HOLOCENE ENVIRONMENTAL CHANGE IN THE SCOTTISH HIGHLANDS: MULTI-PROXY EVIDENCE FROM BLANKET PEATS

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Dedicated to Robert Smithson (1938-1973)

ABSTRACT

This thesis seeks to investigate the Holocene environmental history of two areas of Northern Scotland with specific reference to the evidence for pine woodland density variations and tree-line dynamics. The evidence is derived from the biostratigraphy of peat profiles sampled along altitudinal transects in the two upland areas of Gleann Einich in the Cairngorms (between *c.*500m OD and *c.*930m OD) and Beinn Dearg in the Northwest Highlands (between *c.*270m OD and *c.*600m).

In order to gain a better understanding of the environmental conditions of each site and transect area, detailed study has been undertaken of the pollen stratigraphy, the plant macrofossils, the fungal and algal remains and the degree of humification of the peat profiles. The results have demonstrated the importance of such multi-proxy investigations and highlight the need for further investigation of the inter-relationship of these different lines of evidence.

The biostratigraphic evidence for each profile is described, followed by an interpretation of the evidence for synchronous pine woodland density variations and tree-line changes for each transect area (using linear interpolation of radiocarbon age estimates). The biostratigraphic evidence from both transect areas is then compared in order to identify synchronous tree-line changes and hydrological events. There is evidence from both transect areas for a regional decline in tree-lines and pine woodland densities shortly before *c.*6,400 BP and at *c.*5,400 BP and an increase in tree-lines shortly before *c.*6,000 BP and before *c.*4,000 BP. A regional model for pine woodland density variations and tree-line changes is proposed for Northern Scotland which is subsequently compared with published evidence from Scandinavia and existing models for Holocene climate change.

The investigation of the degree of humification of the peat profiles provides supplementary and complementary data for comparison with the pollen-stratigraphic data. The results demonstrate the importance of such multi-proxy approaches. Synchronous shifts identified in the degree of humification, both for the peat profiles from each transect area, and between Beinn Dearg and Gleann Einich transects are discussed and hypotheses are proposed to provide explanations for the results. The humification evidence is then compared with existing palaeoclimatic models based upon peat-stratigraphic evidence (recurrence surfaces) and inferences for wet phases based upon deuterium isotopic analyses of pine macrofossils.

The evidence of the fungal and algal remains has been found to complement the humification evidence and is compared with the pollen-stratigraphic evidence. The frequency of *Pinus* pollen exhibiting blackening of the grains is compared with the humification evidence and possible explanations for the cause of this feature are proposed.

The future research needs which have arisen from this investigation are outlined and further refinements and research needs are proposed. This project provides an insight into the fossil pollen assemblages preserved in blanket peats within geographically constrained altitudinal transects using established and consistent methodologies. Information is gained regarding temporal variations in pollen frequencies, concentration and influx values in upland environments. This study has highlighted the potential of montane blanket peat profiles for recording temporal changes in vegetation communities and hydrological conditions at the local, regional and inter-regional scales.

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CPG = Carn A' Phris-Ghiubhais (c.630m OD)
LOD = Lochan Odhar (c.700m OD)
MNM = Moine Mhor (c.930m OD)

FIGURE 5.2 Beinn Dearg - location of sample sites

DMR = Dirrie More (c.270m OD)
LDM = Lochdrum (c.420m OD)
MFD = Meall Féith Dhiongaig (c.500m OD)
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CHAPTER 1.0 INTRODUCTION

This thesis investigates the biostratigraphic information preserved in blanket peats in two areas of northern Scotland and attempts a reconstruction of the distribution of pine woodland and the climatic history during the Holocene. The most visually striking evidence for a greater spatial distribution of pine woodland in the past is the presence of sub-fossil stumps preserved in blanket peats in locations above and beyond the limit of today's pine forests. In the Cairngorms, layers of pine stumps have been identified in peat deposits up to 150m above the present tree limit which indicates that at some time in the past the climate was significantly warmer and/or drier (Pears, 1968). Similarly, sub-fossil pine remains have been found as far north as the lowlands of the Flow Country of Caithness and Sutherland, an area which is entirely treeless today. There is evidence to suggest that these sub-fossil pine remains in Caithness represent a short-term latitudinal expansion of the northern limit of pine trees at about 4,000 BP (radiocarbon years Before Present, AD 1950) (Gear & Huntley, 1991).

Since tree-lines (both the altitudinal and latitudinal limit of trees) are sensitive to even minor fluctuations in climatic conditions (Grace, 1989) an investigation of areas which lie close to the latitudinal and/or altitudinal limits of pine preservation might provide palaeobotanical evidence for climate change. However, the absence of sub-fossil pine in the peat deposits at higher altitudes or further North, may not necessarily indicate that pine trees were similarly absent.

A second line of palaeobotanical evidence for the reconstruction of the former limits of pine is pollen stratigraphy. The accumulating peat preserves the pollen rain as a record of the local and regional vegetation and the plants colonising the peat bog surface. In order to interpret the pollen record in terms of spatial and temporal fluctuations in the tree-line, several sites should be investigated along a tight altitudinal (or geographical) transect. By comparing the pollen-stratigraphic evidence (on a temporal scale) from peat profiles along a transect spanning the upper limit of sub-fossil pine stumps, it may be possible to identify which sites were within a relatively dense woodland and which were colonised by upland heath. If this approach is realised then a model for tree-line changes over time can be proposed.

However, if the pollen-stratigraphic evidence indicates the local presence pine but there are no radiocarbon-dated sub-fossil pine remains to support this evidence, then either the pollen evidence is over-representated by *Pinus* or the absence of macrofossils may reflect the preservational conditions of the mire. Pine trees only germinate and become established on a mire when the surface is sufficiently dry and aerated (cf. Birks, 1975). However, for pine remains to be preserved, rapidly accumulating peat and wet, anaerobic conditions are required. The absence of pine macrofossils within the peat stratigraphy may indicate that

long phases of dry, aerobic conditions prevailed which caused the pine wood to decay on the mire surface or alternatively, that mire surface conditions were too wet and anaerobic for pine establishment (although pine may have colonised higher, better drained ground). To test these alternative hypotheses an assessment of the past hydrological conditions of the mire is required. A measurement of the degree of peat decomposition (humification) will allow an assessment of the mire surface conditions over time and thus the potential for the establishment of pine and subsequent preservation of the pine as macrofossils. It should then be possible to assess, in the absence of pine stumps, whether the pollen evidence for a former pine woodland cover is valid.

Since the upper limit of pine stump preservation declines to the north and west of Scotland (cf. Lowe, 1993), the sampling of peat profiles from two climatically contrasting regions (the drier Cairngorms and the wetter Northwest Highlands) allows an investigation of whether this trend reflects the former tree-line gradient across Scotland or is affected by the hydrological conditions of the mire surface. This methodological approach will be adopted in this thesis.

1.1 GENERAL AIMS AND OBJECTIVES OF THIS INVESTIGATION

i) To assess the potential for palaeobotanical evidence from blanket peats for recording changes in tree-lines.
ii) To investigate the relationship between the degree of peat humification and the palaeobotanical record.
iii) To propose a model for climate change in Northern Scotland during the Holocene.

1.2 SPECIFIC AIMS OF THIS THESIS

i) To investigate the upper limit of pine stump preservation in northern Scotland to supplement existing published observations.
ii) To investigate the palaeobotanical record from blanket peat sites along altitudinal transects from i) the relatively dry Cairngorms and ii) the relatively wet Northwest Highlands.
iii) To assess the potential of pollen stratigraphic data for recording past changes in variations in the relative density and altitudinal limits of pine woodland
iv) To propose criteria for the identification of tree-line fluctuations from pollen stratigraphic data
v) To compare and assess the pollen-stratigraphic data from the Northwest Highlands and the Cairngorms for evidence of synchronous variations in the relative density and altitudinal limits of pine woodland
vi) To assess the potential of peat humification data from different site types for identifying local and regional hydrological events
vii) To investigate the relationship between the micro- and macrofossil record and the degree of peat humification.

viii) To propose guidelines for the interpretation of pollen concentration and influx data from peat deposits in the light of the humification evidence.

ix) To examine existing hypotheses for variations in the alitudinal limtis of pine in Northern Scotland and to test these hypotheses with the results presented in this thesis

x) To propose a spatial and temporal hypothesis for tree-line changes during the Holocene in northern Scotland and to compare this with existing hypotheses for climate change, both from Scotland and other parts of Northwest Europe.

CHAPTER 2.0 THE DISTRIBUTION OF *PINUS SYLVESTRIS* IN NORTHERN SCOTLAND DURING THE HOLOCENE AND COMPARISON WITH OTHER AREAS OF NORTHERN EUROPE

The reconstruction of the former distribution of pine woodland during the Holocene is based on two lines of biostratigraphic evidence: the macrofossil record (sub-fossil wood) and the microfossil (pollen) record. In this chapter the Holocene vegetation history of Northern Scotland will be outlined and reviewed based on existing published evidence. Specific reference will be made to work closely related to this investigation both in terms of geographical and subject area. A brief introduction will be given for the Holocene history of pine in Scotland followed by a more detailed consideration of palaeoecological investigations in the Cairngorms and the Northwest Highlands. Studies of Holocene tree-line changes from elsewhere in Northern Europe will be summarised in the final part of this chapter.

2.1 PALAEOBOTANICAL EVIDENCE FOR THE DISTRIBUTION OF PINE WOODLAND IN NORTHERN SCOTLAND DURING THE HOLOCENE

The current evidence for the former distribution of pine in Scotland will be discussed below, and since much of the earlier work was based on interpretations of the sub-fossil pine remains observed in peat deposits, this will be outlined first. To ease comparison between existing published evidence all dates refer to uncalibrated radiocarbon years before present (1950 AD).

2.1.1 THE EVIDENCE OF SUB-FOSSIL PINE REMAINS

Observations of the widespread occurrence of sub-fossil pine stumps in exposed peat profiles in Scotland have been a source of contemplation and interpretation since the 1800's. Lyell (1853, p.720) suggests that "the mosses of northern Europe occupy the place of forests of pine and oak which have disappeared within the historical era. Such changes are brought about by the fall of trees and the stagnation of water, caused by their trunks and branches obstructing the free drainage of the atmospheric waters and giving rise to marsh". Although this interpretation may appear somewhat simplistic today, Lyell's observations provide an important source of reference regarding hypothesis development. For example, Lyell noted that some of the upright tree stumps had their roots embedded in the minerogenic substratum and he proposed that this was evidence that pine had grown on the site and was not brought in by rivers or streams. Lyell also noted that the largest pine stumps were found in the low altitude peat bogs in Scotland and were proportionally smaller in peat bogs at higher elevations (Lyell, 1853, p.720-721). The significance of the sub-fossil pine stumps was therefore appreciated as evidence for i) a greater geographical and altitudinal distribution of pine trees in the past, ii) that the remains were *in situ* and reflected, at least in part, local hydrological conditions and iii) that pine growth rates and abundance varied with climatic stress related to altitude.

Some important pioneering research on the palaeoecology of pine in Scotland was carried out by Lewis (1905-11). He observed that the pine stumps and trunks preserved in peat profiles often appeared to form extensive lateral horizons. He concluded that pine stumps represented Geikie's (1877) interglacial periods (the "Forest beds") and the more homogenous peat layers represented glacial periods (the "Arctic beds"). Blytt (1876) had proposed a climate model based on similar forest beds in Norway which Sernander (1908) subsequently extended to include Sweden. The climatic scheme became known as the Blytt-Sernander model, and assigns the forest beds to drier climatic periods (Boreal and Sub-Boreal) and the intervening homogenous peat to the wetter Atlantic and Sub-Atlantic periods. Largely based on Lewis's research, Samuelsson (1908) applied the Blytt-Sernander model to the British sequence where the scheme was adopted and became firmly established. Since this earlier work was carried out before the advent of radiocarbon dating and because the stumps appeared to form layers, it was assumed that they represented a synchronous regional colonisation of mire surfaces by pine.

There is a general decline in the upper limit of pine macrofossils westwards and northwards from the Cairngorms. For example, some of the published upper limits include 550m in the Southwest Highlands, and 793m and 701m in the Cairngorms (cf. Lowe, 1993) and my field data suggests that the upper limit of preservation is approximately 580m OD in Glen Affric (to the Northwest of Loch Ness), 460m in Beinn Eighe and 350m near Inchnadampf in Wester Ross (see Figure 2.1 for locations) This gradient matches the general trend of the potential tree-line which would exist today (in the absence of interference by humans) where pine survives above birch in the eastern Scottish Highlands and birch above pine in the more oceanic western highlands (Steven and Carlisle, 1959) (see Chapter 3 for description). However the gradient observed for the upper limit of pine stump preservation may not necessarily represent a former tree-line gradient, but reflect the hydrology of the mire system in which the stumps are preserved. The mire surface must be sufficiently dry and oxygenated for pine trees to germinate and become established (cf. Birks, 1975). Similarly, the generally higher precipitation at higher altitudes may also inhibit colonisation on the mire surface. Pears (1968) observed isolated pine stumps in the Cairngorms up to an altitude of *c.*914m (compared to a limit of 793m for layers of stumps) which may indicate an isolated or patchy colonisation of pine or a reduction of the number of trees able to colonise the relatively wet mire surfaces at higher altitudes. So the local and/or short-term establishment of pine at higher altitudes may only be represented in the pollen-stratigraphy of a peat profile and not necessarily accompanied by macrofossil evidence.



Figure 2.1: Map of Scotland depicting location of sample areas (Beinn Dearg and Gleann Einich) and some of the published work mentioned in the text.

2.1.2 POLLEN-STRATIGRAPHIC EVIDENCE

The spread of pine in Scotland following the last glaciation has an unusual pattern. It appears to have expanded independently in the Northern Highlands (at Loch Maree and Loch Scionascaig) between 8,500 and 8,000 BP but the origin of this early pine expansion is not yet established (Birks, 1989). Several hypotheses have been proposed including the survival of pine in sheltered localities in northwest Scotland during the last glaciation (Birks, 1989; Kinloch *et al.*, 1986), jump dispersal from southern Britain (Birks, 1989) and spreading from Ireland through south-western Scotland (Forrest, 1982; Bennett, 1984). Furthermore, the genetic character of modern pine tree populations in northwest Scotland is distinctly different from populations in other parts of Scotland which supports the hypothesis for a separate source (Kinloch *et al.,* 1986). In the light of this evidence, and the pollen evidence for the presence of pine in Donegal, Ireland, as early as 10,000 years ago (Fossitt, 1994), Bennett (1995) suggests that pine originated from northern Ireland and subsequently spread along the west coast of Scotland. Pine subsequently spread to the Eastern Highlands and reached into Upper Speyside and Upper Deeside between 8000 and 7500 BP and became established on Rannoch Moor by 6500 BP (Birks, 1989). Pine appears not to have formed a significant component of woodland in South Central Scotland and the Southwest coastal fringe (Bennett, 1984) apart from in the western Southern Uplands (Loch Dungeon) (Birks, 1972).

Following the relatively rapid establishment of pine across the British Isles, it reached its maximum distribution shortly before *c.*4,000 BP when it reached most parts of Scotland with the exception of the southwest Scotland and Shetland (Bennett, 1984; Birks, 1989). There was a short-term of expansion into the far north and west of Scotland at about 4400BP as shown by the macro- and microfossil evidence from Lochstrathy in Caithness (Gear and Huntley, 1990), Loch Assynt in northwestern Scotland (Birks, H.H.,1973-74 in Birks, 1980), Cross Lochs in the extreme east of Sutherland (Charman, 1994) and Loch Ashik in eastern Skye (Birks and Williams, 1983).

At about 4,000 BP there was a widespread decline in pine woodland cover in Northern Scotland, accompanied by a spread of blanket peat, as indicated by a marked decrease in the number and distribution of radiocarbon-dated pine stumps and by generally lower pine pollen frequencies in local pollen assemblage diagrams from Western and Northern Scotland (Birks, 1980). Several causes for this decline have been proposed, including climate change (Birks, 1975; Gear and Huntley, 1990; Bennett, 1984), soil deterioration, pathogens, and anthropogenic clearance (Bennett, 1984), and fire (Bradshaw, 1993). Blackford *et al.* (1992), suggest that a volcanic ash-layer identified in peat at a site in northern Scotland (which coincides with a decline in pine pollen frequencies) may be a cause for the decline of pine woodland in northern Scotland at *c.*4,000 BP. The authors propose that the volcanic eruption may have contributed to a short term climatic change which led to the subsequent

demise of pine in the region, or by direct acid pollution resulting from the ash fall. However, Hall *et al.* (1994) found no direct correlation between the occurrence of volcanic ash in peat deposits in Northern Ireland and a decrease in pine pollen percentages.

As Bennett (1995) suggests, these hypotheses for the decline in pine populations in Scotland are not necessarily mutually exclusive but identification of the principal factors involved requires high resolution pollen sequences to test for synchroneity and/or variability of pollen-stratigraphic evidence in time and space.

2.2 VARIATIONS IN THE ALTITUDINAL LIMIT OF PINE IN NORTHERN SCOTLAND DURING THE HOLOCENE

The relatively few investigations of variations in the altitudinal limits of pine undertaken in northern Scotland is partly attributed to the scarcity of suitable sediments for palaeoecological reconstruction at the highest altitudes (either for pollen analysis or for the preservation of wood remains) (Tipping, 1994a).

This section will describe the published evidence for the reconstruction of the former upper limit of pine in northern Scotland (the Northwest and Northern Highlands, the Cairngorms and at Rannoch Moor) based on the interpretation of micro- and macrofossil evidence preserved in peat deposits. The evidence from investigations in Scandinavia and the European Alps will be briefly reviewed in the final part of this chapter to establish a model against which the results from this investigation can be compared at the supra-regional scale (in Chapter 8). Such a comparison will enable an assessment of local versus regional climate factors which might have induced variations in the upper limits of pine growth.

2.2.1 NORTHWEST AND NORTHERN HIGHLANDS

In the absence of human interference, the current potential northern limit of pine woodland cover (based on existing woodland fragments, soil types and ecological tolerances of woodland communities) lies just to the north of Loch Broom (McVean and Ratcliffe, 1962). The area described as the Northwest Highlands, which includes the sites investigated in this study at Beinn Dearg, is therefore approaching both the altitudinal and latitudinal (or geographical) potential limits of pine woodland.

Durno and McVean (1958) investigated the postglacial forest history from six sites in the Beinn Eighe Nature Reserve adjacent to Loch Maree (see Figure 2.1). The sites ranged in altitude from approximately 150m to 570m but pine stumps were only found at the lower sites (altitude not published). My investigations show that pine stumps are found up to an altitude of approximately 460m in this region (see Section 5.1.3.3). The pollen diagrams presented by Durno and McVean (1958) use an arboreal sum and the Ericaceae and Empetraceae

pollen types are grouped together as Ericoid. The pine pollen curves for each of the site profiles vary considerably which is surprising given their close proximity to each other. However, since radiocarbon dates were not available, no direct comparison or assessment for synchroneity can be made of the pollen-stratigraphic evidence. Durno and McVean (1958) observed a general reduction of tree pollen frequencies at the higher altitude sites and a corresponding increase in the representation of Ericoid pollen and *Sphagnum* spores. No attempt was made to interpret the pollen data in terms of tree-line fluctuations and the conclusion drawn from the macrofossil evidence was that a zone of *Juniperus* existed above the birch/pine forest for much of the post-glacial period.

2.2.2 THE CAIRNGORMS

There are few examples of natural tree-lines to be found in Britain today. An exception is on Creag Fhiaclach in the western Cairngorms, where the (semi-natural) pine limit lies between 640m and 680m above sea-level depending on topography and local shelter (Pears, 1967) (outlined further in Chapter 3). Although the Cairngorms lie within a large block of potential pine forest cover (McVean and Ratcliffe, 1962) the pine trees at, or near, the tree-line in the Cairngorms should be susceptible to similar ecological stresses as those at or near the altitudinal (and latitudinal limit) of pine in the Northwest Highlands. However, the pollen-stratigraphic evidence for tree-line changes in the Cairngorms may be confused by a high regional *Pinus* pollen influx (or background "noise") derived from the pine woodland prevailing at lower altitudes (as exists today).

The highest isolated pine stumps identified in the Cairngorms lie at approximately 910m OD (location not published), so at some point during the Holocene the climate must have been significantly warmer and/or drier to allow trees to grow at higher altitudes than today (Pears, 1968). Pears also identified an upper limit of preservation of layers of pine stumps in the Cairngorms (Pears, 1968). Peat profiles containing two interstratified layers of sub-fossil pine stumps were found up to *c.*700m OD and sites with one layer extended to 793m OD. Where two layers were identified, the lower layer was usually at the base of the stratigraphic profile, on the minerogenic substrate (the exception was basin peat profiles, where peat accumulation occurred relatively early).

Pears (1968) undertook pollen analysis from three of the sites at altitudes of 610m, 716m and 917m. He used an arboreal pollen sum and did not distinguish the Ericaceae pollen which, as will be discussed later, makes direct comparison with the results presented here difficult. Pears zoned the diagrams in terms of the Blytt-Sernander scheme and did not attempt to identify tree-line fluctuations from the pollen diagrams alone. He concluded that the two lower sites were always below or near the tree-line whereas the highest site (917m OD) was always above the tree-line (although at times not far above). By assessing the pine stumps in relation to the pollen stratigraphy he concluded that the lower stumps at Carn

Mhor (610m OD) were synchronous to the basal (and only) layer of stumps at Sgor Mhor (716m OD) which he placed at the Boreal Atlantic Transition (BAT) (c.7,500 BP).

However, subsequent radiocarbon analyses (Pears, 1969) revealed radiocarbon age estimates for one of the pine stumps at Carn Mhor of *c.*6,700 BP and a stump at Sgor Mhor of *c.*4,100 BP. A pine stump from the upper layer at Carn Mhor revealed a radiocarbon date of 2,280 BP +/- 200 which he placed at approximately the Sub-Boreal/Sub-Atlantic transition. The results showed the ages of the basal stumps were extremely variable and could not be assigned to just two well defined periods (Boreal and Sub-Boreal). Pears suggests that topography is an important factor governing the establishment of pine and subsequent preservation of the wood remains. Topography often controls the hydrology of a site and hence the initiation and rate of peat accumulation. Pears (1969) concluded that the potential of a peat profile to record evidence for regional changes in climate was largely dependent on site specific factors (principally topography).

Pears highlights an important factor regarding the absence of pine stumps at high altitudes in the Cairngorms (Pears, 1969). He states that an increase in altitude of approximately 600m is often sufficient to double the effective local annual precipitation which results in a relatively wet mire and the exclusion of pine trees from the bog surface but not necessarily from drier surrounding substrates.

Birks (1975) reinvestigated some of Lewis' sites (1905-11) and radiocarbon analyses of the pine stumps indicated that although they probably did not represent a synchronous invasion of the mire surface by pine, there was a discernible general grouping of dates. Radiocarbon age estimates of stumps from the Northwest Highlands, Rannoch Moor, and the Cairngorms (Rogart, Sgor Mor and Jean's hut) indicated a cluster of dates between *c.*4500 and 4000 BP. Pennington *et al.* (1972) suggest this is due to deteriorating climatic conditions and Birks (1972) arrived at similar conclusions from her pollen diagram from Loch Maree. The cluster of dates is thought to represent an increase in wetness and windiness which led to the spread of ombrotrophic blanket peat.

Birks (1975) concludes that although there is a wide range of radiocarbon dates for pine stumps in Scotland, there is a cluster of mean radiocarbon ages between c.4,500 BP and 4,000 BP which is associated with a decline in pine pollen percentages represented at many sites in Northern Scotland.

Birks (1975) sampled a basin peat with pine stumps and an overlying layer of birch stumps from the hummocky moraine at the north end of Loch Einich in the Cairngorms. Pollen analysis indicated that pine colonised the mire surface before *c.*6,000 BP but no single cause for the timing of this invasion could be identified from the record of the other taxa. However,

the peat matrix in which the pine stump was located was highly humified and the overlying peat was largely made up of *Sphagnum* leaves and spores. Birks suggests that the *Sphagnum*-rich matrix indicates an increase in the wetness of the mire surface and consequently the more anaerobic conditions killed the pine trees and prevented any further regeneration. Thus the regional pine pollen record remains high since the trees were able to survive on the surrounding drier substrates. The radiocarbon age estimates of the pine stump and surrounding humified peat matrix were 5,970 +/- 120 BP and 5,880 +/- 100 BP respectively. The upper layer of birch wood and *Calluna* stems provided a radiocarbon date of 4,150 +/- 100 BP with similar conditions causing the subsequent death and burial of the birch trees. Birks (1975) stresses that the asynchroneity of the pine and birch macrofossils is largely a result of site specific sensitivity thresholds of factors such as aspect, altitude and local topography. However, in general, pine colonisation depends on the prevailing vegetation communities inhabiting the mire surface. Pine became established after the mire had become acid but before *Calluna* became the dominant component of the surface vegetation community. Birks (1975) proposes that the final decrease in aboreal pollen representation was probably caused by forest clearance and grazing with an artificial lowering of the tree line to today's level of about 412m.

Dubois and Ferguson (1985) investigated the climatic history of *Pinus sylvestris* in the Cairngorms. Forty radiocarbon dates were obtained from samples from a North facing slope just north of Cairngorm (mountain). The oldest proved to be the highest (at *c.*730m OD) providing a radiocarbon date of 7,350 +/- 85 BP but pine stumps with dates between *c.*5,500-6,000 BP were restricted to altitudes between 530m OD and 590m OD. Stumps with radiocarbon dates of less than c.3,000 BP were only found at sites below 530m OD which Dubois and Ferguson suggest may reflect conditions favourable for preservation rather than representing the former upper limit of pine trees.

Dubois and Ferguson (1985) also analysed the deuterium content of some of the sub-fossil pine stumps from the Cairngorms. Dansgaard (1964) had noted that the Deuterium/ Hydrogen (D/H) ratio in precipitation is related to the intensity of the rainfall, i.e. smaller D/H ratios are associated with more intense rainfall. The depletion of Deuterium levels in rainfall is recorded in the D/H ratio of the cellulose of wood which therefore provides a potential record of the relative intensity of rainfall during its growth.

Dubois and Ferguson (1985) analysed the cellulose from 33 dated sub-fossil pine wood samples and compared their D/H ratio with modern values at the same altitude. They identified periods of excessively low deuterium levels (interpreted as indicative of heavy rainfall) at about 7,300 BP, between 6,200-5,800 BP, between 4,200-3,940 BP and at about 3,300BP. They summarised macro-fossil evidence for the history of pine in the Cairngorms as follows:

1. An increase in the intensity of rainfall between 6,200-5,800 BP caused peat formation.
2. The grouping of radiocarbon dated pine stumps at *c.*7,000 BP are, with one exception, from profiles above 700m OD. The dense narrow growth-rings of these samples (due to the increased ecological stress at higher altitudes) reduces the susceptibility to decay. In comparison, the pine stumps below 700m, with wider growth-rings, decomposed before incorporation into the peat matrix.
3. No pine stumps above 620m provided radiocarbon dates between *c.*6,200 and 5,450 BP. The "pluvial" implied between *c.*6,200 and 5,800 BP would not have favoured the growth of pine on the higher slopes .
4. Rejuvenation of blanket peat formation at *c.*4,200 BP produces an environment favourable for the preservation of pine stumps and hence the grouping of dates at this time.
6. The absence of pine stumps after *c.*3,000 BP located above *c.*530m OD is due to the decrease in temperature on a regional scale and an increase in windiness (Lamb, 1977). Markgraf (1974) identified a lower of tree-line in the Alps at this time.

Dubois and Ferguson (1985) suggest that the "pluvials" are probably representative of a broad geographic area, covering most of northwest Europe. This notion, and the hypothesis for the conditions favourable for the preservation of pine macrofossils (*cf.*Dubois and Ferguson, 1985; Birks, 1975 and Pears, 1969) can be tested with the humification data presented in this thesis.

2.2.3 RANNOCH MOOR

Ward *et al.* (1987) investigated the pine pollen representation in peat profiles along an altitudinal transect (between 250m and 350m OD) at Rannoch Moor in Southwest Scotland. Rannoch Moor is located near the boundary of one of the four major potential woodland types proposed by McVean and Ratcliffe (1962) which would exist today in the absence of interference by man. To the west would be predominantly oak forest with birch and to the east predominantly pine with some birch and oak. This boundary between these zones would have fluctuated in the past (latitudinally as well as altitudinally) thus placing Rannoch Moor at an ecologically "sensitive" (sensu. Lowe, 1993) location between the two woodland types. Ward *et al.* (1987) investigated the pine pollen record along an altitudinal transect and demonstrated that pine is consistently recorded at high percentages at low altitudes (<250m), in low percentages at high altitudes (>350m) and fluctuates at intermediate altitudes. Therefore, the pollen-stratigraphic evidence indicates the higher sites were above the tree-line at all times and the intermediate sites showed variations in pine pollen percentages resulting from woodland density variations corresponding to tree-line fluctuations (Lowe, 1993). The data suggest that there was a lowering of the altitudinal limit

of pine to below 293m shortly after 6500 BP and a rise in the altitudinal limit at about 4700 BP.

Bridge *et al.* (1990) showed a possible link between evidence for the local presence of pine and climate in peat deposits from Rannoch Moor. The pollen evidence indicates a widespread and probably rapid colonization of the area by pine between about 6,800 BP and 6,600BP, followed by a reduction in pine woodland density at higher altitudes. A second rise in pine pollen percentages occurs at around 4,970-4,660BP which is interpreted as indicative of a further regional expansion of pine woodland cover. The radiocarbon age estimates and dendrochronological evidence of the sub-fossil pine stumps, however, is not straightforward. The radiocarbon dates from several of the pine stumps sampled from apparently horizontal peat layers indicate that the stumps do not represent a short-lived colonization of the peat bog. The dates range between 6,835+/- 40 BP and 4,000 +/- 40 BP. However, there was an apparent grouping of dates between 5,200-5,050 BP and 6,220-6,040 BP which corresponded with periods of relatively low pine pollen frequencies. The dendrochronological analyses of the sub-fossil pine stumps supported the results of the radiocarbon assays as no cross-matching between the samples was evident. The tree rings also indicate that the growth rates varied considerably and that there were many were short-lived trees with distorted rings. In summary, the pollen-stratigraphic evidence indicated at least two periods of local pine establishment but, paradoxically, the age estimates for the sub-fossil pine stumps falls between these periods. The dendrochronological investigations of the pine stumps suggest the trees were relatively immature and were surviving under ecologically stressed conditions.

Bridge *et al.* (1990) analysed all available Scottish radiocarbon dates of pine stumps preserved in peat deposits, and compared these data with the stable isotope work of Dubois and Ferguson (1985), described above, in the Cairngorms. Bridge *et al.* (1990) observed that the peaks in radiocarbon age estimates of the macrofossils coincide with evidence for the "pluvial" episodes of increased rainfall. They noted that before each "pluvial" episode there was a period of high pine pollen percentages which indicates that conditions were suitable for the growth of pine. Following the "pluvial" episodes there was a marked decline in both macro- and micro-fossil pine representation. They concluded that peaks in modes of radiocarbon age estimates of macrofossil representation coincided with the timing of "pluvials" because of preservation bias of the peat stratigraphy. During a "pluvial" the surface conditions of the relatively wet mire surface would have been favourable for preservation of the pine stumps and the subsequent troughs in pine stump representation were indicative that local conditions were unsuitable for pine establishment.

2.2.4 SUMMARY OF THE STRATIGRAPHIC EVIDENCE FOR THE DISTRIBUTION OF PINE IN NORTHERN SCOTLAND DURING THE HOLOCENE

In summary, there is evidence to suggest that the colonisation of pine in northern Scotland occurred earlier in Wester Ross (*c.*8,500-8,000 BP) than in the Cairngorms (*c.*8,000-7,500 BP). This has been proposed as indicating separate origins for the pine populations, and one explanation for the relatively early arrival in Wester Ross is dispersal from Ireland (Fossitt, 1994, Bennett, 1995). Subsequent variations in the timing and spatial patterning of pine woodland density in Northern Scotland has, with a few exceptions, not been examined in detail. There is evidence for short-term fluctuations in the density of pine woodland cover at Rannoch Moor (Ward *et al.*, 1987) and an extension of the northern range limit shortly before *c.*4,000 BP (Gear and Huntley, 1991; Charman, 1994). The decline in pine pollen frequencies is often relatively abrupt at many sites across northern Scotland (*c.*4,000 BP) and is usually associated with a cluster of similar radiocarbon age estimates of pine macrofossils. However, this is not always the case, and an investigation of a series of sites along well chosen altitudinal transects provides an opportunity to analyse the evidence for a pine decline and to test for synchroneity of the microfossil (and macrofossil) data. By adopting a common methodological investigation strategy for each of the transects, supported by radiocarbon dating, local versus regional factors governing the upper limits of pine growth can be explored. It is only by isolating the signals for local environmental conditions that such data can be compared and assessed against competing existing hypotheses.

If evidence for supra-regional factors governing the distribution of pine are identified it is worth examining the evidence from proximal parts of Europe likely to be influenced by the North Atlantic circulation at comparable latitudes to Northern Scotland. Therefore a brief outline of the evidence for Holocene tree-line variations in Scandinavia and the European Alps will be given.

2.3 HOLOCENE TREE-LINE VARIATIONS IN SCANDINAVIA

The evidence for the history of *Pinus sylvestris* in Scandinavia, based on pollen stratigraphy and radiocarbon dated sub-fossil stumps, indicates that pine spread northwards to northernmost Fennoscandia between 8,500-7,000 BP replacing birch forests everywhere at lower elevations (Hyvärinen, 1976 and 1993). Maximum spread and highest densities of pine woodland were established between *c.*7,500 and 5,000 BP followed by a decline in pollen values shortly after 5,000 BP reflecting a large scale southerly regional retreat of pine which continued until about 3,000 BP (Hyvärinen, 1976).

In the Swedish Scandes, the macrofossil evidence suggests that pine became widespread and reached higher altitudes than present from about 8,600 BP with a subsequent fall in the altitudinal limit of pine from about 4,000 BP (Eronen and Huttunen, 1993). Kullman (1990)

concludes that the decline may have commenced at about 6,000 BP as a response to reduced seasonality and summer temperatures.

The extent of small-scale variations in the upper limit of pine during the period between *c.*7,500 and 5,000 BP is not so clear. Kullman (1992) investigated the radiocarbon age estimates of remains of *Pinus sylvestris, Betula pubescens* ssp. *tortuosa* and *Alnus incana* recovered from peat deposits from an area in Swedish Lapland. He concludes that a high tree-limit was established at about 8,000 BP by pine and this limit subsequently retreated by about 200m in altitude at a mean rate of *c.*25m per thousand years. However, Kullman (1992) believes there may have been periods of transient advances and accelerated decline in the tree-limit since 8,000 BP. Shortly before *c.*6,000 BP birch and alder reached at least 250m above the pine forest limit which Kullman (1992) infers may reflect the general trend towards more oceanic conditions in northwestern Europe at about this time, which would favour the growth of birch. Kullman concludes that the steady pine tree-limit recession, the replacement of pine by birch and the subsequent decline of birch (at *c.*4000 BP) is probably a response to the continuous cooling and change of thermal seasonality caused by a decrease in solar radiation towards the mid-Holocene (Kutzbach and Gallimore, 1988).

Karlén (1976) assumes a number of fluctuations in the upper limit of pine growth occurred in Sweden before *c.*4,000 BP (based on radiocarbon dated pine macro-fossils and palynological data) but others (e.g. Lundqvist, 1969; Moe, 1979) suggest that the fluctuations were relatively minor .

However, Karlén (1976) suggests that a pattern in the radiocarbon dates of subfossil pine samples is only apparent when the altitude of the subfossils is assessed in relation to the present pine tree limit. The results indicate that pine reached its maximum altitude in Northern Sweden around 5,000 BP and then decreased. Similarly, Moe (1979) suggests that there is evidence that a short-term expansion of pine to higher altitudes occurred in Southern Norway shortly before *c.*5,000 BP.

In summary, there is evidence to suggest that pine tree limits were up to 200m higher in Northern Europe during the Early to Mid-Holocene by comparison with those of the present day (Kullman, 1988, Grace, 1989). There is also evidence for a subsequent decline in the upper limit of pine at *c.*6,000 BP (Kullman, 1992) and a short-term higher tree-line at around *c.*5,000 BP (Karlén, 1976, Moe, 1979). However, a major decline in pine woodland is recorded over large areas of Northern Europe at or shortly after 4,000 BP which is similar to the evidence found in Northern Scotland (Lowe, 1991).

2.4 HOLOCENE TREE-LINE VARIATIONS IN THE EUROPEAN ALPS

Relatively few investigations have been undertaken to investigate Holocene tree-line changes in the Alps. Patzelt and Bortenschlager (1973), Patzelt (1974) and Bortenschlager (1982,1989) state that there are no indications for a Holocene climatic optimum from the palaeobotanical evidence recovered from the Tyriolian Alps but postulate that the tree limits, snow-lines and summer temperatures have been fluctuating about the values of today throughout the Holocene. Burga (1988) interprets the palaeobotanical evidence from the Swiss Central Alps as indicative of a moderate mid-Holocene thermal optimum, between 6000-4800 BP, which was followed by a decrease in the timberline by about 100-200m.

Tessier *et al.* (1993) investigated the pollen and macrofossil evidence at lake and peat bog sites on the Taillefer massif, and conclude that the timberline was at least at the altitude of the plateau (2,100m OD) between the Boreal and Sub-Atlantic and probably reached a maximum of *c.*2,400-2,500m OD during the Atlantic optimum. The reduced forest cover after *c.*5,000 BP on the plateau is interpreted as indicative of increased human pressure.

Vorren *et al.* (1993) investigated the pollen stratigraphy from a small mire in Austria (*c.*2,250m OD, approximately 50m above the present tree-line). The evidence indicates that the *Pinus cembra* tree-line exceeded the present tree-line at *c.*9.000 BP and *c.*3,100 BP. Since only one site was investigated it is not possible to judge the height the tree-line reached but it reached, or came close to, the current tree-line at about 9,000-8,000 BP, 6,000-5,500 BP and 3,600-3,000 BP. The highest altitude is reached in the earliest period.

Therefore, in summary, the evidence for Holocene tree-line fluctuations in the Alps is relatively sparse, with an indication of a high tree-line in the early Holocene (*c.*9,000-8,000 BP) and possibly further altitudinal advances between 6,000-5,500 BP and 3,600-3,000 BP. However, the latter high tree-line does not correspond with the remaining evidence particularly well, and there is strong evidence for human impact on the landscape after about 5,000 BP.

2.5 SUMMARY

Investigations of variations in the altitudinal limit of pine woodland in Northern Scotland have been based on the evidence of radiocarbon dated sub-fossil pine stumps (e.g. Pears, 1968, 1969) and pollen stratigraphic evidence (e.g. Ward *et al.*, 1987). However, on the whole, (with the exception of the work on Rannoch Moor (Ward *et al.*, 1987)) the evidence is derived from isolated sites, often at low altitudes, where it may be difficult to distinguish between local, perhaps site specific, stratigraphic developments and changes in regional environmental conditions.

The evidence from Scandinavia indicates that pine tree limits were up to 200m higher in Northern Europe during the Early to Mid-Holocene by comparison with those of the present day (Kullman, 1988). Similarly this interpretation is largely based on the evidence of subfossil pine and to date there are few examples of investigations of a series of sites within a small local area, along an altitudinal transect (e.g. Hyvärinen, 1976).

There is, therefore, a strong case for re-examining the evidence in Scotland along well chosen transects of sites that lay below, close to, and above, the upper limit of pine stump preservation. By adopting common methodological approaches for the investigation of sites along altitudinal transects from climatically contrasting regions of Northern Scotland, synchronous developments over wides areas may become evident. By selecting information from these "sensitive", sites the timing and degree of Holocene tree limit variations (and by inference climatic variations) may be better understood (*sensu* Lowe, 1991).

CHAPTER 3.0 BIOGEOGRAPHICAL CLASSIFICATION OF NORTHERN SCOTLAND AND THE ECOLOGY AND STRATIGRAPHY OF BLANKET MIRES

The aim of this chapter is to outline the geographical distribution of the major vegetation communities in Northern Scotland and to describe how the altitudinal limits of these communities vary spatially. The distribution of vegetation communities is affected by anthropogenic interference, and some of the woodland communities are referred to as "potential limits" (cf. McVean and Ratcliffe, 1962). Since an investigation of pine woodland during the Holocene is one of the principal aims of this study, a brief outline of the ecology of *Pinus sylvestris* will be given. The vegetation communities will then be described in three groups: the present and potential woodland in Northern Scotland, the tree-line ecotone, and the above tree-line vegetation communities (or montane communities).

Since the profiles investigated in this study are from blanket mires, the final part of this chapter will concentrate on the types of blanket mires occurring in Scotland today followed by an outline of mire ecology and the associated vegetation communities. Finally, peat-stratigraphic terms will be described together with an outline of the proxy climatic inference potential of peat-stratigraphic profiles.

3.1 ECOLOGY OF *PINUS SYLVESTRIS*

Pinus sylvestris L. grows to a height of 36m and is native to Britain, forming pure or mixed woodland in the Scottish Highlands (Stace, 1991). Today, pine generally occupies marginal habitats and although it is capable of vigorous growth in more favourable situations, it is commonly competitively excluded by other species because of their light-demanding seedlings. Pine usually avoids waterlogged soils, although it can grow on drained, or naturally dry peat surfaces (Huntley and Birks, 1983). Mycorrhiza often play an important role in seedling nutrition on moorland and peat bogs and the absence of mycorrhiza is the commonest cause of primary pine growth check (McVean, 1963a). Mycorrhizal infection may fail to occur through mycorrhizal inhibitors such as that found in the raw humus of heather moors because of the presence of phenolic substances or fungal antibiotics (Harley, 1959; McVean, 1963b). Waterlogging not only leads to the death of seedlings, but may cause secondary growth-check at any stage of pine maturity following a period of active growth (McVean, 1963b). The ground unfavourable for regeneration of pine is of two main types; firstly that of a dense *Sphagnum* mat under leggy *Calluna* and *Vaccinium* in the more open, western (Scottish) or high-level forests, and secondly under a thick *Vaccinium* sward in the closed-canopy Eastern (Scottish) stands.

3.2 CONTEMPORARY WOODLAND COMMUNITIES OF NORTHERN SCOTLAND

Brown *et al.* (1993a), in their biogeographical classification of the contemporary Scottish uplands, state that woodland communities account for just under 1% of the current total vegetation. This low value demonstrates the patchy distribution of relict woodland stands and highlights the contrast with the dominance of past woodland communities throughout most of the Holocene in Scotland, as mapped by Birks (1988).

McVean and Ratcliffe (1962) produced two maps of woodland cover in Scotland, one showing the present day cover and the other showing the potential woodland cover (that would exist in the absence of human interference) based on existing woodland fragments, historical records and the ecological tolerances of the woodland communities. The map of potential woodland subdivided Scotland into three major zones of forest types.

In the absence of disturbance by man, south and west Scotland would be dominated by oak forest with birch and very little pine. The surviving fragments consist of mainly *Quercus patraea, Betula pubescens* ssp. *odorata*, with *Ulmus gabra, Fraxinus excelsior, Corylus avellana* (in more open areas), and *Alnus glutinosa.* Depending on the soil type the understorey is generally species poor with *Pteridium aquilinum, Deschampsia flexuosa, Vaccinium myrtillus* (with less grazing) (Birks, 1977).

The Central Highlands and east coast of Scotland are potentially pine forest with some birch and oak. *Pinus sylvestris* is the dominant tree species, with birch (mainly *Betula verrucosa*), and *Quercus petraea* in sheltered locations. The understorey of the pinewoods varies with the density of the canopy and geographical location. Significant differences can be detected between the drier eastern areas and the wetter western areas and two phytogeographic associations can be recognised (McVean, 1964).

In the east, the pine woodland understorey is composed mainly of *Vaccinium myrtillus* and *V. vitis-idaea* with some *Calluna vulgaris* under a dense canopy. Under a more open woodland canopy tall *Juniperus communis* may occur, with an increase in the *Calluna vulgaris* cover and a reduction in the proportion of *Vaccinium myrtillus* (Birks, 1977).

This eastern pine woodland is similar to the Pinewood-*Vaccinium*-moss association described by McVean and Ratcliffe (1962) which is characteristic of moderately dense pinewood throughout the Central and Northern Highlands. The association consists of *Pinus sylvestris, Vaccinium myrtillus, V. vitis-idaea, Calluna vulgaris* and *Hylocomium splendens. Betula pubescens* and *Sorbus aucuparia* may form a small proportion of the tree canopy (McVean, 1964). The mosses tend to be more frequent under denser pinewood canopies and the *Vaccinium* species dominate under canopies of average density. The association is found

from sea-level up to over 475m OD (McVean and Ratcliffe, 1962), forming extensive areas of forest in the east but only localised patches in the west.

In the west *Juniperus communis* is more common in the pine woodlands, with *Calluna vulgaris* and *Sphagnum* species frequent in the understorey. In both the western and the eastern pinewoods *Betula verrucosa* and *Sorbus aucuparia* may occur in the canopy. Where birchwoods occur, sometimes on the more fertile soils or where pine has been cleared, the understorey is often more herb rich (with *Potentilla erecta, Oxalis acetosella, Melampyrum pratense* and *Anthoxanthum odoratum*). Where oak occurs is it usually at lower altitudes in sheltered locations (McVean and Ratcliffe, 1962).

The second association, the Pinewood *Vaccinium-Calluna* association of McVean and Ratcliffe (1962) is characteristic of the more open pine forest and pine-birch mixtures. It differs from the Pinewood-*Vaccinium*-moss association in being dominated by tall *Calluna vulgaris*, *Vaccinium myrtillus* and deep *Sphagnum* tussocks. A greater variety of species is often found in the canopy but *Juniperus communis* is the characteristic tall shrub, and is often abundant in some of the central and eastern forests (McVean, 1964). This association is found from sea-level to over 300m in the west and from just under 300m to 600m in the Eastern Highlands where it tends to replace the Pinewood-*Vaccinium*-moss association with increasing altitude (McVean and Ratcliffe, 1962). The light intensity at ground level is one-third to one-fifth full daylight for this association compared to one-sixth for the Pinewood-*Vaccinium*-moss association. Therefore this association is characterised by an increased abundance of *Calluna vulgaris* and tussocks of *Sphagnum* as more light reaches the forest floor.

The birch dominated forest which would cover most of northern Scotland and the Western Isles is dominated by *Betula pubescens* ssp. *odorata* with *Corylus avellana* on the more inaccessible locations (Birks, 1977). The understorey would be similar to the oak and birchwoods of south and west Scotland.

McVean (1964) divides the birchwoods into two associations but they tend to grade into one another. The *Vaccinium*-rich birchwood association is dominated by *Betula pubescens* and the woodland floor is dominated by *Vaccinium myrtillus,* mosses, *Pteridium aquilinum* and some *Vaccinium vitis-idaea*. *Juniperus communis* and *Corylus avellana* may be abundant. Oak (*Quercus petraea* or *Q. robur*) can replace birch as the dominant tree up to about 275m in the southern and east-central Highlands and 150m in the west. *Sorbus aucuparia* may be common. The birchwood association can be distinguished from the pinewood associations by the absence of, amongst other species, *Corylus avellana.*

The second birchwood association, the herb-rich birch and oakwood association, is common to birchwoods and to the poorer stands of oak which typically make up the Highland oakwoods. This association is characterised by the virtual absence of *Vaccinium* species and the increase in (amongst others) *Ranunculus* spp, and grasses.

The two birchwood associations are found throughout Scotland from sea-level to almost 610m. Above the tree-line *Vaccinium* is more frequent and can be regarded as the treeless facies of the *Vaccinium*-rich association.

The two localities under investigation in this study are Gleann Einich in the Cairngorms, which lies well within the predicted potential zone of "predominantly pine forest with some birch and oak". The area is adjacent to a zone of "predominantly oak forest with birch" to the south and west. Beinn Dearg, the other study area, lies towards the predicted potential northern limit of pine forest, almost in the zone of "predominant birch forest" (McVean and Ratcliffe, 1962).

3.3 TREE-LINE PHYSIOLOGY AND ECOLOGY

The limit of the climatic tolerance of trees, whether this be a geographical limit or an altitudinal limit, is expressed in standing vegetation by a change from closed forest to dwarf shrubs. This ecotone is usually referred to as a tree-line. The tree-line varies geographically, but the altitudinal limit is generally coincident with the 10°C summer isotherm (Daubenmire, 1954) which is similar to the temperature conditions for the northern latitudinal tree-line (Kullman, 1979). However, most physiological studies have emphasized the importance of winter conditions in limiting tree growth near its northern or altitudinal limit (Grace and Norton, 1990). Winter browning or frost drought causes the needles of coniferous trees to desiccate during the late winter or early spring leading to foliage death (Wardle, 1974; Tranquillini, 1979).

The altitudinal tree-line may be represented by a sharp transition from closed forest to a treeless alpine zone or gradually over a broad transition zone (Tranquillini, 1979). Where the tree-line occurs over a transition zone it has three main zones:

1. *Forest line or forest limit* (timberline in the United States) - the upper limit of tall, erect trees growing at normal forest densities.
2. *Tree-line or tree-limit* - the limit at which individuals grow as recognisable trees (>2m).
3. *Tree-species line or Krummolz limit* - higher altitudes where trees can survive, but are very deformed, and usually prostrate.

The distinction between these zones is not always clearly defined and the second and third zones can often occur at the same limit. Above the forest line or limit the zone up to the limit of the Krummolz is known as the Kampfzone.

There is some debate as to whether the broad transition zone is a natural condition with isolated trees surviving above the forest limit but suffering from winter damage (e.g. Frankauser, 1901) or whether the sharp transition zone is natural as where one tree can exist above the forest limit, the forest should be able to grow up to this higher limit (e.g. Schiechtl, 1966). So the broad transition zone may be a result of human interference (fire, grazing, and felling) or an expression of a dynamic non-equilibrium situation.

However, the different types of tree-lines may be partly species dependent. Walter (1968) concluded that in general, shade-tolerant species tend to form sharp timberlines, while light-demanding species tend to produce open stands near timberline with a wide transition zone. Topography is also an important factor as shown by the mosaic pattern of trees at the timberline on the eastern slopes of the Pacific Mountains in North America which appears to be linked to the uneven distribution of snow cover. Trees can only survive on the areas of raised ground with early snow-melt (Walter, 1971/1972).

In Scotland, due to the decreasing mean July and January temperatures northwards and increasing wind speed and oceanicity westwards, the altitudinal vegetation zone boundaries decrease towards the northwest and north of Scotland. The potential tree-line varies from above 793m OD in parts of the Cairngorms to c.520 OD in the Northwest Highlands (Birks, 1988).

The remaining pinewoods in Scotland today are generally on north facing aspects (Steven and Carlisle, 1959), the less favourable climatic conditions increasing the competitive power of pine against birch. This is also the case in the altitudinal limit of both these species. Pine forms the upper tree-line in the Eastern Highlands, whereas it is often mixed with birch in the Northwestern Highlands. Birch is also sometimes found to form the upper tree-line above pine, as in Glen Affric. On the whole pine dominates under less favourable and more continental climates (Stephen and Carlisle, 1959) and mixed pine/birch woodlands are more common in the west.

Grace and Norton (1990) assessed the influence of climatic factors on the growth of *Pinus sylvestris* by investigating trees along an altitudinal gradient up to the natural tree-line on Creag Fhiachlach in the Cairngorms. The correlation between ring-width and climatic data showed that temperature is much more important than rainfall, and that the January and February temperature is often just as important, and often more important, than summer

(July-August) temperatures. Grace and Norton suggest this is related to the winter browning or frost damage (mentioned above), due to imperfect cuticle development during the summer months. However, Grace and Norton (1992), also observed that no difference in cuticle thickness could be detected from samples of *Pinus sylvestris* from different altitudes. They suggest that physical damage at the tree-line is likely to be caused by blown particles of soil and ice.

Pears (1967, 1988) surveyed *Pinus sylvestris* seedling establishment above the tree-line on Creag an Leth-choin in the Cairngorm Mountains from an altitude of 550m to 915m OD. He assessed the relative factors which might limit the growth of pine at high altitudes and concludes that strong wind exposure alone would probably be sufficient to prevent any natural re-advance of the forest (Pears, 1967) since exposure to persistent strong wind would greatly increase water deficits in the tissues of the tree seedlings through increased evaporation and transpiration. Soils and competition from other vegetation are not considered to be important factors. Pears (1988) repeated the survey of the pine seedlings 22 years later (Pears, 1988) and observed that the number of seedlings recorded and the pattern of distribution and of damage were similar in both surveys. Pine seedlings were rarely found in very wet sites or amongst tall, extensive stands of heather but most readily became established on well drained slopes where the prevailing vegetation was composed of low, wind-clipped vegetation (heather and other shrubs) and bare mineral grit patches.

3.4 ALTITUDINAL ZONATION OF VEGETATION IN NORTHERN SCOTLAND

Tansley (1939) outlines the upland and mountain zonation of vegetation types above the potential tree-line and describes it as the arctic-alpine zone . He further subdivided this zone into two further zones known as the arctic-alpine zone (grassland and heath associations) and the upper arctic-alpine zone (mainly *Rhacomitrium* heath association, the moss-lichen association on mountain top detritus and snow-patch communities). The lower limit of the arctic alpine zone was placed at 612m in the central Highlands and was shown to descend to almost sea-level in the west. However, this was a rather broad study and it was not until 1948 that Watt and Jones produced a detailed study of upland plant communities in relation to the prevailing environment conditions (Watt and Jones, 1948). They distinguished four zones above the present tree-line, the *Calluna* zone, the *Empetrum-Vaccinium* zone, the *Juncus* zone, and snow-patch vegetation.

Poore and McVean (1957) produced an altitudinal zonation scheme of the Scottish highlands base on the arrangement of floristic noda in ecological series. The forest limit (if realised) is largely determined by exposure and would be expected to show marked local altitudinal variation (for example reaching higher than average levels in sheltered localities). Using Scandinavian terminology they describe the zones above the forest limit as:

i) MIDDLE ALPINE - Grass communities and grass-like hemicryptophytes such as *Juncus trifidus, Festuca vivipara, Luzula spicata, Deschampsia flexuosa* and *Carex bigelowii* (*c.*1,160m to 1,215m in the Cairngorms and *c.*1,065m in Breadalbane, just south of Rannoch Moor) (but altitude depends on exposure)

ii) LOW ALPINE - Moss zone with dwarf shrubs: *Rhacomitrium* heaths, *Nardus* grassland. *Empetrum, Vaccinium* communities. Dwarf scrub zone: Ericoid dwarf shrub heaths. Some willow, juniper and dwarf birch scrub (*c.*690 to 750m in the East and Central Highlands and about *c.*91 to 135m in the west).

iii) SUB-ALPINE - Birch scrub in the West and Central Highlands and in the North, predominantly birchwoods and juniper scrub.

The sub-alpine and forest zones can be described as equivalent to a lower sub-montane zone and the lower and middle alpine zones as equivalent to a montane zone (Brown *et al.*, 1993a).

Poore and McVean (1957) highlight the main differences between the altitudinal zonation of vegetation communities in the Cairngorms and Northwest Scotland. In the Northwest the *Nardus* and *Carex* snow beds are replaced by hypnoid moss heaths, and are characterised by the presence of species-rich moss heaths, the association of *Nardus* with the *Rhacomitrium* heaths, and the disappearance of the snow-bed communities below the potential tree-line.

McVean and Ratcliffe (1962) outlined the regional trends in vegetation distribution in Scotland but were unable to describe them in detail because there had been no systematic survey of upland plant communities.

Ratcliffe and Thompson (1988) provide an example of the affect of oceanicity and topography influence vegetation. Towards the east of Britain there is an increase in the percentage cover of *Calluna-Eriophorum vaginatum* bog and sub-montane *Calluna* heath, but an increase towards the west in the cover of *Scirpus cespitosus-Calluna, Molinia caerulea-Calluna* and *Scirpus-Myrica gale* vegetation.

Brown *et al.* (1993a, b) used a combination of McVean and Ratcliffe's phytosociological classification (1962) and the National Vegetation Classification (NVC) of Rodwell (1991a,1991b and 1992) to produce a new biogeographical classification of the Scottish Uplands. Using two-way indicator-species analysis, Brown *et al.* (1993a,b) identified nine geographical groups of sites, each defined by blocks of indicator communities. Beinn Dearg is placed in the "high, north-west Highland plateaux" and Gleann Einich in the "high, east

Highland plateaux". The two-way indicator-species analysis also classified sites by identifying blocks of communities with a similar distribution across all sites within the group. Significantly, the blocks tend to bring together communities with a similar range of altitude as well as similar geographical distribution. The blocks were subsequently grouped into three altitudinal zones - i) High altitude montane vegetation, ii) Low altitude montane vegetation, and iii) Upland, sub-montane vegetation; the NVC communities and sub-communities were placed in one of these zones. Brown *et al.* (1993b) were then able to assign "constancy" variables to each of plant communities for all of the nine geographical groups. The results showed that the Scottish uplands are mostly sub-montane and dominated by grasslands, heathlands and mires of acid soils with a range of semi-natural montane communities on the higher ground. The work largely supports and supplements the earlier work of Ratcliffe (1977). The strong east-west contrasts (as described by Poore and McVean, 1957) dominate the geographical groups but the north-south contrast (due to temperature lapse) is partly obscured by the uneven distribution of high ground and different soil types.

3.4.1 POTENTIAL FOR IDENTIFICATION OF ALTITUDINAL ZONATION OF PLANT COMMUNITIES USING POLLEN-STRATIGRAPHIC DATA

The potential for the identification of altitudinal zonation of plant communities based on pollen-stratigraphic data is limited by three factors:

i) the communities existing in Northern Scotland today may not be comparable with the communities existing in the past. This is demonstrated by comparison of the "potential woodland cover" and "existing woodland cover" maps produced by McVean & Ratcliffe (1962).

ii) the differentiation of pollen types indicative of a reduction of the density of woodland cover (such as some of the Ericaceae) and the difficulties associated with the identification of moss spores. However, *Calluna vulgaris,* the pollen grain of which is identifiable to species level, appears to be a common component of the more open woodland canopies.

iii) the differentiation of pollen and spore types typical of the zones above the tree-line (alpine and montane zones). For reasons outlined in Chapter 5, grasses and sedges are not distinguished beyond the family level, therefore limiting the assessment of the pollen-stratigraphic evidence for zonation of above the tree-line.

In broad terms, however, it should be possible to distinguish periods of relatively open and relatively dense woodland canopies based upon pollen-stratigraphic data, from above tree-line situations. This will be discussed further in Chapter 5.

3.5 MIRE ECOLOGY

Since one of the principal aims of this project is to assess and interpret the palaeoecological significance of pine macrofossils preserved within peat stratigraphies an outline of mire and bog ecology is presented in this section. The rationale for site selection will be outlined further in Chapter 5 (Methodology) but consideration is given in this section to the classification and characterisation of mire types, a description of the relevant peat-forming vegetation communities and peat stratigraphy.

3.5.1 INTRODUCTION

The two major types of bogs in Britain are raised mires and blanket mires (Moore and Bellamy, 1974) but alternative classifications and transitional types have been described (e.g. Goodwillie, 1980). This section will concentrate on the ecology of blanket mires but reference to raised mires will be made where appropriate.

Firstly, an explanation of the various terms used to describe wetland environments is necessary.

1. A *mire* is a wetland that supports a vegetation which is normally peat forming.
2. An *ombrotrophic mire* is a wetland than receives its nutrient supply directly from atmospheric precipitation.
3. *Bog* is a British colloquial term for ombrotrophic mires.
4. *Blanket mires* are areas where peat formation (paludification) is not confined to basins and lowland areas but spreads to sloping terrain (Lindsay, 1995).
5. *Blanket bogs* are the clearly ombrotrophic parts of a peat-dominated landscape (Moen, 1985).

3.5.2 CLASSIFICATION OF MIRE VEGETATION COMMUNITIES

The principal feature of mire vegetation is the dominance of acidophilous plants such as *Sphagnum* spp., *Erica tetralix* and *Eriophorum augustifolium.* Drier parts of the mire surface are characterised by a greater abundance of vascular plants such as *Calluna vulgaris, Eriophorum vaginatum* and *Scirpus cespitosus.* Mire vegetation communities have been described by a number of authors (e.g. McVean and Ratcliffe, 1962; Ratcliffe, 1964; Good and Ratcliffe, 1977; Lindsay *et al.,* 1985; Rodwell, 1991b) and a summary will be presented here.

Table 3.1 summaries the ombrotrophic topographic mire microforms and the typical vegetation stands found associated with these microforms (adapted from Sjörs, 1948; Lindsay *et al.,* 1988; Lindsay, 1995 and Rodwell, 1991b). Various combinations of these

Table 3.1. Summary of mire microforms and vegetation communities (based on Lindsay 1995, Rodwell 1991b)

ZONES	STRUCTURAL MICROFORM	DOMINANT VEGETATION STANDS
TERRESTRIAL ZONES (T)		
T1	**Low ridge** - generally 1-10cm above above water table	*Sphagnum cuspidatum, Rhynchospora alba, Scirpus cespitosum* , (*Eriophorum vaginatum, Trichophorum cespitosum* and dwarf shrubs on damaged ridge)
T2	**High ridge** - generally 10-20cm above mean water table	*S. magellanicum, S papillosum, Erica tetralix, Eriophorum vaginatum, Vaccinium oxycoccus, Calluna vulgaris, Empetrum nigrum*
T3	**Hummock** - highest microform, generally 20cm to 1m above mean water table, always bryophyte formed	*Sphagnum* hummocks, *Racomitrium* hummocks
T4	**Peat hagg** - associated with erosion, 1-2m above mean water table	*Calluna* /mixed dwarf shrubs, *Racomitrium,* hypnoid mosses, *Cladonia*
T5	**Peat mound** - 1-3m above mean water table, occurs only in Shetlan, Caithness, Sutherland & Outer Hebrides	*Racomitrium,* Hypnoid mosses, *Calluna/Empetrum*
AQUATIC ZONES (A)		
A1	*Sphagnum* **hollow** - 0-10cm below mean water table	Dense *Sphagnum cuspidatum* with other *Sphagnum* spp., *Carex curta* and *Eleocharis multicaulis*
A2	**Mud-bottom hollow** - 5-20cm below mean water table	*Eriophorum augustifolium, Rhynchospora alba, R fusca, Carex limosa, Drosera intermedia, Molinia spp.* and some aquatic *Sphagna.*
A3	**Drought sensitive pool** - 20-50cm below mean table, subject to drying out during droughts	*Menyanthes trifoliata, Sphagnum auriculatum* , *S. cuspidatum* & *S. auriculatum*
A4	**Permanent pool** - area of open water, 1-4m deep	*Sphagnum* spp., *Menyanthes trifoliata*
TA2	**Erosion gullies** - resembling mud-bottom hollows but with flowing water	*Sphagnum cuspidatum, S. tenellum, Trichophorum, Eriophorum augustifolium*

microforms can occur within one mire system, and there is considerable variability within and between sites. In addition, where the climate is particularly wet, as in Northwest Scotland, the form and distribution of these microforms may become very complex. However, for the purpose of this investigation, where multi-proxy data such as the degree of humification, the fossil pollen assemblages and fungal and algal remains are interpreted in parallel, an appreciation of the local variation of the mire surface ecology is necessary.

3.5.3 TYPES OF BLANKET MIRES

The timing of the initiation and the spatial and temporal patterns of blanket peat development are not yet fully understood, principally because of the wide number of variables associated with peat formation (e.g. topography, hydrology, climate, pedology) and the large number of radiocarbon age estimates a comprehensive investigation would require. Blanket peat initiation will be discussed further in Chapter 8 but the generally accepted hypothesis for its development is that peat spreads outwards from "initiation foci" located in basins, lowland and plateau areas (e.g. Edwards and Hirons, 1982; Chambers, 1984; Moore *et al.,* 1984 and Tallis, 1991). The basin peats are often characterised by the presence of "fen" communities at the base of the profile (corresponding to terrestrialisation) and valleyside peats usually form by direct paludification (peat formation directly on the minerogenic substrate).

Based on topography and hydromophology, Lindsay (1995) divides blanket mires into six sub-categories (watershed mire, valleyside mire, spur mire, saddle mire, eccentric mire and unconfined raised bog units) but stresses that the classes are not absolute and that some mires may exhibit characteristics of more than one type. However, the divisions form a useful tool for the categorisation of sites investigated here, and provide a system for which the sensitivity of certain site types for recording humification changes can be tested (*sensu* Chambers, 1984). These divisions are:

i) Watershed mire

On plateaux and ridges where the ground slopes away on all sides. Since the only source of water to this type of mire is directly from precipitation, watershed mires are clearly ombrotrophic.

ii) Valleyside mire

On gently sloping or almost level ground, where the downslope margin is bounded by a river or water body and the upslope margins may be influenced from water seepage from the slope above. The mire often has its crown close to the upslope margin. If a single mound of mineral ground bounded on all sides by streams, is covered by peat which is both of watershed and valleyside mire types then this is categorised as a watershed/valleyside mire type.

iii) Spur mire

On broad spurs where the lower edge of the mire is not associated with a river or water body but is delimited by a steepening slope. The upslope margins may be influenced by seepage water from the slope above.

iv) Saddle mire

On depressions (cols) between two higher slopes which may be a source of water seepage to the mire. The mire is largely ombrotrophic if the adjacent higher ground slopes gradually upwards from the col. The downslope margins are at right angles to the upslope margins, and the downslope margins are bounded by increasing steep slopes.

v) Eccentric mire

On slopes where the peat forms a dome and where at least one axis slopes continuously from an upslope edge, corresponding to the highest part of the mire, to a downslope limit. The surface of the mire is intensively patterned.

vi) Unconfined raised bog units

Where a blanket mire complex forms a dome of peat accumulation which is not confined by the contours of the underlying terrain.

3.5.4 PEAT STRATIGRAPHY AND THE PROCESS OF HUMIFICATION

Ingram (1978, 1983), Clymo (1978, 1984) and others have emphasised the differentiation of bog peat stratigraphy into two zones or layers. An upper 'active layer' or acrotelm (usually 25-30cm deep and at least intermittently aerobic) overlies the permanently waterlogged catotelm which generally occupies most of the depth of the peat. The boundary between these two layers is often not sharp and Ivanov (1981) defines it as lying at the mean minimum level of the water table in summer. The breakdown and decomposition of vegetative matter (humification) takes place in the acrotelm and fluctuations in the water table can therefore greatly influence the degree of humification during peat formation. The acrotelm contains vertical stem structures which aid the lateral water flow which has shown to be up 1,000 times greater than the movement of water in the catotelm (Ingram and Bragg, 1984). Water exchange between the acrotelm and catotelm only takes place very slowly (Lindsay, 1995). However, the catotelm is not entirely inert, in terms of biological and chemical activity, as Clymo (1984) has shown, but processes in the catotelm are less diverse, and any activity takes place much more slowly.

Therefore, most of the humification of the peat matrix occurs in the upper aerated layers (acrotelm) of the profile. Decomposition rates increase when the mire surface becomes dry, (resulting from periods of drought, lower precipitation:evaporation ratios, a change in the

hydrology of the mire complex, or due to the accumulation of the mire surface above the water table, *cf.* Aaby, 1976). The longer the period of a lower water table the higher the degree of humification of the upper layers. In this respect the degree of humification might be considered as a factor of "mean residence time" with the acrotelm. Clymo (1965) stresses the importance of the precipitation:evaporation ratio in determining the length of time decaying plant material spends in the aerobic zone before reaching the sulphide (catotelm) zone. Therefore, the relationship between climate and mean residence time in the acrotelm is a critical link for any climate change interpretation based on humification data.

The changes observable in humification of peat stratigraphy have long been appreciated as a potential source of proxy climate information. It is generally agreed that peat with well preserved plant fragments formed during periods when the climate was cooler or wetter or both, and that peat with highly humified plant remains formed when the climate was warmer or drier or both (Rowell and Turner, 1985). The change from a relatively well-humified, dark peat matrix, rich in *Calluna* remains, to a relatively poorly humified, light-coloured *Sphagnum* peat is known as a Recurrence Surface (Barber, 1982). Godwin (1946) adopted the term following Granlund's (1932) suggestion and they were thought to represent peat formation during periods of climatic deterioration. The most pronounced Recurrence Surface is known as the Grenzhorizont and is recognised in many bogs across Northwest Europe. However, radiocarbon analyses of this main humification change have revealed a wide range of age estimates for the Grenzhorizont. For example, Schneekloth (1965) showed a 1,100 year age range from within one mire system but Barber (1982) suggests that the asynchroneity of age estimates for the Grenzhorizont may be because the investigations largely used borehole samples and the horizons dated may not have been from the same stratigraphic units (cf. Blackford, 1993). Although subsequently, Haslam (1987) demonstrated a wide range of radiocarbon dates at sites between Ireland and Poland for the Recurrence Surface thought to represent the Grenzhorizont, a large majority of peat stratigraphic investigations show evidence for a shift to wetter (and/or cooler) conditions between *c.*2,800 and 2,200 BP (Blackford, 1993).

The growth of peat between Recurrence Surfaces had been thought to follow a cycle of hummock and hollow succession (cf. Oswald, 1923, 1950). The basis of this theory is that the surface of a mire system is composed of a mosaic of hummocks and hollows. Vegetation growth on hummocks ceased due to dryness while the vegetation in the surrounding hollows (usually dominated by *Sphagnum* species) continue to grow and eventually overtop the hummocks. The former hummocks therefore become hollows and *vice versa*. The process repeats and the mire surface accumulates. However, the stratigraphic evidence for this process was not convincing (Walker and Walker, 1961) and Barber, from his investigations of Bolton Fell Moss in Cumbria (Barber, 1981) was able to

demonstrate that no cyclic alternation of hummocks and hollows had occurred for at least 2,500 years. However, an important conclusion reached by Barber was that there is a clear relationship between *Sphagnum* species change, peat type, degree of humification and climate change.

Peat profiles from raised mires and watershed mires are particularly suited to humification analyses since they receive water directly from precipitation which eliminates the complexities induced by water entering the mire complex through seepage and run-off from higher ground. Therefore, the humification signal from raised and watershed mires is more closely linked to the prevailing climate at the time of peat formation (Chambers, 1984), but the additional factors outlined above still need to be considered. An investigation of the degree of humification from peat profiles from valleyside mires, spur mires and saddle mires are potentially valuable, if the affect of site topography is considered. Similarly, evidence for humification changes from a single mire profile may reflect local changes in site hydrology (such as a small-scale local events relating to changes in drainage patterns) rather than reflect large-scale events affecting the whole system (Moore, 1986).

However, if several profiles are investigated from within an area (even if the sites are different mire types) and there is evidence from two or more of the sites for a significant synchronous shift in the degree of humification, this is likely to reflect a response to a regional climatic change, operating through changes in the depth and/or residence time of the peat accumulating within the acrotelm, at the local scale.

Early investigations of peat humification include the work by Granlund (1932) who estimated the rate of peat formation in a raised bog on the basis of archaeological objects found within the peat profile. He suggested that strongly humified peat formed during periods of relatively low precipitation when the upper peat layers were more aerated which resulted in a slower peat growth rate. However, this hypothesis could not be tested by independent methods until the advent of radiocarbon dating. Radiocarbon dating led to a number of investigations being carried out into the relationship between the degree of peat humification and peat accumulation rates in ombrotrophic mires. Some of the work supported Granlund's conclusion (e.g. Tolonen, 1973) but other investigations found no clear correlation between the degree of humification and rate of peat accumulation (e.g. Aaby and Tauber, 1975, discussed below).

Early methods of assessing the degree of humification include that devised by Troels-Smith (1955) who used a five-class scale to describe the colour of the liquid extracted from squeezed peat. Von Post's (1924) 10-point scale was based on the texture, physical deterioration and colour of the peat (plus the colour and texture when squeezed), in particular

the state of the *Sphagna* leaves (which makes the scheme rather difficult to use in the absence of *Sphagnum*). Other methods include an assessment of the colour of freshly exposed peat as an indication of humification (Casparie, 1972), and Dickinson's (1975) assessment of the relative disintegration of *Sphagnum* remains.

The disadvantage of the methods described above is that there is an element of subjectivity in the assessment, depending on the experience of the observer. Less subjective methods include a measurement of the fibre content of the peat (Levesque and Mathur, 1979) and the analysis of humic acids extracted from peat. The latter, which was first developed by Overbeck (1947) and later modified by Bahnson (1968), measures the colorific value (crudely equivalent to the proportion of light transmitted through a liquid) of an alkaline extract of peat.

Aaby and Tauber (1975) adopted the same method to investigate a raised bog in Denmark. Supplementary analyses of the pollen stratigraphy, the frequency of two rhizopods (namely *Assulina* spp. and *Amphitrema flavum*, both indicators of relatively wet conditions) and the frequency of *Sphagnum* leaves, Aaby and Tauber showed a negative correlation between humidity during peat formation and degrees of humification. Using 59 radiocarbon dates from two peat sections growth rates between 0.16 and 0.80mm yr^{-1} were found. The relationship between peat growth rates and the degree of humification, however, is not so clear. The relatively high growth rates in the upper part of the peat section corresponded with a low degree of humification, while the opposite was found in the lower part. The growth rate of peat is a result of the balance between the net production at the mire surface, and the degree of decomposition plus secondary processes such as autocompaction, creep and anaerobic decomposition of the peat after submersion into the anaerobic zone. Therefore it is highly unlikely that a direct correlation between peat accumulation rates and degree of humification could be found. Aaby and Tauber (1975) conclude that autocompaction is an important factor affecting apparent growth rates, as shown by the higher compressibility of *Sphagnum cuspidatum* peat in comparison to peat formed in drier conditions (such as peat with a high proportion of dwarf shrubs).

