be seen to decrease in abundance at this depth. *Calluna* decreases dramatically, from 34% to 8% of TLP. Cyperaceae, including *Rhynchospora*, increase in proportion, as does the representation of *Myrica* and *Narthecium*.

This indicates a change to wetter mire conditions at the time of the onset of the humification change. The pattern as the degree of humification continues to decrease (% transmission to increase) is more complicated, with a variety of combinations of rising and falling values. Although the initial shift appears to have been reflected in the surrounding mire vegetation, the continued inferred change to wetter surface conditions does not. One possibility is that the change represents the acrotelm/catotelm boundary (cf. Ingram 1987), unusually low due to the drainage caused by river cutting. Alternatively, the changing vegetation recorded in figure 6.2 caused the continuing change in % transmission as a secondary effect.

Humification changes LET 3.6, 3.7 and 3.8. 17, 14 and 7 cm.
AD 925 - 1065, 1110 - 1235, 1520 - 1580.

A small upward change in the % transmission curve at a depth of 17 cm correlates with FRK at approximately 15 cm. There are no significant changes in the bog flora at this time as represented by the pollen data. *Myrica* shows a slight increase, but there is no evidence of an assemblage change coinciding with LET3.6.

At 14 cm (correlated to around 12.5 cm), an increase in Cyperaceae, including *Rhynchospora*, and a decline in the abundance of Gramineae are associated with the change to less decomposed peat. This could show a change to wetter surface conditions, although the magnitude of the increases is small.

The change at 7 cm is associated with increases in Cyperaceae including *Rhynchospora* and a slight increase in the representation of *Calluna*. The expansion of both of these does not indicate a clear change in the mire constituents related to a hydrological change. The decomposition decrease could be a result of root material in the peat matrix.

6.4.5. Summary

Given the restrictions of dating techniques and widely spaced pollen samples, it appears that the records of palaeobotany and palaeohydrology from LET1 and LET 2 are reasonably consistent. Major humification changes yield no clear evidence of interference effects on the mire system, and a general coincidence of radiocarbon age evidence.

The wet-shifts shown from LET 1 and LET 2 do not appear to have been related to changes in tree abundance in the way suggested for the Migneint site. Furthermore, the humification changes are usually coincident with changes in the bog flora that indicate a more widespread change in surface wetness conditions.

LET 2 shows a higher abundance of, and therefore possibly closer proximity to the source of, agriculturally-linked types. It is possible that this site was more influenced by past land-use. LET 3 appears to have been influenced by erosion; the coincidences with LET 1 and 2 are rare (see section 8.1), although the time-scale is based on a number of equivocal assumptions. Wet-shifts of varying magnitude do appear to have been recorded.

Narthecium appears to have occupied "middle ground" in terms of hydrological preference. It is generally more abundant in phases of wetter, sedge-dominated conditions than when *Calluna* is the dominant blanket mire species. However, within the wetter phases it responds negatively to wet-shifts. During the drier periods it is more likely to increase with inferred increases in surface wetness.

CHAPTER 7

ANALYSIS OF NON-POLLEN MICROFOSSILS

The NPMs encountered are listed and described in appendix 2, along with observations as to their palaeoecology. Identifications are based on descriptions and plates where available, but are not always clear cut. Where necessary, details of the features used to distinguish each type are given. Results are presented in the following sections:

Firstly, those types previously recorded and named, with suggestions as to their origin or distribution from the sites covered in this study. These are in turn divided according to origin;

1. Rhizopoda
2. Other Zoological remains
3. Algal remains
4. Fungal remains

These are followed by unnamed types, starting with those previously recorded.

5. Types previously recorded, but unnamed, with descriptions and comments.
6. Types previously unrecorded, with descriptions, illustrations and observations.

This chapter aims to summarize the results and discuss some wider implications of the role of NPMs in palaeoecology.

7.1 The use of Non-Pollen Microfossils in Palynology: Theoretical Considerations.

Pollen slides contain a variety of non-pollen microfossils that have rarely been studied in Quaternary palaeoenvironmental work. Van Geel and co-workers have pioneered the counting of these microfossils alongside pollen, as well as examining the fungal content of samples prepared for plant macrofossil examination. The studies of van Geel (cf 1986) and the current project have shown that a great many sub-fossils of fungal types can be characterized, if not identified. This work to some extent contradicts the view of Faegri and Iversen (1975) who barely mention the role that fungal remains might play in palynological studies.

A review by Graham (1962) considered four reasons why fungal remains (in geological palynology) had attracted meagre interest. These were: 1) the lack of readily identifiable remains, 2) the confusion caused by naming indiscreet remains, 3) the lack of features sufficiently diagnostic to allow precise identification, and 4) the lack of pertinent information regarding the stratigraphic or ecological significance of fungal remains. When considering the reasons for the lack of attention paid to fungal remains in Holocene deposits, Graham's four suggestions can be similarly applied.

Firstly, Graham noted a lack of readily identifiable remains. This is not due to a lack of remains, NPMs often out-number pollen grains, but due to the fact that many of the remains are not easily identified. Pollen analysis is facilitated by handbooks and keys, none of which exist for the subfossil remains of fungi or algae. It is possible, though, that as with pollen analysis, once the technique is established, the abundant spores will be readily identifiable.

Secondly, there are problems regarding the naming of remains. It is tempting to assign observed distinctive microfossils to groups or even species they resemble. Handbooks of fungal spores, however, show that many different species, and genera, produce very similar spores. The Ascomycetes, for example, cannot be positively identified to species level in the absence of all but the ascospores. Most types remain unidentified, and as such any ecological significance attached to them is of limited value. Distinctive types have been identified, and their distribution in the subfossil state at one or two sites used to suggest their ecological range (van Geel 1978). Some types have subsequently been used by other authors, such as the *Gelasinospora*, (O'Connell 1987) and Type 10 (Barber 1985) in the manner of an indicator-species approach. The dangers of this approach are clear as the distribution of Type 10 from HB 1 and MIG 1 demonstrates (See appendix 2).

Thirdly, Graham (1962) suggested that fungal remains had been neglected because they lacked diagnostic features. It has been shown both in previous studies and in the current study that in fact there are many types with distinguishing morphological features. This is true of the algal and animal remains as well as the fungi. Many hyphae and mycelium fragments, however, are apparently similar.

Fourthly, even when a non-pollen type is distinguished and identified, the lack of information regarding its ecology often makes the interpretation the same as for unidentified types, based largely on correlation with other variables from the same level.

The technique developed by van Geel has been to describe the distribution of each type and assess its possible indicator value. This forms the basis of the current study, which has introduced a number of new types, and added further information regarding the ecology of some previously recorded ones.

As well as pointing out reasons for the lack of attention to fungal remains, Graham (1962) made comparisons with pollen studies suggesting that consideration of fungal spores could contribute to studies concerning vegetation history. Van Geel (1972) listed these comparisons to outline the potential of including NPMs. Again, Graham's list of points forms a suitable basis for a discussion of the application of NPM remains in Holocene palaeoecology.

(i) Spore production. Graham (1962, p64) pointed out that as plants produce pollen, fungi produce spores and can do so in great numbers.

When dealing with NPMs in general, it must be remembered that some may produce spores at a very specific time and place, and that the place of production and the depositional location may not be the same.

(ii) Pollen and spores are released into the atmosphere and fall in approximate proportion to abundance.

This comparison with pollen can be taken a stage further. As plants produce pollen in different quantities, so do fungi produce spores. The development of correction factors for tree pollen to represent past vegetation more accurately is a refinement as yet impossible in the interpretation of subfossil fungal data. The difference between a life and death assemblage of NPM remains is difficult to reconstruct, especially when considering those types that are relatively unknown.

Not all fungal spores are released into the atmosphere (Alexopoulos and Mims 1979). Many are produced within plant tissue, or underground. Algal spores are often produced in water. This does not make them any less useful, but it does make them less straightforward to interpret.

(iii) Graham pointed out that fungal remains are susceptible to fossilization, and that suitable techniques are available for their recovery.

If the record is compared to that of pollen, then the possibility of differential preservation should be considered. In addition, the acid treatments used in the extraction of subfossil remains could cause differential sampling. Again, these possibilities are unknown quantities, and could well hinder the reconstruction of former NPM assemblages.

(iv) Morphological variation permits relatively precise identification. This point has been discussed above, with the conclusion that some types can be identified, but many more can be distinguished.

(v) Organisms are limited in ecological amplitude and respond to environmental change. This point is again related to one of the reasons given for the lack of earlier research into fossil or subfossil NPMs. The ecological ranges of the different types recorded are unknown. The current status of this branch of palaeoecology is such that recording NPM frequencies is as likely to add to the knowledge of the types themselves as it is to add pertinent palaeoecological data to an integrated study.

The five characteristics enumerated above are based on those presented by Graham (1962). In addition, various features of fungal growth need to be considered when attempting to interpret the distribution of their remains.

It is noted in appendix 2 that T10 can be produced in a different stratigraphic context to the identifiable remains of its host. This pattern could be typical of many fungal types, as well as other micro-organisms that exist in the subsurface zone. The Mycorrhizal fungi associated with higher plants, for example, would be found in a different horizon from the pollen grains.

Remains could also be deposited in the "wrong" horizon if the surface of a mire dried enough to crack, allowing the invasion of aerobic types. Additional problems could be caused by the vertical movement of small, single spores within an undisturbed mire.

Fungal cells can be restricted in their growth by the physical constraints of host tissue. Amongst the fungal remains classified as fungi undifferentiated are an infinite amount of possible shapes and sizes. Type K10 has been shown to produce fungal cells within a pollen grain, the structure of the cluster depending on the shape of the grain.

Many species of microscopic fungi are specific to certain host plants. Their presence in the palaeoecological record therefore strongly suggests the presence of the host plant. Their absence, however, does not suggest the lack of the host plant, as other environmental parameters may be important.

7.2 The future potential of NPM analysis.

The potential of this field is clear. Where macrofossil analysis is not possible due to decomposition or sample size, or lack of time and expertise, specific fungi may give the same type of information. Examples of this are *Anthostomella fuegina, Phaengellina empetri, Meliola niessleana* and T10.

Certain NPMs, especially algal remains, may be used to demonstrate the nature of this depositional environment. For example, an abundance of septate hyphae suggests dry land conditions. If algal spores such as the *Zygnema* type are present, this suggests at least temporary open water, as do the remains of the Copepoda. The form of deposition has a bearing not only on past surface conditions, but also on pollen recruitment.

Van Geel (1972) noted the possibility of cultivated plants bearing specific fungal parasites. There is considerable potential in the various fungal types relating to anthropogenic activity, in particular dung fungi and those favoured by burning. The use of NPMs in this context has proved difficult in the current study, partly because of the inconsistency of the distribution of the relevant types and partly because of the lack of recent/surface analogues.

Within the context of the current study it was hoped to use previously recorded types as indicators of past surface conditions. Some types appear to be useful for distinguishing between particularly wet or dry phases of peat growth.

The potential of NPM analysis in every direction could be greatly enhanced by surface sampling from different depositional environments, and by collaboration with mycologists and freshwater zoologists in trying to identify the microfossils recovered.

7.3 Conclusions.

Van Geel (1972) wrote;

> *"Conceivably there are species among the fungal remains (fossilised in peat) whose occurrence gives information about certain climatic factors, such as temperature and humidity, prevailing at the time of deposition of their spores in the bog"* (p.269).

It is unlikely, however, that NPMs will be directly linked to environmental parameters. It is more likely that, as a part of a multivariate approach to palaeoecology, these types may add further information about ecological conditions. As these conditions change, a response in the abundance of NPMs could indirectly provide evidence of that change.

The conclusions, where there are any, regarding the NPMs distinguished in the current project are outlined in appendix 2. The content of the appendix should not be used as a list of types and what they show, but rather as a guide to how they have been interpreted from the blanket peat sites studied. Although some types appear to have an independent indicator value, they are best used as one variable in an integrated study.

CHAPTER 8

DISCUSSION AND CONCLUSIONS

8.1 Dates of humification changes from blanket mires.

Chapter 6 described the humification curves from each profile and the associated microfossil data. This section summarizes and compares the dates of inferred wet-shifts, in the form of table 8.1 and figure 8.1.

Table 8.1 below gives the estimated date of all the wet-shifts as recorded by humification changes, irrespective of the microfossil evidence. As such, it provides a database of the principal results obtained in the study.

HB 1	MIG 1	MIG 2	MIG 3	LET 1	LET 2	LET 3
BC	BC	BC	AD	BC	BC	BC
1170	2010	1795	340	3870	340	980
750	1900	1600	460	2129	200	750
495	1580	880	740	1520	AD	440
20	1490	325	825	1280	150	190
AD	1290	AD	975	800	410	AD
140	1180	1210	1080	230	620	65
250	1050	1800	1210	AD	730	995
310	910	1865	1375	230	865	1175
530	525	1890	1690	655	920	1550
635	390		1775	1170	1085	
810	150			1400	1130	
1025	AD			1520	1260	
1130	50			1630	1320	
1330	260			1720	1480	
1380	490			1810	1545	
1450	580				1650	
1565	650					
1605	750					
1750	850					
	930					
	1090					
	1195					
	1315					
	1540					
	1750					

Table 8.1. Calibrated dates of changes to inferred wetter conditions. Dates shown are the mid-points of the calibrated ranges to the nearest 5 yr. The extent of the ranges are shown on figure 8.1.

Figure 8.1 shows all the changes recorded on an AD/BC time scale. Attempting to distinguish synchronous changes is difficult, firstly because of the large ranges covered by the calibrated 95% confidence interval, and secondly because of the increasing resolution, and hence apparent clustering of dates, in the top part of the diagram. Horizons dated by interpolation at 80-100 year intervals are statistically indistinguishable. Coincidences in the recorded ages of some of the major changes can be discerned, however, and these are outlined below.

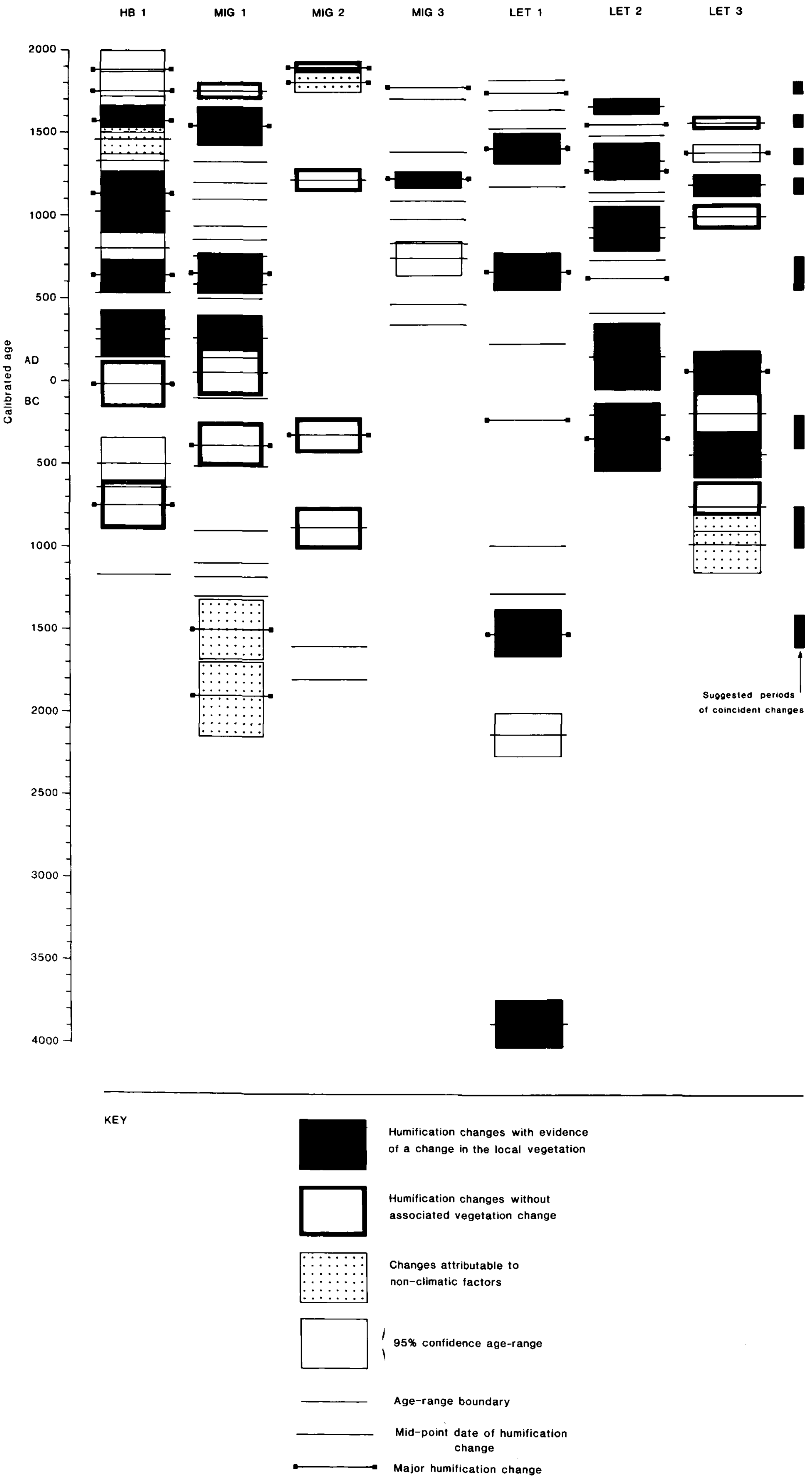
c. 1500 BC. All profiles covering the appropriate period show changes to apparently wetter conditions at around 1500 BC. MIG 1 and LET 1 show changes dated to 1490 and 1520 BC respectively, and MIG 2 shows an increase in % transmission within the 95% age limits. The change from MIG 1 was, however, tentatively linked to anthropogenic activity and tree-clearance.

1,000 - 750 BC. All three sites, but not all the profiles studied, record a change between 1,000 and 750 BC. Interpolated or determined ages for these humification changes are within the 95% range. The evidence is not of a widespread change at each site, however, and LET 3.1 could be related to human activity.

400 - 200 BC. Major humification changes have been recorded from MIG 1, MIG 2, LET 1 and LET 2 between 400 and 200 years BC.

c. AD 650. Major humification changes have been dated at around AD 650 from all three sites. Four of the shifts have been the horizons dated, with determinations from HB 1, MIG 1, LET 1 and LET 2 all falling within a 10-year interval. All of the sites investigated palynologically at the appropriate level provided evidence of a wet-shift in the vicinity of the coring point. None showed a pattern associated with an anthropogenic cause of the humification or vegetation changes.

Figure 8.1. Dates of humification changes towards inferred wetter conditions.
Dates are based on calibrated ^{14}C determinations and interpolated mid-points of 95% age-ranges. Some of age-ranges are shown, but many are omitted for clarity. The suggested periods of coincidence are based on the estimated ages of major changes, with greater importance being given to those actually radiocarbon dated.


HB 1
MIG 1
MIG 2
MIG 3
LET 1
LET 2
LET 3
Calibrated age
2000
1500
1000
500
AD
0
BC
500
1000
1500
2000
2500
3000
3500
4000
Suggested periods of coincident changes
KEY
Humification changes with evidence of a change in the local vegetation
Humification changes without associated vegetation change
Changes attributable to non-climatic factors
95% confidence age-range
Age-range boundary
Mid-point date of humification change
Major humification change

AD 1150 - 1200. Significant changes in the humification curve from MIG 3 and LET 2 have been dated at between AD 1150 and 1200. Coinciding with these (within the 95% span) are smaller changes from profiles HB 1, MIG 2, LET 1 and LET 3.AD 1300 -1400. A large concentration of dates on figure 8.1, combined with overlapping age-ranges makes interpretation of the pattern over the last 700 years difficult. There is possibly a coincidence of increases in % transmission between AD 1300 and 1400.

AD 1520 - 1600. Major changes from HB 1, MIG 1 and LET 2 coincide with smaller changes at LET 1 and LET 3 within the AD 1520 - 1600 time-span.

AD 1730 - 1800. Finally, a coincidence of humification changes from 5 of the profiles has been recorded in the period AD 1730 - 1800. Distinguishing which features on figure 8.1 do, and which do not coincide, is difficult in the top part of the diagram, as most dates are based on a zero-age for the surface and many have overlapping age-ranges.

8.2 Correlation with other data.

Having outlined the nature of any coincident changes above, the next step is to compare these results with those from other sources. Firstly, other peat-stratigraphic records are compared. Secondly, a combination of other information is used; the range available increases as the age-ranges in question get younger.

8.2.1 c. 1500 BC.

Evidence for a wet-shift shown by other peat stratigraphic studies at this time comes from a variety of sources. Mitchell (1956) suggested that 3450 BP was a time favouring regeneration in Irish raised bogs. Other Irish evidence comes from O'Connell (1986), who published a surface wetness index for a blanket peat site in Co. Mayo. This index showed a change to wetter conditions beginning at around 3250 BP, 250 years later than the change at LET 1. This date is based on uncalibrated ^{14}C years. Calibration of this date gives a range of 1688-1416 BC, mid-point of 1522 BC.

Coles and Orme (1980) reported a date for flooding horizons on the Somerset Levels of around 1400 BC (within the 2-sigma age range of 1500 BC). However, the possibility of marine influence on the base-level of the Levels makes a climatic interpretation uncertain. The same can be said of the similarly dated flooding horizon from the West Netherlands recorded by Bakker and van Smeerdijk (1982).

Aaby (1976) showed a change in the degree of humification and Rhizopod assemblage of Danish raised mires at 1520 BC. Van Geel (1978) suggested that a change to wetter conditions could be interpreted from the palaeoecological record at the Engbertsdijksveen, Netherlands.

The evidence is sufficient for Barber (1982) to conclude that peat-stratigraphic data show a climatic deterioration c. 1500-1400 BC .

8.2.2 1,000 - 750 BC.

There is a great deal of evidence for peat stratigraphic evidence for climatic deterioration in the first millennium BC. The original delimitation of a transition from the Sub-Boreal to the Sub-Atlantic chronozones suggested more Oceanic conditions in Western Europe (see section 2.1). Peat-stratigraphic studies give the impression that the change is of major proportions.

Botanical evidence other than mire stratigraphy has also been assessed for this period. Beug (1982) describes the change as one to a cooler and moister climate. Frenzel (1966) reviewed palynological evidence from a wide range of sites and concluded that the climatic change was slight. It would appear, then, that the climatic change that did take place was of a nature particularly important to the water balance of ombrotrophic mires.

Climatically-interpreted features in peat bogs have been dated between 900 and 500 BC by Granlund (1932), Nilsson (1964), Lundqvist (1962), Mitchell (1956), Overbeck (1975), Godwin (1966), Barber (1981), Dickinson (1975), Coles and Orme (1980), Casparie (1972, although lake-drainage complications are referred to), Aaby (1976) van Geel (1978) and Svensson (1988a).