Aaby (1976) investigated the degree of humification (together with rhizopod analyses) of a Danish raised bog and identified a statistically tested periodicity in shifts to phases of wetter peat formation (lower degree of humification) of 260 years over a period of 5,500 years. Aaby stressed that shifts from dark to light peat (i.e. decreasing humification) could indicate either higher precipitation or lower temperatures, or a combination of the two. However, a shift from light to dark peat (i.e. increasing humification) may reflect a change in the relative distance to the water table as peat accumulates. Therefore, Aaby ignored shifts to a higher degree of humification as indicators of climate change. Barber (1982) notes that if shifts

which occur close together from at least three bog profiles (as indicated by Aaby) are identified then the following (calibrated radiocarbon) dates of major change are highlighted: 450, 900, 1500, 1700, 2550, 3450 and 3950 years ago (approximately 350 BP, 950 BP, 1550 BP, 1750 BP, 2500 BP, 3300 BP uncalibrated).

Blackford and Chambers (1993) reviewed the methods for determining the degree of peat humification and concluded that the assessment of fibre content (Levesque and Mathur, 1979) and measurement of an alkali-extraction (devised by Bahnson, 1968, and subsequently adapted by Chambers, 1984, Rowell and Turner, 1985 and Blackford and Chambers, 1993) are the most suitable methods. The alkali extraction method is adopted for the analysis of the degree of humification in this thesis (see Chapter 5, Section 5.2.6) since it has been shown to produce reliable and replicable results (Blackford and Chambers, 1993). While previous studies have investigated the relationship between peat accumulation rates and the degree of humification, they have mostly been tested on lowland bogs and the method and approach remains to be tested from a series of peat profiles on a tight altitudinal transect.

Finally, reference should be made to the likely hydrological consequences of gully erosion of blanket peats and any affect they may have on the stratigraphic record. Many of the mires investigated for this study contain deep erosion gullies, and, as will be described later, these gullies often form the basis of excavation of the peat profile to produce a fresh section. On sloping ground the gullies often run nearly parallel to each other and are sparsely branched, whereas on flat ground there is an anastomosing system of branched gullies (Tallis, 1995). Tallis summarises the various suggestions for the origin of these gulley systems as (i) related to the drying of the mire surface following a natural cessation of peat growth (Clymo, 1984), (ii) the product of catastrophic termination of peat accumulation in an increasingly unstable system (Conway, 1954; Pearsall, 1956) and (iii) occurring on a damaged mire system following disruption of the surface by burning, ditching or pollution damage (Bower, 1962). Studies from a limited number of sites indicate a clustering of dates for the initiation of gullying between *c.*4,500 to 1500 BP, *c.*1200 to 900 BP and *c.*600 to 250 BP which Tallis (1995) suggests may be a result of clearance of hillslope forests in later prehistoric times, grazing pressures or may simply represent the natural break-up of unstable peat masses. The affect of gullying on the hydrology of a blanket mire system has been investigated by Stewart and Lance (1983) and they conclude that it results in enhanced drainage of the surface layers of the peat mass adjoining the gullies, up to a distance of about 5m from the gully edge. The likely affect of gullying on the degree of humification of the upper layers of peat profile should therefore be appreciated. In this investigation the affect may be minimal since the principal period of interest is usually below a depth of about 50cm from the mire surface).

CHAPTER 4.0 POLLEN ASSEMBLAGE-VEGETATION RELATIONSHIPS

This purpose of this chapter is to discuss some of the limitations of interpreting vegetation change from pollen stratigraphic data, and in particular for this investigation, pollen-stratigraphic data from peat deposits. Consideration will be given to the relative pollen productivity of plant taxa typical of Holocene vegetation in the Scottish Highlands, the representation in the fossil record and the problems associated with interpreting relative pollen stratigraphic data. Pollen concentration and influx diagrams are presented for each of the sites investigated for this study, and the potential of this type of pollen data for the reconstruction of vegetation communities is discussed. The final parts of this chapter will discuss the potential of pollen stratigraphy for reconstructing former woodland density variations, and changes in the altitudinal limit of pine. Finally, the criteria to be adopted to identify such changes will be presented.

4.1 POLLEN-STRATIGRAPHIC DATA FROM PEAT DEPOSITS

The pollen-stratigraphic data presented in this thesis are all from peat deposits (the rationale for which will be discussed in the following chapter) but it is important to highlight the distinctions between the mode of pollen recruitment and pollen preservation in peat substrates in comparison to lake sediments.

Pollen tends to be relatively well preserved in peat deposits and all transport to the site is aerial with minimal horizontal or vertical mixing of pollen after deposition (e.g. Birks and Birks, 1980). Any mixing which does occur is likely to be in the uppermost, surface layers of peat, but this is negligible once the peat matrix becomes compact (5-10 years in the case of *Sphagnum*, Clymo, 1973) and will not greatly affect the temporal interpretations under consideration here. The principal problem of interpreting pollen data from peat deposits is that the pollen spectra represent palynomorphs recruited both from the vegetation colonising the mire surface and the vegetation surrounding the mire. Although this is similarly the case for lake deposits, the aquatic pollen types can be easily distinguished from the terrestrial pollen being used to reconstruct past upland vegetation (Bradshaw, 1991).

Tauber's theoretical model of pollen source and recruitment to a small lake or mire within a wooded landscape (Tauber, 1965) proposes three major dispersal components: i) the trunk space component (pollen from within the forest which moves beneath the canopy), ii) the canopy component (pollen from both within the canopy itself and distal sources which moves above the canopy) and iii) the rain component (long-distance dispersal of pollen brought to earth by raindrops). Tauber's model is more suited to peat deposits since it assumes all pollen is derived from the atmosphere which is often not the case with lake sediments. Moore and Webb (1978) refer to an additional component, the local component, which represents *in situ* pollen production, which in the case of lakes is aquatic plants and for mires, the species colonising the mire surface. This is similar to the 'gravity component' proposed

by Jacobson and Bradshaw (1981). Moore *et al.* (1991), refer to a secondary component, that transported by water from the catchment surrounding the site.

The process of pollen recruitment to a site is therefore likely to be a complex combination of the components outlined above. Not only are there site specific factors affecting relative proportion of the pollen recruitment components, such as the size of the site area, but the pollen-stratigraphic data must reflect the dynamic changes of pollen recruitment to a site over time. For example, for mire sites, there may be stages when the surface is forested, and hence the trunk space component will be relatively important. If the tree canopy becomes more open, and there is an expansion of species more typical of a heathland environments on the mire surface, then presumably the canopy, rain and gravity component become more important (i.e. an increase in the regional pollen source, or far-travelled pollen). However, even in non-forested peatland environments, on-site pollen production has been shown to remain an important component of the pollen rain. Evans and Moore (1985) demonstrated a linear relationship between *Calluna* pollen frequencies in modern pollen samples and the abundance of *Calluna* within 1m of the sampling point.

The recruitment of pollen to a blanket mire site, as outlined above, is likely to be affected by the vegetation colonising the mire surface. As outlined above, pollen to such sites comes from the rainfall component (Cr), the canopy component (Cc) (regional pollen signal) and from the local mire plants (Cl) (Moore *et al.*, 1991). The first two components (Cr and Cc) are influenced by the local wind patterns, and Price and Moore (1984) observed a considerable variation in the representation of the canopy component (lowland coniferous trees) across an upland plateau site in southern Wales. Price and Moore (1984) stress that the geographic and topographical location of a mire must be taken into consideration when interpreting the pollen-stratigraphic evidence since this will affect the pollen catchment source area. This is obviously a key point for the sites selected in this study and consideration shall be given to the regional component of the pollen recruitment to each site.

A reconstruction of past plant populations from pollen data also requires consideration of the relative pollen productivity of the different species and the subsequent representation in the pollen stratigraphy. The quantification of the under- and over-representation of pollen of certain species was attempted by Iversen (1947), and Andersen (1970) demonstrated the correspondence between the pollen samples taken from single points in a forest floor in Denmark and the composition of the surrounding 20-30m. From these data Andersen calculated correction factors for pollen spectra within forests, where for example *Pinus* and *Betula* pollen are over-represented by a factor of four. Bradshaw (1981) and Heide and Bradshaw (1982) confirmed Andersen observations and subsequently Bradshaw (1988) demonstrated the good spatial resolution potential of small hollows within forested areas for recording local variations in vegetation. However, very little information is available of the

likely factors of over- and under-representation of pollen of species at high altitude and this will be discussed further in Section 4.4.

4.2 THE INTERPRETATION OF RELATIVE POLLEN DATA

The pollen diagrams presented in this study take the form of relative pollen diagrams (individual grains counted for specific taxon expressed as a percentage of the total terrestrial pollen sum) and pollen concentration and influx diagrams (which will be described in the following section).

The principal feature of the relative pollen diagram is the interdependency of the frequencies of the pollen taxa which make up the pollen sum. This problem is particularly severe if the local pollen taxa (such as *Calluna vulgaris* in the case of mires) are relatively profuse pollen producers, which causes a corresponding decrease in the other components of the sum (*cf.* Moore *et al.,* 1991). If, using the mire example, the local species (i.e. *Calluna*) are removed from the pollen sum, this may produce an over-representation of tree pollen types following a decline in woodland. Since woodland reconstruction is one of the principal aims of this investigation, an exclusion of the local pollen taxa may mask local changes in the density of the woodland canopy. Therefore the pollen sum adopted for this investigation is the total land pollen (TLP).

4.3 THE INTERPRETATION OF POLLEN CONCENTRATION AND INFLUX DATA

The inherent problem of interdependency of pollen taxa in relative pollen data may be partially resolved by a supplementary investigation of pollen concentration and influx values. Although pollen concentration and influx data can be used to examine more realistically the composition and abundance of past vegetation communities there is an element of higher data uncertainty.

Pollen concentration is estimated by adding *Lycopodium* tablets (Stockmarr, 1971) to a known volume of sediment and counting the exotic spores in routine pollen analysis (Birks and Birks, 1980). Pollen influx is subsequently calculated by dividing the pollen concentration values by the sediment deposition time (in years per cm), based on linear interpolation between the radiocarbon age estimates. The potential sources of error from this type of data stem from the precision of sediment volume measurements, the number of exotic spores in the *Lycopodium* tables and the counting of the spores (particularly for sites where *Lycopodium* pollen types are represented), and additionally for the influx data, the accuracy of the radiocarbon age estimates and the linear interpolation between these age estimates. In addition, depositional and post-deposition processes may influence the pollen concentration and influx values, such as heterogeneity in peat causing short-term variations in matrix accumulation rates (Aaby and Tauber, 1975) and autocompaction, leading to apparent increases in pollen concentration calculated on a volumetric basis.

On-site factors such as vegetation structure may also have an influence on the pollen concentration values. Dupont (1985) demonstrated that rough hummock vegetation traps pollen more efficiently than smooth *Sphagnum* hollows. In modern samples between 4,000 to 5,000 grains $cm^{-2} yr^{-1}$ were found on hummock peat (composed largely of *Calluna vulgaris* and *Eriophorum vaginatum*) compared to 2,000 to 4,000 grains $cm^{-2} yr^{-1}$ found in the shallow *Sphagnum* hollows. Dupont concludes that the figures represent the higher filtration efficiency of the hummock type vegetation, in filtering pollen from the air mass.

Following allowance for differential pollen production (Anderson, 1970), Aaby (1988) reduces the pollen influx values of hummock type vegetation by 30% to allow for Dupont's observation (1985) and notes the importance of cautious interpretation of influx data from ombrotropic mires.

Pollen concentration and influx data are further complicated by the observations of Iversen (1973) that an increase in arboreal pollen influx may not indicate an increase in the density of trees surrounding a site. Aaby (1988) observed a positive relationship between the level of cultural activity and arboreal pollen influx which he explains by structural changes in the forest vegetation. When the forest was relatively dense the arboreal pollen influx was low but forest clearing produces an open structured forest which enables a larger part of the tree's crown to flower. Aaby (1988) therefore concludes that arboreal pollen influx responds positively to increased cultural activities within forested regions.

As mentioned above, Aaby and Tauber (1975) note the problems of short-term variations in matrix accumulation rates (expressed as cm yr^{-1})and autocompaction as potential sources of error when calculating pollen concentration and influx data. Where Aaby (1988) found no obvious relationship between maximum pollen influx values and the degree of humification or macrofossil composition within the peat matrix, he assumes that any broad trends in arboreal influx values reflect general changes in annual pollen deposition. Although Rowell and Turner (1985) found no consistent relationship between the degree of humification and pollen concentration values this does not necessarily invalidate the observations of Aaby (1988) since the relationship may be site specific (such as dependent upon large shifts in the degree of humification or the type of vegetation forming the majority peat matrix).

The degree of humification of the peat matrix is also likely to be related to the proportion and taxonomic type of macrofossils which make up the measured volume and therefore affect pollen concentration values. If, for example, 50% of the peat matrix is composed of wood or shrub macrofossils the volume of sediment in which pollen is likely to be preserved is already reduced by half. Consequently, the pollen concentration will therefore be effectively doubled. It is likely, however, that such an increase in pollen concentration will be reflected by all taxa. If one species displays a trend significantly different to the pollen concentration

curves of other pollen taxa, then this may be reflect a real change in pollen influx to the site for that taxa. Therefore, the composition of the peat matrix should be considered when interpreting pollen concentration diagrams. However, there is a lack of information in published sources on this important implication for pollen concentration stratigraphic data.

Thirdly, and perhaps most importantly, is the affect of the degree of humification of the peat matrix on the pollen concentration and influx values. Under drier and/or warmer conditions the mire surface will be more aerated and subject to effective aerobic decomposition for longer than under colder and/or wetter conditions. Aerobic decomposition of the surface will therefore lead to a **slower** accumulation rate and in theory, even under a constant pollen rain, the effective pollen concentration values will increase. Between two radiocarbon measurements, this, possibly, short-term decrease in peat accumulation rates will not be identified and hence will similarly be reflected as an increase in pollen influx values. During wetter and/or colder conditions the vegetation at the surface will enter the anaerobic (catotelm) sooner and decomposition, or humification, will almost cease. So a decrease in humification should have the affect of decreasing the apparent pollen concentration and pollen accumulation rate. These mechanisms will be specifically tested against field and laboratory data in Chapters 5 and 6.

4.4 THE IDENTIFICATION OF TREE-LINE CHANGES FROM POLLEN-STRATIGRAPHIC EVIDENCE

Having considered the complications surrounding the reconstruction of past vegetation communities from pollen-stratigraphic data what is the potential for the identification of past changes in the tree-line from such data?

The pollen evidence for the Holocene history of the pine limit in Northern Fennoscandia is mainly based on pollen influx studies of lake sediment cores (e.g. Hyvärinen, 1976; Eronen and Hyvärinen, 1982). Comparison of core-top values (taken from small, closed lake basins) showed that recent or subrecent pine pollen accumulation rates were quite different at sites within and outside the present pine limit. Hyvärinen (1976) interpreted the high fossil pine pollen at sites now outside the present pine limit as indicating that pine had been locally present at these sites in the past.

Lamb (1985) suggests that the problem of studying the forest-tundra ecotone by pollen analysis is further complicated by the relatively high representation of tree pollen types beyond the limit of trees (particularly acute since tundra communities tend to be low pollen producers).

Investigations of modern pollen rain through a tree-line also suggest that tree pollen may be over-represented on mountain tops in relative pollen data. Hicks (1993), using pollen traps,

monitored the annual pollen rain within the major forest belts of Northern Finland. The traps on the open summit show a good representation of herbs and dwarf shrubs typical of tundra environments, but the pollen spectra was dominated by tree pollen. Hicks suggests that the long distance transported pollen is virtually all that is present on the mountain tops since the local plants produce very little pollen. Within the pine forest over 65% (total pollen) pine pollen was recorded. The more open the local vegetation, the greater the proportion of pollen is derived from outside the local area (Tauber, 1977; Prentice, 1985) but the pollen influx (cm^{-2} yr^{-1}) values showed that the highest annual pollen influx is recorded in the pine forest and the lowest on the bare mountain tops. Therefore annual pollen influx for each vegetation zone is also characteristic and should be included as part of the "pollen picture" (sensu Hicks, 1993).

However, as indicated in the previous section, the pollen concentration and influx data recorded from peat deposits is further complicated by the effect of the degree of breakdown of the peat matrix. If the degree of humification can be identified as a possible contributing factor to the pollen concentration values (as for example where high pollen concentration values correspond with a relatively high degree of humification) then this may aid the elucidation of the pollen signal.

Jennifer McConnell (personal communication) investigated the pollen rain on modern moss polsters from a transect through the contemporary tree-line at Creag Fhiachlach in the Cairngorms. She identified the ratio of *Pinus sylvestris*:*Calluna vulgaris* pollen representation as being indicative of the relative position of the tree-line. Samples from within the pine forest showed a ratio of >1 and samples from above the tree-line showed a ratio of <1.

4.5 CRITERIA TO BE ADOPTED FOR THE IDENTIFICATION OF TREE-LINE FLUCTUATIONS ON THE BASIS OF POLLEN-STRATIGRAPHIC DATA

Since one of the inherent characteristics of relative pollen stratigraphic data is the interdependency of the taxa which form the pollen sum, pollen concentration and influx data should also be assessed in parallel. In addition the degree of humification should be considered when intrepreting pollen concentration and influx data from peat deposits.

For high altitude sites, where the local vegetation communities may be relatively poor pollen producers, the long distance pollen signal may be over-represented. Since pollen concentration values often decrease with altitude, an estimation of the factor of over-representation in the relative pollen spectra might be gained from the concentration data (after consideration of the degree of humification of the matrix).

Therefore the key factors for the identification of the relative position of the tree-line from pollen stratigraphic data in Northern Scotland might be:

i) *Pinus sylvestris*:*Calluna vulgaris* pollen ratio (>1 = below tree-line and *vice versa*)
ii) High *Pinus* pollen concentration and influx values corresponding with high relative values
iii) High *Pinus* pollen concentration and influx values corresponding with a low degree of humification of the peat matrix
iv) Increase in pollen representation of taxa typical of vegetation found above the tree-line (e.g. *Empetrum* sp.)

CHAPTER 5.0 METHODOLOGY

Variations in pine woodland density and tree-lines may provide valuable palaeoclimatic information but Lowe (1991) identifies three possible sources of "noise" in the available data: i) data from atypical sites, where local changes may have little to do with sustained changes in regional climatic changes, ii) errors in dating and iii) failure to differentiate between "complacent" and "sensitive" records. Investigations of pollen-stratigraphic data from a number of spatially close sites along an altitudinal transect (such as that undertaken on Rannoch Moor by Ward *et al.* (1987)) provides a method for the identification of crucial altitudinal variations in woodland density. In this way, atypical sites might be distinguished and "complacent" versus "sensitive" records identified. Errors in dating can only be assessed by independent dating methods, such as tephrochronology, and since no tephra layers were identified in this investigation, this potential source of error must be taken into consideration, especially when small temporal variations are interpreted. As Lowe (1991) stresses, further studies similar to Ward *et al.* (1987) and Gear (1989) may provide comprehensive information on tree-line gradients and canopy variations in the Scottish Highlands during the Holocene.

To assess the altitudinal limits of pine trees during the Holocene at any single locality, an investigation should be undertaken of palaeobotanical records along a transect which crosses the upper limit of pine stump preservation. To assess the tree-line dynamics across northern Scotland as a whole, at least two transects are required, each from climatically contrasting locations. The palaeobotanical records can then be compared and evidence for synchronous changes in the upper limit of pine can then be assessed in terms of regional rather than local responses to climatic conditions.

The rationale and the techniques employed during the field and laboratory analyses generated by this project are outlined in this chapter.

5.1 FIELDWORK

5.1.2 RATIONALE FOR SITE SELECTION

As discussed in Chapters 2 and 3, a comparison of the present "potential" woodland cover of Scotland (McVean and Ratcliffe, 1962) and the location of sub-fossil pine stumps (Bennett, 1984) indicates a greater distribution of pine forest in the past. This, and other research, has suggested that pine was more widely dispersed and reached higher altitudes than modern-day pine woodland counter-parts. A major objective of this project was to test how precisely these former altitudinal limits can be reconstructed using palaeobotanical methods.

Several areas were chosen for reconnaissance surveys for the identification of suitable sampling transects. The principal criteria for transect selection were as follows:

i) transects should be obtained from the relatively "oceanic" Northwest Highlands and from the relatively "continental" Grampians to provide data from contrasting climatic contexts. Continentality is usually characterised by greater daily and annual thermal amplitude, lower relative humidity, lower and irregular precipitation and greater seasonality contrast (and *vice versa* for oceanicity).

ii) the transects should ideally be restricted to slopes with similar aspect and within single catchment systems, in order to reduce the "noise" effects that may result if sites have very different hydrological settings

iii) the transects should cross the expected, or previously reported, upper limit of the preservation of pine stumps.

Secondary criteria for site selection were:

iv) that published pollen diagrams from the area should exist, preferably from lake sequences, in order to allow direct comparisons with the results of this investigation from peat sequences

v) areas with extensive blanket peat cover at the required altitudes should be selected, in order that the study was not constrained by poor site selection opportunities

vi) sites should be reasonably accessible for employment of coring and other field methods.

5.1.3 RECONNAISSANCE SURVEYS

Reconnaissance surveys were undertaken of potential sampling transects in five main areas of northern Scotland. The field observations will be described in the following sections, the reasons for the final selection are given in Section 5.1.4. For locations see Figure 2.1.

5.1.3.1 GLEANN EINICH - THE CAIRNGORMS

As discussed in Chapter 2, Pears (1968, 1969) undertook an investigation of the postglacial tree-line variations in the Cairngorms, based on the evidence of pollen-stratigraphic and sub-fossil pine data. He identified a regional upper limit for the presence of pine stump layers at c.793m OD and although Pears' published pollen diagrams do not differentiate between the Ericaceae pollen types the data provide a reference for general trends in the vegetation history of the region. In addition, Birks (1975) published a radiocarbon dated pollen diagram

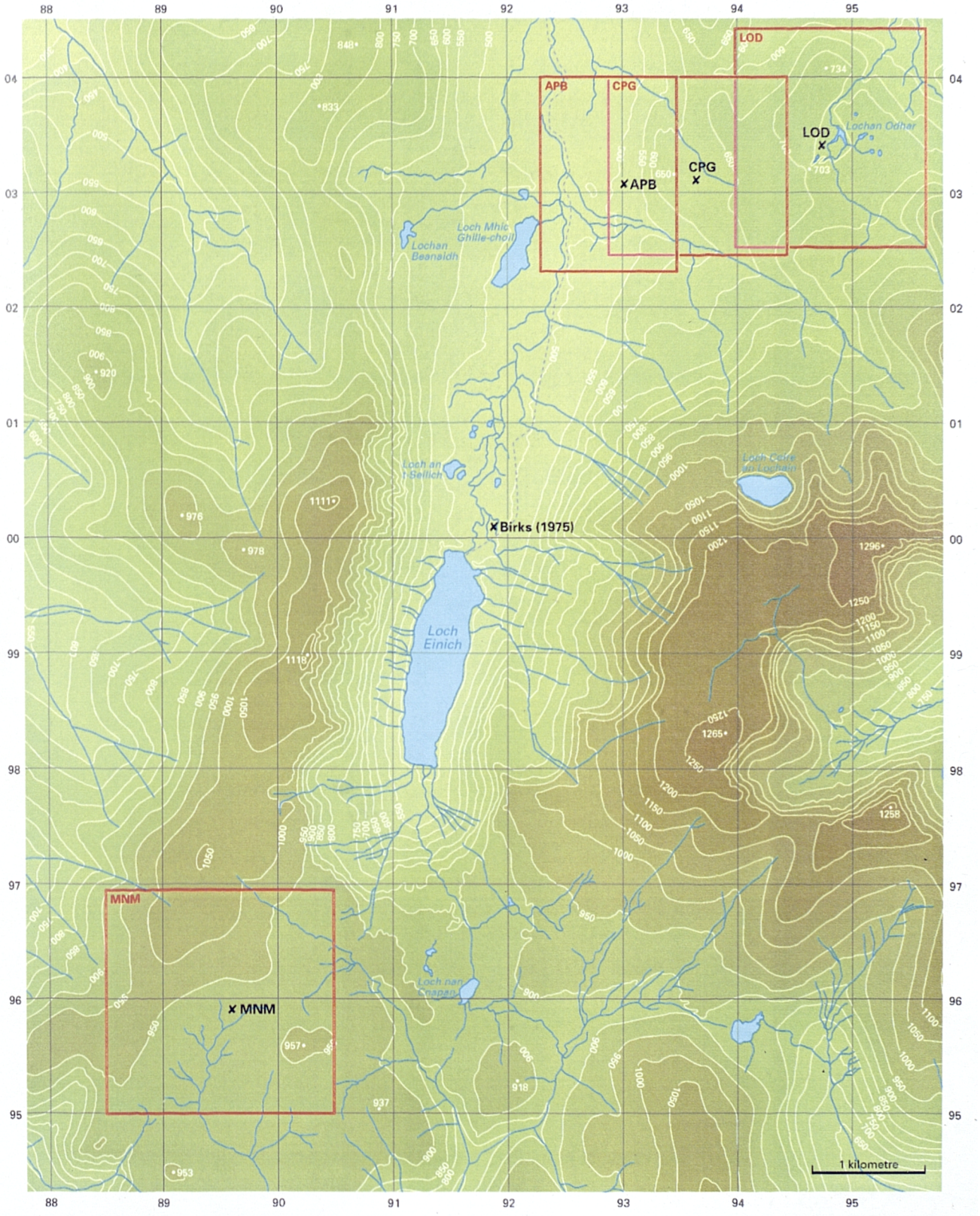


Figure 5.1:Gleann Einich – location of sample sites

Red boxes denote area covered by individual site location maps referred to later in the text

TABLE 5.1. SUMMARY CLIMATOLOGICAL DATA FOR THE CAIRNGORMS, BEINN DEARG AND GLENN AFFRIC REGIONS (TEMPERATURES REDUCED TO MEAN SEA-LEVEL)

THE CAIRNGORMS

Mean monthly air temperatures °C

January	July	Mean minimum	Mean maximum
2.5	14.0	-1.0	19.0-19.5

Precipitation/humidity/evapotranspiration

Mean annual rainfall (mm)		1000-1600
Coefficient of variability of annual rainfall		14-16%
Average number of rain-days		225
Relative humidity	January mean	<85%
Relative humidity	July mean	65%
Relative humidity	Mean annual value	75%
Potential evapotranspiration (mm)		350-400

BEINN DEARG REGION

Mean monthly air temperatures °C

January	July	Mean minimum	Mean maximum
3.0	13.5	0.0	17.5

Precipitation/humidity/evapotranspiration

Mean annual rainfall (mm)		Almost 1600mm
Coefficient of variability of annual rainfall		10-12%
Average number of rain-days		250
Relative humidity	January mean	<85%
Relative humidity	July mean	70-75%
Relative humidity	Mean annual value	75-80%
Potential evapotranspiration (mm)		350

GLEN AFFRIC REGION

Mean monthly air temperatures °C

January	July	Mean minimum	Mean maximum
3.0	13.5-14.0	0.0	17.5-18.0

Precipitation/humidity/evapotranspiration

Mean annual rainfall (mm)		Almost 1600mm
Coefficient of variability of annual rainfall		10-12%
Average number of rain-days		225-250
Relative humidity	January mean	<85%
Relative humidity	July mean	65-70%
Relative humidity	Mean annual value	75%
Potential evapotranspiration (mm)		350

Source: Goudie Brunsden (1994)

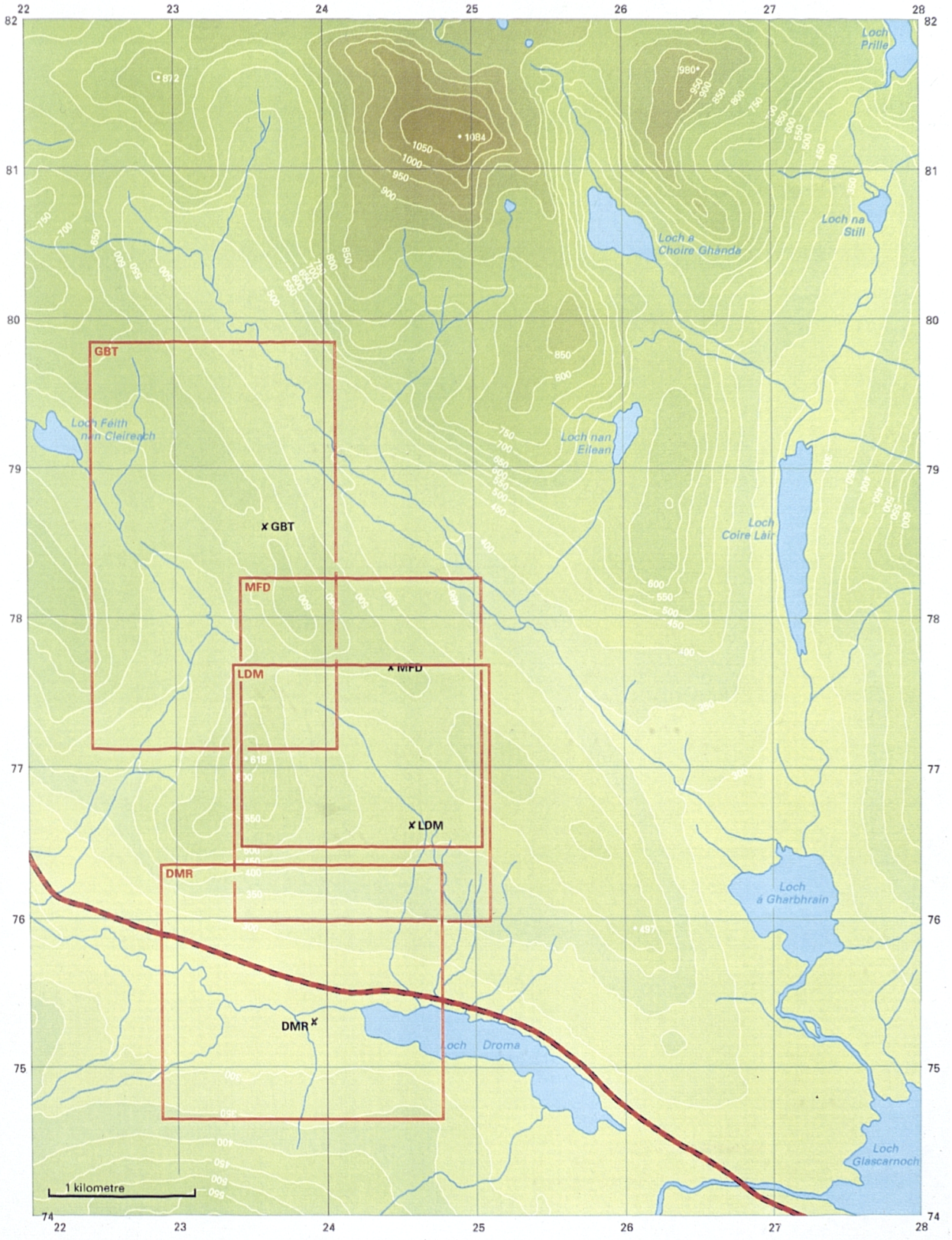


Figure 5.2:Beinn Dearg – location of sample sites

Red boxes denote area covered by individual site location maps referred to later in the text

(and sub-fossil pine and birch samples) from the head of Gleann Einich (see Figure 5.1 for location) and Dubois and Ferguson (1985) proposed a hydrological model based on their isotopic work on subfossil pine in the Cairngorms. The area therefore provided a suitable geographic framework for testing existing models of Holocene tree-line dynamics and hydrological change, using the novel mixture of analytical methods to be employed within the thesis.

Gleann Einich (see Figure 5.1) showed potential for extensive sampling since aerial photographs and the Ordnance Survey maps suggested there were extensive blanket peat covering an altitudinal range of c.500m to c.700m OD. Since isolated sub-fossil pine stumps have been located at altitudes up to 914m (Pears, 1968) additional sites at 800m OD and 900m OD would have been desirable. The only site located above 700m lies above the head of Gleann Einich on Moine Mhor at *c.*930m OD (Rob Stoneman, personal communication). Although this does not form part of a continuous transect with the lower sites, it does provide a high altitude, above the potential tree-line reference site. In this investigation, pine stumps were located to an altitude of *c.*700m OD in the region of Gleann Einich.

Climatological data for the Cairngorms is summarised in Table 5.1, and in comparison to the Beinn Dearg (below), in the Northwest Highlands, the Gleann Einich region experiences a relatively "continental" climate regime (i.e. greater daily and annual thermal amplitude, lower relative humidity, lower and irregular precipitation and greater seasonality contrast).

5.1.3.2 BEINN DEARG - NORTHWEST HIGHLANDS

Very extensive deep blanket peats are located from *c.*300m to 600m OD in a northwest-southeast trending valley near Beinn Dearg in the Northwest Highlands (Figure 5.2). A further deep peat sequence was located to the west of Loch Droma (at an altitude of *c.*270m OD).

Two lower peat sequences (*c.*270m and *c.*400m OD) contain birch macrofossils at the base of the deposit overlain by 2-3 layers of pine stumps interstratified within the peat. The upper limit of pine preservation in the local region appears to be *c.*500m OD, but no large pine stumps were found above *c.*490m OD. A peat sequence at *c.*600m OD in this locality contains birch macrofossils at the base of 2m of peat with no observable pine macrofossils. The two highest sequences (*c.*500m and 600m OD) are located on cols, and represent "water-shedding" sites (cf. Chambers, 1984) . These are ideal for humification analysis since the signal is thought to be closely related to climate change (Blackford and Chambers, 1993) and less influenced by the topographic factors such as water seepage from higher ground. Potential sampling sites were located *c.*270m OD and *c.*400m OD, *c.*500m OD and *c.*600m OD.

The climatological data for the Beinn Dearg region is summarised in Table 5.1. Although the figures represent mean values for a much greater area of the Northwest Highlands than just Beinn Dearg (and generally for the years 1941-70) a comparison of the Cairngorms data indicates that the Beinn Dearg region experiences a relatively more "oceanic" climate, i.e. less seasonal extremes, warmer winters, cooler summers and higher relative humidity. Therefore, assuming that the Beinn Dearg region was relatively more "oceanic" during the Holocene, this region should provide data representing a climatically contrasting context to the Cairngorms.

5.1.3.3 BEINN EIGHE - NORTHWEST HIGHLANDS (Figure 2.1)

The topography in this region is very different to that of the Beinn Dearg. Beinn Eighe has less extensive blanket peats and large areas of exposed bedrock (Torridonian sandstone and Cambrian quartzite). Suitable sampling sites were located up to 590m OD, with an apparent upper limit of pine stumps preservation at *c.*460m OD. The highest site observed has a deep peat sequence (approximately 1.9m) with only one single layer of small wood macrofossils (not identified). Peat profiles were sampled at *c.*230m OD, *c.*300m OD, *c.*380m OD (on the same hillside but with different aspects), and at *c.*590m OD. The region of Beinn Eighe proved to be of limited use for this project, however, because the sites recorded following reconnaissance do not lie along a constrained altitudinal transect.

Durno and McVean (1958) undertook an investigation of peat deposits from altitudes up to 570m in the Beinn Eighe Nature Reserve, but their pollen diagrams do not distinguish between the Ericaceae family which, as outlined earlier (Chapter 2), is considered important in the understanding of tree-line changes.

5.1.3.4 GLEN AFFRIC

Glen Affric (Figure 2.1) has fairly extensive blanket peat deposits with large pine stumps identified up to 530m. Potential sampling sites were located from 370m to 580m OD and as yet, there are no other Holocene pollen-stratigraphic data published from this part of Scotland. Table 5.1, however, indicates that the climate in the Glen Affric region neither contrasts significantly with the Cairngorms or the Northwest Highlands. In climatic terms, Beinn Dearg offers a greater contrast with the Cairngorms than the Glen Affric region. Therefore assuming that the same may have been true in the past, this is a good reason for choosing the Beinn Dearg region in preference to the Glen Affric region.

5.1.4 FINAL TRANSECT SELECTION

Two transects were selected for further investigation, Gleann Einich and Beinn Dearg. The rationale for their selection is outlined below.

5.1.4.1 GLEANN EINICH - THE CAIRNGORMS

Glean Einich was selected for further investigation for the following reasons:

i) As stated above, the climate data for the Cairngorms indicates that this part of the Scottish Highlands experiences a relatively "continental" climatic regime, with a greater degree of seasonality, higher summer temperatures, lower winter temperatures, and a lower mean annual rainfall. Not only is it important to compare the pollen stratigraphic-data for the history of pine during the Holocene from two contrasting climatic regimes (and therefore test the synchroneity of tree-line changes between these two areas), but the generally lower humidity of the Cairngorms enables a comparison of the relative the degree of humification of peat profiles from two contrasting areas, for comparable time periods.

ii) Pears' (1968, 1969) investigation of tree-line in the Cairngorms suggest that pine woodland reached a maximum altitude of *c.*793m during the Holocene. Radiocarbon dating indicated that the wood layers were asynchronous and could therefore not be assigned to particular climatic period (i.e. the Blytt-Sernander scheme). Further investigation is therefore required from this region to assess the local site topographical and hydrological factors controlling pine stump preservation. In addition, Pears' pollen diagrams are the only pollen-stratigraphic data available at altitudes above *c.*500m, but further detailed palynological investigation is required on a spatially close altitudinal transect to identify evidence for changes in the upper limit of pine (supplemented by radiocarbon dating).

iii) The most detailed previously published pollen diagram from the region is from the northern end Loch Einich at *c.*500m OD (Birks, 1975). She described a lower layer of pine stumps and an upper layer of birch stumps embedded in blanket peat and suggests that increased waterlogging led to the demise of pine at the site (although pine trees continued to grow on the valley sides). Radiocarbon dates from the peat profile are presented together with dates of pine and birch stumps interstratified within the profile, but no humification analyses were undertaken (the latter was assessed on the basis of lithostratigraphic analysis).

iv) Dubois and Ferguson (1985) investigated the climatic history of the Cairngorms using stable isotope analysis and radiocarbon dating of fossil pine stumps. On this basis they identified four periods of increased rainfall but Pears (1988b) cautioned against interpretation of the stable isotope data purely in terms of precipitation since site specific factors, such as density of woodland canopy, could equally cause high local values of relative humidity. An assessment of local mire surface conditions from

alternative proxy environmental indicators, such as the degree of humification and the representation of particular fungal and algal types, may provide further information regarding conditions favourable for the establishment and subsequent preservation of pine wood remains.

The reasons outlined above provide a regional stratigraphic framework with which further data can be evaluated with the use of additional proxy climatic and environmental indicators.

Additional reasons for further investigation of the Cairngorms were:

v) Some of the pioneering descriptions of the upland vegetation zones have been undertaken in the Cairngorms (e.g. Poore and McVean, 1957) and in particular Gleann Einich (e.g. McVean, 1963a). This provides a reference for the type of vegetation which can be found today above the tree-line and an increase in the frequency of one or more of these taxa in the pollen record may help in the understanding of past tree-line changes.

vi) Creag Fhiachlach, one of the few remaining natural tree-lines in Scotland, lies approximately 3km to the west of Gleann Einich and several investigations of the growth of pine at its upper limit have been published (e.g. Grace and Norton, 1990; James *et al.*, 1994) against which the data from this investigation can be compared (in particular the dendrochronological investigations).

vii) Three of the four potential sites identified are located on a relatively spatially "tight" transect on a west-facing slope. This reduces the affect of site specific factors might have on the altitudinal limit of pine growth, such as aspect or exposure when making inter-site comparisons of proxy climate signals derived from peat stratigraphies.

5.1.4.2 BEINN DEARG - THE NORTHWEST HIGHLANDS

Beinn Dearg was selected as the second of the transects for the following reasons:

i) In contrast to Gleann Einich, Beinn Dearg experiences a relatively "oceanic" climate (**see Table 5.1**), i.e. higher relative humidity, smaller diurnal and annual temperature ranges, which allows a comparison of the affect of a different climatic regime on the vegetation communities as indicated by pollen-stratigraphic data.

ii) The extensive blanket peat cover, with deep erosion gullies, enables a more precise identification of the upper limit of sub-fossil pine and birch.

iii) Two of the sites are saddle mire types (watershedding) and the other two are valleyside mire types (see Section 3.5.3 for definitions). This provides an opportunity to test the notion that the peat stratigraphy from watershedding blanket peat sites are more sensitive indicators to regional climatic change as indicated by the degree of humification (cf. Chambers, 1984; Blackford and Chambers, 1993).

5.1.5 FIELD SAMPLING METHODS

Following transect selection, potential sampling areas were identified at approximately 100m altitudinal intervals. Preliminary selection was based on investigation of peat exposures in existing erosion gullies to identify the deepest area of peat accumulation (and hence potentially providing a greater down-profile stratigraphic resolution) and subsequent probing of the immediate area with a narrow gouge auger.

Having identified potential sampling locations, each site was systematically probed (again using a narrow gouge auger) on a 5m grid system to assess the underlying sub-peat topography and to identify the deepest peat accumulation for that site.

It was decided to use monolith tins (as opposed to an auger or corer) to sample the profiles for the following reasons:

i) Excavation of a profile enables a detailed study of the peat stratigraphy, and in particular the relative stratigraphic position of pine and birch macrofossils.
ii) During the probing of the site area, the use of the auger was often inhibited by the presence of interstratified, impenetrable, wood remains.
iii) Monolith tins sample a large volume of undisturbed peat (110cm by 10cm by 5cm minimum) which reduces the thickness (i.e. depth) of peat required to be sampled for radiocarbon dating and hence increases the accuracy of the age estimate.
iv) Sub-samples would also be required for humification analyses and therefore, the larger peat volume provided by monolith tins would be required.
v) Disturbance and contamination are minimised.

Having identified the deepest peat accumulation for each site, the nearest existing erosion gully was excavated to this point (where possible) to provide a fresh peat profile.

Each section profile was described in the following terms:

i) Position of macrofossils within the stratigraphy (where identification in the field was not possible samples were collected for identification in the laboratory)
ii) Changes in the degree of humification of the peat matrix (assessed on the 10 point scheme devised by Von Post (1924))
iii) Colour (Munsell colour charts were found to be of little use since the exposed peat takes time to stabilise its colour when the profiles tended to all exhibit the same, or very close, numbers)
iv) Stratigraphic contacts and textural properties
v) Minerogenic substrate

Following a description of the section, the monolith tins (110cm x 10cm x 5cm) were placed where a representative profile could be sampled, away from areas where there was evidence

of erosion (such as water pipes) and between large sub-fossils of pine and birch. As much of the profile was sampled as possible, but the basal sediments at some of the sites proved to be unconsolidated and friable, making sampling difficult. The monolith tins were then wrapped in thick plastic and sealed. Pine and birch macrofossils were sampled for dendrochronological investigation and if sawing was required, as much of the lower stump and bole was retained as possible.

5.2 LABORATORY ANALYSES

The analyses carried out in this investigation are described in this section together with the methods adopted for the presentation of the data.

5.2.1 LITHOLOGY DESCRIPTION AND MACROFOSSIL IDENTIFICATION

The monolith tins were stored at 4°C and all sub-sampling was undertaking in the laboratory. Following unwrapping of the monolith samples, approximately 2 to 3cm of the surface was removed (using a "cheese-wire") to reduce the possibility of any contamination which may have occurred following extraction. The surface was then "cleaned" with a spatula (horizontal movements, parallel to the peat layers) to prepare a fresh surface to ease description.

Each of the sampled profiles was described in terms of the following:

i) Colour (visual description, Troels-Smith (1955) scheme)
ii) Composition of peat (i.e. dominant macrofossils, homogeneity) (Troels-Smith, 1955)
iii) Wood macrofossils (confirmation of identification with reference to Schweingruber (1978) where necessary)
iv) Degree of humification (using the Von Post (1924) 10-point system)
v) Boundaries between units
vi) Minerogenic inclusions (Troels-Smith, 1955, modified by Aaby and Berglund, 1986)

5.2.2 RADIOCARBON DATING

In a project such as this, where a key objective is to make inter-site comparisons between biostratigraphic "events", the radiocarbon dating of the sediment and subsequent interpolation between the age estimates is of paramount importance. Correlation between sites depends on accurate independent age estimates (and the subsequent interpolation between these estimates) and without the aid of independent chronostratigraphic horizons (such as tephrochronology) there are limited possibilities of assessing the likely errors involved in the radiocarbon measurements.

All of the peat profiles investigated at Gleann Einich and Beinn Dearg were sampled for radiocarbon analysis, material being submitted to Beta Analytic Inc., Florida. The rationale for the sub-sampling is discussed along with the results (Chapters 6 and 7), but usually 4 or 5

samples were submitted for radiocarbon analysis for each site to enable age-depth plots to be constructed.

Beta Analytic recommend 100g of peat is submitted for their Standard Service since following the necessary pre-treatments and chemical syntheses the samples should contain at least 1.0 to 4.0g final carbon. Where possible between 90g and 100g of peat were submitted for radiocarbon assay, representing between 1-3cm depth of sampled profile. About 1cm was removed from the surface of each sample to reduce the possibility of modern contamination. Following weighing, samples were wrapped in aluminium foil, sealed in plastic bags and stored at 4°C before dispatch to Beta Analytic, Florida.

All samples were submitted for conventional radiocarbon dating (using the benzene method) and the dates are reported as R/C YRS BP (radiocarbon years before present, "present" = 1950 AD). The modern reference standard was 95% of the ^{14}C content of the National Bureau of Standards' Oxalic Acid and is calculated using the Libby ^{14}C half life (5568 years).

The incorporation of younger or older carbonaceous sediments into a sample, or the incorporation of radiocarbon by different pathways introduces differing degrees of isotopic fraction (and can therefore alter the ratio of ^{14}C to other carbon isotopes, and hence age). Often it is difficult to determine when this has occurred, but a measure of the ^{13}C:^{12}C ratio can often reveal where this may have been a serious source of error. The normal range of ^{13}C:^{12}C ratio for most terrestrial plants is *c.*25±5 ‰. Thus, for fossil samples, the measured age is uncorrected where the value lies within this range. For samples giving ^{13}C ratios that deviate significantly from the standard ratio, correction can be applied. However, in this case, since the ^{13}C:^{12}C ratio was not analysed (due to the extra cost) the conventional radiocarbon years reported by Beta Analytic are normalised to -25 per mil and the ^{13}C:^{12}C is estimated based on values typical of terrestrial peat .

It should be noted, however, that the correction only helps to overcome one potential source of error in the age estimates, that affecting isotopic ratios (e.g. 'hard-water' errors and different uptake pathways of radiocarbon into plants). Other sources of error exist, such as the mixing of peats of different age, but where both peat layers have 'normal' ^{13}C values. In such a case, the resulting age will represent an average of the younger and older true values, proportional to the degree of mixing of older and younger 'sources' of ^{14}C. Isotopic fractionation between ^{13}C and ^{12}C is not involved in such stratigraphic mixing.

The conventional radiocarbon dates show quoted errors representing 1 standard deviation statistics (68% probability) and are based on combined measurements of the sample, background, and modern reference standards.

The rationale for the use of uncalibrated radiocarbon age estimates in this investigation is based on the following grounds:

i) To enable comparison with existing published data from northern Scotland.
ii) The calibrated dates contain an asymmetric error which cannot be used with the TILIA program.

However, the relationship between radiocarbon years and calendric years is non-linear so the use of radiocarbon years produces an uneven age scale (cf. Bennett, 1995). In an investigation of radiocarbon dated pine macrofossils, and the subsequent identification of clusters of age estimates (e.g. Bridge *et al.*, 1990), the non-linearity of the radiocarbon age scale has a direct implication on such analyses.

Although desirable, the use of calibrated calendric year timescales, would make in-text comparison of results with previous reported ages difficult. Therefore, all radiocarbon dates are reported as conventional radiocarbon ages at 1 sigma. However, following reporting convention, when calibration was applied using CALIB (Rev. 3.0.3) Stuiver and Reimer (1993) results are reported at 2 sigma levels of probability for the intercept between the radiocarbon age and calendar time scale curves. Calibrated results are shown plotted against conventional radiocarbon age estimates for each site (Chapters 6 and 7) with error terms.

5.2.3 POLLEN ANALYSIS

Sub-sampling for pollen analysis was undertaken initially at 4cm intervals throughout each of the sampled profiles and subsequent sub-sampling was undertaken at intervening depths where necessary. The surface layer of the profile was first cleaned using a sharp scalpel in a direction horizontal to the axis of the monolith tin (to reduce the risk of contamination or mixing in the outer layers) and a 3mm wide spatula was used to obtain a sample of peat from the centre of the sampled column. Every effort was made to limit the risk of contamination, all equipment was washed in distilled water between each sample extraction. The sub-samples were then stored in air-tight flat-bottom tubes at 4°C.

5.2.3.1 PREPARATION OF SAMPLES FOR POLLEN ANALYSIS

For the purpose of pollen concentration (and influx) assessment exotic markers (2 tablets of *Lycopodium* spores, as devised by Stockmarr, 1971) were added to a measured volume of peat (by displacement in water). The samples were prepared for pollen analysis using Erdtman's acetolysis method (Erdtman, 1960) following alkali ingestion, as described in Moore *et al.* (1991). Approximately 10ml of 5% sodium hydroxide (NaOH) was added to the sample (with *Lycopodium* tablets) in a polypropylene test-tube and placed in boiling water for approximately 40 minutes. This alkali digestion process breaks up the peat matrix and

dissolves humic materials. The sample was passed through a coarse sieve (180 microns) with distilled water and the retained debris was collected for macrofossil assessment where necessary. The fines which passed through the coarse sieve were washed in distilled water using a 10 micron micro-sieve. When the liquid passing through the micro-sieve became clear, the sample was returned to the test-tube and placed in a centrifuge for 3 minutes at 3000 rpm. For one profile (site LOD in the Cairngorms) the basal minerogenic sediments required treatment with hot hydrofluoric acid (HF) to remove the siliceous material. Following treatment with 0.1M hydrochloric acid (HCl) (to remove any carbonate material) approximately 6ml of concentrated HF was added to the sample in a polypropylene tube which was placed in a boiling water bath for approximately 15 minutes. If siliceous material was present after this time (checked for using a polypropylene rod) the boiling was continued for a further 30 minutes. Following 3 minutes in the centrifuge at 3000 rpm the supernatant HF was decanted and the pellet was treated with 0.1M HCl to remove any silicofluorides produced during HF treatment. The sample pellet was washed in distilled water. Erdtman's acetolysis treatment (Erdtman, 1960) was used to remove plant cellulose. The washed pellet was suspended in glacial acetic acid (to dehydrate the organic material) and approximately 6ml of acetolysis mixture (nine parts acetic anhydride and one part concentrated sulphuric acid) was added. The suspension was placed in boiling water for 3 minutes and following a spin in the centrifuge (as above) the supernatant was decanted into running water. The pellet was resuspended in glacial acetic acid and following centrifuge, the pellet was washed twice in distilled water (a few drops of 5% NaOH was added to the second wash to aid subsequent staining).

For the staining, two drops of 5% aqueous safranine solution were added to the pellet which was then washed with distilled water and placed in the centrifuge (as above). Melted glycerine jelly was added to the pellet (approximately twice the volume of the pellet) and microscope slides placed on a slide drying hotplate. One drop of sample was placed on the slide, and using a clean glass rod, the drop was smeared over the slide before placing the cover slip. An even smear may reduce the potential dispersal of different types of pollen grains across the slide (which may create a zonation of pollen types across the slide) (cf. Brooks and Thomas, 1967).

5.2.3.2 POLLEN AND SPORE IDENTIFICATION

An initial inspection was made of each of the mounted slides to assess the density of the pollen and spores. This enabled an crude estimation to be made of the number of microscope slide traverses required to provide a representative pollen count and therefore reduce the potential error of non-random dispersal of pollen grains across the slide (cf. Brooks and Thomas, 1967, mentioned above).

A total of 300 land pollen (excluding obligate aquatics and spores) was counted for each slide but where pollen concentration was exceptionally low this was not always possible. Magnification of x400 and x1000 was used (the latter with phase contrast where necessary) an Olympus BH2 microscope.

Pollen identification followed the key in Moore *et al.* (1991) with additional reference to Faegri and Iversen (1989), Erdtman *et al.* (1963), Verbeek-Reuvers (1977), Clarke and Jones (1977), Punt (1984) and Jones and Blackmore (1988). Because acetolysis treatment and glycerine jelly causes swelling of pollen grains (Reitsma, 1969; Faegri and Deuse, 1960), identification using size as a criteria, even when the reference pollen material is treated to similar preparation techniques, could not be used with confidence. This largely affected the separation of *Betula nana* from tree birches by the size of the vestibulum (e.g. Birks, 1968) and distinguishing the Poaceae family into cultivated and wild grasses by the size of the grain and the annuli (e.g. Andersen, 1979; Faergri and Iversen, 1989).

The nomenclature of the vascular plants follows that of Stace (1991) as recommended by Bennett *et al.* (1994). The main nomenclature changes relevant to this investigation (with reference to Clapham *et al.* (1987)) are Compositae are named Asteraceae, Gramineae are named Poaceae, Umbelliferae are named Apiaceae and Polypodiaceae (Filicales) are named Pteropsida monolete (undiff.).

The convention for the identification of pollen grains of certain plant families and genera follows that adopted by Birks (1973). The Ranunculaceae are distinguished into *Ranunculus acris* type (columellae of two orders, with fine columellae fused arranged around each of the coarse columellae, includes *Ranunculus acris* and *Ranunculus repines*) and *Ranunculus trichophyllus* type (fine columellae evenly distributed, includes *Ranunculus flammula*). Rosaceae are distinguished into *Filipendula* type, *Potentilla* type, *Alchemilla* type, *Sorbus aucuparia* and a final group of Rosaceae undifferentiated. The Plantaginaceae are differentiated into *Plantago lanceolota* and *Plantago major/media*. Due to the relatively small number of Saxifragaceae, Asteraceae and Apiaceae pollen encountered, these pollen types are often plotted as families. Ericaceae and Empetraceae are identified using the key of Moore *et al.* (1991).

During routine pollen counting an assessment of the state of preservation of pollen grains was made using the following classification:

i) **Corroded pollen** (pitted or etched surface)

ii) **Amorphous (degraded) pollen** (waxy surface, loss of surface structural detail)

iii) **Broken pollen** (split or ruptured)

iv) **Crumpled pollen** (folded or twisted)

This scheme follows that used by Lowe (1982) based on a modification by Birks (1970) of a classification originally proposed by Cushing (1964, 1967). Cushing (1967) identified and Lowe (1982) proposes a hierarchical scheme for the deterioration of the pollen grains, in order of i) to iv) given above, since the categories are not mutually exclusive.

5.2.3.4 LOCAL POLLEN ASSEMBLAGE ZONES

All pollen diagrams have been structured and plotted using TILIA and TILIAGRAPH programs (Grimm, 1991). The pollen-stratigraphic data for each profile are plotted on a depth axis with a secondary age axis. The age axis is calculated by linear interpolation between the radiocarbon age estimates, and extrapolation above the uppermost age estimate (to the top of the profile).

Local pollen assemblage zones (LPAZ's) were defined by identifying changes in the pollen curves of some of the major taxa (for example, trees such as *Betula, Pinus*). Major taxa are defined as species or genera which have been selected for special attention in this study as they may provide information concerning the main Holocene vegetation changes, and especially allow inferences to be made about tree-line changes. In this respect, the pollen assemblage zones may be regarded as speculative to some extent, but since the same criteria are applied to each of the diagrams, the descriptive zonation is held consistent. Thus, particular attention has been paid to the curves for pollen percentage variations in *Betula, Pinus, Calluna vulgaris, Empetrum, Vaccinium,* Poaceae, Cyperaceae, plus a combined curve for the remaining open habitat herbs (for example Caryophyllaceae, *Ranunculus* spp, *Filipendula, Artemisia* type and *Potentilla* type).

A more objective test of the definitions of local pollen assemblage zones has been obtained through the use of cluster analysis (CONISS), using the facility provided as a component of the TILIA program (Grimm, 1991).

The local pollen assemblage zones, defined on the basis of the relative pollen data, are used as a reference scheme for comparing the trends in the other palaeoecological and stratigraphic data available for each site. The zones, therefore, often serve as appropriate guides for assessing common trends in the different lines of evidence, such as for example the fungal and algal remains and the humification evidence.

5.2.3.5 POLLEN CONCENTRATION AND INFLUX DATA

Pollen concentration and influx data were investigated in order to assess the records of individual taxa without the problem of interdependence that are encountered in relative (percentage) pollen diagrams (discussed in Sections 4.2 and 4.3). The record of an individual taxon can therefore be assessed on the evidence of changes in the absolute

number of pollen grains between stratigraphic horizons.. With the application of radiocarbon dating, the number of grains per square centimetre per year (pollen influx) can be calculated from the pollen concentration data. However, as discussed in Section 4.3, the data are subject to a number of limitations, such as higher data uncertainty, enhanced pollen concentration in highly humified peat, and the assumption of constant rates of peat accumulation between radiocarbon dated horizons. Despite these problems, absolute pollen data can, nevertheless, provide new insights into the history of vegetational change as will be illustrated in subsequent chapters. Only the principal taxa are included in the pollen concentration and pollen influx diagrams, since spurious fluctuations may be contained in records of taxa that are recorded in low concentrations.

5.2.4 FUNGAL AND ALGAL REMAINS

During routine pollen counting a record of the fungal and algal remains was made, the identification of which was largely based on the Type number system used by Van Geel (1972, 1976, 1978, 1986), Van Geel *et al.* (1980/1981, 1982/1983), Pals *et al.* (1980) and Van der Wiel (1982). In many cases it is not possible to identify the microfossil types, but significant palaeoecological changes can often be inferred through clear positive or negative correlations between the frequency curves for fungal and algal remains and other data, such as pollen percentages (Van Geel and Middeldorp, 1989). In particular, variations in the number and type of fungal and algal remains are thought to provide important supplementary information concerning the relative wetness or dryness of a site, and can be used in conjunction with, for example the humification and pollen stratigraphic data (with specific reference to the local colonisation of pine on the mire surface)

A summary of the fungal and algal types recorded in the profiles and their environmental indication is given in Appendix 5.1 The fungal and algal remains data are presented in separate diagrams for each profile, together with the principal pollen taxa (with the exception of *Pinus* pollen, the reason for which is explained in the following section). The Types are calculated as a percentage of total land pollen sum.

5.2.4.1 BLACKENED *PINUS* POLLEN GRAINS AND STOMATAL GUARD CELLS

During routine pollen counting a record was made of the number of *Pinus* pollen grains which exhibited a dense, black, central body. The cause of this is not known (by the author), but it is thought to have been caused by a fungus within the peat matrix. The blackened *Pinus* grains are expressed as a percentage of the pollen sum, and the frequency curve, together with non-blackened *Pinus* grains (ordinary *Pinus*) is shown on the Fungal and Algal remains diagram for each site.

During routine pollen counting stomatal guard cells were also searched for, but none were observed. An explanation for this cannot yet be provided.

5.2.5 CHARCOAL ANALYSIS

The relative frequency of charcoal fragments was assessed during routine pollen analysis, although no distinction was made to sort the fragments into size classes (cf. Tolonen, 1986). The charcoal frequency is therefore plotted merely as a guide to charcoal presence, and since the size of fragments was not assessed the frequency, expressed as a percentage of total land pollen, is not an accurate representation of abundance.

5.2.6 HUMIFICATION ANALYSIS

An investigation of the relative degree of humification throughout each peat profile was carried out for the following principal reasons:

i) to establish whether this may throw some light on the environmental conditions that favoured the invasion of the mire surfaces by pine and birch trees
ii) to establish whether this may throw some light on the environmental conditions that led to the demise of trees and their subsequent burial and preservation within the peat column
iii) to establish whether there were synchronous shifts in the degree of humification within sites along a transect, and
iv) to establish whether there were synchronous shifts in the degree of humification at a regional scale, i.e. common to the Gleann Einich and Beinn Dearg sites.

Secondary reasons were:

v) to explore the relationship between the degree of peat humification and peat accumulation rates
vi) to explore the relationship between the degree of peat humification and peat stratigraphy (i.e. *Sphagnum*-rich, *Eriophorum*-rich peat matrix)
vii) to explore the relationship between the degree of peat humification and pollen concentration and pollen accumulation rates
viii) to explore the relationship between peat humification and the presence or absence of fungal and algal remains
ix) to explore the relationship between peat humification and the frequency of blackened *Pinus* grains.

Some of the methods available for the assessment of the degree humification of peat profiles are discussed in Section 3.5.4, including that devised by von Post (1924). This is uses a 10-class scale and is based upon an assessment of colour, identifiable macroscopic plant remains, and the amount of peat matrix which can be squeezed between ones fingers. This

method was used to provide a guide to the main humification changes in each of the profiles and is included in the lithostratigraphic descriptions for each site. However, a less subjective method was required to obtain values for the decomposition of the matrix. Aaby (1986) recommends the procedure devised by Overbeck (1947) and subsequently modified by Bahnson (1965). It consists of a colorimetric determination of an alkali extraction of peat where the alkali absorption is proportional to the amount of humic matter dissolved. The degree of humification is calculated relative to 0.2g of a standard (=100%).

However, since humic acid is variable and highly complex, the use of a standard against which to compare the peat transmission values is not practical (Blackford and Chambers, 1993). So they suggest the use of distilled water as a standard and all values can be expressed as percentage transmission (the amount of light transmitted through the alkali extraction is inversely proportional to darkness or intensity of the colour extracted from each sample). Percentage transmission values should not be interpreted as absolute changes in humification since NaOH solutions of peat contain contaminants of non-humic material (Kaila, 1956; Hayes, 1985).

Blackford and Chambers (1993) thoroughly tested the alkali extraction method. They assessed the affect of different alkali concentrations on transmission values and the optimum length of time following the addition of sodium hydroxide for replicable transmission measurements. Blackford and Chambers (1993) conclude that the alkali extraction method produces replicable results and is more suitable than alternative methods for peat based climate studies (in particular an assessment of the fibre content which is affected by changing species composition).

Due to the large number of samples that would be required, humification measurements were not carried out on contiguous samples for each site. Sub-samples were initially extracted at 8cm intervals but where the results showed large changes in transmission values between adjacent samples, further intervening sub-samples were taken and transmission values determined. Although this introduces a potential source of error, since an assumption is made of a linear relationship between two data points, the method should provide a reliable indication of *temporal trends* in the relative degree of humification.

The method is described in full in Appendix 5.2 and is based on that recommended by Blackford and Chambers (1993) with a few minor modifications. Correction factors need to be applied for the inorganic fraction of the peat matrix (assessed using loss-on-ignition measurements) and for fading of the alkali extraction (for measurements after the required four hours).

An important factor to be considered in humification analyses is that the breakdown of the peat matrix to form humic acids can often be species dependent. Blackford and Chambers (1993) noted that different plants, whose fragments start at different sizes, have different decomposition characteristics when subjected to the same decomposition environment. For example, most *Sphagna* break on decomposition but the leaves are identifiable, *Eriophorum* tends to remain in a matted matrix surrounded by a well-decomposed amorphous material and Ericaceous plants tend to break up into small particles. Furthermore, Coulson and Butterfield (1978) show that during the first year, under the same conditions, *Sphagnum recurvum* underwent a 16.2% mass loss in comparison to a 25.6% loss for *Calluna vulgaris.* However, a change to wetter conditions if often accompanied by an increase in *Sphagnum* growth on the mire surface which would be accompanied by a decrease in humification. So, the lower mass loss of *Sphagnum,* relative to *Calluna,* would exaggerate the effect on the extract colour when species composition changes, for example a change to *Sphagnum* leads to a lower degree of humification which is accompanied by relatively low mass-loss which is registered as a higher transmission value, and therefore a lower degree of humification. So species composition is likely to exaggerate the humification signal rather than understate it (Blackford and Chambers, 1993).

To ease the assimilation and interpretation of the results of the humification analysis, the transmission values are plotted on a reverse scale, since lower transmissivity equates with higher degree of humification. The stratigraphic depth of large wood macrofossils identified in the peat profile are also shown on the humification diagrams.

5.2.7 DENDROCHRONOLOGY

The aims of the dendrochronological investigation of the tree stumps recovered from each site were:

i) to estimate the number of years each tree lived
ii) to assess the growth patterns of the trees
iii) to attempt to cross-match samples, to establish which trees were contemporaneous
iv) to establish a framework for testing whether cross-matched samples provided consistent radiocarbon ages

As many large macrofossils of pine and birch as was feasible were collected from each site, though the total number was limited by the size of the samples, both because of the difficulty of cutting with a hand saw and the difficulty of transport.

Previous dendrochronological investigations identified several problems associated with chronology building and palaeo-climatic reconstructions based on sub-fossil pine stumps. Ward *et al.* (1987). These include generally short ring sequences, locally absent rings and variability of single ring widths around the circumference of a tree. Initial results showed that

only 8% of the samples have more than 200 rings which is of little use for erecting preliminary chronology building. Ward *et al.* (1987) suggest that extensive collecting is necessary, involving many sites, to ensure an adequate amount of material is available.

The location of each of the samples within the peat profile was recorded before extraction and subsequent sawing. The dendrochronological investigations were undertaken by A.K.Moir (Department of Geography, London Guildhall University) and the methods, and initial results, are described in Appendix 5.3.

5.3 SUMMARY OF RESEARCH METHODOLOGICAL OBJECTIVES AND RATIONALE

The methodology adopted in this thesis seeks to

i) follow established standard procedures and methodologies

ii) to apply these methods uniformly across all sites to establish comparability between sites and transects

iii) to use a variety of multi-proxy techniques which allows the data to be "tuned" to specific research objectives, such as the supplementary evidence of the fungal and algal remains, and the degree of peat humification

iv) create a tightly constrained comparative database

v) to compare the results of the analyses with other Northern Scotland and European data (facilitated with the use of uncalibrated radiocarbon age)

A comparatively small number of pollen diagrams have been published from altitudes above *c.*500m OD in Scotland (e.g. Pears, 1968, but no distinction is made between the Ericaceae; Allt Na Feith Sheilich at *c.*600m in the Monadhliath Plateau (Birks, 1975), and very few investigations have been undertaken at sites along altitudinal transects (with the exception of Ward *et al.*, but the highest site in this study was at 350m OD). Therefore the pollen-stratigraphic evidence from this investigation has the potential not only to provide an insight into upland vegetation change during the Holocene but also allows an investigation of changes in the local and regional pollen rain (and pollen concentration and influx variations with altitude) both on a temporal and spatial scale. This study may therefore set up a high altitude "benchmark" against which future studies can be compared to and added to.

Finally, the use of multi-proxy techniques, such as the assessment of the degree of humification and fungal and algal remains, provides important supplementary data for the reconstruction of environmental change. The methodology therefore seeks to set up protocols for future research and may provide important guidelines for future investigations.

CHAPTER 6.0 RESULTS - GLEANN EINICH

This chapter presents the results obtained from the sites investigated in Gleann Einich in the Cairngorms, while Chapter 7 will present the results obtained from Beinn Dearg in the Northwest Highlands. In Chapter 8, both sets of results will be compared and evaluated. The locations of the sites at Gleann Einich are shown on Figure 5.1.

The results from each site will be described under the following headings:

i) Site description
ii) Lithostratigraphy
iii) Radiocarbon measurements
iv) Local pollen assemblage zones
- percentage pollen and spore diagram
- pollen concentration and influx data
- fungal and algal remains diagram
- the degree of humification
- summary

The reasons for describing the pollen concentration, pollen influx, fungal/algal remains data and the humification data in the local assemblage zones assigned for the percentage pollen data are given in Section 5.2.3.4.

6.1 ALT A' PHRIS-GHIUBHAIS - SITE CODE : APB (500m OD) (NGR: NH 930031)

6.1.1 SITE DESCRIPTION

The Cairngorms massif largely comprises a granite pluton intruded during the Caledonian orogeny in late Silurian-early Devonian times, into Pre-cambrian Moine metamorphic country rocks. The region exhibits some fine examples of Devensian and Lateglacial glacial, glaciofluvial and periglacial features.

The site area name incorporates the Gaelic word "Ghiubhais" meaning pine which suggests that pine grew at or near this site until relatively recently. However, it may simply refer to the presence of the pine stumps or be a descriptive term for the area as a whole.

Many pine stumps were found in the area of APB, most of which were interstratified in the deep peat hag profiles formed by erosion. However, some small pine trunks and pine stumps (with the lower part of the trunk intact), were also found, often in the bottom of gulleys, presumably having been eroded from the peat hags.

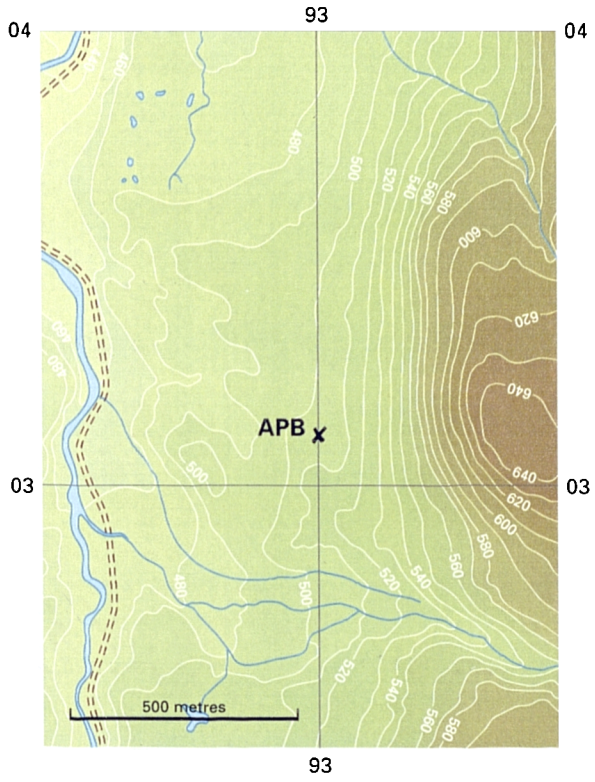


Figure 6.1: Gleann Einich – location of sample site APB (Alt A'Phris-Ghiubhais) c.500m OD

This site is situated on the boundary between two drainage systems, one to the north and one to the south (Figure 6.1). However, the site receives drainage predominantly from the east with only a minor component derived from the south and southeast. The drainage away form the site is to the west and northwest. Therefore, the site can be categorised as a valleyside mire type with some spur mire characteristics (see Section 3.5.3 for definitions of these categories).

The site area was first probed on a 5m grid system to locate the deepest part of the peat deposit (*c.*260cm). This was adjacent to an erosion gulley which was excavated to form a section, approximately 100cm wide and 260cm deep on a coarse minerogenic base. Three monolith tins (110cm x 10cm x 5cm) were required to sample the section from the coarse mineral base to the rooted peat just below the current vegetated surface.

The vegetation cover at this site is dominated by *Calluna vulgaris* with a minor component of grasses, *Eriophorum*, *Erica cinera* and *Erica tetralix*. *Sphagnum* was occupying the wetter parts of the mire surface.

6.1.2 LITHOSTRATIGRAPHY

The excavated profile contained one layer of small pine stumps (between approximately 70-80cm) in addition to smaller pine and birch macrofossils at 247-253cm and an Ericaceous-rich layer between 220-240cm.

The following stratigraphy was recorded in the laboratory from the samples recovered from the monolith tins. The notation is based on Troels-Smith (1955) where n=degree of darkness, Th=*Turfa herbaceae*, Tl = *Turfa lignosa*, Tb = *Turfa bryophytica*, Sh = *Substantia humosa* (all on a 5-class scale, 0 to 4); G min = *Grana minora* (minerogenic particles of 0.06mm to 2.0mm), G maj = *Grana majora* (minerogenic particles of 2.0mm to 60.0mm) (modification of Troels-Smith system (Aaby and Berglund, 1986)); H = humification (based on von Post, 1924) on a 10-class scale. This notation is used for all of the profiles investigated.

DEPTH

DATUM (0) = TOP OF UPPER MONOLITH TIN

1-25cm	Dark brown, herbaceous peat. Some root penetration from above. Ericaceous twig at 22cm. H3; n2-3; Th3; Tb1.
25-57cm	Medium to light brown *Sphagnum-Eriophorum* peat (becoming lighter towards 25cm). Ericaceous twig at 49cm. H3-4; n2; Tb3; Th1.
57-65cm	Medium brown, *Eriophorum* peat. H6; n2; Th4.
65-71cm	Dark brown, *Eriophorum-Sphagnum* peat. H7; n2-3; Th3; Tb1.

71-90cm Humified dark brown peat. No distinct plant remains. H6; n2-3; Sh4.

90-93cm Dark brown, *Eriophorum* peat. H6; n3; Th4.

93-128cm Well humified dark brown, homogeneous peat. No distinct plant remains. H6; n3; Sh4.

128-160cm Medium brown, *Eriophorum* peat. Ericaceous twig at 132cm and birch twig at 135cm. H5; n2-3; Th3; Tl1.

160-188cm Very dark brown to black, *Sphagnum* peat. H3-4; n4; Tb4.

188-209cm Very dark brown to black, homogeneous peat with sand-sized minerogenic inclusions. Occasional small, very degraded, wood fragments (not possible to identify); birch bark present at 209cm. H8; n4; Sh3; g min 1.

209-232cm Medium dark brown, wood-rich peat. High proportion of Ericaceous twigs, particularly between 221cm and 231cm. Pine fragment with bark between 214cm and 215cm. H3; n2-3; Tl3; Sh1.

232-256cm Very dark brown to black homogeneous peat with sand-sized minerogenic inclusions. Occasional wood fragments remains. Ericaceous twig at 244cm. H8-9; n4; Sh2; g min 1; Tl1.

6.1.3 RADIOCARBON MEASUREMENTS

Five samples were submitted for radiocarbon analysis from the APB sampled column (see Table 6.1 for laboratory details and results). The sampling strategy was to obtain radiocarbon age estimates at approximately equal depth intervals (*c.*50cm) below 75cm (Datum 0cm = top of upper monolith tin) since the pollen diagram indicates that 75cm post-dates the decline of pine, *c.*4,000 BP.

The radiocarbon measurements (and the quoted errors representing 1 standard deviation statistics [1 sigma]) are shown plotted in Figure 6.2 together with the calculated sediment accumulation rates and the calibrated ages (with 2 sigma levels of probability).

Linear interpolation between the radiocarbon dates shows that the sediment accumulation rate is fairly constant (between 18 yr cm^{-1} and 24 yr cm^{-1}) above 212-213cm *c.*5,740 BP). The slower accumulation rate of 40 yr cm^{-1} below *c.*213cm corresponds approximately with the top of a poorly humified peat overlying a minerogenic base (see lithology section above).

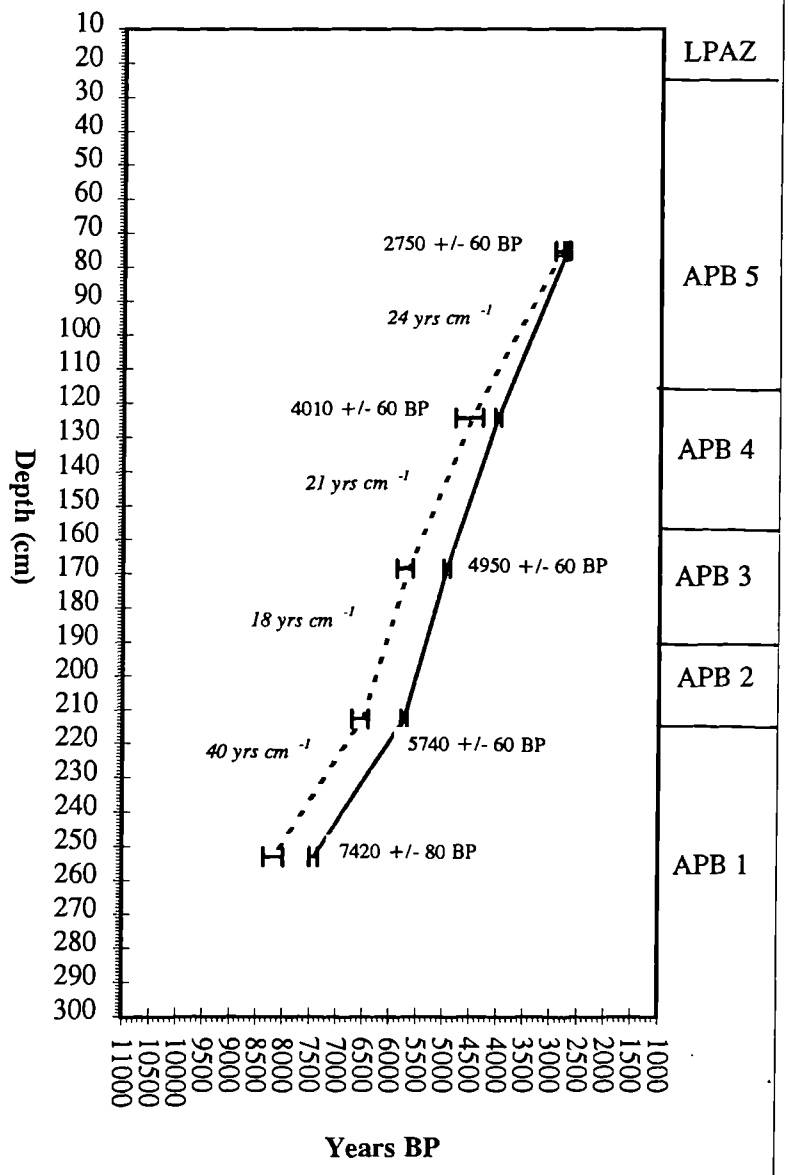
TABLE 6.1 GLEANN EINICH - RADIOCARBON SUBMISSION AND REPORTED DATES

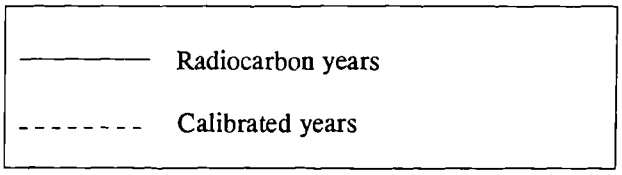
LGU Lab. Operator No.	Radiocarbon Lab Analysis No.	Type of sample	Depth of sample (cm)	Wet weight of sample (g)	Conventional ^{14}C Age (Years BP)*	Calibrated ages (cal yrs BP)	+	-
APB 1	Beta-78455	Peat with minerogenic inclusions	253.0-256.0	53.2	7420 +/- 80	8163	201	169
APB 2	Beta-78456	Peat	212.0-213 0	87.0	5740 +/- 60	6510	206	101
APB 3	Beta-78457	Peat	167.5-169.0	86.6	4950 +/- 60	5658	227	70
APB 4	Beta-78458	Peat	123.5-125.0	90.5	4010 +/- 60	4492	312	197
APB 5	Beta-78459	Peat	74.0-75.5	90.6	2750 +/- 60	2832	128	79
CPG 1	Beta-78460	Peat	164.0-165.5	86.9	7240 +/- 80	7991	147	148
CPG 2	Beta-78461	Peat	157.0-158.5	81.1	6660 +/- 70	7493	91	105
CPG 3	Beta-78462	Peat	143.0-144.5	85.1	6050 +/- 70	6887	266	151
CPG 4	Beta-78463	Peat	94.0-95.5	79.8	4870 +/- 50	5598	119	115
CPG 5	Beta-78464	Peat	52.0-53.5	84.4	3560 +/- 60	3836	150	147
LOD 1	Beta-78465	Peat	226.0-228.0	100.9	7970 +/- 60	8875	114	320
LOD 2	Beta-78466	Peat with minerogenic inclusions	185.0-187 0	99.7	7430 +/- 80	8167	200	169
LOD 3	Beta-78467	Peat	148.0-149.0	108.7	6600 +/- 80	7468	84	179
LOD 4	Beta-78468	Peat	100.0-101.5	85.0	5610 +/- 70	6406	128	120
LOD 5	Beta-78469	Peat	52.0-53.5	106.9	4440 +/- 80	5010	297	171
LODW 4	Beta-78470	Sub-fossil pine	Not from profile	24.8 (dry)	6270 +/- 80	7178	183	226
LODW 6	Beta-78471	Sub-fossil pine	Not from profile	23.3 (dry)	6440 +/- 70	7325	96	120
MNM 1	Beta-78472	Peat	143.5-146.0	91.8	4270 +/- 70	4837	146	262
MNM 2	Beta-78473	Peat	113.5-115.5	96.0	3570 +/- 60	3841	223	149
MNM 3	Beta-78474	Peat	83.0-85.0	90.0	3060 +/- 60	3261	119	188
MNM 4	Beta-78475	Peat	64.0-66.0	84.1	2980 +/- 70	3197	155	254

APB = Alt a' Phris Ghiubhais
CPG = Carn a' Phris Ghiubhais
LOD = Lochan Odhar
MNM = Moine Mhor

* All conventional ^{14}C ages are reported as uncorrected years BP calculated on the Libby half-life and on assumed ^{13}C ^{12}C sample ratios of 25‰

Figure 6.2.
APB - Radiocarbon measurements (uncalibrated and calibrated) and interpolated peat accumulation rates (expressed in years per cm) plotted against depth (cm)





6.1.4 LOCAL POLLEN ASSEMBLAGE ZONES (LPAZ)

6.1.4.1 LPAZ - APB 1 (255-214cm) (*c.* 7440-5800 BP)

Percentage pollen and spore diagram **(Figure 6.3)**

This zone is characterised by fluctuations in the proportion of tree pollen (up to 88%) and shrub pollen (maximum for the section of 68% at 255cm). *Pinus* pollen forms the major component of the tree sum reaching a maximum of 71% at 240cm while *Betula* pollen frequencies decrease from 23% at the base of the zone to a minimum of 4% at 228cm. There is a decline in the percentage of *Pinus* pollen at 232cm from 71% to 28% with a corresponding increase in *Calluna vulgaris* pollen from 3% to 50%. The fall in the percentage of *Pinus* pollen frequencies to less than 5% at 248cm coincides with the high minerogenic input of sediment at this depth. *Vaccinium* pollen frequencies increase to *c.*4% at 240cm.

The date of the basal sediment at APB of 7420 +/- 80 BP provides an approximate minimum date for the arrival at pine at this site, since the pollen spectra at 255cm indicating low frequency for *Pinus* pollen, is not sufficient evidence for the exclusion of pine.

Pollen concentration and influx diagrams **(Figures 6.4 and 6.5)**

The concentration values at this site show a good correspondence with the degree of humification of the peat matrix (Figure 6.6), particularly below *c.*170cm. For example, the low pollen concentration at 228cm corresponds with a relatively high transmission value (hence a lower degree of humification). The pollen concentration values may therefore represent:

i) a real decrease in the pollen influx, or,
ii) the affect of a lower degree of humification which may result in a higher peat accumulation rate, or
iii) or a combination of i) and ii)

Conversely, an increase in the degree of humification may enhance the apparent pollen concentration values (as at 238cm). Consequently, the interpretation of pollen concentration diagrams from peat deposits requires consideration of the degree of humification of the peat matrix.

Total pollen concentration values for land taxa decrease from *c.*790,000 grains cm^{-3} at 248cm to *c.*50,000 grains cm^{-3} at the top of this zone. This trend is followed by most of the taxa, with the exception of *Ranunculus* type.

FIGURE 6.3
PERCENTAGE POLLEN AND SPORE DIAGRAM FOR SITE APB (c.500m OD)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)
OUTLINE CURVES REPRESENT AN EXAGGERATION OF X10 FOR MINOR TAXA

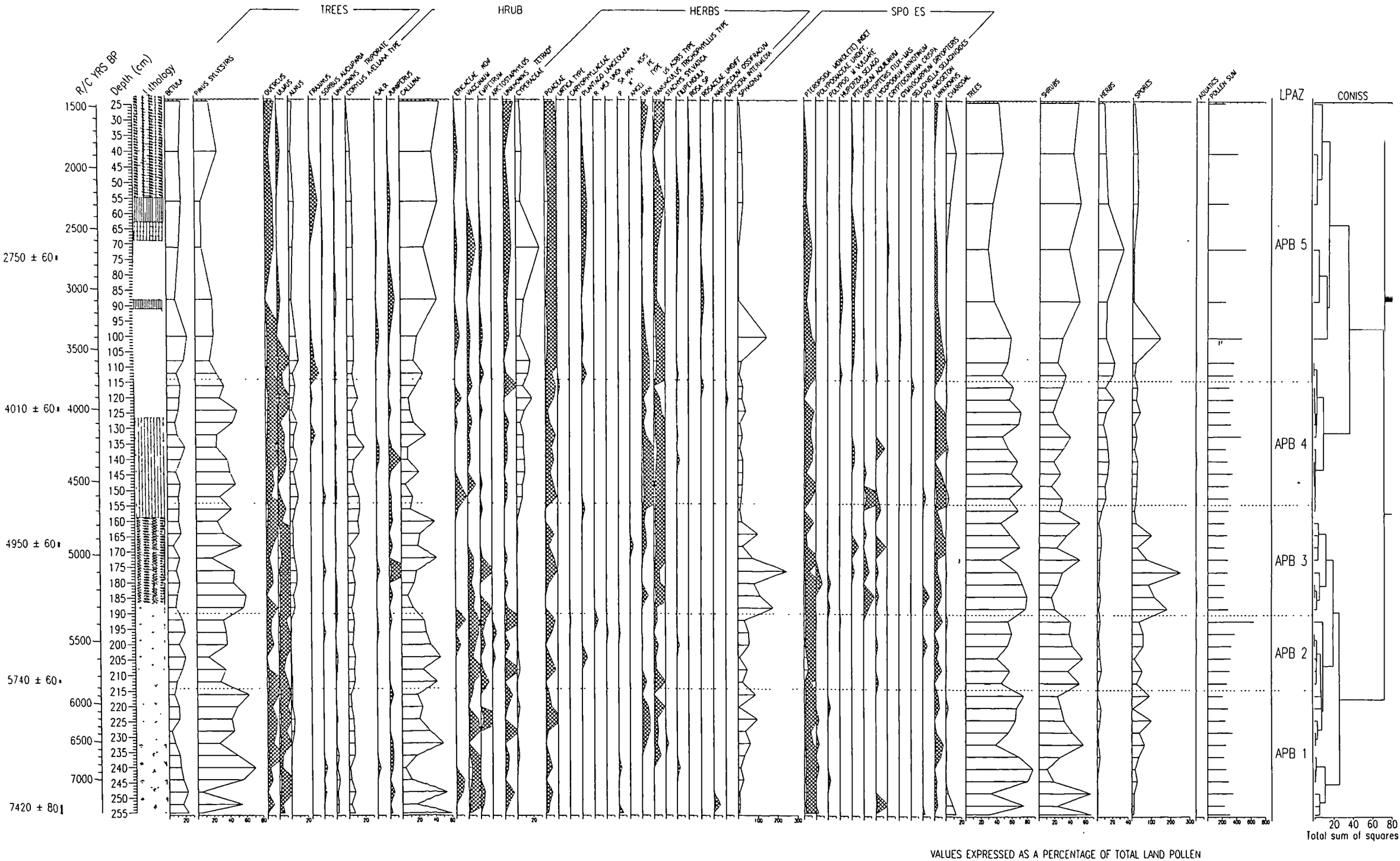


FIGURE 6.4 POLLEN CONCENTRATION DIAGRAM FOR STE APB .50 m D)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

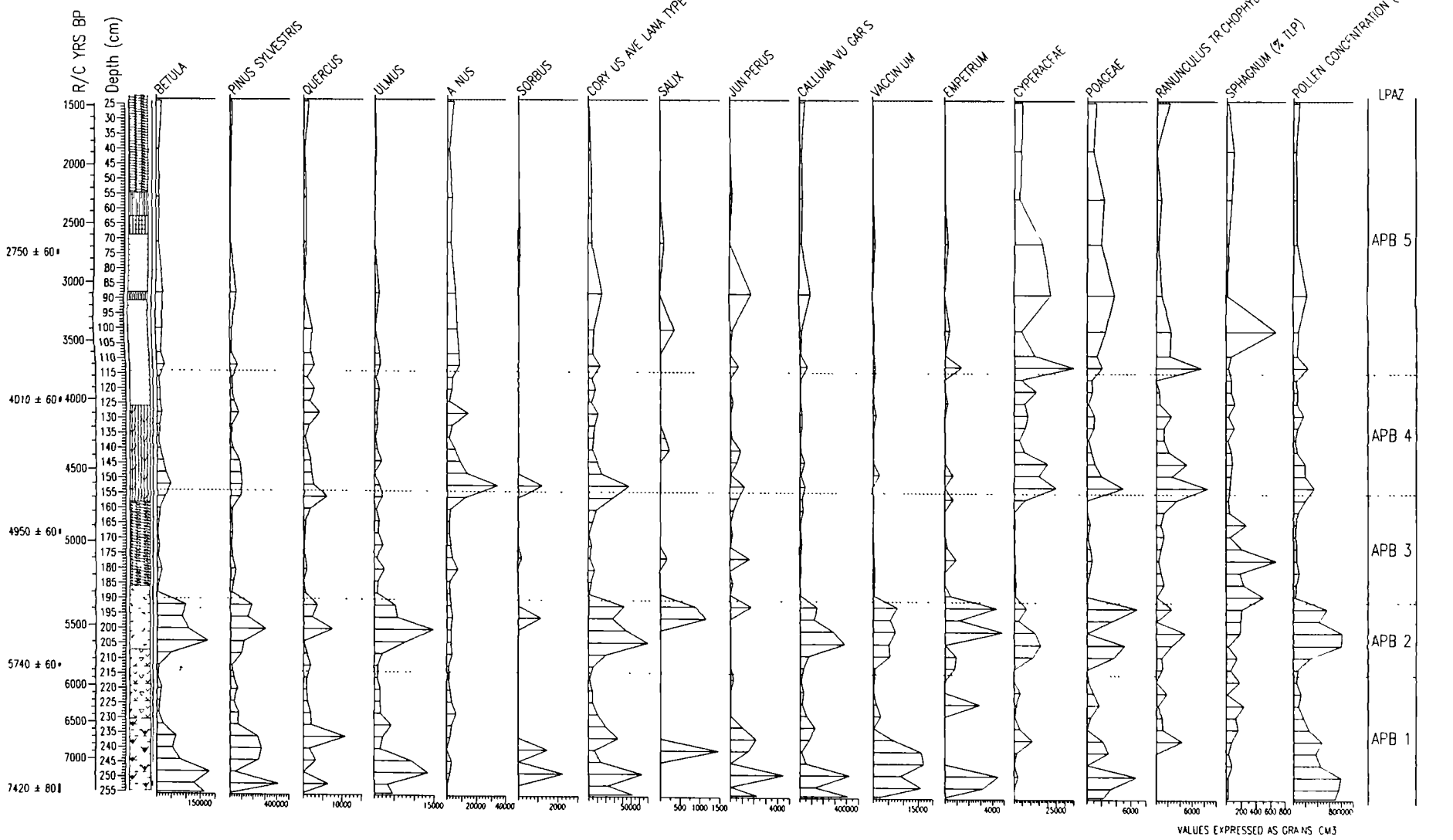


FIGURE 6.5 POLLEN INFLUX DIAGRAM FOR SITE APB (5 m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

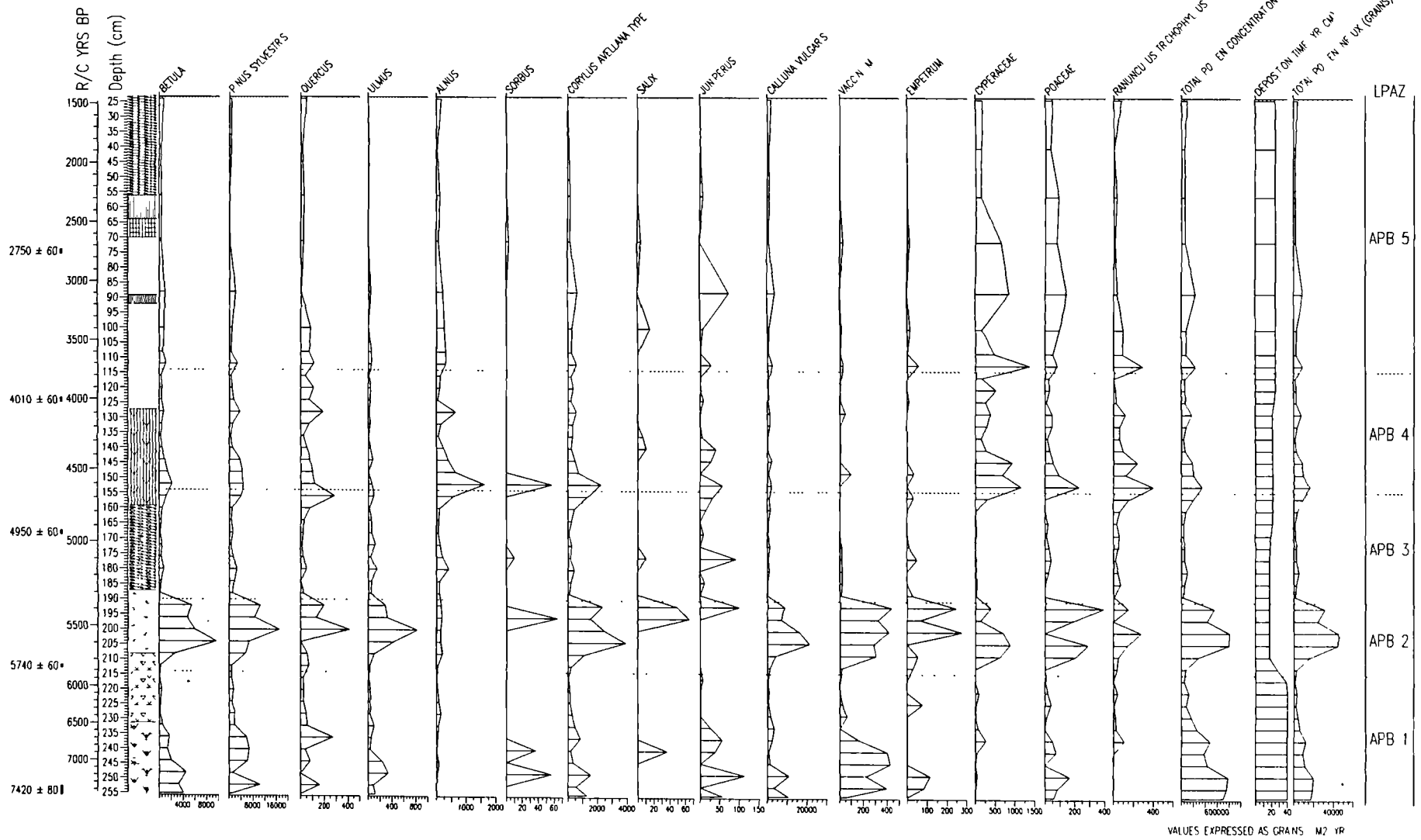
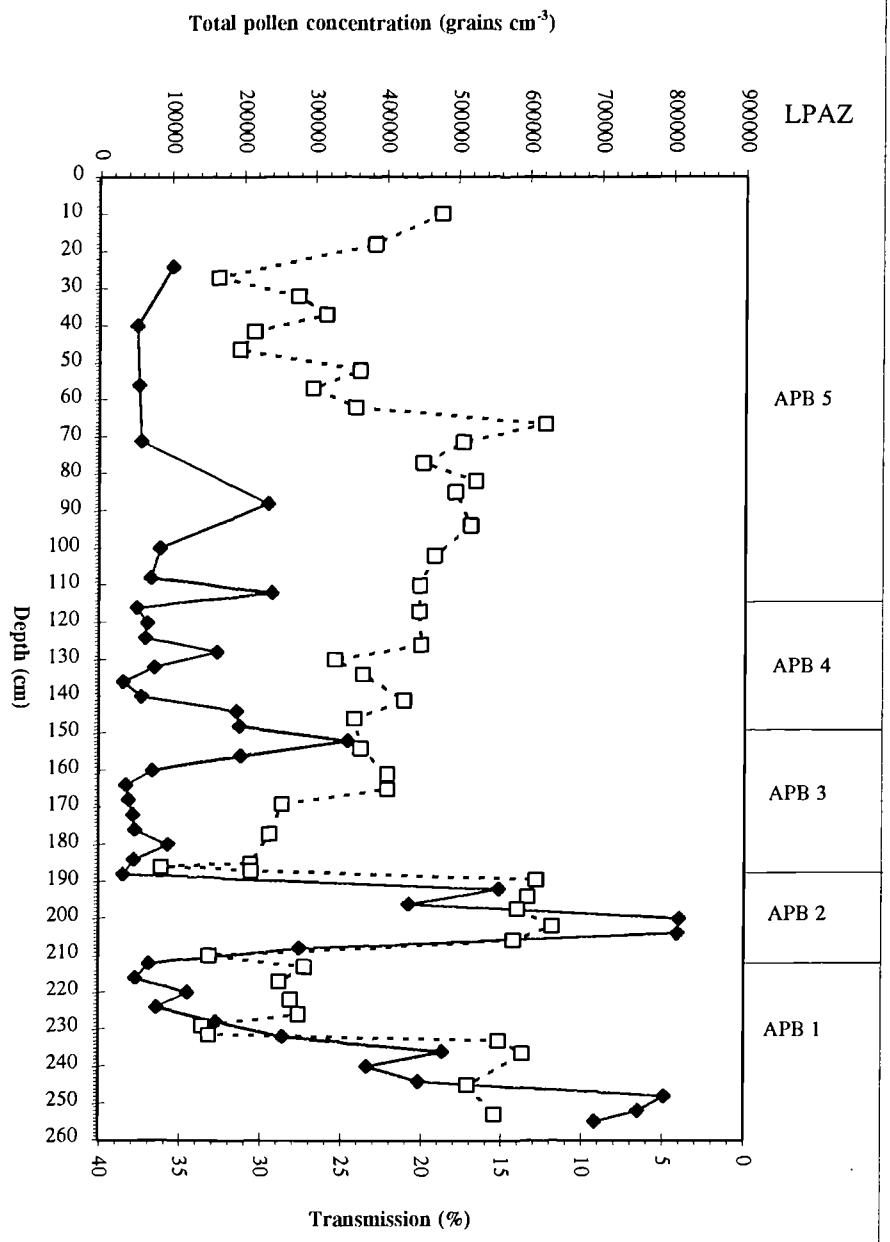


Figure 6.6.
Profile APB - Degree of humification (expressed as the inverse of percent transmission) and total pollen concentration (expressed as grains cm^{-3}) plotted against depth (cm).



Pollen concentration (grains cm^{-3})
---------- Transmission (%)

The influx values for terrestrial pollen fall from *c.*19,700 grains cm^{-2} yr^{-1} to a minimum for the whole diagram of *c.*1,300 grains cm^{-2} yr^{-1} at the top of the zone.

***Fungal and algal remains diagram* (Figure 6.7)**

The fungal spore Type 27 (*Tilletia sphagni*) is represented in this zone and the higher frequency at 232cm corresponds with the rise in the frequency of *Sphagnum* spores and the presence of occasional *Sphagnum* leaves in the peat matrix (and a shift to a lower degree of humification). The frequency of Type 27 has been linked with *Sphagnum* spore frequencies (Dickson, 1973). However, Van Geel suggests that if there is correlation it is perhaps only with *Sphagnum cuspidatum* (Van Geel, 1978) but the fungus can be used to indicate a transition from drier to wetter sediment.

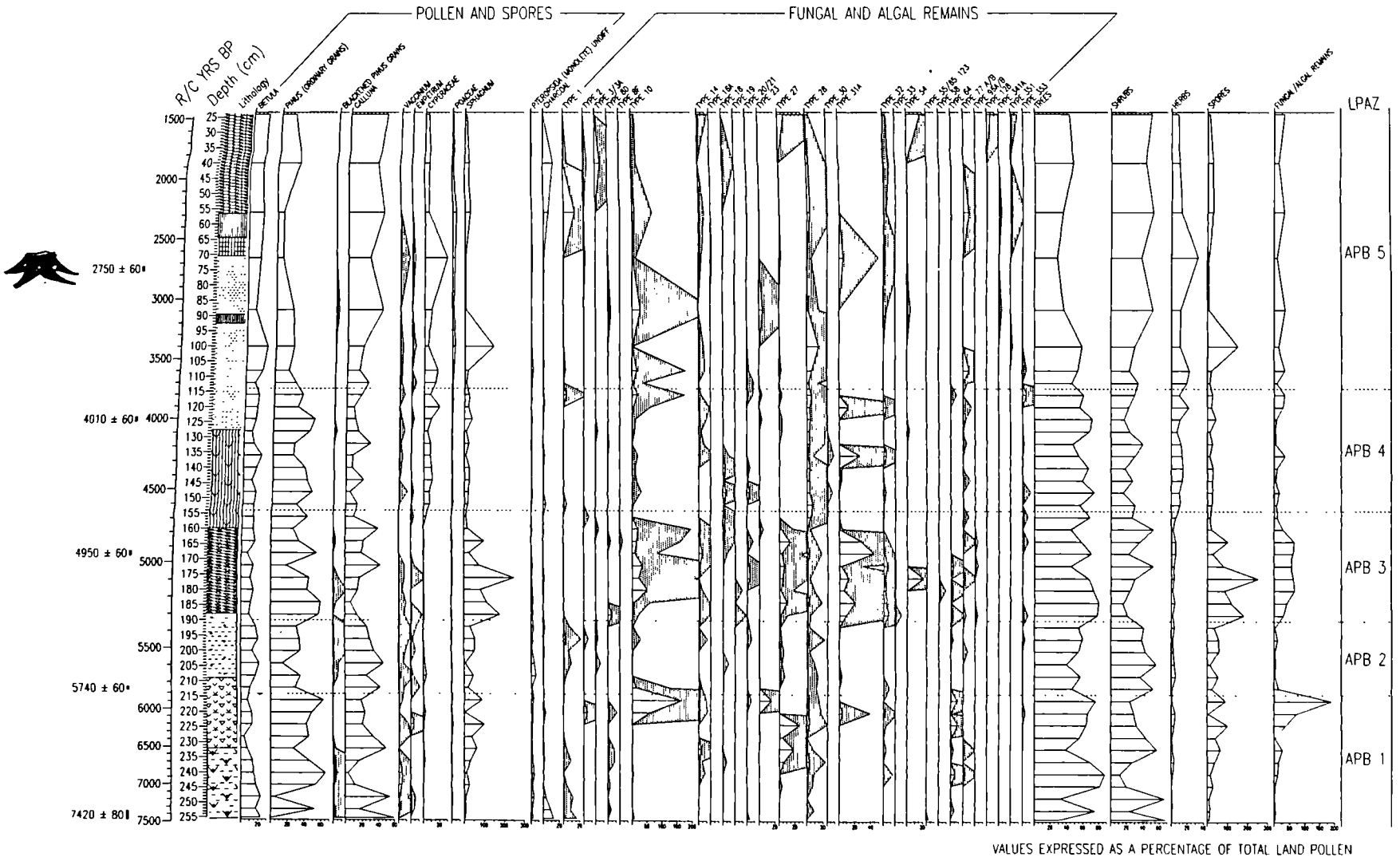
Type 77a/b (*Geoglossum sphanophilum*), which is also associated with *Sphagnum* (*Sphagnum* cf *rubellum*) (Van Geel, 1978), is present, but at low frequencies in this zone.

The top of the zone shows a sharp increase in the percentage of Type 10. Van Geel (1978) suggests this fungus is a good indicator of locally dry conditions since circumstantial evidence links it with the roots of *Calluna vulgaris*. However, this conclusion is reached on the basis that very few macro-remains of other Ericales were identified at levels with a high frequency of Type 10. However, Blackford (Blackford, 1990) demonstrated that Type 10 cannot be used as a reliable indicator of *Calluna vulgaris* or dry phases of peat growth since maximum *Calluna* pollen frequencies do not always correspond with abundant Type 10 remains. Blackford (1990) suggests this may be related to three factors:

i) the rooting depth of *Calluna vulgaris* (down to at least 30cm) results in the representation of the remains of Type 10 fungi at lower depths than *Calluna* pollen, or
ii) different source areas (the pollen may represent *Calluna* over a much wider area than the locally produced fungal remains), or
iii) the ecological range of Type 10 (environmental conditions are too dry and beyond the hydrological tolerance of Type 10).

The peak in Type 10 frequencies at the top of APB1 does not correspond with the peak in *Calluna vulgaris* frequencies but does coincide with the records of Ericaceous twigs identified both in the sampled column and in the profile.

FIGURE 6.7 FUNGAL AND ALGAL PEMAIN DIAGRAM FOR SITE APB (c.500m OD)
(WITH SELECTED POLLEN AND SPORES)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)
SHADING REPRESENTS AN EXAGGERATION OF ×10 FOR MINOR TYPES



The frequency of blackened *Pinus* grains also shows a good correspondence with the degree of humification in this zone (Figure 6.8)

***Degree of humification* (Figure 6.9)**

The shift up the profile from a high to a low degree of humification at approximately 232cm coincides with a change in lithology to a less minerogenic-rich peat matrix. A large number of macrofossils are present in this zone, both within the sampled column (monolith samples) and in the peat profile. This concentration of macrofossils corresponds with the shift to a lower degree of humification.

Summary

The pollen evidence represented in this zone indicates the local presence of a relatively dense pine woodland with birch and an understorey dominated by *Calluna vulgaris*. The lower pine frequency at *c.*232cm corresponds with an increase in the frequency of *Calluna* pollen and may represent a temporary opening of the pine woodland canopy.

The fungal and algal remains evidence indicates a shift to wetter conditions between approximately 235cm and 225cm (Type 27). This corresponds with a shift to a lower degree of humification and evidence for the local presence of *Sphagnum.*

6.4.1.2 LPAZ - APB 2 (214-190cm) (*c.* 5800-5338 BP)

Percentage pollen and spore diagram

This zone is characterised by a reduced representation of tree pollen types (a minimum for the zone of 40%). This is largely a result of the decrease *Pinus* pollen frequencies (to 15% at 204cm) and a corresponding rise in *Calluna vulgaris* pollen frequencies to 47%. *Betula* pollen frequencies increase slightly (21% at 204cm). Pteropsida (monolete) indet. spores reach a maximum of 6% at 208cm.

Pollen concentration and influx diagrams

Terrestrial pollen concentrations rise from *c.* 69,000 grains cm^{-3} at the base of this zone to a site maximum of *c.*810,000 grains cm^{-3} at 200cm. The terrestrial pollen show similar pollen concentration trends, with *Betula* and *Pinus sylvestris* reaching maximum concentration and influx values in this zone (*c.*9,700 grains $cm^{-2}\,yr^{-1}$ and *c.*169,000 grains $cm^{-2}\,yr^{-1}$ respectively).

The pollen influx rates show a similar trend to the pollen concentration values, also reaching a site profile maximum at 200cm of *c.*45,400 grains $cm^{-2}\,yr^{-1}$. The rise in

Figure 6.8.
Profile APB - Degree of humification (expressed as the inverse of percent transmission) and the frequency of blackened *Pinus* pollen grains (expressed as a percentage of total land pollen) plotted against depth (cm).

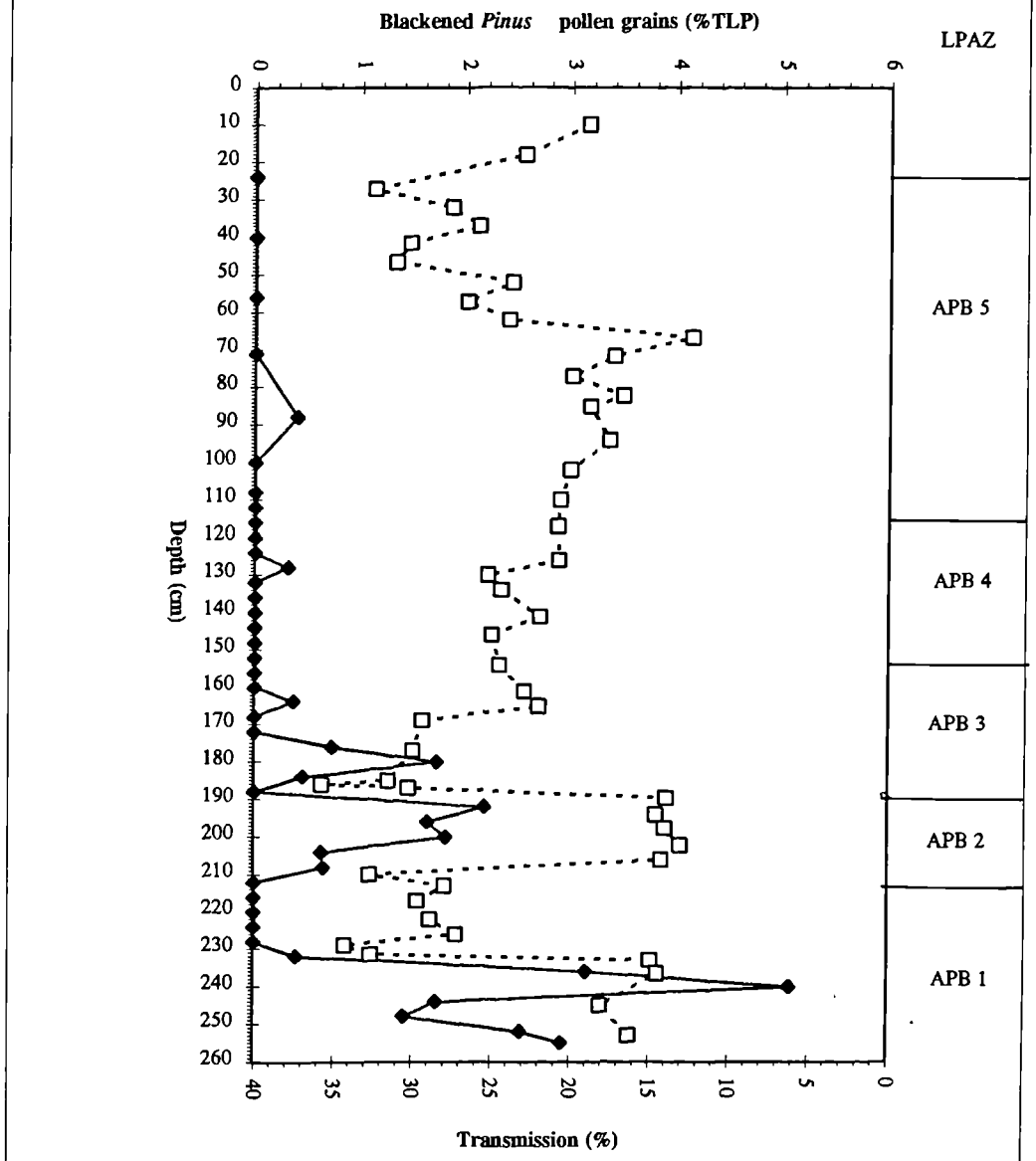
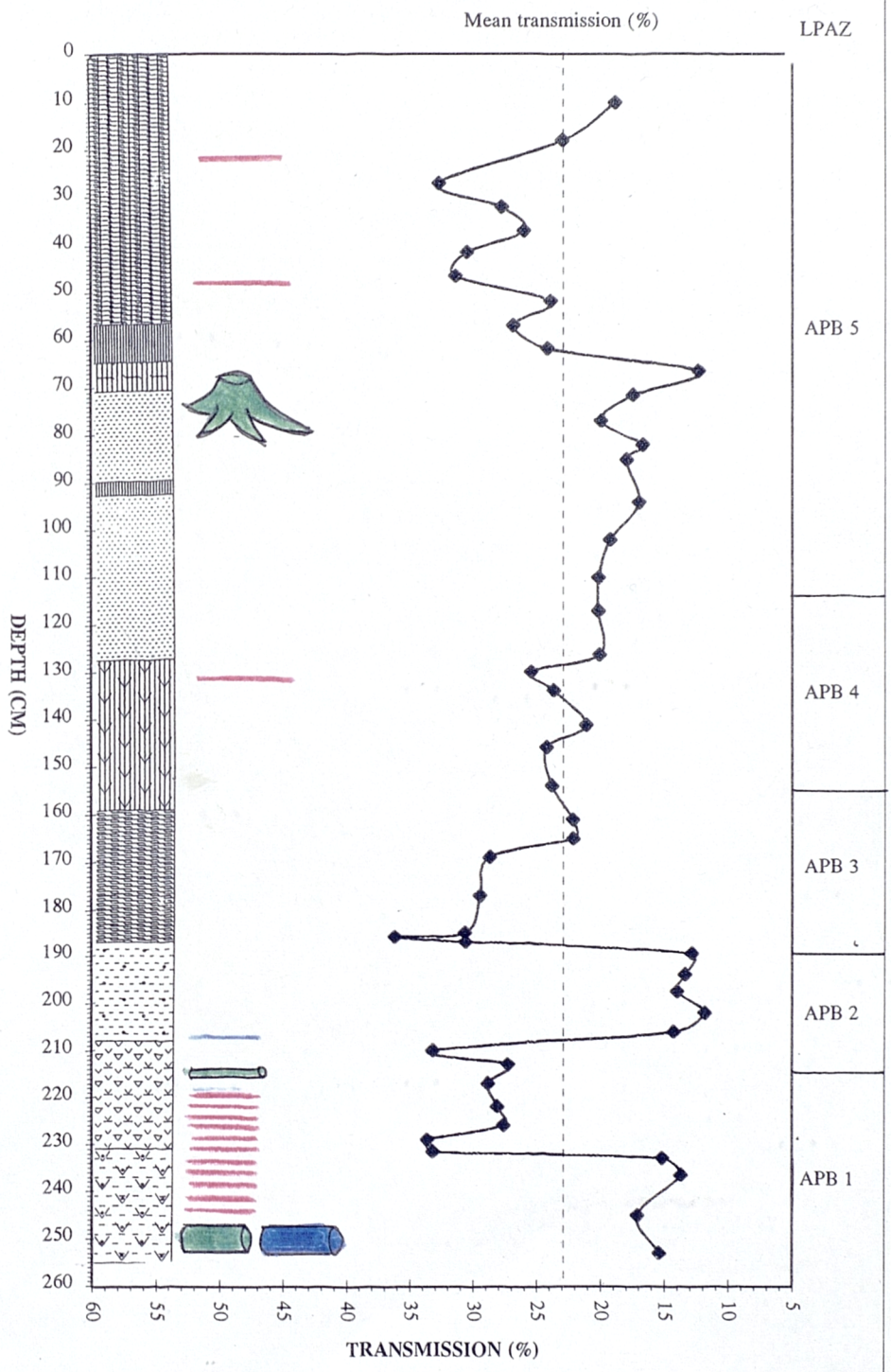


Figure 6.9.
Profile APB - Degree of humification (expressed as the inverse of percent transmission) plotted against depth (cm). Macrofossils are represented (green = pine; blue = birch; red = Ericaceous)



concentration and influx values again corresponds with the degree of humification in this zone, since minimum transmission values are represented (therefore indicating a high degree of humification) (Figure 6.6).

If the pollen influx rate remains constant, the increase in the peat accumulation rate (deposition time) from *c.*40 yr cm^{-1} to *c.*18 yr cm^{-1} at the base of this zone should correspond with lower pollen concentration and influx values. The increase in the pollen influx represented in this zone must therefore be a result of one, or both, of the following factors:

i) an increase in the pollen influx to the site
ii) an increase in humification of the peat matrix causes a concentration of the pollen grains and is reflected in the pollen stratigraphy as an increase in pollen concentration (apparent increase in pollen influx)

This enhancement of the pollen concentration may be related to the discrepancy between the *Pinus* pollen frequency and concentration/influx values. Figure 6.10 (*Pinus* pollen values on an age-depth axis) shows an increase in influx and concentration values at 200cm but relatively low values for the *Pinus* pollen percentage (*c.*40%) are represented at the same depth. This highlights the necessity for considering the degree of peat humification when interpreting pollen concentration and influx data from peat sites.

Fungal and algal remains diagram

Very low frequencies of fungal and algal remains were recorded for this zone which may, of course, be a direct result of the high degree of humification recorded for this zone. The low representation of fungal and algal remains also appears to be related to the high minerogenic component of the peat matrix (as for the lower half of APB1).

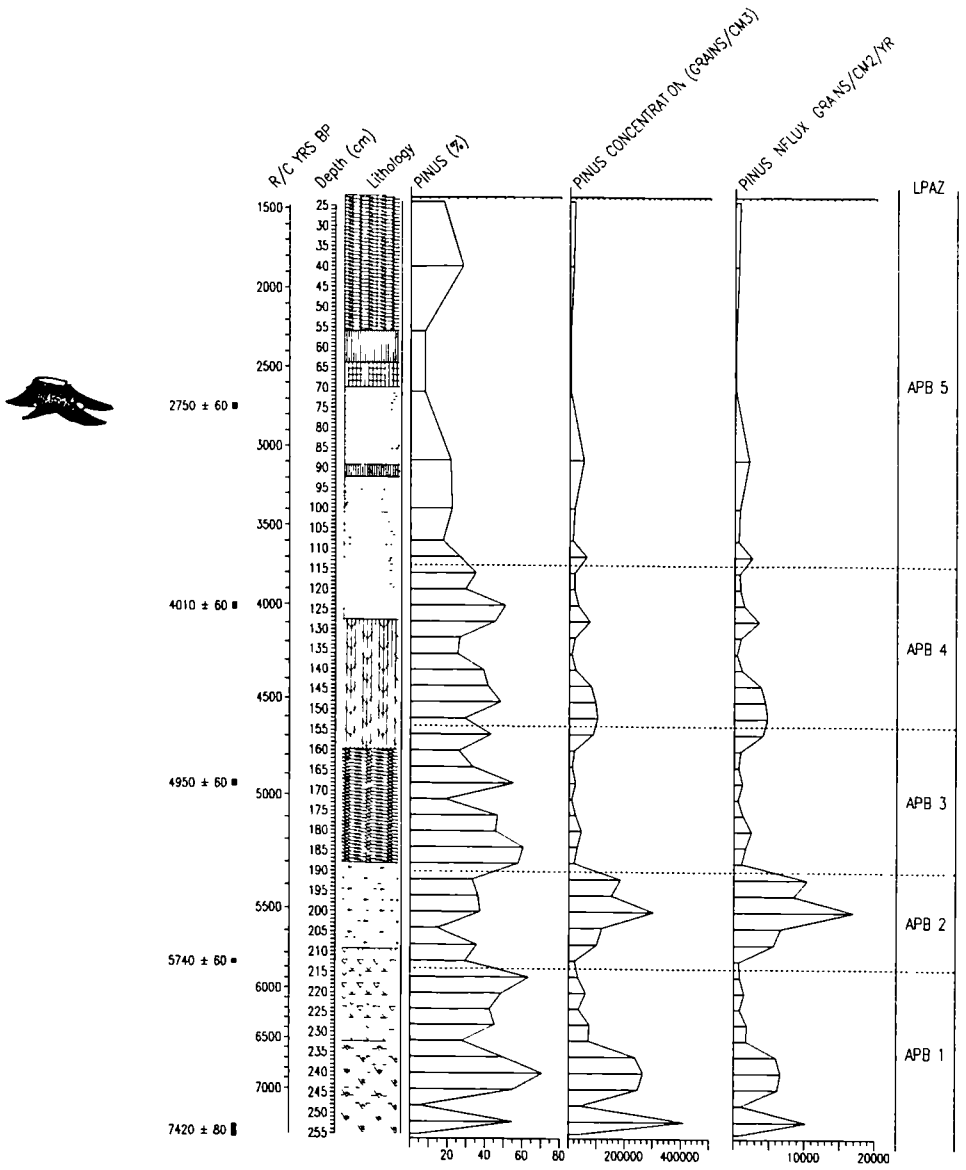
Degree of humification

The low degree of humification at the base of this zone coincides with the presence of a single birch twig. The subsequent sharp increase in humification coincides with a change in lithology to a minerogenic-rich peat matrix.

<u>Summary</u>

The pollen evidence in this zone indicates a relatively open pine woodland with an increase in the importance of the *Calluna* understorey. The pine canopy became most open shortly before *c.*5,600 BP which is supported by the evidence of the increase in Pteropsida (monolete) indet. spore frequencies.

FIGURE 6.10
PINUS POLLEN DATA FOR SITE APB (c.500m OD)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)



The relatively high degree of humification of the peat matrix in this zone coincides with an increase in the minerogenic component of the peat. The inwash (which may be associated with the opening of the pine woodland causing an increase in the run-off from surrounding slopes) may have caused relatively oxygenated conditions at the mire surface resulting in an increase in the breakdown of the peat matrix (and hence a higher degree of humification).

6.1.4.3 LPAZ - APB3 (190-154cm) (*c.* 5338-4646 BP)

Percentage pollen and spore diagram

This zone is characterised by high representation of tree pollen types (78% at the base of the zone) and a rise in the shrub pollen types (to 53% at 172cm).

Pinus pollen is the most frequent pollen type, but shows a decrease in frequency to 19% at 172cm. *Alnus* pollen frequencies are represented at frequencies consistently greater than 2% above 188cm (*c.*5,300 BP) which has been interpreted as indicating local but sparse presence (Huntley & Birks, 1983).

Sphagnum spores reach a maximum frequency of 249% of the total land pollen sum at 176cm.

Pollen concentration and influx diagrams

The pollen concentration and influx values are relatively low at the base of this zone. This coincides with a decrease in the degree of humification (see below) and a change in lithology to a *Sphagnum*-rich peat (*c.*90% *Sphagnum* in the peat matrix).

Betula pollen concentration values fall to a minimum at 169cm (*c.*2,700 grains cm^{-3}). The only species to show a significant increase in the influx and concentration values in this zone is *Juniperus.*

Fungal and algal remains diagram

The fungal and algal remains indicative of wet and dry conditions are represented in this zone. Type 10 frequencies are relatively high between 178cm and 160cm but the maximum frequencies recorded do not coincide with maximum *Calluna* pollen frequencies (see discussion of Type 10 in APB1, Section 6.1.4.1).

The remains of Types 31a and 32 (rhizopods, *Amphitrema flavum* and *Assulina* type respectively) have been shown to indicates shifts to locally wet conditions (e.g. Aaby & Tauber, 1975). Similarly, Van Geel (1978) shows a correlation between the

frequency of Type 31A and the proportion of *Sphagnum* cf. *rubellum* macro-fossils preserved in the peat matrix.

These observations are supported by the fungal/algal evidence presented in this zone. Type 31a rises to 43% (TLP) at 168cm and Type 32 is consistently represented between 188cm and 164cm. There is also a good correspondence with the change to a *Sphagnum*-rich peat (90% *Sphagnum* leaves at 170cm) and maximum frequencies for Type 31a.

Blackford (1990) recorded Type 31A only from levels above apparent major wet shifts. This is not wholly supported by the evidence in this zone, since the major wet shift indicated by the humification evidence (below) between *c.*190cm and *c.*186cm (Figure 6.9) does not correspond with the highest frequencies of Type 31A (between 168cm and 164cm).

Type 32 has also been shown to be generally restricted to *Sphagnum*-rich peats (Van Geel, 1978). Blackford (1990) recorded the first appearance of Type 32 after the significant wet shifts he identified using humification and pollen stratigraphic evidence. This relationship between *Sphagnum* macrofossils and Type 32 is generally supported in this zone, although maximum frequencies of Type 32 do not correspond with the most *Sphagnum*-rich peat. However, the highest frequency of Type 32 (at 188cm) does corresponds with the major wet shift indicated by the humification data (below).

The representation of Type 27 (*Tilletia sphagni*) in this zone supports the evidence that this fungus indicates the local growth of *Sphagnum* (see APB1, Section 6.1.4.1) since there is a good correspondence with the increase in the representation of *Sphagnum* spores and *Sphagnum* leaves and a lower degree of humification of the peat matrix.

Degree of humification

The sharp rise in transmission values (36.5% at 186cm) at the base of this zone indicates a shift to a lower degree of humification. This corresponds with a high proportion *Sphagnum* leaves preserved in the peat matrix. Similarly, the shift to a more humified peat at 165cm coincides with the decline in the proportion of *Sphagnum* leaves in the peat matrix.

Summary

The pollen evidence in this zone indicates the presence of a relatively dense pine woodland with an increase in the importance of the *Calluna* understorey towards the

top of the zone. The appearance of alder at *c.*5,300 BP may represent colonisation at lower altitudes or in isolated locations in moister conditions.

The high frequency of Types 27, 31a and 32 fungal remains in this zone is consistent with a shift to locally wet conditions and generally supports the humification evidence. Van Geel's (1978) interpretation that Type 10 indicates the local presence of *Calluna vulgaris* and relatively dry conditions is not wholly supported by the evidence in this zone. The apparent discrepancy between the Type 10 frequencies and *Calluna* pollen frequencies supports Blackford's suggestion (Blackford, 1990) that this type cannot be reliably used to indicate dry conditions.

The evidence for a shift to a higher degree of humification towards the top of the zone is supported by the increase in *Calluna* pollen frequencies, a decrease in the frequency of the Types 27, 31A and 32 and a reduction in the proportion of *Sphagnum* leaves in the peat matrix.

6.1.4.4 LPAZ - APB 4 (154-114cm) (*c.* 4646-3749BP)

Percentage pollen and spore diagram

The proportion of tree pollen types fluctuates between 47% and 74% in this zone and the shrub pollen component is generally lower (compared to APB 3), falling to 18% at 140cm. There is a gradual rise in the frequency of herbaceous pollen types (reaching 20% at 120cm).

Pinus pollen frequencies show a slight decrease to *c.*25% at 136cm and 132cm and a subsequent decline from 51% at 124cm to 35% at the top of the zone. The lower representation of shrub pollen types is largely a result of the lower *Calluna vulgaris* pollen frequencies (decreasing to 5% at 148cm).

The herbaceous pollen types increase in this zone, and reach 22% at 120cm which is largely a result of the rise in Cyperaceae pollen (to 20% at 120cm). *Ranunculus trichophyllus* type pollen frequencies reach a maximum of 4% in this zone.

Pollen concentration and influx diagrams

The correspondence between pollen concentration and the degree of humification is not so evident in this zone (Figure 6.6). The pollen concentration data may therefore reflect real variations in the pollen influx to the site.

Pollen concentration and influx values decline gradually from a peak at the base of the zone (*c.*356,000 grains cm^{-3} and *c.*16,200 grains cm^{-2} yr^{-1} respectively. Cyperaceae, Poaceae and *Ranunculus* type all show relatively high concentration and influx values at the base of this zone.

Fungal and algal remains diagram

Low frequencies of fungal and algal remains are recorded for this zone with the exception of the small peaks in Types 31a and 32 at 136cm and 120cm which may indicate wetter conditions. This corresponds with lower *Calluna* pollen frequencies, although the relationship does not extend to the low frequencies represented at 148cm.

The rise in Type 28 in this zone coincides with a rise in the frequency of Cyperaceae pollen and a change in the peat matrix to a more sedge-rich peat matrix. However, Van Geel found no clear relation with Type 28 and peat-forming vegetation or humification (e.g. Van Geel, 1972, 1978).

Type 10 is almost absent in this zone apart from the small rise in frequencies at 116cm. This coincides with the decrease in the *Calluna vulgaris* pollen frequencies and the increase in the importance of sedge. The lower frequency of fungal and algal remains in this zone correspond with a higher degree of humification. This supports the idea proposed in Section 6.1.4.2 (APB2), that the preservation potential of the fungal and algal remains appears to be related to the minerogenic component of the peat matrix and the degree of humification.

Degree of peat humification

The transmission values in this zone show small fluctuations about the mean with no strong indications of major changes in the degree of humification. The two macrofossils (*Betula* wood and Ericaceae stem) found between *c.*130cm and 135cm coincide with a slight shift towards a less humified peat matrix.

The peak in the frequencies of Types 31a and 32 at 130cm (mentioned above) corresponds to a shift to a lower degree of humification, however the peaks at 120cm do not appear to support the humification evidence.

<u>Summary</u>

The pollen evidence for this zone indicates a fairly dense pinewood canopy (but less than APB3), particularly at *c.*4,500 BP and just before *c.*4,000 BP. However, the evidence suggests that the pinewood canopy becomes more open towards the top of the zone which is accompanied by an expansion of the *Calluna* understorey.

There is evidence for an increase in the importance of the sedges on the mire surface in this zone (macrofossil evidence suggests this is likely to be *Eriophorum*).

The transmission values represented in this zone indicate small fluctuations about the mean degree of humification for this site, with evidence of a short-term wet shift at *c.*4,250 BP (as indicated by the fungal and algal remains evidence).

6.1.4.5 LPAZ - APB 5 (114-24cm) (*c.* 3749-1458 BP)

Percentage pollen and spore diagram

This zone is characterised by a further rise in the herbaceous pollen types to 33% at 71cm. Tree pollen frequencies fall to a minimum of 28% at 71cm and the shrubs show a gradual increase to 53%. The decline in tree pollen frequencies is largely a result of a distinct fall in *Pinus* pollen percentages at the base of this zone which reach a minimum of 8% at 56cm. *Betula* pollen frequencies rise from 11% at the base of the zone to 25% at 100cm.

There is a general increase in *Calluna* pollen frequencies from 15% at 108cm to 48% at the top of the zone. There is also a small rise in Poaceae and *Ranunculus* type pollen frequencies.

Pollen concentration and influx diagrams

Pollen concentration and influx values are relatively low in this zone, in particular above 88cm. Cyperaceae pollen show a peak concentration value of *c.*34,900 grains cm^{-3} at the base of this zone. *Pinus sylvestris* has extremely low values for both concentration and influx values which supports the percentage pollen data (Figure 6.10).

Fungal and algal remains diagram

Type 10 shows a rise in the lower half of the zone which corresponds with the rise in *Calluna* pollen frequencies but this relationship does not extend to the top of the zone where relatively high *Calluna* pollen frequencies are represented. This may indicate an increase in the regional *Calluna* pollen source towards the top of the zone (as suggested by Blackford, 1990) (see Section 6.1.4.1, APB 1).

The peak at 100cm of Type 28 occurs just below a thin layer of *Eriophorum*-rich peat, and corresponds with high Cyperaceae pollen frequencies. This therefore supports the relationship proposed above (see Section 6.1.4.4, APB 4) and may indicate that the fungus is associated with members of the Cyperaceae family but

further interpretation is not possible in this zone (for example whether the fungus is likely to be associated with the sedge roots or the above ground parts).

Types 31a and 32, probable indicators of wet conditions, are less well represented in this zone, which, together with the small peaks in the frequencies of Types 1 and 3 at 56cm and 40cm respectively (thought to indicate dry conditions, Van Geel, 1978) may indicate a change to drier conditions.

Degree of humification

The humification data shows a shift toward less humified peat at *c.* 65cm which coincides with an increase in *Sphagnum* leaves found in the peat matrix. The Ericaceous twigs identified at 49cm and 22cm are located in the less humified peat. However, the fungal and algal evidence for drier conditions at 56cm and 40cm is not particularly well supported by the humification evidence.

A layer of small pine stumps is located in the section between approximately 70cm and 80cm. This corresponds with the top of a phase of a higher than average degree of humification which commences at *c.*165cm. The shift to less humified peat at *c.*65cm occurs just above the pine stump.

The shift to a lower degree of humification at *c.*65cm corresponds with lower *Pinus* pollen frequencies (Figure 6.10) and a further sub-zone within APB 5 might be justified.

<u>Summary</u>

The pollen evidence in this zone indicates a *Calluna* dominated heath with isolated pine and birch trees. The mire surface is colonised by sedge.

The shift to less humified peat at 65cm is partially supported by the fungal and algal remains data. Since the fungal/algal evidence suggests the local presence of *Calluna* only in the lower half of the zone, this may represent an increase in the regional source of the *Calluna* pollen towards the top of the zone (*cf.* Blackford, 1990).

The pine stump layer does not correspond with relatively high *Pinus* pollen frequencies indicating that the trees were either not producing significantly large quantities of pollen and/or that the density of the pine trees colonising the mire surface (and the surrounding higher, better drained ground) was very low. The humification evidence indicates that pine colonised this site when the surface of the mire had been relatively dry (as indicated by the humification evidence) for

approximately 2,000 years (although the pine stump has not be radiocarbon dated to confirm this estimate). In addition there is evidence for a shift to a less humified peat matrix and a change to a *Sphagnum*-rich peat matrix just above the pine stump (thus supporting the hypothesis of Birks (1975) that pine stumps are often overlain by *Sphagnum*-rich peat).

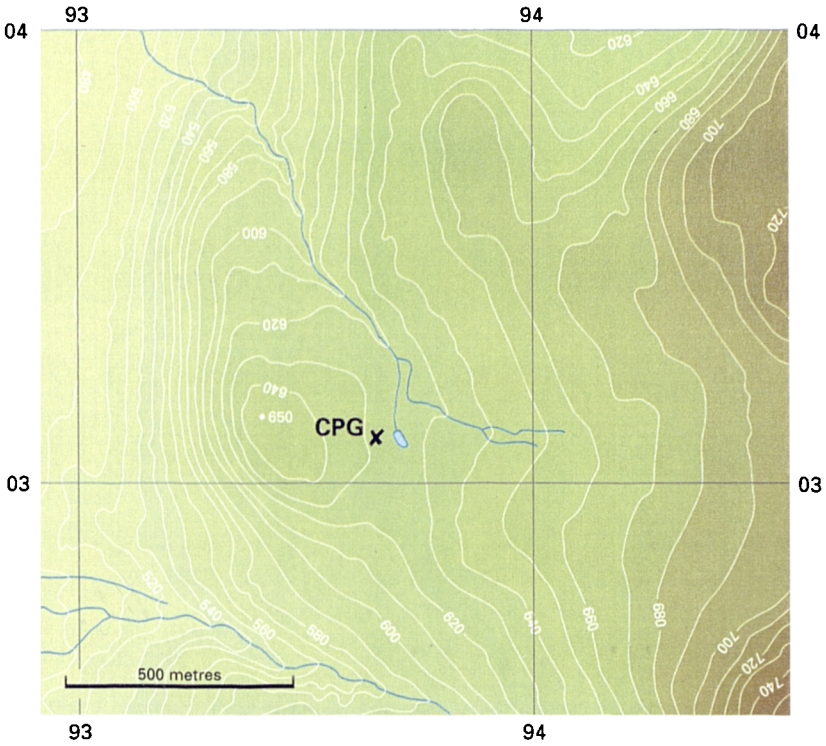


Figure 6.11: Gleann Einich – location of sample site CPG (Carn A-Phris-Ghiubhais) c.630m OD

6.2 CARN A' PHRIS GHIUBHAIS - SITE CODE : CPG (*c.*630m OD) (NGR: NH 936032)

6.2.1 SITE DESCRIPTION

This site is situated in within an area of deeply eroded peat hags surrounding a small lochan which drains to the north (Figure 6.11). The site area was selected because the deep profiles exposed in erosion gulleys contained numerous pine stumps, some of which appeared to form layers. The area was first surveyed to identity the thickest accumulation of peat, using a narrow gouge auger to assess the depth in the middle of the peat hags. Following identification of the thickest peat, the area was systematically probed on a 5m grid system to locate the deepest point (*c.*180cm).

An erosion gulley adjacent to this point was excavated to produce a *c.*1m wide and 180cm deep section, resting on coarse, angular gravels. Since the site is situated on a slope with water drainage away from the site principally to the east, this site can be categorized as a valleyside mire type.

The dominant contemporary vegetation cover at this site is *Calluna* heath, with *Erica tetralix,* grasses, sedges and occasional *Sphagnum* growth in the wetter hollows.

6.2.2 LITHOSTRATIGRAPHY

There appeared to be two layers of pine stumps interstratified in the profile excavated at CPG, one between 140-150cm and the other between 80-90cm. The stumps in the upper layer were generally larger than those in the lower layer. Samples were recovered for dendrochronological analysis, both from the profile and in the immediate vicinity of the site. Very few other wood macrofossils were identified in the section which was very dark and highly humified. The section was sampled using two monolith tins, the lower being approximately 5cm above the coarse pebbles and the upper just below the current vegetated surface.

The following stratigraphy was recorded in the laboratory from the sampled profile recovered from the monolith tins:-

DATUM (0) = TOP OF UPPER MONOLITH TIN

0-21cm Medium dark brown, herbaceous peat with *Eriophorum.* Medium humification. H4; n2-3; Th2; Sh2.

21-44cm Very dark brown, homogeneous peat (occasional *Eriophorum* remains). H7; n3; Sh3; Th1.

44-62cm Medium dark brown, homogeneous peat (occasional *Eriophorum* remains). H4-5; n2-3; Sh3; Th1.

62-77cm Medium dark brown, *Eriophorum* peat with occasional Ericaceous wood fragments. H5-6; n2-3; Th2; Tl1; Sh1.

77-97cm Highly humified, very dark brown to black peat with sedges (*Eriophorum*) and occasional *Sphagnum.* H7; n4; Sh2; Th1; Tb1.

97-100cm Medium dark brown *Eriophorum*-rich peat. H6; n2-3; Th4.

100-110cm Very dark brown to black, homogeneous peat; no distinct plant remains. H7-8; n4; Sh4.

110-122cm Medium dark brown *Eriophorum*-rich peat. H5; n2-3; Th4.

122-126cm Dark brown detrital peat with Ericaceous twigs. H6; n3; Tl3 (Eric); Sh1.

126-140cm Medium brown peat with *Eriophorum.* H4; n2; Th4.

140-146cm Medium brown *Sphagnum* peat. H3-4; n2; Tb4.

146-159cm Very dark brown, homogeneous peat with occasional degraded wood remains (143cm and 147cm, not identified). H6; n3-4; Sh3; Tl1.

159-167cm Highly humified, very dark brown to black (lightening very slightly towards 159cm), crumbly, homogeneous peat. H8; n4; Sh4.

167-169cm Coarse sand with organic staining and oblique but sharp contact with overlying peat. Coarsening upwards. G min 4.

169-171cm Coarse sand with granite inclusions (up to 0.5cm diameter). Some organic staining. G min 2; G maj 2.

171-175cm Coarse sand with occasional organic staining. Small degraded twig at the base (not identified). G min 4.

6.2.3 RADIOCARBON MEASUREMENTS

Five samples were submitted for radiocarbon analysis from the CPG sampled column (see Table 6.1 for laboratory details and results). The samples were selected to obtain radiocarbon age estimates for the following:

i) peat initiation

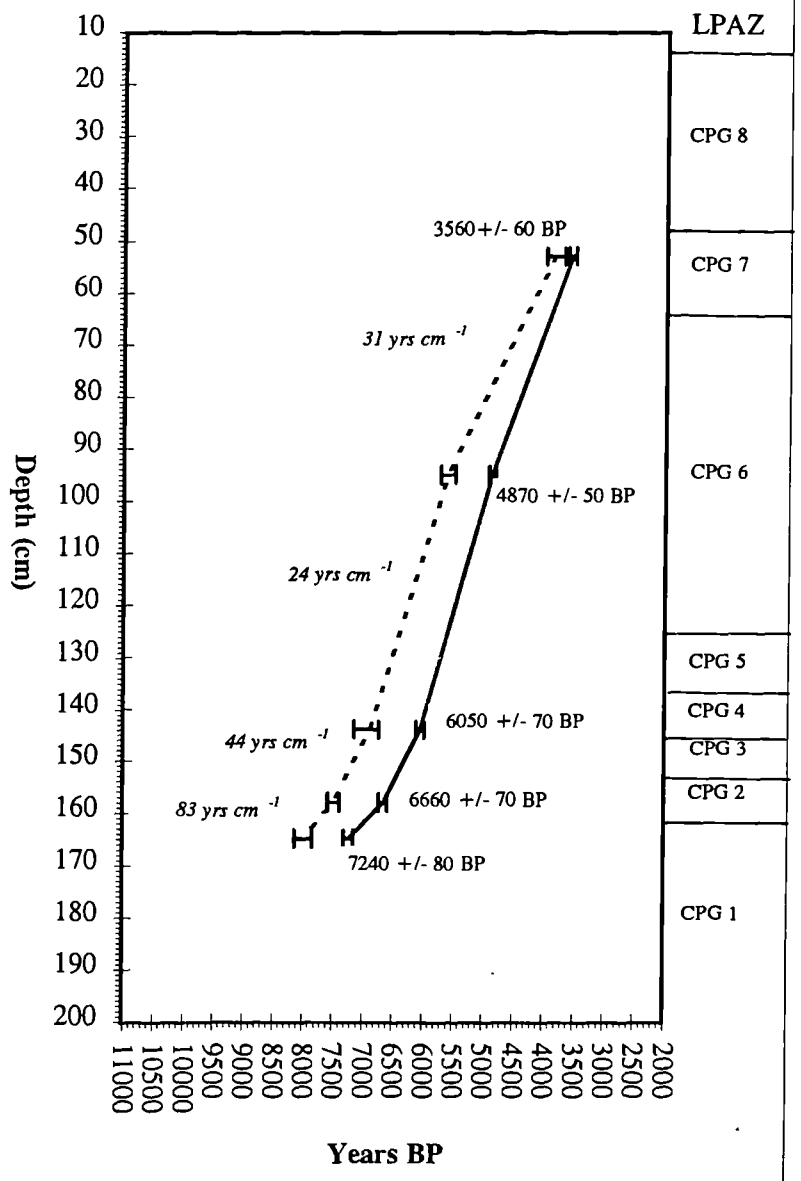
ii) the increase in pine pollen frequencies at *c.*158cm

iii) the base of the second phase of higher pollen frequencies at *c.*144cm

iv) two subsequent age estimates for the remaining part of the sampled column, one at *c.*53cm (estimated to post-date the decline of pine, *c.*4,000 BP) and one at the intervening depth of *c.*95cm (approximately mid-point between the samples at 53cm and 144cm).

The radiocarbon measurements (and the quoted errors representing 1 standard deviation statistics) are shown plotted in Figure 6.12 together with the calculated sediment accumulation rates (or deposition times) and the calibrated ages (2 sigma).

Figure 6.12.
CPG - Radiocarbon measurements (uncalibrated and calibrated) and interpolated peat accumulation rates (expressed in years per cm) plotted against depth (cm)



Radiocarbon years

Calibrated years

6.2.4 LOCAL POLLEN ASSEMBLAGE ZONES

6.2.4.1 LPAZ - CPG 1 (166-161cm) (*c.* 7340-6930 BP)

Percentage pollen and spore diagram **(Figure 6.13)**

This zone is characterised by a rise in the proportion of tree pollen types (31% to 41%) and a fall in the proportion of shrub pollen types (61% to 49%). *Betula* forms the largest component of the tree pollen types and reaches a maximum frequency of 30% at 164cm, whereas *Pinus sylvestris* pollen frequencies are relatively low and remain below 12% in this zone.

Corylus avellana type pollen frequencies fall from 16% to 6% at the top of this zone but *Calluna* forms the largest component of the shrub pollen types (up to 37%).

Cyperaceae and Poaceae pollen are represented at low frequencies in this zone (maximum of 8% and 3% respectively) and there is a small rise in the frequency of Pteropsida (monolete) indet. spores.

Pollen concentration and influx diagrams **(Figures 6.14 and 6.15)**
As at APB, there is a evidence for a correspondence between the degree of humification and pollen concentration at this site, particularly in zones CPG1-CPG5. As for APB, this correspondence will be taken into consideration when interpreting the pollen concentration and influx data.

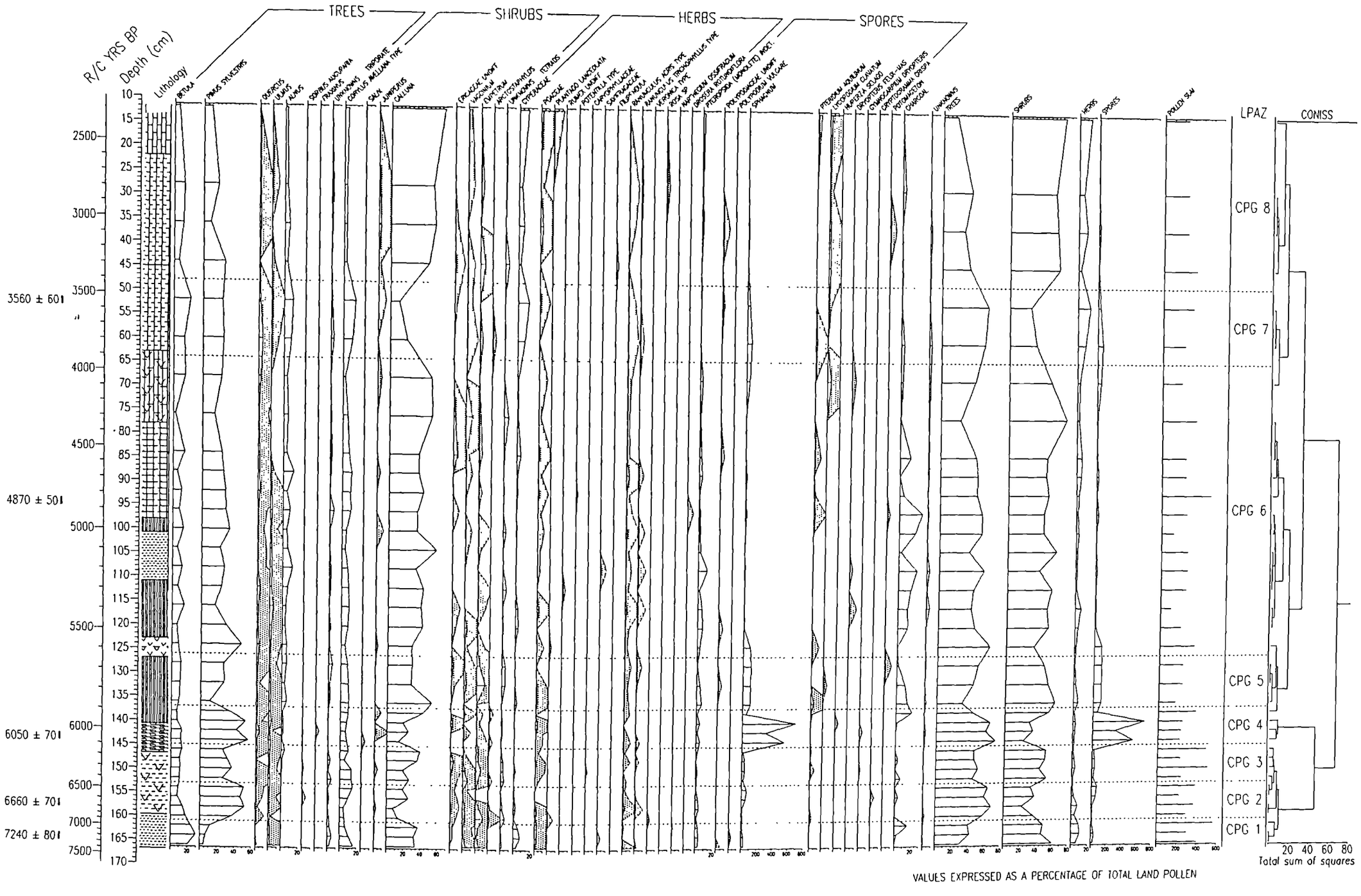
Pollen concentration and influx values are very high at the base of this diagram, reaching a peak of *c.*1,670,000 grains cm^{-3} and *c.*20,000 grains cm^{-2} yr^{-1} respectively. The pollen concentration data in this zone generally supports the evidence presented in the pollen percentage diagram and indicates a relatively dense birch population with *Calluna,* sedges and grasses.

The basal sediment accumulation rate is very low in this zone (*c.* 80 yr cm^{-1}).