Barber (1982) concluded that there was evidence for;

> ***"A catastrophic decline to a cooler and/or wetter climate around 2850-2550 BP (900-600 bc); taking into account the sensitivity of individual bogs the earlier date may be more generally applicable"*** (p110)

The evidence from the blanket peat profiles studied is slightly less definitive (see above) but can be seen to support the evidence for a change to conditions more suited to fast growing, less humified peat. This correlation adds evidence to the argument that blanket peats can yield proxy climatic data, although the evidence from the sites studied here is not of a catastrophic decline. The correlation of all peat-hydrological changes is hindered by the response rates, or sensitivity, of individual bogs.

A further complication is added by the variation in natural carbon ratios at this time. The radiocarbon calibration curve is particularly broad and fluctuating during the time period 1000-500 BC. A half-millenium age range may be obtained for a ^{14}C determination at the 95% confidence level (Pilcher 1990), and there are two possible calendar dates for many determinations. Despite these problems, it appears that the blanket mire sites have recorded changes comparable to those from elsewhere.

8.2.3 400 - 200 BC.

Major humification changes from Migneint and Letterfrack are dated at between 400 and 200 BC. There is little evidence of a similar change elsewhere although Nilsson (1964) recorded a recurrence surface at 300 BC from Ageröds Mosse in Sweden. This is the reverse of the situation regarding the 1,000-750 BC change, where evidence from elsewhere outweighed the results from blanket peats. A possible explanation is that the two data sources, raised bogs and blanket mires, are recording different climatic elements. Alternatively, one or both of the data sources are not a true reflection of climate. Evidence from another source is required to resolve this problem.

8.2.4 c. AD 650.

The change recorded, and consistently dated, from c. AD 650 correlates with results from a number of other studies. Firstly, the record from other blanket mires (see figure 8.2) can be compared. Data from Wood Moss, Cheshire (Chambers, unpub., analysis by I Wilshaw) and Brecon Beacons, South Wales (Chambers 1984) show a change to less humified peat at around this time. A change to apparently wetter and more variable conditions may be interpreted from

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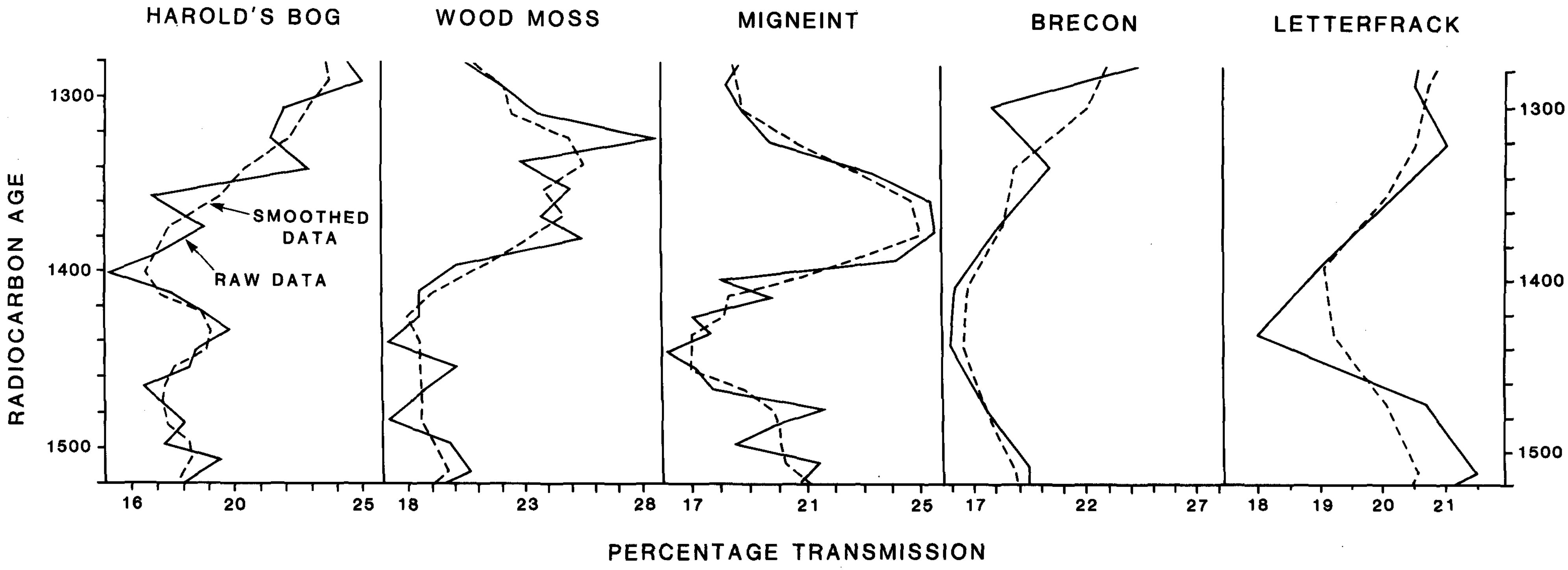
Figure 8.2. Humification curve extracts, 1520 - 1280 bp . Includes data from Chambers (1984).


HAROLD'S BOG
WOOD MOSS
MIGNEINT
BRECON
LETTERFRACK
RADIOCARBON AGE
1300
1400
1500
SMOOTHED DATA
RAW DATA
16
20
25
18
23
28
17
21
25
17
22
27
18
19
20
21
PERCENTAGE TRANSMISSION

the work of Rowell and Turner (1984) at a slightly later date.

Records from raised-bog stratigraphies published by Mitchell (1956), Barber (1981), Svensson (1988a) and Overbeck et.al. (1957) show changes to wetter surface conditions within the 95% confidence limits of ^{14}C dating. Huttunen (1983) referred to faster growing stages in several bogs from work published by Tolonen and Ruuhijärvi (1976). This implies that a reasonably synchronous change in climate can be detected in Ireland, England and Wales, Sweden, Finland and Germany. Finally, it is worth noting that Granlund's (1932) RY II was dated at AD 400 by archaeological correlation. Svensson's (1988a) ^{14}C dated recurrence surface of c. 1500 age is from the same area studied by Granlund, and might be a better age approximation for RY II.

Evidence from other sources also points to a climatic "deterioration" around this time. Various documentary sources suggest that a period of particularly warm, dry conditions appears to have ended around 400-500 AD (Lamb 1977, 1982a). Lamb (1982a) suggests that the climate became ***"rather colder and more disturbed"*** (p157). Additionally, a period of particularly narrow tree-rings, implying unfavourable tree-growth conditions, has been dated to 541 AD (Baillee and Munro 1988), which is within the 2-sigma age-range.

There is a body of evidence, then, supported by the current study, to suggest a climatic shift in the mid-first millennium AD.

8.2.5 AD 1150 - 1200.

There is evidence to suggest a change in peat stratigraphies at around AD 1150-1200. Other blanket peat data show changes to apparently wetter conditions at around the same time (Chamber 1984, and unpub.). RY I, recorded by Granlund (1932) and Lundqvist (1962) has been dated at AD 1200.

Barber (1981) recorded a change to wetter conditions at around AD 900, followed by a drying phase. This drying phase is interrupted, however, by a short reversion to wet-lawn conditions as shown by his figure 76 (Barber 1981, p192). This wet-shift is recorded at AD 1150.

Documentary sources do not appear to support this inferred climatic change. Lamb (1977) and Le Roy Ladurie (1971) suggest that this was a time of particularly warm weather for much of Europe. A possible explanation of this is that the climatic change involved was small. The dry period within which the possible wet-shift is contained may be the reason for its being recorded. Alternatively, the apparent coincidence of dates could be simply a matter of chance, individual site factors being responsible for the patterns shown.

8.2.6 The last 600 years.

Figure 8.1 shows the profusion of inferred wet-shifts recorded for the last 600 years. 95% age-ranges overlap, as shown by the HB 1 column. Additional problems in correlating the upper sections of the profiles arise from the number of "modern" radiocarbon determinations from humic and visible stratigraphic changes. Tentative suggestions are made, however, as to the timing and correlation of humification changes. These are plotted on figure 8.1 and are the date-ranges AD 1300-1400, AD 1520-1600, and AD 1730-1800.

The first of these changes coincides with a switch from dry to very wet surface conditions at Bolton Fell Moss (Barber 1981), which is apparently in agreement with other proxy data sources. Nilsson (1964) dated a recurrence surface from Swedish mires to this time. Further afield, increased humidity has been inferred from bogs in South and West Greenland at around 600 bp (B. Fredskild, fig. 11 in Berglund 1983).

The fourteenth century AD is thought by Lamb (1982) to be a time of cooling and wetness, although some of the farm abandonments and famines documented may be attributable to the plague. Increased variability of climate is suggested.

The second change again correlates with the surface wetness curve from Bolton Fell Moss. Interpolated mid-point dates of AD 1520, 1545 and 1550 from LET 1,2 and 3, 1565 from HB 1 and a ^{14}C determination calibrated to 1540 from MIG 1 coincide with the shift shown by Barber (1981). Aaby (1976) suggested that AD 1500 is one of the dates occuring in a 260-year cycle. Given the errors of dating and different mire-response rates, these shifts can all be correlated, although the degree of certainty is unknown.

Other sources of climatic evidence, notably documentary records, are more abundant by the sixteenth century. These data are summarized by Lamb (1982a), who suggested that the period AD 1500-1550 was "relatively genial", especially compared to the predominantly cold, wet years that followed. This is the ideal situation for recording a wet-shift from ombrotrophic mires. It appears that sites in Ireland, England and Wales have now recorded the end of a warm period at the beginning of the sixteenth century.

The so-called "Little Ice-Age" is the dominant feature of the climate over the last 600 years. Evidence from a variety of sources, including instrumental records, points to colder conditions throughout Europe and elsewhere. As such, it is an ideal time period with which to test the usefulness of a potential new source of proxy climatic data. Pin-pointing the beginning of the Little Ice Age is, however, difficult. The onset of climatic worsening, in human terms, can be placed anywhere between 1190 and 1560 AD. Lamb (1982a, 1984) notes an abrupt change in the middle of the sixteenth century, followed by what he views as the broad climax of the cold period until around AD 1700. The blanket peat records appear to show this abrupt deterioration. A coincident change in the humification curves from 5 out of the 7 profiles analysed, despite the potential inaccuracies of the time-scales used, suggests that at this time a valid proxy record has been obtained. The nature of the record obtained is discussed in section 8.3. The two remaining profiles are LET 3, influenced by a down-slope position and river erosion, and a poorly dated, also down-slope profile, MIG 3.

A third period with possibly more recorded wet-shifts (see figure 8.1) is that between AD 1730 and around AD 1800. Correlations with other mire-sources are difficult at this time as many raised bogs have lost the upper layers. Aaby (1976, 1978), predicted a wet-shift at 1760, but did not find one. Barber (1981, 1982) however, recorded a change from wet to very wet mire surface conditions at approximately the date predicted by Aaby. Although the evidence shown on figure 8.1 is inconclusive, it may be that the blanket peat profiles studied here support the argument for a wet-shift in the mid-eighteenth century. The general climatic trend as recorded from a wide variety of sources was of gradual "improvement" from AD 1700 onwards. An exception to this is the period between 1760 and 1790, when cold conditions prevailed in Switzerland (Pfister 1974) and elsewhere (Lamb 1982b)

8.2.7 Summary.

Blanket peats appear to have recorded humification changes that coincide with other proxy records of climatic change. The degree of change has differed from that recorded by other mire types, and the pattern recorded by each profile was by no means the same.

8.3 The nature of the climatic changes concerned.

8.3.1 The link between peat humification and climate.

It has been argued in the preceding sections that "climatic changes" have been recorded by blanket peat humification records. This section attempts to comment on the possible nature of the changes recorded.

The variable measured and used to the greatest extent was the degree of humification. The blanket mires investigated are not continuously waterlogged, but may become dry at the surface in summer. It is at this time that the aerobic humification process takes place. Although anaerobic decomposition may continue while waterlogged, this is believed to be at a much slower rate (Clymo 1984). The length of time that the surface is exposed to aerobic humification each year might be the critical factor in determining the degree of decomposition. Factors influencing the summer water table, in particular rainfall and evaporation during late spring and summer, may be the variables indirectly recorded. Each 0.5 cm sample represented between 10 and 40 years. This suggests that humification curves are indirect, semi-quantitative measures of average summer effective rainfall. If a mire surface is waterlogged throughout the year, it is possible that a change to even wetter conditions could have no further effect. An example of the implications of this is given below.

The documentary sources concerning the period AD 100-400 suggest relatively warm and dry conditions. This was followed by a climatic "deterioration" (increased effective rainfall and/or reduced temperature) as implied from biological proxy data. As such a wet-shift is initiated marking the end of the warmer period. The wet-shift is as much dependent on, and therefore as valid a record of, the preceding dry period as it is on the subsequent wetter conditions.

8.3.2 The possibility of a cyclic element in the data.

In chapter 6 it was frequently mentioned that the % transmission against depth curves had what looked like a visually-cyclic element. Some parts of figure 8.1 reflect this. An objective appraisal of any possible periodicity is hampered by a number of factors. Firstly, there are errors involved in calibrated age-ranges. Secondly, there is a large interval between many of the dates obtained, and thirdly there is a reliance on linear interpolation (see chapter 9). Referring to table 8.1, however, two possible cycles can be tentatively observed. These are of 60 and 100-110 years, with double-length intervals (120 and 200-220) also occurring.

Other mire-based studies have demonstrated the possibility of a cyclic signal in different variables (Aaby 1976, 1978, Wijmstra 1984, Dupont 1986). The results presented here imply that blanket peat humification might also be subjected to a periodic climatic influence.

8.4 Hydrological considerations.

The water balance of an ombrotrophic mire has been considered by Ivanov (1981), Ingram (1983), Dupont (1986) and Haslam (1987). Of particular relevance to the blanket bogs studied here are the basic equations;

$$1. \quad \frac{dW}{dt} = Q_1 - Q_2 + P_p + P_{gr} + P_e$$

and

$$2. \quad \frac{dW}{dt} = (P_p - P_e)w - q_n L_2$$

where;

Q_1 = Total input across front of influx,

Q_2 = Total output across front of efflux,

P_p = Precipitation,

P_{gr} = Underground efflux,

P_e = Evaporation and transpiration,

w = Area of bog (front of influx),

q_n = Seepage in the direction of the boundary,

L_2 = Length of boundary (front of efflux).

and

$\frac{dW}{dt}$ = Rate of accumulation of water by the bog system.

In considering the response of various mires to changes in climate (P_p and P_e), Haslam (1987) noted that increasing the length of the front of efflux (L_2) increased the rate at which a bog discharged surplus moisture; reducing its responsiveness.

In the case of the blanket mires studied, defining the edge of the bog is impossible. Ombrotrophic parts tend to grade into mineral soils or valley mires, or gradually become water receiving/accumulating systems at the point of inflection of a sloping hillside. A hypothetical situation is envisaged, then, where a convex plateau mire is considered to be a watershedding ombrotrophic bog. The boundary is considered circular, L_2 being the circumference of a circle radius *R*, centred on the summit of the plateau. If the radius is considered to be the square root of 1/Pi (in any units) then *w* in equation 2 above becomes 1 square unit, and can be disregarded. Similarly, L_2 becomes quantified, (1.12 x Pi), leaving:

$$3. \quad \frac{dW}{dt} = (P_p - P_e) - 3.54q_n$$

The only variable left to control the relationship between rate of water accumulation and the rates of precipitation and evaporation is that of q_n, the seepage in the direction of the boundary at every point on it.

The rate of efflux from the mire will depend on a number of factors. The mobility of water in a blanket mire is much greater in the acrotelm than in the catotelm and so the relative thickness of these two layers may be an important factor. The degree of decomposition, related to fibre content and pore space, is another factor effecting q_n. This can be summarized in that q_n will be proportional to the permeability of the peat (*Z*) at, upslope and downslope of the arbitrary front of efflux.

The drainage of water away from the watershedding summit also depends to some extent on the slope angle. Faster drainage might be expected on steeper slopes. The factor q_n is therefore also proportional to the drop over distance *R*, i.e. $R\tan T^\circ$ where T° = the angle of the tangent of the slope to the horizontal at the point considered. As T° increases, if all other factors remain equal, the potential rate of efflux increases.

This leaves:

$$4. \quad q_n = \text{(proportional to) } ZR\tan T^\circ = Z\tan T^\circ$$

as *R* is considered to be root 1/Pi and therefore quantified and irrelevant in a proportional equation.

It is now possible to consider the implications of equations 3 and 4. A steep-sided mire position, for instance the LET 1 site on the summit of Bealnascalpa, would have a high value of T°. An increase in the effective precipitation (P_p - P_e), would be counteracted by a high value of q_n, causing the response at the summit to be limited. A flatter site would have a more immediate response to a change to wetter climatic conditions, if all other factors remained equal. T^o and therefore q_n would be low.

The response rates to a change to drier conditions would be reversed, steeper sided sites discharging more effectively, causing a drier surface more quickly than where the slope angle is lower.

Equations 3 and 4 also predict that blanket peats over steep hilltops can only occur in areas of high effective rainfall, and further, that if the peat is of low density and high permeability, the climate must be, or have been, extremely wet.

One serious problem remains with these suggestions, however, that cannot be fully considered without field measurements; the factors Z and T^o are not independent. A steep-sided blanket mire summit would be more likely to be in a dry state than a shallow sloping area. Over the years of peat development, then, it is probable that more humified, less permeable (lower Z) peat would cover a steep location than a flat one. The opposite might be expected from plateau sites such as MIG 1 and 2.

The data obtained from Harold's Bog, Migneint and Letterfrack can be used to some extent to test the validity of the arguments above. The table below shows the ratios of humification changes towards wetter conditions per 1,000 years for five profiles. LET 3 and MIG 3 are not included due to their slope positions. The sites are arranged in order of steepness of slope.

Profile	Angle*	No. wet-shifts	Calendar years	Changes per 1000 yrs.
LET 1	14°	14	6,000	2.3
LET 2	8°	14	2,600	5.4
MIG 1	5.5°	22	4,000	5.5
MIG 2	1.5°	9	3,800	2.4
HB 1	1.5°	20	3,400	5.9

* Maximum slope angle 20 m from the site.

Table 8.2; No. of wet-shifts per 1,000 years related to mire slope angle.

LET 1 is from a particularly steep location, and has the lowest frequency of responses indicating wet-shifts. The plateau sites MIG and HB appear more responsive, with the exception of profile MIG 2. This could be due to a number of factors, including the possibility that the basal peat depth is "too old" (as suggested by correlation with the palynostratigraphy of MIG 3), and that the resolution gained by sampling at 0.5 cm intervals was too coarse to record some changes.

Various factors need to be taken into consideration here: the effects of permeability, growth-rate and therefore resolution, and the distinct possibility that climate has not changed in the same way at all three sites over the period of peat accumulation. Although some evidence supports the arguments above, it is clear that more sites are required to investigate the response/slope realationship.

8.5 Response rates and mechanisms of blanket mire systems.

The preceding sections have led to the tentative conclusion that some degree of the variability in mire hydrology can be attributed to an externally-forced input. In some instances, climatic controls appear to have been important. Sections 6.2.5, 6.3.5 and 6.4.5, however, demonstrated the asynchroneity of response of some of the microfossil variables and peat humification curves. Some explanation of this is offered in this section. The conclusions have a bearing on the interpretation of the changes, and on the response of bogs to climatic change. A hypothetical example, or a model, of the response rates of different "responder variables", in particular in terms of the range used in the current study, is used to explain the patterns shown.

An area of blanket peat on a watershedding (convex) area of pre-peat and peat topography, is envisaged. Contained within the area is a patchwork of wet and dry biotypes and a corresponding range of different species is envisaged. A major assumption of the model is that different vegetation assemblages are in approximate proportion to the area of wet and dry areas according to their favoured hydrological positions as reviewed in section 6.1. A second assumption is that the microfossils recorded from a central profile are in approximate proportion to the relative abundance within the catchment. It is necessary that changes in abundance of species have been recorded accurately, in terms of the direction and timing of the changes.

8.5.1 The effect of a change in surface wetness.

An externally forced change in the water table, for example a climatic change to one of wetter summer conditions, first affects the degree of humification. The difference between, for example, four months of aerobic conditions at the surface rather than two months, or four dry years in ten rather than six, should be recorded and detected by less humified peat over the timespan of a sample.

Vegetational responses appear to be slower, although this is not always the case and at times the inadequacies of the pollen record, including the effects of very local pollen production ("super-local" effects), obscure the pattern. A change to wetter conditions would cause an expansion of the wetter, higher water-table vegetation communities at the expense of drier assemblages. The pollen record appears to respond after the humification profile in the examples given below. Taxa indicative of wetter environments appear to follow humification changes to less decomposed peat. Cyperaceae are generally favoured, and *Calluna* often becomes less abundant after humification changes. *Sphagnum* spores are sometimes much more frequent after % transmission increases, the inconsistency of this particular variable demonstrating the extremely localised distribution of the spores. Factors affecting the response rates of the mire surface types include the diffusion rates of the species concerned, the inertia, or stability, of the existing community, and the time-span of the preceding drier period (A *Sphagnum*-dominated mire may well grow above the water table. In these cases the longer the dry phase lasts, the more extreme a wet-shift is needed to cause a change in surface humidity). The initial state of the surface community appears to be particularly important in the case of the Gramineae, changes from a very dry assemblage at Harold's Bog are marked by an increase in grass pollen: at Letterfrack the reverse is sometimes true.

The third level of responder variables are those that involve the vegetation changing exactly at the sampling point. The stratigraphy and macrofossils would follow the pollen record unless the coring point was particularly sensitive and a rapid vegetation change occurred. The record of various non-pollen types is also linked to the peat state at the precise point of coring. The open water types such as Copepoda and Zygnema would be expected to respond after other variables, and parasitic fungi could only be recorded when the host species were present. Airborne spores may respond in a similar way to pollen frequencies.

Thus a sequence of humification, pollen and then stratigraphic change is the complete, idealised sequence following a climatically controlled change in mire surface wetness. Once the stratigraphy changes, however, the humification degree will again be altered, as the source material of humic substances will have changed (see section 4.7). The most immediately obvious change, that of peat stratigraphy, may in fact be only a second-phase response to an earlier environmental change. This is shown by the curves of % transmission from the humification changes at LET 1 and 2 especially, from Harold's Bog at HB1.4 and HB1.5, and from the uppermost major humification changes from MIG 2 and MIG 3. MIG 1 appears to have responded immediately to wet-shifts with corresponding vegetation changes.

The importance of this relationship to the interpretation of stratigraphic changes in ombrotrophic mires, and the precise dating of environmental changes, is clear. The time-lag between humification and vegetation records suggests an advantage to the former line of evidence. Changes should be recorded more rapidly and more continuously than when a species change is needed. Furthermore, it may be possible to interpret changes to drier conditions, contradictory to the suppositions of previous authors (see chapter 2).

The summary chart below presents the consequences of the model. Estimates of the time-scales involved are based on the examples of the current study and are very approximate, the sampling interval and growth rates determining the resolution possible.

Summary chart 1.