Fungal and algal remains diagram **(Figure 6.16)**
Low frequencies of fungal and algal remains are recorded for this zone. Types 2 and 3/3a frequencies rise slightly at the top of the zone. Van Geel (1972, 1978) suggested that the Type 2 fungus are restricted to highly humified peats and Domsch & Gams (1972) observed Type 2 from a variety of modern host material, including *Calluna* heathland soils. Blackford (1990) found these ascospores only in levels of highly humified peat where *Calluna* pollen percentages were high. The rise of Type 2 in this zone corresponds with these observations, as the *Calluna* pollen frequencies

FIGURE 6.13
PERCENTAGE POLLEN AND SPORE DIAGRAM FOR SITE CPG (c.630m OD)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)
SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TAXA



VALUES EXPRESSED AS A PERCENTAGE OF TOTAL LAND POLLEN

FIGURE 6.14 POLLEN CONCENTRATION DIA RAM FOR SITE CPG (.630m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

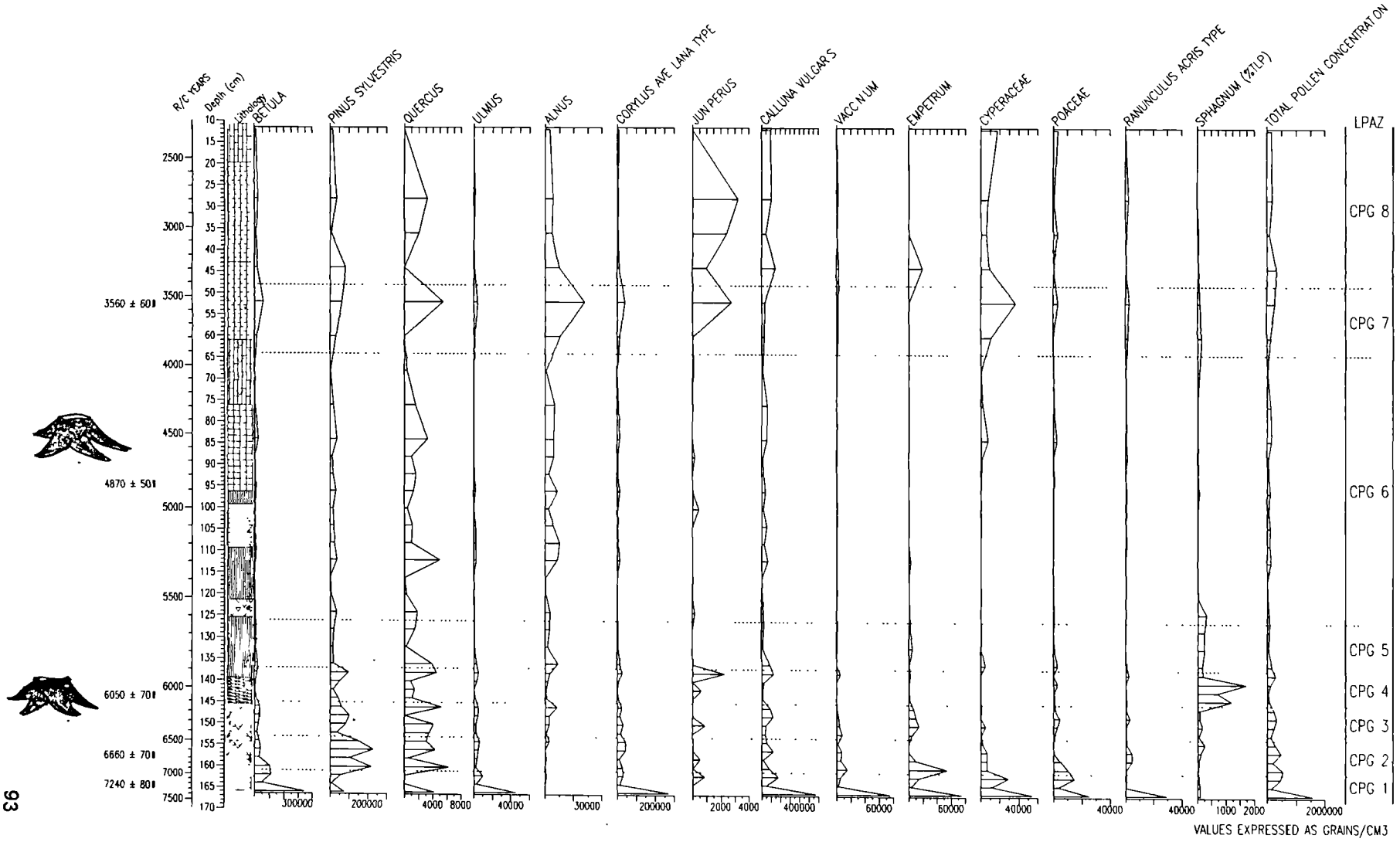


FIGURE 6.16 FUNGAL AND ALGAL REMAINS DIAGRAM FOR STE CPG (c.630m OD (WITH SELECTED POLLEN AND SPORES)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TYPE

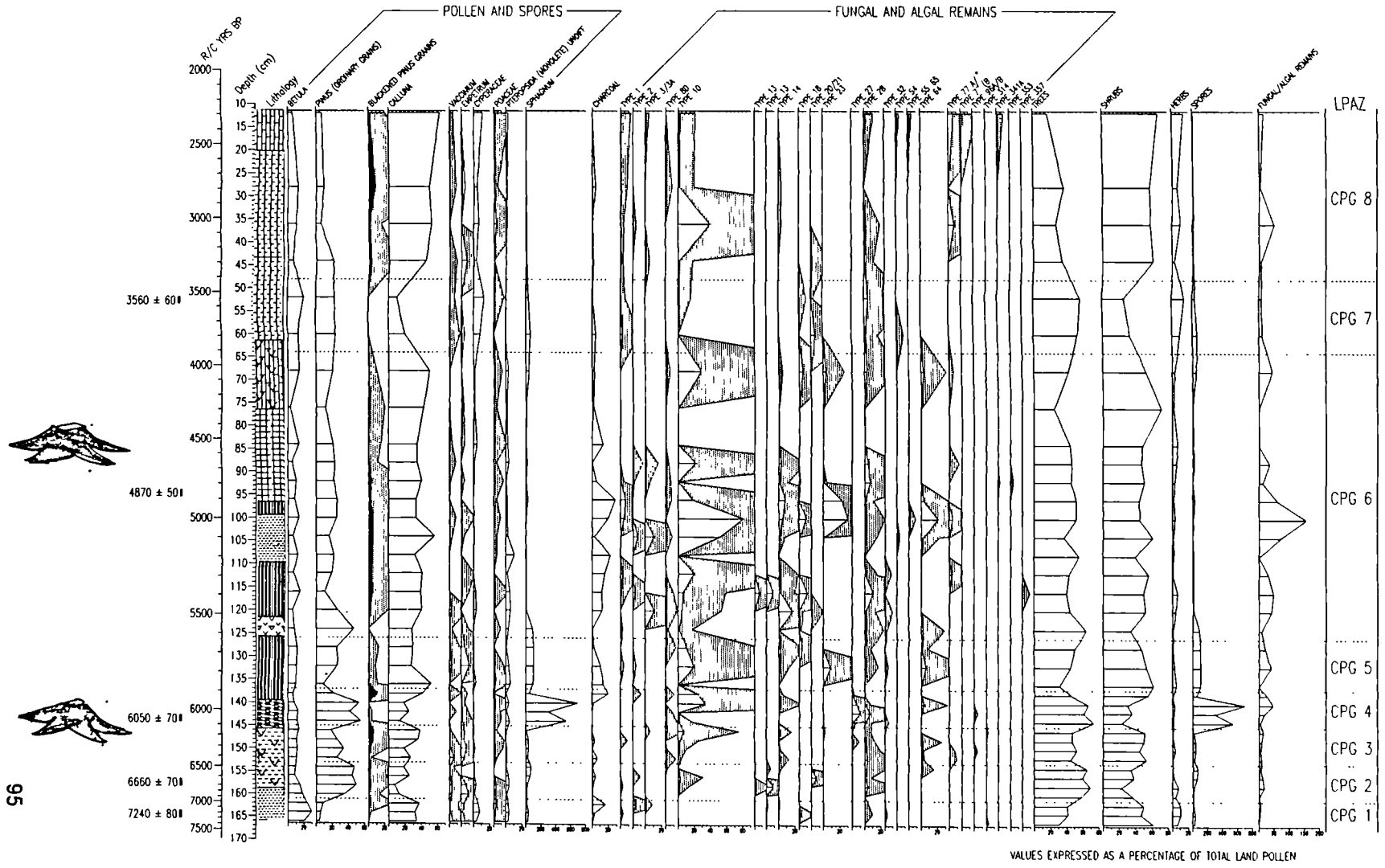
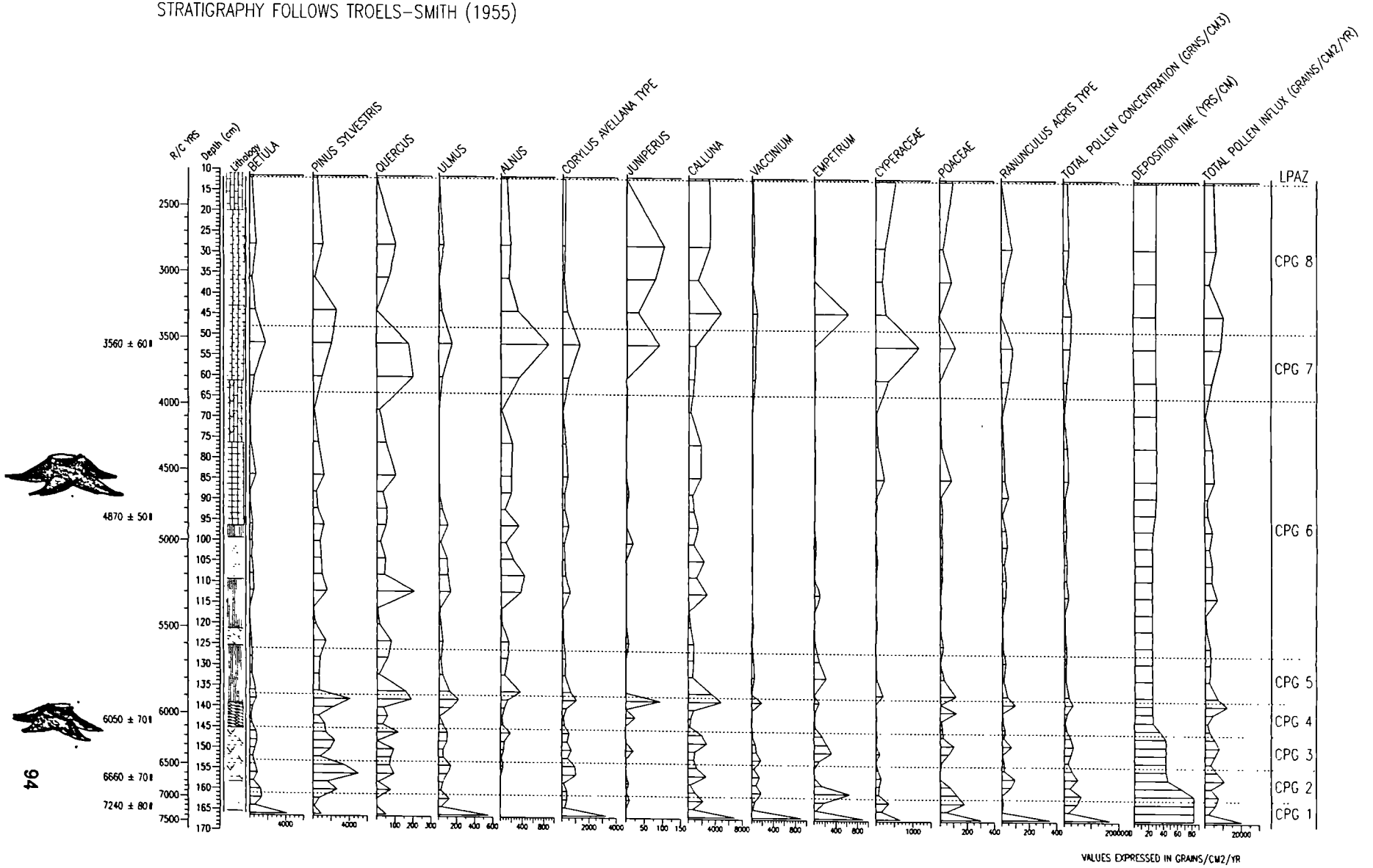


FIGURE 6.15 POLLEN INFLUX DIAGRAM FOR SITE CPG (c.630m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)



are relatively high and the peat matrix shows a high degree of humification. Type 3/3a ascospores are also found in highly humified peat (Van Geel, 1972) and in peat layers formed under very dry conditions (Van Geel, 1978). Type 3/3a are found in very low frequencies at the top of this zone but correspond with the observations of Van Geel.

Degree of humification **(Figure 6.17)**

The single transmission value represented in this zone shows a greater mean degree of humification.

Summary

The pollen-stratigraphic evidence indicates that this zone represents a birch woodland with an understorey of *Calluna* with some grasses and sedges. The few fungal and algal remains present indicate that the conditions are relatively dry which is supported by the highly humified and dark, crumbly consistency of the peat matrix.

6.2.4.2 LPAZ - CPG 2 (161-153cm) (*c.* 6930-6450 BP)

Percentage pollen and spore diagram

This zone shows a high proportion of tree pollen types (up to 70% at 158cm) and a corresponding decrease in the proportion of shrub and herbaceous pollen types (to 23% and 1% respectively). *Betula* pollen frequencies fall from 17% to 9% in this zone and *Pinus sylvestris* pollen frequencies rise to over 50% in the upper half of the zone. *Calluna vulgaris* pollen frequencies fall to a minimum of 8% towards the middle of this zone but this coincides with an increase in the pollen frequencies of some of the other dwarf shrubs such as *Vaccinium* spp., *Empetrum* spp.(9%) and *Arctostaphylos*. The subsequent increase in *Calluna* pollen coincides with a decrease in the frequency of the other dwarf shrubs. There is a reduction in the representation of Poaceae and Cyperaceae pollen in this zone.

Pollen concentration and influx diagrams

The high pollen influx values in this zone (*c.*10,500 grains cm^{-2} yr^{-1}) at 156cm (and to a lesser extent the pollen concentration values) is matched by peak values for *Pinus sylvestris* pollen influx (up to 4,900 grains cm^{-2} yr^{-1}) and concentration values (*c.*229,000 grains cm^{-3}). The *Pinus* pollen data is plotted on an age-depth axis in Figure 6.18 and shows that the percentage and influx/concentration data indicate a relatively high influx of *Pinus* pollen in this zone.

Figure 6.17.
Profile CPG - Degree of humification (expressed as the inverse of percent transmission) plotted against depth (cm). Macrofossils are represented (green = pine; blue = birch; red = Ericaceous)

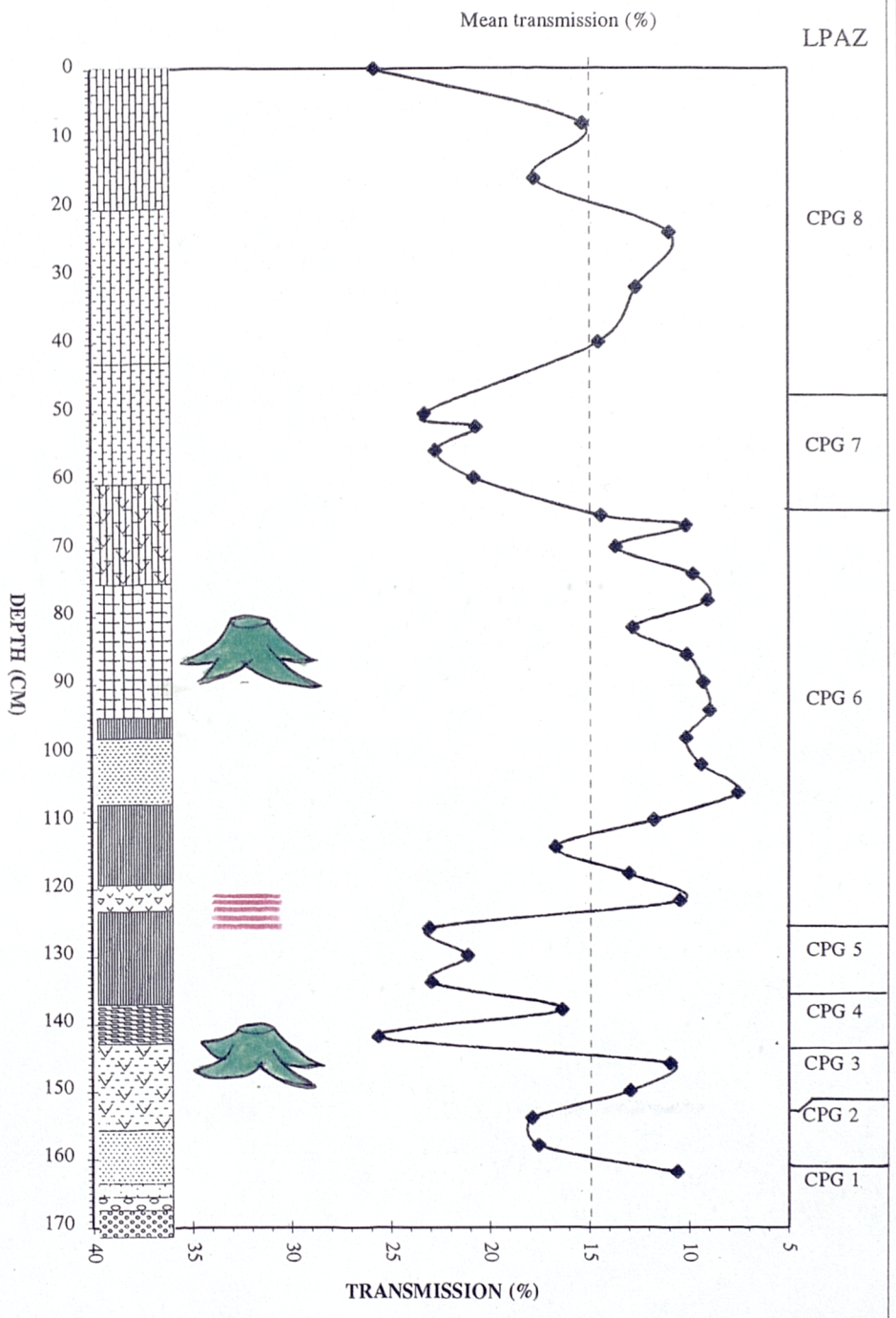
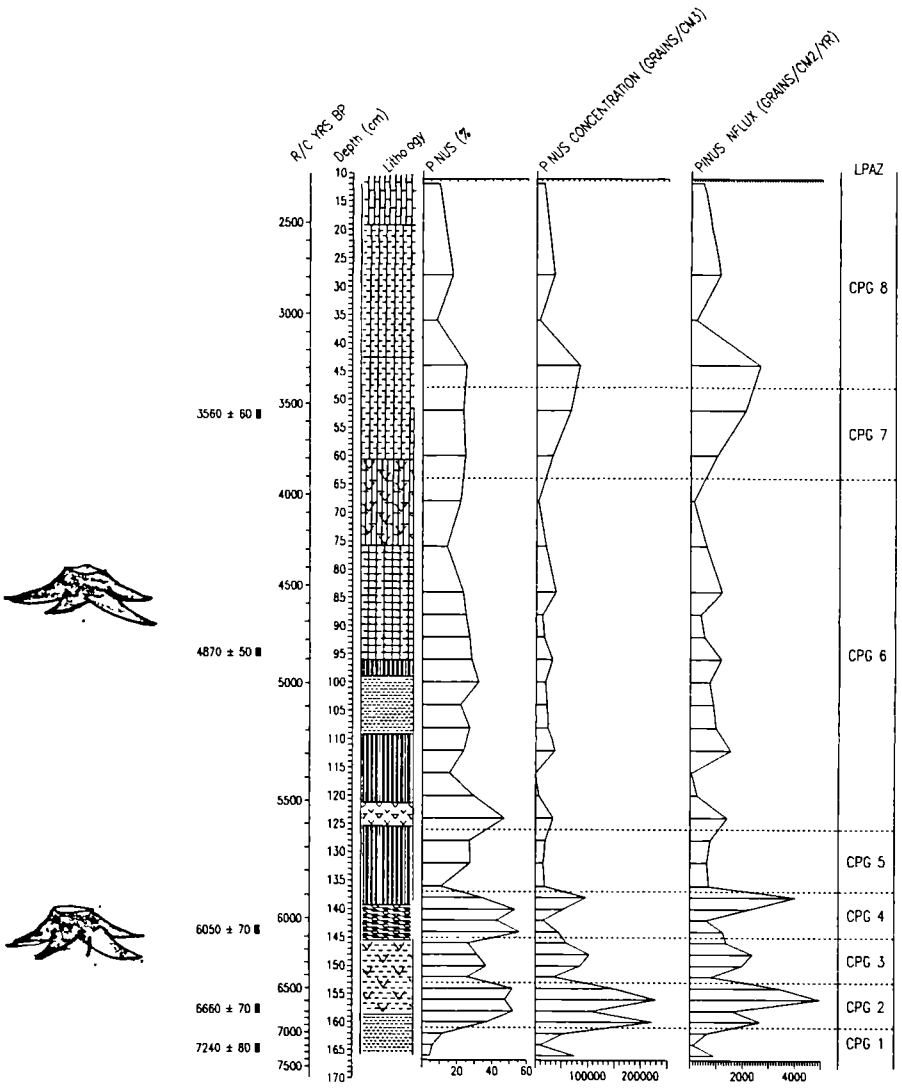


FIGURE 6.18
PINUS POLLEN DATA FOR SITE CPG (c 630m OD)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)



There is a gradual rise in the sediment accumulation rate from *c.*80 yrs cm^{-1} at the base of the zone to *c.*40 yrs cm^{-1} at the top.

Fungal and algal remains diagram

Low values for most types of fungal and algal remains were recorded for this zone. Type 13, the sporangia of a fungus, possibly *Entophlyctis lobata,* (Willoughby and Townley, 1961) shows a small rise at 158cm. Macrofossil analysis by Van Geel (1978) found this fungus to be attached to the leaves of a variety of hosts, such as *Polytrichum alpestre, Scheuchzeria palustris, Calluna vulgaris* and also *Sphagnum imbricatum.* The small peak in Type 13 frequencies in this zone does not enable further interpretation of the palaeoecological significance of this fungus at this stage.

Type 23 shows a small rise in frequency at 156cm but the significance of this fungus is not yet clear, although Van Geel (1978) did show a correlation with ombrotrophic *Sphagnum* peat. There is a small rise in *Sphagnum* spores towards the top of this zone, although there are no *Sphagnum* leaves preserved in the peat matrix so it is not possible to confirm the association with the fungus in this zone.

The presence of Type 10 remains at low frequencies at 156cm corresponds with a slight increase in the *Calluna* pollen frequencies. However, an association with *Calluna* cannot be confirmed since greater *Calluna* pollen frequencies are represented in CPG1 with no representation of the Type 10 fungus (*cf.* Blackford, 1990).

Type 28 is present at very low frequencies but there is no significant rise in Cyperaceae pollen frequencies to support the previous evidence that the two are associated (for example in APB4, Section 6.1.4.4).

There is a gradual increase in the frequency of blackened *Pinus* grains in this zone. This will be discussed further below (in CPG3).

Degree of humification

The two data points within this zone indicate a lower than mean degree of humification.

Summary

The pollen evidence in this zone indicates that pine first colonised this site at approximately 6,850 BP causing a reduction in the existing *Empetrum* cover, and temporarily reducing the *Calluna* understorey. The pollen evidence also indicates

that pine colonisation was relatively rapid at this site, and a dense pine woodland became quickly established.

The palaeoecological significance of the fungal and algal evidence is inconclusive in this zone but the two transmission values suggests a less than average humified peat matrix.

6.2.4.1 LPAZ - CPG 3 (153-145cm) (*c.* 6450-6100 BP)

Percentage pollen and spore diagram

There is a decrease in the proportion of tree pollen types (to *c.*45%) in this zone and a corresponding increase in the percentage of shrub pollen types (to 53%). This is largely a result of the fall in the frequency of *Pinus sylvestris* pollen (to 26%) and the rise in the *Calluna vulgaris* pollen (to 39% at 146cm). *Empetrum* pollen frequencies increase to 6% at 158cm and there is a small peak in *Vaccinium* pollen (6%) at the base of the zone.

The herbaceous pollen types show low values in this zone (between 1% and 3%).

Pollen concentration and influx diagrams

The rise in pollen concentration and influx values in the middle of this zone coincides with a high degree of humification (Figure 6.19) which might provide an explanation for the relatively high *Pinus* pollen values at 148cm.

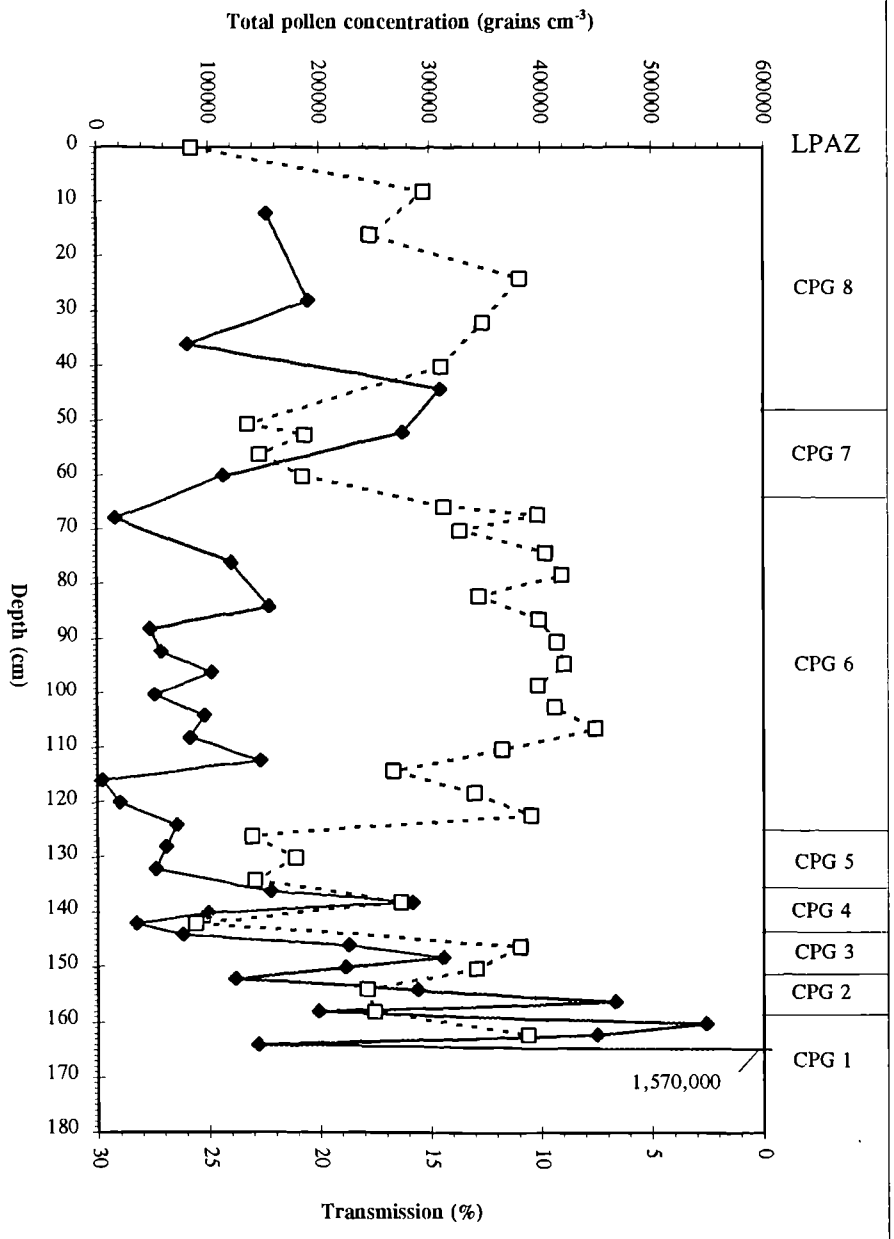
However, in general, the pollen concentration and influx data support the percentage data, showing the reduced influx of *Pinus* pollen to the site and an increase of dwarf shrubs.

Fungal and algal remains diagram

The characteristic feature of the fungal and algal remains in this zone is the rise in frequency of Type 10 and the decrease in representation of Type 28. Type 10 corresponds with the peak in the *Calluna* pollen frequencies (discussed in APB 1, Section 6.1.4.1) and therefore supports the observations of Van Geel (1978).

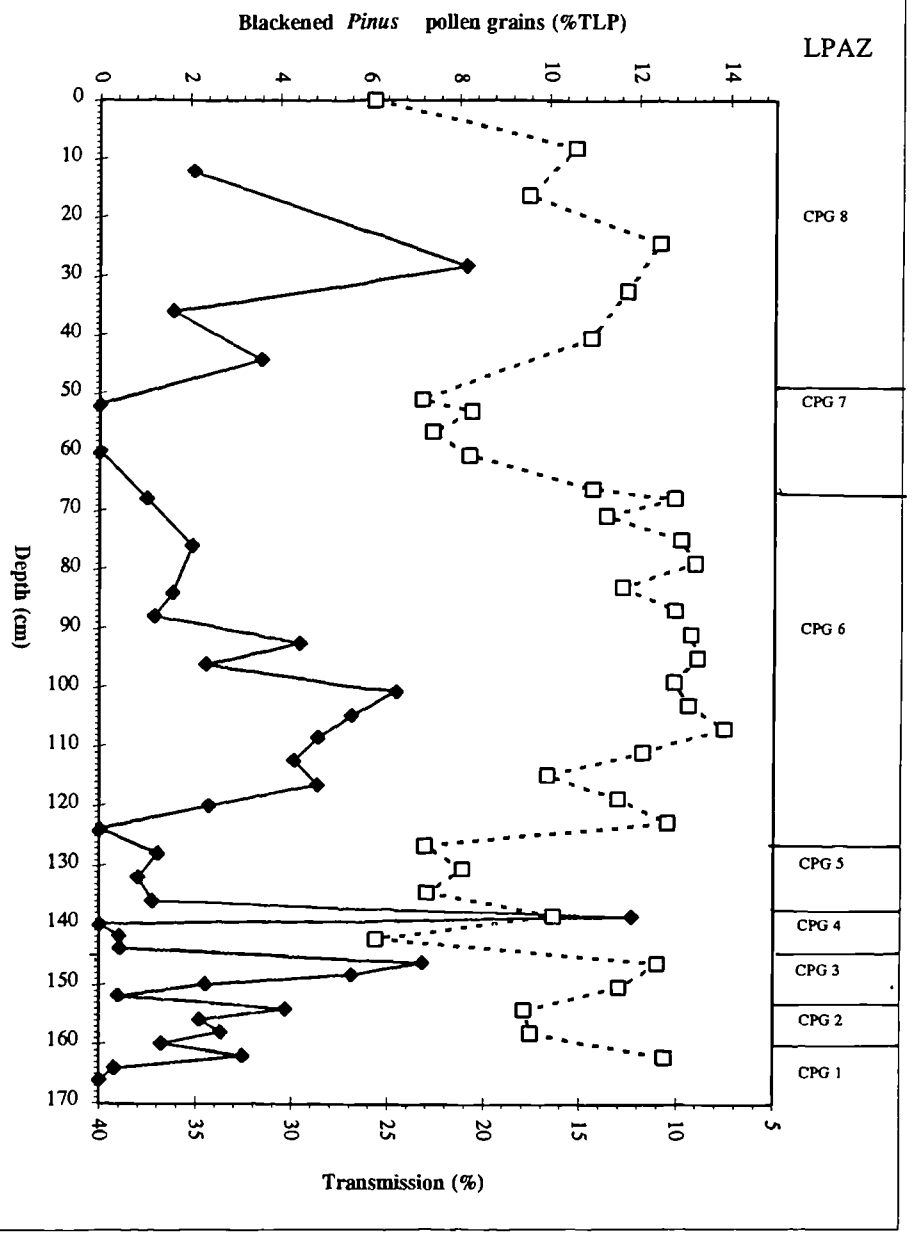
There is a rise in the frequency of blackened *Pinus* pollen grains in this zone particularly towards the top. Figure 6.20 shows the proportion of blackened *Pinus* grains (expressed as % TLP) and the transmission values plotted on a depth axis. A higher frequency of blackened *Pinus* grains are found to correspond with a relatively high degree of humification at this site. In this zone, the increase in blackened *Pinus*

Figure 6.19.
Profile CPG - Degree of humification (expressed as the inverse of percent transmission) and total pollen concentration (expressed as grains cm^{-3}) plotted against depth (cm).



Pollen concentration (grains cm^{-3})
---------- Transmission (%)

Figure 6.20.
Profile CPG - Degree of humification (expressed as the inverse of percent transmission) and the frequency of blackened *Pinus* pollen grains (expressed as a percentage of total land pollen) plotted against depth (cm).



grains also corresponds with high *Calluna* pollen frequencies and a rise in Type 10, both of which are thought to indicate relatively dry conditions.

Degree of humification

The two transmission values represented in this zone indicate a trend towards a higher degree of humification at the top of this zone. This coincides with the presence of a single wood fragment (unidentified) in the sampled column. The pine stump roots (recorded in the peat profile) coincide with the high degree of peat humification recorded at the top of the zone.

Summary

The pollen evidence indicates that this zone represents an open pine woodland and an increase in the importance of the *Calluna* understorey. The greater *Calluna* cover indicated towards the top of the zone corresponds to a reduction in *Vaccinium,* and to a lesser extent, the *Empetrum* cover.

The increase towards the top of the zone of fungal and algal remains indicative of drier conditions corresponds with a shift towards a higher degree of humification.

6.2.4.4 LPAZ - CPG 4 (145-137cm) (c. 6100-5890 BP)

Percentage pollen and spore diagram

This zone is characterised by a high proportion of tree pollen types at the base (74% at 144cm) but a decrease towards the top (45% at 138cm). The opposite trend occurs for the shrub pollen frequencies, with the lowest representation at the base of the zone (23 at 144cm). The herbaceous pollen types show a low representation in this zone (maximum of 7%).

The peak in *Pinus* pollen frequencies at 144cm (56%) corresponds with the mid-point of the pine stump located in the peat profile between 140cm and 150cm. The increase in *Pinus* pollen values is equated with a decrease in the proportion of *Calluna* pollen frequencies (13% at the base of the zone but rising to 42% at the top) and very low frequencies of *Empetrum* and *Vaccinium* pollen are represented.

A high frequency of *Sphagnum* spores are represented in this zone (a maximum of 692% of total land pollen) but only a few *Sphagnum* leaves were found (approximately 10% of the peat matrix at 145cm) to support the micro-fossil evidence.

Pollen concentration and influx diagrams

The low pollen concentration and influx values represented towards the base of this zone coincides with a shift to a lower degree of peat humification (Figure 6.19) and a peak in the frequency of *Sphagnum* spores (and presence of *Sphagnum* leaves at the base of the zone).

The *Pinus* pollen concentration and influx data supports the percentage data and indicate the local presence of pine (Figure 6.18). However, the peak in *Pinus* pollen percentages at 144cm is not matched by the concentration values. The peak in *Pinus* coincides with the decrease in the degree of humification between 146cm and 142cm (see below) and the change to a fresher peat (with *Sphagnum* leaves at 145cm). The change to a more highly humified peat at the top of the zone corresponds to high *Pinus* pollen concentration values but relatively low *Pinus* pollen percentages.

Fungal and algal remains diagram

This zone is characterised by a high frequency of Types 27 and 28 in the lower half of the zone and an increase in Type 10 (and a small rise in Type 140 towards the top of the zone. Types 10 may indicate relatively dry conditions (see Section 6.1.4.1, APB 1) and Type 14 (ascospores of *Meliolo* cf. *niessleana*) has also been associated with *Calluna vulgaris.* Van Geel (1978) found remains of Type 14 on the leaves of *Calluna* (but not from modern material). However, Blackford (1990) found no clear relationship between Type 14 and the frequency of Ericales type pollen in samples analysed from blanket peats and concluded that other factors must be important in determining its distribution. The rise in Types 10 and 14 at 138cm in this zone corresponds with relatively low *Calluna* pollen frequencies and therefore supports the observations of Blackford (1990).

Type 27 (*Tilletia sphagni*) frequencies rise to a peak at 142cm which coincides with the rise in *Sphagnum* spores (but occurs just above the *Sphagnum* leaves observed at 145cm). This relationship supports the observations of Dickson (1973) and Van Geel (1978) (Section 6.1.4.1, APB1). However, Blackford (1990) found no consistent parallel relationship between Type 27 spores and *Sphagnum* spores but the relationship did hold for some of the peat layers investigated.

Very few blackened *Pinus* pollen grains were found between 144cm and 138cm (Figure 6.20). This corresponds with the sharp decrease in the degree of humification at 142cm (see below), an increase in *Sphagnum* spores frequencies, and an decrease in *Calluna* pollen frequencies. Similarly, the sharp increase in the

proportion of blackened *Pinus* grains at the top of the zone corresponds with a change to a high degree of humification which suggests that the blackening of the *Pinus* pollen grains is related to the hydrological conditions of the mire surface. This feature will be discussed further in Section 6.5.2.3.

Degree of humification

The two transmission values represented in this zone indicate an increase in the degree of humification in the upper half of the zone. The low degree of humification at 142cm coincides with the presence of a single pine twig at 143cm, the top of the pine stump (between 140cm and 150cm.) and the presence of *Sphagnum* leaves in the peat matrix. The evidence for a shift to a lower degree of humification at 142cm is supported by the corresponding increase in Types 27 and *Sphagnum* spores. The subsequent shift to a more humified peat at 138cm corresponds with the rise in frequency of Types 10 and 14 and the increase in the proportion of blackened *Pinus* grains.

Summary

The pollen-stratigraphic evidence in this zone indicates the presence of a relatively dense pine woodland with a *Calluna vulgaris* understorey. The pine canopy becomes more open towards the top of the zone (*c.*5,900 BP) with a corresponding expansion of *Calluna vulgaris.*

The shift to a less humified peat at the base of the zone is supported by the preservation of *Sphagnum* leaves in the peat matrix and an increase in the representation of wet-indicating fungal and algal remains. The subsequent shift to a more humified peat is again supported by the evidence of the fungal and algal data, with an expansion of Types 10 and 14.

The top of the pine stump in this zone coincides with the shift to a lower degree of humification and the presence of *Sphagnum* in the peat matrix, indicating wetter, less humified conditions are favourable for the preservation of the stumps.

6.2.4.5 LPAZ - CPG 5 (137-126cm) (*c.* 5890-5620 BP)

Percentage pollen and spore diagram

This zone is characterised by a gradual increase in the frequency of tree pollen types (31% at the base of zone rising to 50% at the top) and a corresponding decrease in the frequency of the shrub pollen types.

The frequency of *Pinus sylvestris* pollen rises from 11% at the base of the zone to 27% at the top. *Alnus* pollen frequencies are recorded at values consistently greater than 2% above 136cm (*c.*5,850 BP) (thought to indicate the local occurrence of alder, *cf.* Huntley & Birks, 1983).

The decrease in the representation of the shrub component is largely a result of the fall in *Calluna vulgaris* pollen percentages (from 52% at the base of the zone, to 29% at the top). *Empetrum* pollen frequencies increase in this zone (to 10% at 132cm) together with a small rise in *Vaccinium* pollen frequencies.

The herbaceous pollen component remains low (maximum for this zone is 5% at 136cm) and the spore component is largely composed of *Sphagnum,* which along with the small rise in Pteropsida (monolete) indet. spores frequencies at 136cm, corresponds with the lower representation of *Pinus* pollen frequencies at the base of the zone.

Pollen concentration and influx diagrams

The pollen concentration and influx decrease to low values at the top of this zone (to *c.*55,000 grains cm^{-3} and *c.*2,300 grains $cm^{-2}\ yr^{-1}$ respectively) which coincides with a lower degree of humification (Figure 6.19). The concentration and influx data generally support the evidence represented in the percentage diagram (described above) including the increase in the importance of *Empetrum* in this zone.

The *Pinus* pollen data indicate a decrease in the influx of *Pinus* pollen in this zone (Figure 6.18).

Fungal and algal remains diagram

This zone is characterised by a peak in the frequency of Types 10, 23 and 64 in the middle of this zone. Type 10 frequencies correspond with a slight increase in the degree of humification at 130cm (see below) but again maximum Type 10 frequencies do not coincide with maximum *Calluna* pollen frequencies.

The peak in Type 64 (*Phaengellina empetri*) corresponds with the peak in *Empetrum* pollen frequencies. Van Geel (1978) correlated Type 64 with the presence of macroscopic remains of *Empetrum nigrum* and since *P. empetri* forms and sporulates on the above ground parts of *Empetrum,* any correspondence with the pollen rain is likely to be more dependable (Ellis & Ellis, 1985; Blackford, 1990). The presence of *P. empetri* can therefore be used as an indicator of the local presence of *Empetrum* which is indicative of relatively dry conditions (Blackford, 1990). However, the transmission values (below), indicate a relatively low degree of humification during this zone. There is only a slight shift towards a higher degree of humification corresponding to the increase in *Empetrum* pollen and Type 64 frequencies .

Type 23 frequencies increase at the same level as the rise in Type 64 frequencies. However, Type 23 has been correlated with both ombrotrophic *Sphagnum* peat and higher frequencies of *Erica tetralix* (Van Geel, 1978) and the evidence provided in this zone does not provide any further evidence regarding its significance.

The increase in the Type 18 frequencies at the top of this zone corresponds with the increase in Type 14 and a small rise in Cyperaceae pollen frequencies.

The relatively low frequency of blackened *Pinus* grains in this zone corresponds with a shift to a lower degree of humification (Figure 6.20).

Degree of humification

The three transmission measurements from this zone indicate a relatively low degree of humification. This is supported well by the fungal and algal remains data but there is a trend towards the top of the zone of a decrease in the types indicative of relatively dry conditions, such as Types 10 and 64.

Summary

The pollen evidence in this zone indicates a very open pine woodland at the base of this zone (*c.*5,850 BP) with an understorey dominated by *Calluna vulgaris.* The subsequent gradual increase in the density of pine woodland corresponds with a short-term expansion of the *Empetrum* cover (at *c.*5,750 BP) and reduction in the importance of the *Calluna* understorey.

The transmission values indicate a relatively low degree of humification in this zone. Although the fungal and algal remains data do not show any strong evidence for a shift towards wetter conditions there is a reduction in types indicative of relatively dry conditions towards the top of the zone.

6.2.4.6 LPAZ - CPG 6 (126-64cm) (*c.* 5620-3910 BP)

Percentage pollen and spore diagram

The proportion of tree and shrub pollen types fluctuates through this zone and the herbaceous pollen types are represented in relatively low frequencies.

Pinus sylvestris pollen frequencies decrease from 47% at the base of this zone to *c.*20% at the top. This corresponds with an general increase in the frequency of *Calluna vulgaris* pollen which reach a peak of 56% at 104cm.

Pollen concentration and influx diagrams

The pollen concentration and influx values are relatively low in this zone, both decreasing to a minimum at 116cm, despite the relatively high degree of humification (Figure 6.19). This is also shown by the *Pinus sylvestris* pollen concentration and influx data, which fall to a minimum at 116cm and corresponds to a low *Pinus* pollen frequency (Figure 6.18). The presence of the pine stump between 80cm and 90cm does not correspond with high *Pinus* pollen frequencies and concentration influx values (in contrast to the relationship shown with the pine stump located between 140cm and 150cm).

Fungal and algal remains diagram

This zone is characterised by high frequencies of fungal and algal remains, reaching a peak of almost 150% of the total land pollen sum at 100cm.

The majority of the fungal and algal remains represented are indicative of relatively dry conditions. There is a peak in values for Type 10 and Type 64 at 100cm, although the latter does not coincide with a significant rise in *Empetrum* pollen frequencies (see Section 6.2.4.5, CPG 5). Other indicators of drier conditions include Types 1, 2, 3/3a, and 14.

Van Geel (1978, 1980/81) observed that Type 1 (*Gelasinospora* spec) reached highest frequencies in highly decomposed peat containing charcoal layers. The increase in Type 1 values at 96cm, 100cm and the small rise at 112cm, supports Van Geel's observations since there is a correspondingly higher proportion of charcoal at these levels.

There are few fungal or algal remains indicative of relatively wet conditions. The increase in the values for Type 18, which Van Geel (1978) correlated with *Eriophorum vaginatum* peat (see Section 6.2.4.4, CPG4), does not coincide

significantly well with the Cyperaceae pollen curve. However, the rise in Type 18 frequency at 100cm occurs just below a *Eriophorum*-rich peat layer between 97-98cm.

Type 23 reaches high frequencies at 100cm and 96cm but the palaeoecological significance of this fungus is not clear (see Section 6.2.4.2, CPG2). However, like Type 18, Type 23 frequencies may be related to the *Eriophorum*-rich peat layer (between 97-98cm).

Higher Type 28 frequencies are again found to correspond with higher Cyperaceae pollen frequencies which supports the earlier suggestion of an association (although higher Type 28 or Cyperaceae pollen frequencies are not associated with the *Eriophorum*-rich layer between 97-98cm).

There appears to be an inverse relationship between the proportion of blackened *Pinus* grains and the frequency of *Pinus* pollen in this zone (also shown in part in the zones CPG1-CPG5). However, the correspondence between the blackened *Pinus* grains and the degree of humification (Figure 6.20) appears not to be significant in this zone since there is a decrease in blackened *Pinus* pollen towards the top of the zone, despite the consistently high degree of humification. This suggests that the cause of the blackening of the *Pinus* grains may be a combination of a variety of factors.

Degree of humification

The shift, at the base of the zone, from a low to a high degree of humification corresponds with the presence of Ericaceous twigs in the sampled column. The degree of humification for the remainder of this zone is consistently high , despite the presence of *Sphagnum* leaves at 80cm (*c.*10% of the peat matrix).

The position of the pine stump in the peat profile between 80-90cm is not associated with any major change in humification values but does occur immediately below the *Sphagnum*-rich peat at 80cm and towards the top of a phase of relatively highly humified peat.

Summary

The pollen stratigraphic evidence indicates a relatively dense pinewood canopy at the base of the zone and a subsequent gradual opening of the canopy shortly after *c.*5,500 BP which is associated with an increase the importance of the *Calluna* understorey. The pine stump located between 80cm and 90cm in the profile (not

radiocarbon dated) indicates the local growth of pine on the mire surface but corresponds to relatively low *Pinus* pollen frequencies (<*c.*20%).

The evidence for relatively high humification values in this zone is supported by the fungal and algal remains, the majority of which indicate drier conditions (e.g. Types 1, 2, 3, 10 and 14).

The pine stump/root is located towards the top of a phase of highly humified peat and is immediately below a *Sphagnum*-rich peat layer . It also corresponds to a decrease in the frequency of fungal/algal remains indicative of relatively dry conditions. This supports the observations of Birks (1975) that the pine stumps found at Loch Einich tend to occur at the top of relatively humified peat with *Sphagnum* rich peat overlying the stumps.

6.2.4.7 LPAZ - CPG 7 (64-48cm) (*c.* 3910-3410 BP)

Percentage pollen and spore diagram

This zone is represented by only two pollen spectra but is characterised by the increase in the proportion of trees pollen types and a decrease in the proportion of shrubs pollen types. This appears to be largely a result of the increase in *Betula* pollen frequencies (to 20%) and *Alnus* pollen (to 10%) and a corresponding decrease in *Calluna vulgaris* pollen to 11%.

The herbaceous component increases to 15% which reflects the increase of Cyperaceae pollen frequencies to 13%.

Pollen concentration and influx diagrams

Pollen concentration and influx values increase in this zone to *c.*280,000 grains cm^{-3} and *c.*9,000 grains cm^{-2} yr^{-1} respectively which corresponds to a decrease in the degree of humification (Figure 6.19). This is in contrast to the trends observed in the lower zones (CPG1-5) and the pollen concentration and influx values in this zone are therefore likely to reflect real changes in the pollen influx to the site.

The rise in *Pinus* pollen concentration and influx values in this zone, therefore might indicate an increase in *Pinus* pollen influx, which is not clearly demonstrated by the percentage *Pinus* pollen values (Figure 6.18).

Fungal and algal remains diagram

Very low frequencies of fungal and algal remains are represented in this zone. The small rise in Type 28 frequencies corresponds to the rise in Cyperaceae pollen

frequencies and supports the association proposed earlier (for example in Section 6.1.4.3, APB3), although the peat matrix is not particularly sedge-rich. This may indicate that Type 28 is only associated with the above ground parts of the sedge plant.

Type 20/21 is present in low frequencies but shows no significant correspondence with other types or pollen frequencies, humification, etc. Apart from *Empetrum* being a possible host (Van Geel, 1978) no ecological significance has be assigned to these fungi and Blackford (1990) noted that there was no particular pattern in the distribution of this group of fungi.

This zone can therefore be characterised by a decrease in the frequency of fungal and algal remains, and in particular, a decrease of the types indicative of relatively dry conditions.

Very few blackened *Pinus* grains were found in this zone which strengthens the suggestion proposed here that the blackened grain frequency is related to the relative degree of humification of the peat matrix.

Degree of humification

The four sampled transmission values in this zone indicate a relatively low degree of humification which corresponds with the evidence for a reduction of fungal and algal remains indicative of relatively dry conditions.

Summary

The pollen evidence in this zone indicates a sedge-rich mire with occasional isolated birch and pine trees (probably extending to the better drained surrounding ground). The expansion of Cyperaceae corresponds to a reduction in the importance of the *Calluna* cover and other dwarf shrubs.

The transmission values indicate a relatively low degree of humification of the peat matrix which corresponds with a poor representation of dry indicating fungal/algal remains and blackened *Pinus* grains.

6.2.4.8 LPAZ - CPG 8 (48-12cm) (*c.* 3410-2290 BP)

Percentage pollen and spore diagram

This zone is characterised by a decrease in the representation of tree pollen types and a high proportion of shrub pollen types.

Betula, Pinus sylvestris, Alnus and *Corylus avellana* type pollen frequencies all decline to low values towards the top of this zone. There is a corresponding increase in *Calluna vulgaris* frequencies which rise to 63% at 12cm and a small peak of 6% *Empetrum* pollen at 44cm. *Juniperus* and Poaceae pollen are present at very low frequencies and Cyperaceae pollen frequencies are lower at the base of this zone but rise to 11% at 12cm.

Pollen concentration and influx diagrams

There appears to be no significant correspondence between pollen concentration values and the degree of humification in this zone, although only four pollen spectra are represented which limits such an interpretation. The concentration and influx diagram generally supports the trends observed in percentage diagrams indicating the increase in the importance of *Juniperus* and Poaceae pollen in this zone.

The *Pinus* pollen data (Figure 6.18) shows evidence for a decease in the *Pinus* pollen influx to the site during this zone and again supports the evidence of the percentage data.

Fungal and algal remains diagram

Type 77a (*Geoglossum sphanophilum*) frequencies increases in this zone. Van Geel (1978) noted that Type 77a was more frequent in *Sphagnum* cf. *rubellum* peat and Blackford (1990) noted a distinct peak in the distribution of this type similar to the distribution of the microfossil record of Cyperaceae and/or *Sphagnum.* Whilst very few *Sphagnum* spores were observed in this zone there is a consistent presence of Cyperaceae pollen. However, in the previous zone (CPG 7), higher Cyperaceae pollen frequencies are recorded but there is no corresponding increase in the frequency of Type 77a.

There is a peak in the values for Type 10 at 36cm which corresponds with the rise in *Calluna* pollen but does not extent to the higher frequencies of *Calluna* pollen represented at 12cm and 26cm. As suggested earlier (Section 6.4.1.1, APB 1) Type 10 has been found associated with the roots of *Calluna vulgaris* (Van Geel, 1978) so

the increase in the *Calluna* pollen frequencies towards the top of this zone may indicate a wider source area for the pollen.

The high frequency of blackened *Pinus* grains represented in the upper two spectra, correspond to a higher degree of humification (Figure 6.20).

Degree of humification

The degree of humification rises to a peak in the middle of this zone followed by a trend to a less humified peat matrix towards the top of the zone.

Summary

The pollen evidence in this zone indicates the presence of a *Calluna* dominated heathland with sedge. *Empetrum* is present towards the base of the zone but its exclusion corresponds with the increase of *Calluna* cover. There is a small increase in the frequency of *Juniperus* and Poaceae but this probably represents isolated Juniper bushes and sparse grass cover.

The increase in the degree of humification towards the middle of this zone is associated with an increase of fungal/algal remains indicative of relatively dry conditions.

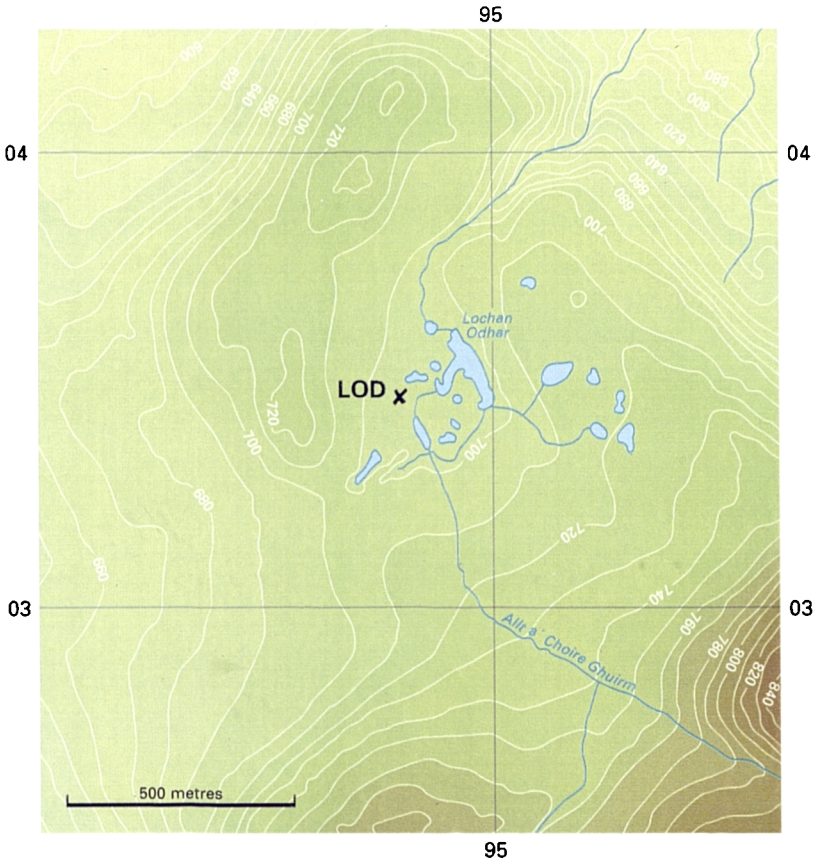


Figure 6.21: Gleann Einich – location of sample site LOD (Lochan Odhar) c.700m OD

6.3 LOCHAN ODHAR - SITE CODE : LOD (*c.*700m OD) (NGR: NH 947034)

6.3.1 SITE DESCRIPTION

Lochan Odhar, and the surrounding small pools, are situated in a very shallow basin at an altitude of *c.*700m OD. Higher ground lies to the west and the southeast (Figure 6.21) and the main drainage channel runs to the Northeast. Deep peat hags are located around Lochan Odhar, and the gullying appears to be related to drainage into the Lochan.

Numerous pine stumps were identified within the peat sequences at Lochan Odhar, but they were restricted to the relatively shallow blanket peat towards the periphery of the mire. Although it would have been ideal to choose a sampling profile from a section with pine stumps interstratified within the peat, priority was given to obtaining as deep a profile as possible. Following field walking to identify areas of deep accumulation of peat, an area was probed on a 5m grid system to locate the deepest profile (265cm). An adjacent erosion gully was dug to form a section approximately 250cm deep and 100cm wide. Three monolith tins were required to sample the profile, from the base, which incorporated the minerogenic sands and gravels, to the top, just below the current vegetated surface.

The nearest stumps to the site, approximately 100m to the east, were sampled for dendrochronological investigation. Although these stumps were not directly related to the sampled profile, dendrochronological investigations were carried out to attempt to cross-match the trees on a local and regional scale. Subsequent radiocarbon dating would enable the stumps to be related to the sampled profile.

The site receives run-off from the higher ground to the west and drainage away from the site is predominantly to the east. The site can be categorised as a valleyside mire type, but due to its proximity to Lochan Odhar, LOD can be expected to show characteristics of the basin mire type. The contemporary dominant vegetation cover is *Calluna vulgaris, Vaccinium myrtillus, Empetrum nigrum* and a variety of grasses.

6.3.2 LITHOSTRATIGRAPHY

The following stratigraphy was recorded in the laboratory from the samples recovered from the monolith tins:

DATUM (0) = TOP OF UPPER MONOLITH TIN

0-17cm Medium brown, *Eriophorum* peat. H3; n2; Th4.

17-92cm Very dark brown to black, *Eriophorum*-rich peat. Occasional *Sphagnum* leaves in matrix. H5-6; n4; Th3; Tb1

92-100cm Very dark brown, *Sphagnum-Eriophorum* peat. H5; n3-4; Tb2; Th2.

100-146cm Very dark brown, *Sphagnum* peat. Pine wood macrofossil at 134cm (7cm in length). H4; n3-4; Th4; Tl $^{+}$.

146-168cm Very dark brown to black, herbaceous peat with occasional sedges and wood fragments. Small birch macrofossils present, e.g. 164cm but decreasing in frequency towards 146cm. Ericaceous macrofossils between 159cm and 167cm. H5; n4; Th2; Tl2.

168-183cm Dark brown (becoming darker towards 167cm) *Eriophorum*-peat with occasional wood fragments. Small birch twigs present (e.g. 179cm & 171cm). H6; n3-4; Th2; Sh1; Tl1.

183-190cm Medium brown, sedge peat with sand-sized minerogenic inclusions. Occasional remains of grasses and *Carex* seeds. H3-4; n2-3; Th2; g min 2.

190-200cm Light brown, *Sphagnum*-rich peat with high proportion of sand-sized minerogenic inclusions. Sedge present. H3; n1; Tb3; g min 1; Th^{+}.

200-218cm Very pale brown, fine grained sand with organic staining. Diffuse contact over *c.*1cm with lower unit. Organic staining decreasing towards 200cm. Occasional remains of sedges, grasses and *Sphagnum.*
N1; g min 3; Th1; Tb^{+}.

218-230cm Dark brown, fibrous peat (sedges and grasses). Diffuse contact with lower coarse sand unit. Occasional *Sphagnum* leaves present at 220cm.
H3; n3-4; Th3; Tb1.

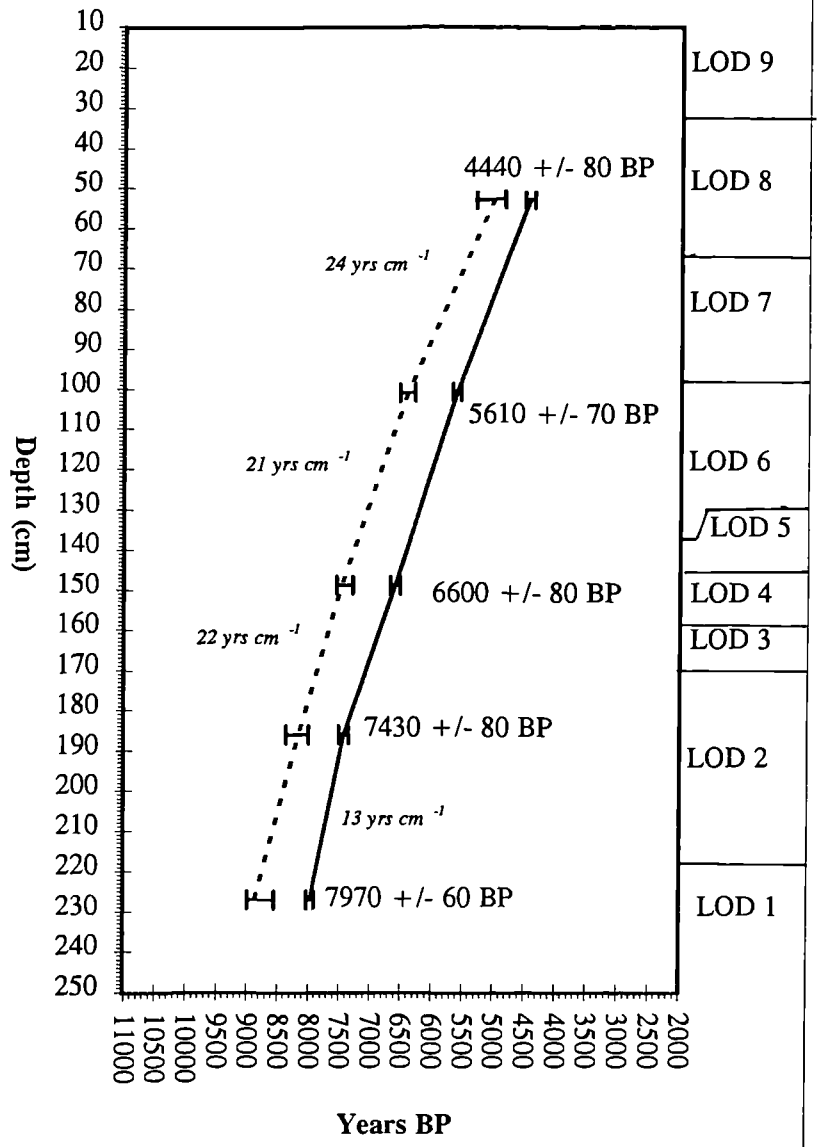
230-250cm Coarse sands and gravels (mainly quartzite). G maj 4.

6.3.3 RADIOCARBON MEASUREMENTS

Five samples were submitted for radiocarbon analysis from the LOD sampled column (see Table 6.1 for laboratory details and results). The strategy for selection of the samples was to obtain radiocarbon age estimates at approximately equal depth intervals (*c.*45-50cm) below 52cm (the pollen diagram indicates that 52cm post-dates the decline of pine, *c.*4,000 BP). The basal sediments of this site are the oldest recovered from any of the four Gleann Einich sites. The lowest radiocarbon date (*c.*7,970 BP) is taken from the lowest organic rich sediment. Linear extrapolation from the upper radiocarbon age estimate indicates that the top of the section dates to approximately to 3,500 BP, which suggests that the top of the profile may be absent. If this is so the profile may have been subject to erosion or cutting (although it is rather remote from human settlement for the latter to be significant in the recent historic period).

The radiocarbon measurements (and the quoted errors representing 1 standard deviation statistics) are shown plotted in Figure 6.22 together with the calculated sediment accumulation rates and the calibrated ages. The calibration results are shown in Table 6.1.

Figure 6.22.
LOD - Radiocarbon measurements (uncalibrated and calibrated) and interpolated peat accumulation rates (expressed in years per cm) plotted against depth (cm)



Radiocarbon years

Calibrated years

Linear interpolation between the radiocarbon dates shows that the sediment accumulation rate is fairly constant (between 22 yr cm^{-1} and 24 yr cm^{-1}) above 187-188cm (*c.*7430 BP). The faster accumulation rate of 13 yr cm^{-1} below 187-188cm corresponds approximately with the top of the alternating layers of organic-rich peat, minerogenic-rich peat and fine sands (see lithostratigraphy above).

Dendrochronological analysis was undertaken on sub-fossil pine stumps from the sites investigated at Gleann Einich and Beinn Dearg (as discussed in Section 5.2.7). Although no pine stumps were located in the sampled profile at LOD, pine stumps were sampled from the periphery of the basin mire. Dendrochronological analyses indicate that five of the seven stumps investigated show evidence for a significant cross-matching of the tree rings (see Appendix 5.3). The samples ranged between 96 years and 151 years in length and were combined into a 161 year site chronology. To test these results two of the samples (LODW 4 and LODW 6) were submitted for radiocarbon analysis to check the accuracy of the dendrochronology results.

The radiocarbon age estimates for LODW 4 and LODW 6 are 6,270 +/- 80 yrs BP and 6,440 +/- 70 yrs BP respectively. The radiocarbon date obtained by Dubois & Ferguson (1985) for a pine stump at the similar altitude of 730m but from a north facing slope on the northern flank of the Cairngorms is 7,350 +/- 85 BP. So this predates the two pine stumps from the vicinity of LOD as well as the pollen-stratigraphic evidence for the local colonisation of pine at LOD (*c.*6,800 BP). This may be due to the possibility that pine not only reached higher altitudes on the north facing slopes in the northern Cairngorms, but also that pine may have colonised the northern Cairngorms at an earlier date than at the LOD site. The dates reported here for the LOD stumps fall into the timespan for which Dubois & Ferguson (1985) report a dearth of pine stumps in the region.

6.3.4 LOCAL POLLEN ASSEMBLAGE ZONES

6.3.4.1 LPAZ - LOD 1 (228-218cm) (*c.*7980-7850 BP)

Percentage pollen and spore diagram **(Figure 6.23)**

This zone is characterised by a high proportion of tree pollen types (57% at the base of the zone) and herbaceous pollen types (up to 34% of TLP).

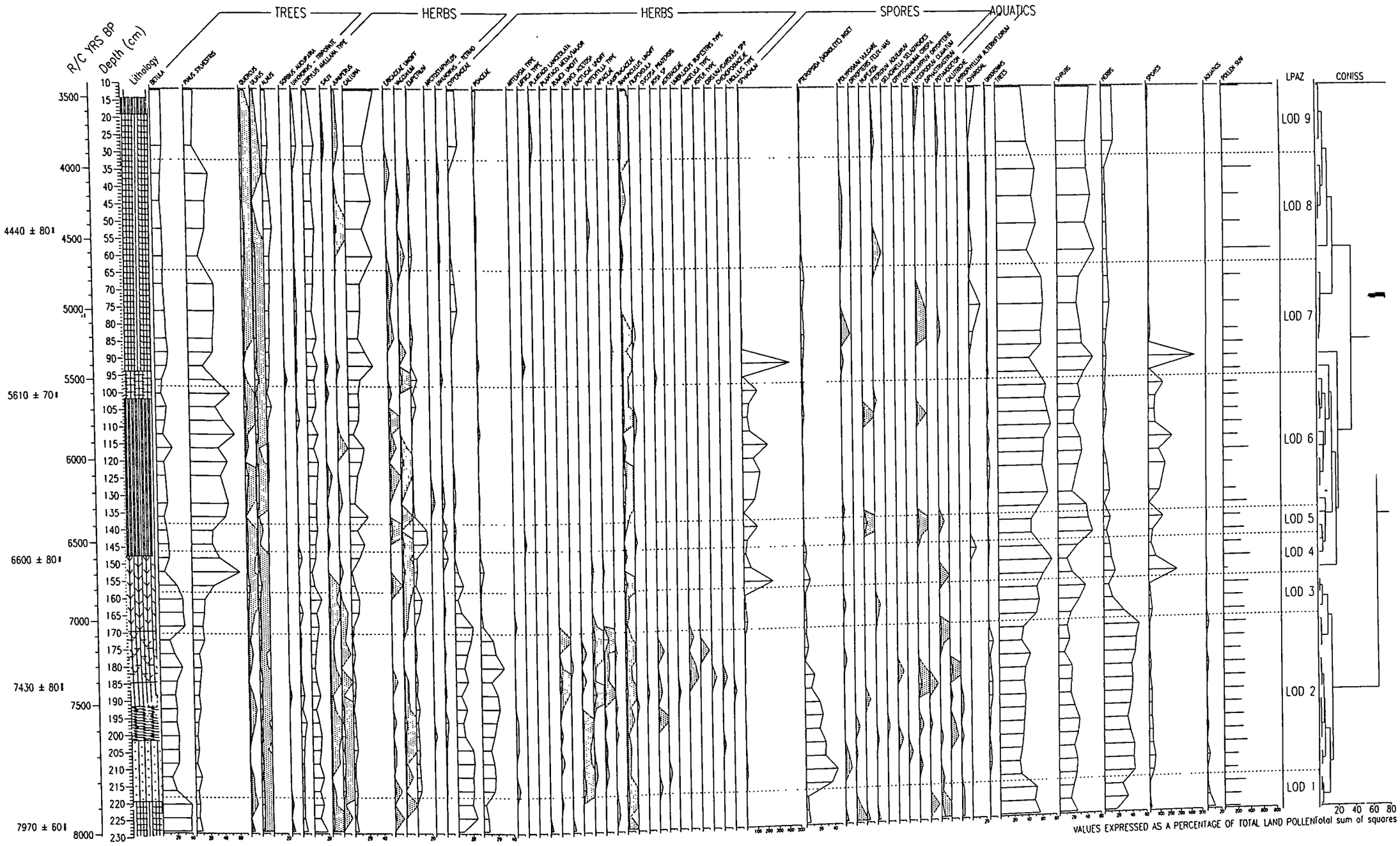
Betula is the most frequent component of the tree pollen types represented in this zone (up to 40%) and the shrub component shows a relatively high proportion of *Corylus avellana* type pollen (18% at the base). *Salix* pollen is represented at low frequencies in this zone, reaching a maximum of *c.*2.5% is at 224cm.

FIGURE 6.23

PERCENTAGE POLLEN AND SPORE DIAGRAM FOR SITE LOD (c.700m OD)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TAXA



Cyperaceae pollen frequencies show a peak of 26% at 224cm and Poaceae pollen is consistently represented in this zone (reaching a maximum of 7%).

Aquatic pollen types are represented at the base of this zone (for example *Potomageton* and *Myriophyllum alterniflorum*).

Pollen concentration and influx diagrams **(Figures 6.24 and 6.25)**
In general this profile does not demonstrate a significant correspondence between the pollen concentration variations and the degree of peat humification, particularly below *c.*100cm (Figure 6.26). The pollen concentration and influx data presented for this site, therefore, might provide a reliable indication of real variations in pollen influx to the site, or alternatively, the proximity of the lochan may be influencing the height of the water table of the site, and hence the depth of the acrotelm.

Terrestrial pollen concentration and influx values decline towards the top of this zone from *c.*120,000 grains cm^{-3} and *c.*9,000 grains $cm^{-2}\,yr^{-1}$ at the base respectively. This is reflected in the maximum values for *Betula*, *Salix* and Cyperaceae pollen at the base of the zone.

Fungal and algal remains diagram **(Figure 6.27)**
Very few fungal and algal remains are represented in this zone. Type 3/3a, indicative of highly humified peat and relatively dry conditions (Van Geel, 1978; see Section 6.2.4.1, CPG 1) is recorded at low frequencies but is not associated with a high degree of humification (see below).

Type 28 is present at very low frequencies (which limits the interpretation of its presence) but there is a corresponding increase in Cyperaceae pollen frequencies which supports earlier observations (e.g. APB3, Section 6.1.4.3 and CPG7, Section 6.2.4.7).

Degree of humification **(Figure 6.28)**
The four transmission values in this zone show evidence for a relatively low degree of humification.

FIGURE 6.24 POLLEN CONCENTRATION DIAGRAM FOR SITE LOD (c.700m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

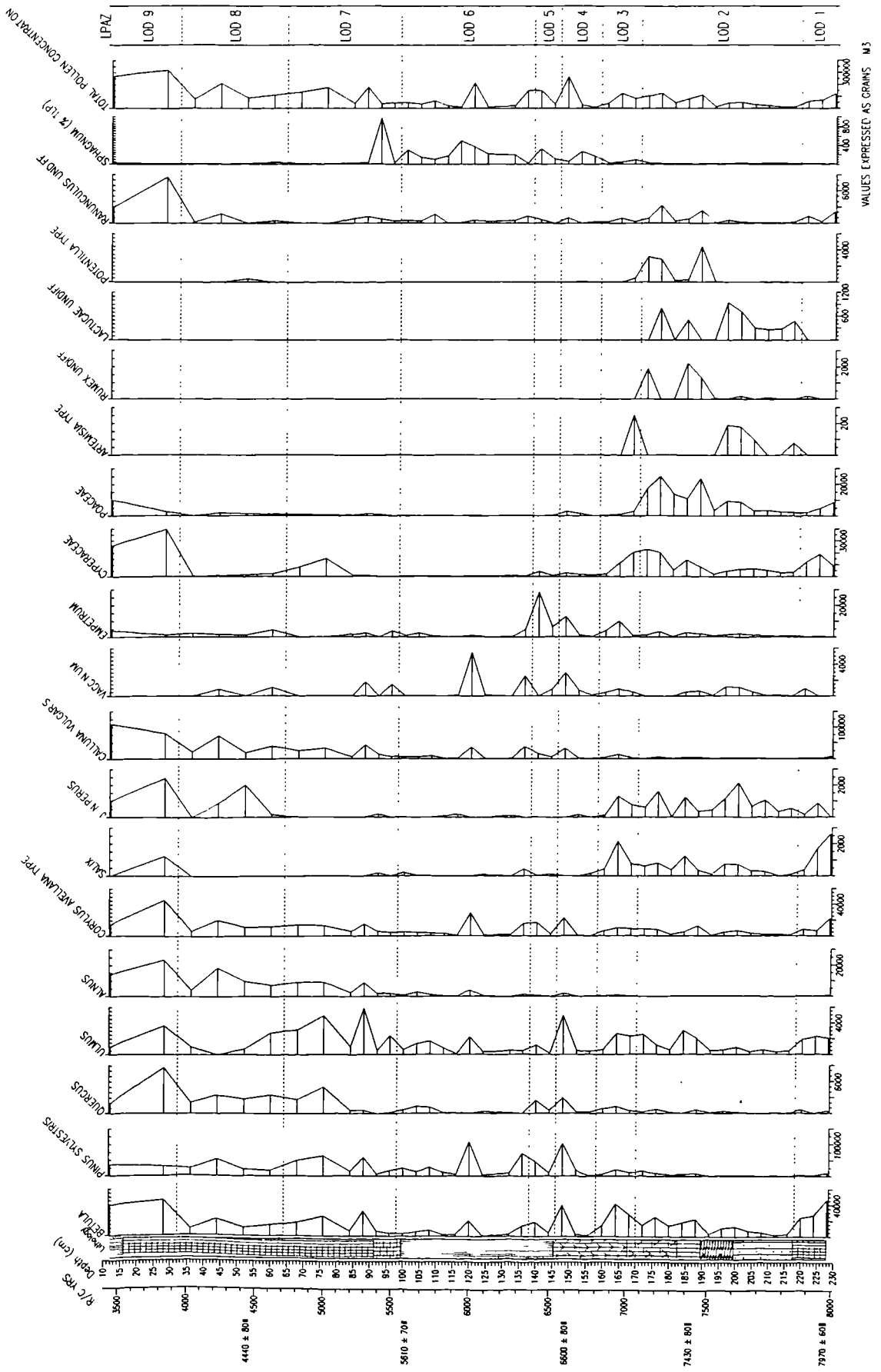


FIGURE 6.25 POLLEN INFLUX DIAGRAM FOR SITE LOD (c.700m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

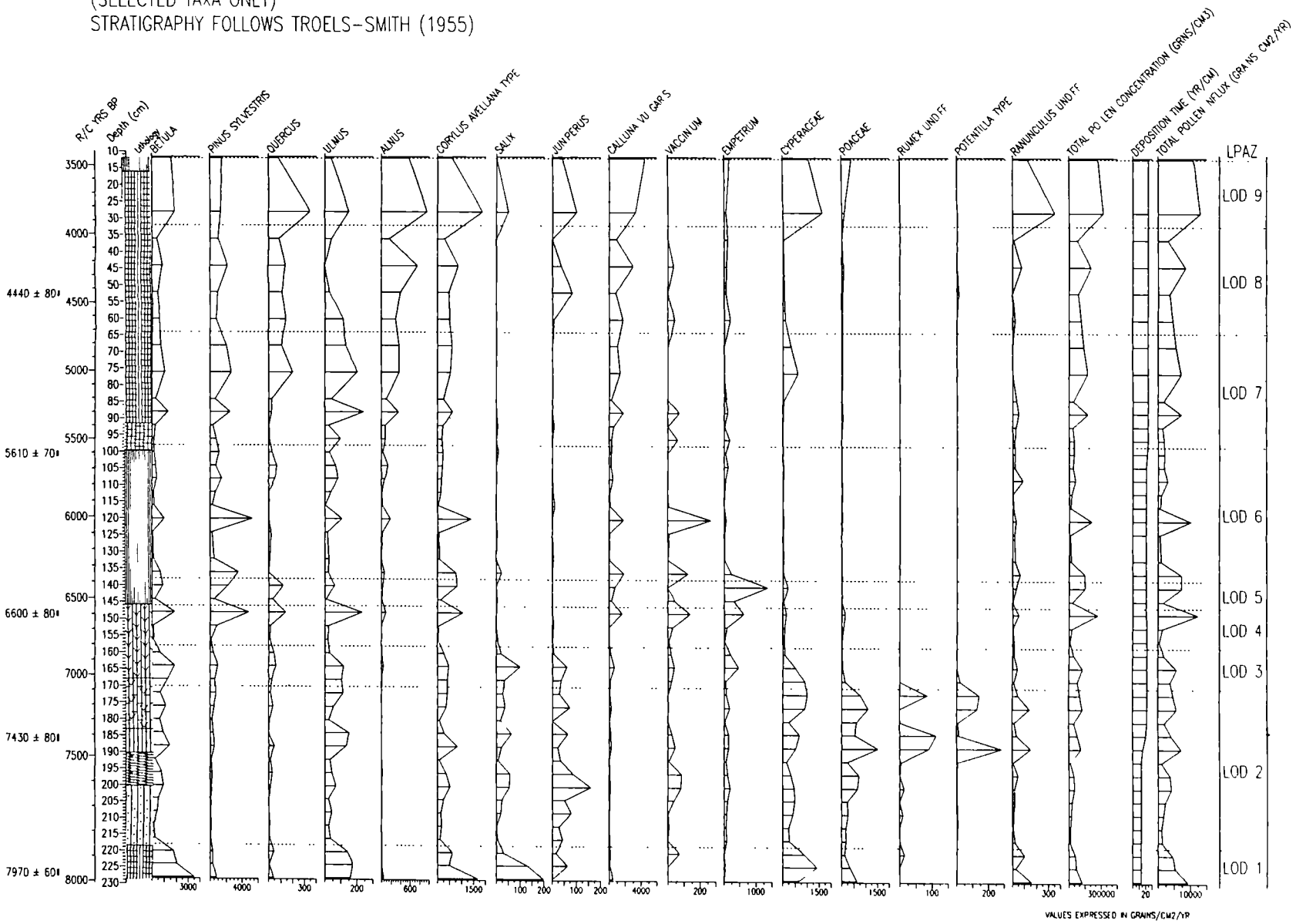
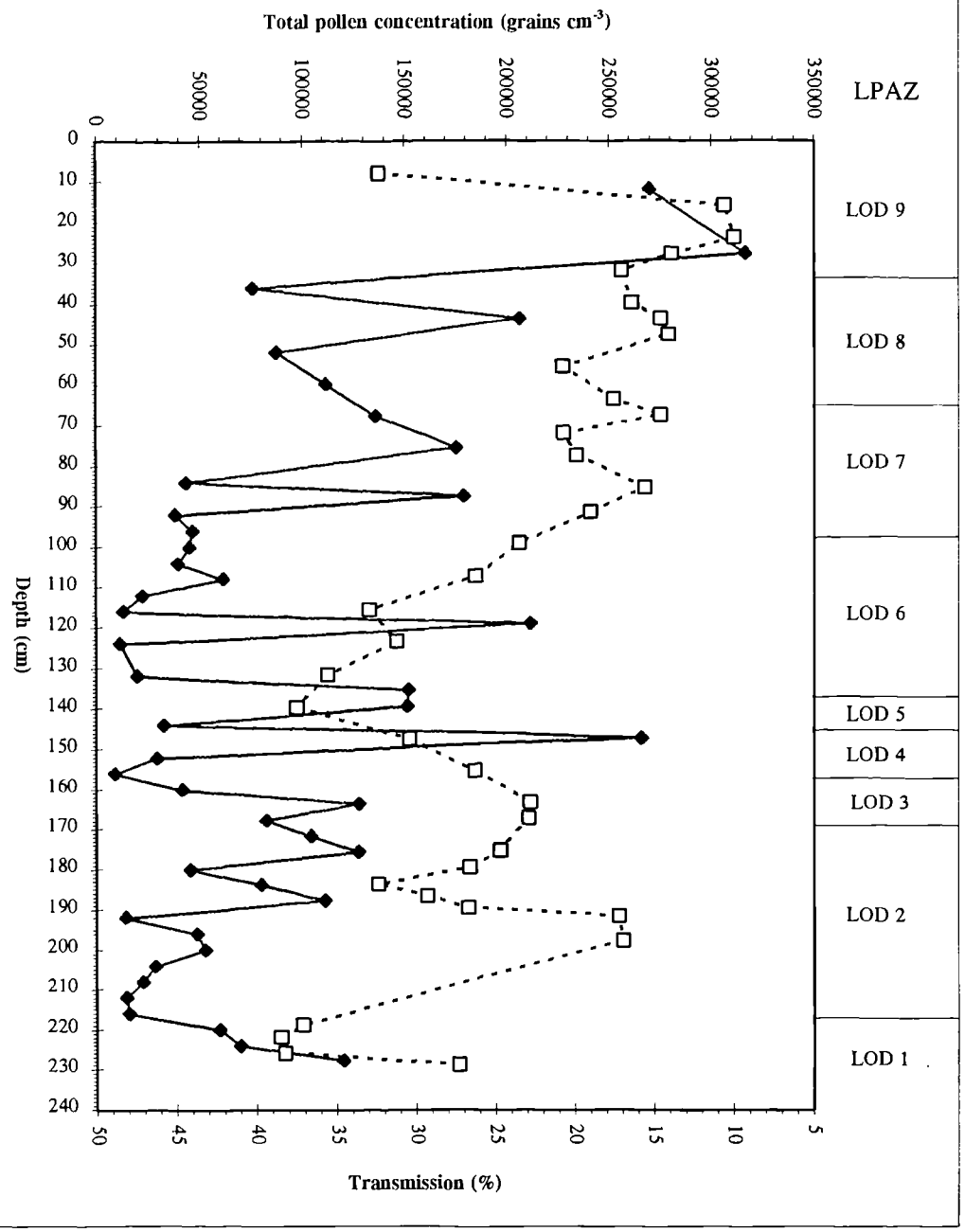


Figure 6.26.
Profile LOD - Degree of humification (expressed as the inverse of percent transmission) and total pollen concentration (expressed as grains cm^{-3}) plotted against depth (cm).



Pollen concentration (grains cm^{-3})
---------- Transmission (%)

FIGURE 6.27 FUNGAL AND ALGAL REMAINS DIAGRAM FOR TEAL D (c.73 m OD)
(WITH SELECTED POLLEN AND SPORES)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TYPES

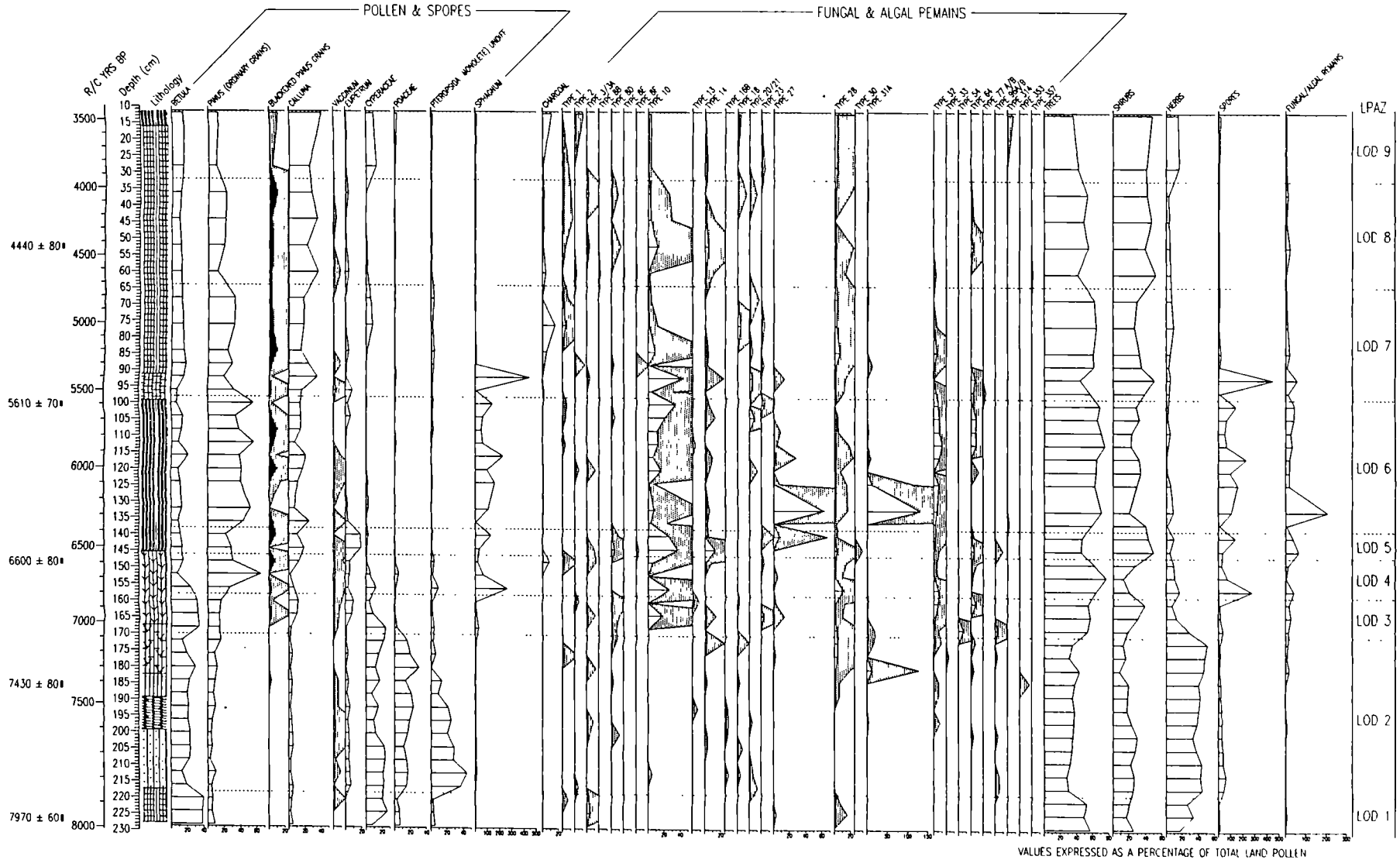
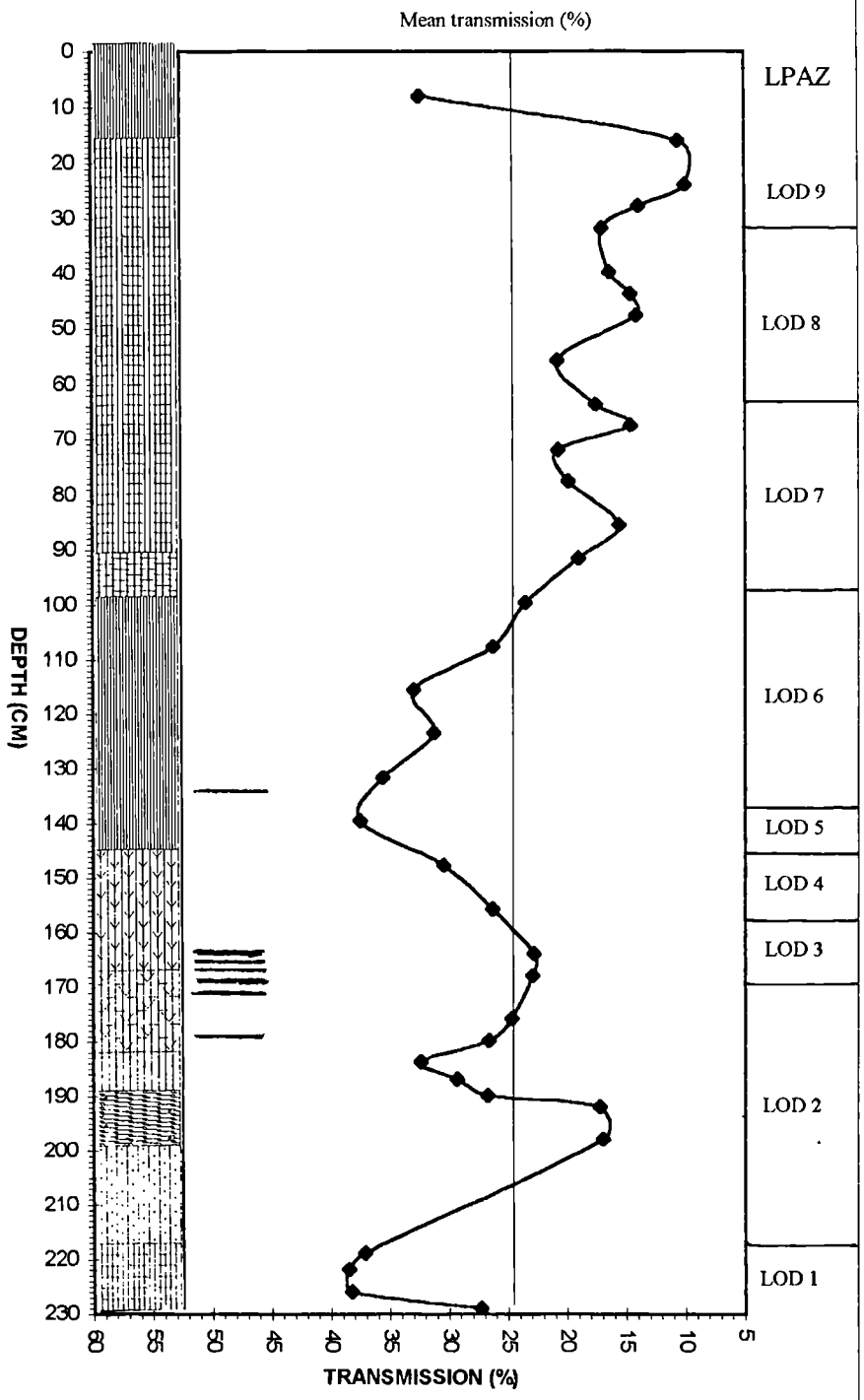


Figure 6.28.
Profile LOD - Degree of humification (expressed as the inverse of percent transmission) plotted against depth (cm). Macrofossils are represented (green = pine; blue = birch; red = Ericaceous)



Summary

The pollen evidence suggests that this zone represents a closed birch woodland with Cyperaceae and grasses. The presence of *Myriophyllum alterniflorum* and *Potomageton* indicates the presence of nearby, slow flowing water, but the sedges probably colonised the surrounding wet ground. The low degree of humification recorded in this zone is not strongly supported by the fungal and algal remains evidence, but the representation of aquatic pollen types indicates relatively wet conditions.

6.3.4.2 LPAZ - LOD 2 (218-170cm) (c.7850-7070 BP)

Percentage pollen and spore diagram

This zone is characterised by a high proportion of herbaceous pollen types, which reach 52% at the top of the zone (172cm). The tree pollen types are lower in this zone, and this is largely a result of lower *Betula* pollen frequencies. The shrub pollen types show a steady decline to a minimum of 8% at 180cm.

Although lower *Betula* pollen are represented in this zone, it still forms the majority of the aboreal pollen and *Betula* frequencies rise to 30% at 180cm. *Pinus sylvestris* pollen is represented at very low frequencies and shows a steady rise in values from 5% at the base of the zone to 16% at the top.

The decrease in representation of shrub component towards the top of this zone is a result of a decrease in the values for *Corylus avellana* type, *Juniperus* (to less than 1%) and *Empetrum.*

The high proportion of herbaceous pollen types in this zone is largely a result of the high frequency of Cyperaceae (maximum of 22%) and Poaceae (maximum of 31%). Some of the smaller, open habitat taxa, are recorded in significant frequencies in this zone such as *Rumex* undiff., *Artemisia* type, Lactucae undiff., *Potentilla* type, Apiaceae, *Saxifraga* spp., *Angellica* type, and together with continuous, but low, values for *Ranunculus* type.

Pteropsida (monolete) indet. spores reach a peak in this zone of 45% at 212cm.

Pollen concentration and influx diagrams

The terrestrial pollen concentration and influx data generally support the percentage pollen data in this zone. The low concentration and influx values in the lower half of the zone coincide with a high minerogenic component in the peat matrix.

The peat accumulation rate falls from 13.2 yr cm^{-1} to 22.3 yr cm^{-1} at the top of the zone which coincides with the change in lithology to a more organic peat matrix (see lithostratigraphy above).

Fungal and algal remains diagram

Very few fungal and algal remains were recorded for this zone, but Types 31a and 28 show a rise in frequencies towards the top of the zone. Type 31a (*Amphitrema flavum*) is thought to indicate a shift towards relatively wet conditions (Van Geel, 1972, 1978, 1980/81, Aaby & Tauber, 1975) which is supported by the humification data derived from samples in this zone (see below).

Degree of humification

The high degree of humification recorded in this middle of this zone coincides with a change in lithology to a *Sphagnum*-rich peat (with minerogenic inclusions). The subsequent shift to a less humified peat corresponds with a change to an organic-rich peat matrix and a rise in the frequencies of wet indicating fungal remains.

Summary

The pollen stratigraphic evidence in this zone indicates a herbaceous-rich open birch woodland with sedges and ferns. The reduction in *Juniperus, Empetrum* and Pteropsida (monolete) indet. towards the top of the zone corresponds with the increase in the importance of grasses in the understorey and a slight increase in the density of the birch woodland canopy.

The shift towards a less humified peat matrix above 190cm corresponds with a rise in the values for Type 31a, a rhizopod indicative of relatively wet conditions.

6.3.4.3 LPAZ - LOD3 (170-158cm) (*c.*7070-6810 BP)

Percentage pollen and spore diagram

This zone, represented by three pollen spectra, is characterised by a rise in the proportion of tree and shrub pollen types (to 57% and 39% respectively) and a decline in the proportion of herbaceous pollen types (from 29% to 7%).

The majority of the tree pollen component is formed by *Betula* (*c.*34%) and *Pinus sylvestris* (rising to 17% at the top of the zone).

The rise in the representation of the shrub component is largely a result of the increase in the frequencies of *Calluna vulgaris* (to 11%) and *Empetrum* (to 10.1%).

The fall in the herbaceous component is a result of lower values for Cyperaceae (from 25% to 5%) and Poaceae (3% to 1%) and a marked reduction in the representation of open habitat taxa.

Pollen concentration and influx diagrams

The terrestrial pollen concentration and influx values decrease at the top of this zone which corresponds with a trend towards a lower degree of humification (Figure 6.26). The data generally support the evidence of the percentage pollen diagram.

Fungal and algal remains diagram

This zone is characterised by a small peak in the frequency of Type 10 which coincides with the rise in *Calluna* pollen and supports the association observed by Van Geel (1978).

Type 64 shows a small peak at the top of the zone which corresponds with the peak in *Empetrum* pollen frequencies (Van Geel, 1978; CPG5, Section 6.2.4.5). These two types indicate relatively dry conditions which corresponds with the high degree of humification indicated for this zone (see below).

The rhizopod, Type 32, (*Assulinea* sp.) increases in representation towards the top of this zone and is indicative of wetter conditions (*cf.* APB 3, Section 6.1.4.3). However, since only two transmission values are represented in this zone it is difficult to directly compare the two sets of data.

Degree of humification

The two transmission values represented in this zone indicate a higher than average degree of humification. This is supported by the increase in Types 10 and 64 (above) but is not supported by the increase in Type 32 which indicates relatively wet conditions.

The top of this zone includes Ericaceous twigs in the sampled column (between 159-167cm) but due to the low number of transmission values represented in this zone the significance of these macrofossils is difficult to assess.

<u>Summary</u>

The pollen evidence in this zone indicates a relatively dense birch woodland with an understorey of *Calluna* and *Empetrum*. The greater than average degree of humification corresponds with evidence for the generally drier conditions indicated by the fungal and algal data (but not with the increase in Type 32 towards the top of the zone).

6.3.4.4 LPAZ - LOD 4 (158-146cm) (*c.*6810-6540 BP)

Percentage pollen and spore diagram

The three pollen spectra represented show a peak of tree pollen types in the middle of the zone. This is largely a result of the rise in *Pinus* pollen frequencies (from 30% at the base to a peak of 66%) with a corresponding fall in *Betula* frequencies (to 8%).

The peak in arboreal pollen frequencies is matched by a trough in shrub type pollen frequencies, most notably *Calluna* (to less than 2%) and *Empetrum* (to 3%).

The herbaceous pollen component is largely represented by Cyperaceae, which declines from 12% at the base to 1% at the top of this zone, and Poaceae, which increases slightly to 5% in the middle of the zone.

The frequency of Pteropsida (monolete) indet. spores increases to 9% at the base of the zone and high values *Sphagnum* spores are represented (267% TLP).

Pollen concentration and influx diagrams

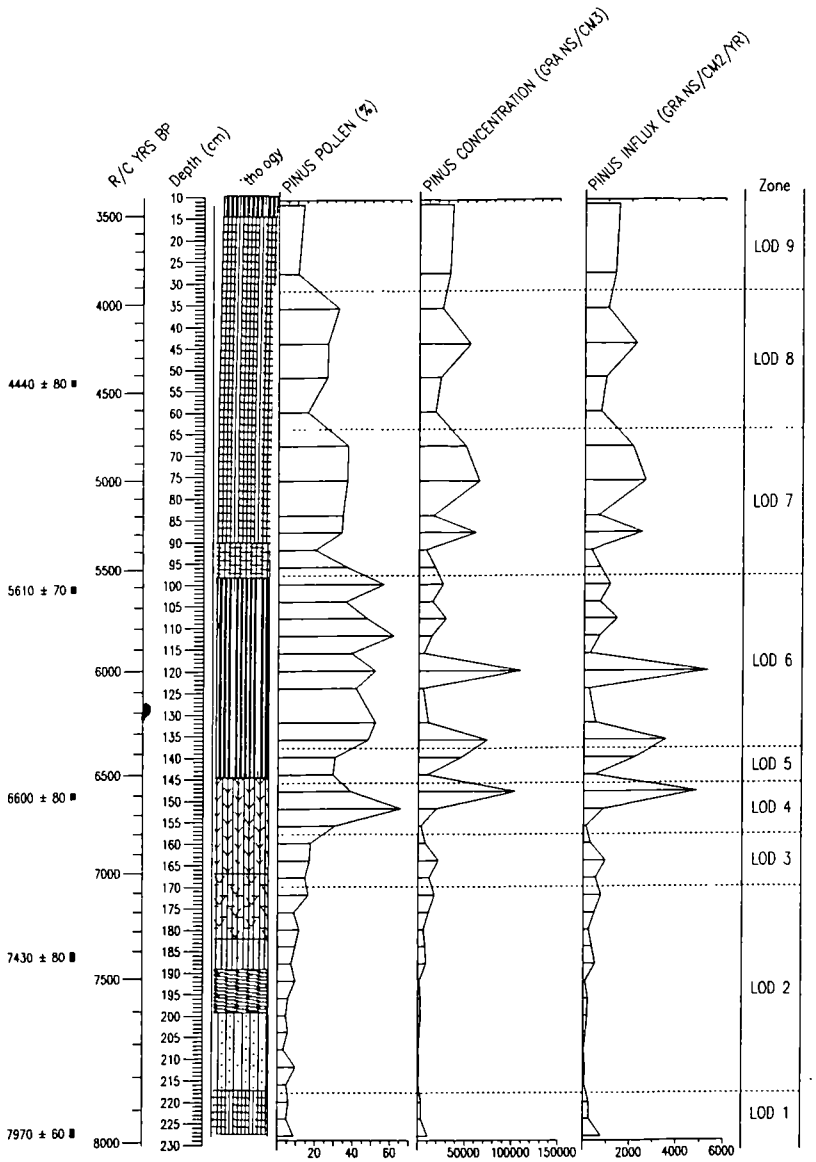
The terrestrial pollen concentration and pollen influx values rise to a peak at the top of this zone (*c.*266,000 grains cm^{-3} and *c.*12,500 grains cm^{-2} yr^{-1} respectively). Comparison of the *Pinus* pollen values (Figure 6.29) shows that the peak in *Pinus* pollen influx to the site (at 148cm) is not matched by a peak in *Pinus* percentage values (at 152cm). Since there is an apparent inverse relationship between pollen concentration and the degree of humification in this zone (Figure 6.26) the high influx values probably provide a reliable indication of a real increase in pollen influx to the site.

Fungal and algal remains diagram

The Type 10 frequencies match the *Calluna* pollen frequencies in this zone, thus supporting the observation of Van Geel (1978). However, peak values of Type 10 also correspond with peak values of *Sphagnum* spores, but since no leaves were observed in the peat matrix there is no direct evidence for the local presence of *Sphagnum.*

The increase in the frequency of Type 32 at the base of the zone suggests relatively wet conditions (e.g. Van Geel, 1978). Blackford (1990) observed the first appearance of Type 32 only after significant wet shifts as recorded by humification and local pollen curves. This might provide an explanation for the high frequencies of Type 32 recorded at the top of LOD3 and the base of LOD4 as there is

FIGURE 6.29
PINUS POLLEN DATA FOR SITE LOD (c.700m OD)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)



corresponding shift towards a lower degree of humification at the boundary of these two zones (see Figure 6.28).

The small peak in Type 28 at the base of the zone corresponds with the small increase in Cyperaceae pollen frequencies. Although there is often a correspondence between Type 28 and Cyperaceae pollen frequencies, there is consistent relationship to determine the significance of the fungus (or which species of Cyperaceae it is associated with). This inconsistency was also found in the samples from the profiles at APB and CPG.

A high frequency of blackened *Pinus* grains are represented at the top of this zone but, unlike at APB and CPG, there does not appear to be a close correspondence with this feature and the degree of humification (Figure 6.30).

Degree of humification

The two transmission values in this zone indicate a trend is towards a lower degree of humification.

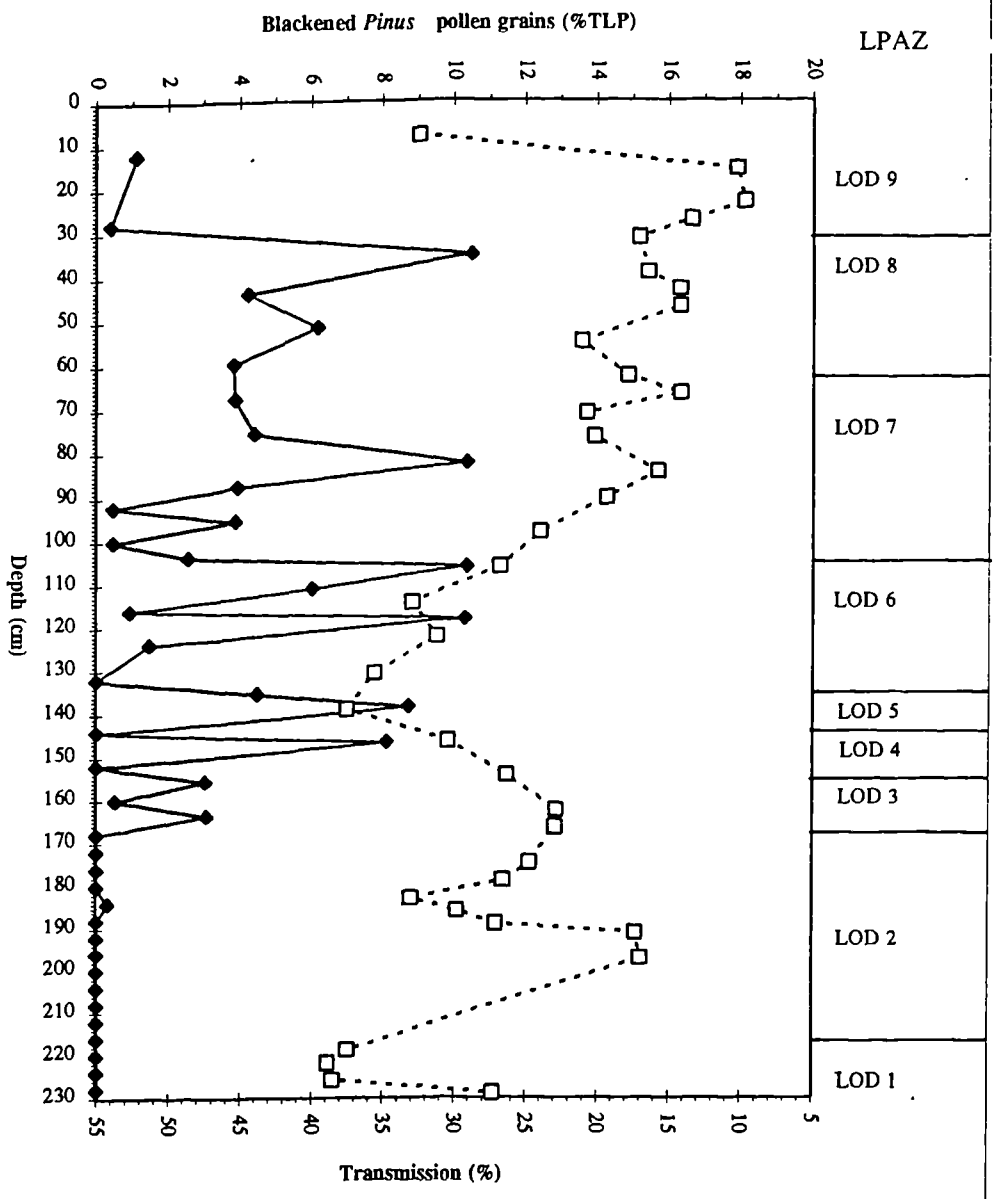
Summary

The rise in pine pollen frequencies in this zone indicates that pine colonised this site during this period (*c.*6,700 BP). The subsequent rapid establishment of pine woodland towards the middle of the zone appears to have led to a reduction of birch and the *Calluna* and *Empetrum* cover. However, at the base of the zone, shortly before the pine woodland becomes too dense, there is a short-term expansion of Cyperaceae, Poaceae, *Ranunculus* sp. and Pteropsida (monolete) indet..

The maximum pollen influx values for pine at the top of the zone do not appear to be enhanced by a higher degree of humification and probably reflect a real increase in pollen influx.

The humification evidence in this zone indicates a continuation of the trend towards a lower degree of humification but this is not clearly demonstrated by the fungal and algal data.

Figure 6.30.
Profile LOD - Degree of humification (expressed as the inverse of percent transmission) and the frequency of blackened *Pinus* pollen grains (expressed as a percentage of total land pollen) plotted against depth (cm).



Blackened *Pinus* grains (%TLP)

Transmission (%)

6.3.4.5 LPAZ - LOD 5 (146-138cm) (*c.*6540-6380 BP)

Percentage pollen and spore diagram

The two pollen spectra represented in this zone suggest a reduction in tree pollen types (to *c.*46%) and a corresponding increasing of shrub pollen types (to 50%).

The reduced representation of the tree component is largely a result in the decrease in *Pinus sylvestris* pollen frequencies to *c.*30%.

The rise in the shrub types is a result of the increase in the percentage of *Calluna vulgaris* (to 19%) and *Empetrum* pollen which reaches a peak of 19% at 144cm.

Pollen concentration and influx diagrams

Minimum values for terrestrial pollen concentration and influx values are recorded at the base of the zone (8,800 grains cm^{-3} and 396 grains cm^{-2} yr^{-1} respectively) which coincides with a rise in the proportion of *Sphagnum* leaves observed in the matrix (*c.*30%). The pollen concentration and influx values for pine support the percentage data for a reduction in the frequency of pine at the base of this zone (Figure 6.29).

Maximum values are recorded for *Empetrum* pollen concentration and influx (*c.*28,000 grains cm^{-3} and *c.*1,400 grains cm^{-2} yr^{-1} respectively) at the top of this zone.

Fungal and algal remains diagram

This zone is characterised by a rise in Types 14 and 10, which are probable indicators of dry conditions and correspond with the rise in *Calluna* and *Empetrum* pollen frequencies (*cf.* Van Geel, 1978).

A high frequency of blackened *Pinus* grains was recorded at the top of this zone (*c.*28%) which corresponds with the higher *Calluna* and *Empetrum* pollen frequencies, but as in the previous zone, there is not a good correspondence with a high degree of humification (Figure 6.30).

Very few wet indicating fungal/algal remains are recorded for this zone, the exception being a rise in Type 27 which supports Van Geel's observation (1978) that Type 27 is associated with *Sphagnum* leaves.

Degree of humification

The one transmission value in this zone indicates a very low degree of humification. Although, this does not support the evidence for the relatively dry conditions

indicated by the fungal and algal remains data, it does coincide with the preservation of *Sphagnum* leaves in the peat matrix.

Summary

The pollen evidence in this zone indicates a reduction in the density of the pine woodland canopy and increase in the importance of the *Calluna* and *Empetrum* understorey.

One of dated pine stumps from the site area (approximately 50m from the sampled LOD stratigraphic profile) provided a radiocarbon age estimate of 6,440 +/- 70 and confirms the local presence of pine in this zone.

The low transmission value in this zone coincides with the preservation of *Sphagnum* leaves in the matrix but, apart from the representation of Type 27, the fungal/algal remains evidence generally indicates relatively dry conditions.

6.3.4.6 LPAZ - LOD 6 (138-98cm) (*c.*6380-5540 BP)

Percentage pollen and spore diagram

LOD 6 is characterised by a high proportion of tree pollen types (up to 70% at 132cm) and a corresponding lower representation of shrub pollen types which decease to 20% at 132cm. The representation of herbaceous pollen types falls to a minimum of less than 1% in the middle of this zone.

The high arboreal representation is largely a result of high *Pinus* pollen frequencies, with values in the range of 39% to 61%; however, the *Betula* pollen frequencies are relatively low, remaining below *c.*20%.

Calluna forms the largest proportion of the shrub component, showing fluctuating values between *c.* 7% and 25%. There is a marked decline in the values for *Empetrum* at the base of this zone (to 3%) but there is a small rise in frequencies at the top of the zone (6% at 104cm).

Very few herbaceous pollen types are represented in this zone, the exception being a low frequency of *Ranunculus* sp. (3% at 124cm).

Sphagnum spores were consistently recorded in this zone, the peak at 116cm shows a value of 230% (%TLP).

Pollen concentration and influx diagrams

The total terrestrial pollen concentration and influx values rise to a peak in the middle of this zone (*c.*212,000 grains cm^{-3} and *c.*10,300 grains cm^{-2} yr^{-1} respectively) which corresponds with a reduction in the proportion of *Sphagnum* leaves preserved in the peat matrix (*c.*20% at 120cm). The peak in pollen concentration values at 120cm, and similarly at 136cm, in this zone cannot be explained by the evidence of the degree of humification. As with the lower zones, there appears to be a very limited correspondence between the degree of humification and pollen concentration (Figure 6.26) and the peat matrix (*Sphagnum*-rich). The concentration peaks at 120cm and 136cm are therefore likely to represent real increases of pollen influx to the site at the time periods represented by these stratigraphic levels.

Similarly, maximum concentration and influx values for *Pinus sylvestris* are recorded in this zone (*c.*109,000 grains cm^{-3} and *c.*5,300 grains cm^{-2} yr^{-1} respectively) (Figure 6.29). These values are probably indicative of a relatively dense pine woodland in the local site area.

Fungal and algal remains diagram

The peak in the representation of wet indicating fungal and algal remains at the base of this zone (Types 27 and 31a) corresponds with evidence for a low degree of humification (see below) and a high proportion of *Sphagnum* leaves preserved in the peat matrix. In addition, Type 32 (remains of the rhizopod family *Assulinea* sp.), is consistently recorded in the upper half of this zone. Van Geel (1978) correlates this rhizopod with *Sphagnum*-rich peat (see APB3, Section 6.1.4.3), which is supported by the macro-fossil (and micro-fossil) evidence in this zone. However, Blackford (1990) recorded the first appearance of Type 32 only after significant wet shifts but this is not strongly supported in this zone (although it is at LOD3/LOD4 boundary).

However, this zone is also characterised by an increase in fungal/algal remains indicative of relatively dry conditions (e.g. Type 10 and 64). Whilst this supports the evidence for a trend towards a lower degree of humification towards the top of the zone, the presence of Type 32 indicates that the conditions remained relatively wet (as indicated by the presence of *Sphagnum* leaves). This apparent discrepancy between the fungal/algal evidence might be explained if *Sphagnum* was cohabiting the mire surface with *Calluna* and *Empetrum* (and hence the simultaneous presence of Types 32 and Types 10 and 64).

In addition, the increase in Type 64 toward the middle of the zone does not match the higher *Empetrum* frequencies recorded towards the top of the zone (cf. Van Geel, 1978; CPG5, Section 6.2.4.5). This might indicate that either:

i) *Empetrum* was present earlier than the pollen evidence suggests but was not producing significant quantities of pollen
ii) that the *Empetrum* pollen was not incorporated in the fossil record, or
iii) there is not a conclusive association between *Empetrum* and Type 64

This zone also shows relatively high frequencies of blackened *Pinus* grains in the upper half of this zone. Although there is an inconsistent relationship with this feature and the degree of humification at this site (Figure 6.30), the evidence for relatively wet conditions at 132cm (an increase in Types 27 and 31a) corresponds with an absence of blackened *Pinus* grains.

Degree of humification

The transmission values in this zone indicate a low degree of humification but with a trend towards a higher degree of humification towards the top of the zone. This corresponds well with the reduction in the proportion of *Sphagnum* leaves preserved in the peat matrix and an increase in fungal/algal remains indicative of relatively dry conditions.

Summary

The pollen evidence in this zone indicates a relatively dense pine woodland with an understorey of *Calluna vulgaris.* The increase in *Empetrum* pollen frequencies at the top of the zone corresponds with a short-term reduction in the density of the pine woodland canopy (as indicated by the pine pollen percentage and concentration/influx data).

The transmission values indicate a trend towards a higher degree of humification towards the top of the zone which is generally supported by the evidence of the fungal and algal remains and a reduction of *Sphagnum* macro- and micro-fossils.

One of the cross-dated pine stumps (dendrochronology) found approximately 50m from the LOD stratigraphic profile revealed a radiocarbon date of 6270 +/- 80 BP, thus confirming the local presence of pine.

6.3.4.7 LPAZ - LOD 7 (98-64cm) (*c.*5540-4710 BP)

Percentage pollen and spore diagram

This zone is characterised by an increase in the representation of *Calluna* pollen (up to 35%) and a decrease in *Pinus* pollen (to 20% at 92cm). *Empetrum* pollen frequencies show a small peak at the base of the zone (9%) but the subsequent increase in *Calluna* frequencies corresponds to a reduction of *Empetrum* pollen frequencies to less than 0.5%.

Cyperaceae pollen frequencies increase in the upper half of this zone and *Sphagnum* spores reach a peak of 445% (total land pollen) at 92cm.

Pollen concentration and influx diagrams

Pollen concentration and influx values rise to *c.*140,000 grains cm^{-3} and *c.*5,600 grains cm^{-2} yr^{-1} respectively at 88cm which corresponds with a higher degree of humification (Figure 6.26).

The pollen concentration and influx data generally supports the percentage pollen data but comparison of the *Pinus* pollen values indicates that the pine density represented in this zone might have been higher than in the previous zone. However, since there is a higher degree of humification of the peat matrix in this zone this may enhance the pollen concentration values.

Fungal and algal remains diagram

The majority of the fungal and algal remains recorded in the lower part of this zone indicate relatively dry conditions (e.g. Types 10 and 64) which is matched by a corresponding reduction in Type 32 (indicative of wetter conditions). In addition, the reduction in Type 32 values coincides with a reduction in the proportion of *Sphagnum* leaves preserved in the peat matrix (although the frequency of *Sphagnum* spores reaches a peak at 92cm).

The peak in the frequency of Type 10 corresponds with higher *Calluna* pollen frequencies and the pollen evidence for the local presence of *Empetrum* is supported by the presence of Type 64. However, the small peak in *Empetrum* frequencies at 84cm is not matched by the representation of Type 64.

The subsequent reduction in the number of fungal and algal remains recorded above 84cm corresponds with evidence for a high degree of humification. This is partially supplemented by the small rise in Type 1 (indicative of highly decomposed peat, Van Geel, 1980/81) and a high proportion of charcoal fragments recorded on the slide.

The frequency of blackened *Pinus* grains also reaches a peak at 84cm and corresponds well with the higher degree of humification (Figure 6.30).

The change in lithology to a sedge-rich peat matrix above 90cm is supported by evidence for higher Cyperaceae pollen frequencies and corresponds with a rise in Type 18 (correlated with *Eriophorum vaginatum* peat, Van Geel, 1978) and Type 28.

Degree of humification

The transmission values represented in this zone indicate a relatively high degree of humification in the upper half of this zone. This coincides with a change from *Sphagnum*-rich peat to sedge-rich peat and a reduction in the representation of fungal and algal remains.

Summary

The pollen stratigraphic evidence represented in this zone indicates a reduction in the density of the pine woodland and a corresponding increase in the importance of the *Calluna* understorey. The peat stratigraphy and pollen evidence indicate that sedges colonised the mire surface.

The humification evidence indicates a high degree of humification in the upper half of this zone with a corresponding reduction in the representation of fungal and algal remains.

6.3.4.8 LPAZ - LOD 8 (64-32cm) (*c.* 4710-3930 BP)

Percentage pollen and spore diagram

This zone is characterised by a further reduction in the proportion of tree pollen types and a corresponding increase in the representation of shrub pollen types. This is largely a result in lower frequencies of *Pinus* pollen (15% at the base of the zone, rising to 32% at the top) and a corresponding rise in *Calluna* pollen frequencies (to 36%). There is a small rise in the frequency of *Empetrum* pollen (4%) at the base of the zone and a subsequent small rise in *Juniperus* pollen frequencies.

This zone is also characterised by a reduction in the frequency of Cyperaceae pollen, which falls to values of less than 2%.

Pollen concentration and influx diagrams

The pollen concentration and influx values show a peak at 44cm (*c.*206,000 grains cm^{-3} and *c.*8,500 grains cm^{-2} yr^{-1} respectively) which corresponds to a high degree of

humification (Figure 6.26) and may therefore partially reflect an enhanced pollen concentration.

However, the concentration and influx data generally supports the percentage pollen data in this zone. This is demonstrated by the reduction in the percentage of *Pinus* pollen in this zone which is matched by lower concentration and influx values (Figure 6.29).

Fungal and algal remains diagram

Very few fungal and algal remains are represented for this zone. The small rise in the frequencies of Type 10 and Type 14 at 52cm indicate relatively dry conditions which corresponds with an absence of wet indicating types. The high frequency of blackened *Pinus* pollen grains observed towards the top of this zone corresponds with a relatively high degree of humification (Figure 6.30).

Degree of humification

The transmission values represented in this zone indicate a higher than average degree of humification, particularly between *c.*44-48cm.

Summary

The pollen evidence represented in this zone indicates a *Calluna* dominated heathland with isolated stands of pine which increase in density towards the top of the zone. Humification data indicates a well humified peat matrix which is supported by the presence of dry-indicating fungal and algal remains.

6.3.4.9 LPAZ - LOD 9 (32-12cm) (*c.*3930-3450 BP)

Percentage pollen and spore diagram

The two pollen spectra represented in this zone indicate a decrease in the frequency of *Pinus* pollen (to *c.*10%) and a rise in *Calluna* pollen (reaches 41% at the top of the zone).

The herbaceous pollen types increase in this zone, which is largely a result in the higher frequencies of Cyperaceae (up to 28%), and small rises in the frequencies of Poaceae and *Ranunculus* type.

Pollen concentration and influx diagrams

There is an increase to maximum values for total pollen concentration and influx values at the base of this zone *c.*317,000 grains cm^{-3} and *c.*13,000 grains cm^{-2} yr^{-1} respectively).

The pollen concentration and influx data show some correspondence with the high degree of humification recorded in the lower half of this zone. Therefore the pollen concentration and influx values may be enhanced in the more humified peat.

The general trends identified above for the percentage pollen and spore diagram are supported by the concentration and influx data. This is also shown by the rise and maximum values for *Calluna vulgaris* at the top of this zone (concentration of *c.*110,000 grains cm^{-3} and influx of *c.*4,500 grains cm^{-2} yr^{-1}). Cyperaceae and *Juniperus* also have maximum values in this zone. *Pinus sylvestris* values remain low while *Betula* increases to high values once more in both diagrams.

Fungal and algal remains diagram

Very few fungal and algal remains were recorded for this zone. Type 28 is recorded at low frequencies and shows a correspondence with the rise in Cyperaceae pollen frequencies, thus supporting the previous observations.

It is interesting to note that despite high Calluna pollen frequencies, Types 10 and 14 (indicators of the local growth of Calluna and relatively dry conditions) are not well represented in this zone. This may be due to the reasons proposed by Blackford (1990) (see APB1, Section 6.1.4.1) for a humification threshold for the records of Type 10 or alternatively may be related the provenance of the Calluna pollen to the site. If Type 10 does indicate the local presence of Calluna, an increase in Calluna pollen frequencies in the absence of a rise in Type 10 frequencies may indicate a more distal source of the pollen.

Degree of humification

Minimum transmission values were recorded towards the base of this zone indicating a high degree of humification. The increase in the transmission measurement above 15cm coincides with a change in lithology to a less sedge-rich peat matrix.

Summary

The pollen evidence for this zone indicates a *Calluna* heath with sedge and an increase in the more open habitat taxa such as grasses and *Ranunculus* sp. The humification evidence indicates a high degree of humification at the base of the zone but this is not strongly supported by the fungal and algal evidence.

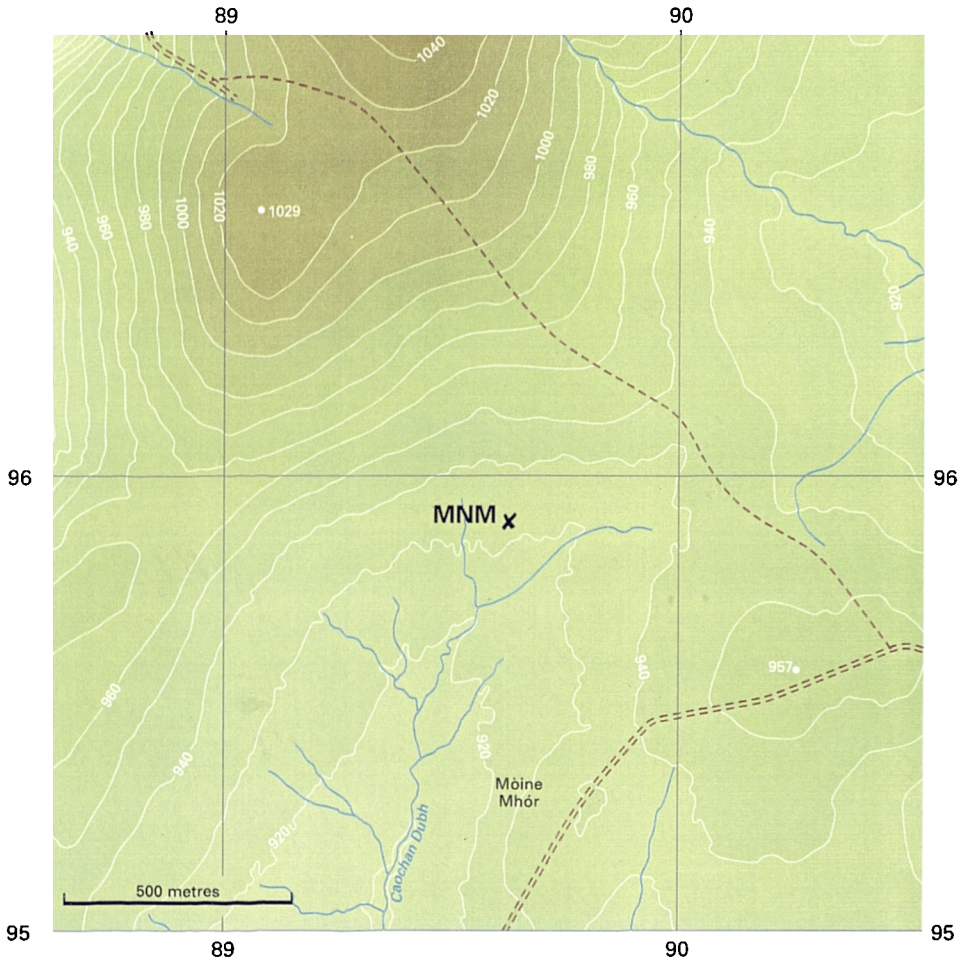


Figure 6.31: Gleann Einich – location of sample site MNM (Moine Mhor) c.930m OD

6.4 MOINE MHOR - SITE CODE - MNM (*c.*930m OD) (NGR: NN 896958)

6.4.1 SITE DESCRIPTION

This site, at *c.*930m OD, represents the highest of the four sites investigated in the Gleann Einich region. Moine Mhor is a gently sloping expanse of eroded and incised blanket peat overlying coarse, angular, quartzite gravels. The principal drainage direction in this area is towards the south (Figure 6.31). No pine stumps were located in the region of Moine Mhor but Pears (1968) identified pine stumps up to c.914m in other locations in the Cairngorm area (grid references are not included in the publication).

The blanket peat at Moine Mhor is generally thin (less than 1m deep) but after extensive field walking and test probing, an area of deeper peat accumulation was located. After test probing (with a narrow gouge auger) this area of deeper peat accumulation on a 5m grid system, a potential sampling location was identified with a profile of *c.*150cm. A 1m wide exposure was excavated into an existing erosion gulley adjacent to the sampling location. The final profile proved to be *c.*157cm deep, the base of the peat overlying a coarse, gravel-sized, minerogenic base.

The contemporary dominant vegetation cover in the region and at this site is *Empetrum nigrum* and Rhacomitrium heath with grasses and *Sphagnum* spp. The site can be categorised as a valleyside mire type.

6.4.2 LITHOSTRATIGRAPHY

It was not possible to sample the lowermost 10cm of the profile since water movement along the minerogenic basal sediments had eroded the overlying peat. However it was possible to extract a 146.5cm sample column using two monolith tins (up to approximately 14cm below the current vegetated surface). The majority of macrofossils identified in the section were Ericaceous twigs which were most frequent between approximately 70cm to 140cm. However, no pine or birch macrofossils were identified in the sampled profile.

The following stratigraphy was recorded in the laboratory from the samples recovered from the monolith tins:

DATUM (0) = TOP OF UPPER MONOLITH TIN

0-70cm	Medium dark brown, *Sphagnum*-rich peat. H4; n2-3; Tb4.
70-95cm	Medium dark brown, coarse, herbaceous peat. Rich in shrubby twigs (microscopic sections indicate they probably belong to the Ericaceae family). H3; n2-3; Tl2; Th2
95-97cm	Medium brown *Sphagnum* peat. H3; n2; Tb4.

97-100cm Medium dark brown *Sphagnum* peat with occasion shrubby twigs (probably Ericaceae). Over 90% *Sphagnum* leaves. Very fresh looking. H2-3; n2-3; Tb3; Tl1.

100-104cm Medium dark brown, *Sphagnum* peat with high frequency of shrubby twigs (probably Ericaceae), e.g. 101cm and 104cm. Over 90% *Sphagnum* leaves. H3; n2-3; Tb2; Tl2.

104-108cm Medium dark brown, *Sphagnum* peat with occasional shrubby twigs (probably Ericaceous). Fresh looking. Over 90% *Sphagnum* leaves. H2-3; n2; Tb3; Tl1.

108-129cm Medium dark brown, coarse, herbaceous peat. *Eriophorum* present, e.g. 125-126cm and 127-128cm. VP=H4. High frequency of long thin twigs (*c.*0.5mm diameter, not identified). Decrease in *Sphagnum* downwards, 10% *Sphagnum* leaves at 125cm. H4; Th3; Tb1.

129-146.5cm Dark brown, *Sphagnum* peat with sedges. H3; n2-3; Tb2; Th1; Sh1.

6.4.3 RADIOCARBON MEASUREMENTS

Four samples were submitted for radiocarbon analysis from the MNM sampled column (see **Table 6.1** for laboratory details and results). The rationale for the selection of the sample depths was to obtain radiocarbon age estimates of the following:

i) peat initiation

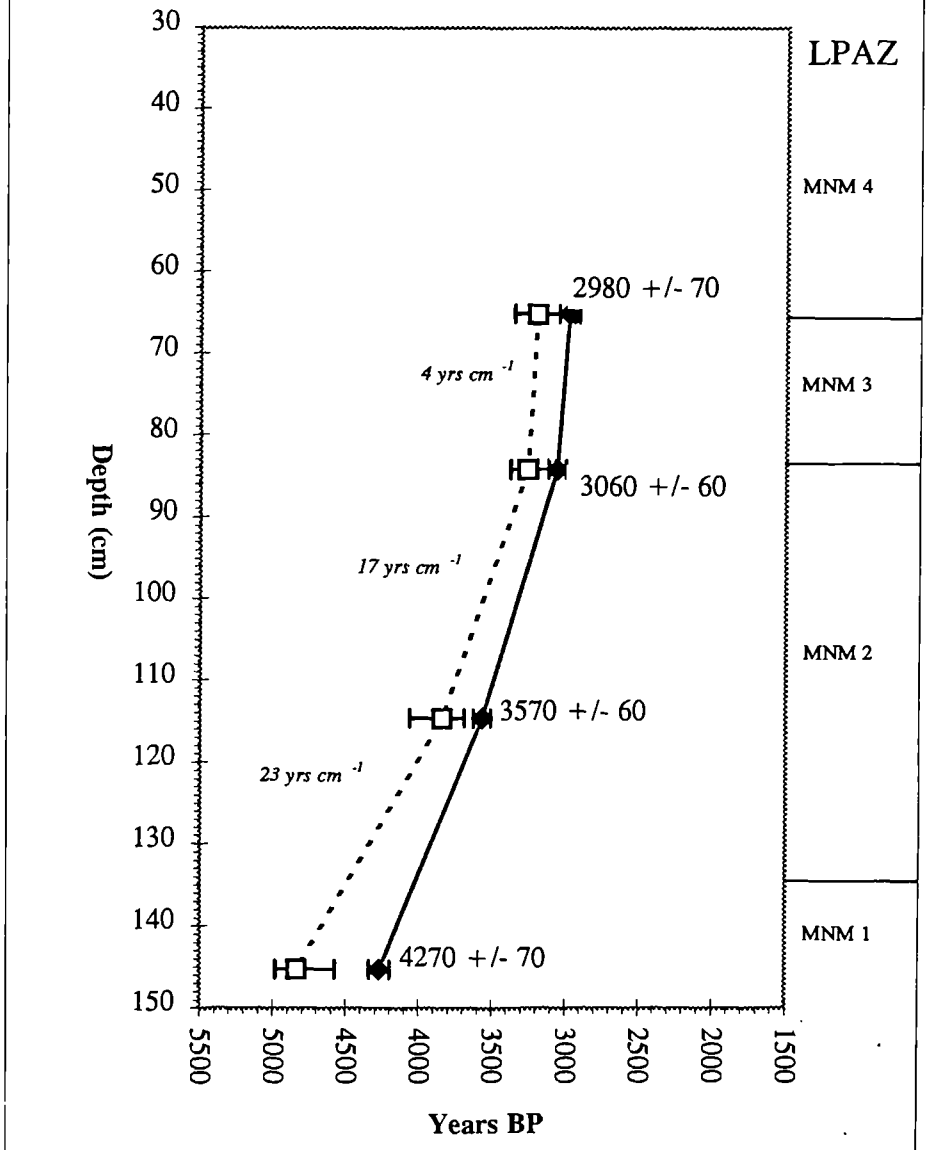
ii) the peak in pine pollen frequencies at *c.*66cm and 84cm and hence the upper and lower limit of the intervening low pine pollen representation

iii) an intervening age estimate between 84cm and 144cm (approximately mid-point at *c.*114cm).

The radiocarbon measurements (and the quoted errors representing 1 standard deviation statistics) are shown plotted in Figure 6.32 together with the calculated sediment accumulation rates and the calibrated ages. The radiocarbon measurements and laboratory details, together with the calibration results, are shown in Table 6.1.

The basal sediments of this site are the youngest recovered from any of the four Gleann Einich sites (*c.*4,270 BP). The relatively fast sediment accumulation rate between *c.*84cm and *c.*65cm (4 yr cm^{-1}) suggests there may have been erosion of the peat stratigraphy from this site, or it may simply reflect an artificially high accumulation rate derived from one or two erroneous dates. Linear extrapolation above the upper radiocarbon date (to *c.*14cm below the current vegetated surface) produces an age estimate for the top of the upper monolith tin (Datum 0) of *c.*2,710 BP. This suggests that the upper surface of the profile is absent or there is an error associated with the radiocarbon age estimate at *c.*66cm (2,980 +/- 70 BP).

Figure 6.32.
MNM - Radiocarbon measurements (uncalibrated and calibrated) and interpolated peat accumulation rates (expressed in years per cm) plotted against depth (cm)



Radiocarbon years

Calibrated years

6.4.4 LOCAL POLLEN ASSEMBLAGE ZONES

6.4.4.1 LPAZ - MNM 1 (145-134cm) (*c.*4280-4020 BP)

Percentage pollen and spore diagram **(Figure 6.33)**

This zone is characterised by a high representation of tree pollen types (in the range of 59-66%) and herbaceous pollen types (up to 33% at the top of the zone).

Pinus and *Betula* form the majority of the tree pollen types reaching 28% and 22% respectively. *Alnus* and *Quercus* pollen are represented at low frequencies (less than 10%).

Cyperaceae pollen forms the major component of the herbaceous pollen types rising to 26% at the top of the zone. Poaceae pollen and *Ranunculus* sp. pollen are present at low frequencies (6% and 4% respectively)

Pollen concentration and influx diagrams **(Figures 6.34 and 6.35)**

The pollen concentration values show some correspondence with the degree of humification (Figure 6.36), particularly in the lower half of the sampled column.

The total terrestrial pollen concentration and influx values increase to *c.*148,000 grains cm^{-3} and *c.*6,400 grains cm^{-2} yr^{-1} respectively at the top of the zone. The pollen concentration data generally support the percentage pollen data but the high values at the top of the zone may be partially enhanced by the high degree of humification (Figure 6.36).

Fungal and algal remains diagram **(Figure 6.37)**

This zone is characterised by a continuous representation of Type 28, which corresponds to the high frequency of Cyperaceae pollen and supports the previous observations of an association between sedge and the abundance of Type 28.

Type 64 is present at low frequencies in this zone but the *Empetrum* pollen frequencies are less than 1% which may not represent the local presence of *Empetrum* (*cf.* Huntley & Birks, 1983). As suggested on in Section 6.3.4.6 (LOD6) if Type 64, does indicate the local presence of *Empetrum* (Van Geel, 1978) then the low *Empetrum* pollen frequencies in this zone may indicate that *Empetrum* was locally present but that the pollen is not represented in the peat stratigraphy.

The significance of the small peaks in Type 16a (possible indicators of Poaceae as part of the local vegetation, Van Geel 1978) and Type 19 (correlated with *Sphagnum*

FIGURE 6.33

PERCENTAGE POLLEN AND SPORE DIAGRAM FOR SITE MNM (c.930m OD)

STRATIGRAPHY FOLLWOS TROELS-SMITH (1955)

SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TAXA

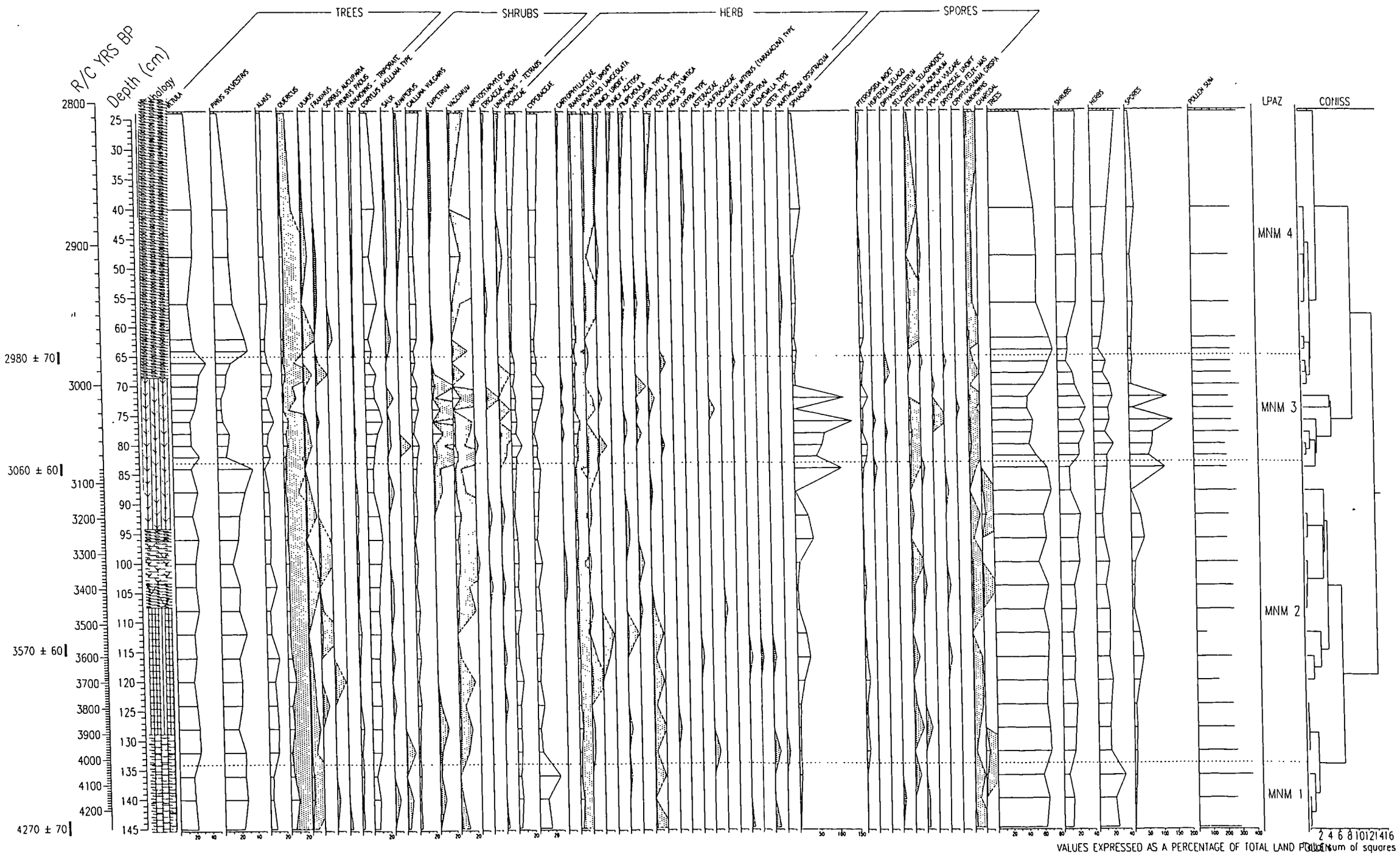
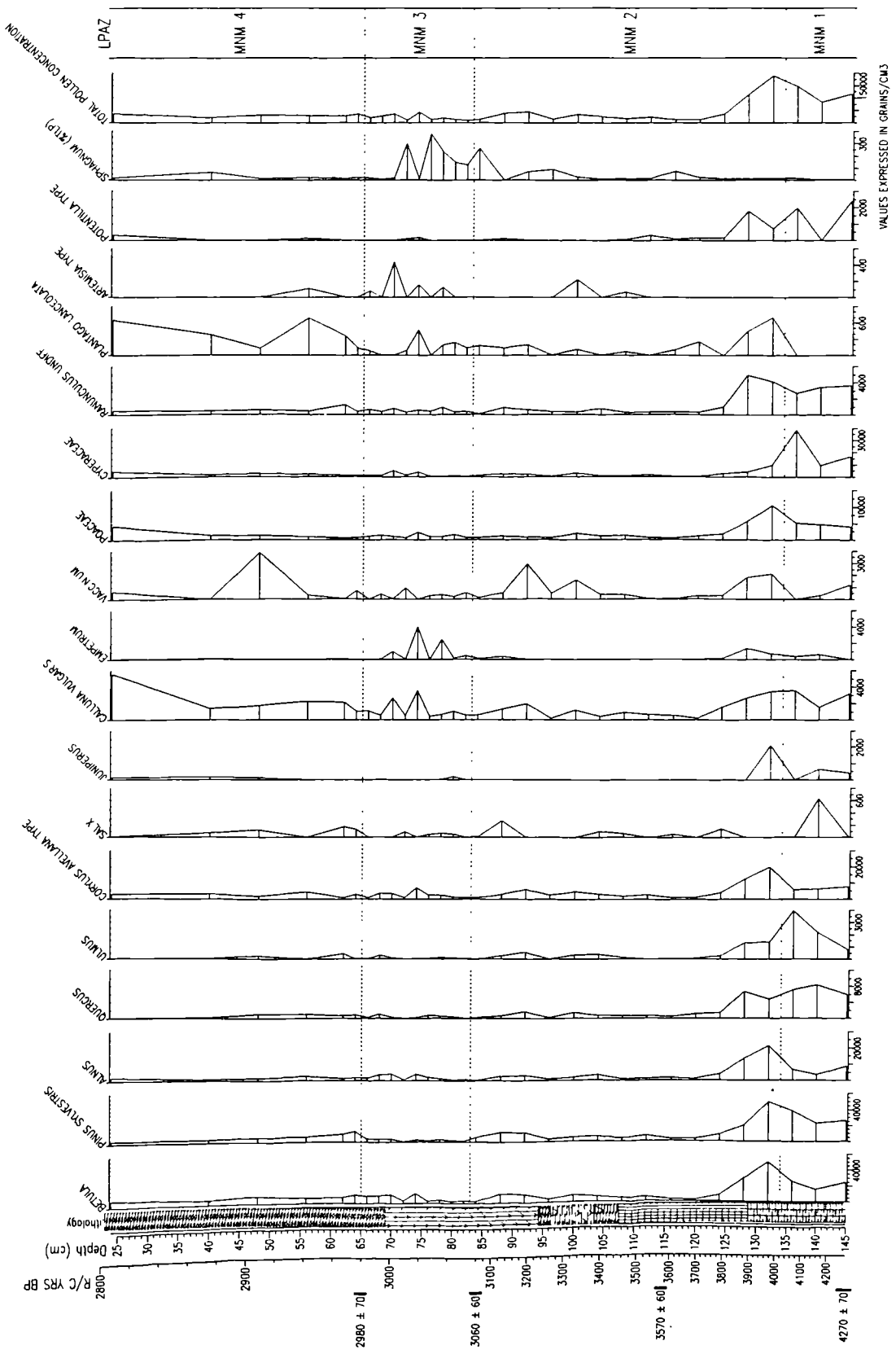


FIGURE 6.34 POLLEN CONCENTRATION DIAGRAM FOR SITE MIIM (c.930m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)



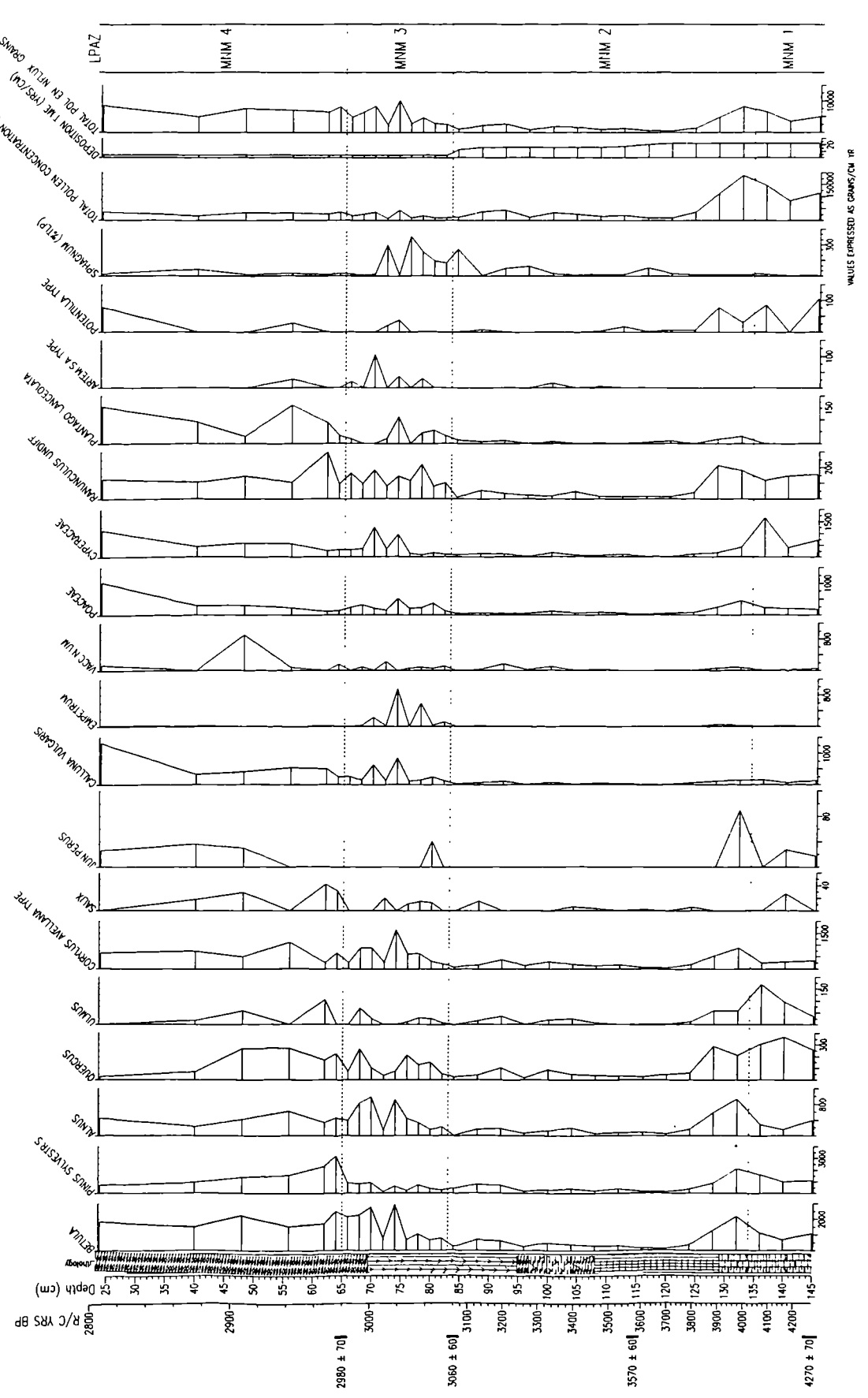
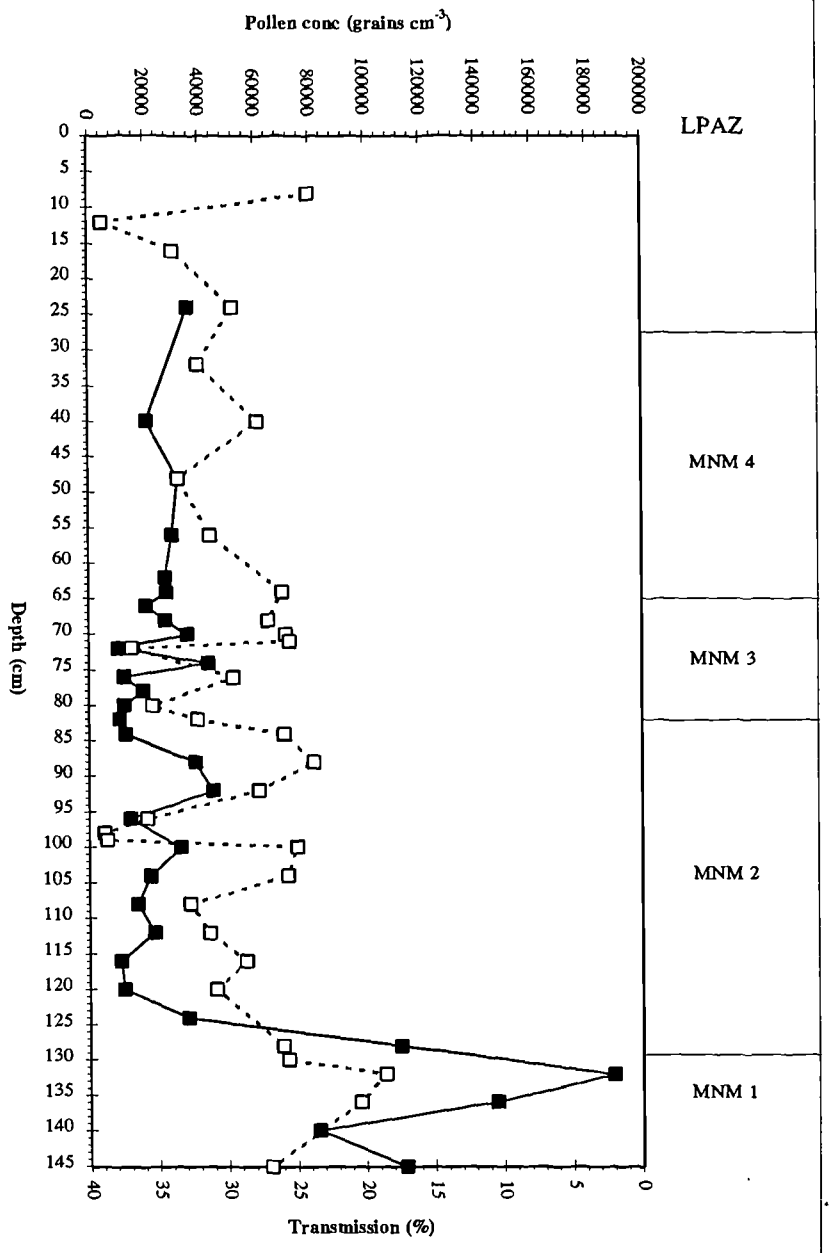


FIGURE 6.35 POLLEN INFLUX DIAGRAM FOR SITE MNM (.930m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

Figure 6.36.