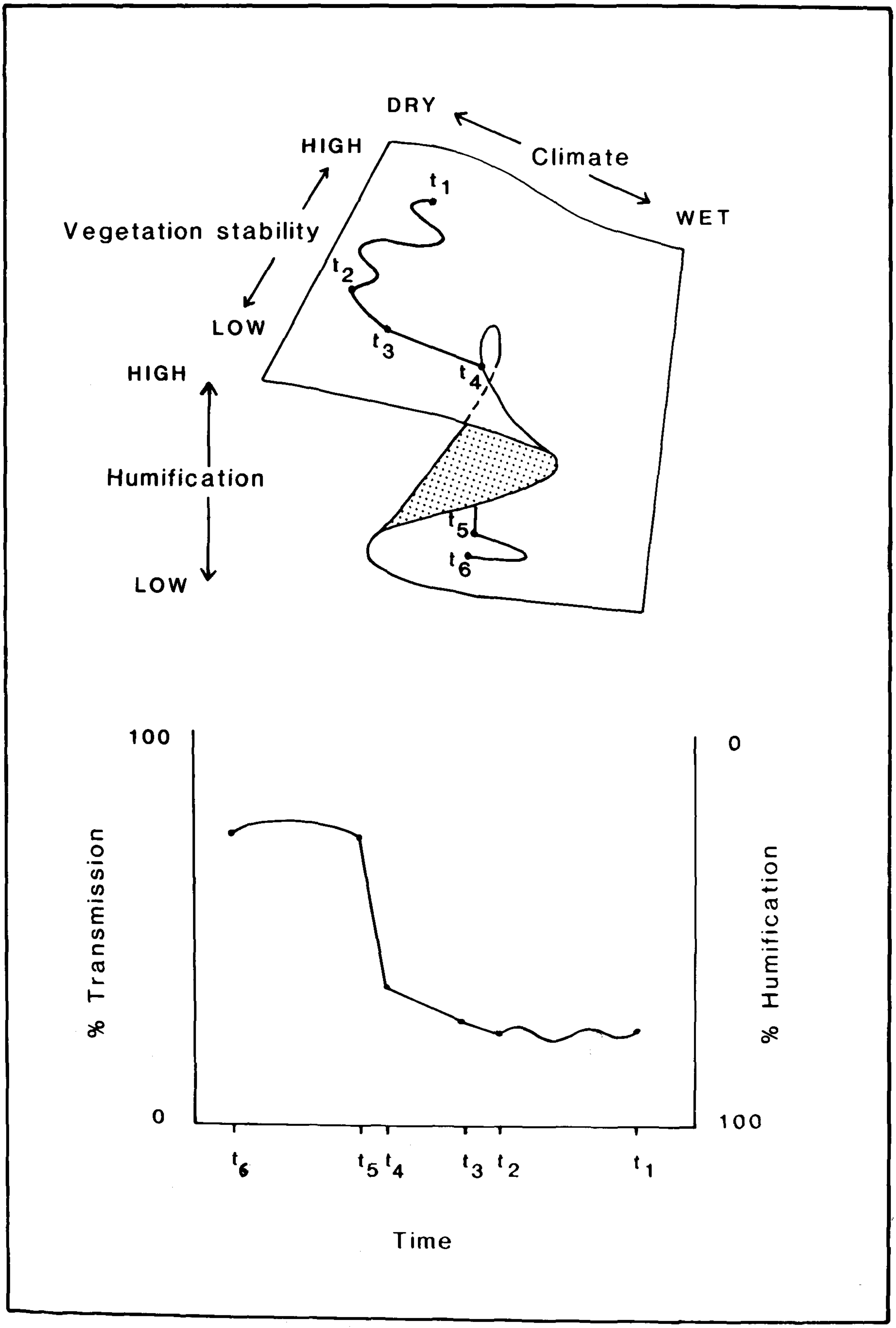
1. Climatic change to increased summer wetness.

   * Less humified peat.
   * Less "dry" association pollen types,
     more "wet" types.
   * NPM's, Macrofossils and stratigraphic change.
   * Secondary change to less humified peat.

The way in which the variables respond to change may be expressed in terms of catastrophe theory (Wagstaff 1976). Figure 8.3 shows how, given a change to wetter climatic conditions, the humification curve and then the vegetation structure would follow. Woodcock

Figure 8.3. Catastrophe model of the response of peat humification to climatic change.

Catastrophe model of humification changes



and Davis (1978) suggested that this type of graph should be seen not as an explanation of the changes but as a description. In the present case, however, by describing the palaeoecological changes in this manner some degree of explanation of the sequences recorded may be attempted, as in the form of summary chart 1.

8.5.2. Changes caused by tree clearance.

Distinguishing between the effects of tree clearance on peat surface hydrology and those of surface wetness on trees can be achieved by close interval sampling, and examining the direction and order of the changes recorded. For example, if tree pollen decreases ***before*** the degree of humification changes, however marginally, and if there is palynological or macrofossil evidence for the existence of trees close to the coring point, then tree death or removal may be considered a probable cause of the palaeohydrological event (cf. Moore 1983, 1988). Examples of this are the changes in the Migneint 1 profile (humification changes MIG1.1, and possibly MIG1.3).

The reverse situation could equally be recorded in this way. If the first two events of chart 2 were reversed, the probable explanation would be that changes in mire hydrology had made conditions unsuitable, or less suitable, for tree growth. This would in turn cause a feedback effect by raising the water table. It is the order of the changes in the first instance that appears to give the best evidence for or against either explanation.

This situation can again be described in the terms of a catastrophe model, with trees being eliminated after a hydrological threshold is reached, followed by a secondary rise in surface wetness. Both these possibilities are found in the profiles analysed, the changes at MIG1.1 and MIG1.3 being examples.

Summary chart 2.

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2. Changes caused by tree clearance.

   - * Arboreal pollen types decline, open ground species increase.
   - * Less humified peat,
   - * Less "dry" indicators, "wet" types increase,

8.5.3 Changes caused by anthropogenic activity.

A third type of sequence in palaeohydrological and palaeobotanical events has been identified from the blanket peat profiles studied. This involves the possibility of externally forced change caused by grazing and/or burning pressure on the surface vegetation. Section 6.1 discussed the possibility of detecting the effects of land use on the bog from the palynological record and concluded that in particular *Potentilla erecta* might be used as an indicator of grazing and light burning. Several of the hydrological changes examined in detail revealed evidence that *Potentilla* increased in abundance. A change in humification could be caused by a non-hydrological event causing a species change (see section 4.7). If that were the case, anthropogenic activity would be recorded before the change in humification. Chart 3 below demonstrates the sequence of this third model of response; it is simplified in that following a change in surface wetness or vegetation composition the land-use practices might again be modified.

Summary chart 3.

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3. Changes caused by anthropogenic activity.

   - Pollen types indicative of grazing or burning increase.
   - Humification changes due to a change in the surface vegetation. As such, stratigraphic and NPM changes should be coincident.
   - Secondary effects of humification and microfossil changes follow.

8.5.4 Summary.

A model of the response of the blanket mire system to a climatic change to wetter surface conditions has been presented, and illustrated, with examples from which the model was derived. In addition, two alternative models based on a non-climatic cause of humification change are suggested. These inductively-derived proposed models require deductive testing with data from new profiles to assess their applicability to systems other than those studied here.

A general conclusion from sections 8.3 and 8.4 is that the response of an ombrotrophic mire to a change in conditions, howsoever caused, depends not only on the direction and size of the change, but on the initial conditions of the mire.

8.5 CONCLUSIONS.

It has been shown that blanket mires can yield proxy climatic data. The quality of those data is now assessed in terms of the properties of proxy data sources as discussed in chapter 2.

i) Resolution.

The resolution obtained from a 0.5 cm sample interval has been between 10 and 40 years. Assuming that three samples are required to show a climatic event, the resolution becomes 30-120 years. Closer sampling would be possible in future studies. The resolution varies between and within profiles, younger deposits generally providing greater resolution.

ii) Time span.

The time interval covered by the present study is 4,000 BC to the present. Older blanket mires do exist, although watershedding sites will always tend to be younger than basin peats. Greater resolution, comparability and areal extent have been shown from the last 2,800 years.

iii) Interference.

In chapter 2 it was suggested that the interference effects applying to peat deposits are potentially overpowering. The principal interference factor appears to be the effect of man, particularly on woodland in the vicinity of the sample site. Some measures have been demonstrated for detecting the influence of anthropogenic interference effects, but the more subtle alterations of the blanket mire systems remain largely enigmatic.

iv) Measurement.

Sections 2.1 to 2.3 showed how increasing the detail of study improved the proxy climatic record obtained from peat deposits. Analysis at a variety of sampling intervals has reaffirmed this conclusion; the most valuable record was obtained where close interval, multi-variable analysis was conducted. The degree of humification appears to have been partly influenced by climatic variation, operating through fluctuating water tables, and can be measured consistently.

Unfortunately the link between degree of humification and water-table has not been quantified. At the beginning of chapter 6 it was asked "how far would Pooh have sunk?" This question cannot yet be answered, but it is possible to suggest when he might have sunk deeper, or shallower.

Microfossil content has also been measured, and appears to be to some extent dependent on surface conditions, including the height of the water table.

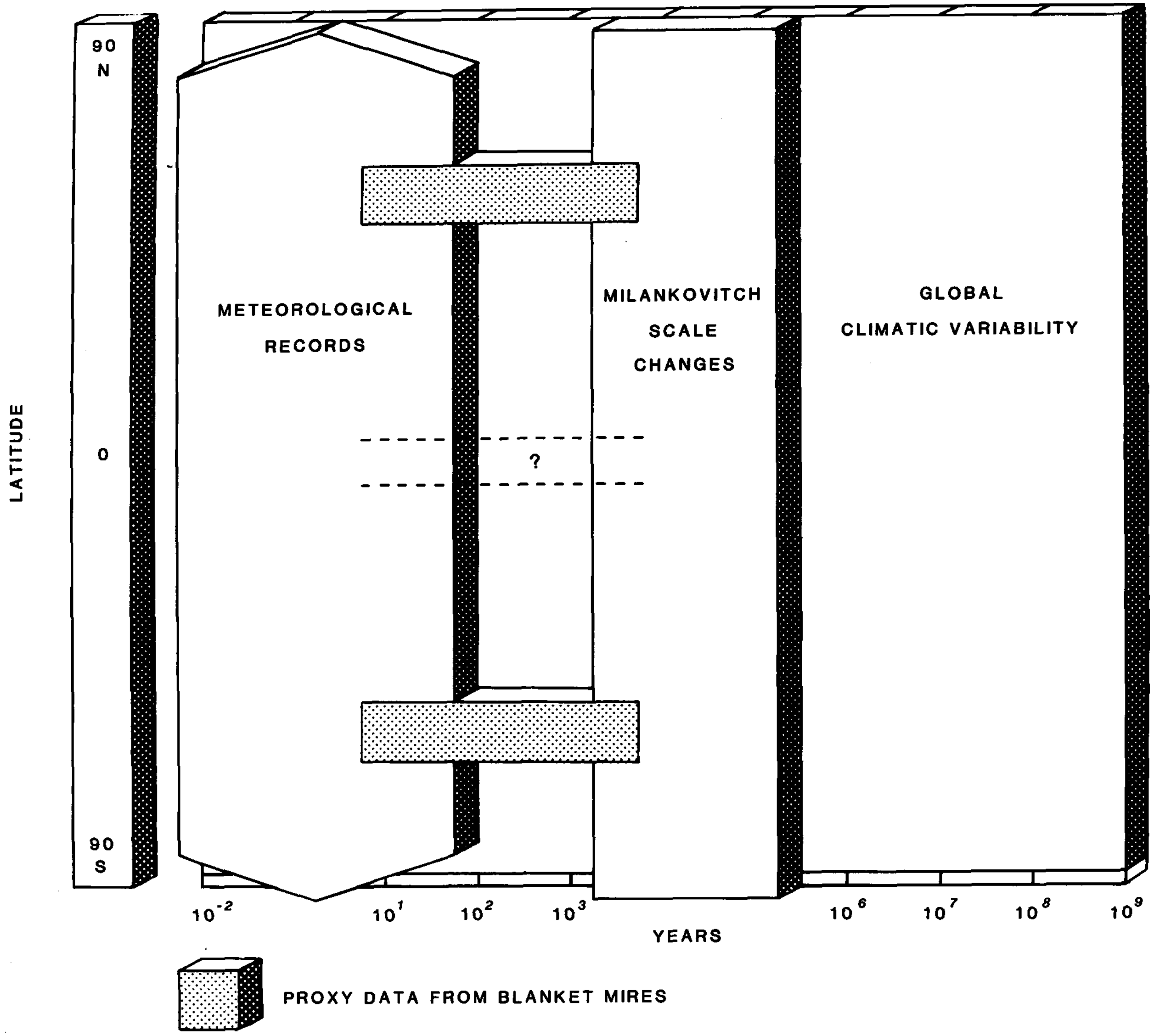
v) Areal extent.

The global distribution of blanket mires is shown by figure 1.1. The Western European-type has been shown to have some of the properties required of a source of proxy climatic data. The replicability of the results suggests that each humification curve is representative of the immediate vicinity, but not necessarily of the whole mire area. The differences between the curves from MIG 1, 2 and 3 demonstrate this. The amount of variation between different sampling points from the same area appears to vary from site to site, as the Letterfrack curves are more consistent. Some inferred "climatic" wet-shifts appear to have been recorded from all the areas studied, although not from every profile from each area. It could be argued, therefore, that the "noise" of local hydrology, (interference effects), is variable. The terms sensitivity and responsiveness are now applied to those bogs where the background, non-climatic variability of degree of humification is less than that caused by climatic change. Given data from a range of mires with a variety of sensitivities, a unanimous response to any given climatic shift is unlikely, and a majority response might be considered sufficient. The number of sites showing a simultaneous wet-shift might be indicative of the magnitude of the climatic change involved.

Figure 8.4 shows how the climatic record from blanket mires may fill a gap between the Milankovitch-scale variability recorded by off-shore and ice-core records, and that within the range of instrumental records. Variability within the time-scale 10^2 - 10^3 years appears to be measured indirectly by properties of peat deposits. Figure 8.4 also shows the latitude ranges within which blanket peats have been discovered (after Lindsay et.al. 1988).

Figure 8.4. Time-space diagram showing the latitudinal range and time-scale of variability of the proxy record available from blanket mires. The ranges covered by meteorological records, blanket peats and "Milankovitch"- scale variability are set against a background of global climatic variability. Dashed lines indicate that the central African mountain mire-type could be used if they can be shown to be ombrotrophic.

THE ROLE OF BLANKET MIRES IN PALAEOCLIMATOLOGY



CHAPTER 9

REMAINING PROBLEMS AND FUTURE RESEARCH

Chapter 8 demonstrated the potential of blanket peats as a source of proxy climatic data and illustrated the mechanisms involved in the response of a mire system. The application of the record of peat humification could be improved in a number of ways in future research by the solution of remaining problems. Some remaining problems have been mentioned in the appropriate place in the text. This chapter aims to discuss the principal problems and possible improvements; namely dating the profiles, testing for periodicity, and relating microfossil assemblages more directly to past environments by surface sampling.

9.1 Dating.

9.1.1 Problems with radiocarbon dates from peat.

In a review of radiometric dating techniques, Olsson (1986) commented that;

> *"A radiocarbon dating, far from being an isolated laboratory result, is based on the sample's deposition in nature, its collection, the relation of the sample to an event or process, measurement of the isotope activity, and an interpretation of the result."* (p.275)

Once a series of radiocarbon determinations has been performed, interpretation of the results should take into account the problems involved rather than treating the result as an absolute date. In many cases, as in the case of the upper dates from many of the profiles in the current study, the dates appear wrong, that is they do not appear to fit with what would be logically expected from the relationship of the dated sample to either depth or other samples. Schiffer (1986) discussed the inferential component of radiocarbon dating and stated;

> ***"The traditional way to deal with "conflicting" (i.e. variable) dates is to select only those dates that are in agreement with one's prior position on chronological issues; this is the widely practised art of "accepting" and "rejecting" dates."*** (p.79)

Examples of this selectivity from blanket peats include the date at 0.60m from Wheeldale Gill, disregarded by Simmons and Cundill (1974) because it was older than those from the levels below and was the only one that did not fit into the sequence. Caseldine and Maguire (1986) rejected the basal date from Black Ridge Brook because it was younger than the dates above. In this case an explanation was offered; that roots from later growth had accumulated at the base.

Rejection of dates in this way presents a serious problem. If all samples are collected, pre-treated and dated in the same way, the rejection of one date must cast considerable doubt on the validity of others. For example, it is quite likely that roots accumulate at the base of a peat profile as the surface extends away from it. However, it is equally likely that roots from younger levels accumulate and decompose in all horizons, causing all dates to be to some extent too young (i.e. younger than the date at which the horizon in question was the peat surface). In many blanket peat profiles the rooting depth of some species is considerable. Problems may occur especially when the water table drops causing, and allowing, deeper rooting. The examples of the uppermost dates from HB1, MIG2, MIG3 and LET1 may be examples of this.

The sample quality used in the present study was probably poor, with slices of peat being sent to the laboratory without sorting. Pretreatment followed the guidelines of Dresser (1970) but would still allow contamination by partially decomposed root material, giving a date slightly "too young". Future research needs to refine or replace the dating technique.

Sorting the material to select horizontally bedded leaf material might be helpful, although the reduced yield would need to be compensated for by either an increased thickness of peat (with inevitable loss of resolution) or a counting technique applicable to small samples such as AMS dating (Hedges 1990).

9.1.2 Calibration.

The problem of calibration is one that must be addressed if any peat deposits are to be used as a proxy climatic record. Correlation with historical events or other proxy series is essential for the current technique to be properly assessed. The difference between radiocarbon and calendar years is considerable, and affects growth-rate calculations as well as the dates of wet-shifts.

A number of calibration curves have been published, none of which give quite the same results. Trees from different regions have been used to measure past concentrations of atmospheric ^{14}C, and different tree species have been used. The treatment and counting techniques used by those constructing calibration curves has also varied.

Pilcher (1990) suggested that the curves produced by Stuiver and Pearson (1986) and Pearson and Stuiver (1986) are accepted as standard. These curves are obtained from tree-ring series from both sides of the Atlantic, and on determinations from 20-year intervals. Stuiver and Pearson (1986) found that both the systematic errors between the Belfast and Seattle laboratories and the concentrations recorded from different tree-ring series were within acceptable limits. No explanation is offered, however, as to why the curves are different from those produced by previous attempts at calibration (eg. Klein et.al. 1982).

9.1.3 Future dating techniques.

The problems discussed above lead to the conclusion that the current state of radiocarbon dating from peat deposits, and in particular the dates obtained from the sites in this study, are insufficiently precise to allow the exact comparison of profiles or further analysis of individual curves.

Improvements in the accuracy of radiocarbon dating would be the most readily applicable method of establishing an accurate time scale. Sample quality would seem to be critical and could be improved in two ways. Firstly, by selecting particular fragments of peat-forming material that could not have been transported vertically in the profile or deposited at depth. Horizontally bedded leaves may be the best material. Secondly, the application of ERS dating (Hedges 1990) would allow very small sample to be selected, allowing only the best material to be used.

Calibration of the dates obtained against a calendar year time scale could be improved by dating more precisely than the 60 - 70 year standard error reported in this study (cf. Stuiver and Pearson 1986). The possibility of precise calibration by the wiggle-matching of closely spaced dates (van Geel and Mook 1989) would also be applicable to blanket peat profiles.

This would still leave problems of fractionation, the uptake of water containing hard-old carbon and counting errors.

An alternative to radiocarbon dating is the identification of specific layers of tephra in peat deposits (Dugmore pers.comm., 1989, Olsson 1986, Persson 1971). This technique has the potential of locating precise horizons of presumed age, rather than dating the horizons of particular interest. Tephra layers have been used as valuable time markers in various sediments, including peat deposits (Einarsson 1986). The distribution of tephra layers from Icelandic eruptions overlaps with the extent of blanket peat. A combination of tephra dates (where possible), and numerous, improved radiocarbon dates from horizons showing wet-shifts would provide a time-scale accurate enough for time-series analysis.

9.2 Site selection.

The importance of watershedding sites in reducing interference effects is important. However, the resolution and time-span advantages of sampling on a convexity but not the absolute summit of an area of peat, as shown at the Migneint site, should be taken into account. The definition of "watershedding" and "spur" mires by Lindsay et.al. (1988) is useful in this context.

The advantage of watershedding locations would be emphasised if tephrochronology was required as tephra layers could otherwise be redeposited. Site selection on a broader scale would also need to take into account the possibility of using tephra. Sampling too near the source of the tephra (assuming the source to be Icelandic), for example in Iceland, the Faroes or even Northern Scotland), might cause the ash layers to affect the bog directly. Dugmore (1989) reported the find of a valuable tephra isochrone from Scotland, and suggested that its identification could become a standard part of palynological work in Northern Britain. Sampling too far south and east would negate the possibility of tephra dating.

Of the sites investigated in this study, the western Irish one appears to have had the least disturbed and most continuous record. Humification can be seen as a virtually continuous record in climatic regimes where the conditions remain favourable for growth. Less favourable areas, where the water balance is more variable may be in some way more sensitive, but can be too marginal to provide a continuous sequence. The comments in section 8.4 may be useful in this context.

9.3 Time-series analysis.

By obtaining 55 dates from a single profile, Aaby (1976) was able to demonstrate an apparent periodicity in peat humification data. Some of the humification curves from blanket mires show what appears to be a cyclic pattern. If a time scale can be firmly established by a more accurate dating techniques, time-series analysis could provide a test of this periodicity. A programme developed by Briskin and Harrell (1980) and used on palaeobotanical data sets by Wijmstra et.al. (1984) would seem appropriate.

The potential of time-series work in the 10^2 to 10^3 years range is to some extent hinted at by the work done by Aaby (1976), Wijmstra et.al. (1984) and by Dupont (1986). Testing Aaby's 260 year cycle might be a valuable research strategy. Alternatively, or simultaneously, the approx. 200-year period in palaeobotanical data shown by Wijmstra et.al. (1971, 1984) and Dupont (1986) and suggested by the curves from blanket peat humification could be tested.

The possibility of then linking this type of research to the known periodicity in sunspot cycles (Dewey 1960, Eddy 1976 Wijmstra et.al. 1984) could test a possible cause for inferred changes in climate.

9.4 Surface sampling.

During the course of this investigation a large amount of palaeobotanical data has been collected. For some of this the interpretation has been negligible. In addition, the curves of some taxa have been only tentatively used. The principal cause of this is the lack of information regarding the present day distribution and ecology of many of the types recorded.

Subsequent research would benefit from a programme of surface sampling, isolating the sources of NPM types and numerically relating their distribution to surface conditions, water-table height and plant assemblages. The paucity of information regarding the relative pollen representation of mire types in relation to distance, area cover and surface conditions could be similarly improved. This approach would improve the utility of the data obtained and lead to a more accurate assessment and description of inferred wet-shift features.

Combined with improved dating techniques, blanket peats could then provide proxy climatic information of valuable accuracy and continuity.

APPENDIX 1

SPREADSHEET FORMULAE FOR CORRECTING HUMIFICATION DATA

Chapter 4 described the different experiments conducted to test the humification determination method. The results of some of these experiments have been incorporated into a spreadsheet to correct all measured % transmission values. The formulae were applied on a "VIP Professional" spreadsheet working on an Atari 1040 microcomputer.

In the description below, *italics* indicate an input value into the cell. **Bold** type denotes a formula programmed into the cell.

Column A: *Depth*

Column B: *% Transmission*

Column C: *Loss-on-Ignition*

Column D: *Time*

The first column (A) contained depths (mid-point of samples). The second (B) contained the mean humification reading for each depth. The third (C), the loss-on-ignition result for each sample, in the form 0.995 for 99.5%, 0.6 for 60% etc. The fourth input column (D) contained the elapsed time, in minutes, greater than four hours, between mixing samples and recording % transmission (see section 5.1). Column E corrected the humification reading for the effect of mineral content. Columns F-K calculated a correction factor for fading, if the time elapsed exceeded four hours. This was very rarely used. The example of row 3 is given below.

Column E contained the formula: **(B3xC3)**

(the number changing for each row).

Column F contained the formula: **@IF(D3>0)#AND#(D3<40),(D3x0.02125),0)**

The @IF command is similar in function to a BASIC IF...THEN command. Column F asks if D3 is less than 40 but greater than 0. If it is, D3 is multiplied by the correction factor appropriate (0.02125, as calculated from the results plotted in figure 4.2), and the resulting number entered into the cell. If D3 is not in the specified range, then 0 is entered in the cell. Formulae in subsequent columns were:

Column G: @IF(D3> =40)#AND#(D3<63),(D3x0.0198+0.0776),0)
Column H: @IF(D3> =63)#AND#(D3<120),(D3x0.0092+0.746),0)
Column I: @IF(D3> =120)#AND#(D3<315),(D3x0.005897+1.1432),0)
Column J: @IF(D3> =315)#AND#(D3<600),(D3x0.00296+2.0686),0)
Column K: @IF(D3> =600)#AND#(D3<1200),(D3x0.0011364+3.14997),0)

The correction factor in formulae F-K involves two components, one controlled by the time elapsed within the specified range and one for the time elapsed before. For example, (cell G3), the 0.0198 factor compensates for the time period between 40 minutes and the time entered in column D. The additional 0.0776 is a mean value for fading in the first 40 minutes after 4 hours. The first factor diminishes as the rate of fading decreases with time. The additional figure increases as fading continues.

The rate of fading was found to be proportional to the time elapsed, and not to the optical density of the solution. As such, the formulae above are based on the time, not humification, input columns. This is the reverse of a normal decay-curve.

Columns F-K all had an assigned value, with one column containing a correction value, the others containing 0. If there was no excess time, F-K all registered 0. Column L picked out the correction value by finding the maximum value in the row. This value was then subtracted from the humification reading in column E (ie already corrected for mineral content).

Column L: @MAX(F3..K3)
Column M: (E3-L3)

Running means of three consecutive values were calculated on the spreadsheet:

Column N: (M2+M3+M4)/3

Thanks are due to Bryan Dawson, Department of Geography, Keele, for assistance.

APPENDIX 2

DESCRIPTIONS, ILLUSTRATIONS AND COMMENTS REGARDING NON-POLLEN MICROFOSSILS

The identification of non-pollen microfossils has been discussed in the methods section (chapter 5) and in chapter 7. This appendix aims to describe and illustrate the microfossils recorded, and where possible comment on their apparent ecological preferences. The frequencies of selected types have been plotted in chapter 6. Tabulated data of the other types are available on request.

A2.1 Rhizopoda

Rigorous analysis of Rhizopod tests requires specific pre-treatment and counting techniques (Tolonen 1986). In the present study those remains present in acetolysed pollen samples were the only ones counted, giving a very restricted range. Identification was based on the illustrations of Tolonen (1966), Simms (1973) and van Geel (1978).

Amphitrema flavum.

Described and illustrated by a number of previous authors (Tolonen 1966, van Geel 1972, 1978) from peats. The test is not destroyed by acetolysis, and this species was used by Aaby and Tauber (1975) to reconstruct past surface humidity, apparently showing locally moist conditions. Van Geel (1978) pointed out that it is probably not suited to open water conditions, and hence may be more frequent in less humid phases.

Generally scarce in the blanket peats studied, *Amphitrema* achieves low frequencies only when sedges or *Sphagnum* are well represented in what appear to be the wettest sections.

Amphitrema flavum are recovered only from levels above what appears to have been the major wet shifts.

Assulina type.

Like *Amphitrema*, this type has been used by previous authors as a wet-phase indicator, *Assulina* spp, particularly *A. muscorum*, was described and illustrated by van Geel (1978). The examples counted in blanket peat profiles were generally degraded, rarely showing the characteristic "scaley" appearance. Although Grospietch (1972) suggested that *A. muscorum* can be distinguished from *A. seminulum* on a size basis, the similarity in shape between *Assulina* and some other tests of Rhizopoda means the definition as "*Assulina* type" is preferred.

Curves from Harold's Bog and Migneint 1 indicate that *Assulina* type microfossils are more common in *Sphagnum* rich, "wet" peat. The first appearance in both profiles is after a significant wet shift recorded by humification and local pollen curves.

Hyalosphenia subflava.

Described and illustrated by van Geel (1978), examples from Harold's Bog have been identified by van Geel (pers. com.) as this species (Plate 1). Previously described as an indicator of disturbed peat surfaces, van Geel (1972, 1978) associated the presence of *H. subflava* with the preparation of the mire surface for buckwheat cultivation.

H. subflava is present throughout the LET 1 profile in a variety of peat types, leading to a number of possible conclusions. It is possible that the surface was continually disturbed, although the stratigraphic continuity suggests otherwise. The conditions of the raised mires studied by van Geel after drainage for cultivation may be similar to those pertaining on the generally "drier" blanket peats for much of the period of peat growth. Alternatively, the habitat created by burning the peat surface may be hospitable to *Hyalosphenia subflava.*

Between 45 and 50 cm in the Harold's Bog curve, *Hyalosphenia* shows a distinct maximum. The pollen frequencies of Ericales increase and the pollen of Cyperaceae declines over the same period. In this instance, *Hyalosphenia subflava* shows a preference for drying conditions.

A2.2 OTHER ZOOLOGICAL REMAINS.

Copepoda

Spermatophores of *Canthocamptus* or other freshwater planktonic forms have been identified from raised mires and freshwater pool environments (van Geel 1972, 1978, Pals et al 1980). Examples varying little in size (between 50-60 *u*m) were recorded from blanket peats quite consistently, but rarely in abundance. Previous authors have suggested that this microfossil type indicates the presence of temporary open water.

A second type of microfossil, similar in shape and recognisable as Copepoda remains has also been identified in pollen slides. Smaller (30-45 *u*m), hyaline, thin walled and with a more bulbous shape (see plate 1), this second type shows a similar distribution in the peat profiles.

Both types show an increase in the HB 1 section following the wet shift recorded at 55 cm. The larger type also increases in abundance after the less influential changes in surface humidity at 44 cm and 23 cm. Copepoda are less frequent in the other profiles, but still show a general preference for apparently wetter horizons.

Rotiferae

Loricae of *Callidina angusticollis* (Murray) were described and illustrated by van Geel (1978), showing their ability to survive pollen preparation techniques. Similar microfossils were found in levels 22+ and 16+ from Harold's Bog and level 8+ from profile MIG 2. These finds of single individuals cannot at present be used as indicators of particular conditions.

Insect remains.

Mandibles.

Microfossils with morphology characteristic of the mandibles of larval Acari and those of Coleoptera have been identified in pollen slides. However, a range of types were counted simply as mandibles undifferentiated, only late in the analysis were distinctions made. As such the results are plotted as a broad class. The distribution pattern is typically widespread but low frequency; little or no palaeoecological significance can be attached at this stage.

Hairs.

Microfossils of varying sizes were identified as being hairs of animal, probably insect, origin.

Claws.

Conical, regularly ornamented microfossils unattached to any other sections were recorded. Varying in size between 60 and 100 *u*m, these fossils are often "hairy", with 3,4 or 5 thicker spines protruding from the apex of the conical structure. These microfossils resemble the furthest, smallest section of the claw of Acari. Closer examination could reveal the species, some of which have particular ecological requirements.

Unidentified zoological remains.

Type 75 of van Geel (1978) was tentatively described as being of animal origin. The distinctive arrangement of spines and denticles (cf van Geel 1978 Plate X) was found on rare occasions in the blanket peat samples of the current study, but as yet no significance can be attached to this microfossil.

A2.3 ALGAL REMAINS.

Zygnema type.

Hyaline, pitted microfossils illustrated by van Geel (1978) and van Geel and van der Hammen (1978) (see plate 1) and coded "Type 58" are now considered to be zygospores of the Zygnemataceae. A variety of environments, including peats, ditches and lake sediments have contained this type. Examples from the blanket peat samples of the current study have been circular in polar view, with concentic rings of 3 *u*m diameter pits. Zygnemataceae produce spores in spring in shallow (less than 0.5 m deep), stagnant pools which warm up quickly.

Zygnema type spores were recorded from the HB 1 section from a number of different levels, increasing in abundance up the profile. Increased surface wetness above 55 cm and again above 23 cm can be inferred if this microfossil indicates open pools. Other profiles contained isolated examples only.

Mougeotia cf. *gracillisma* type.

Various types of *Mougeotia* (Zygnemataceae) have been described from peat and other sediments (cf. van Geel et.al. 1989). Occasional examples from the profiles examined most closely resembled the illustrations of *M. gracillisma*. Their indicator value is similar to that of the *Zygnema* type (above).

The distribution of these types from the blanket peats sites is very sparse, single spores occurring in the upper part of the MIG 2 and LET 2 profiles. They are found in what appear from other indicators to be relatively wet conditions.

A2.4 FUNGAL REMAINS

Anthostomella fuegiana Speg.

Described and illustrated by van Geel (1972, 1978). Ascospores of *Anthostomella* have a distinctive shape and are common in the peats studied by previous authors as well as in the blanket peats of the current study. Francis (1975) isolated *A. fuegiana* from a number of host species including *Cladium mariscus* and *Eriophorum vaginatum*. In the case of van Geel (1978) the most likely host was *Eriophorum*, and when fruit bodies as well as ascospores were present it was thought to be a good indicator of the presence locally of *Eriophorum* spp.

Data from HB 1 and MIG 1 support this conclusion. *Anthostomella fuegiana* shows a good correlation with the pollen curve of the Cyperaceae (see figure 6.4). At the lower end of the profile both curves are reasonably high, until 94 cm when both fall to low values. Peaks at 56 and 43 cm are represented by both curves, and although the section around 45 cm has generally high *Anthostomella* values, it does not rise as high or as sharply as the sedge pollen curve. Both microfossils decline at 22 cm.

The pattern from the MIG 1 profile is not as clear, although the zones in which Cyperaceae are very abundant and those in which they are absent are reflected by the *Anthostomella* curve. The potential of this fungal spore is clear, especially in studies like this where macrofossil evidence is not available.

Cercophora type.

Sordiceous type described by Pals et.al. (1980). Lunqvist (1972) describes and illustrates a number of *Cercophora*, associated with dung decomposition. Some types are, however, present on decaying plant material free from dung. The ascospores are not currently identifiable to species level. Individual examples were recorded from a variety of horizons from all profiles except MIG 3. As yet no particular significance can be assigned to the distribution of this type.

Chaetomium spp.

Lemon-shaped ascospores, prone to crumpling and disfigurement, described and illustrated by van Geel (1978). *Chaetomium* are cellulose-decomposing ascomycetes occurring commonly on all kinds of plant remains. Their frequency may reflect the state of decomposition of the host matrix.

Spores from all three blanket peat sites were classed as *Chaetomium* type, characterised by shape and a red to pink staining after sample preparation. Ellis and Ellis (1985) describe *Chaetomium* as a genus of plurivorous species common on grasses. The erratic curve of *Chaetomium*-like spores from HB 1 does not show a close connection with the curve for Gramineae pollen, although peaks at 80+ and at 48+ coincide, and the relatively low Gramineae counts from 22+ and 53+ are levels that contain no *Chaetomium*. A possible interpretation of this is that while the Gramineae pollen describes the distribution over a wide area, the spores of what may be fungi on the same plants have a more localised distribution. This difference could cause the pattern seen, where only the extremes coincide.

Clasterosporium caricinum.

Spores counted in various levels from LET 1 and LET 2 resembled those described and illustrated by van Geel (1978) and identified by M B Ellis (Kew) as *C. caricinum*, found on sedge leaves. No correlation could be made between the indicators of sedges and this fungal species in van Geel's work. All the examples recorded in the current study came from samples containing more than 20% Cyperaceae pollen. This could be significant, but the rarity of the ascospores and the frequency of Cyperaceous pollen in some parts of the profiles precludes a definite conclusion.

Coniochaeta cf. *xylariispora* (Ell. and Everh.) Cooke.

Described and illustrated by van Geel (1972), the ascospores of *Coniochaeta* can be distinguished by their morphology- single celled, oval ascospores with a single germ split along one side. Measuring around 12 x 5 *u*m in equatorial view, these spores are brown or reddish brown in pollen slides.

Although van Geel (1978) found examples attributable to the species level, Ellis and Ellis (1985) illustrate a variety of species producing seemingly identical ascospores. Macroscopic examination of peat samples to find fruit bodies may be necessary to distinguish between, for example, *C. malacotrich, C. ligniaria* and *C. pulveraceae*, all of which have different hosts.

The examples recorded from Harold's Bog appear to have a general preference for drier conditions. This pattern is reaffirmed from MIG 3, although the pattern is less clear. Their frequency, as a proportion of NPMs, often declines when the humification curve indicates a wet-shift, and they are best represented in the lower part of the profile where Ericales pollen percentages are high and where the peat is well humified. The Irish profiles show that *Coniochaeta* ascospores are more frequent in wetter horizons. This could be due to the variety of species involved.

Entophlyctis lobata Will. and Townley.

Described by van Geel (1978) who suggested similarities to microfossils identified from the Eocene. *E. lobata* is a saprophytic species from aquatic environments, characterised by a circular exit pore. Godwin and Andrew (1951) linked similar types to Microthyriaceous fruit bodies in peat from Cross Fell, suggesting that they were an early stage of the same species. Van Geel (1978) thought this unlikely, due to the lack of common features and the absence of any microfossils from a stage between the two. The current study has shown an additional lack of common occurrence, although the identification of *Entophlyctis* is not entirely certain.

Gelasinospora spp.

Distinctive ascospores described and illustrated by van Geel (1972, 1978) typified by evenly spaced pits in a dark brown spore wall. Three categories have been distinguished, the first of which is those similar to van Geel's Type 1, *Gelasinospora* undifferentiated.

Gelasinospora cf. reticulispora (Greis and Greis-Dengler) C and M Moreau.

Secondly, spores resembling *G. reticulispora* (van Geel's Type 2) can be distinguished by longer and larger pits. Domsch and Gams (1972) identified this species from a variety of host material, including *Calluna* heathland soil, rabbit dung and tree fibre. Some association between the presence of this type and burnt material has also been suggested (van Geel 1978, O'Connell 1986).

A third *Gelasinospora* type, coded Type K1, is characterised by being larger than the rest by a factor of 1.5 (typically 30 *u*m long by 22 *u*m), and small (1 *u*m), circular, deep surface pits. These dark brown coloured ascospores are infrequent, occurring only in levels of highly humified peat where *Calluna* pollen percentages are high. All the *Gelasinospora* are best represented in the lower part of the HB 1 section, where microscopic charcoal levels are higher than average. The palaeoecological application of this group would be greatly enhanced by the collection of surface samples and the identification of specific environmental parameters from modern material.

Geoglossum sphagnophilum Ehrenb. ex Wallr.

Seven-septate ascospores reported from *Sphagnum* peat by van Geel (1978). Samples from the Wietmarschermoor and Engbersdijksveen sections revealed a preference for the drier, hummock forming phases of *Sphagnum* peat. Identifications from the samples analysed in the current study are not certain, a group of slightly different spore types (see plate 1) with or without an eighth, hyaline, slightly swollen cell (see van Geel 1978) were originally identified as *G. sphagnophilum*, but have since been classed as a group including *Geoglossum sphagnophilum* (see plate 1). A distinctly larger, hyaline end cell is characteristic of

Sporidesmium spp.

The distribution of this type from the HB1 section shows a distict peak in the section 53 - 49 cm and at 43 - 39 cm. This indicates a similar distribution to Cyperaceae and/or *Sphagnum*, the microfossil representation of which also have distinct maxima at these levels.

Helicoon spp. and *Helisporium* spp.

Ellis (1971) and Barnett (1955) illustrate conidophores and conidia of various *Helisporium* species. Multi-septate, coiled conidia gradually tapering to a narrow point are characteristic of this type, and distinguishable from the larger, tighter coil of *Helicoon* species.

Both *Helisporium* and *Helicoon* remains were frequently encountered from the HB 1 section, but never in abundance and at present cannot be assigned any indicator value.

Meliola cf. *niessleana* Winter.

Described and illustrated by van Geel (1972). Van Geel recognized two identifiable remains from this species, the ascospores and mycelium, often found together. The dark brown, three-septate, curved ascospore is distinguished from other similar sporomorphs by the pore with annular thickening in the centre of each septum and by the curved side of the spore (see plates VII and VIII of van Geel 1978).

Van Geel (1978) repeatedly found *Meliola* remains attached to the leaves of *Calluna vulgaris*. Although not isolated from modern *Calluna* material, hosts of *Vaccinium vitis-idaea* (Dennis 1968) and other *Vaccinium* species have been suggested (Erikson 1974). The positioning of this fungal type on the leaves of its host rather than the roots suggests that it may be used as an indicator of the local presence of *Calluna vulgaris*, or other host species if these can be identified. *C. vulgaris* is the most likely host plant in the blanket peat communities of the current study.

Results from blanket mires show that neither the spores or mycelium of *Meliola* show a clear relationship to the frequency of Ericales type pollen. Other factors must be important in determining the distribution of this type as well as the presence of its host.

Microthyrium type.

Ellis and Ellis (1985) illustrate a large number of Microthyracious fruit bodies from a wide variety of host plant and substrates. Van Geel (1978) attempted to identify the subfossil remains of this type to genus level, as some have distinguishing features of structure, ornamentation or appendages. The examples encountered from blanket peats were often fragmented and/or degraded, and rarely in any numbers. As such, no attempt has been made to distinguish between types, other than a division between those with linear, regular radial rows of cells (similar to van Geel's Type 8B) and a generally smaller, irregularly structured type with a tighter cell network.

Peridinium spp.

Van Geel (1972) first described Type 35 from the Wietmarschermoor section. Described and illustrated by van Geel (1978), this variable microfossil is distinguished by its yellow wall, large size and most importantly by the way it breaks into angular, often hexagonal sections. Bakker and van Smeerdijk (1982) found this type more commonly in wetter conditions. Van Geel et.al. (1989) have suggested that the type resembles the plates of peridinoid cysts (Bint 1983). From the lateglacial section they are restricted to meso- and oligotrophic conditions (van Geel et.al. 1989).

These microfossils were encountered from most levels of the HB 1, MIG 1 and MIG 2 sections, although in small numbers. Their distribution shows no particular pattern.

Phaengellina empetri (Phill.) Dennis.

Van Geel (1978, cf. plate XIII) noted a one-septate, brown spore type (Type 64), correlated to the macrofossil remains of *Empetrum nigrum*. Ellis and Ellis (1985) describe an ascomycete fungus specific to *Empetrum* called *Phaengellina empetri*, the ascospores of which progress from a hyaline unseptate form to dark brown one-septate spores. Apparently identical spores were recovered from peat samples coinciding with the presence of *Empetrum* pollen from Harold's Bog and Migneint profiles. *P. empetri* form and sporulates on above surface parts of the plant, making the relationship with the pollen rain possible. It appears that the presence of *P. empetri* can now be used as an indicator of the local presence of *Empetrum*, which in the case of the mires under investigation here in turn indicates relatively dry conditions.

Puccinia spp.

Distictive teleutospores of *Puccinia* have been found in samples from all three study areas. Ellis and Ellis (1985) describe and illustrate a number of species, often but not exclusively associated with Gramineae species. The spores have two conical cells, one slightly longer and narrower than the other, both with an apical pore. The thick walls are matched by a thick septum, interrupted by a central, circular pore with annulus. Domsch and Gams (1972) note that *Puccinia* are often airborne and so their interpretation in a sub-fossil state is therefore difficult. Types K50 and K57 may be types of *Puccinia* spores. This type was never abundant in the blanket peats studied.

Spadicoides bina (Corda) Hughes.

Described and illustrated by van Geel (1978), the conidia of *S. bina* have two small cells, one with an apical pore and one, slightly rounder, with a pore or appending hyphae on the side of the cell wall. The spores are characteristically less than 10 *u*m in length. Ellis and Ellis (1985) recorded this species from a number of arboreal hosts, and the airborne spores could be transported long distances.

Sporidesmium spp.

Many fungal types produce spores of this nature, a series of cells forming a five, six or seven septate chain. The central cells are often darker and thicker. *Sporidesmium* is distinguished by an eighth, swollen hyaline cell as illustrated by van Geel (1978 plate XI).

Sporidesmium type conidia (?) were frequently found in the Harold's Bog profile, especially in samples with a high percentage of sedge pollen. It is possible that their identification was confused in the early stages of analysis with the spores of *Geoglossum*.

Tilletia sphagni Naw.

Described by various authors, the *Sphagnum* rust fungus is one of the few non-pollen microfossils previously noticed by palynologists. This type is also known as *Hymanoscyphus schimperii* (Eckblad 1975), and as Type 27 (van Geel 1972). Dickson (1973) suggested that the curves of *Sphagna* and *Tilletia* run parallel, but this was not confirmed by van Geel

(1978). Peaks in the frequency of *Tilletia* were found to be associated only with *Sphagnum cuspidatum* if at all (van Geel 1978). Maxima from the Engbertsdijksveen section coincided with transitions from drier to wetter types of vegetation. *Tilletia* spores were only found in Harold's Bog in levels where the spores of *Sphagna* were reasonably abundant, but there is no consistent parallel in the curves. In the upper layers of the MIG 3 profile, *Tilletia* spores were consistently present, correlating with *Sphagnum* remains in the stratigraphy.

A2.5 TYPES PREVIOUSLY RECORDED BUT UNNAMED.

These types have been recorded at the Hugo De Vries Laboratory, University of Amsterdam (van Geel 1986). Specific publications are noted in the text. Some identifications have been confirmed by Dr. B van Geel from original material or from photographs.

Type 3A (van Geel 1972, 1978).

Brown coloured multiseptate ascospores, oval in shape. From the Wietmarscher Moor, Type 3A spores were most common in very dry phases of peat growth. The Engbertsdijksveen section was generally wetter, and as such had lower frequencies of this type.

Recorded from all the profiles analysed, 3A were most commonly found in the HB 1 section. The distribution in this section shows a general, but not consistent, parallel to the curves of Type K2 and Ericales pollen.

Type 5 (van Geel 1972, 1978).

Conidia or chlamydospores, tubular and hyaline. Microfossils similar to those illustrated by van Geel (1978, plate I) were found in very low numbers from the Migneint site. In addition, a second type of similar, and possibly related microfossil was recognised. This type had a swollen mid-section, a similar tubular form and distribution, and has been designated the code K5. Thought to be related to dry phases of peat growth (van Geel 1978), this type was too infrequent in the samples analysed to reach any conclusions.