Profile MNM - Total pollen concentration (expressed as grains cm^{-3}) and degree of humification (expressed as the inverse of transmission values) plotted against depth.

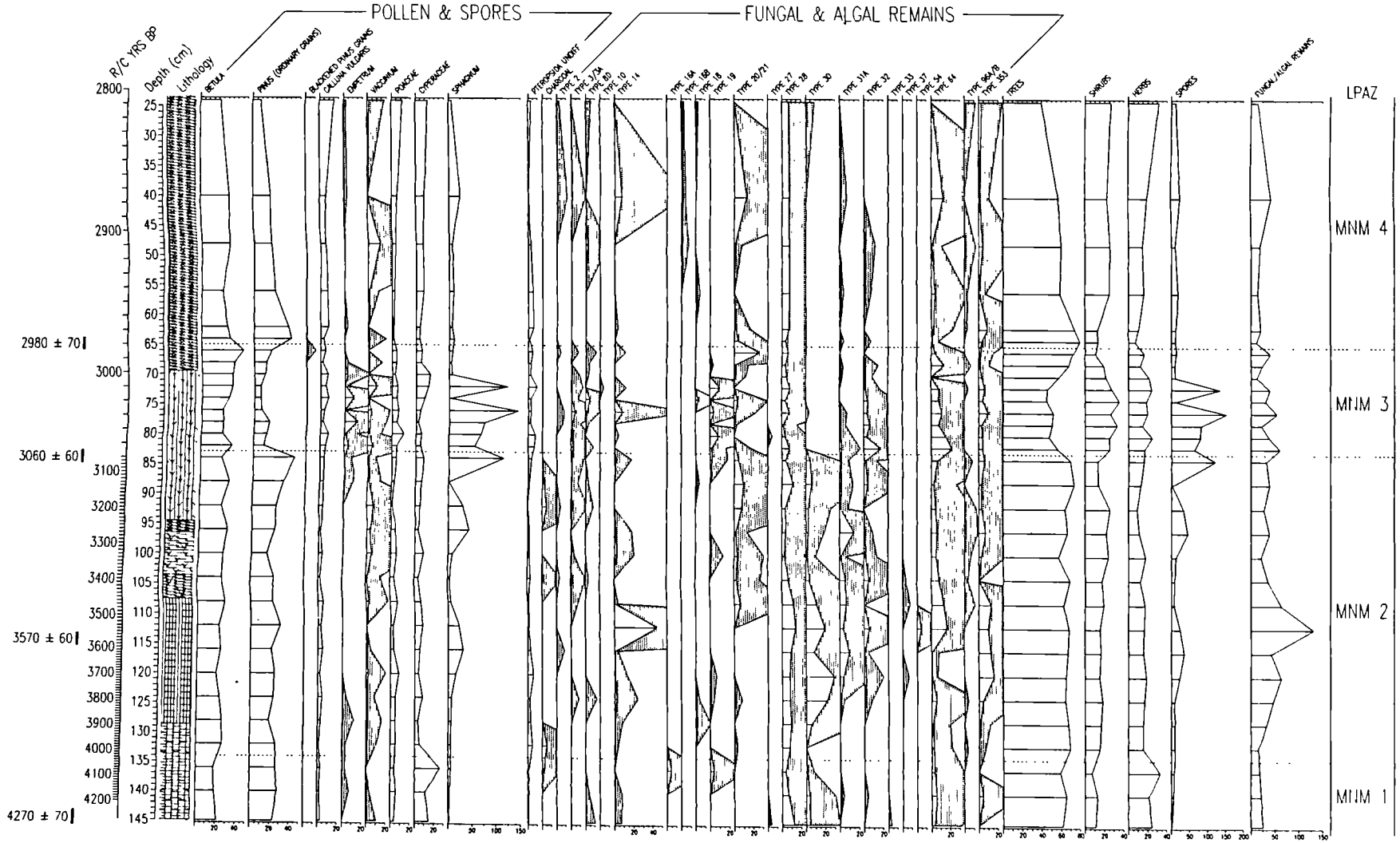


Pollen concentration (grains cm^{-3})

Transmission (%)

FIGURE 6.37 FUNGAL AND ALGAL REMAIN DIAGRAM FOR SITE MNM (c.930m OD) (WITH SELECTED POLLEN AND SPORES)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)
SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TAXA AND TYPES



papillosum-S. imbricatum peat, Van Geel 1978) corresponds with moderately high Poaceae pollen frequencies and a *Sphagnum*-rich peat matrix (respectively).

Degree of humification **(Figure 6.38)**

The two transmission values from this zone indicate a higher than average degree of humification.

Summary

The pollen evidence in this zone indicates an upland sedge heath colonised by grasses and the occasional presence of herbaceous types such as *Ranunculus* sp. and *Potentilla* type. The transmission values indicate a higher than average degree of humification of the peat matrix which is supported by the presence of Type 64, an indicator of locally dry conditions. However, the pollen evidence does not suggest the local presence of *Empetrum.*

6.4.4.1 LPAZ - MNM 2 (134-83cm) (*c.* 4020-3060 BP)

Percentage pollen

This zone is characterised by a decrease in the representation of the herbaceous pollen types and slightly higher frequencies of tree pollen types.

Pinus pollen frequencies gradually increase to 42% at the top of the zone and *Betula* pollen frequencies are slightly higher, rising to 30% at 96cm. *Alnus* pollen frequencies rise to 14% in this zone.

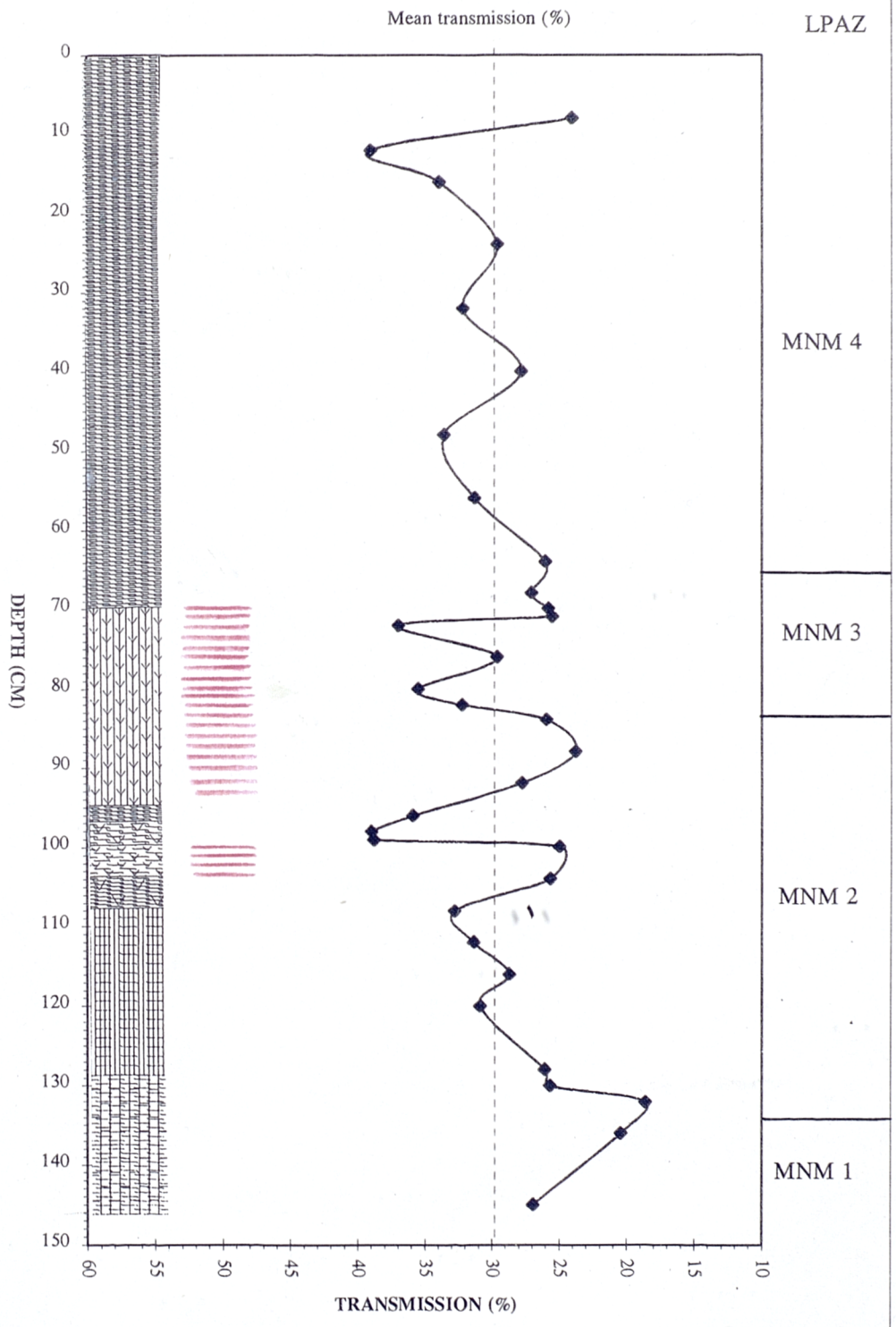
Vaccinium pollen frequencies increase between 100cm and 92cm and *Calluna* is represented throughout the zone but at frequencies of less than 5%.

The reduction in the herbaceous pollen component in this zone is largely a result of the lower frequencies recorded for Cyperaceae pollen (less than 9%). Low frequencies are also recorded for Poaceae (maximum of 9%) and *Ranunculus* (maximum of 4%).

Pollen concentration and influx diagrams

The maximum pollen concentration and influx values recorded at the base of this zone (*c.*190,000 grains cm^{-3} and *c.*8,200 grains cm^{-2} yr^{-1} respectively) correspond with a high degree of humification (Figure 6.36) and a less *Sphagnum*-rich peat matrix (less than 20% *Sphagnum* leaves in the peat matrix).

Figure 6.38.
Profile MNM - Degree of humification (expressed as the inverse of percent transmission) plotted against depth (cm). Macrofossils are represented (green = pine; blue = birch; red = Ericaceous)



Fungal and algal remains diagram

Relatively high frequencies of fungal and algal remains are recorded for this zone, with both wet and dry indicators represented.

There is an increase in values for Types 31a and 32, indicative of relatively wet conditions (Van Geel, 1978) between 120cm and 96cm. The peak in Type 31a frequencies corresponds with the very low degree of humification recorded between *c.*95-100cm (Figure 6.38).

The relatively high frequencies of Types 31a and 32 overlaps the rise in Type 64, indicative of relatively dry conditions and the local presence of *Empetrum.* However, Type 64 frequencies in this zone do not correspond well with the humification evidence, since the peak in Type 64 at 112cm corresponds with a relatively low degree of humification. Similarly, *Empetrum* pollen is represented at very low frequencies in this zone. This is similar to the observations in MNM1, and this again indicates that *Empetrum* may have been present in this zone but the conditions were not favourable for the production of *Empetrum* pollen, i.e. it may have been too wet (or too cold). However, the peak of Type 14, another indicator of relatively dry conditions, at 112cm corresponds with the peak of Type 64 and so interpretation is not straightforward.

Types 30 and 353 are recorded in relatively high frequencies between 124-108cm but the significance of these fungal/algal remains cannot be determined in this zone since no consistent relationship is observed with the remaining palaeoecological data.

Type 28 is recorded throughout this zone which corresponds with the consistent records for Cyperaceae pollen. The relationship between the relative magnitude of the two sets of data, however, is difficult to assess.

Degree of humification

Major oscillations in the transmission values are recorded in this zone. The high degree of humification indicated at the base of the zone corresponds with a low proportion of *Sphagnum* leaves in the peat matrix, whereas the reverse relationship is recorded just above 100cm where *Sphagnum* leaves comprise approximately 95% of the peat matrix. In addition, as mentioned above, the peak in dry indicating fungal/algal remains recorded at 112cm does not coincide with lower transmission values.

Summary

The pollen evidence for this zone indicates an upland heath with sedges and grasses with a high proportion of *Sphagnum* forming the peat matrix. The *Pinus* pollen frequencies at the top of the indicate that pine trees (probably isolated) may have reached the site during this period. However, the concentration and influx values for *Pinus* pollen (Figure 6.39) are relatively low in comparison with the sites at lower altitude (this will be discussed further in section 6.5). Similarly, the rise in *Alnus* frequencies to 14% indicates that there may be an over-representation of non-local pollen types.

The transmission values indicate large oscillations in the degree of humification are represented in this zone, which shows some correspondence to the proportion of *Sphagnum* leaves in the peat matrix. The fungal and algal data show evidence for the simultaneous presence of both wet and dry indicators.

6.4.4.3 LPAZ - MNM 3 (83-65cm) (*c.*3060-2980 BP)

Percentage pollen and spore diagram

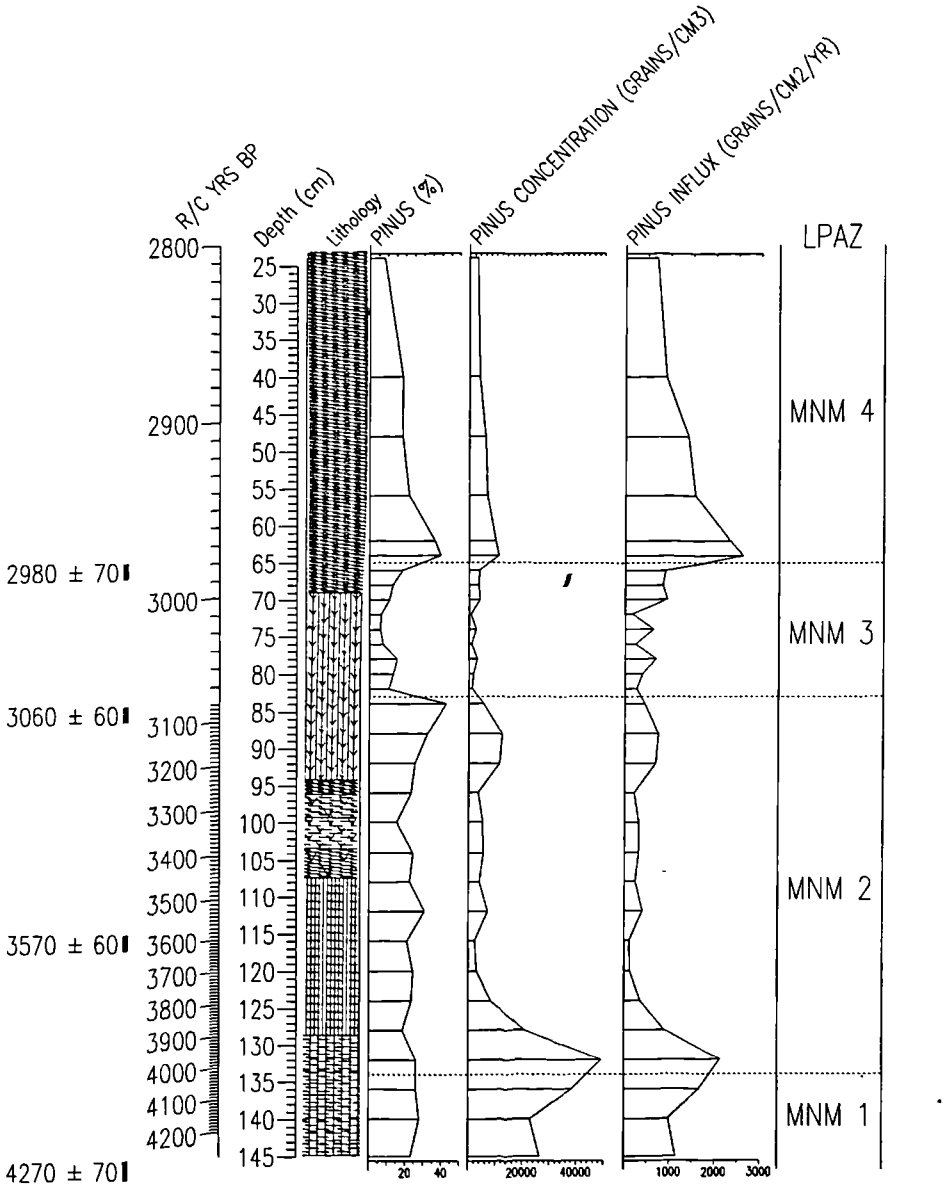
This zone is characterised by a decrease in the representation of tree pollen types in the middle of the zone (*c.*45%) and a corresponding rise in shrub pollen types to 35%.

The decrease in the representation of the tree component is largely a result of the lower *Pinus* pollen frequencies (falling to 6% at 74cm). In contrast, *Betula* pollen frequencies generally increase in MNM3, reaching a peak of 44% at the top of the zone.

This zone is also characterised by a increase in the representation of *Alnus, Corylus avellana* type (to 20%), *Calluna, Empetrum* (to 13%), Poaceae (to 13%), Cyperaceae (to 15%) and *Ranunculus* (undiff.) (to 8%). However, it is likely that *Alnus,* and possibly *Corylus avellana* type, represent a proportion of the regional pollen rain. The increase in the frequency of *Empetrum* and *Ranunculus* sp. (together with the increase in the representation of Pteropsida (monolete) indet. spores) indicate that conditions were more open.

The increase in the representation of the spores in this zone is largely a result of the rise in the frequency of *Sphagnum* spores to almost 150% (TLP) in the middle of the zone. However, the peaks in the frequency of *Sphagnum* spores do not always correspond with a high proportion of *Sphagnum* leaves in the peat matrix.

FIGURE 6.39
PINUS POLLEN DATA FOR SITE MNM (c.930m OD)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)



Pollen concentration and influx diagrams

Pollen concentration values fall to a minimum of *c.*5,400 grains cm^{-3} at the base this zone but in contrast the pollen influx values increase to *c.*5,000 grains cm^{-2} yr^{-1} at 74cm. However, the increase in the influx values may reflect the overlapping radiocarbon measurements of 3060 +/- 60 BP (at *c.*82cm) and 2980 +/- 70 BP (at *c.*65cm). This would provide an explanation for the possibly artificially high peat accumulation rates of 4.2 yr cm^{-1} derived from the interpolation of these close dates. If the peat accumulation rate is high between two radiocarbon dated horizons, even a constant pollen influx rate would be reflected as an increase in values. In addition, the lower pollen concentration values might be explained by the decrease in the degree of humification at the base of the zone (Figure 6.36).

Comparison of the *Pinus* pollen data (Figure 6.39) indicates a reduction of *Pinus* pollen representation, therefore suggesting a reduction in the local presence of pine (a reduction in the number of isolated pine trees) during this zone. This is supplemented by the evidence for an increase in *Empetrum* pollen frequencies.

Fungal and algal remains diagram

Relatively high frequencies of the wet indicating Types 19 and 32 and the dry indicating Types 64, 3/3a and 14 are recorded for this zone.

The decrease in representation of the wet indicating Types 19 and 32 at the top of this zone coincides with the evidence for a shift to a higher degree of humification above 72cm (see below). Similarly, the only record of blackened *Pinus* grains at this site is represented at 66cm, which corresponds with the shift to a higher degree of humification.

The increase in the frequencies of Types 19 and 32 have been correlated with *Sphagnum*-rich peat (Van Geel, 1978, Blackford, 1990) which is supported by the macro- and micro-fossil evidence in this zone (although Type 19 was not recorded in significant frequencies in the previous and subsequent zones). The rise in Type 32 at the base of this zone also supports the observation of Blackford (1990) that high frequencies of this type indicate a significant shift to wetter conditions. However, an explanation for the low frequencies of Type 31a in this zone, also indicative of wetter conditions, is not straightforward.

The increase in the representation of Type 64 corresponds well with the rise in *Empetrum* pollen frequencies. However, the humification and fungal/algal evidence indicates that the drier conditions at the top of the zone would be favourable for the growth of *Empetrum,* but low pollen frequencies were recorded. The apparent

contradictory evidence of the simultaneous presence of both wet and dry fungal indicators below *c.*73cm in this zone can be explained if *Empetrum* colonised the drier parts of the mire surface (possibly the hummocks) whilst *Sphagnum* is more dominant in the wetter parts (possibly in the hollows).

The small rise in Types 3/3a and 14 at 76cm (indicators of drier conditions) coincides with a shift towards a higher degree of humification (Figure 6.38) a decrease in the frequency of remains of Types 19 and 32 (wet indicators).

Degree of humification

The shift to a higher degree of humification above 72cm in this zone corresponds with a reduction in the proportion of Ericaceous twigs in the peat matrix. As mentioned above, there is also a reduction in the frequency of the wet-indicating fungal and algal remains above 72cm which suggesting a significant shift to drier conditions.

Summary

The pollen evidence represented in this zone indicates an open upland heath colonised by *Empetrum,* grasses and sedges with occasional birch trees. Since there is no macrofossil evidence for the local presence of pine and relatively low *Pinus* pollen concentration values are represented, it is not possible to determine whether the reduction in *Pinus* pollen frequencies represents a local or regional reduction of pine.

The reduction of the *Empetrum* cover towards the top of the zone and the corresponding increase in *Betula* pollen frequencies, may indicate that the birch pollen is *Betula nana,* since this species would be in direct competition with the dwarf shrub layer. In addition, the representation of Type 64 to the top of the zone suggests the continued local presence of *Empetrum.*

The evidence for a relatively high degree of humification towards the top of this zone is supported by the reduction of the frequency of wet indicating fungal and algal remains and the only record of blackened *Pinus* grains in this profile.

6.4.4.4 LPAZ - MNM 4 (65-24cm) (*c.*2980-2810 BP)

Percentage pollen and spore diagram

This zone is characterised by a decrease in the representation of tree pollen types towards the top of the zone (from *c.*80% to *c.*40%) and a corresponding increase in the representation of shrub and herbaceous types (to 27% and 32% respectively).

The reduction in tree pollen frequencies in this zone (from *c.*80% at the base to *c.*40% at the top) is largely a result in the decrease in the frequency of *Pinus* pollen (from 39% to 8%). This corresponds with an increase in the proportion of *Betula* pollen frequencies.

Corylus avellana type pollen is more frequent and *Calluna* shows a small increase in frequencies reaching a maximum of 16% at the top of the zone. *Empetrum* pollen is recorded at very low frequencies (less than 0.5%) but there is a small peak in *Vaccinium* pollen frequencies at 48cm.

The increase in the representation of herbaceous types is largely a result of the rise Poaceae and Cyperaceae pollen frequencies and a small increase in *Ranunculus* (undiff.) pollen frequencies at the base of the zone.

Pollen concentration and influx diagrams

The relatively high pollen influx values in this zone probably reflect the high peat accumulation rates (4.2 yr cm^{-1}) (discussed above) but the pollen concentration values do not appear to correspond with the degree of peat humification (Figure 6.36).

The pollen concentration and influx data generally supports the percentage pollen data and highlights the increase in the importance of *Calluna* towards the top of the zone (rising to a peak of *c.*5,600 grains cm^{-3}). The high *Pinus* pollen concentration and influx values at the base of the zone correspond with the peak in *Pinus* percentage values (Figure 6.39) and may indicate the local presence of isolated pine trees. However, as suggested earlier, the *Pinus* concentration values are relatively low in comparison to the sites at lower altitudes.

Fungal and algal remains diagram

Type 28 is again consistently represented in this zone, as with all the lower zones. Since Cyperaceae pollen frequencies are recorded at significant frequencies throughout this and the lower zones it is likely that Type 28 can be interpreted as an indication of the local presence of sedge.

Type 64 rises to a peak at 40cm which corresponds with a small peak in the degree of humification (Figure 6.38) but there is only a small rise in *Empetrum* pollen frequencies (*c.*0.5%). Type 14, is also represented at 40cm, indicating relatively dry conditions.

Type 20/21 is also represented at 40cm. Van Geel (1978) suggests that *Empetrum* may have been a host for one of these fungi which supports the evidence at this site that there is a correspondence between the frequencies of Types 20/21 and Type 64 (also associated with *Empetrum*) although the *Empetrum* pollen frequencies are relatively low in this zone. This supports the suggestion proposed above, that *Empetrum* is present on the mire surface but is not producing pollen, or that the pollen fails to become incorporated in the fossil record in significant quantities.

Degree of humification

The transmission values represented in this zone oscillate about the mean value. As mentioned above, there is a decrease in the transmission value at 40cm which coincides with the rise of dry indicating fungal and algal remains.

Summary

The pollen evidence in this zone indicates an open upland heath colonised by sedges, grasses and the occasional occurrence *Calluna vulgaris.* Birch is present (possibly *Betula nana*) and the pollen-stratigraphic evidence indicates the presence of isolated pine trees at the base of the zone. However, there is no macrofossil evidence to confirm the local presence of pine (or birch).

The reduction of the representation of wet indicating fungal and algal remains and an oscillation about mean transmission values indicates that this zone represents slightly drier conditions. The presence of Types 64 and 20/21 despite the low frequencies of *Empetrum* pollen indicates that *Empetrum* was present but is not represented in the pollen record.

6.5 SUMMARY OF GLEANN EINICH RESULTS

6.5.1 POLLEN-STRATIGRAPHIC EVIDENCE

A summary of the interpretations made of the local pollen assemblage zones of the four sites investigated at Gleann Einich is shown on an age axis (radiocarbon years BP) in Figure 6.40. The pollen stratigraphic evidence will now be described and discussed in terms of the history of the establishment and decline of pine in the area.

6.5.1.1 THE COLONISATION OF PINE AT GLEANN EINICH

Figure 6.41 shows the *Pinus* pollen frequencies for the sites investigated at Gleann Einich plotted to a common temporal scale (Radiocarbon years BP). Assessing the pollen frequencies in terms of whether pine was absent or present at a point in time requires the confirmation of radiocarbon dated pine macrofossils. However, since none of the pine macrofossils from the sampled profile were submitted for radiocarbon dating their ages can only be crudely estimated from their stratigraphic depth. Pine macrofossils which are immediately adjacent to pollen sub-samples, facilitates an estimation of pine pollen frequencies which are indicative of the local presence of pine, but again synchroneity cannot be assumed. The tree may have been dead for several years before incorporation into the peat matrix, and the wood may have been from the root system, in which case the "palaeo-mire surface" cannot be established with confidence.

However, some form of simplification of the four sets of pollen data is required before an attempt can be made to interpret the evidence for the establishment and decline of pine. Where pine macrofossils were identified from the sampled profile (as at APB and CPG), pine pollen percentages from adjacent peat sub-samples are above 40% total land pollen (TLP). To aid an assessment of the relative timing of pine migration and colonisation at each of the sites, a semi-arbitrary threshold figure of 30% pine pollen (Total Land Pollen sum) is adopted as indicative of the local presence of pine. This figure represents a compromise between the 40% pine pollen mentioned above and the 20% (TLP) used to indicate the local presence of pine by Bennett (1984).

Using this 30% *Pinus* pollen threshold figure, an assessment will be made of the evidence for the relative timing of the colonisation of pine at each site (using linear interpolation of the radiocarbon age estimates) and to then estimate the rate of altitudinal migration of pine between the sites along the transect (Table 6.2).

FIGURE 6.40. SUMMARY OF LOCAL POLLEN ASSEMBLAGE ZONES FOR THE SITES INVESTIGATED AT GLEANN EINICH (RADIOCARBON YEARS BP)

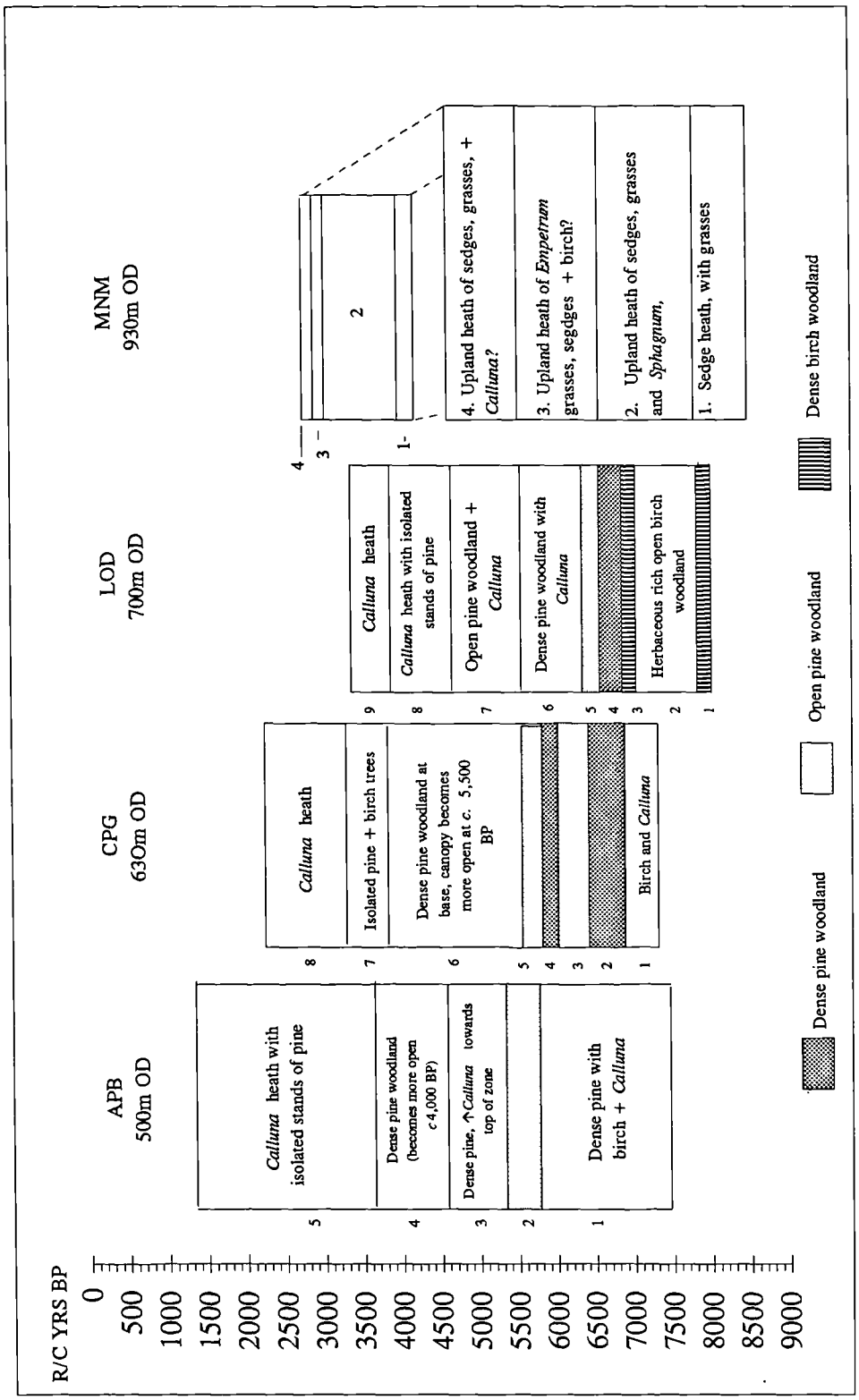


FIGURE 6.41. *PINUS* POLLEN FREQUENCIES FOR SITES INVESTIGATED AT GLEAN EINICH PLOTTED ON AGE AXES (RADIOCARBON YEARS BP)

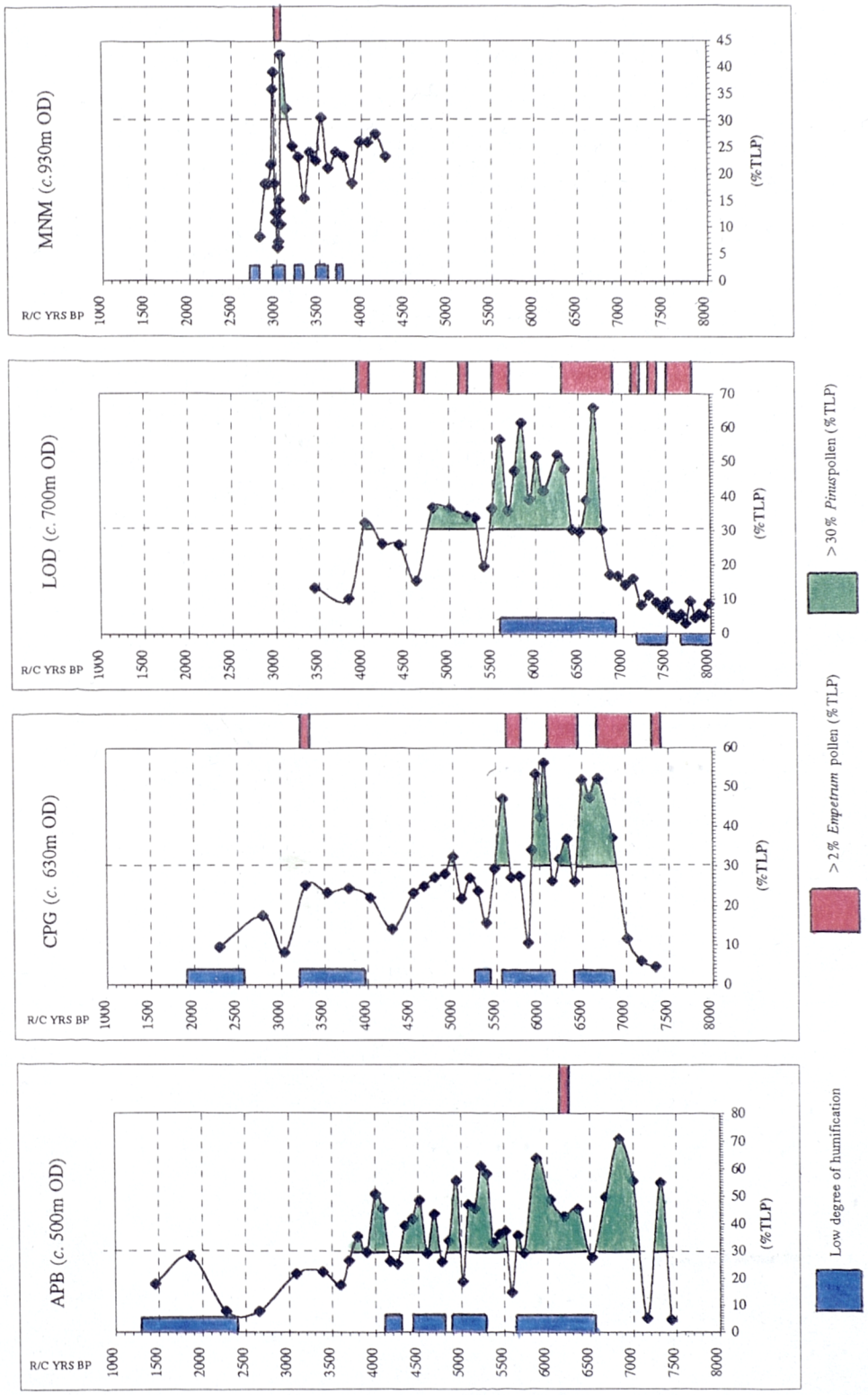


TABLE 6.2 Estimation of pine migration rates at Gleann Einich

SITE CODE	ALTITUDE (m OD)	PINE COLON-ISATION R/C YRS BP (>30% TLP)	HORIZONTAL DISTANCE TO NEXT SITE (m)	MIGRATION RATE (m yr^{-1})
APB	500m	7,320 BP	650m	**APB to CPG = 1.3 m yr^{-1}**
CPG	630m	6,850 BP	1250m	**CPG to LOD = 15.0 m yr^{-1}**
LOD	700m	6,700 BP	1900m	
MNM	930m	3,530 BP?	N/A	
MEAN RATE OF PINE MIGRATION				**APB to LOD = 3.3 m yr^{-1}**

The key points of interest in Table 6.2 are that the interpolation of the radiocarbon dates indicates a consistent upslope trend of progressively later colonisation of pine. This would suggest that pine migrated upslope as a "front" at Gleann Einich as opposed to a pattern of patchy colonisation and establishment. However, Dubois and Ferguson (1985) report a radiocarbon age estimate of 7,350 +/- 85 BP for a pine stump at an altitude of 730m OD from the northern flanks of the Cairngorms. This suggests that the pine may have been established at the equivalent height of LOD (700m OD) in isolated stands in other, possibly more favourable, parts of the Cairngorms or that the pine pollen frequencies are under-representative of local pine establishment at this time at LOD.

Since the horizontal distance between the sites represents a measurement directly from the Ordnance Survey map and as the intervening topography and steepness of slope are not taken into consideration the migration rates are very crude estimates. However, it is interesting to note the order of magnitude of these estimates. The values indicate that pine migrated from APB to CPG at a slower rate than from CPG to LOD. In theory, the opposite trends would be expected, since with increasing altitude pine would have been approaching the limit of its ecological tolerance. Explanations for this may be related to climate changes during the period concerned or to the type of vegetation cover already in existence when pine colonised the site.

At CPG pine migrates into a pre-existing birch woodland with a dense *Calluna* understorey, whereas at LOD, pine migrates into birch woodland (possibly even dwarf birch) with an understorey of sedge and *Empetrum* and only a sparse cover of *Calluna*. The faster rate of migration might be because the understorey was open and more favourable for pine establishment and growth between CPG and LOD. McVean (1961) concluded that pine seedlings often failed to become established in mature *Calluna* stands "because of the deep, loose moss mat which builds up between the heather stands" which prevents the seeds

reaching the peat surface. Gimmingham (1995) suggested that in uneven-aged stands of *Calluna* the establishment of pine is restricted to gaps occurring in the *Calluna,* and Gong (1984) observed that the invasion of gaps by pine is prevented during the dense building phase of *Calluna.* Following successful succession to woodland *Calluna* is subsequently shaded out (Gimmingham, 1995). So the less dense *Calluna* cover between CPG and LOD may have been more favourable for the germination and growth of pine seedlings and therefore reflected in the pollen stratigraphy as a relatively fast migration rate.

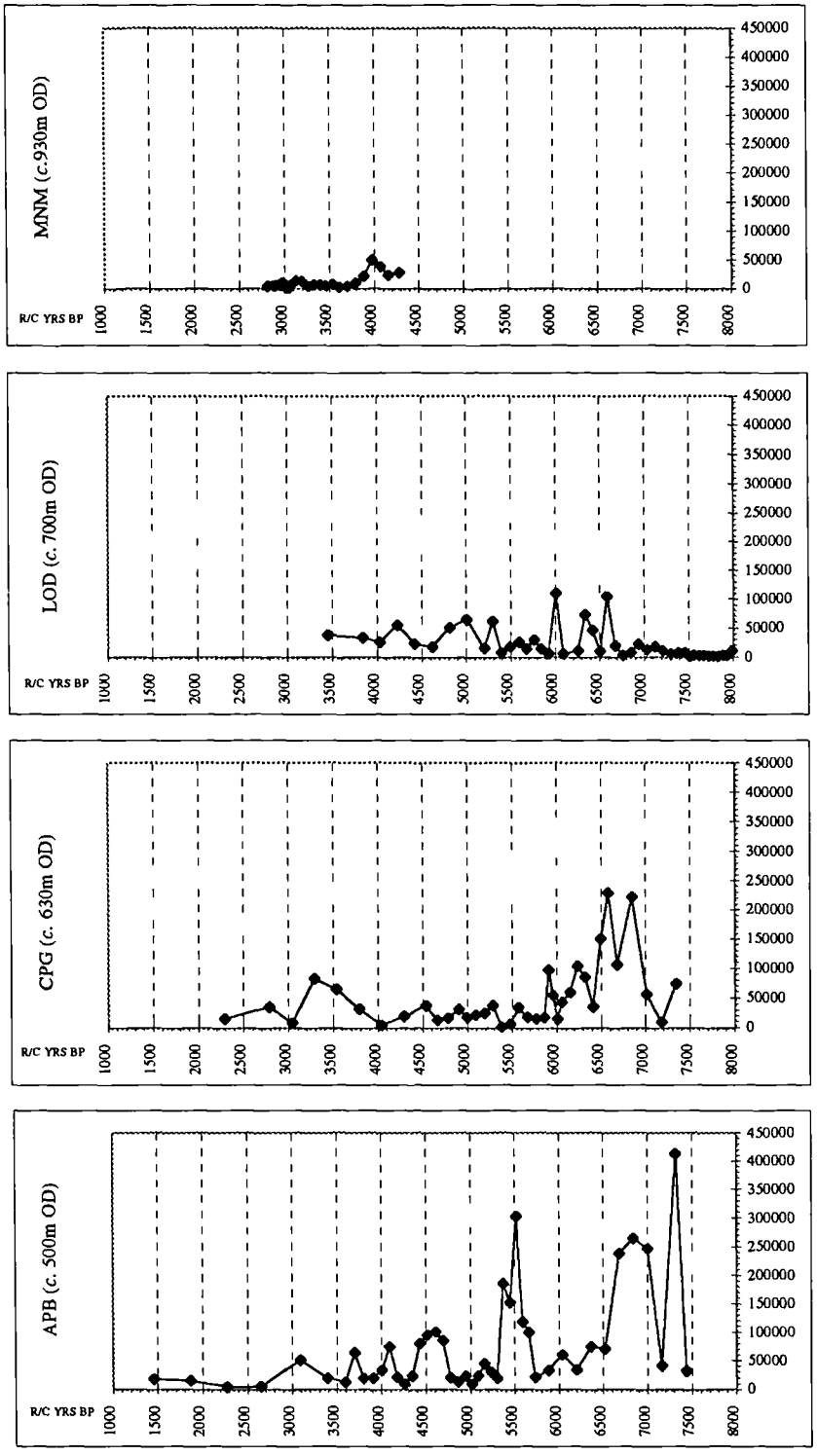
The estimated figures for the altitudinal migration of pine given above can be compared with the geographical spread of pine across Britain. Birks (1989) estimates that pine spread north to central England, the southern Lake District and the northern Pennines between *c.*9,000 and 8,500 BP at a rate of *c.*300-700m yr^{-1}. By 8,000 BP the rate of spread had decreased to 60-100m yr^{-1}. In Bennett's investigation of the post-glacial history of pine, he proposes that between *c.*9,000-7,500 BP the average rate of spread was about 280m yr^{-1} in Britain (Bennett, 1984).

So the crude estimate for the rates of altitudinal spread of pine at Gleann Einich (of 1.3 to 15.0 m yr^{-1}) are considerably less than the estimates for the geographical spread of pine calculated across Britain. However, the rates are of an order of magnitude which might be expected if pine is approaching its altitudinal and/or latitudinal limit of distribution.

Although isolated pine stumps have been found in the Cairngorms up to 914m (Pears, 1968) none were found in the vicinity of MNM (930m) in Gleann Einich. MNM was selected as an "above tree-line" reference site, and was envisaged as having always lain above the tree-line during the Holocene. The relatively late initiation of peat accumulation at MNM prevents the investigation of the history of pine prior to *c.*4,270 BP at this locality, but surprisingly high pine pollen frequencies are found after this date. Pine pollen frequencies exceed 30% at *c.*3,530 BP, *c.*3100 BP and *c.*2970 BP which suggests pine was present at this site during these times (even on the more stringent threshold criterion than that adopted by Bennett, 1984). Paradoxically, the evidence from the other sites investigated indicates that pine was absent, or was poorly established, at this time, which implies that the pine pollen represented at MNM was unlikely to be derived from adjacent lower altitudes.

The relatively low *Pinus* pollen concentration values recorded at MNM also suggest that the *Pinus* pollen at this site is unlikely to be over-represented by a high regional signal (Figure 6.42 shows the *Pinus* pollen concentration values on a temporal scale for each site). Although there is evidence to suggest that the pollen concentration values often show a correspondence with the degree of peat humification (as at APB), a comparison of the relative magnitude of pollen concentration values at each of the sites can provide an insight into the record of pollen rain influx. The generally lower pine pollen concentration values at

FIGURE 6.42. *PINUS* POLLEN CONCENTRATION VALUES (EXPRESSED GRAINS CM^{-3})
FOR SITES INVESTIGATED AT GLEANN EINICH
PLOTTED ON AGE AXES (RADIOCARBON YEARS BP)



higher altitudes suggests that the regional pine pollen signal at the higher sites is not significantly greater than at lower altitudes.

However, the consistent presence of Alnus (a lowland species) at relatively high frequencies at MNM indicates that there is a regional component in the pollen rain. Alnus pollen frequencies reach almost 16% at MNM and values over 2% have been interpreted as indicating the local but sparse occurrence of alder (Huntley & Birks, 1983). So a proportion of the pollen recruited at MNM is likely to have been derived from a regional source, and this presumably included pine pollen.

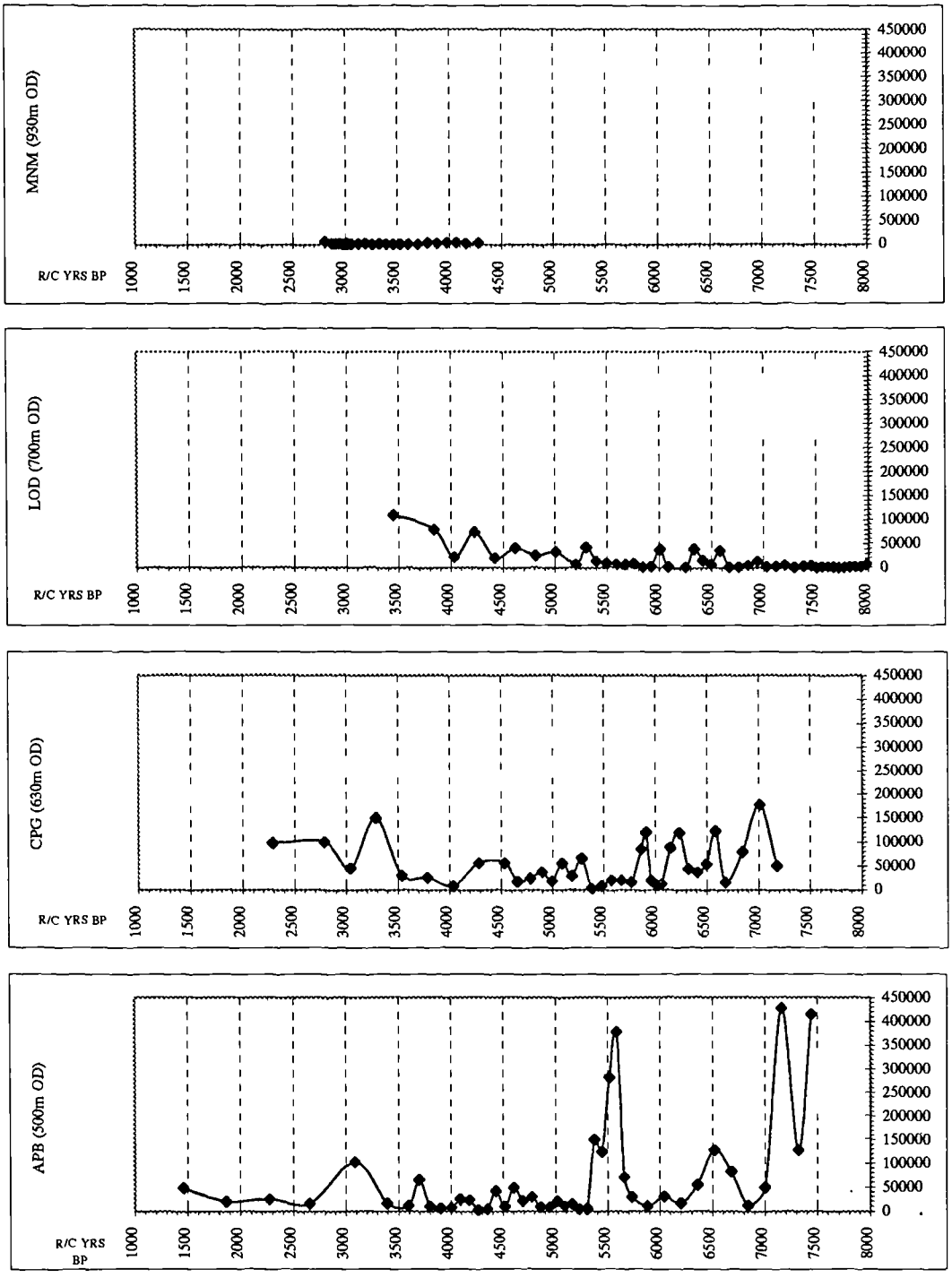
The *Pinus* pollen frequencies for MNM therefore indicate that pine trees may have reached higher altitudes than the upper limit of pine macro-fossil preservation in this area suggests. However, the significant feature of the pollen stratigraphic evidence at MNM (in comparison to the lower altitude sites investigated) is the low representation of *Calluna vulgaris,* a profuse pollen producer which, for relative pollen data, would suppress the *Pinus* pollen frequencies. The *Pinus* frequencies at MNM are therefore likely to be over-represented which is supported by the observations of Hicks (1993) that long distance transported pollen is virtually all that is present on the mountain top since the local plants produce very little pollen (see Section 4.4). Since no pine macrofossils were located at this altitude there is no conclusive evidence that pine reached the site of MNM (this will be discussed further in Section 6.5.1.2) but the 30% threshold figure adopted here allows for over-representation and therefore sparse pine woodland is possible.

6.5.1.2 TREE-LINE DYNAMICS

The identification of a synchronous regional change in the altitude of the former tree-line from the pine pollen stratigraphic data from Gleann Einich is not straightforward. Figure 6.41 shows the *Pinus* pollen frequencies on temporal scales (radiocarbon years BP) of the four sites investigated at Gleann Einich. One of the features of relative pollen diagrams is the interdependency of the taxa which make up the pollen sum, therefore the composition of the understorey needs to be considered.

Pine pollen frequencies reach higher values at LOD (maximum of 65%) than at the lower site, CPG (maximum of 56%). This may indicate that the density of the pine woodland was greater at LOD than at CPG, but is more likely to be related to the lower density of *Calluna* cover at LOD. As suggested in 6.5.1.1., *Calluna* is a profuse pollen producer and a high concentration of *Calluna* pollen would have the effect of suppressing the pine pollen frequency at the lower site of CPG. This is supported by the evidence of the *Calluna* pollen concentration values, which generally decrease with increasing altitude (see Figure 6.43).

FIGURE 6.43. *CALLUNA VULGARIS* POLLEN CONCENTRATION VALUES (EXPRESSED AS GRAINS CM^{-3}) FOR SITES INVESTIGATED AT GLEANN EINICH PLOTTED ON AGE AXES (RADIOCARBON YEARS BP)



The problem is probably exacerbated at MNM where *Calluna* pollen representation is very low (maximum concentration value of 5,600 grains cm^{-3} and maximum frequency of less than 1.5%). This corresponds with pine pollen frequencies rising to values of over 40% (TLP) but the pine pollen concentration only rises to a maximum *c.*5,500 grains/cm^{-3} (in comparison to a maximum values of *c.*500,000 grains cm^{-3} at CPG).

If pine pollen concentration or pollen influx values are used as threshold figures to indicate the local presence of pine, post-depositional processes such as the degree of humification and matrix accumulation rates need to be considered and quantified. As the results from Gleann Einich have shown, the trends in the pollen concentration data often show episodes of correspondence with the degree of humification of the peat matrix, but the relationship is not sufficiently consistent to allow for a standard correction of the concentration and influx values.

In summary, the relative pollen data can be used as evidence for estimating the former density of pine woodland if consideration is made of site specific factors such as the taxa contributing to the pollen sum, the pine pollen concentration values and the degree of humification of the peat matrix.

In Section 6.5.1 the semi-arbitrary figure of 30% *Pinus* pollen was adopted as indicative for the local colonisation of pine at a site. For the same reasons, significant deviations from the value of 30% *Pinus* pollen will be used as a guide of the changing density of pine stands at each site. Frequencies greater than 30% *Pinus* pollen indicate an increase in the density of the pine woodland canopy and frequencies of less than 30% indicate a change to an open canopy.

The episodes of pine establishment at Gleann Einich based on the relative pine pollen data (Figure 6.43) can be summarised as follows:

i) Relatively dense pinewood canopy at APB between *c.*7,300 BP and *c.*3,800 BP
ii) Relatively dense pinewood canopy at CPG and LOD between *c.*6,800 BP and 5,500 BP
iii) Short-term re-establishment of pine at CPG and LOD at *c.*5,000 BP.
iv) Short-term establishment of pine at MNM at *c.*3,500 BP, *c.*3,100 BP and *c.*2,950 BP (although there is no macro-fossil evidence to support this)

Fluctuations in the density of the pinewood canopy occur within these main phases identified as indicated by the fluctuations in the pine pollen frequencies.

However, the pine pollen concentration and influx values sometimes show a poor correspondence with the pine pollen percentage values. Peaks in pine percentages often

match low concentration values and *vice versa* (e.g. for APB at *c.*5,500 BP and for CPG at *c.*6,000 BP). But as suggested in the results for APB and CPG this appears to be related to the degree of humification of the peat matrix.

Having identified the main phases of pinewood establishment at the three lower sites, and the possibility of short-term phases of pine establishment at the highest site, is it possible to distinguish synchronous episodes of opening of the pinewood canopy, and to interpret these episodes in terms of changes in the altitude of the tree-line?

Since there is radiocarbon dating evidence for diachroneity in the migration and colonisation of pine along the Gleann Einich transect, it is reasonable to assume that the pollen signal should also record a diachronous response of the woodland canopy to regional climatic change. Opening of the woodland canopy as a response to regional climatic deterioration should be recorded in the pollen stratigraphy at the higher sites first and similarly, a subsequent return to a denser pinewood canopy as a response to climatic amelioration should occur at the lowest site first and the highest site last. However, the identification of such a sequence of events would be dependent on the accuracy of the radiocarbon age estimates and without independent chronological evidence (such as tephra layers) it is not possible to test these dates. Therefore, the interpretation of the pollen stratigraphic evidence is limited, not only by the inherent problems associated with pollen analysis (see Sections 4.2 to 4.4) but by the accuracy of the radiocarbon dates.

The general trends in the pine pollen evidence for changes in the density of the pine woodland canopy at Gleann Einich are as follows:

1. Following migration and colonisation of pine at each of the three lower sites there is a rapid establishment of a relatively dense pinewood canopy
2. Reduction in the density of the pinewood canopy at APB and CPG between *c.*6,500-6,100 BP and at LOD between *c.*6,600-6,400 BP.
3. Dense pine wood canopy at APB, CPG and LOD at *c.*6,000 BP
4. Open pinewood canopy at APB, CPG and LOD at *c.*5,500 BP
5. Marked fluctuations in the density of the pinewood canopy at APB between *c.*5,400 and *c.*4,000 BP.
6. Short-term re-establishment of denser pine woodland at *c.*5,000 BP at CPG and LOD.
7. Relatively open pinewood canopy at CPG and LOD after *c.*4,800 BP.
8. Short-term re-establishmishment of relatively dense pine woodland at APB and LOD (and possibly (MNM) at *c.*4,200-4,000 BP.
9. Relatively open pinewood canopy at APB after *c.*3,800 BP.

10. Possibly a short-term establishment of isolated stands of pine at MNM at *c.*3,100 and *c.*2,900 BP.

The evidence for changes to relatively open pinewood canopies at the three lowest sites may be refined by assessing the pollen evidence for the synchronous expansion of taxa normally found in greater abundance above the tree-line, such as *Empetrum* spp. *Empetrum* is also found, at low frequencies, within the pine woodland understorey and an increase of *Empetrum* pollen frequencies at the lower altitude sites might also indicate an opening of the pine woodland canopy. *Empetrum* does not produce pollen profusely and the pollen is usually poorly dispersed; frequencies above 2% of the pollen sum are interpreted as indicative of local growth (Huntley & Birks, 1983). The bars on the right of the pine pollen frequencies on Figure 6.41 indicate periods of high *Empetrum* pollen frequencies.

As shown, there are episodes of relatively low pine pollen frequencies which do not correlate with an increase in *Empetrum* pollen frequencies. This may indicate that a deterioration in climate was not the only cause for the opening of the pinewood canopy. So the identification of episodes of less that average pine pollen frequencies which correspond with episodes of high *Empetrum* pollen frequencies may indicate a regional lowering of the tree-line at higher altitudes and an opening of the pinewood canopy at lower altitudes.

This matrix approach to a combination of a decrease of pine pollen frequencies and an increase in *Empetrum* pollen frequencies is found to occur at:

TABLE 6.3 Synchronous decrease in *Pinus* pollen frequencies and increase in *Empetrum* pollen frequencies

APB	CPG	LOD	MNM
			c. 3,000 BP
			c. 3,900 BP
		*c.*4,600 BP	
*c.*5,100 BP	*c.*5,300 BP	*c.*5,400 BP	
	*c.*5,600-5,800 BP		
*c.*6,200 BP	*c.*6,400-6,100 BP	*c.*6,500 BP	

The combined evidence of a decrease in pine pollen frequencies and an increase in *Empetrum* pollen frequencies suggests regional opening of the pine-woodland canopy or lowering of the tree-line at *c.*6,500-6,100 BP, and *c.*5,400 BP.

This evidence therefore supports, but also refines, the signal for a regional lowering of the tree-line indicated between *c.*6,400 and 6,100 BP based solely on the relative pine pollen data. However, the supplementary *Empetrum* evidence indicates that the pinewood canopy at APB was relatively open at *c.*6,200 BP rather than at *c.*6,500 BP as indicated by the pine pollen frequencies.

In conclusion, the strongest evidence for a regional synchronous opening of the pine woodland canopy or depression in the tree-line at Gleann Einich is between *c.*6,600-6,100 BP which correlates with the similar depression in the tree-line identified at Rannoch Moor shortly after 6,500 BP (Ward *et al.*, 1987).

As outlined in Section 6.5.1.1, there is no conclusive evidence for the establishment of pine at the highest site investigated at Gleann Einich, MNM. However, for the tree-line fluctuations identified at the lower three sites to be valid, the same criteria should be adopted at MNM. Episodes of relatively high frequencies of *Empetrum* pollen and low frequencies of *Pinus* pollen at MNM are recorded just before 3,000 BP and possibly just after *c.*4,000 BP (and the former corresponds with an increase in *Betula* pollen frequencies). The presumably local expansion of *Empetrum* indicates that either there was a reduction of pine trees at this time (as at the lower sites), or that *Empetrum* successfully competed with the mosses that make up the *Rhacomitrium* heath found at high altitudes. This corresponds with an expansion of Poaceae and *Ranunculus* type pollen frequencies which indicate more open conditions. *Empetrum* favours relatively dry conditions but the synchronous expansion of *Sphagnum* and the low degree of humification indicates that the increased *Empetrum* pollen frequencies was not simply a result of the mire surface becoming drier.

Therefore, if the same criteria are adopted for the identification of periods of relatively open pinewood canopy using pollen stratigraphic data, then the evidence at MNM indicates that there was a reduction in tree cover at *c.*4000 BP and *c.*3,000 BP. However, as mentioned above (7.5.1) there is no conclusive macrofossil evidence to support this interpretation.

However, the evidence that pine may have colonised the remote, high altitude site of MNM, but also shows indications of a fluctuation of the tree-line at *c.*3,000 BP appears to contradict the evidence for the absence of pine during this period at lower altitudes. Either the pollen evidence is affected by a high regional pollen signal (unlikely given the evidence of low pine pollen concentrations at MNM) or alternatively a climatic deterioration was not the primary cause for the decline of pine in the region. Alternative hypotheses, such as anthropogenic influences, must be considered.

6.5.1.3 THE DECLINE OF PINE AT GLEANN EINICH

The widespread occurrence of pine stumps dated to *c.*4,000 BP and a corresponding decline in pine pollen frequencies suggest that pine virtually disappeared from many parts of Scotland at this time (Bennett, 1984). However, the pollen stratigraphic data of the sites investigated at Gleann Einich do not indicate a synchronous decline of the pine woodland cover and interpretation of the data is complicated by the relatively high pine pollen frequencies recorded at the highest site MNM, as described above.

The pollen stratigraphic evidence indicates that there was a marked opening of the pinewood canopy at APB at *c.*3,800 BP followed by an expansion of *Calluna* heath after *c.*3,600 BP. The presence of the pine stump at APB (between 70-80cm in the peat profile), although not submitted for radiocarbon dating, suggests that pine was present at this site after *c.*3,600 BP but the *Pinus* pollen evidence indicates that the pine trees were probably in isolated stands. The lower pine pollen representation at APB at *c.*4,000 BP therefore corresponds with the general "pine decline" model.

The "pine decline" or the demise of dense pine woodland cover at CPG and LOD occurred at *c.*5,500 BP followed by a short-term phase of higher pine pollen frequencies, possibly representing an open pine woodland, at *c.*5,000 BP. It appears from the pollen data that pine trees failed to become re-established at equivalent densities at CPG and LOD following the initial decline at *c.*5,500 BP. A possible explanation for this is that climatic conditions at altitudes above 500m (APB) after *c.*5,500 BP were less favourable for the re-establishment and growth of pine. Alternatively, it may be related to the composition of the shrub layer. As suggested in Section 6.5.1.1, the faster migration rate of pine between CPG and LOD may have been related to the reduced *Calluna* understorey favouring the establishment of pine. *Calluna* became more dominant at LOD and CPG following the reduction in pine cover at *c.*5,500 BP which may have similarly inhibited the re-establishment of pine at these sites. APB is not affected by this local factor since the pinewood canopy never became sufficiently open to allow the expansion and dominance of *Calluna*.

The open pine woodland or isolated stands of pine which existed after *c.*5,000 BP at LOD gave way to *Calluna* dominated heathland after *c.*4,000 BP. The final decline of pine at this site corresponds with the opening of the pinewood canopy and expansion of *Calluna* heath which occurs at APB (Figure 6.41).

However, the pollen evidence recorded for MNM still poses the same questions, as discussed above, as to whether pine ever reached this site. The isolated pine stumps Pears observed at 914m (Pears, 1968) provide evidence that pine reached altitudes close to that of MNM in the Cairngorm area (although the location of these isolated pine stumps is not published). So although the pine pollen recorded in the peat stratigraphy at MNM may not be derived from trees growing directly on the mire surface (since there are no macrofossils to confirm the local presence of pine), it may be derived from trees growing on adjacent areas of drier mineral ground substrate. The principal problem with this hypothesis is that the relatively high pine pollen percentages indicate that pine trees survived at this remote, high altitude site at a time when the lower sites indicate a reduced pine woodland cover or isolated stands of pine. The pine pollen concentration values at MNM are generally less than the values

from the lower sites (Figure 6.42). However, maximum values are recorded of *c.*49,000 grains cm^{-3} at *c.*4,000 BP at MNM when the lower sites show relatively lower values. Similarly the peak in pine frequencies and concentration values shortly before and after *c.*3,000 BP indicates the local presence of at least isolated pine trees at MNM. Finally, the fall in pine pollen values at MNM is represented as a gradual decline after *c.*2,950 BP and cannot, therefore, be described as a distinct " pine decline".

The pollen evidence from the sites investigated at Gleann Einich therefore indicate that the decline in pine woodland cover was not a synchronous event, but occurred gradually over a period of *c.*2,500 years. The presence of pine macrofossils in the peat profile also indicate that isolated pine trees were able to survive up to an altitude of at least *c.*600m (CPG) following the reduction of pine woodland cover. The high pine pollen frequencies and moderately high pine pollen concentration values recorded at MNM, (together with macrofossil evidence for the presence of pine up to altitudes of 914m in the Cairngorms, Pears, 1968)) indicate that pine may have reached MNM or reached altitudes very close to that of MNM.

As mentioned above, in 6.5.1.2, alternative hypotheses for a reduction of pinewood density should be considered since a deterioration in climate may not be the primary cause. Another possibility is the felling of the pine forests by the local inhabitants. However, it is difficult to envisage an anthropogenic cause for the decline of pine at *c.*5,500 at CPG and LOD whilst the lower, more accessible site of APB, remained under a relatively dense pinewood canopy.

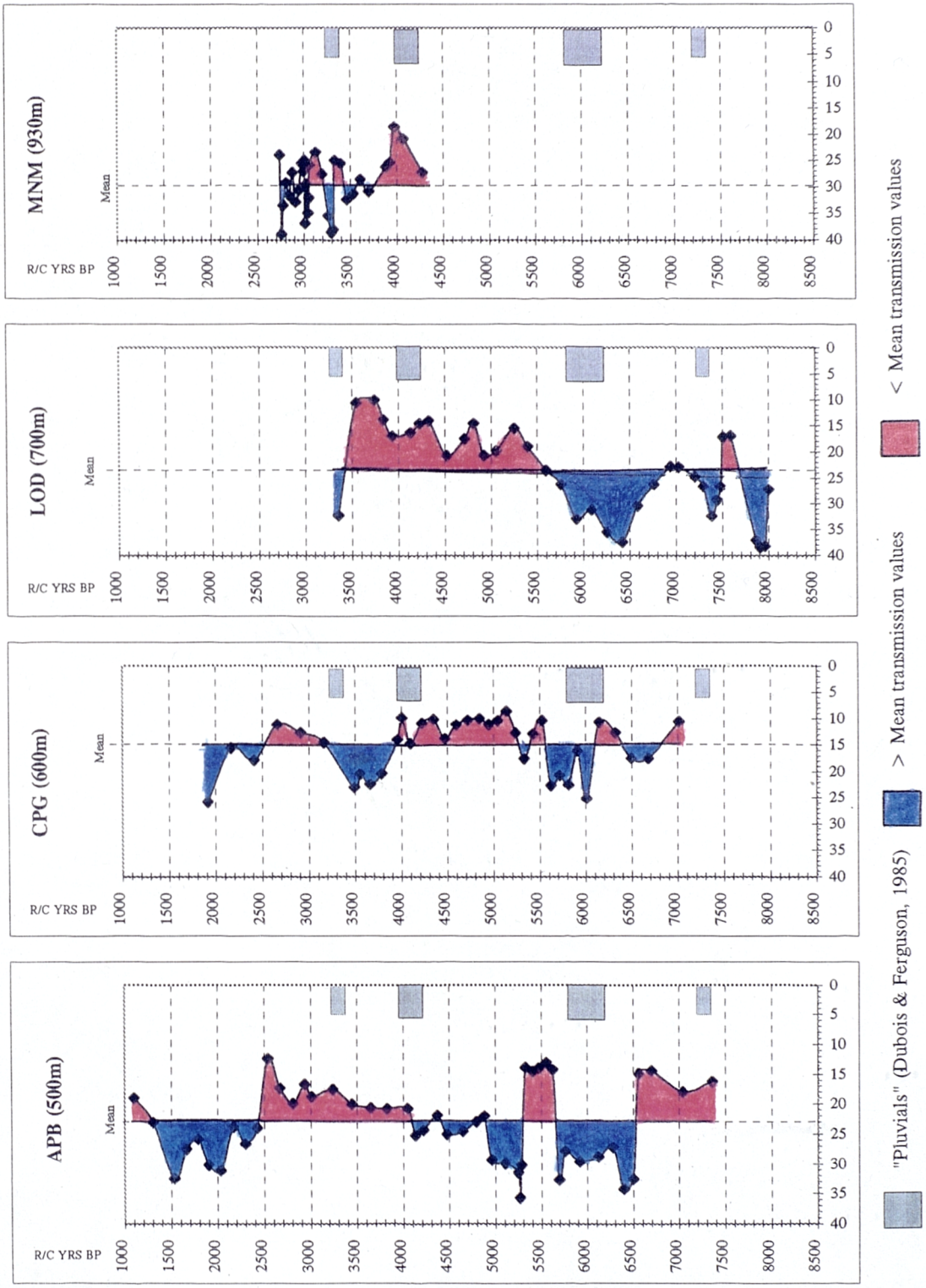
6.5.2 SITE HYDROLOGY

6.5.2.1 DEGREE OF HUMIFICATION

Figure 6.44 shows the humification evidence from the sites investigated at Gleann Einich on a temporal scale (using the linear interpolation of the radiocarbon dates) together with the "pluvials" identified by Dubois & Ferguson (1985). The degree of humification is inversely proportional to the transmission values which are therefore plotted on a reverse scale, with the mean transmission value for each site marked as a dotted line. To ease the visual assimilation of the humification data the less than mean transmission values are shaded red (to indicate a higher than average degree of humification) and the greater than mean transmission values are shaded blue (to indicate a higher than average degree of humification).

CPG has the lowest mean transmission value (15.9%) suggesting it is generally more humified than the other three sites investigated at Gleann Einich. The site with the highest mean transmission value (29.5%) is MNM. Since none of the Glean Einich sites are

FIGURE 6.44. DEGREE OF HUMIFICATION FOR THE SITES INVESTIGATED AT GLEANN EINICH, SHOWING DEVIATIONS FROM THE MEAN TRANSMISSION VALUES FOR EACH SITE AND COMPARISON WITH "PLUVIALS" IDENTIFIED BY DUBOIS FERGUSON (1985)



watershedding sites (col sites) the degree of humification may be affected by local factors such as site hydrology, (for example the influence of run-off from higher slopes). However, a synchronous shift towards a higher or lower degree of humification at two or more of the sites is likely to reflect a response to regional climatic change (denoted in bold in Table 6.4).

TABLE 6.4 Synchronous shifts to a lower than mean degree of humification (wet shifts) for the Gleann Einich profiles (synchronous shifts registered by three sites denoted in bold)

R/C YRS BP	500m	630m	700m	930m
2,400-1,900 BP	APB	CPG		
3,300-3,200 BP		**CPG**	**LOD**	**MNM**
3,750-3,450 BP		CPG		MNM
6,100-5,700 BP	**APB**	**CPG**	**LOD**	
6,400-6,100 BP	APB		LOD	
6,550-6,400 BP	**APB**	**CPG**	**LOD**	
6,500-5,700 BP	APB		LOD	

The strongest evidence for a synchronous shift to a lower degree of humification is therefore between *c.*6,500-5,700 BP (but the transmission values indicate that CPG shows evidence for a short-term shift to a higher degree of humification between *c.*6,300 BP and *c.*6,150 BP). This corresponds approximately with the "pluvial" identified by Dubois & Ferguson (1985) between *c.*6,200-5,800 BP.

The "pluvial" inferred by Dubois & Ferguson's data at *c.*3,300 BP corresponds with higher than average transmission values at CPG, LOD and MNM but not at APB. The *c.*4,200-3,940 BP pluvial is indicated by the data presented here, although there is a shift towards higher transmission values at APB, CPG and LOD at *c.*4,300 BP and at *c.*4,000 BP at CPG and MNM.

TABLE 6.5 Synchronous shifts to a higher than mean degree of humification (dry shifts) for the Gleann Einich profiles (synchronous shifts registered by three sites denoted in bold)

R/C YRS BP	500m	630m	700m	930m
2,950-2,450 BP	APB	CPG		
3,000-2,950 BP	**APB**	**CPG**		**MNM**
3,050-3,000 BP	APB	CPG		
3,200-3,050 BP	**APB**	**CPG**		**MNM**
3,450-3,300 BP	APB			MNM
3,750-3,450 BP	APB		LOD	
3,950-3,750 BP	APB		LOD	MNM
4,100-3,950 BP	**APB**	**CPG**	**LOD**	**MNM**
4,300-4,100 BP		CPG	LOD	MNM
4,400-4,300 BP	**APB**	**CPG**	**LOD**	
4,800-4,400 BP		CPG	LOD	
4,900-4,800 BP	**APB**	**CPG**	**LOD**	
5,300-4,900 BP		CPG	LOD	
5,400-5,300 BP	APB		LOD	
5,550-5,400 BP	**APB**	**CPG**	**LOD**	
5,900-5,800 BP	APB	CPG		
7,000-6,900 BP	**APB**	**CPG**	**LOD**	
7,200-7,000 BP	APB		LOD	

The dry shifts are more complex to interpret but the synchronous dry periods at three or more sites are at *c.*7,000-6,900 BP, 5,550-5,400 BP, 4,900-4,800 BP, 4,400 BP-4,300, 4,100-3,950 BP, 3,200-2,950 BP (denoted in bold font).

The most significant synchronous shift towards a higher degree of humification is at *c.*5,500 BP where APB, CPG and LOD all show low transmission values. Paradoxically, all four sites show a higher than average degree of humification at *c.*4,000 BP which corresponds with the "pluvial" episode suggested by Dubois & Ferguson (1985) between *c.*4,200-3,940 BP.

To summarise, the strongest evidence for synchronous shifts to a lower degree of humification at the Gleann Einich sites is between *c.*6,500-5,700 BP and at *c.*3,300 BP and after *c.*2,000-2,500 BP (APB and CPG). The strongest evidence for episodes of well humified peat is more patchy, but all four sites show a relatively dry phase at *c.*4,000 BP. This is surprising considering that one of the pluvials interpreted by Dubois & Ferguson (1985) based on their isotopic data in the Cairngorms is interpreted for *c.*4,200-3,940 BP. On Figure 6.41, the shifts to a lower degree of humification are shown plotted to the left of the *Pinus* pollen frequency curves for the four sites at Gleann Einich. The most striking correspondence is between the higher *Pinus* pollen percentages (interpreted above as evidence for a relatively dense pine woodland canopy) and a relatively low degree of humification, e.g. *c.*6,500-4,100 BP at APB and *c.*6,800-5,500 BP at CPG and LOD.

This correspondence might indicate that the degree of humification of peat is partly a function of the local vegetation cover. A dense pinewood canopy may increase the local

humidity of the mire surface and hence effectively lower the degree of humification of the peat matrix. Similarly, an opening of the tree canopy and a corresponding expansion of dwarf shrubs may reduce the local humidity of the mire surface which is reflected as a relatively high degree of humification. Alternatively, a change to drier conditions, as indicated by the degree of humification, might favour the expansion of dwarf shrubs. However, this can obviously lead to series of circular arguments.

Pears (1988) highlights the caution required in inferring a palaeoclimatic signal from the analysis of stable isotope values in sub-fossil pine (e.g. Dubois & Ferguson, 1985). Pears notes the observations by several workers (e.g. Geiger, 1965) that "relative humidity values at and just above the ground surface within well developed forest stands are much higher than those to be found at similar levels in open sites outside the forest" (Pears 1988, p.178). The degree of humification of the mire surface, therefore, may well be influenced by, or indeed be a reflection of, the relative density of the pinewood canopy above the mire surface.

If less humified peat does indicate the presence of a relatively dense pinewood canopy then this would suggest that pine was present, in a greater density than indicated by the pollen evidence, after *c.*4,000 BP at CPG and after *c.*2,500 BP at APB.

However, the opposite relationship between pine pollen frequencies and the degree of humification generally occurs at MNM. The wet shifts at *c.*3,700 BP and 3,500 BP correlate with episodes of relatively high pine pollen percentages (as at the lower sites). However, the large wet shifts at *c.*3,250 BP and *c.*3,000 BP correlate with low pine pollen frequencies. At *c.*3,000 BP the isolated pine trees may well have been temporarily excluded from the region of MNM (as described in the section above). This might be accounted for by consideration of the hydrological tolerance of pine. Pine was not growing on the peat surface at MNM, as indicated by the absence of pine macrofossils. If pine did reach MNM it was probably growing on the better drained higher ground surrounding the mire. The mire surface was never sufficiently dry for pine trees to become established on its surface. The relative wetness of the peat at MNM is indicated by the humification evidence (it has the highest average transmission value for all four sites investigated - 29.5%), plus the dominance of wet-indicating fungal and algal remains (see below). The shift to extremely wet conditions at *c.*3,250 and 3,000 BP causes a reduction in the number of isolated pine trees in the area (or cessation of pollen production).

This would also provide an explanation for why the humification evidence does not correspond so well with higher pine pollen frequencies (as at the lower altitude sites). Pine trees never grew on the peat surface at MNM, it was too wet, and could not therefore induce an increase in local humidity as suggested for the lower sites. A subsequent shift to even wetter conditions (as indicated by the humification and the fungal and algal evidence)

resulted in the hydrological tolerance of pine being exceeded, even on the better drained surrounding ground.

In conclusion, isolated pine trees probably did reach altitudes approaching that of MNM (930m). However, the trees would have been at the limit of their ecological tolerance for growth and any additional stress, such as a shift to wetter conditions, resulted in a substantial reduction in their numbers.

6.5.2.2 FUNGAL AND ALGAL REMAINS

The fungal and algal remains data provide information regarding the environmental conditions of the mire surface, since some types have been shown to be associated with particular plant species or families which in turn often have limited hydrological tolerances (Van Geel, 1972, 1976, 1978, 1986). Therefore, the presence or absence of certain Types can help elucidate the humification and pollen-stratigraphic evidence.

The fungal and algal remains at APB support the humification evidence for wetter conditions identified in APB1 and APB3 (local pollen assemblage zones), with an increase in the frequency of Types 27, 31A, and 32. Type 28 corresponds well with the rise in Cyperaceae pollen frequencies and is suggested as an indication of the local presence of sedges. However Type 10 does not show a consistently good correlation with *Calluna* pollen frequencies, this has been found at the other sites, particularly after the expansion of *Calluna* heath. This may of course indicate that Type 10 fungus is associated other plant species (cf. Blackford, 1990) but it could be a reflection of an increase in the regional *Calluna* pollen signal to a site after the decline of pine trees from the area.

The site with the lowest mean transmission value of the sites investigated at Gleann Einich is CPG, suggesting a generally well humified peat profile. This is supported by the relative high frequencies recorded at this site of dry indicating fungal/algal remains (such as Types 1,2,3,10,14 and 64). This is demonstrated particularly well in LPAZ - CPG 6 (Section 6.2.4.6), which also corresponds with consistently low transmission values between *c.*5,250-4,000 BP. Similarly, very few types of wet indicating fungal/algal remains are recorded in the peat profile from CPG.

A mixture of both wet and dry indicating fungal/algal remains are recorded in the peat profile at LOD. However, a higher frequency of wet indicating types are represented in LOD6 (LPAZ) (e.g.Types 27, 31A and 32) which corresponds well with the episode of a relatively low degree of humification. The increase in the frequency of Type 64 correlates well with the expansion of *Empetrum* pollen, which indicates the local growth of *Empetrum.* The reduction in *Empetrum* pollen frequencies and maintenance of high frequencies of Type 64 might also indicate that *Empetrum* was present on the mire surface but failing to produce significant

quantities of pollen to be incorporated in the fossil record. Finally, Type 10 correlates well with the increase in *Calluna* pollen frequencies, apart from in LOD 7, LOD 8 and LOD 9, which might indicate a regional rather than local pollen source (see above).

MNM, the site with the highest mean transmission value (and hence least humified peat profile as supported by the evidence of high frequencies of *Sphagnum* leaves in the peat matrix) shows a relatively high representation of wet-indicating fungal and algal remains (such as Types 31a and 32). Type 28 correlates well with the Cyperaceae pollen frequencies, but very few remains of Type 27 were identified, which is surprising since it has been correlated with *Sphagnum* leaves (Van Geel, 1978). Type 64 is consistently recorded at this site, often at high frequencies, which supports the pollen evidence for the local growth of *Empetrum*. In addition, Type 10 is virtually absent from this site, thus supporting the association of this fungus with *Calluna vulgaris* (as indicated by the low *Calluna* pollen frequencies and the generally wetter conditions).

So if fungal and algal remains are clearly associated with a particular plant species, these remains can provide additional evidence for the regional/local pollen provenance of that plant species. This is demonstrated by the reduced frequency of Type 10 often found associated with the expansion of *Calluna* heath at site APB, CPG and LOD and the virtual absence of Type 10 at MNM where *Calluna* heath failed to become established. Since Type 10 is associated with the roots of *Calluna vulgaris*, the increase in *Calluna* pollen frequencies and the corresponding low frequencies of Type 10 may be interpreted as an increase in the regional pollen rain following the reduction of the pinewood cover and expansion of *Calluna* heath (cf. Blackford, 1990).

6.5.2.3 BLACKENED *PINUS* POLLEN GRAINS

The cause of the blackening of the central body (and sometimes the air sacks) of the *Pinus* pollen grain is not known (by the author), but there is often an increase in the frequency of this feature on *Pinus* pollen grains in highly humified peat. This is particularly evident at the site with the highest mean degree of humification (CPG) where there is a good correspondence with low transmission values and an increase in the proportion of blackened *Pinus* grains (Figure 6.20). In contrast, at the site with the lowest mean degree of humification, MNM, blackened *Pinus* grains were recorded at one level only, (66cm) which corresponds to a shift to a relatively more humified peat matrix (but does not correspond with the lowest transmission values recorded). The lack of a consistently good correspondence with the degree of humification at APB and LOD indicates that other local site specific factors are probably related to the blackening of the *Pinus* grains.

Since CPG is relatively well humified (as supported by the high frequency of dry indicating fungal and algal remains) this suggests that the blackening of the *Pinus* grains is related to the decomposition of the peat matrix occurring in the aerated zone of the mire surface (and hence a higher degree of humification).

The virtual absence of blackened *Pinus* grains above 170cm (*c.*5,000 BP) at APB is difficult to explain since the transmission values indicated a relatively well humified peat above this level. Since LOD exhibits a high proportion of blackened *Pinus* grains at transmission values equivalent to those recorded above 170cm at APB this again indicates that other factors are involved, possibly related to rate of peat accumulation or density of pinewood canopy.

Further investigation is required regarding the rate of peat accumulation, the degree of peat humification and the frequency of blackened *Pinus* grains. However, this is limited in this project by the number of radiocarbon dates and interpolation of the accumulation of the peat between the dates. The significance of the blackened *Pinus* grains will be discussed further in Section 8.7.

6.5.2.4 PRESENCE/ABSENCE OF MACROFOSSILS

The preservation of wood macrofossils in a peat matrix is dependent upon the peat accumulating at a sufficiently fast rate to incorporate the wood into the anaerobic zone before decomposition takes place. Presence of macrofossils should therefore correspond with relatively low degree of humification of the peat matrix, and a relatively fast rate of peat accumulation.

A second (obvious) requirement for the preservation of wood macrofossils is that the tree or shrub needs to grow either on the mire surface or sufficiently close (laterally) for the wood to become incorporated in the peat matrix. If the mire surface becomes too wet, the trees and shrubs will be restricted to drier parts of the mire or surrounding better drained ground.

The presence of wood macrofossils in a peat deposit is therefore a balance between the conditions being sufficiently dry for the establishment of trees and shrubs on or near the mire surface, followed by a subsequent shift to wetter conditions with a relatively fast accumulation of the peat matrix for the incorporation and preservation of the wood as a macrofossil.

Wood macrofossils in a peat profile should therefore be expected to occur at higher frequencies where there is evidence for a shift to wetter conditions and/or a shift to higher peat accumulation rates.

Due to the few radiocarbon dates available (4 or 5 per profile) short term changes in the peat accumulation rate cannot be identified. However, short term changes in the degree of humification can be assessed and a comparison with the presence of macrofossils in the section and monolith samples can be made.

At APB, there is an increase in the frequency of wood macrofossils in the peat profile below *c.*210cm (see Figure 6.9), which coincides with a change from a highly humified peat associated with the minerogenic-rich peat to the less humified, organic-rich peat. No macrofossils were found in the *Sphagnum*-rich peat between *c.*190cm and 160cm. The small shift to less humified peat at 130cm coincides with the presence of a birch twig and an Ericaceous twig between 135-130cm. The pine stump at *c.*70-80cm (not radiocarbon dated) occurs at the top of a relatively dry (or warm) phase as indicated by the humification evidence in the profile. So the presence of macrofossils at APB generally agree with the conditions outlined above.

Very few macrofossils were recorded from the sampled profile at CPG (Figure 6.19). The small twigs at *c.*145cm (possibly pine, but very decomposed) and 125cm (Ericaceous) coincide with shifts to less humified peat. The pine stump at *c.*140-150cm (not radiocarbon dated) coincides with the shift to less humified peat at *c.*145cm and the stump at *c.*80-90cm (not radiocarbon dated) coincides with the top of a phase of relatively well humified peat. With the exception of the Ericaceous twigs identified at *c.*125cm, the sparse presence of macro-fossils at CPG again generally agrees with the conditions proposed above. The low frequency of macro-fossils at this site corresponds to a relatively high mean degree of humification (as supported by the very low frequency of wet indicating fungal/algal remains, and the high frequency of dry indicating Types) indicates that the mire surface was subject to relatively long periods of aeration and decomposition (humification). Some of the wood or shrub fragments which were present at the mire surface may therefore have failed to become incorporated into the peat matrix. This is also supported by the low frequency of *Sphagnum* leaves preserved in the peat matrix, in contrast to the micro-fossil evidence of the high frequency of *Sphagnum* spores represented in CPG 4 (LPAZ).

Few macro-fossils were recorded in the sampled profile from LOD (Figure 6.28). Ericaceous and (possibly) birch twigs were identified between *c.*160-180cm which coincide with a change of lithology to an organic-rich peat matrix and a higher degree of humification. The relatively low degree of humification between *c.*150-105cm coincides with a high frequency of *Sphagnum* leaves preserved in the peat matrix. The reason for the generally low frequency of wood macrofossils at LOD is not straightforward, unless there was a lower density of woodland cover as indicated by the pollen stratigraphy. The pine stumps recorded from the immediate area of the LOD sampling position tended to occur in higher frequencies at the

periphery of the site area, in the shallow peat, which suggests that the central part of the mire surface may have been generally too wet for the establishment of trees.

The macro-fossils at MNM (probably Ericaceae) are present at a higher frequency below 70cm (*c.*3,000 BP) (Figure 6.38). The frequency of *Sphagnum* leaves recorded is extremely high in this profile, forming up to *c.*95% of the peat matrix. This supports the evidence of the low mean degree of humification and the high frequency of fungal and algal remains indicative of relatively wet conditions. The peat profile at MNM has therefore been relatively wet throughout much of the accumulation record. The absence of pine macrofossils identified from the peat profile at MNM indicates that pine was either absent from the site area or failed to become established on the mire surface (since the preservation potential of the peat matrix would have been high) As discussed (Section 6.5.2.2), this does not exclude the possibility that trees were growing on better drained substrates nearby.

In conclusion, the environmental conditions which favour the preservation of wood macro-fossils are a relatively dry mire surface (as indicated by the well humified peat matrix) for the establishment of the trees and shrubs and a subsequent shift to wetter conditions for the preservation of wood in the peat matrix. This supports the conclusion reached by Birks (1975) regarding the preservation of pine and birch stumps being a function of the local hydrological conditions of the mire surface. This will be discussed further in Chapters 7 and 8.

CHAPTER 7.0 RESULTS - BEINN DEARG

This chapter presents the results of analysis of the sites investigated in Beinn Dearg, in the Northwest Highlands (Figure 2.1). The results will be presented under the same headings as for Gleann Einich and subsequently in Chapter 8, the results from both regional data-sets will be compared and evaluated. The location of the sites at Beinn Dearg are shown in Figure 5.2.

7.1 DIRRIE MORE - SITE CODE : DMR (*c.*270m OD) (NGR: NH 251754)

7.1.1 SITE DESCRIPTION

Numerous pine stumps are exposed on the shores of Loch Droma and preserved in the deep peat sequences in the surrounding local area. It was therefore considered to be an ideal location for the lowest site of the Beinn Dearg transect. The area was first surveyed to identify the thickest accumulation of blanket peat and this was subsequently confirmed using a gouge sample on a 5m grid system. The thickest profile proved to be adjacent to an erosion gulley running northwards into the river draining from Loch Droma (Figure 7.1). The pine stumps preserved in the peat in this area are not very large, the average diameter of the base of the trunks being 20cm, and the shallow root systems are fairly extensive in the horizontal direction (up to 3m laterally). The drainage to the site is generally from the higher ground to the south and the site is therefore categorised as a valleyside mire type.

A 1m wide exposure was excavated into the existing erosion gulley to produce a profile in the peat to *c.*200cm depth, the base of the peat overlying a minerogenic base. Numerous birch and pine macrofossils were observed in the section, the former more frequent towards the base, while pine macrofossils appeared to form two higher layers. Two monolith tins were used to sample the section from the mineral base to approximately 40cm below the modern vegetated surface. The reason for placing the top monolith tin below the highest pine stump was that the dense network of pine roots made the sampling of the peat very difficult. It was assumed at the time that the upper layer of pine stumps, which lies close to the modern vegetated surface represented relatively recent trees. Estimation of the age-depth ratios by interpolation of the radiocarbon dates (see below) indicates that the top of the section is probably truncated and may have been subjected to cutting.

7.1.2 LITHOSTRATIGRAPHY

The following stratigraphy was recorded in the field and supplemented by laboratory observations of the profile collected in the monolith tins. The depths (cm) given are relative to the top of the upper monolith tin. Methods of descriptions and notation follow those

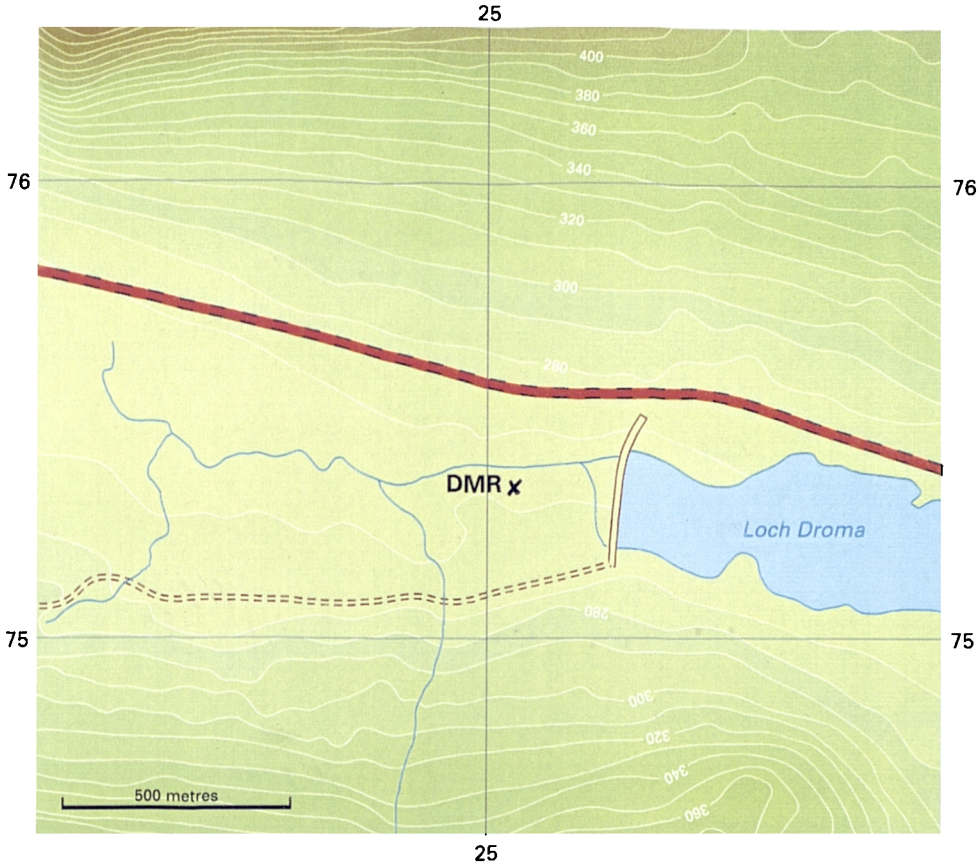


Figure 7.1: Beinn Dearg – location of sample site DMR (Dirrie More) c.270m OD

outlined previously in Section 6.1.2. and are directly comparable with those adopted for the Gleann Einich sites.

Birch macrofossils (branches and roots) were found adjacent to the sampled profile at 155-165cm, 129-134cm, 82-84cm and pine roots were located adjacent to the monolith tin at 106-109cm, 56-57cm and 34-35cm. Large pine stumps were located at 90-117cm, -20cm (above the monolith sample)-10cm and a further sample (8.6m to the south of the sample point) at approximately 40-69cm. The pine stumps were sampled for dendrochronological analysis (see Appendix 5.3).

DATUM (0) = TOP OF UPPER MONOLITH TIN

0-31cm Very dark brown, detrital peat. Occasional fine rootlets (*Eriophorum*). H4; n3; Th3; Sh1.

31-34cm Medium brown, detrital peat. Approximately 33% *Sphagnum* leaves (observed in the peat matrix). H3; n2; Tb2; Sh2.

34-55cm Very dark, brown detrital peat. Occasional fine rootlets. H4; n3; Th2; Sh2.

55-75cm Very dark, brown detrital peat. Flattened rootlets present (*Eriophorum*). Occasional *Sphagnum* leaves observed (c.10% of the peat matrix). H3; n3; Th1; Tb1; Sh2.

75-88cm Medium dark brown, detrital peat, *Eriophorum* present. H6; n2; Th2; Sh2.

88-115cm Very dark brown to black, detrital peat. No distinct plant remains. H5-6; n3; Sh4.

115-126cm Very dark brown to black, wood-rich peat. Large rotted birch twig 121-124cm (9x4x3cm), birch twig 118-119 birch (5x1x1cm). H7-8; n4; Tl4.

126-147cm Very dark brown to black. Occasional wood fragments present. Birch twig at 130cm, very rotten birch twig (2x1x0.5cm) at 132-134cm. Some *Eriophorum* and *Sphagnum*. Sedge-rich band between 143-144cm. H8-9; n4; Tl2; Th1; Tb1.

147-175cm Very dark brown to black-wood rich, peat. Layer of *Eriophorum*-rich peat at 163cm. Occasional *Sphagnum* leaves observed at 140cm and 150cm. Birch twigs located between 151-158cm (10x2x4cm) (oblique across tin), 172-173cm (2x1x1cm),161-162cm (3x0.5x0.5cm),157cm, 147-148cm (5x1.5x1cm). H7; n4; Tl2; Th1 Tb1.

175-180cm Dark brown, detrital peat with sand-sized minerogenic inclusions. H8; n3; Sh3; g min 1.

180-185cm Dark brown, sand-rich, detrital peat. Some wood remains - degraded birch twigs present 181-182cm (12x1.5x1.5cm). H6; n3; Tl2; g min 2.

7.1.3 RADIOCARBON MEASUREMENTS

Four samples were submitted for radiocarbon analysis from the DMR sampled column (see Table 7.1 for laboratory details and results). Since the samples were submitted to Beta Analytic for radiocarbon analysis before pollen analysis was undertaken it was decided to sample at regular depth intervals (approximately every 50cm) from below *c.*50cm (Datum 0) to the base of the profile.

The radiocarbon measurements (and the quoted errors representing 1 standard deviation statistics) are shown plotted in Figure 7.2 together with the calculated sediment accumulation rates and the calibrated ages. The calibration results are shown in Table 7.1.

The basal sample (182-183.5cm) provided a radiocarbon age estimate of 8,300 +/- 130 BP which overlaps with the age range of the sample from 139-140.5cm (8,220 +/- 60 BP). Since the basal peat is sand-rich the lower date may represent a hiatus in the stratigraphy or contamination by younger humic/fulvic acid from above. However, since the pollen diagram shows no evidence for a hiatus in the stratigraphy (Figure 7.3) the latter is more likely. Harkness (1981) suggests that the erroneous radiocarbon dates obtained by Pennington at Williamson's Moss in Cumbria were caused by the downward percolation of the humic fractions. In a reinvestigation of Williamson's Moss, Tipping (1994b) submitted chemically separated 'humic', 'humin' (the less mobile fraction) and 'fulvic' fractions for radiocarbon assessment and demonstrated that the 'humin' fraction was consistently younger than the other fractions. Radiocarbon analysis on the separate fractions would provide a method for assessing the evidence for movement of the 'humic' fraction in the lower sediments at this site, DMR. In addition, if the radiocarbon measurements did indicate movement of the humic fraction, an assessment could then be made of the significance of the humification signal at that depth.

An alternative method for assessing the radiocarbon measurements would be to submit one of the wood macrofossils from the monolith sample for radiocarbon dating. The basal birch macrofossils are not well preserved, however, and they may also have been subject to reworking. Further peat samples should be submitted for radiocarbon analysis from samples at *c.*160cm and *c.*120cm, but funds were not available.

Chronological assessments are further complicated, by the plateau in the radiocarbon curve which occurs at *c.*8,200 - 8,300 BP, as shown by the calibration of the radiocarbon dates. The lowermost radiocarbon age estimate (8,300 +/- 130 BP) is calibrated to 7,545 to 7,015 cal BC (2 sigma) and the age estimate at 139.0-140.5cm sample (8,220 +/- 60 BP) is calibrated to 7,425 to 7,035 cal BC.

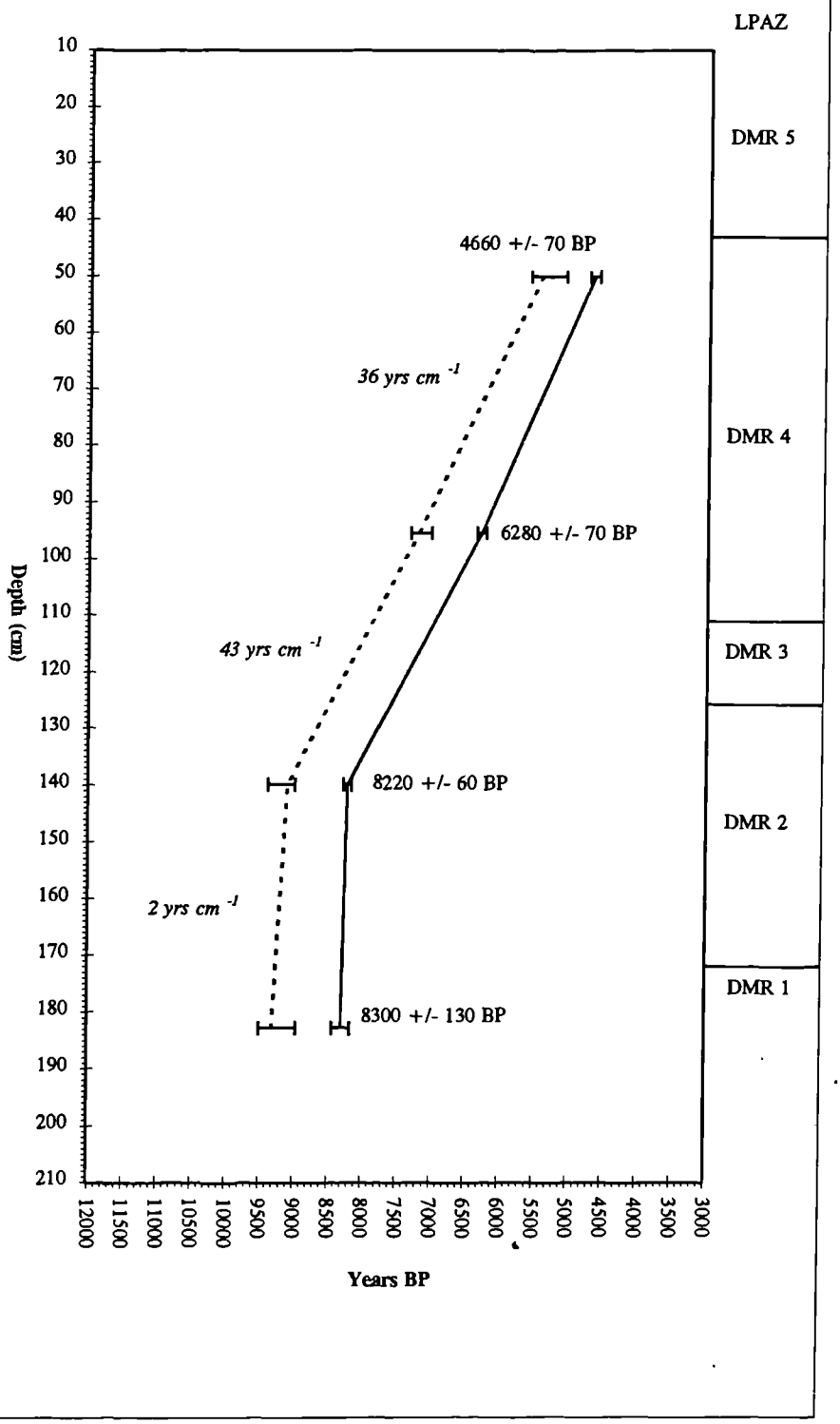
TABLE 7.1 BEINN DEARG - RADIOCARBON SUBMISSION AND REPORTED DATES

LGU Lab. Operator No.	Radiocarbon Lab Analysis No.	Type of sample	Depth of sample (cm)	Wet weight of sample (g)	Conventional ^{14}C Age (Years BP)*	Calibrated ages (cal yrs BP)	+	-
DMR 1	Beta-83069	Peat with minerogenic inclusions	182.0-183.5	116.6	8300 +/- 130	9312	184	355
DMR 2	Beta-83070	Peat	139.0-140.5	114.8	8220 +/- 60	9098	279	112
DMR 3	Beta-83071	Peat	94.5-95.5	83.4	6280 +/- 70	7195	125	187
DMR 4	Beta-83072	Peat	49.0-50.5	93.7	4660 +/- 70	5416	166	344
LDM 1	Beta-83073	Peat with minerogenic inclusions	173.0-176.0	84.3	8050 +/- 70	8979	220	368
LDM 2	Beta-83074	Peat	132.0-134.0	102.7	7850 +/- 60	8560	388	132
LDM 3	Beta-83075	Peat	90.0-92.0	84.3	5880 +/- 50	6724	124	161
LDM 4	Beta-83076	Peat	49.5-50.5	92.9	4290 +/- 90	4847	358	280
MFD 1	Beta-83061	Peat	170.5-172.5	90.3	6950 +/- 70	7713	191	125
MFD 2	Beta-83062	Peat	127.0-129.0	87.4	5470 +/- 60	6286	118	174
MFD 3	Beta-83063	Peat	89.0-91.0	89.1	4650 +/- 80	5432	152	379
MFD 4	Beta-83064	Peat	49.5-50.5	86.9	3420 +/- 70	3670	168	198
GBT 1	Beta-83065	Peat	168.5-170.5	86.6	4990 +/- 60	5726	175	127
GBT 2	Beta-83066	Peat	129.0-131.0	88.7	4320 +/- 60	4826	212	167
GBT 3	Beta-83067	Peat	89.5-90.5	84.5	1640 +/- 60	1531	163	137
GBT 4	Beta-83068	Peat	49.0-50.5	79.9	990 +/- 60	925	59	180

DMR = Dirrie More
LDM = Lochdrum
MFD = Meall Feith Dhiongaig
GBT = Grouse Butt

* All conventional ^{14}C ages are reported as uncorrected years BP calculated on the Libby half-life and on assumed $^{13}C/^{12}C$ sample ratios of -25‰

Figure 7.2.
DMR - Radiocarbon measurements (uncalibrated and calibrated) and interpolated peat accumulation rates (expressed in years per cm) plotted against depth (cm)



Radiocarbon years

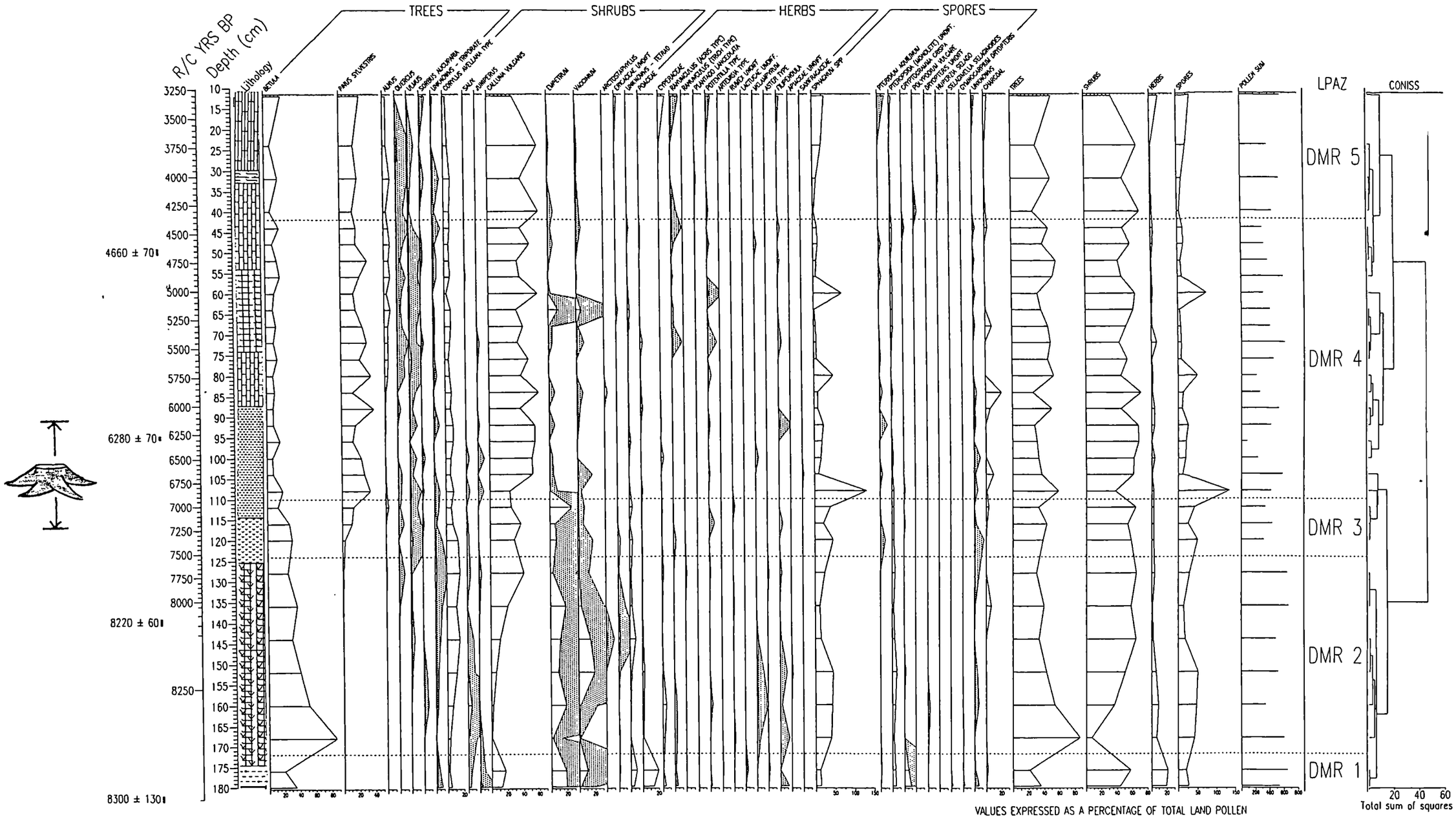
Calibrated years

FIGURE 7.3

PERCENTAGE POLLEN AND SPORE DIAGRAM FOR SITE DMR (c.270m OD)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TAXA



So the relatively fast peat accumulation rate of 1.9 yr cm^{-1} implied for the sediments between *c.*182 cm and 139 cm may be highly misleading. Comparison of the data below 139cm with data from other sites at Beinn Dearg of similar radiocarbon age cannot therefore be made with confidence.

7.1.4 LOCAL POLLEN ASSEMBLAGE ZONES

7.1.4.1 LPAZ - DMR 1 (180-172cm) (*c.* 8,295-8,280 BP)

Percentage pollen diagram **(Figure 7.3)**

This zone, represented by two pollen spectra, is characterised by a high proportion of shrub pollen types (up to 57% TLP). This is largely a reflection of the high *Empetrum* pollen frequencies (19% TLP at the base of zone), with significant representation of *Vaccinium* and *Calluna vulgaris.*

The most frequent tree pollen type is *Betula* (35% at the base of the zone) and Cyperaceae and Poaceae are the most frequent herbaceous types. *Cryptogramma crispa* spores are present at *c.*10% (TLP) at the base of the zone.

Pollen concentration and influx diagrams **(Figures 7.4 and 7.5)**
There appears to be a correspondence between the pollen concentration values and the degree of humification at this site (Figure 7.6), the possible effect and implications of which will be discussed where necessary.

The peak values for pollen concentration (over *c.*500,000 grains cm^{-3}) and pollen accumulation rates (*c.*280,000 grains cm^{-2} yr^{-1}) in this zone correspond with a high degree of humification and may, therefore, represent partially enhanced values.

Pinus sylvestris shows a relatively high influx of *c.*2,200 grains cm^{-2} yr^{-1} at 176cm which is poorly represented in the percentage and concentration diagrams (see Figure 7.7 for direct comparison of the *Pinus* pollen values). The high influx values are probably a reflection of the interpolation of the two lower radiocarbon dates which produces a very high sediment accumulation rate of 1.9 yr cm^{-1} (discussed above in Section 7.1.3). This high sediment accumulation rate would have the effect of enhancing the pollen accumulation rates to extremely high apparent values.

Fungal and algal remains **(Figure 7.8)**
Very low frequencies of fungal and/or algal remains are recorded in this zone.

FIGURE 7.4 POLLEN CONCENTRATION DIAGRAM FOR SITE DMR (c.270m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

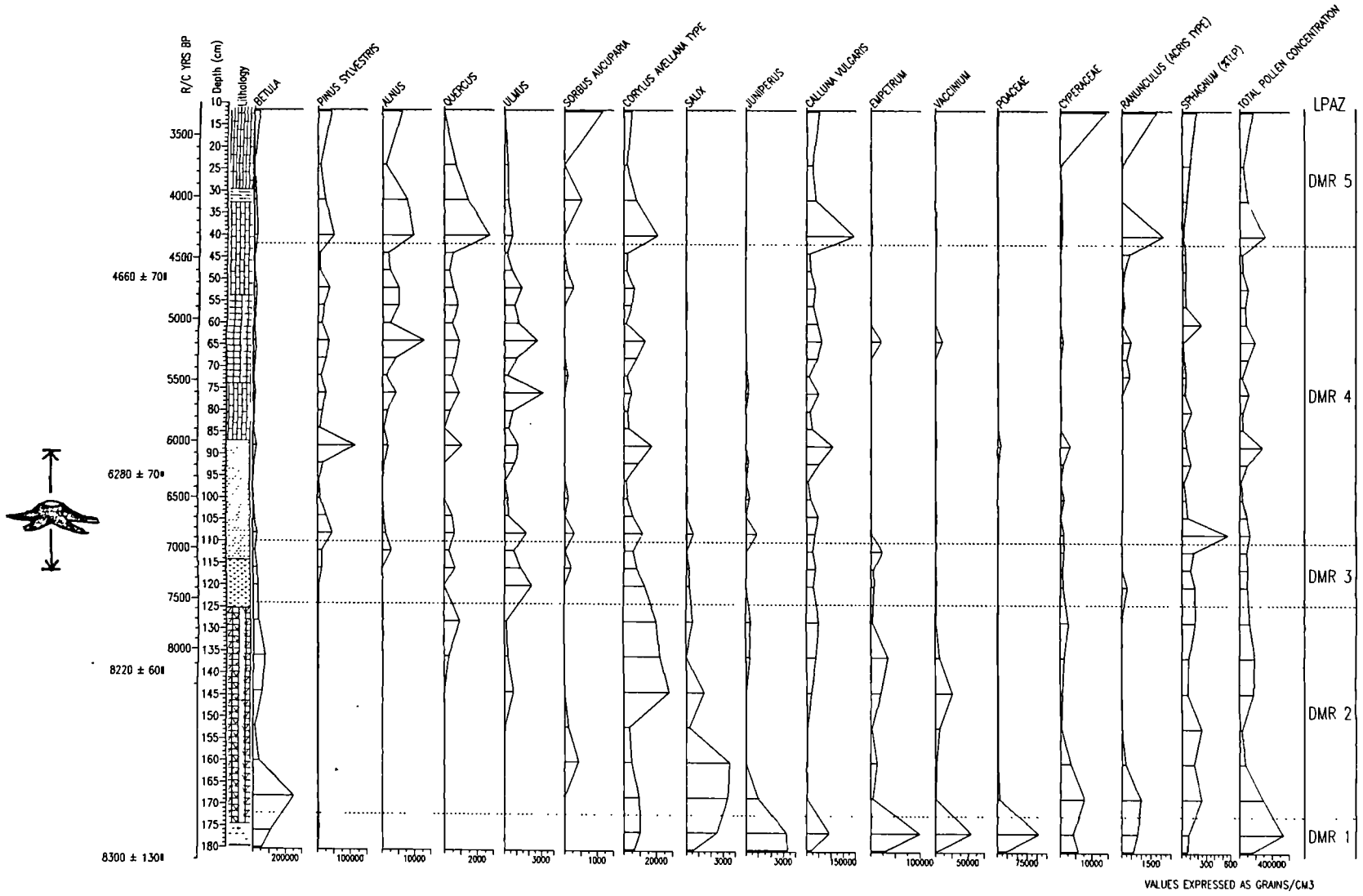


FIGURE 7.5 POLLEN INFLUX DIAGRAM FOR SITE DMR (c.270m OD)
(FOR SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

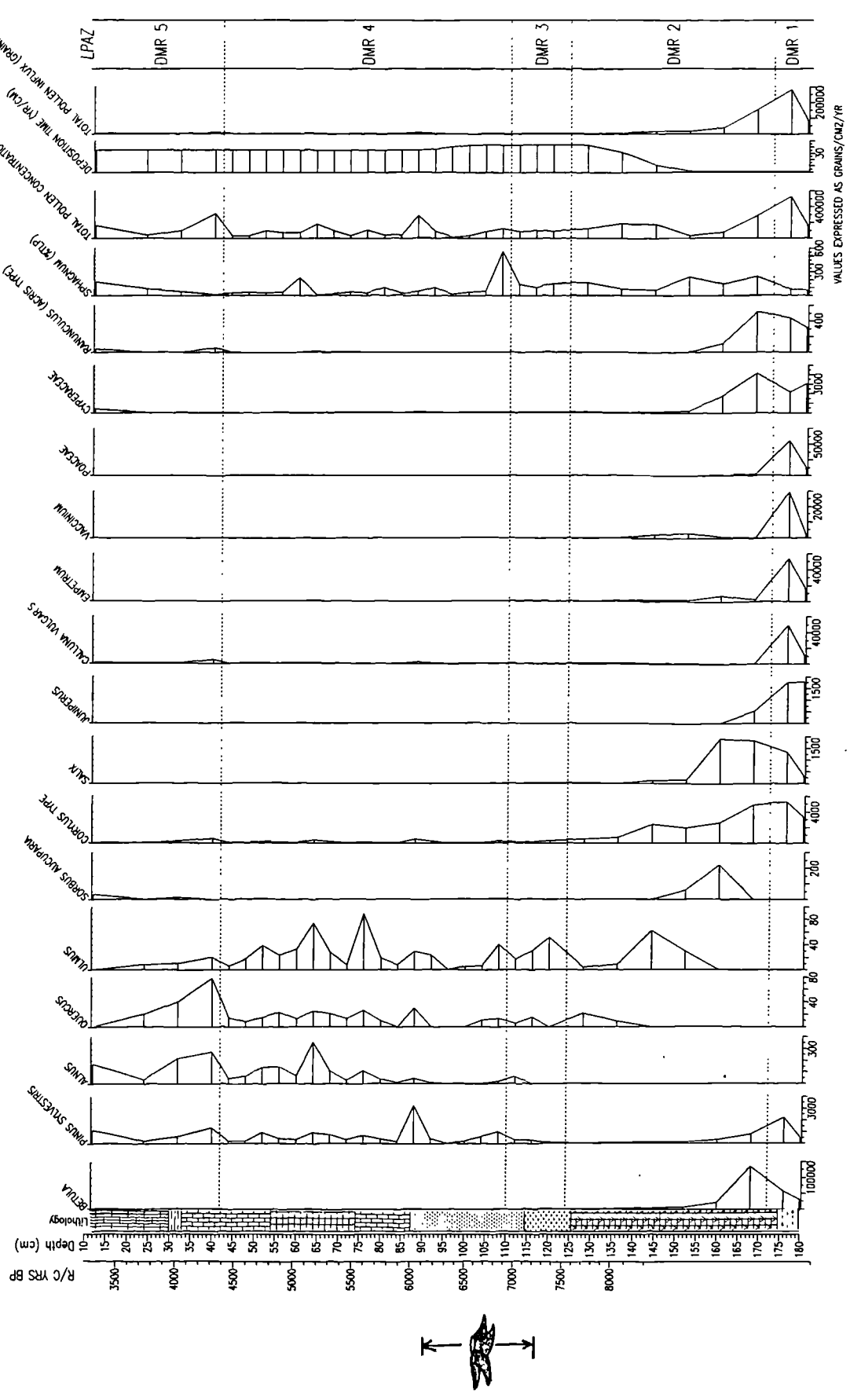


Figure 7.6
Profile DMR - Degree of humification (expressed as the inverse of percent transmission) and total pollen concentration (expressed as grains cm^{-3}) plotted against depth (cm).

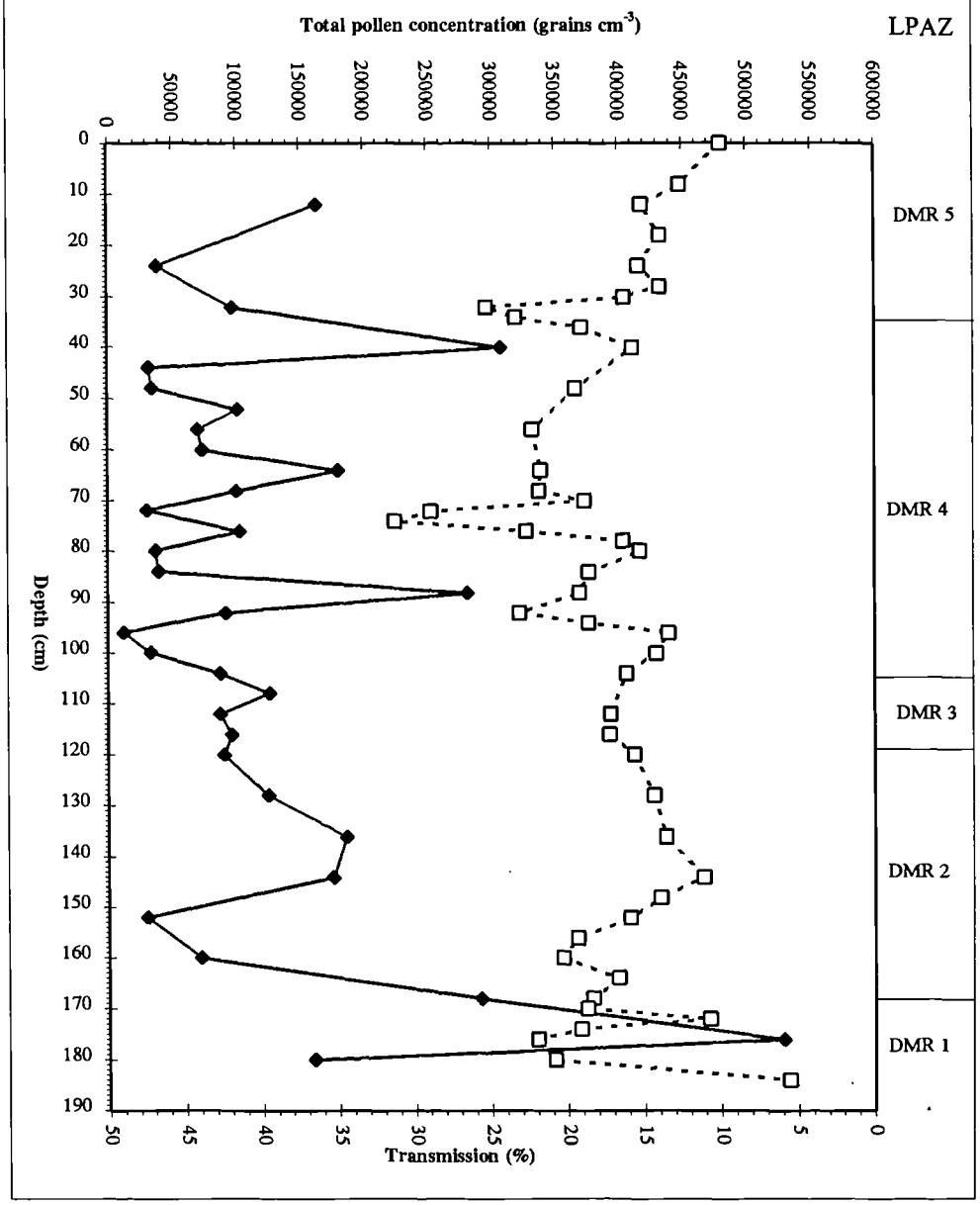


FIGURE 7.7
PINUS POLLEN DATA FOR SITE DMR (c.270m OD)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

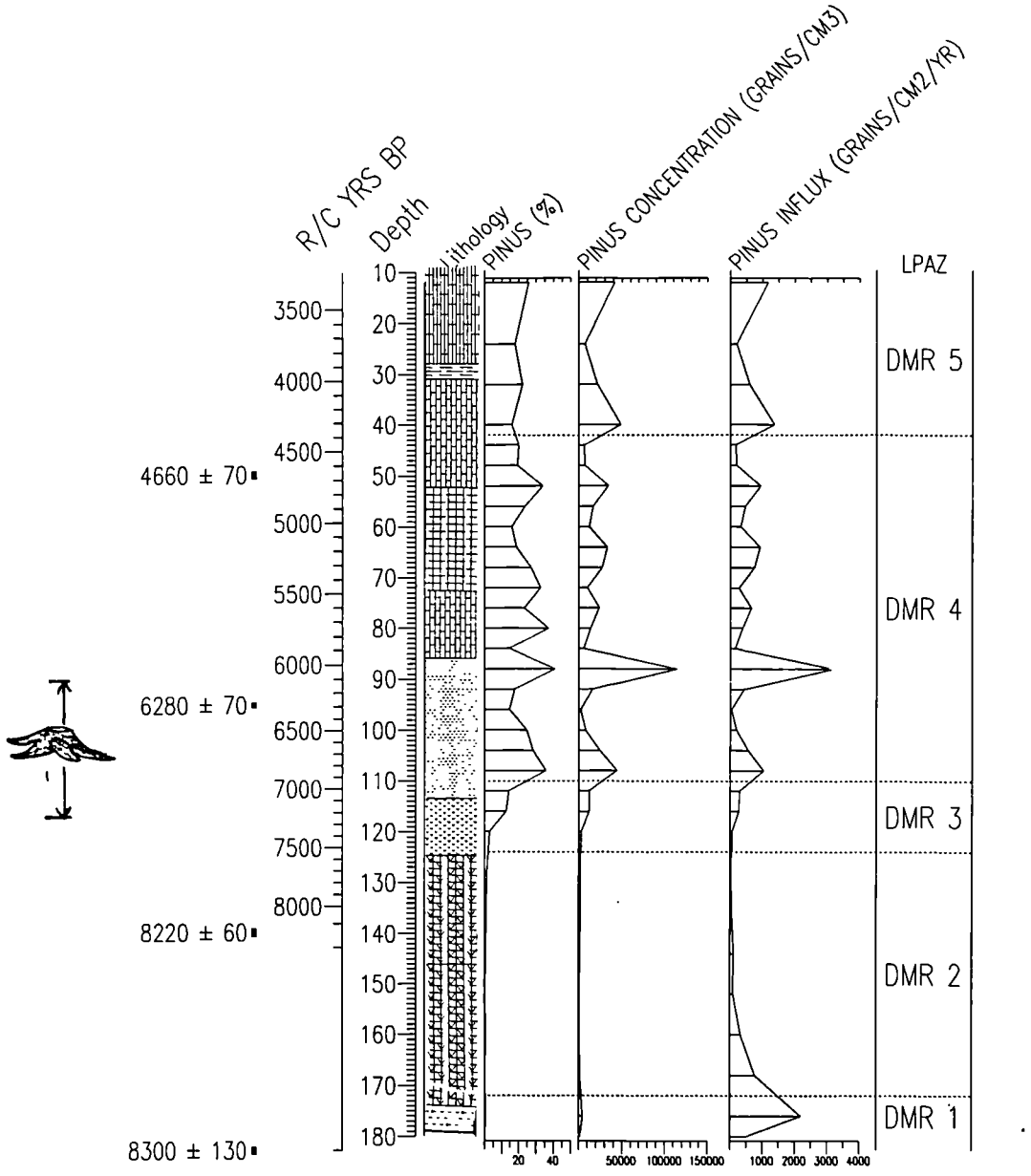
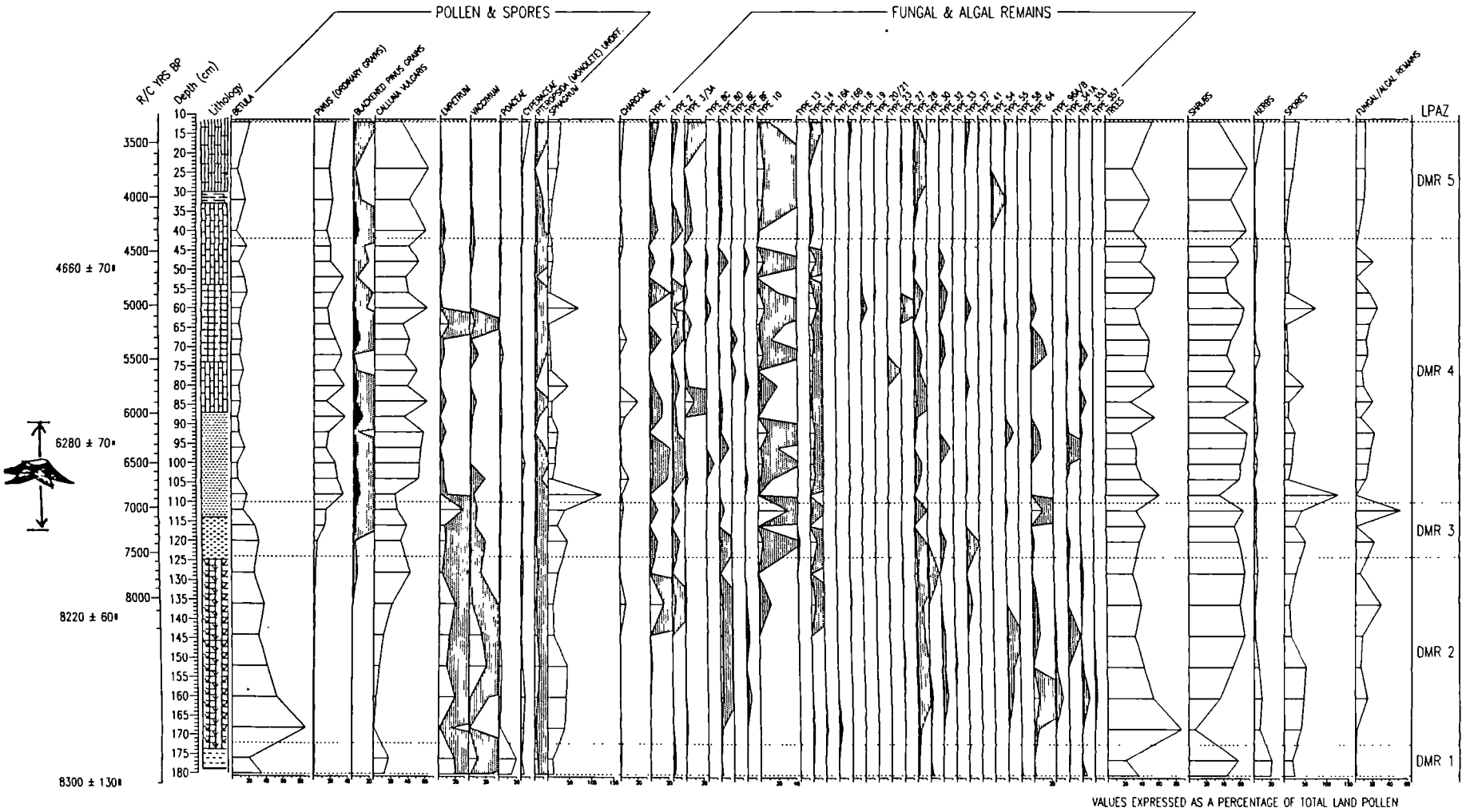


FIGURE 7.8 FUNGAL AND ALGAL REMAINS DIAGRAM FOR SITE DMR (c.270m OD)
(WITH SELECTED POLLEN AND SPORES)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOP TAXA AND TYPES



***Degree of humification* (Figure 7.9)**

The fall in the degree of humification in this zone is associated with the decrease in the minerogenic component incorporated in the peat matrix between *c.*180-175 cm. The poorly preserved basal birch macrofossils are located within the minerogenic-rich peat which suggests that there may have been reworking and oxidation of the basal sediment. The well preserved birch macrofossil at 172cm is located within the organic rich peat and corresponds with a change to a more humified peat matrix.

Summary

The pollen evidence suggests that this zone represents an open birch forest with an understorey of *Empetrum, Vaccinium* and *Calluna* and grasses and sedges. The incorporation of minerogenic sediment and the rotten birch macrofossils in this zone suggests that the peat matrix may have been subject to reworking and aeration.

7.1.4.2 LPAZ - DMR 2 (172-124cm) (c.8,280-7,535 BP)

Percentage pollen diagram

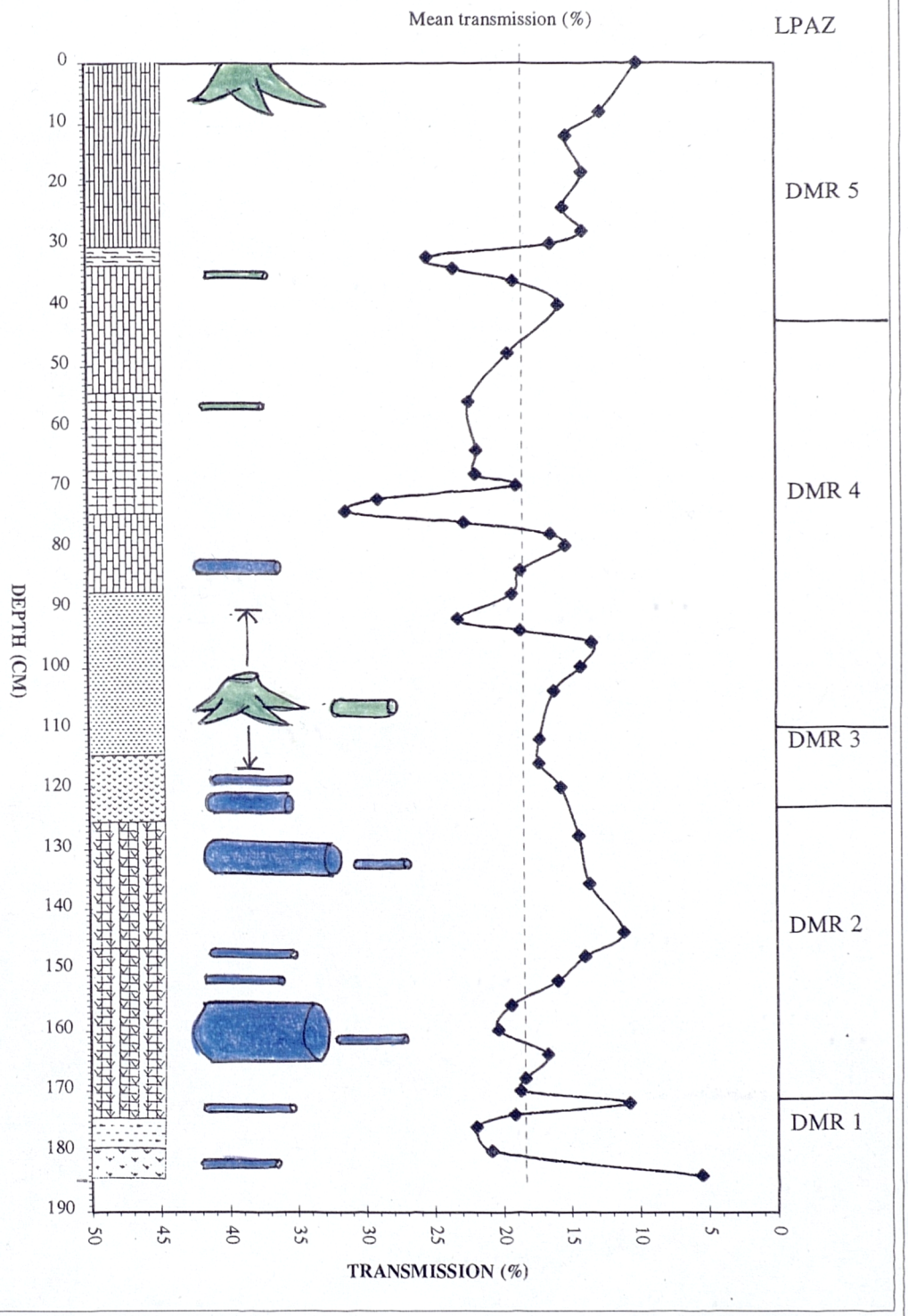
This zone is characterised by relatively high frequencies of arboreal pollen (up to 86%) at the base and a subsequent increase in shrubs (up to 65%). *Betula* pollen rises to a maximum frequency of 86% at the base of the zone and gradually decreases to *c.*26% at the top. *Corylus avellana* type pollen frequencies rise to 16% and there is a corresponding decrease in the frequency of *Salix* pollen. The dwarf shrubs are represented by a gradual rise of *Calluna vulgaris* pollen (to 42%), *Empetrum* pollen (rises to a maximum of 19% and subsequently falls to 3% at 128cm) and *Vaccinium* pollen reaches a maximum of 20%. Poaceae , Cyperaceae, *Filipendula* and *Melampyrum* are recorded at low frequencies in the lower half of the zone.

Pollen concentration and influx diagrams

As for DMR1, there is a correspondence between the pollen concentration values and the degree of humification in this zone. The lower pollen concentration values represented between 150-160cm coincide with an increase in transmission values (Figure 7.6) and may therefore be partially reflecting a decrease in the break-down of the peat matrix.

In general the pollen concentration and influx rates decrease at the base of this zone and this trend is reflected by most taxa with the exception of *Ulmus* pollen and *Corylus avellana* type pollen. *Betula* pollen concentration and influx values fall from a peak at the base of this zone and subsequently remain relatively low. The

Figure 7.9.
Profile DMR - Degree of humification (expressed as the inverse of percent transmission) plotted against depth (cm). Macrofossils are represented (green = pine; blue = birch; red = Ericaceous)



decrease in *Betula* pollen concentration at 160cm corresponds with an increase in the influx of *Empetrum* and (to a lesser extent) *Vaccinium*.

The peat accumulation apparently decreases sharply to 43.4 yr cm^{-1} in the upper half this zone, but this may simply reflect the artificially high accumulation rates derived from the lower, probably erroneous, dates (discussed above). The interpretation proposed above that the pollen influx rates partially reflect the peat accumulation rates is supported in this zone. The faster peat accumulation rates indicated from the interpolation of radiocarbon dates towards the top of this zone have the affect reducing the pollen influx values.

Fungal and algal remains

The fungal and algal remains represented in this zone indicate relatively dry conditions. There is only a small peak in Type 64 at 160cm (correlated with the presence of macroscopic remains of *Empetrum nigrum*, Van Geel, 1978; see CPG5, Section 6.2.4.5) despite the relatively high *Empetrum* pollen frequencies.

There are also small increases in the frequencies of Types 1, 2 and 14 at 135cm, all of which are thought to indicate relatively dry conditions (Van Geel, 1978) and correspond with a relatively well humified peat matrix.

Degree of humification

The transmission values in this zone indicate a shift to relatively well humified peat above *c.*150cm. A high frequency of birch macrofossils is found in the less humified peat between *c.*148cm and *c.*162cm, which corresponds with an increase in the proportion of *Sphagnum* leaves in the peat matrix. The birch macrofossils at the top of the zone coincide with a trend towards less humified peat.

Summary

The pollen evidence indicates a relatively dense birch woodland at the base of the zone. The subsequent reduction in the density of birch is indicated by increases in *Empetrum* and *Vaccinium* percentages, and subsequently by *Calluna vulgaris*.

The fungal and alga evidence indicates relatively dry conditions and correspond with the trend towards a higher degree of humification.

7.1.4.3 LPAZ - DMR 3 (124-110cm) (c.7,535-6,930 BP)

Percentage pollen diagram

The decrease in the frequency of *Betula* pollen (to 14% TLP) in this zone corresponds with the increase in *Pinus* pollen frequencies (14%). *Corylus avellana* type pollen frequencies decrease slightly from the peak at the base of this zone. *Calluna vulgaris* pollen frequencies fall slightly to 25% and *Empetrum* reaches a peak of 28% at the top of the zone.

The presence of the large pine stump with roots (not radiocarbon dated) across the boundary of DMR 4 and DMR 3 confirms the local presence of pine. However, since only the roots extend into DMR 3, the stump will be considered in the discussion of DMR 4 (below).

Pollen concentration and influx diagrams

In general, pollen concentration and influx values are fairly low in this zone (less than *c.*96,000 grains cm^{-3} and *c.*2,200 grains cm^{-2} yr^{-1} respectively) which corresponds with a trend towards a lower degree of peat humification (Figure 7.6). This is reflected by most taxa, with the exception of *Ulmus,* which shows high values at the base of the zone.

Fungal and algal remains

The peak in the frequency of fungal and algal remains in this zone is largely a result of rise of Types 10, 13, and 64, all of which indicate relatively dry conditions. The peak in Type 64 corresponds well with the high *Empetrum* pollen frequencies (Van Geel, 1978).

Degree of humification

The three transmission values measured for samples in this zone indicate a trend towards a lower degree of humification. The birch macrofossils at the base of the zone correspond with the slightly more humified peat.

<u>Summary</u>

The pollen stratigraphy in this zone indicates a birch woodland colonised by *Empetrum* and *Calluna vulgaris*. Pine may have arrived at this site during this zone but the low pollen frequencies indicate either isolated stands of pine trees and/or a distal source of the *Pinus* pollen. The reduction in the birch woodland canopy towards the top of the zone led to an increase in *Empetrum* cover.

The fungal and algal remains recorded for this zone indicate relatively dry conditions which corresponds with the higher than mean degree of humification (drier conditions).

7.1.4.4 LPAZ - DMR 4 (110-42cm) (*c.*6,930-4,385 BP)

Percentage pollen diagram

The frequency of tree and shrub pollen types fluctuates in this zone, but the shrub pollen representation is generally greater.

Consistently high frequencies of *Calluna* pollen are recorded for this zone (62% of the pollen sum at 84cm) but very low frequencies of the other dwarf shrubs are represented, with the exception of small rise in *Empetrum* and *Vaccinium* frequencies at 64cm. This corresponds with the general decline in *Pinus* pollen frequencies between 68cm and 60cm.

Betula pollen frequencies are relatively low in this zone, falling to a minimum of *c.*7% at 100cm (*c.*6,500 BP) but the characteristic feature of this zone is the rise in the *Pinus* pollen frequencies, to 36% at 108cm (coinciding with a pine macrofossil in the profile) and reaching a maximum of 41% at 88cm. The pollen evidence for the presence of pine during this zone is supported by the large pine stump in the section (pine roots which extend in DMR 3).

Alnus pollen frequencies increase to values consistently over 2% at 80cm (*c.*5,750 BP), which have been interpreted as indicating the local, but sparse, occurrence of alder (Huntley and Birks, 1983).

Pollen concentration and influx diagrams

Pinus pollen concentration and influx values increase in this zone and supports the evidence of the percentage pollen data for the presence of pine from the base of this zone (Figure 7.7 for direct comparison of values).

The increase in pollen concentration and influx rates at 64cm may be enhanced by the general trend towards a higher degree of humification at *c.*70cm. However the peak in pollen concentration which occurs at 88cm (Figure 7.6) corresponds with a lower degree of humification and therefore might provide a reliable indication of a real increase in pollen influx. *Pinus sylvestris* pollen concentration and influx values reach a peak at 88cm of *c.*114,000 grains cm^{-3} and *c.*3,200 grains cm^{-2} yr^{-1} respectively, which supports the pine pollen percentage data in suggesting that a relatively dense pinewood canopy was established in the area at *c.*6,030 BP

(Figure 7.7).

Fungal and algal remains

This majority of fungal and algal remains recorded for this zone are indicative of relatively dry conditions. Type 14 is represented throughout most of this zone, the exception being the lowest level (108cm) which coincides with a peak in *Sphagnum* spore frequencies. However, no *Sphagnum* leaves were observed in the peat matrix at this depth (see Section 7.1.2) and there is no inverse relationship between *Sphagnum* spores and Type 14 between at 60cm and 80cm.

The evidence of high *Calluna vulgaris* pollen frequencies throughout this zone and the high values for Types 10 and 14 supports Van Geel's proposal (1978; see APB 1, Section 6.1.4.1) that *Calluna* is probably the host for this fungus.

The remaining indicators suggesting relatively dry conditions in this zone include Types 1 and 2 which are present at low frequencies.

The proportion of blackened *Pinus* pollen grains fluctuates in this zone, but there does appear to be some correspondence with the degree of humification (Figure 7.10), for example at 96cm, 92cm and *c.*74cm. However the high frequency of blackened *Pinus* grains at 88cm does not correspond with a significantly high degree of humification and similarly the relationship does not extend to the top of the zone, for example at *c.*52cm.

Degree of humification

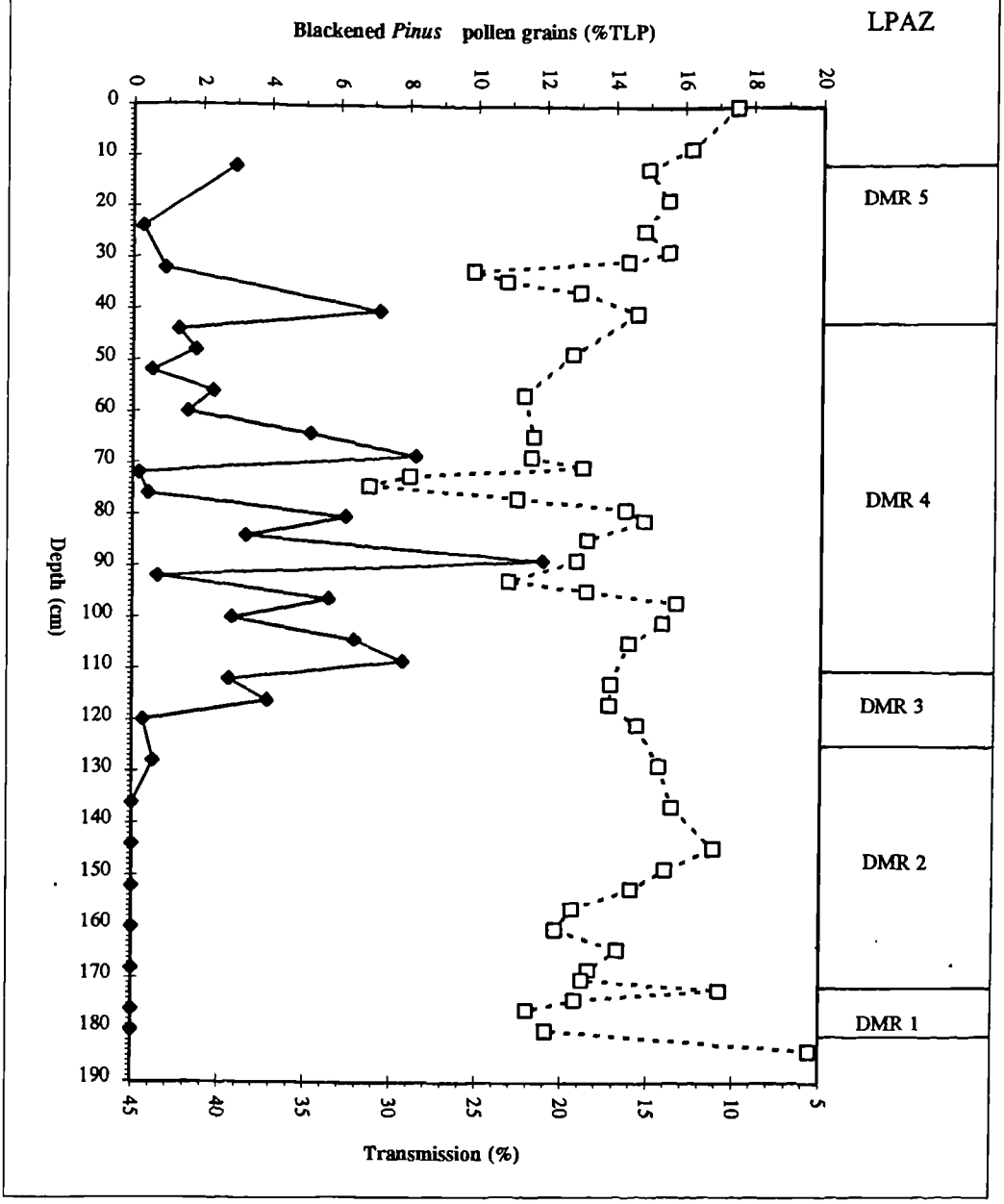
This zone shows large fluctuations in the degree of humification but there is a general shift towards less humified peat above *c.*75cm. The large pine stump between *c.*90cm and *c.*117cm corresponds with the top of a phase of relatively well humified peat (between *c.*145cm and *c.*96cm) followed by a shift towards less humified peat above *c.*96cm. The large birch macrofossil in the section (*c.*82cm) corresponds with a shift towards more humified peat.

The sharp fall in the degree of humification recorded at *c.*74cm coincides a small increase in the proportion of *Sphagnum* leaves (*c.*10% of the peat matrix).

Summary

The pollen evidence for this zone indicates a relatively dense pine woodland with occasional birch trees and an understorey of *Calluna vulgaris*. Pine colonised the

Figure 7.10.
Profile DMR - Degree of humification (expressed as the inverse of percent transmission) and the frequency of blackened *Pinus* pollen grains (expressed as a percentage of total land pollen) plotted against depth (cm).



site at *c.*6,840 BP with subsequent reduction in the density of the woodland canopy at *c.*6,300-6,170 BP, *c.*5,890 BP and *c.*5,030 BP. There is a general decline in pine pollen frequencies at *c.*4,600 BP. The relative and concentration pine pollen data indicate that the pinewood canopy was most dense at *c.*6,030 BP.

The pollen evidence for the local presence of pine is supported by presence of a pine stump in the profile. The humification evidence indicates that there is a shift towards a lower degree of humification immediately above the pine stump. This evidence supports the hypothesis proposed by Birks (1975) for conditions favourable for the establishment and subsequent preservation of pine stumps. The fungal and algal remains indicate relatively dry conditions throughout this zone but the transmission values indicate shifts towards less humified peat at *c.*6,200 BP and *c.*5,500 BP.

7.4.1.5 LPAZ - DMR 5 (42-12cm) (*c.*4,385-3,310 BP)

Percentage pollen diagram

This zone is characterised by lower *Pinus* pollen frequencies (*c.*16% TLP at the base of the zone) and corresponding high frequencies of *Calluna vulgaris* (up to 63% TLP). However, the presence of the large pine stump at the top of the section (above the level of the highest pollen spectrum), plus the trend towards higher *Pinus* pollen frequencies towards the top of the zone, suggests that pine was present at the site after *c.*3,500 BP.

Cyperaceae pollen frequencies increase at the top of the zone together with small increases in the frequency of open-habitat taxa, such as *Ranunculus* sp., *Potentilla* type and *Filipendula.*

Pollen concentration and influx diagrams

Pollen concentration and influx values rise sharply at the base of this zone to *c.*308,000 grains cm^{-3} and *c.*8,600 grains cm^{-2} yr^{-1} respectively. However this corresponds with a higher degree of humification and may partly reflect an enhancement of the pollen concentration as a result of lower peat accumulation rates.

Fungal and algal remains

The only fungal/algal type present in significant frequencies in this zone is Type 10, which is associated with the roots of *Calluna vulgaris* and relatively dry conditions (Van Geel ,1978).

The peak in the proportion of blackened *Pinus* grains at 40cm and the subsequent trough at 32cm corresponds well with the degree of humification (Figure 7.10).

Degree of humification

The shift to a lower degree of humification between 40-32cm coincides with the presence of a single pine macrofossil in the section (at *c.*34cm) and an increase in the proportion of *Sphagnum* leaves in the peat matrix (*c.*20%) at 32cm. Above *c.*30cm the trend is to a higher degree of humification.

Summary

The pollen-stratigraphic evidence in this zone indicates a relatively open pine woodland with a corresponding expansion of the *Calluna* understorey. The fungal and algal evidence indicates relatively dry conditions and corresponds with a shift towards a relatively well humified peat matrix above 32cm(*c.*4,000 BP).