Type 7B (van Geel 1972).

Possibly ascospores, possibly related to Beltrania type as the curves coincide (van Geel 1978). Spores of similar morphology to that described and illustrated by van Geel were found in blanket peat from sections HB 1, and MIG 1-3. A small appendage to the end pore was common, occasionally extending into a tube (mycelium) or spherical, hyaline cell.

Type 7B becomes increasingly common after the major wet shifts on both the HB 1 and MIG 1 profiles. Their distribution could be related to preservation, a preference for moist conditions, or indirectly related to surface humidity through the preferences of its host plant.

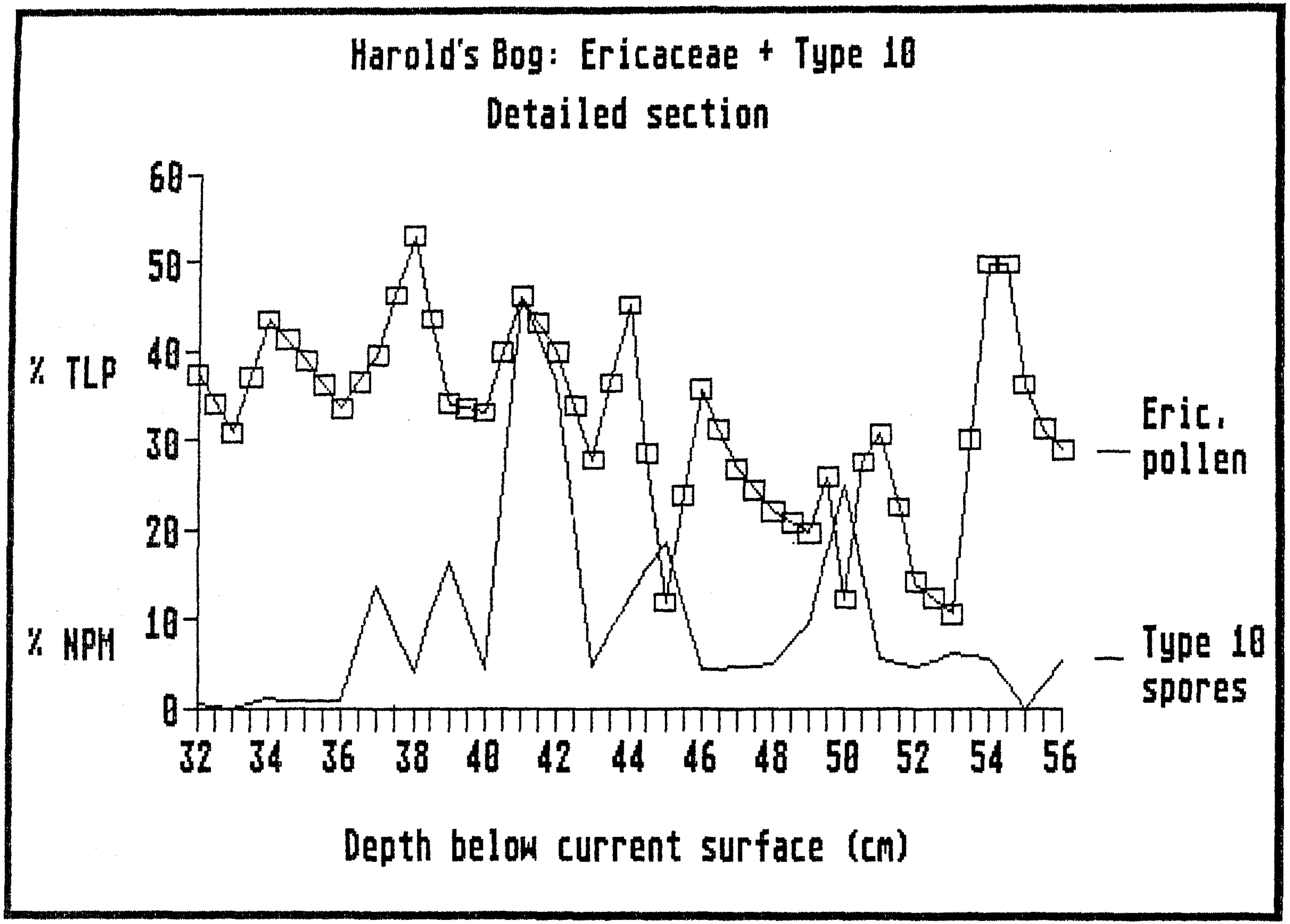
Type 10 (van Geel 1972).

Conidia or chlamydospores, varying in length and septa, occurring as 2-7 celled spores. Similar microfossils of only 1,2 or 3 celled form were initially counted separately as type numbers HB23, HB32, HB33 and HB 108 (see plate 1). Suggestions by van Geel (pers. com.) that these sporomorphs are also Type 10 is confirmed by the almost identical distribution of the types. For other profiles the data concerning types HB23, HB32, HB33 and HB 108 are combined with those of T10.

In a number of detailed palaeoecological studies (van Geel 1972, 1978, 1986, van Geel and Middledorp 1987), Type 10 (T10) spores have been particularly abundant in what has been taken to be the drier phases of peat growth. Type 10 has been observed on the roots of *Calluna vulgaris*, and possible identifications are that they could be the conidia or chlamydospores of *Bactrodesmium* or *Trichocladium* species (van Geel 1978). Bakker and van Smeerdijk (1982) considered other Ericaceous species to be the most likely host.

Calluna vulgaris occurs on raised bogs under relatively dry conditions, explaining why peat formed under wet conditions may lack T10 spores altogether. The increase in T10 spores as the inferred surface conditions become drier can be explained by increased structural decomposition of the root material liberating more spores (van Geel 1978).

Figure A2.1. Ericaceae pollen and Type 10 plotted against depth for the detailed section from HB 1. Subsequent checking has shown that almost all the Ericaceae pollen is that of *Calluna vulgaris*. Peaks in the abundance of Type 10 microfossils do not coincide with those of *Calluna* pollen, especially at depths of 50 and 41 cm. *Calluna* is best represented at 55 cm, when Type 10 are absent.



Harold's Bog: Ericaceae + Type 10
Detailed section

This pattern is not confirmed, however, by the results from the peat sections studied here. During the driest phases of peat growth T10 is not at its most abundant. When T10 is at its maximum, other indicators tend to show an intermediate phase of surface hydrology. Furthermore, a lack of correlation between the curves of *Calluna* and T10 is evident, best illustrated by the detailed section from Harold's Bog (see figure A2.1). The Letterfrack sections have T10 only in the uppermost sections, after the most significant change to seemingly wetter surface conditions. The relationship between *Calluna* the probable host and T10 has been investigated further using data from the two most closely sampled profiles, HB 1 and MIG 1. T10 was too infrequent in the Irish profiles for this type of detailed analysis.

Figures A2.2 and A2.3 show the relationship between T10 percentages and *Calluna* pollen data divided into abundance classes. Abundance classes are derived by calculating the mean percentage of *Calluna* pollen from all the analysed samples from each site. Each pollen record is then placed into an abundance class, the class boundaries being defined by the standard deviation; 0.5, 1, 1.5, and 2 standard deviations above and below the mean. The vertical bars represent the mean percentage of T10 spores in the pollen samples for each *Calluna* abundance class.

Reading from left to right these bar charts show the changing frequency of T10 as *Calluna* increases its contribution to the pollen rain. Figures A2.4 and A2.5 show the reverse; percentages of T10 are divided into abundance classes, with the mean percentages of *Calluna* pollen plotted as columns for each T10 abundance class.

Figure A2.2 (Migneint) shows that when *Calluna* is least abundant, T10 is either absent or infrequent. As *Calluna* increases so does T10, following the pattern expected from earlier

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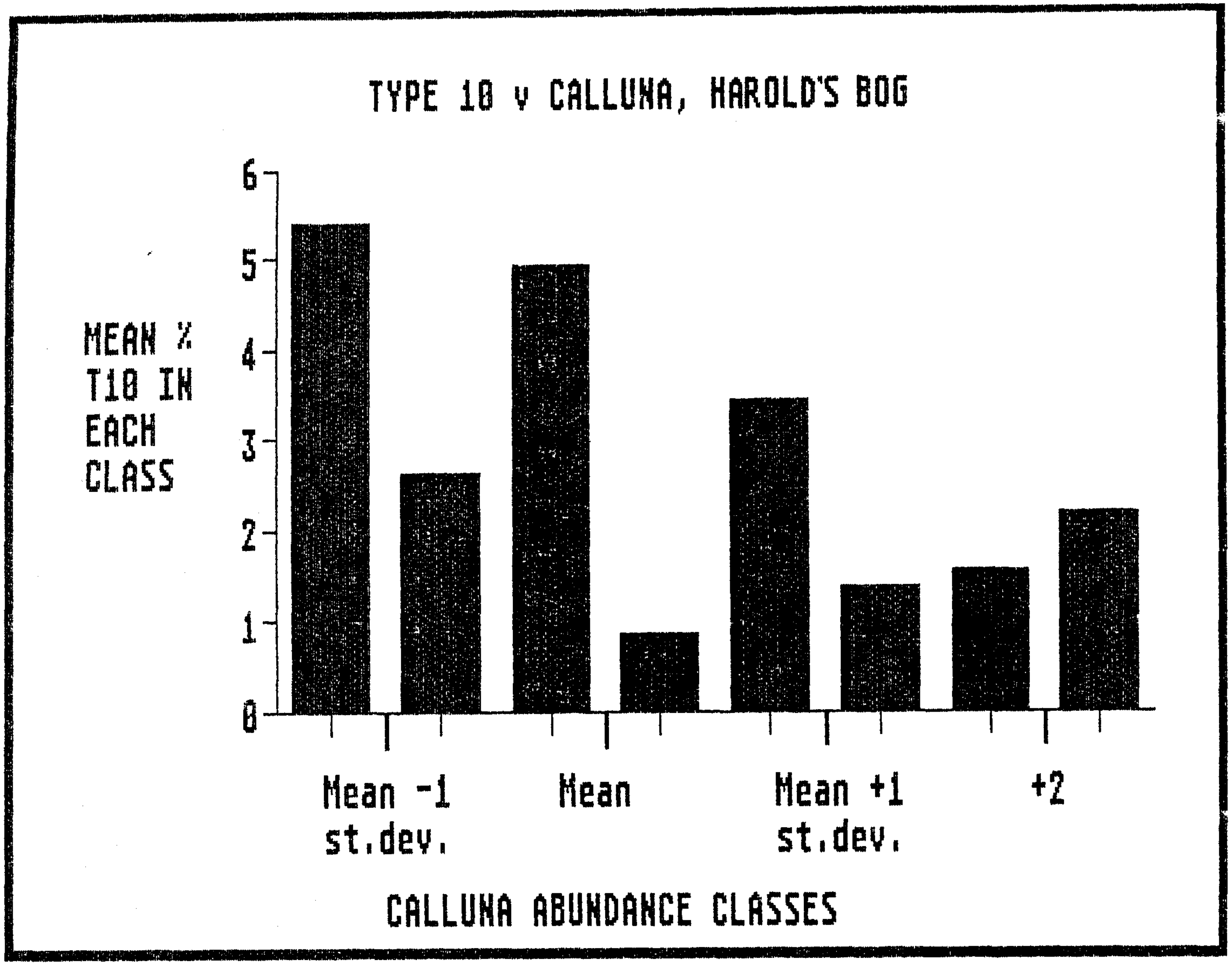
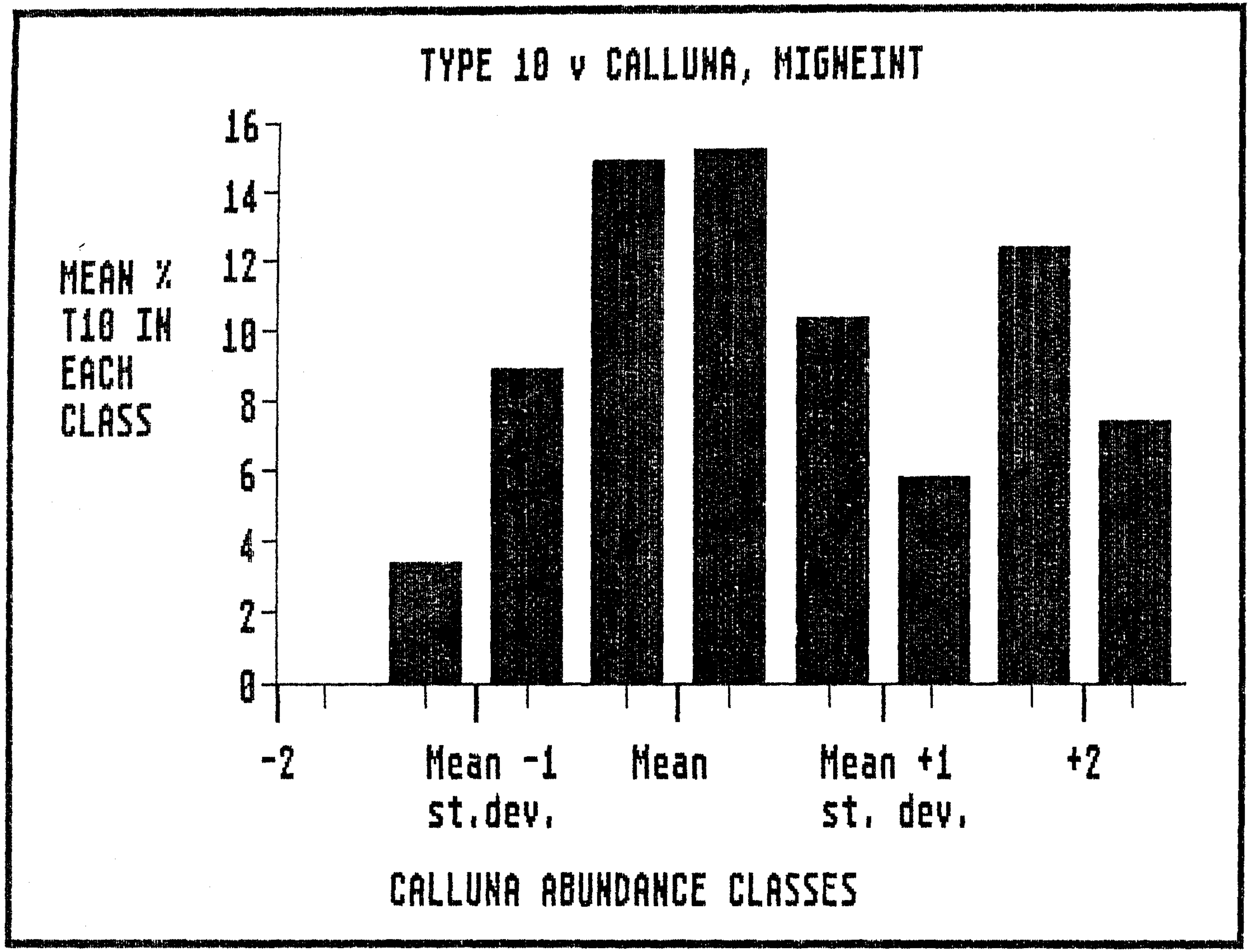
Figure A2.2. Mean Type 10 frequencies in samples divided into *Calluna* pollen abundance classes from MIG 1. From left to right, the horizontal axis represents increasing *Calluna* pollen.

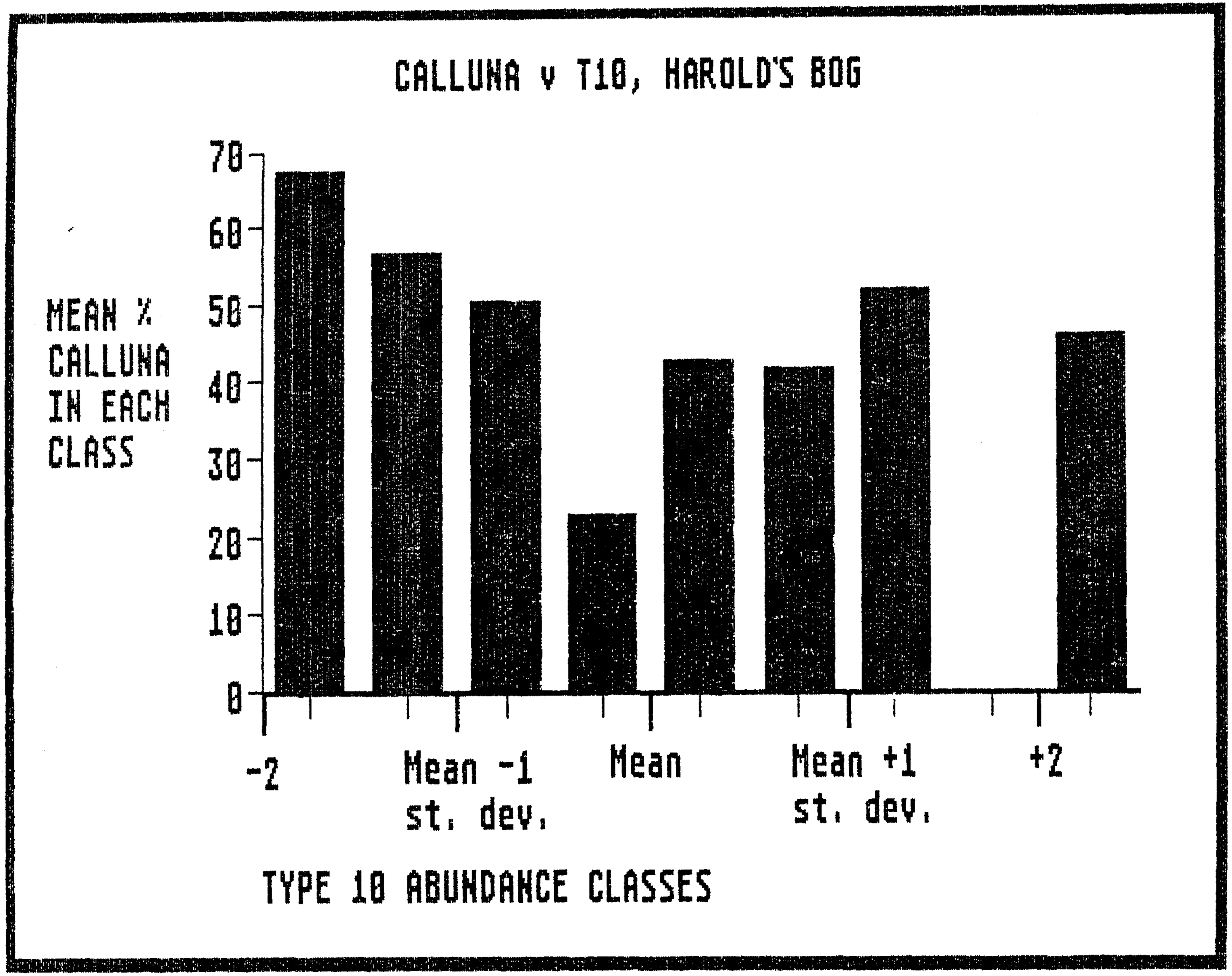
Figure A2.3. Mean Type 10 frequencies in samples divided into *Calluna* pollen abundance classes from HB 1.

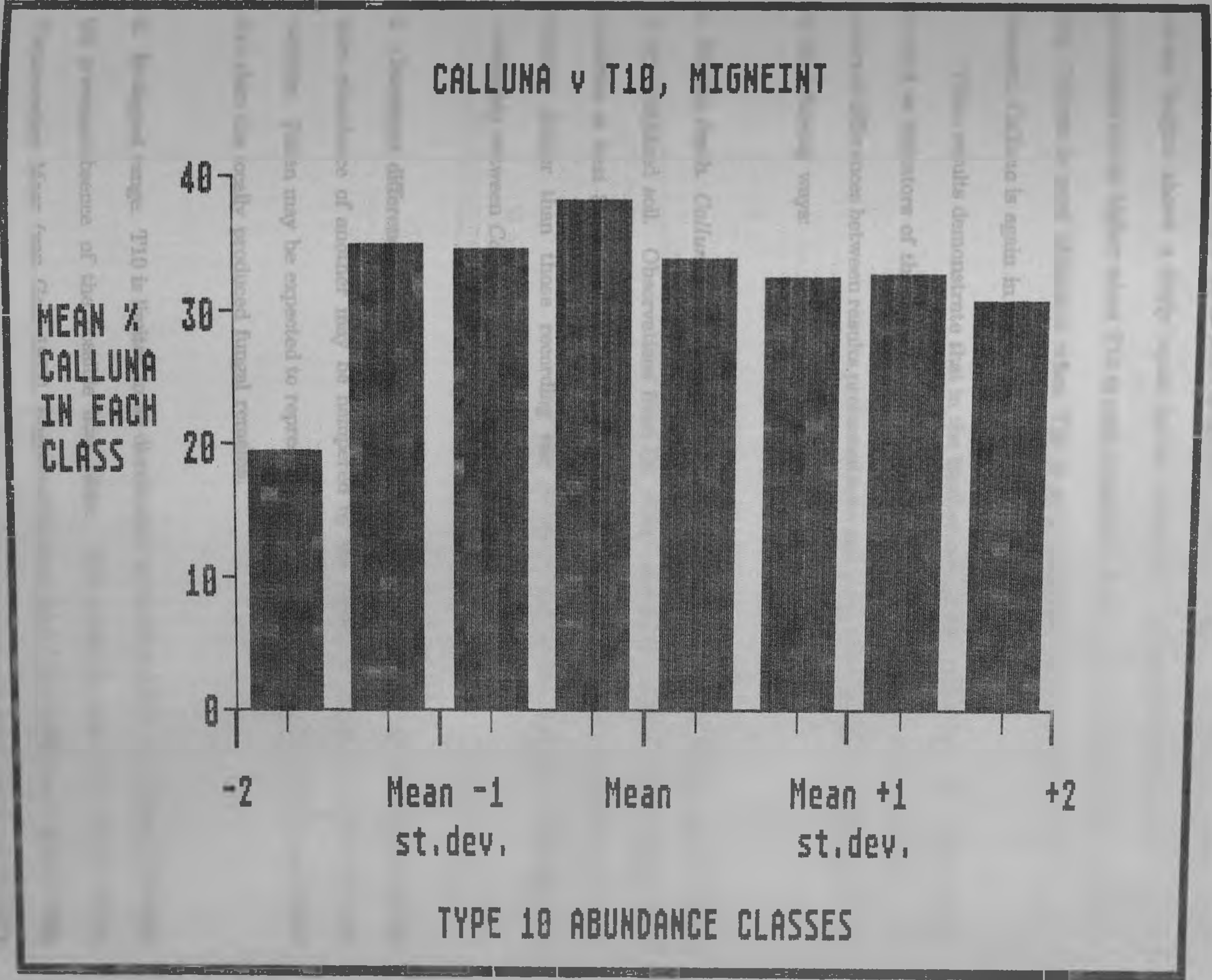
Figure A2.4. Mean *Calluna* pollen percentages in samples divided into Type 10 abundance classes, MIG 1. Reading left to right, the x-axis represents increasing Type 10 percentages.

Figure A2.5. Mean *Calluna* pollen percentages in samples divided into Type 10 abundance classes, HB 1.


TYPE 10 v CALLUNA, HAROLD'S BOG
MEAN % T10 IN EACH CLASS
0
1
2
3
4
5
6
Mean -1 st.dev.
Mean
Mean +1 st.dev.
+2
CALLUNA ABUNDANCE CLASSES


TYPE 10 v CALLUNA, MIGNEINT
MEAN % T10 IN EACH CLASS
16
14
12
10
8
6
4
2
0
-2
Mean -1 st.dev.
Mean
Mean +1 st. dev.
+2
CALLUNA ABUNDANCE CLASSES


CALLUNA v T10, HAROLD'S BOG
MEAN % CALLUNA IN EACH CLASS
70
60
50
40
30
20
10
0
-2
Mean -1 st. dev.
Mean
Mean +1 st. dev.
+2
TYPE 10 ABUNDANCE CLASSES


CALLUNA v T10, MIGNEINT
MEAN % CALLUNA IN EACH CLASS
40
30
20
10
0
-2
Mean -1 st.dev.
Mean
Mean +1 st.dev.
+2
TYPE 10 ABUNDANCE CLASSES

studies. However, in samples where *Calluna* is most abundant, T10 is again less frequent. Figure A2.3 (Harold's Bog) shows that as *Calluna* increases T10 decreases, although unevenly.

Figure A2.4 shows that when T10 is at its most frequent, *Calluna* is around its mean percentage. Where T10 is at its least abundant, *Calluna* is also. The lack of variation in the column heights shows a fairly equal spread across the T10 abundance classes. *Calluna* percentages are no higher when T10 is most abundant. Figure A2.5 shows that from Harold's Bog, *Calluna* is most abundant when T10 is at a minimum, and that when T10 is most frequent, *Calluna* is again in the middle of its range.

These results demonstrate that in the blanket peat profiles analysed, T10 spores cannot be used as indicators of the presence of *Calluna vugaris* or dry phases of peat growth. The observed differences between results presented here and those from elsewhere can be explained in the following ways:

i. Rooting depth. *Calluna vulgaris* roots have been recorded by Sewell (1959) down to 60 cm in dry heathland soil. Observations from the study sites have confirmed that thin rootlets penetrate at least 30 cm into peat deposits. T10 fungi on these roots could well appear in horizons deeper than those recording the contemporary pollen spectra, obscuring the relationship between *Calluna* and T10.

ii. Catchment differences. Correlation between the pollen frequency of one species and the spore abundance of another may be hampered by the difference in source area of the two variables. Pollen may be expected to represent the abundance of *Calluna* over a much wider area than the locally produced fungal remains.

iii. Ecological range. T10 is limited in its distribution by environmental constraints, including the presence/absence of the possible host plant. T10 occurs in the drier phases of the Wietmarscher Moor (van Geel 1972), Engbertsdijksveen (van Geel 1978) and Carbury Bog, Ireland (van Geel and Middledorp 1988), but is most frequent in the wetter phases at Harold's

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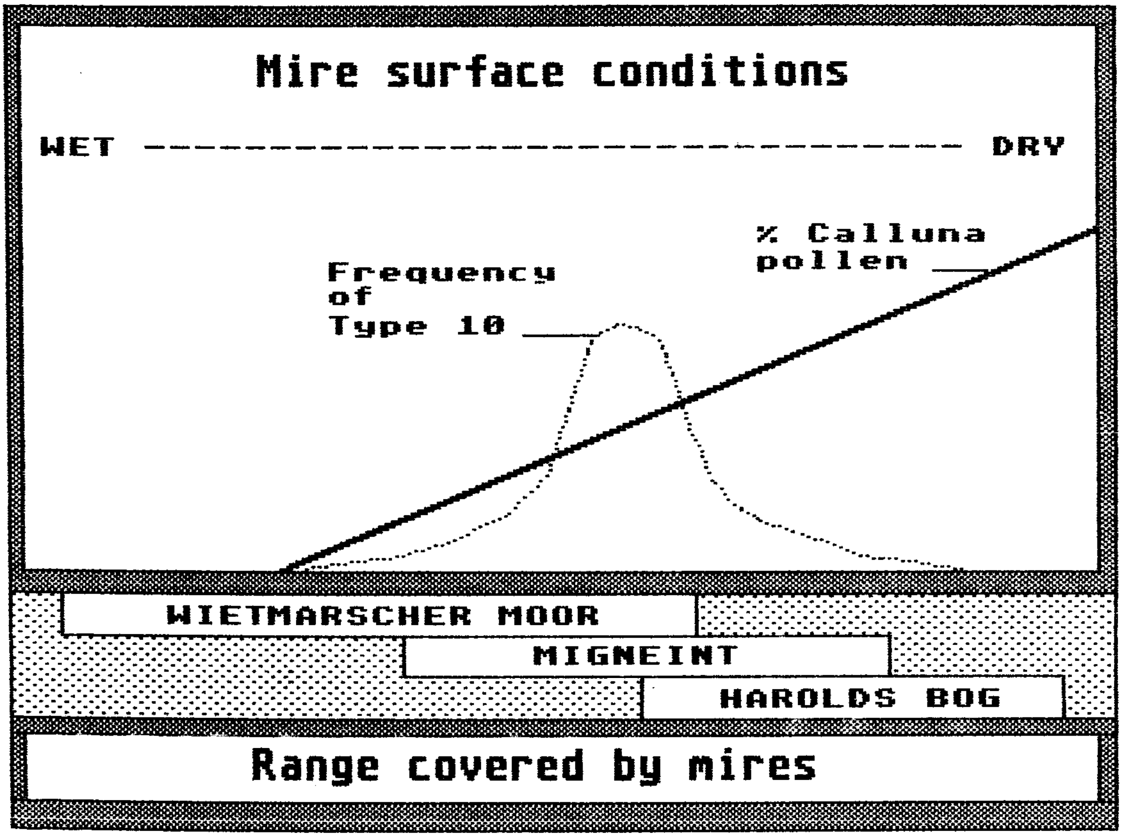
Figure A2.6. Possible ecological range of Type 10 spores related to different sites. See text.

THE RANGE OF TYPE 10 SPORES IN RELATION TO SURFACE WETNESS CONDITIONS AT THREE SITES



Bog and intermediate horizons at the Migneint site. Figure A2.6 attempts to show how the abundance of *Calluna* and T10 may be related to the relative wetness of the sites it has been recorded from.

The range of surface wetness conditions experienced at the Wietmarscher Moor is such that the drier phases are similar to the wettest phases at Harold's Bog. As bog surface conditions dry out, T10 increases rapidly in frequency. This is possibly due to the breakdown of host plant material beyond the point at which the spores would be retained in the seiving stage of pollen preparation (van Geel, pers. com. 1990). The evidence suggests that in extremely dry conditions favouring *Calluna* growth, T10 is for some reason disadvantaged. T10 declines beyond a peak in optimal conditions.

The model may be tested by recording the frequency of T10 from sites with a variety of hydrological regimes, and by continuing the comparison of abundances of different microfossils. Of great value would be the isolation of T10 spores from modern material, and the identification and description of its life cycle.

Type 11 (van Geel 1972, 1978).

Possibly chlamydospores, found by van Geel (1978) in cyperaceous leaves. A variety of forms, slightly different in size and shape, were designated this code on the basis of the very dark brown to black end cell and hyaline smallest cell. Type 11 spores were rarely recorded and show no clear pattern.

Type 12 (van Geel 1972).

Possibly chlamydospores, typically three celled as described and illustrated by van Geel (1978 plate VI). The cells are progressively less stained in descending size order, the whole spore having a curved shape. T12 has been recorded from drier phases of ombrotrophic raised bog growth (van Geel 1972) and mesotrophic conditions (van Geel et.al. 1981). Type 12 and Type 12-like spores were the most frequent in the blanket mires studied. This confirms the pattern of those occurring in the drier phases of raised bogs being more common in blanket

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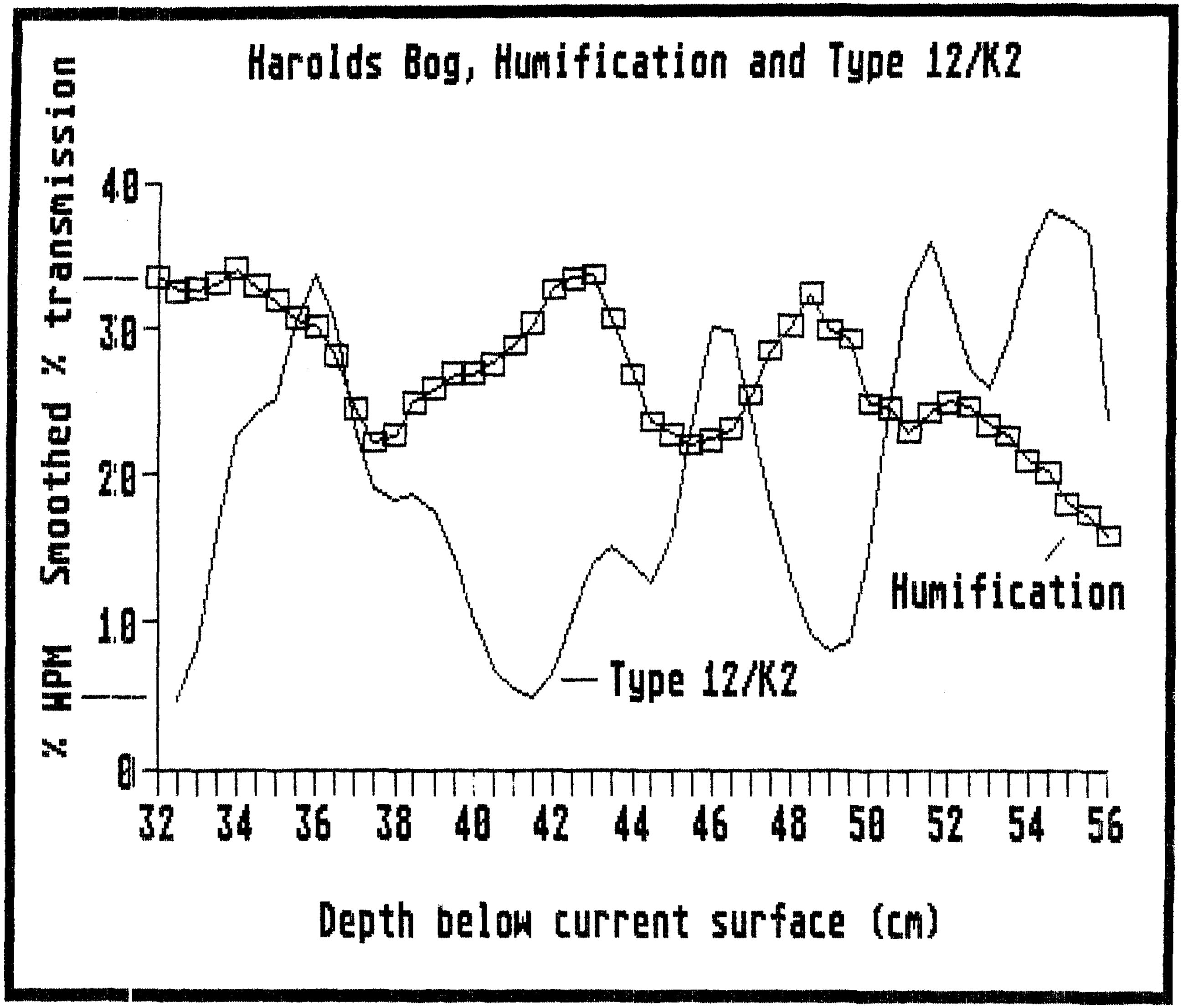
Figure A2.7. Detaled section from Harold's Bog, showing Type 12\K2 and humification.


Harolds Bog, Humification and Type 12/K2
% HPM Smoothed % transmission
40
30
20
10
0
32
34
36
38
40
42
44
46
48
50
52
54
56
Depth below current surface (cm)
Type 12/K2
Humification

peats. The lack of a second or third cell to many examples led to the distinguishing of T12 by the presence of a ring, showing the place of former attachment. As many examples had no such marking a new type number was designated, K2, for these otherwise identical spores. It is possible that they represent either a related but different species, or an immature stage of the same (see plate 1).

The palaeoecological significance of the Types T12 and K2 are similar, both become more abundant in drying conditions. The detailed section from HB 1 shows that K2 is closely linked to humification changes (see figure A2.7). From the Migneint, however, a tendency to increase in some periods of apparently wetter surface conditions was noted. As in the case of Type 10, it may be that the relative wetness of the bog before the hydrological change dictates the response.

Type 16 (van Geel 1972, 1978)

Type 16A, B and C fungal remains were first described by van Geel (1972) who suggested they might be the conidia of *Curvularia tuberculata* Jain. Van Geel (1978) later noted the lack of certain identifying features of *C. tuberculata*. Possible host plants were thought to be graminaceous, the spore type possibly increasing in drier, mesotrophic conditions (van Geel et.al. 1981). Examples from the blanket peat sites (see plate 1) included both 16A and 16C of van Geel (1978), and more significantly intermediate examples, half covered with the epispore ornamentation characteristic of 16C. This observation implies that these are one type in different states of preservation or stages of development rather than different types.

The distribution of type 16 from HB 1 could confirm the possibility of a graminaceous host. Type 16 spores are most frequent in the samples where Gramineae pollen is most abundant.

Type 18 (van Geel 1972)

Type 18 ascospores are one septate, brown, oval spores with a small pore at each end. The septum is sometimes lost or dislodged. Samples from the Wietmarscher Moor revealed a possible connection with *Eriophorum vaginatum*, where the sedge formed thick layers of peat (van Geel 1972).

The distribution of this type in the current study is inconsistent and no particular significance can be claimed.

Type 19 (van Geel 1972)

Uniseptate ascospores, one small pore at the apex of each conical cell. Constricted at the septum (unlike T18), this feature is more pronounced in some of the examples from HB1 than in the illustrations of van Geel (1978, plate IX). They have been found previously in *Sphagnum papillosium* and *S. imbracatum* peat.

Type 19 was very rarely found, but is possibly related to wetter phases and *Sphagnum* peat.

Type 20 (van Geel 1978)

van Geel (1978) described Type 20 as a group of three septate ascospores, amalgamating previously identified different types (van Geel 1972). T20 are distinguishable from *Meliola cf. niessleana* (see section 7.5) by the lack (plate 1) of one curved and one straight side, and the absence of annular thickening. T20 spores from MIG 1-3 had two paler almost hyaline cells either side of two darker brown thicker cells. Van Geel (1978) suggested that *Empetrum nigrum* might be the host of one of the T20 species.

Data from the blanket peat profiles analysed do not show any particular pattern in the distribution of Type 20 spores.

Type 23 (van Geel 1972).

Described by van Geel as a type "not well differentiated" (van Geel 1978, p.72), but characterised by the cylindrical form of each cell, slight constrictions at the septa and rounded end cells. It was previously correlated with the presence of ombrotrophic *Sphagnum* peat, although it showed higher frequencies where *Erica tetralix* became important (van Geel op.cit.). Only two examples were confidently recorded both from HB 1 sample 50+.

Type 24 (van Geel 1972, 1978).

Spores of this type were found in level 22+ of the HB 1 profile, always with three darker, swollen cells in the middle of the spore. Previous research associated this type or very similar sporomorphs with drier vegetation types. Compared to the hydrological conditions at the mires where this type was previously recorded, 22+ represents a dry sample. The absence of more than one or two similar microfossils from elsewhere precludes conclusions as to any possible indicator value.

Type 41 (van Geel 1972).

This type was originally described, illustrated, and referred to as Hystricosphaeridae by van Geel (1972). This identification was later rejected (van Geel 1978), although the distictive hyaline, "turreted" wall and oval shape should allow succesful comparison to modern reference material (plate 1). The protruberances are evenly spaced and equal in height, with wider "caps" on each protruberance. A second type, very similar in form but without the caps has been identified (Type K41). Both forms are rare, recorded only from what appear to be "wetter" samples.

Type 44 (van Geel 1972).

Dark brown ascospores, described and illustrated by van Geel (1978). Examples from the Irish sections analysed were typically 32-35 μm in length. They were distinguished from Type 6 by size and length/breadth ratio. Van Geel (op.cit.) suggested that these spores may be airborne and of non-local origin.

Type 44 spores were recorded in low frequencies showing no particular pattern.

Type 59 (van Geel 1972).

Microfossils similar to those described and illustrated by van Geel have been recognised from various samples from MIG 1. Around 25 μm in diameter, the microfossils have hyaline, round-ended protruberances giving a tangled appearance. First recognised in sandy subsoil (van Geel 1978), similar examples have been recorded from oligo- and ombrotrophic peat sections (Bakker and van Smeerdijk 1982) and now from blanket peats. As yet, however, no ecological information can be ascertained from Type 59.

Type 69 (van Geel 1978).

Described and illustrated by van Geel (1978), Type 69 is of unknown origin. Examples from the sections analysed from the Migneint site have been generally smaller than those described by van Geel although diagnostically similar in surface morphology. Van Geel found this type in layers of *Molinia* peat.

Type 69 have been recorded too infrequently to allow any conclusions.

Type 82 (van Geel 1978).

Type 82 spores appear to represent a group of similar fungal types rather than a single species. Characteristic features are somewhat lacking, with variation in size and shape. They are grouped on the basis of an ovaloid shape, at least one germ pore, and a thick brown wall. Van Geel found that Type 82 spores came from the same type of fruit body, indicating a homogeneous origin despite the variation. Previously retrieved from ombrotrophic peat, the only records of T82 from HB 1 are from the layers above the transition to *Sphagnum*-rich peat at 23 cm. This type could be useful in determining the nature of the peat deposit in samples where excessive decomposition has removed the possibility of identifying plant structures.

Type 90 (van Geel 1978).

Described by van Geel (1978), these spores are ellipsoidal with a bottle-neck protruberance and irregularly spaced hyaline spots on an otherwise brown to yellow-brown wall. Type 90 was restricted to the ombrotrophic part of the Engbertsdijksveen section.

Initial identification of Type 90 was possibly confused with Type 7B, brief rescanning of the HB 1 samples indicates that both types are present, curves from the lower part of this section may therefore be unreliable. The spores described by Pals et.al. (1980) are also very similar.

No correlation was possible with other variables from the LET 1 profile, where representation was low.

Type 96 (van Geel 1978).

Described and illustrated by van Geel (1978), Type 96 has been identified as the conidiophores or setae of dematiaceous fungi. Originally found on the leaves of *Vaccinium oxycoccus* by van Geel (1972) and correlated with two other fungal types, 7B (possibly conidia) and type 54, not recovered in the current study. Type 96 are almost certainly under-represented in the subfossil state because when broken from the basal cells the septate section is indistinguishable from hyphae of unknown origin.

Type 96 conidiophores were recorded from a number of horizons, and the curve from HB 1 includes maxima in a variety of positions covering all the perceived hydrological conditions.

Type 99 (van Geel 1978).

Type 99 are three-septate ascospores or conidia, slightly curved in shape. They consist of brown cells other than a light yellow to hyaline, tapering conical end cell. They were present in the blanket peat profiles only in sample 53+ from Harold's Bog, a sample extremely high in cyperaceous pollen and from a matted layer of *Eriophorum* peat.

Type 343 (van Geel et.al. 1981).

Small (10 *u*m) quadrangular spores, with thick, dark corners and thinner, pale, very slightly concave walls were described and illustrated by van Geel et.al. (1981) and tentatively identified as *Scopinella barbata*. Hawksworth (1975) describes the ascospores of *S. barbata* having a z-shaped band, not present in the examples recovered in the present study. As such, the originally assigned type number is retained. An additional problem in the recognition and identification of this type may be the variable morphology mentioned in chapter 7. Type 343 may represent fungal spores that grew within the constraints of quadrangular host cells.

A2.6 TYPES PREVIOUSLY UNRECORDED.

Following the suggestion of van Geel (pers. com.) a laboratory code prefix has been used to denote types distinguished for the first time during the current study, or remaining ambiguously identified. This code is K, preferred to a three letter code due to simplicity. Numbers have been allocated usually on the basis of first occurrence, in order of sites investigated. Exceptions to this rule are those that were initially recorded as a type number following van Geel and co-workers, but later found to be different. In these cases a K prefix has been added to the original type number.

Identifications are all to some extent preliminary. Further research will undoubtedly show that some types are in fact indistinguishable, or alternatively may be subdivided. Descriptive terminology follows the glossary of Ellis and Ellis (1985).

If no mention is made of any apparent palaeoecological preference or association, then it can be assumed that none has as yet been distinguished. Outline drawings and plates are included. These are intended to be referred to in conjunction with the written descriptions.

Types K1 and K2, see text under *Gelasinospora* and Type 12.

Type K3.

Fungal spores of unknown origin. 12-14 x 5-7 *u*m in equatorial view. Bicellular, with two round - ended cells, slightly constricted at the septum which has a small, central pore (plate 2). Lighter or hyaline dots are present in the otherwise brown to light brown cell walls.

Type K3 becomes an important component of the NPM assemblage after the transition to wetter conditions at 55 cm. The greatest abundance of K3 spores occurs in samples with very high *Sphagnum* values.

Type K4.

Fungal remains, possibly fragments rather than intact structures, of unknown origin. Typically 8 *u*m long with one rounded and one flattened end. A single pore is located in the centre of the flat end (plate 2). They are hyaline or show a pinkish tint. The form of this type to some extent resembles one part of Type K3 or the end cell of Type 10.

The distribution within the microfossil analyses is apparently independent, however, showing a slight preference for material rich in sedge pollen and/or *Sphagnum* spores. Clusters of Type K4 from the MIG 1 160+ sample suggest that they might be ascospores, and make it less likely that they represent the broken or degraded parts of other types.

Type K5.

Type K5 is similar in most ways to van Geel's (1972) Type 5. K5 has a swollen mid section in a manner not previously recorded by van Geel (pers. com.). They are probably ascospores, although they have not been identified in asci or host material. Type K5 is hyaline, measures around 14 x 8 *u*m, and is tubular in shape with a bottleneck opening at one end.

Type K6.

Type K6 is a possibly inorganic object frequent in pollen slides. The origin is unknown; a possible identification is that K6 are wind-blown sand particles. They are roughly rounded in appearance from all angles, with a central, angular or star shaped dark region in the centre (plate 2). Viewing through a polarizing microscope suggests they consist of quartz (R Sheil, pers.com.). They usually occur singly, but sometimes in attached clusters of 3-10. They vary in size from 7-25 *u*m diameter, therefore in volume (assuming spheroidal form) from 180-8,000 um^3. This would give an approximate weight of $1\text{-}10^{-4}$ g, light enough to be transported by wind on a hemispheric or even global scale (Pye 1987).

Type K6 could represent a contaminant from either the slides used, coverslips or silicon oil. A mount containing no other material was inspected, however, and found free of Type K6-like objects.

Plant phytoliths could survive pollen preparations and would be expected to occur in peat deposits. The unusual central dark configuration, however, makes this an unlikely origin for type K6.

Andrew Dugmore (pers. com.) suggested that it was very unlikely that volcanic glass could survive the acidic pre-treatments used in preperation for pollen analysis.

Further problems are presented by the ability of type K6 to withstand hydroflouric acid treatment. They are present in samples that have, and those that have not, been boiled in HF. A silicaceous structure is therefore less likely, despite the polarized appearance. A possible explanation is that the particles are somehow hardened by exposure, temperature or compression. The distribution from all the blanket mire profiles described here is roughly linked to the pollen concentration curve (see figure 6.18).

Before more is known about Type K6 it is unwise to reach any conclusions as to its distribution within the peat profiles studied here. Identical objects have since been found in samples from mineral soil, estuarine clay, fen peat, and interstadial-aged mud.

Type K7

Fungal spores (conidia or ascospores) of unknown origin. Smooth, spherical spores, 12-16 *um* in diameter with a thick (2-3 *um*) wall (see plate 2). Brown to dark brown colour, except for occasional spots of wall that are lighter brown, or even hyaline, and thinner. Two very small (1 *um*) germ pores are almost always present. They are Similar, but not diagnostically so, to Type 303 as described by Bakker and van Smeerdijk (1982) and also similar to Type K2 other than in size and staining. The absence of spores of intermediate size indicates that they are a different type.

Type K7 is very common in what appear to be drier phases of peat growth, and in the "driest" profile (HB 1) it is never absent.

Type K8

Spores of unknown origin, possibly algal resting spores. Smooth, spherical when intact but often split into hemispheres that remain attached, Type K8 microfossils vary in size from 8-18 *um* in diameter. The spores are hyaline, with a thick wall that appears glossy in cross section (see plate 2). Intact examples have no openings, and strongly resemble the resting spores of *Closterium didymotocum* Ralfs. described and illustrated by Starr (1958). Starr's description of a resistant, spherical smooth-walled spore, and the photographs of intact and germinating examples are consistent with Type K8.

Their distribution is inconsistent, perhaps being more common in the *Sphagnum* spore and Cyperaceae pollen-rich samples from HB 1. Profile MIG 3 shows the clearest pattern, with K8 microfossil frequencies increasing sharply after apparent wet-shifts. The Irish sites re-affirm this connection. *Closterium didymotocum* would be expected to exist in an environment of at least temporary open water. The existence of these rarely produced (Starr 1958) resting spores, however, suggest that the environment was not optimal. Comparison with modern material is required to confirm or reject the possible identification of Type K8.

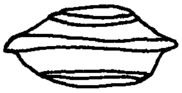
Type K9

Spores of unknown origin. Type K9 spores have a spherical structure beneath a number of appendages. Around 15 *u*m in diameter, the central body is surrounded by 8 - 12 hemispherical protruberances, 2-3 *u*m high (plate 2). The shape of K9 is similar to that af Type 365 described by van Geel et.al. (1981), but these spores are much smaller and are unstained.

They are most common in relatively wet peat from the Irish sites and also occur in the organic soil at the base of the Harold's Bog profile. Their distribution is similar to that of K8 from LET 2, revealing an apparent preference for wetter peat surface conditions.

Type K10

Groups of fungal cells inside pollen grains were recorded as a separate type. The cells were always circular, interlinked and brown, ranging in size from 6 to 15 *u*m in diameter (plate 2). The cells were particularly common inside the structure of *Corylus* pollen grains. Some examples completely filled and split the grains, and some groups of similar cells were found isolated from any host grain, indicating the destruction of the pollen. The particular preference towards *Corylus* pollen, and towards *Pinus* pollen in the LET 1 profile, suggests that Type K10 may cause some differential pollen preservation. It s abundance might also suggest the degree of decomposition of the peat, as it is most common in seemingly drier horizons. It is not known, however, whether the fungi infect the host before the grains leave the tree or at ground level. The analysis of airborne pollen grains could provide the information required.



Type K11

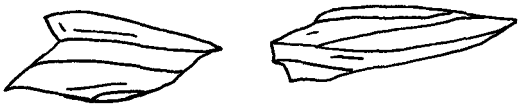
Spores of unknown origin. Type K11 are between 15-18 x 10-12 *u*m in size when viewed equatorially. The spores have three lateral ridges, one central and two subpolar, formed by the thickening of the hyaline wall. They are similar in shape to the zygospores of *Debarya*, but are much smaller than any previously recorded and lack the characteristic radial ridges in the polar regions (cf. van Geel and van der Hammen 1978). These microfossils are possibly of algal origin, then, but of unknown species. They are rare in the NPM assemblages from HB 1 with no clear connections to other variables.

Type K12

Microfossils of unknown origin. These relatively large (50 *u*m diameter), spherical microfossils are characterised by a greenish tint and a very irregular, almost stringy wall structure (plate 2). The semi-opaque spheres are free of attachment or apertures, and are never present in clusters. Their frequency distribution indicates a very localised nature, being very abundant in single samples yet absent either side. They are most common in the upper horizons from MIG 1.

Type K13

Fungal remains, possibly conidia or ascospores. Around 20 *u*m long, including a tubular protruberance of 3 to 5 *u*m. Light brown coloured, thin walls which are often broken or folded. Present in the lower part of the HB 1 profile in low numbers, showing no particular correlations to other measured variables.



Type K14

Microfossils of the Type K14 are common in pollen preparations from a number of substrates and probably include a number of remains of different origin. The features used to classify the type in this study are the angular nature of the apparently folded structure and the hyaline, thin walls. K14 are possibly cocoons of some sort, or could represent the exospore left by germinating fungal or algal types.

Often abundant and widespread, the only notable feature of the distribution of K14 appears to be its absence from the most decomposed samples.

Type K15

Fungal remains of unknown origin. Type K15 spores are brown, barrel shaped with rounded corners in equatorial view, and measure 15 x 10 *u*m. They have two pores, one at either end, characteristically blocked by hyaline 2 *u*m thick plugs. These plugs could be mycelium, broken off entering the cell (conidia?) or after germination. As K15 spores are very rare no conclusions can be drawn as to their palaeoecology.

Type K16

Type number K16 has been used to describe groups of similar fungal cells arranged in a particular manner. Given the ability of fungal structures to adapt to different host bodies, K16 may be indicative of a particular mode of formation as well as, or rather than, a distinct fungal type. K16 are irregular arrangements, around a spherical theme, of small circular cells. The individual cells are between 8 and 12 *u*m in diameter, have at least one pore, are generally light brown coloured and are densely packed within the clusters. Arrangements of between 10 and over 100 cells range in size from 15 *u*m to 120 *u*m. The overall colour varies from light brown to very dark brown, depending to some extent on the density and size of the cluster (plate 2).

Van Geel (pers. com.) has observed such structures and recorded them under the classification of *fungi diversi*. They have a distinctive distribution in the blanket mire profiles, being either totally absent or very abundant, and sometimes showing a preference for an apparently more humid depositional environment.

Type K17

Spherical microfossils of unknown origin. Type K17 spores are 12 - 16 *u*m in diameter, grey, rough walled, inaperturate spheres. They resemble the spores of various bryophytes (Dickson 1975) but could also be algal resting spores. Macrofossil analysis might help resolve this problem. Their frequency distribution in the profiles shows no clear pattern.

Type K18

Animal remains? Type K18 microfossils are characterised by their tapering tubular form, with a broad aperture at one end and a much narrower one at the other. The remains are grey, and up to 80 *u*m long and 25 *u*m wide, with the additional length of thin black hairs at each end up to 20 *u*m long. They are rare microfossils, occurring in relatively wet horizons.

Type K19

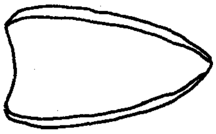
Hyaline fungal? spores of unknown origin. These microfossils are 20 - 35 *u*m in diameter, including a dense covering of 2-3 *u*m long straight sided spines. Several species of Dematecious Hyphomycetes produce spine encrusted ascospores (Ellis 1971). The variability of size suggests that Type K19 encompasses more than one species. The distribution of this type suggests very little.

Type K21

Spores of unknown origin, possibly the sporangia of *Synchytrium*. They are small (10 *u*m diameter), spherical spores ornamented with an estimated 70 pits. K21 spores are light grey in colour with a thin wall, resembling a golf ball. They are not dissimilar to a number of Bryophyte spores (Dickson 1975). The algal spores illustrated by Lingappa (1955) of *Synchytrium* are very similar to those recorded as Type K21. Microfossils similar to the resting spores of the same species have also been recorded from the HB 1 section (see type K27).

Never abundant, K21 are most common in sample HB1 84+, a level of high percentages of Ericaceous pollen. No particular indicator value can be attached to this type as yet.

Type K22



Animal remains (?) of unknown origin. Type K22 microfossils are 28-30 *u*m long by 17 *u*m wide and have a thick double wall thinning at either end. One end of the microfossil has a hyaline wall, the other thins to a barely visible, hyaline covering giving a pore-like effect. Very rare microfossils; no particular indicator value can be attached.

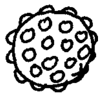
Type K23

Possibly animal remains. Type K48 are 80 *u*m long, 60 *u*m wide, bulb-shaped microfossils, tapering to small spines at the top, and a tubular attachment at the base (see plate 2). The blue-grey surface has a series of dark, curved spines, up to 15 *u*m long, pointing towards the top of the bulb structure. Occasionally, Type K48 occurs in a line of attached microfossils, joined by a continuous tube through the centre. This type was recovered twice from a blanket peat samples, including what appeared to be the wettest and the driest horizons from MIG 2.

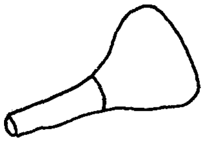
Type K24

Spores of unknown origin. 8-14 *u*m in diameter, spherical, hyaline microfossils with 2-6 small holes and occasional short, very thin spines. Type K24 is similar in form to K8. The wall is much thinner, however, and this type lacks the characteristic split form. The thin walled, fragile structure means that examples of K24 are often folded or crumpled (plate 2). K24 were not properly distinguished from K8 at first, and are included in the Type K8 curve for the HB 1 profile.

Type K25



Spores of unknown origin. Type K25 microfossils are spherical, hyaline, varied in size from 20-40 *u*m, and are characterised by short (1-1.5 *u*m), evenly and densely arranged round-ended protruberances. Approximately 40 of these lumps are found on any one microfossil. Type K25 are possibly of algal origin. They were recorded from a variety of samples and no patterns can be established.



Type K26

Pipette-shaped microfossil of unknown origin, possibly conidia. Two-celled microfossils, coloured like fungal spores, have been recorded from a number of levels from HB 1. The broader, brown cell is seperated from a tubular, hyaline cell by a porate septum. The examples from HB 1 were around 60 *um* long, although two much smaller examples (25 *um*) were recovered from the MIG 2 samples at 40+ and 32+. The structure suggests that K26 might be conidia, with the hyaline cell being the last part of the conidiophore. No particular significance can be assigned to this low-frequency type unless it can be identified.

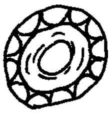
Type K27

Resting spores, possibly *Synchytrium*. K27 are spherical spores, 30-35 *um* diameter, with a yellow to yellow-orange, thick, smooth wall. They have a single, 2-3 *um* diameter pit or pore (see plate 2).

Lingappa (1955) describes and illustrates the resting spores of *Synchytrium*. The spores recorded as K27 are very similar to those referred to by Lingappa, and may be these or a related type. K21 spores appear to be similar to the sporangia of the same species.

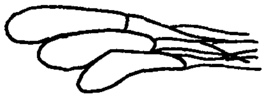
Type K28

Fungal (?) spore or cell of unknown origin. Type K28 are spherical, unicellular, dark brown, scabrate walled microfossils around 16 *um* in diameter (see plate 2). Possibly related to Type K7, K28 could be a charred or partly decomposed form of the same microfossil, or could be in a less decomposed state. The lack of intermediate forms and different distribution suggests, however, that they are a different type.



Type K29

Microfossil of unknown origin. One example of K29 was retrieved from the 56+ level of profile HB 1. Measuring 30 *um* in diameter, the disc-shaped microfossil had an outer ring 8 *um* thick. This ring was ornamented by semicircular cells, the rounded ends of which pointed inwards. The outer ring was grey coloured, the inner zone 14 *um* in diameter, psilate and hyaline.



Type K30

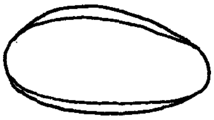
Fungal spore, possibly conidia. Type K30 spores have one lobate, pinkish-brown cell, 14-18 *u*m long with a small, indistinct, circular hyaline area (plate 2). Hyaline mycelium is still attached, separated from the spore by a porate septum. The spores tend to occur in clusters, in contact with each other and with the mycelium arranged parallel. Ellis and Ellis (1985) illustrate and describe a number of species that resemble K30, indistinguishable without the rest of the fungal remains.

Type K31

Four-celled spore of unknown origin. Type K31 spores are arranged as a tetrad, each cell being pink coloured and 8 - 10 *u*m in diameter. There is no visible means of connection between the four cells. The tetrads are irregular, but uniplanar in form. Some bryophyte spores may be of a similar form. K31 spores were recorded from wetter horizons in the HB 1 profile.

Type K32

Microfossil of unknown origin. Ovaloid spores (?), 25 x 15 *u*m including spines of 2 *u*m length. A central, hyaline circle is surrounded by a thick, echinate, grey coloured wall (plate 3). Two examples only were recovered from the sample at 52+ from the HB 1 profile, which has very high representation of Cyperaceae pollen.



Type K33

Microfossil of unknown origin. Egg-shaped, hyaline, 80 *u*m x 45 *u*m inaperturate structures. Type K33 has a hyaline wall of variable thickness, 3 *u*m in the middle tapering to a very thin single wall at each end. Very rare, recorded from quite well decomposed peat from Harold's Bog.

Type K34

Microfossil of unknown origin. Ovaloid, 20-25 x 15-18 *u*m, hyaline objects with one end sometimes flattened and a small pore in the flattened face. Type K34 is distinguished by a ridge feature twisting around the outer surface (plate 3), the ridge being formed by a thickening of the wall. K34 are rare microfossils and show no significant pattern.

Type K35

Possibly zygospores of *Spirogyra*. Large, (100-150 *u*m) long narrow oval microfossils, hyaline to slightly grey coloured (plate 3). Surface patterning is variable, including the most frequent type which has sparsely distributed short spines. Some examples, not necessarily the same type, had a more regular speckled appearance, either with or without short spines. Some of the microfossils described as Type K35 were undoubtedly the zygospores of some species of *Spirogyra*, similar to types illustrated by van Geel and van der Hammen (1978). Unfortunately throughout most of the analysis these were not distingushed properly from other long, ovaloid sporomorphs. Type 35, then is a group of microfossils including large examples of *Spirogyra*.

Type K36

Microfossils of unknown origin. Approximately spherical structures, 60 *u*m diameter including 8 *u*m high turret-like protrusions on the surface. These turrets are latitudinally ridged, and have a distict swollen top, appearing as a clear round circle when the protrusions are viewed from above. Single K36 microfossils were recovered from two samples, one from HB 1 and the other from MIG 2.

Type K37

Microfossils of unknown origin. 60 *u*m diameter, hyaline to grey or dark grey coloured spheres. Type K37 fossils are characterised by being encrustated to a varied extent by irregularly arranged, scabrate areas, which in sectional view appear as a plated wall. Different states of preservation were found, from examples that were smooth and clear of platy structures, to those virtually totally covered.

Type K37 were most frequently recorded from the "wetter" horizons of LET 1 and LET 2, and the upper layers of HB1, at the top of and above the *Sphagnum* band.

Type K38

Spores of fungal origin, possibly *Neurospora* spp. 12 *um* x 12 *um* spores, including aperturate tubular extensions at opposite ends. The surface of this type is ornamented by pole-to-pole narrow ridges, similar to the patterning of *Neurospora* spores described by van Geel (1986). Definite identification of K38 as *Neurospora* spp. is precluded because of the poor state of preservation of the examples found. K38 spores were too infrequent to allow meaningful comparison with other variables.

Type K39

Microfossils of unknown origin, possibly higher plant remains. Type K39 are up to 120 *um* long, 15 *um* wide, usually psilate structures tapering to a branched "thread". They are brown coloured, with a dark, thick wall. Similar microfossils were found with a darker staining, and scabrate surface patterning. As only a short acetolysis treatment was applied, these microfossils could be cellulose plant remains. They were recorded from the upper layers of the HB1 profile.

Type K40

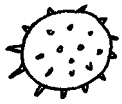
Fungal remains. 18 *um* x 14 *um*, dark brown coloured, cylindrical\barrel shaped microfossils (plate 3). K40 spores were distinguished by their shape and by their lack of pores or even thin areas of spore wall. They were recorded in the upper two samples from HB 1.

Type 41

K41

Type K41

Possibly algal remains; see previous description under T 41.



Type K43

Microfossil of unknown origin. Type 43 spores are yellow, 50 *um* in diameter, including their characteristic short (3 *um*), yellow spines. The spines are regularly but sparsely distributed. Two examples were recorded, both from the minerogenic layer at the bottom of the MIG 1 profile. Both were split, the two halves joined only at one end.

Type K44

Fungal spores. Type K44 are three-septate, 35 x 20 *u*m rectangular-ovaloid spores. They are dark brown, thin walled and have no constriction at the septum. Septa are inaperturate. K44 are possibly ascospores, as there is no visible means of attachment.

Type K45

Fungal spores. Type K45 spores are brown, two-septate, 18-22 *u*m x 12-15 *u*m. The central cell is largest and slightly darker than two peripheral, hemispherical cells at opposite ends, very slightly constricted at the septa. There is no visible means of attachment, indicating that K45 may be ascospores.

Type K45 have been recorded on only two occasions from well decomposed peat from MIG 1.

Type K46

Fungal remains, possibly derived from T10, possibly *Curvularia* spp. Type K46 are three septate, brown fungal spores, similar in structure to Type 10, with progressively smaller, lighter cells ending in a tubular cell attached to hyphae. They are distinguished, however, by being always four-celled, and always curved by a full 180 degrees. They could represent a form of T10, constricted in development by the constraints of their host cell. Their distribution does not suggest such an origin, however, being most abundant when T10 is rare. Alternatively, species of *Curvularia* produce ascospores of a curved nature (Ellis and Ellis 1985). These types, however, tend to have larger, darker middle cells, rather than the end cell as in the case of K46. K46 fungal cells, then, appear to represent a distinct type.

As yet no ecological distinction can be identified.

Type K47

Fungal remains, 36 x 25 *u*m, with a thin wall and pink coloration after acetolysis. Type K47 consist of a single, lobate cell (conidia?) with an attached tubular structure (conidiophore?), initially 4-5 *u*m wide, but quickly narrowing to 2 *u*m away from the spore.

Type K48

Microfossils of unknown origin. Type K48 are oval, hyaline microfossils characterized by parallel lines of spines around the surface (see plate 3). They are 35-40 *u*m long and the spines are 4 *u*m high.

Type K48 microfossils were recovered from relatively dry blanket peat from the lower section of MIG 1, and one example was found inthe uppermost sampled horizon of MIG 2.

Type K49

Fungal spore, 16 x 10 *u*m, reddish brown oval. Characterised by a hyaline exospore, irregular and crumpled, attached in such a way as to form a wide net pattern on the spore wall.

K49 are possibly ascospores, and increase in abundance in the MIG 1 profile as blanket bog vegetation takes over from arboreal species.

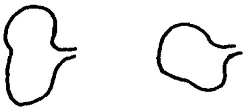
Type K50

Fungal spore, 5-6 *u*m, reddish brown in colour. These very small spores are characterised by their bicellular form, the straight sided conical shape of each cell and a thickening in the centre of the septum. They may represent a species of *Puccinia*, but lack visible pores at the apex of each cell and in the septum.

Type K51

Fungal remains. Type K51 represents a group of microfossils that consists of clusters of small, 6 *u*m diameter, brown spherical cells. They are characteristically arranged in groups of three or five, the smaller groups perhaps being broken versions of the larger ones. The cells are similar to Type K2, generally slightly smaller, and may be related to K2 which occur singly.

Type K52

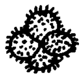


Fungal remains. K52 are lobate, 40 - 45 *u*m maximum length, irregularly shaped, brown spores. The surface is smooth, with a number (3-6) of tiny pores and hyaline spots. The main cell (conidia?) tapers to a tubular appendage (coidiophore?) 5 *u*m wide and hyaline.

Type K53

Fungal spores, 12 *u*m long excluding two 2-3 *u*m appendages. Type K53 is barrel shaped, has a brown cell body, thick walls and slightly concave end walls. Each end wall has a very small, central pore. Attached to either end is a hyaline, thin folded sack, 2-3 *u*m long and wide.

Type K54



Microfossils of unknown origin. Type K54 consists of a cluster of four small cells arranged as a tetrad. The total diameter of the whole microfossil is around 16 *u*m, including spines 1-2 *u*m long. Each cell is brown and covered with spines.

Type K55

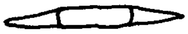
Microfossils of unknown origin, possibly animal remains. Type K55 are 70 x 25 *u*m, grey to hyaline, crinkly surfaced bag structures, with a 10 *u*m opening at one end. The wall thickens around the opening. K55 remains are never abundant, but present in a number of horizons. They never occur in the drier, well humified peat layers. They could be the remains of Rhizopoda or other microorganisms.

Type K56

Fungal spores, 40 *u*m long x a maximum of 10 *u*m wide, 3 or occasionally 4 septate. K56 are light brown coloured, with each cell being the same colour (see plate 3). The spores appear to be inaperturate and there is no constriction at the septa. They are probably ascospores as they occasionally occur in clumps and are never attached to any mycelium or hyphae.

Type K57

Fungal spores, 12 x 5 *u*m, brown with very thick walls. Type K57 are two-celled, with straight sided or even slightly concave conical cells joined by a thick septum. The septum has an annular pore in the centre. A small apical pore, or very thin area, is found at the end of each cell.



Type K58

Fungal remains, 18 x 5 *u*m, 2-septate, pink coloured after acetylation. Type K58 is a long, thin spore with conical end cells tapering to inaperturate, pointed ends. The cell walls are quite thick. They are probably ascospores, but their distribution gives no clue as to their origin.

Type K59

Microfossils of unknown origin. Type K59 are folded, generally ovaloid structures (see plate 3). They are hyaline, and 50 -60 *u*m along their longest measurements. K59 microfossils have a characteristic folded shape that suggests an originally inaperturate, bag-like structure.

They are very abundant in one sample (MIG1, 88+), which is not otherwise an exceptional level, but present in small quantities from a variety of horizons.

Type K59B

Type K59B

A separate group of microfossils were distinguished from K59 after good examples of each type were found together. They are of a similar size and form, but often broken or folded to a greater extent than K59. The surface is patterned by small rounded protrusions, although some examples, possibly more corroded than the rest, have only spots on the surface.

Occasionally found in MIG 1, 2 and 3, Type K59B was most common in sample 88+ of the MIG 1 profile.

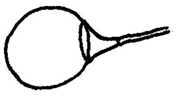
Type K60

Microfossils of unknown origin, possibly fungal cells (plate 3). Type K60 is the code used to describe groups of cells of a certain type. Each cell is yellow to light brown, 16 *um* in diameter, spherical, smooth walled (2 *um* thick) and has 1, 2 or 3 white or hyaline spots. Clusters of around 6-8 cells are common, with a minimum of 3 and a maximum of around 20. Type K60 was never observed attached to any other fungal remains or plant material.

K60 peaks in abundance when *Sphagnum* spores are equally well represented, for example at 94+ in the MIG 1 profile. Unless it is a coincidence, this could indicate either that they are associated in some way with *Sphagnum* or that both prefer similar environmental conditions.

Type K61

Fungal spores, varying in length and number of cells up to a maximum of 7 cells and 70 *um*. These dark brown fungal remains are characterised by having almost square cells and straight, dark septa. They are often split along a septum in the middle part of the spore and are often detached (see plate 3). Two or three larger, central cells are usually darker coloured. The spores taper away from the centre and end with a flat, possibly broken face.



Type K62

Fungal remains, possibly conidia. Type K62 are nearly spherical, 20 *um* in diameter, uniseptate spores. One cell comprises most of the microfossil, a second cell is formed by a thin septum sectioning off a small part of the sphere. This cell is hyaline or light brown, the larger cell being dark brown. The smaller cell tapers into an attached hypha (conidiophore?).

Type K62 occurs in the upper section of the MIG 1 profile in association with what appear to be indicators of dry conditions.

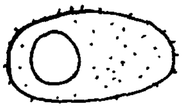
Type K63

Fungal spores, 25 x 18 *um*, three septate. Type K63 has two large, central cells and two smaller, peripheral ones. All are dark brown and enclosed by a folded hyaline exospore. Similar in form to Type 16, K63 are distingushed by a thick hyaline exospore. In addition, the central two cells are much larger than the outer two, the difference is more pronounced than in the case of Type 16.

Type K64

Fungal remains, uniseptate, double walled. Measuring 35 x 25 *um*, this type consists of two cells, one rounded and one conical, separated by a thick septum. K64 spores are characterized by their dark red colour, and an apical aperture in the conical cell. They resemble the conidia of a large range of Hyphomycetes.

The distribution of K64 suggests a preference for dry surface conditions; it occurs in the MIG 1 profile where high *Calluna* and *Empetrum* pollen frequencies coincide with a fall in the % transmission curve.



Type K65

Microfossils of unknown origin, possibly animal remains. They are oval-shaped, grey microfossils distictive because of a circular area towards one end of the oval, delimited by a thin wall. The surface of Type K65 is speckled with very small, irregularly distributed spines other than in the circular area.

Type K66

Fungal remains, uniseptate, 24 *um* in length and 6 *um* thick. K66 spores consist of two long, narrow cells, one pinkish coloured and inaperturate and the other hyaline with a pore at the end. There is a slight constriction at the thin septum.

Type K67

Fungal remains, 50 - 70 *u*m long and up to 20 *u*m wide. Type K67 are curved, brown spores and consist of 5, 6 or 7 cells, each of equal colouration. The last three cells taper to a final conical end cell, and are arranged in a curved manner giving one concave and one convex surface. Type K67 is characterised by the uneven interval between septa and uneven sides to the spore, with considerable constriction at the septa.

Type K68

Microfossils of unknown origin. Type K68 microfossils were distinguished from the MIG 2 profile. They are light brown, 50-60 *u*m long, feather-shaped structures, lacking a distinctive wall or any surface patterning.

Type K69

Fungal remains of unknown origin, possibly ascospores. Type K69 are yellow, thick walled, apparently inaperturate uniseptate spores, with two slightly curved conical cells attached by a thin septum. They are distinguished by their size (50 *u*m long), colouration, and a thick, crinkly wall. K69 spores were recovered from the sample at 63- (MIG 3) in a clustered form, suggesting that they may be ascospores.

K69 microfossils were rarely encountered, but when they were found they coincided with high values of K2 and usually relatively dry phases of peat growth.

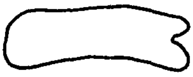
Type K70

Microfossils of unknown origin, possibly animal remains. Type K70 are 90 x 30 *u*m fragments, with hyaline, punctate walls and short dark spines orientated towards the narrower end. The structures taper slightly towards a 20 *u*m wide end with 8 parallel, crooked spines, hyaline, 15 - 20 *u*m long. K70 microfossils were retrieved from the sample at 23+ from the MIG 3 profile, associated with a high frequency of sedge pollen and relatively unhumified peat.

Type K71

Possibly fungal remains. Type K71 are very small (3-5 *u*m diameter) spherical microfossils. They are, at the magnification observed at, smooth walled and inaperturate. They vary in colouration from hyaline to grey to light brown, and often occur in clusters (plate 3).

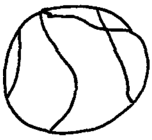
The distribution of K71 in the LET 1 profile is closely related to that of Type K2, indicating either a common source or a common range. When first recorded, it was considered to be a possibility that these types were an immature form of Type K2 or Type 12 (after van Geel 1978). However, the lack of any intermediate forms makes this unlikely. K71 are more frequent in what appear to be drier phases of peat growth, or rather before wet shifts.



Type K72

Microfossils of unknown origin, possibly animal remains. 32 *u*m long, 12 *u*m wide, rather amorphous, rounded-rectangular structures. One end is convex, the sides are often slightly concave, and one end is characteristically indented. The indentation is off-centre, leaving one larger and one smaller lobe. There is no distinction between the wall and the body of this type in sectional view.

K72 microfossils were recorded in abundance from the lower part of the LET 1 profile, becoming less common in what appears to have been increasingly wet conditions in the middle part of the profile.



Type K73

Microfossils of unknown origin, 40-50 *u*m in length along the greatest axis. K73 are grey coloured, thin walled, folded but generally intact, inaperturate and rounded in shape. Their distribution is sparse and in a variety of hydrostratigraphic positions in the LET 1 profile.

Type K74

Fungal spores, dark red, 40 x 26 *u*m. Distinguished by the colouration and by one end of the otherwise ovaloid shape being flattened, leaving a single, central annular pore on the flattened end. One example had a broad attached hyaline hypha at the pore. Type K74 are probably conidia or ascospores. They were recorded from a variety of horizons in the LET 1 profile but never in abundance. As yet they do not reveal any particular correlation with other variables.

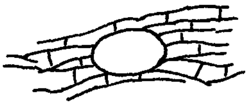
Type K75

Fungal remains, oval in section, light brown coloured. Type K75 microfossils are found in chains, end to end, severely constricted at each join. Individual cells vary in length from 10 - 18 *u*m, the width being uniform, around 10 *u*m.

Common in the Irish profiles, K75 does not appear to show any particular pattern. These remains are possibly fungal mycelium, or conidiophores.

Type K76

Microfossils of unknown origin. Type K76 are oval, hyaline, 80-90 *u*m long and up to 30 *u*m wide. They are distinguished by having what appear to be multiple folds, running the full length of the structure, meeting at a sharp tapering end point (plate 3). Despite being apparently thin-walled, K76 microfossils generally survive intact. They are present in various levels above 64 cm in the LET 1 profile, being most abundant in a sample where Cyperaceae pollen reaches 30% of TLP.



Type K77

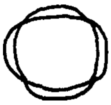
Fungal remains. These remains are single cells, brown 18-22 *u*m long and 15-16 *u*m broad, found between strands of hyaline hyphae. The hyphae are attached at porate septa. K77 were recovered from the upper horizons of both the Letterfrack profiles examined for NPMs in small numbers.

Type K78

Fungal remains, consisting of 4 or 5 cells with a total length up to 70 *u*m and a width of 8 *u*m for the first two cells and 4 *u*m for the others. The end cell is pinkish coloured after acetylation, round ended and inaperturate. The second, tubular cell is the same colour, separated by a small septa. The third, fourth and where present fifth cells are hyaline but thick walled.

A slight constriction in the wall is notable at every septum.

Type K78 are sparsely distributed in the LET 2 profile and shows no particular pattern. They probably represent the conidia of a species of Hyphomycete.



Type K79

Microfossils of unknown origin. Type K79 are rounded-cubic microfossils, with a structure made up of six convex/lenticular walls. They are hyaline, 23 *u*m across, with walls 5 *u*m thick in the middle. They are consistently high in the same levels as Cyperaceae pollen in the LET 2 profile and absent elsewhere.

Type K80

Microfossils of unknown origin, similar in size and form to Type K76. Type K80 are hyaline, oval, 80 *u*m long structures distinguished by regularly spaced hyaline protrusions on the surface. The protrusions are flat topped and look circular from above.

Type K81

Type K81 are unidentified, spherical microfossils. They are 16-18 *u*m in diameter, and occur in twos as illustrated (plate 3). They have a scabrate, or sometimes rugulate surface patterning, and are yellow to yellow brown after acetylation. They were distinguished in the LET 2 samples, but had been infrequently present in other samples, being previously recorded as broken Type K60. Their distribution in the LET 2 profile showed no correlation with other variables.

A2.7 PLATES.

Examples of some of the types described above have been photographed. The plates should be used in conjunction with the written descriptions.

PLATE 1. Including previously recorded microfossils.

a *Hyalosphenia subflava*, x 500.

b Spermatophore of Copepoda, x 830.

c Spermatophore of Copepoda; Type B, x 320.

d *Zygnema*-type algal spore, x 500.

e *Sporidesmium*-type fungal spore, x 500.

f *Geoglossum*-type fungal spore, x 200.

g *Helicoon* fungal remains, x 500.

h,i Type 12/K2 fungal spores, **h** with small appendage, **i** intact, x 250. See also plate 3,p.

j,k Type 16, Germinating ascospores of Type 16, partly enclosed by hyaline exospore, x 600.

l Fragments of fungal spores, HB108 and HB23, later included in Type 10 counts, x 400.

m Type 10 fungal spore, x 850.

n Type HB32, later included in Type 10 counts, x 400.

o Type 18 fungal spore, x 600.

p Type 20 fungal spore, x 500.

q Type 41 algal(?) spore, x 500.

r Type HB33, later included in Type 10 counts, x 850.

PLATE 1

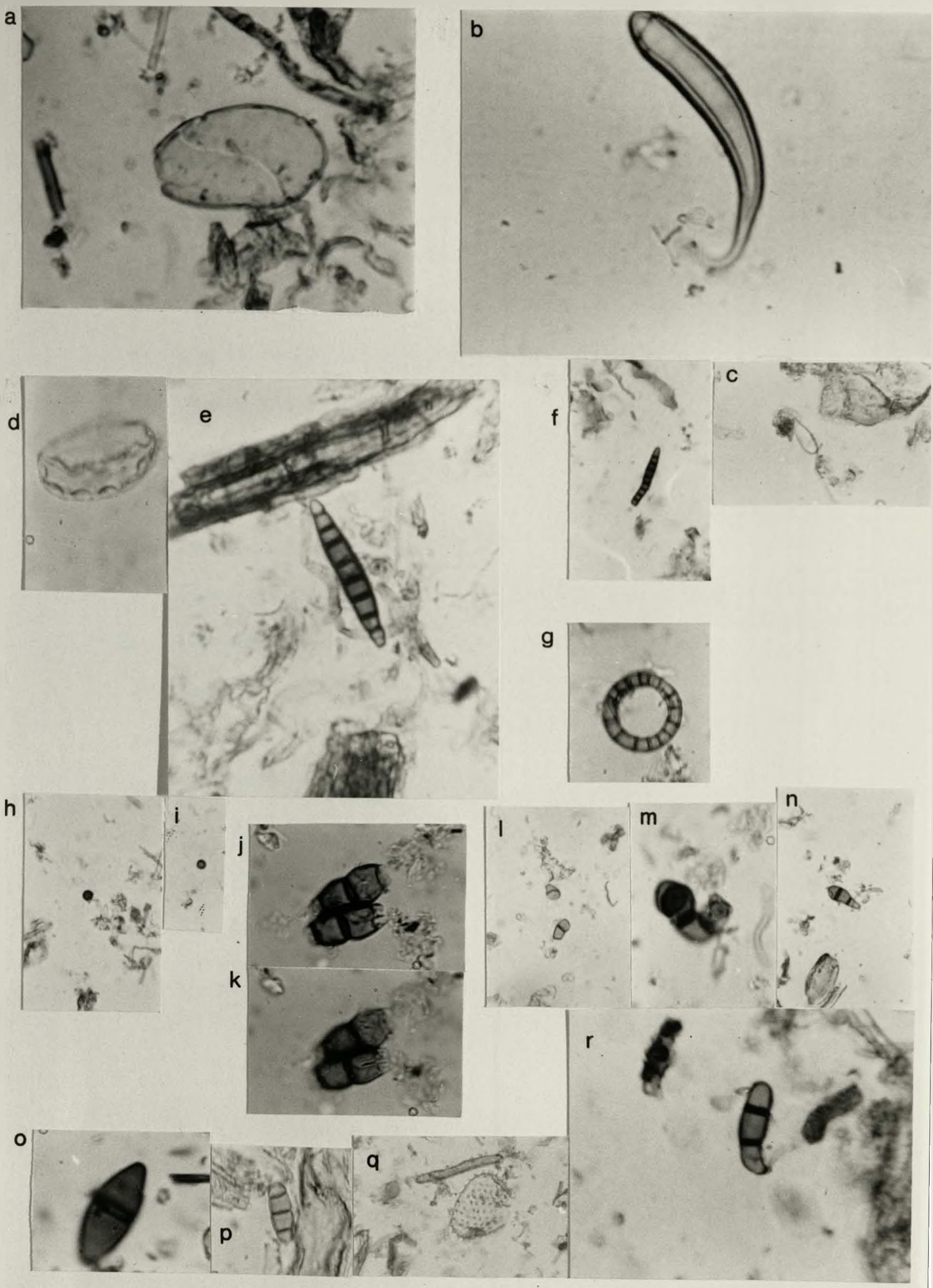


PLATE 2. Including previuosly unrecorded microfossils.

a	Type K3 fungal spore, x 1000.
b	Type K4 fungal spore, x 1000.
c	Type K6 unidentified microfossils, x 1000.
d,e	Type K7 fungal spores, x 570.
f	Type K24, unidentified spore, broken, x 700.
g	Type K8, intact spores, x 700.
h	Type K9, unidentified spore, x 1230.
i	Type K10 fungal spores within *Corylus* pollen grain, x 520.
j,k	Type K16 fungal remains, x 450.
l	Type K12, unidentified microfossil, x 250.
m	Type K23, unidentified microfossil, x 590.
n	Type K23, attached in row, x 110.
o	Type K27, possibly *Synchitrium* resting spore, x 315.
p	Type K28 fungal(?) spore, x 570.
q	Type K30 fungal spores, x 700.

PLATE 2

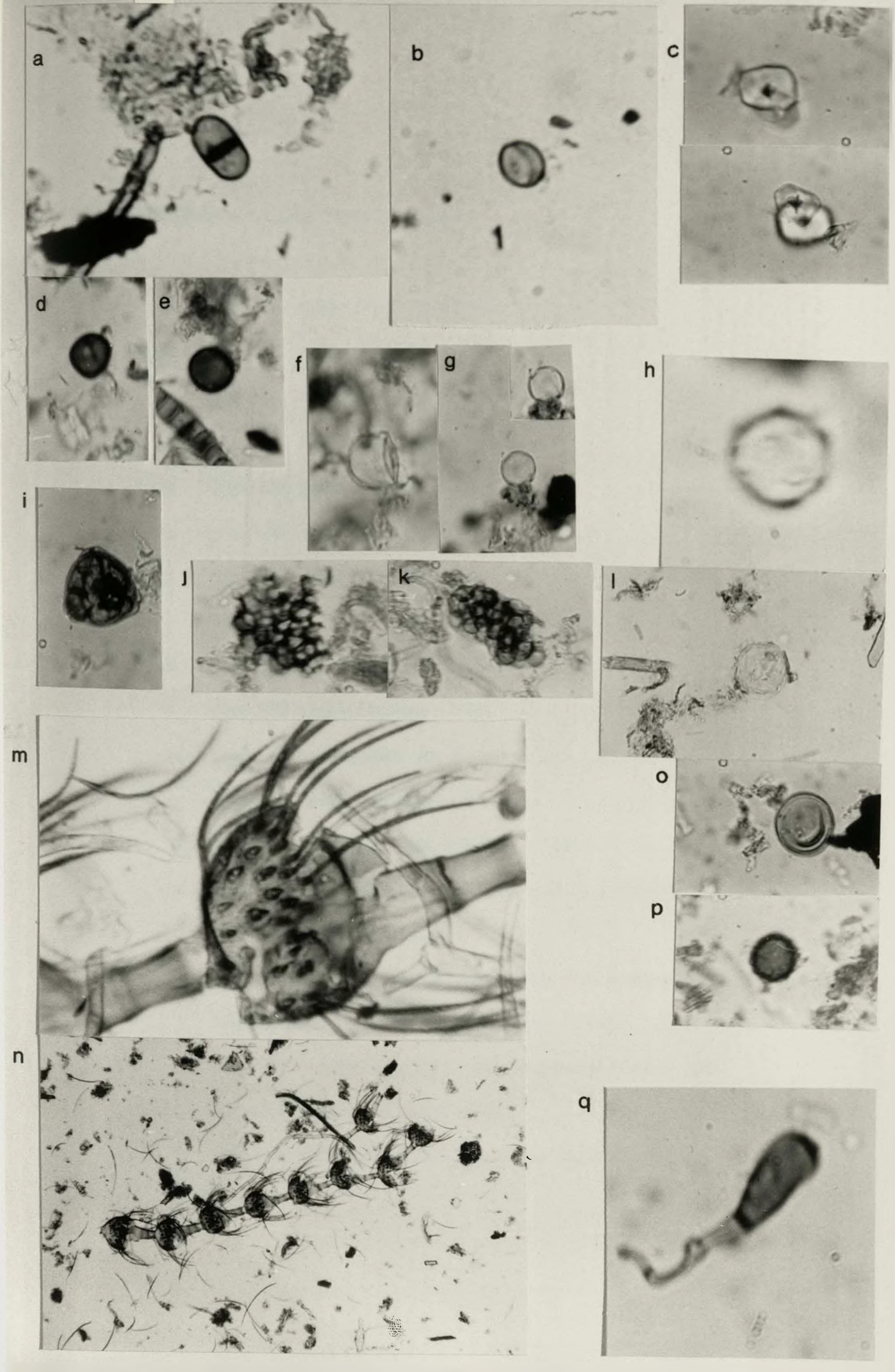
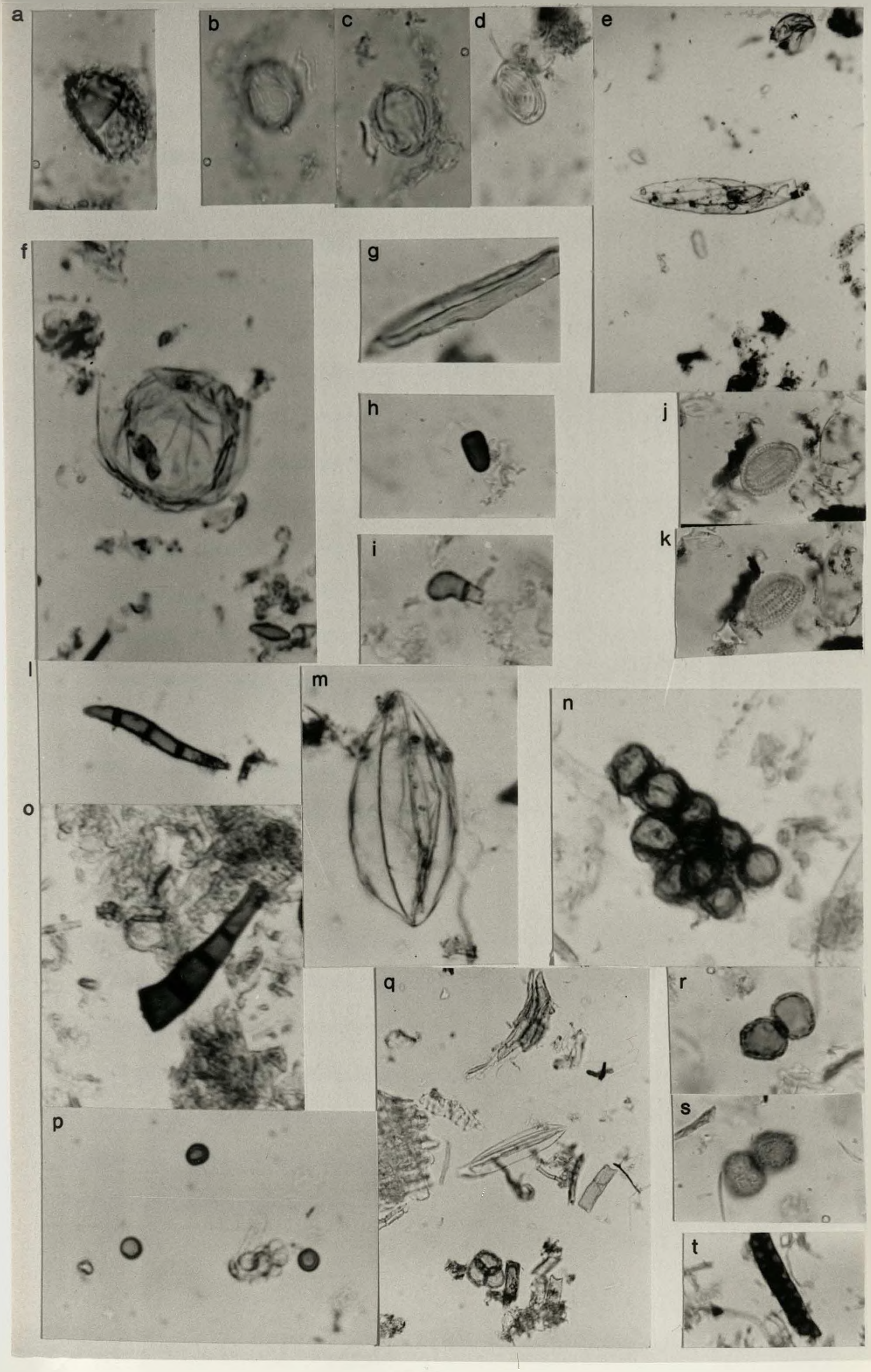


PLATE 3. Including previously unrecorded types.

a	Type K32, unidentified microfossil, x 800.
b,c,d	Type K34, unidentified microfossil, x 640.
e	Type K35, unidentified microfossil, x 280.
f	Type K37, unidentified microfossil, x 470.
g	Type K39, Plant remains? x 1000.
h	Type K40 fungal spore, x 440.
i	Type K47 fungal (?) spore, the hyaline tube (Conidiophore?) is bent behind, re-emerging poiting up and right), x 330.
J,k	Type K48, microfossils of unknown origin, x 310.
l	Type K56 fungal remains, x 750.
m	Type K59, unidentified microfossils, x 750.
n	Type K60 fungal remains, x 625.
o	Type K61, (broken) fungal remains, x 640.
p	Type K71, unidentified microfossils (hyaline, clustered, lower right), with Type K2 for comparison, x 1000.
q	Type K76, unidentified microfossil (long oval, hyaline, central) with *Calluna* pollen grain for size comparison, x 250.
r	Type K81, unidentified microfossil, equatorial focus, x 1000
s	Type K81, surface focussed, x 1000.
t	Example of "Mycelium undifferentiated" class, x 325.

PLATE 3



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