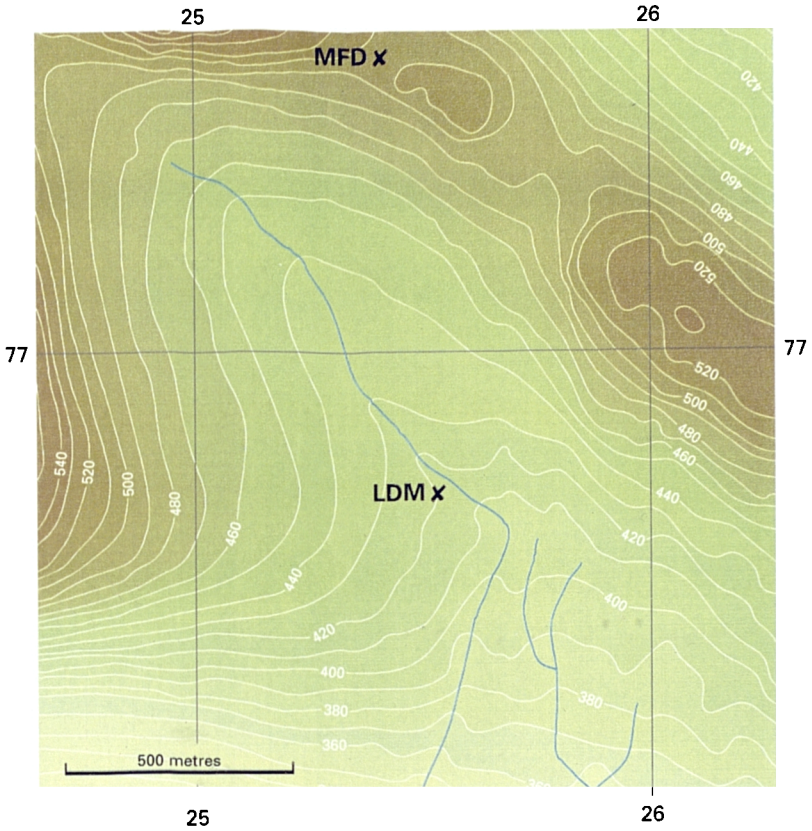


Figure 7.11: Beinn Dearg – location of sample site LDM (Lochdrum) c.420m OD

7.2 LOCH DROMA SITE CODE : LDM (c.420m OD) (NGR: NH 255766)

7.2.1 SITE DESCRIPTION

This site area was selected because the deep peat hags exposed by erosion showed numerous interstratified pine stumps overlying layers of birch stumps on a minerogenic ground. Following field walking to identify the deepest accumulation of peat in the area, (which was confirmed using a gouge auger), a suitable sampling site was located by probing the area on a 5m grid systems to identify the deepest profile. An adjacent erosion gulley was excavated to form a profile approximately 1m wide and 180cm deep. Two monolith tins were used to sample the section from approximately 4cm above the coarse minerogenic basal sediments to just below the current vegetated surface.

The site of LDM can be considered as a valleyside mire type since it lies on a slope (east-facing) and receives drainage principally from the west and southwest (Figure 7.11). The dominant vegetation cover at the site is *Calluna* heath with *Erica tetralix, Erica cinerea* and *Vaccinium myrtillus.*

7.2.2 LITHOSTRATIGRAPHY

The following stratigraphy was recorded in the field and supplemented by laboratory observations of the sampled column recovered from the monolith tins.

The two layers of pine stumps with roots at *c.* 53-55cm and 100-107cm overlie layers of birch roots and branches at *c.* 109-115cm, 121-124cm and 158-160cm. The extensive blanket peat in the region of the site contained a high frequency of pine and birch macrofossils. Samples were collected for dendrochronological analysis in addition to those sampled from the section.

DATUM (0) = TOP OF UPPER MONOLITH TIN

0-5cm Dark brown, detrital peat. *Calluna* root penetration from above. H7; n3; Th2, Sh2.

5-26cm Medium dark brown, *Eriophorum* peat. H7; n2; Th; Sh2.

26-67cm Dark brown to black, detrital peat with occasional flattened rootlets (*Eriophorum*). Occasional Ericaceous remains present. Unidentified wood remains (very degraded) at 42cm and 30cm, Ericaceous twigs between 58-60cm and at 33cm. H6-7; n4; Th2; Tl1 (Eric.); Sh1.

67-77cm Black, homogeneous peat. H9; n4; SH4.

77-100cm Very dark brown, herbaceous detrital peat. Occasional flattened rootlets (sedges or grasses). Birch twig at 91cm (approximately 6cm long). H6; n3; Th3; Tl1.

100-149cm Homogeneous, dark brown to black, detrital peat with occasional birch macro-fossils (146cm - 1.5cm long; 136cm - 4cm long; 123cm - 5cm long; 116cm - 4cm long). H7-8; n4; Sh3; Tl1.

149-153cm Dark brown, *Eriophorum*-rich peat. H8; n3; Th4.

153-161cm Very dark brown to black, detrital peat. Rich in long, thin twigs (Ericaceous). 153-54cm - birch macro-fossil (approximately 3cm long). H5; n4; Th1; Tl1.

161-172cm Very dark brown to black, wood-rich peat. Two birch twigs at 170cm (*c.*2.0cm long) and 163cm (approximately 3cm long). H8; n4; Tl3; Sh1.

172-177cm Very dark brown to black, detrital peat with sand-sized minerogenic inclusions. H7; n4; Sh2; g min 2.

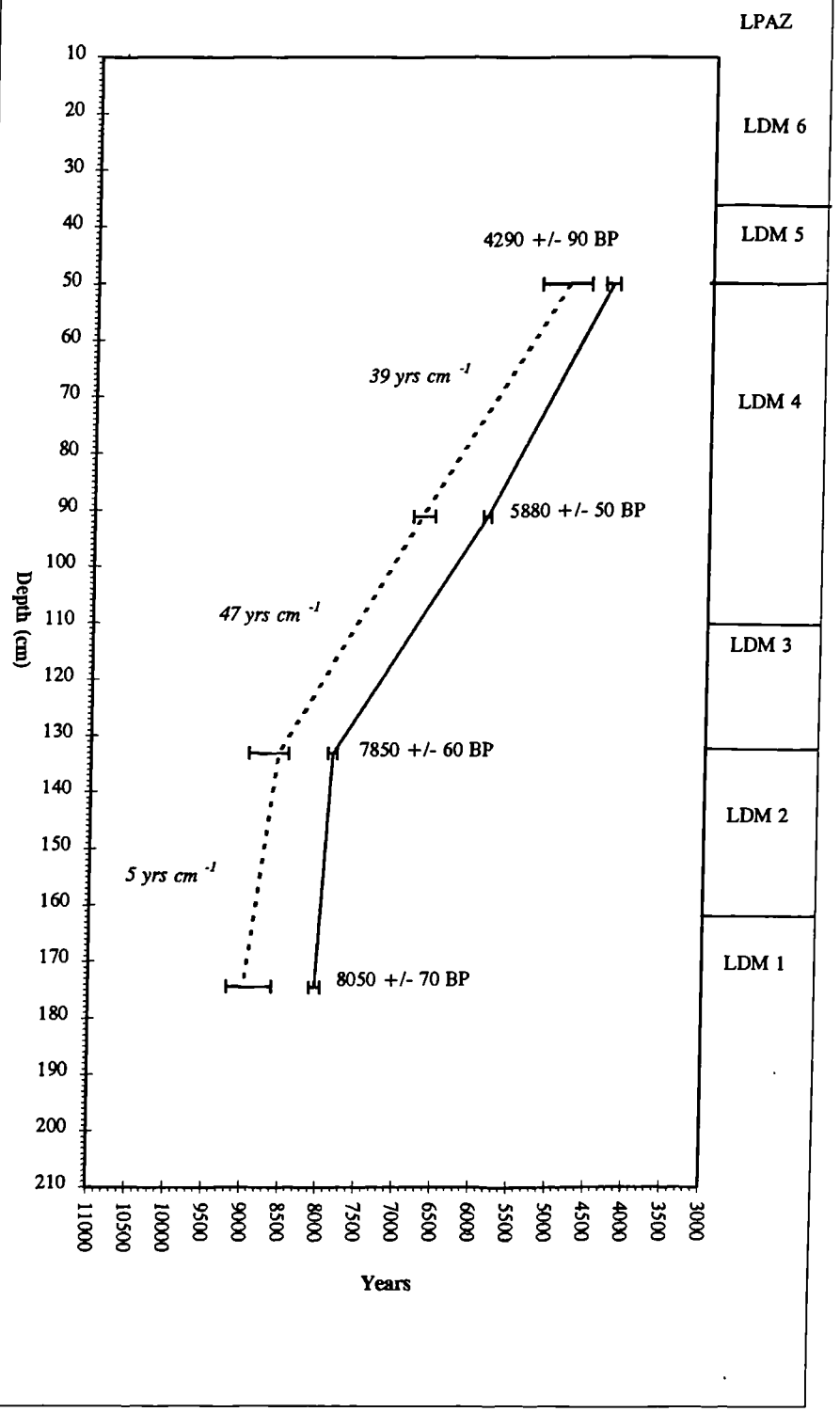
7.2.3 RADIOCARBON MEASUREMENTS

Four samples were submitted for radiocarbon analysis from the LDM profile at approximately 40cm intervals from 50cm below the top of the monolith sample to the basal peat (approximately 174cm). The sampling strategy was the same as for the DMR profile (Section 7.1.3) (approximately every 40cm from *c.*50cm down to the base of the profile). The radiocarbon measurements (and the quoted errors representing 1 standard deviation statistics) are shown plotted in Figure 7.12 together with the calculated sediment accumulation rates and the calibrated ages. The radiocarbon measurements and calibration ages are shown in detail in Table 7.1.

As at DMR, the two lower samples (*c.*133cm and 174cm) produce overlapping age ranges (8050 +/- 70 BP and 7850 +/- 60 BP respectively) but the minerogenic component of the basal sample is not as high as at DMR. The pollen evidence shows no clear evidence of a hiatus in the stratigraphy or for sediment mixing so the relatively fast basal peat accumulation rate of 4.8yrs cm^{-1} is likely to be spurious.

The top of the sampled profile, just below the current vegetated surface, reveals an extrapolated age estimate of *c.*2,350 BP, which indicates that either the top of the profile is absent or that there may be an error associated with the upper radiocarbon age estimate.

Figure 7.12.
LDM - Radiocarbon measurements (uncalibrated and calibrated) and interpolated peat accumulation rates (expressed in years per cm) plotted against depth (cm)



Radiocarbon years

Calibrated years

7.2.4 LOCAL POLLEN ASSEMBLAGE ZONES

7.2.4.1 LPAZ - LDM 1 (176-162cm) (*c.*8,060-7,990 BP)

***Percentage pollen diagram* (Figure 7.13)**

LDM1 is characterised by a high representation of herbaceous pollen types at the base of the zone (61%) and a subsequent increase in the proportion of tree and shrub pollen types towards the top of the zone.

The most frequent tree pollen type is *Betula* pollen which rises to 51% (%TLP) at 162cm. The tall shrubs are represented by *Corylus avellana* type, *Salix* , and *Juniperus* (particularly in the lower half of the zone) which reaches a maximum of *c.*16% at 168cm. Towards the top of the zone *Vaccinium* and *Empetrum* pollen become frequent, rising to 18% and 12% respectively.

Cyperaceae and Poaceae pollen frequencies decrease towards the top of the zone (Poaceae shows a peak of 31% at the base) and some of the open habitat herbs are represented, such as *Ranunculus* sp., *Rumex* (undiff.) and Lactucae undiff.

Pteropsida (monolete) indet. spores are represented at relatively high frequencies and *Sphagnum* spores reach a very high frequency in this zone (almost 450% TLP). However, no *Sphagnum* leaves were observed in the peat matrix at this site (see Section 7.2.2.

***Pollen concentration and influx diagrams* (Figures 7.14 and 7.15)**

The relationship between the degree of humification and pollen concentration for this site is shown in Figure 7.16 and there appears to be some correspondence between the two sets of data, particularly below *c.*90cm. For LDM1 correspondence appears to be relatively good, although only three transmission values and four pollen concentration values are represented. However the trends are very similar and the lower pollen concentration at *c.*168cm may partially reflect the decrease in peat humification (and hence a faster peat accumulation rate). The peat accumulation rates can are calculated by interpolation of the radiocarbon rates (approximately 50cm intervals). Therefore short-term fluctuations in peat accumulation rates can only be indirectly inferred based on the humification evidence.

The pollen concentration and influx values at the base of the zone are *c.*226,000 grains cm^{-3} and *c.*47,000 grains $cm^{-2}\,yr^{-1}$ respectively. However, the influx value

FIGURE 7.13

PERCENTAGE POLLEN AND SPORE DIAGRAM FOR SITE LDM (420m OD)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TAXA

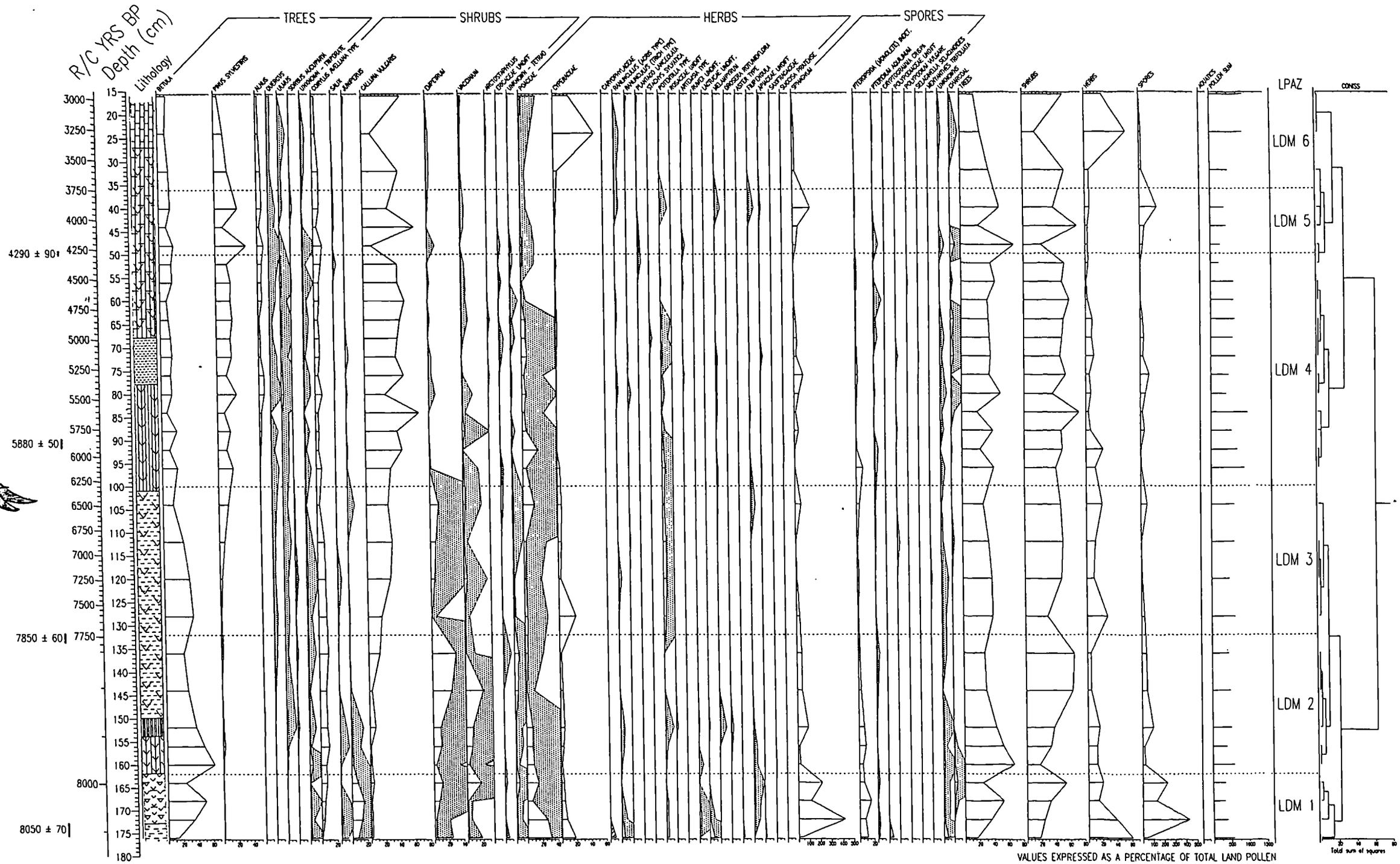


FIGURE 7.14 POLLEN CONCENTRATION DIAGRAM FOR SITE LDM (c.420m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

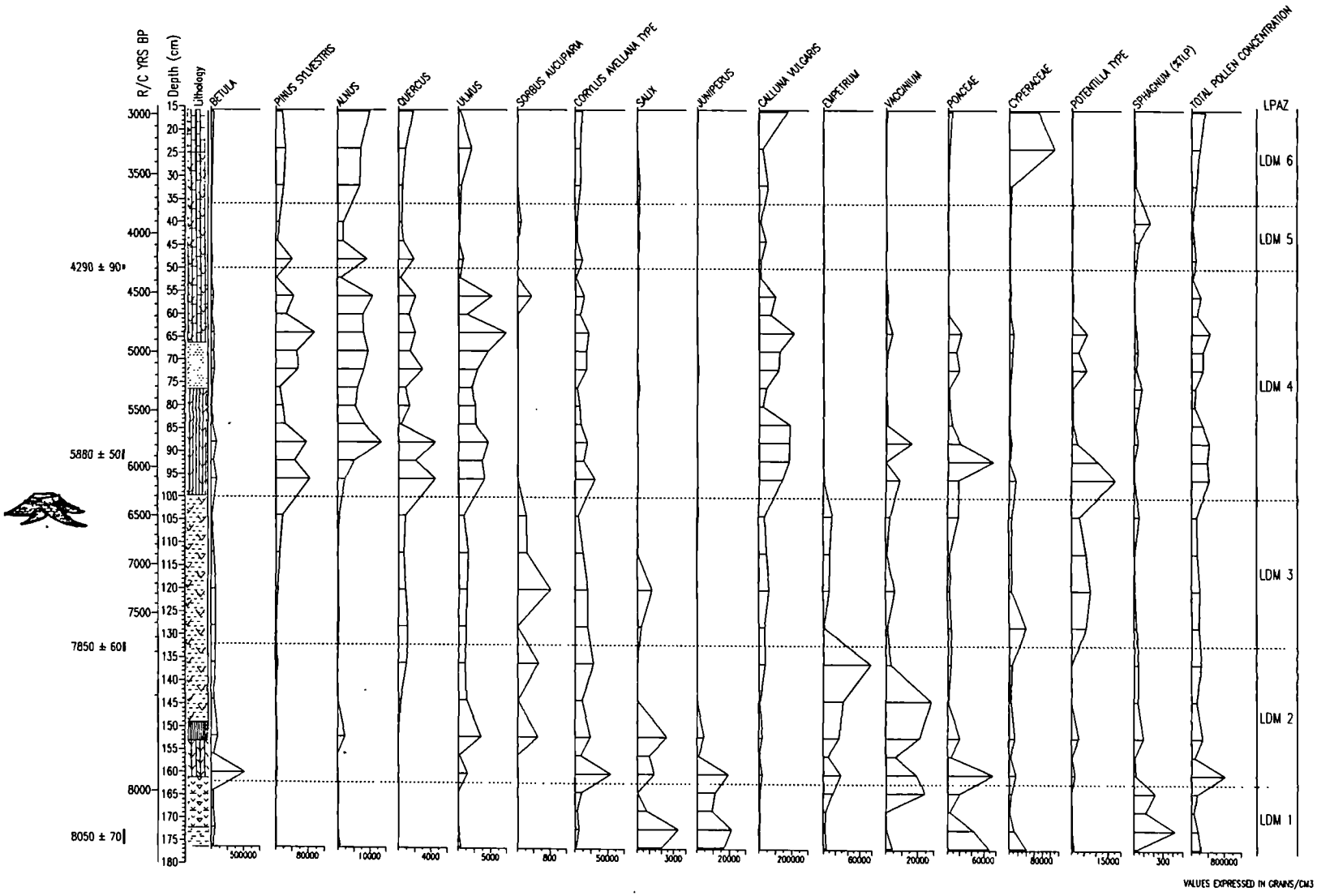


FIGURE 7.15 POLLEN INFLUX DIAGRAM FOR SITE LDM (c.420m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

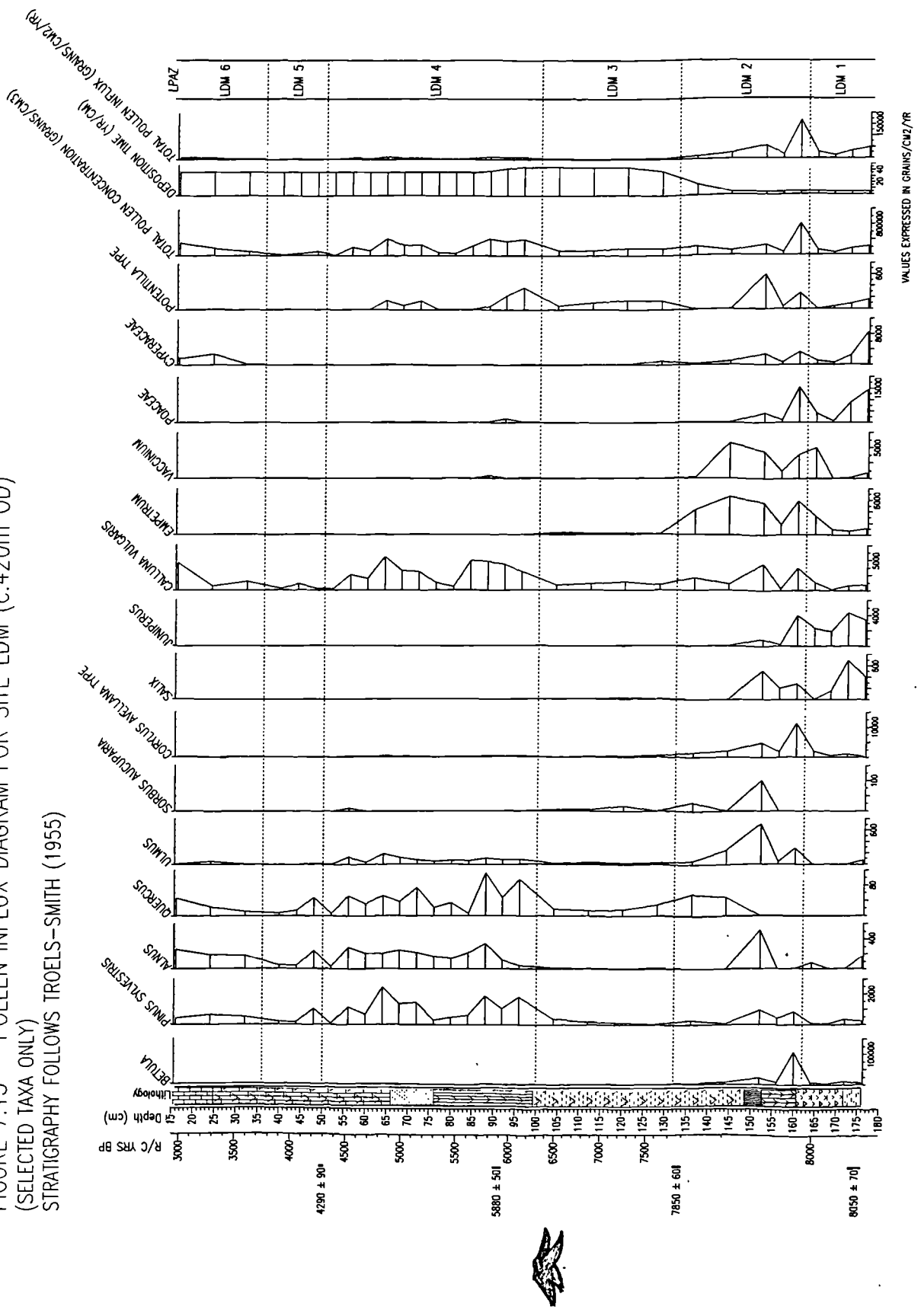
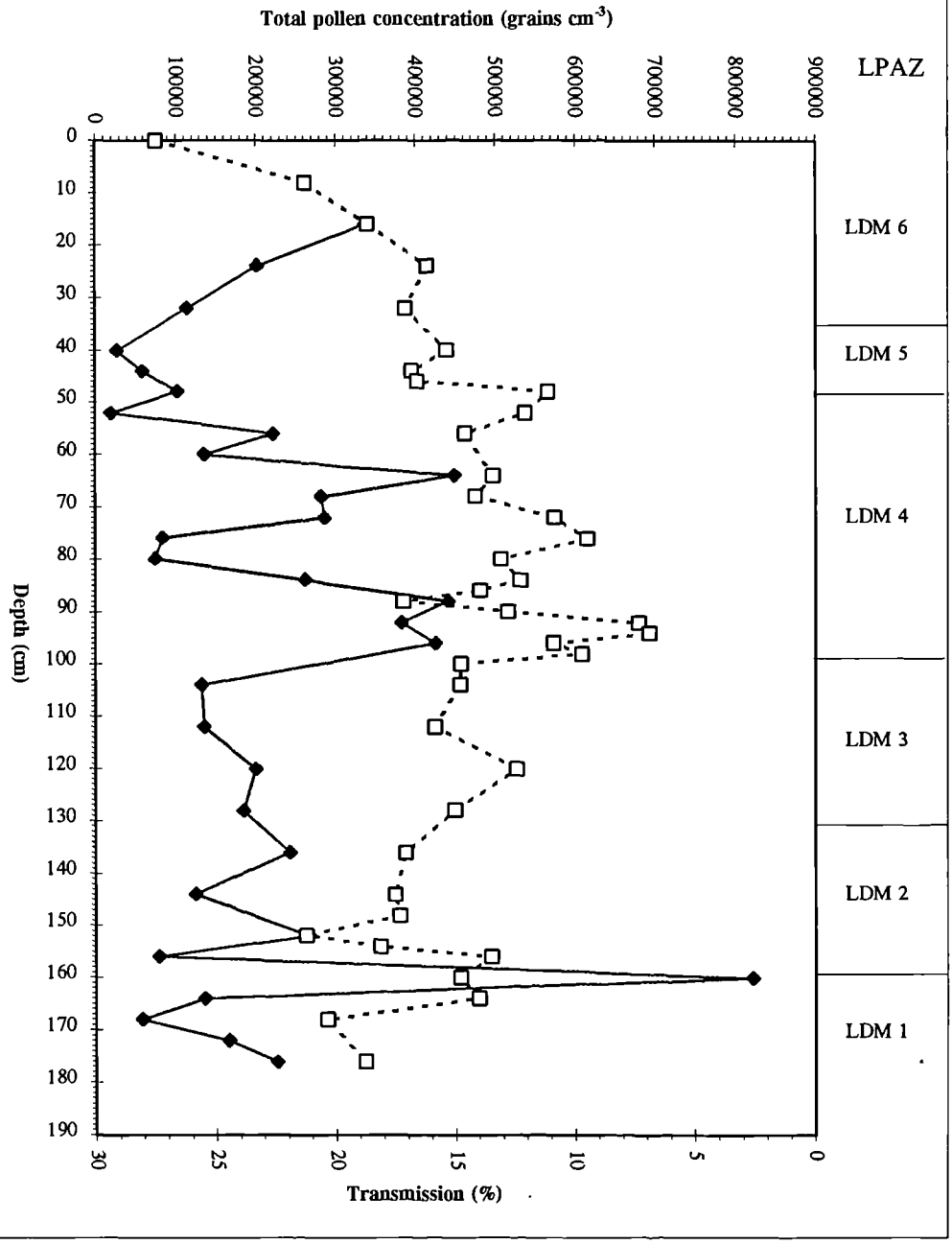


Figure 7.16
Profile LDM - Degree of humification (expressed as the inverse of percent transmission) and total pollen concentration (expressed as grains cm^{-3}) plotted against depth (cm).



Pollen concentration (grains cm^{-3})
Transmission (%)

may be enhanced by the high peat accumulation rate inferred from the close radiocarbon age estimates (as discussed for DMR, Section 7.1.4.1).

Relatively high pollen concentration and influx values are represented for *Salix, Juniperus*, Poaceae, Cyperaceae and some of the open habitat herbs which therefore generally supports the relative pollen data. The principal exception is the relatively low concentration and influx of *Betula* pollen in this zone.

***Fungal and algal remains* (Figure 7.17)**

Despite the peak in *Sphagnum* spores frequencies at 172cm, Type 27 (*Tilletia sphagni*) is only recorded in significant frequencies in the upper half of this zone. However, since no *Sphagnum* leaves were observed in this zone it is not possible to assess the relationship between Type 27 and *Sphagnum* further since the *Sphagnum* macro- and micro-fossil record often do not correspond. Although, Type 27 is thought to indicate a change from drier to wetter sediment (Van Geel, 1978; CPG4, Section 6.2.4.4) this is not supported by the humification evidence in this zone (see below).

The rise in Type 64 and *Empetrum* pollen frequencies towards the top of this zone supports the observations of Van Geel (1978) and Ellis and Ellis (1875) that this fungus is specific to *Empetrum nigrum* and corresponds with the evidence for a shift to a higher degree of humification.

Type 96a/b has been found on the leaves of *Vaccinium oxycoccus* (Van Geel, 1972) but the small rise in Type 96a/b in this zone occurs just below the increase in *Vaccinium* pollen frequencies. (This may indicate that Type 96a/b is associated with the roots of *Vaccinium*).

Type 28 is represented in the upper half of in this zone but does not correspond with the highest Cyperaceae pollen frequencies, as previously observed.

***Degree of humification* (Figure 7.18)**

The three transmission values from this zone indicate a shift to a higher degree of humification towards the top of the zone. The wood macrofossils coincide with the highest transmission values (hence the less humified peat matrix).

FIGURE 7.17 FUNGAL AND ALGAL REMAINS DIAGRAM FOR SITE LDM (c.420m OD)
(WITH SELECTED POLLEN AND SPORES)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TAXA AND TYPES

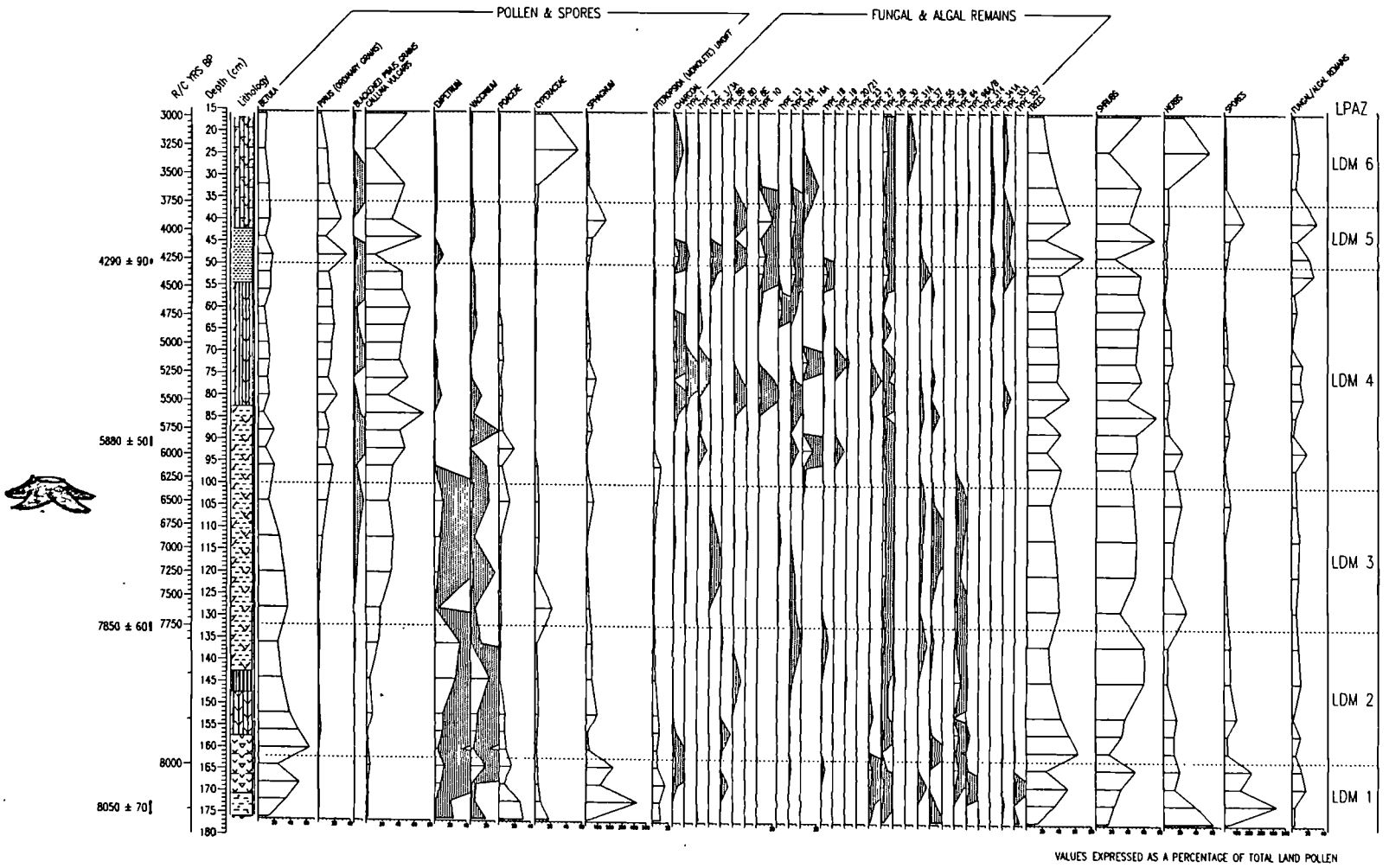
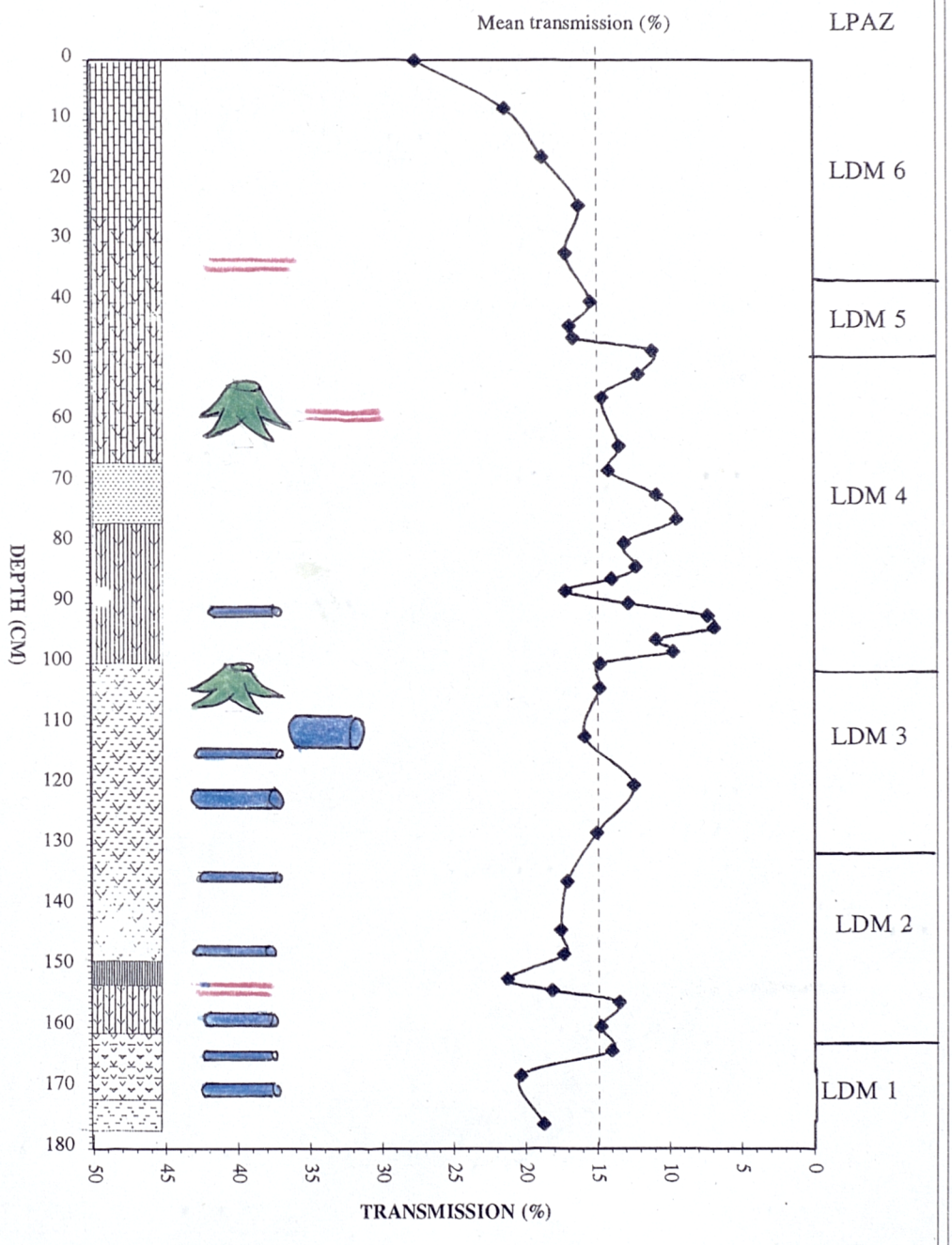


Figure 7.18.
Profile LDM - Degree of humification (expressed as the inverse of percent transmission) plotted against depth (cm). Macrofossils are represented (green = pine; blue = birch; red = Ericaceous)



Summary

The pollen evidence in the lower half of this zone indicates a relatively dense birch woodland with juniper and a decreasing representation of Poaceae, Cyperaceae and some open habitat herbs. The opening of the birch woodland canopy towards the top of the zone corresponds with a reduction in *Juniperus* and an expansion of *Vaccinium, Empetrum* and Poaceae.

The shift towards a higher degree of humification at the top of this zone corresponds with an increase of fungal types indicative of relatively dry conditions, such as Types 64 and 96a/b. Paradoxically, however, there is a simultaneous rise in the frequency of Type 27 which is indicates wetter conditions and the local presence of *Sphagnum.*

7.2.4.2 LPAZ - LDM 2 (162-132cm) (c.7990-7800 BP)

Percentage pollen diagram

This zone is characterised by a decline in the representation of tree type pollen types (decreasing from 68% at the base to 28% of TLP at the top) and a corresponding rise in shrub pollen types (rising from 18% at the base to 67% at the top of the zone). Herbaceous pollen frequencies are relatively low (maximum of 17%).

Betula pollen frequencies show a gradual decrease from a peak of 63% at the base of this zone to 24% at the top. The major components of the shrub pollen types are *Empetrum* (32% at the top of the zone) and *Vaccinium* (maximum of 23%) with an increase in the *Calluna* pollen frequencies towards the top of the zone. Cyperaceae pollen is recorded in low frequencies throughout the zone and there is a decrease in Poaceae pollen frequencies to almost zero in the middle of the zone.

Pollen concentration and influx diagrams

The maximum values for pollen concentration and influx values at the base of this zone (*c.*800,000 grains cm^{-3} and *c.*171,000 grains cm^{-2} yr^{-1} respectively) correspond with a relatively high degree of humification (Figure 7.16).

In general the concentration data support the evidence of the relative pollen data described above. However, for similar reasons described in LDM1 (and DMR1) the high peat accumulation rates and high degree of humification may provide an explanation for the relatively high *Pinus* pollen influx values at the base of the zone

(which is not reflected by the *Pinus* pollen concentration and percentage data) (Figure 7.19).

Fungal and algal remains

Type 64 is the most frequent fungal/algal type represented in this zone which corresponds with the high proportion of *Empetrum* pollen frequencies. However, the maximum frequency of Type 64 (144cm) does not correspond with maximum *Empetrum* pollen frequencies (136cm).

Degree of humification

The low degree of humification between *c.*154cm and 152cm coincides with a change in lithology from an Ericaceous-rich to a sedge-rich peat and the notable absence of Type 64 remains. This evidence therefore suggests a short-term change to wetter conditions.

Summary

The pollen evidence indicates a relatively dense birch woodland (with grasses and sedges) at the base of this zone. The decrease in the density of birch towards the top of the zone is associated with a corresponding decrease in grasses and an expansion of *Empetrum* and *Vaccinium* cover.

The humification evidence indicates a temporary shift towards relatively wet (and/or cool) conditions at *c.*154 cm. The subsequent shift to a more humified peat matrix is associated with increase of *Vaccinium* and *Empetrum* (and an increase in Type 64 fungal remains).

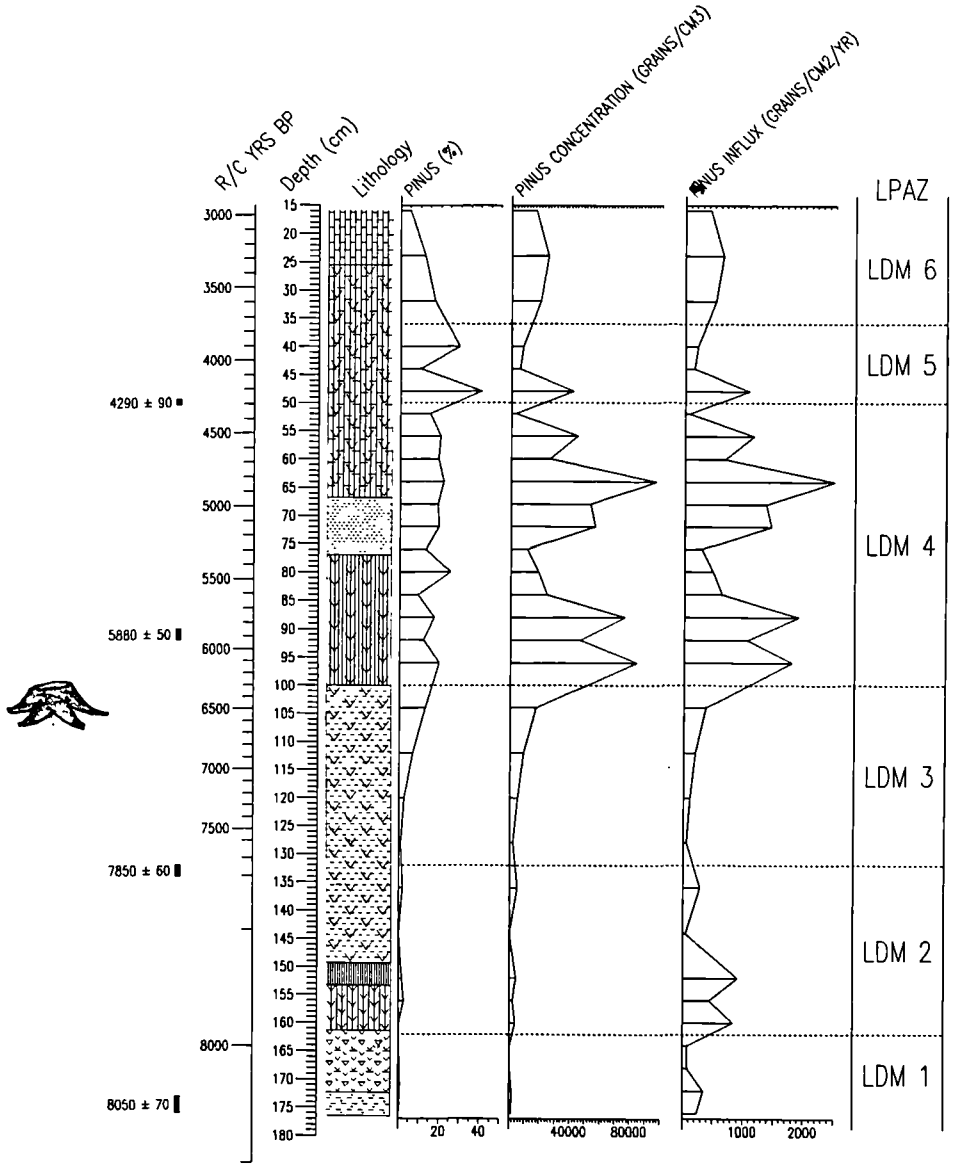
7.2.4.3 LPAZ - LDM3 (132-100cm) (*c.*7,800-6300 BP)

Percentage pollen diagram

This zone is characterised by a higher proportion of herbaceous pollen types which largely results from the higher Cyperaceae and Poaceae pollen frequencies (and *Potentilla* type, which is consistently represented up to a maximum of 4%).

Betula pollen frequencies decrease towards the top of this zone which corresponds with the increase in *Pinus* and *Calluna* pollen frequencies. *Empetrum* pollen frequencies are lower in this zone (compared to LDM2) but increase to *c.*12% at 104cm.

FIGURE 7.19
PINUS POLLEN DATA FOR SITE LDM (c.420m OD)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)



The rise in *Pinus* pollen frequencies towards the top of this zone (to 13%) corresponds with the pine macrofossil identified in the profile between *c.*106-100cm. However since the macrofossil (possibly a root) has not been radiocarbon dated it cannot be correlated directly (or precisely) with the recorded changes in pine pollen frequencies.

Pollen concentration and influx diagrams

The low pollen influx in this zone (less than *c.*4,700 grains cm^{-2} yr^{-1}) corresponds to the decrease in the peat accumulation rate at the base of this zone to *c.*47 yr cm^{-1} (as discussed in LDM1, this is partly a reflection of the close radiocarbon dates at *c.*133cm and 174cm). The trends described above, for the percentage pollen diagram, are largely supported by the evidence presented in the pollen concentration and influx diagrams, but the concentration diagram does highlight the representation of *Sorbus aucuparia.*

Fungal and algal remains

The most frequent fungal type remain represented in this zone is Type 28, the significance of which has not yet been determined, but there is evidence to suggest an association with Cyperaceae pollen (in this investigation). This association is supported in this zone although there is not corresponding consistent association with the sedge macro-fossil record. However, Van Geel (1978) suggests that Type 28 probably represents spermatophores of a variety of species or may possibly be associated with *Narthecium* root peat (Van Geel and Middeldorp, 1988).

The frequency of Type 64 in this zone corresponds well with the *Empetrum* pollen frequencies in this zone.

There is an increase in blackened *Pinus* pollen grain frequencies towards the top of this zone, but there is no significant correspondence with the degree of humification (Figure 7.20).

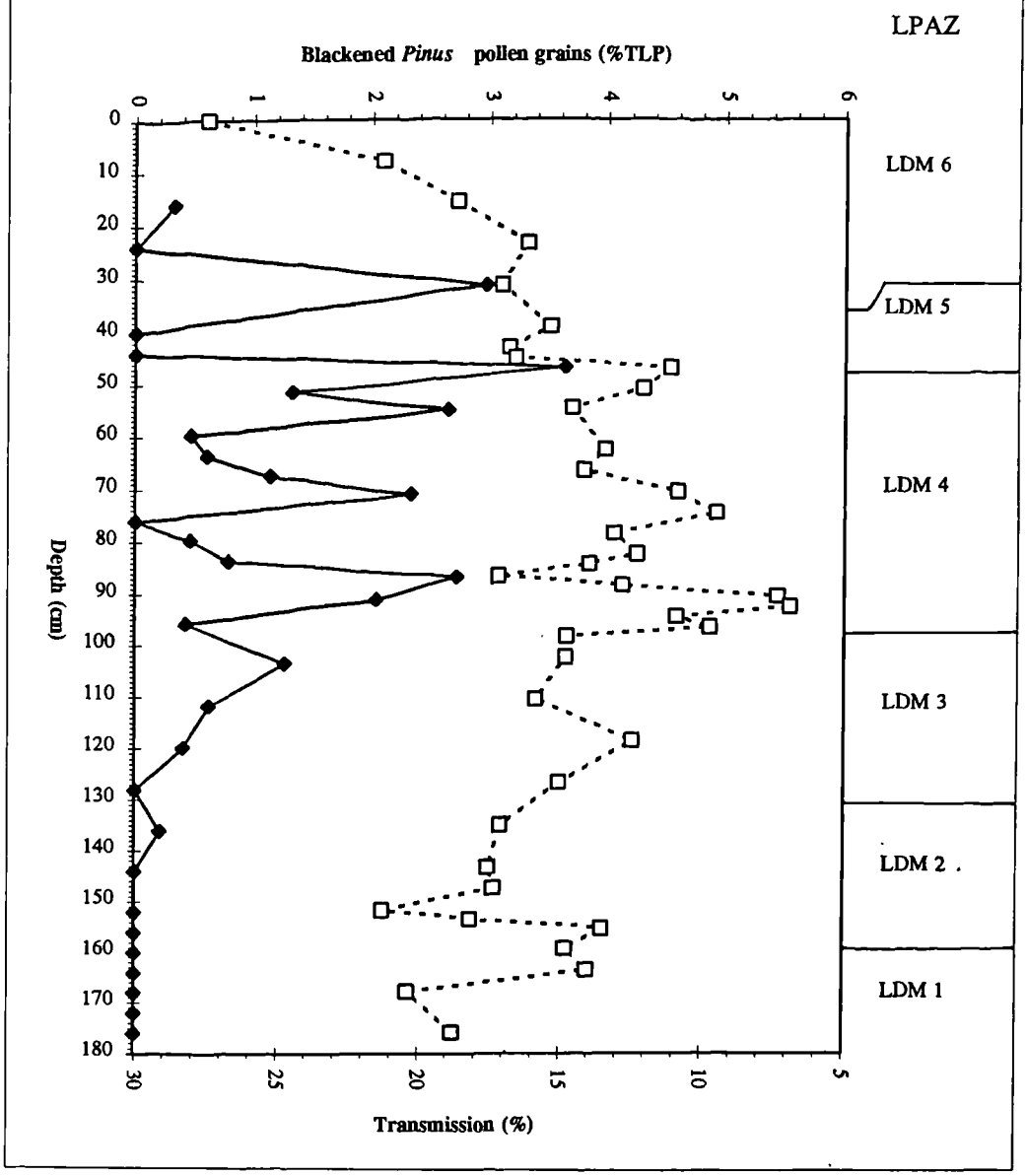
Degree of humification

The transmission values represented in this zone show a short-term shift to a higher degree of humification at 120cm.

Summary

The pollen evidence suggests an increase in the density of birch woodland at the base of this zone with a subsequent gradual opening of the birch canopy. This opening is associated with an increase in *Calluna vulgaris, Empetrum* and Poaceae

Figure 7.20.
Profile LDM - Degree of humification (expressed as the inverse of percent transmission) and the frequency of blackened *Pinus* pollen grains (expressed as a percentage of total land pollen) plotted against depth (cm).



and a rise in *Pinus* pollen frequencies. The pine macrofossil at the top of the zone cannot be taken as evidence for the presence of pine at the site since the roots may have penetrated downwards at a later date and no radiocarbon date is available for this specimen.

7.2.4.4 LPAZ - LDM4 (100cm-50cm) (*c.*6,300-4,290 BP)

Percentage pollen diagram

This zone is characterised by a generally higher proportion of shrub pollen types than tree pollen types. Herbaceous pollen types decrease to relatively low frequencies at the top of this zone.

Betula pollen frequencies are generally low (below 20%) but the presence of a single birch macrofossil at 92cm confirms the local presence of birch at the base of this zone. *Pinus* pollen frequencies increase, reaching a maximum for this zone of 25% at 80cm.

The pine macrofossil identified in the profile at the equivalent depth of the top of LDM3 indicates the local presence of pine (but as explained in LDM3 cannot be correlated precisely with the pollen stratigraphy). However, the *Pinus* pollen frequencies at the base of LDM4 reach 20%, which together with the high concentration values (Figure 7.19) probably indicate the first appearance of pine at this site (providing a minimum colonisation date of *c.*6,115 BP). The presence of a pine macrofossil in the profile at *c.*54cm indicates the local presence of pine at the top of this zone, but again cannot be precisely correlated with the pollen stratigraphy.

Alnus pollen frequencies rise in this zone reaching 7% at 80cm and the dominant shrub pollen is *Calluna vulgaris* reaching a peak of 72% at 84cm.

Poaceae pollen frequencies decrease towards the top of the zone (from 20% at 92cm) and *Potentilla* type pollen falls to very low frequencies above 92cm..

Pollen concentration and influx diagrams

Although the concentration values may be enhanced by the high degree of humification at 100-92cm, the high concentration at 64cm corresponds with a trend to a less well humified peat matrix. Similarly, the low pollen concentration values between 80-76cm correspond with a shift towards a higher degree of humification. Therefore the fiuctuations in the pollen concentration values above *c.*98cm are likely to provide a reliable indication of real variations in pollen influx. If this is the case, the high *Pinus* pollen frequencies at 80cm, indicating a relatively dense pinewood

canopy, are not supported by high concentration values (Figure 7.19). In contrast, the concentration data at 65cm indicates a dense pine woodland whereas only a small increase is observed in the *Pinus* pollen frequencies.

Fungal and algal remains

There is an increase in the variety types of fungal and algal represented in this zone, but the majority indicate relatively dry conditions (such as Types 1, 2, 10 and 14). Type 16a, thought to be associated with Poaceae (Van Geel, 1978) shows a peak in this zone corresponding with the peak in Poaceae pollen at 92cm. However, Type 16a was not recorded in LDM 1 where Poaceae pollen frequencies reach a maximum.

Despite the relatively high degree of humification indicated in this zone (see below) there is not a consistent correspondence with peaks in the proportion of blackened *Pinus* grains. The significance of the peaks of blackened *Pinus* grains at *c.*90cm, 72cm and 55cm cannot therefore be ascertained in this pollen assemblage zone (Figure 7.20).

Degree of humification

The transmission values in this zone indicate a well humified peat matrix with the exception of a short term shift towards a lower degree of humification at *c.*90cm. The latter corresponds with the presence of a single birch macrofossil at 92cm. The humification evidence generally supports the fungal and algal evidence for drier (or warmer) conditions between *c.*76cm and 80cm and at the top of the zone.

<u>Summary</u>

The pollen stratigraphy in this zone indicates a fairly open pine/birch woodland with a *Calluna* understorey. The increase in the density of the *Calluna* understorey appears to have led to a reduction of grasses and the exclusion of *Empetrum, Vaccinium* and *Potentilla* type.

The evidence for a high degree of humification in this zone is supplemented by an increase in the frequency of fungal and algal remains indicative of relatively dry conditions.

7.2.4.5 LPAZ - LDM 5 (50-36cm) (c.4,290-3,750 BP)

Percentage pollen diagram

The three pollen spectra represented in this zone show high pine frequencies (40% and 29%) with an intervening spectra showing a high *Calluna* pollen frequency

(69%). The lower percentage of *Calluna* at the top of the zone corresponds with the presence of pollen of open habitat taxa (at very low frequencies) such as *Ranunculus* sp., *Potentilla* type and *Filipendula.* There is a rise in *Sphagnum* spores in this zone.

Pollen concentration and influx diagrams

The *Pinus* pollen concentration and influx values at the base of this zone are relatively high which supports the relative pollen data. However, the upper peak in *Pinus* pollen (29%) is not reflected by an increase in *Pinus* pollen concentration (Figure 7.19)

Fungal and algal remains

Increases in the frequencies Types 10 and 14, indicative of relatively dry conditions and the local presence of *Calluna,* are represented in this zone. Type 3/3a (Van Geel, 1978, found this type in highly humified peat formed under dry conditions) is present at the base of the zone and corresponds with a high degree of humification. The proportion of Type 28 generally decreases towards the top of the zone but the Cyperaceae pollen is poorly represented.

The absence of blackened *Pinus* pollen grains at 40cm and 44cm corresponds with a shift to a lower degree of humification and paradoxically with an increase of fungal/algal remains indicative of drier conditions.

Degree of humification

The shift to a lower degree of humification above *c.*48cm corresponds with the presence of a single unidentified, decomposed, twig at *c.*42cm. However, the fungal and algal data do not support the transmission values for a shift to less humified peat.

<u>Summary</u>

The pollen evidence in this zone indicates a relatively dense pine woodland with birch and a *Calluna* dominated understorey.

The trend towards a less humified peat matrix at the top of the zone is only partially supported by the fungal/algal evidence but the latter does indicate the local presence of *Calluna* (Types 10 and 14).

7.2.4.6 LPAZ - LDM 6 (36-16cm) (*c.*3,750-2,970 BP)

Percentage pollen diagram

The three pollen spectra represented in this zone indicate a rise in herbaceous pollen frequencies to 57% which is largely a result of the increase in Cyperaceae pollen (54%). The decrease in the representation of tree pollen types towards the top of the zone is reflected by the fall in *Pinus* pollen frequencies (to 5%).

Pollen concentration and influx diagrams

The increase in *Pinus* pollen concentration and influx values towards the middle of the zone (Figure 7.19) corresponds with a decrease in *Pinus* pollen frequencies. This is not a response to an increase in the degree of humification since the trend is towards a less humified peat towards the top of the zone (Figure 7.18). The pollen concentration and influx diagrams therefore probably show real variations in the pollen influx in this zone and the relative pollen diagram may be partly affected by the interdependence of the taxa which make up the pollen sum. In this case, the increase in the frequency of Cyperaceae pollen at 24cm suppresses the frequencies of *Calluna* and *Pinus.*

Fungal and algal remains

Relatively few fungal and algal remains are represented in this zone. Type 28 values rise slightly in this zone which corresponds with the increase in the frequency of Cyperaceae pollen. However, the inconsistent relationship between Type 28 and Cyperaceae pollen frequencies does not allow any conclusions to be reached regarding Type 28's significance. Very few fungal/algal remains of types indicative of relatively dry conditions were recorded for this zone which corresponds to a decrease in the degree of humification towards the top of this zone (see below).

Degree of humification

Maximum transmission values are recorded at the top of this zone indicating a trend towards a lower degree of humification. The Ericaceous twigs and a single rotted twig (unidentified) at the base of the zone corresponds with the more humified peat.

<u>Summary</u>

The pollen evidence in this zone indicates a very open pine/birch woodland with an understorey of *Calluna vulgaris* and sedges. The humification and fungal/algal remains evidence indicates a trend to a lower degree of humification and wetter conditions towards the top of this zone.

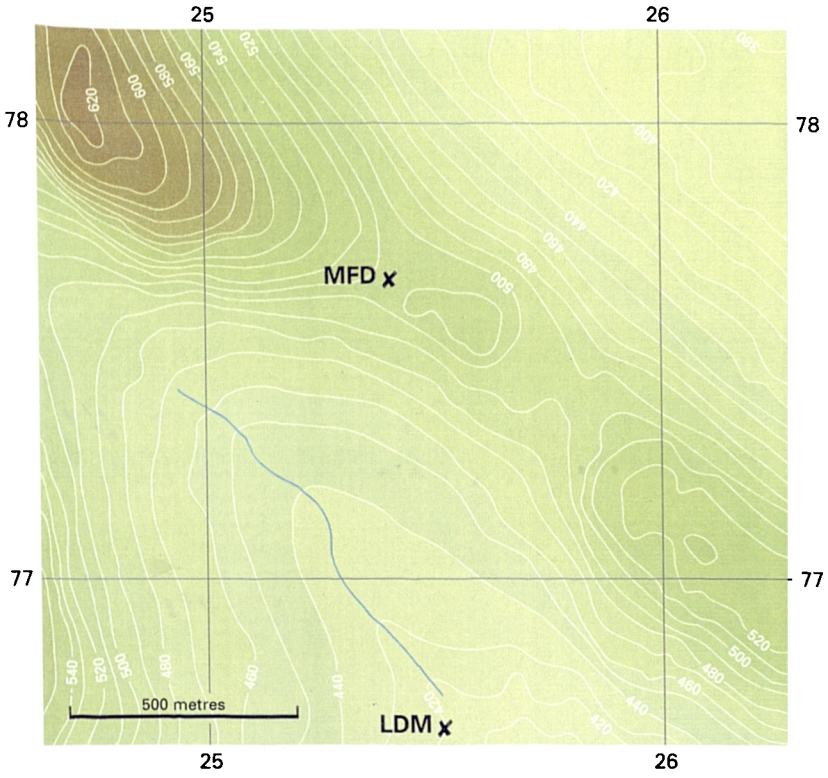


Figure 7.21: Beinn Dearg – location of sample site MFD (Meall Féith Dhiongaig) c.500m OD

7.3 MEALL FÉITH DHIONGAIG- SITE CODE : MFD (c.500m OD) (NGR: NH 254776)

7.3.1 SITE DESCRIPTION

Although no pine stumps were located in the immediate vicinity of the site area, the highest being at *c.*490m (approximately 0.5km to the southwest of MFD), it was selected because of the deep peat profiles exposed in the erosion gulleys and its topographic situation (a col site, therefore thought to provide a potentially sensitive humification signal, *cf.* Chambers, 1984). Numerous birch branches and roots were, however, identified at the base and interstratified in the exposed profiles.

This site is located on a col, with drainage away from the site towards the northeast and southwest , and can therefore be categorised as a saddle mire type (Figure 7.21). As for the other sites investigated, the area was surveyed to locate the deepest accumulation of peat and subsequently systematically probed on a 5m grid system to identify the deepest point. This proved to be approximately 175cm deep, and a section was excavated into an existing adjacent erosion gulley (approximately 1m wide). Two monolith tins were used to sample the section from the minerogenic base at 173cm to approximately 35cm below the current vegetated surface.

Heathland vegetation types dominate this site today, namely *Calluna vulgaris, Vaccinium myrtillus* and *Empetrum nigrum.*

7.3.2 LITHOSTRATIGRAPHY

The following stratigraphy was recorded in the field and supplemented by laboratory observations of the sampled column recovered from the two monolith tins.

Birch macrofossils (twigs) were identified at the base of the profile at 160-162cm and 154 cm.

DATUM (0) = TOP OF UPPER MONOLITH TIN

0-20cm Medium brown, detrital peat with occasional fine rootlets (*Eriophorum*). H4; n2; Th3; Sh1.

20-52cm Medium dark brown, detrital peat with sedge (*Eriophorum*) and occasional *Sphagnum* (*c.*10% *Sphagnum* leaves at 30cm). H5; n2; Th2; Tb1; Sh1.

52-79cm Dark brown, detrital peat; some sedge. H6; n2-3; Sh3; Th1.

79-96cm Dark brown, *Eriophorum*-rich peat. H5; n3; Th4.

96-103cm Very dark brown to black, detrital peat. No distinct plant remains. H9; n4; Sh4.

103-147cm Very dark brown to black, detrital peat with fine rootlets (not identified) and wood remains. Ericaceous twigs - 115-116cm. Birch twig - 146cm (8cm long), pine twig - 125cm (6cm long), degraded wood fragment (unidentified) - 105cm (3cm long). H7; n4; Tl2; Th1; Sh1.

147-150cm Medium brown, *Eriophorum*-rich peat. H7; n2; Th4.

150-171cm Very dark brown to black, detrital peat with very fine rootlets and wood remains. Birch twig - 160cm (*c.* 2cm long) and 154cm (*c.*2cm long). H8; n4; Tl2; Th1; Sh1.

171-173cm Very dark brown to black, homogeneous peat with sand-sized minerogenic inclusions. H9; n4; Sh3; g min 1.

7.3.3 RADIOCARBON MEASUREMENTS

A similar sampling strategy was adopted for radiocarbon analysis for this site as was for DMR and LDM (see Sections 7.1.3 and 7.2.3), that is at *c.*40cm intervals, from a depth of 50cm down to the base of the profile.

The radiocarbon measurements (and the quoted errors representing 1 standard deviation statistics) are shown plotted in Figure 7.22 together with the calculated sediment accumulation rates and the calibrated ages. Table 7.1 shows further details regarding the radiocarbon measurements and the calibration ages Table. The sample from 127-129 cm was submitted for a further extended count due to insufficient carbon.

The peat accumulation rates (Figure 7.22) are relatively similar in value compared to the range of the two lower altitude sites (DMR and LDM), the rates ranging between 21.6 yrs cm^{-1} and 34.0 yrs cm^{-1} for MFD.

7.3.4 LOCAL POLLEN ASSEMBLAGE ZONES

7.3.4.1 LPAZ - MFD 1 (170-152cm) (c.6,900-6,290)

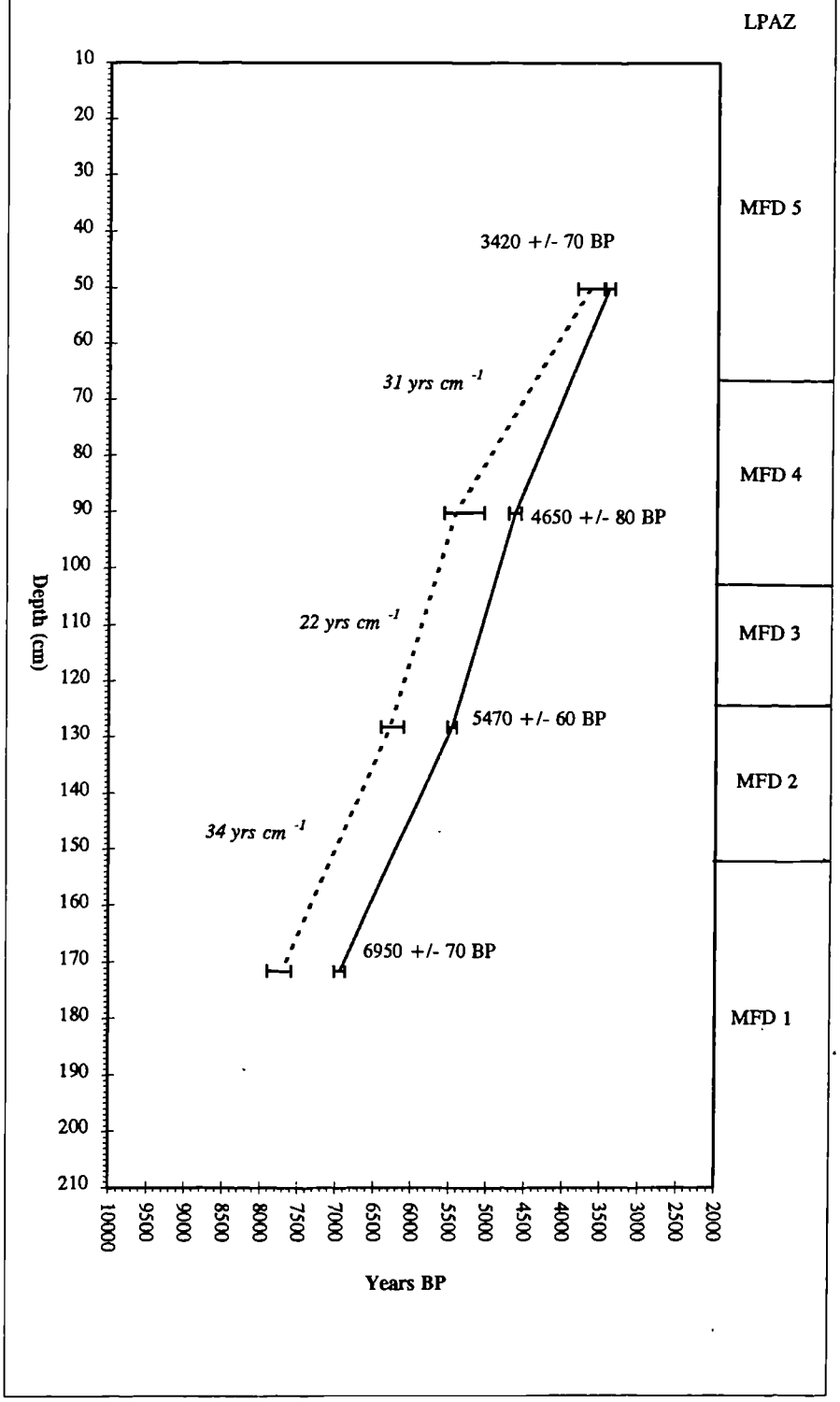
Percentage pollen diagram **(Figure 7.23)**

This zone is characterised by a high proportion of shrub pollen types (80% at the base of the zone) and a gradual increase in the representation of tree pollen types.

Pinus pollen frequencies increase from 2% to 17% (at 158cm) and *Betula* pollen frequencies reach 16% at the top of the zone. The shrub pollen component is largely represented by *Calluna vulgaris* which reaches a peak of 75% at 170cm.

Poaceae pollen frequencies reach a peak of 23% at 166cm.

Figure 7.22.
MFD - Radiocarbon measurements (uncalibrated and calibrated) and interpolated peat accumulation rates (expressed in years per cm) plotted against depth (cm)



Radiocarbon years

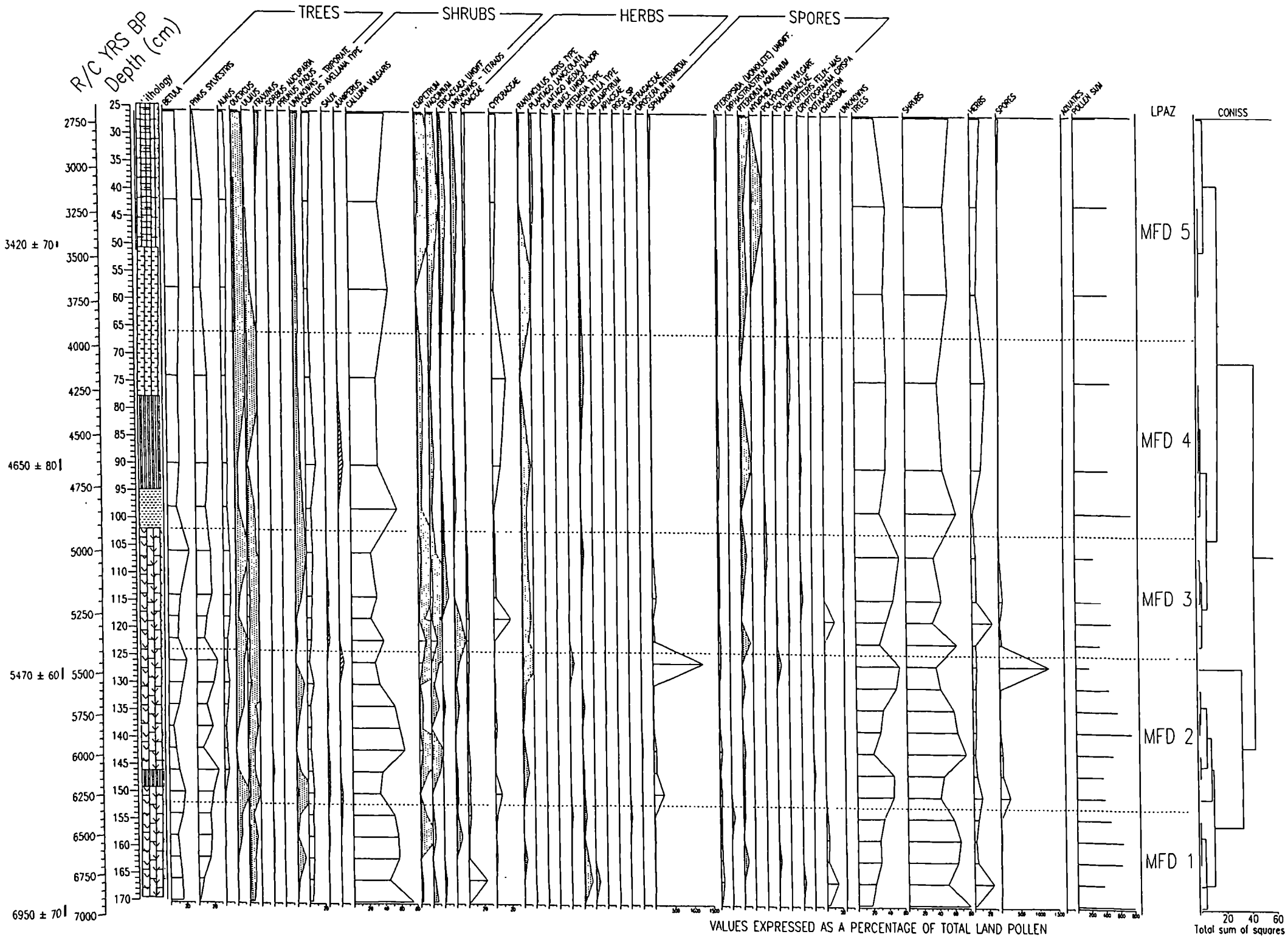
Calibrated years

FIGURE 7.23

PERCENTAGE POLLEN AND SPORE DIAGRAM FOR SITE MFD (c.500m OD)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TAXA



Pollen concentration and influx diagrams **(Figures 7.24 and 7.25)**
Below *c.*126cm (zones MFD1 and MFD2) there appears to be a general correspondence between the degree of humification and the pollen concentration (Figure 7.26). For the reasons outlined above (for example in Section 7.1.4.1, DMR1) the possible effect of the degree of humification on the pollen concentration and influx values will discussed where appropriate.

The base of this zone shows maximum pollen concentration and influx values (*c.*630,000 grains cm^{-3} and *c.*18,500 grains cm^{-2} yr^{-1} respectively) which corresponds to the minimum transmission values recorded for this site. The sediment accumulation rate is 34.0 yr cm^{-1}.

The pollen concentration/influx values in this zone generally support the trends outlined for the percentage pollen diagram, indicating a rise in *Pinus* and a fall in *Betula* and *Calluna vulgaris* pollen concentration and influx values.

Fungal and algal remains **(Figure 7.27)**

A wide variety of fungal and algal remains were recorded for this zone but all are represented in relatively low frequencies. Types indicative of drier conditions are slightly more frequent at the base of the zone (for example Types 2, 3/3a, 10) with a small increase in the frequency of Type 28 towards the top.

The increase in the frequency of blackened *Pinus* grains towards the top of this zone coincides with the relatively well humified peat matrix (Figure 7.28).

Degree of humification **(Figure 7.29)**
The below average transmission values (less than 19%) indicate a relatively high degree of humification in this zone.

<u>Summary</u>
The pollen stratigraphy indicates that this zone represents an open birch woodland with an understorey of *Calluna vulgaris* (and grasses at the base of the zone). The local growth of birch is confirmed by the presence of macrofossils both in the profile and in the sampled column. The *Pinus* pollen frequencies rise above 15% TLP in the middle of this zone but since no *Pinus* macrofossils were located it is not possible to establish whether the pollen evidence is indicative of the local growth of pine. If the *Pinus* pollen frequencies in the upper half of this zone do represent a local pollen source (rather than representing the regional establishment of pine

FIGURE 7.24 POLLEN CONCENTRATION DIAGRAM FOR SITE MFD (c.500m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

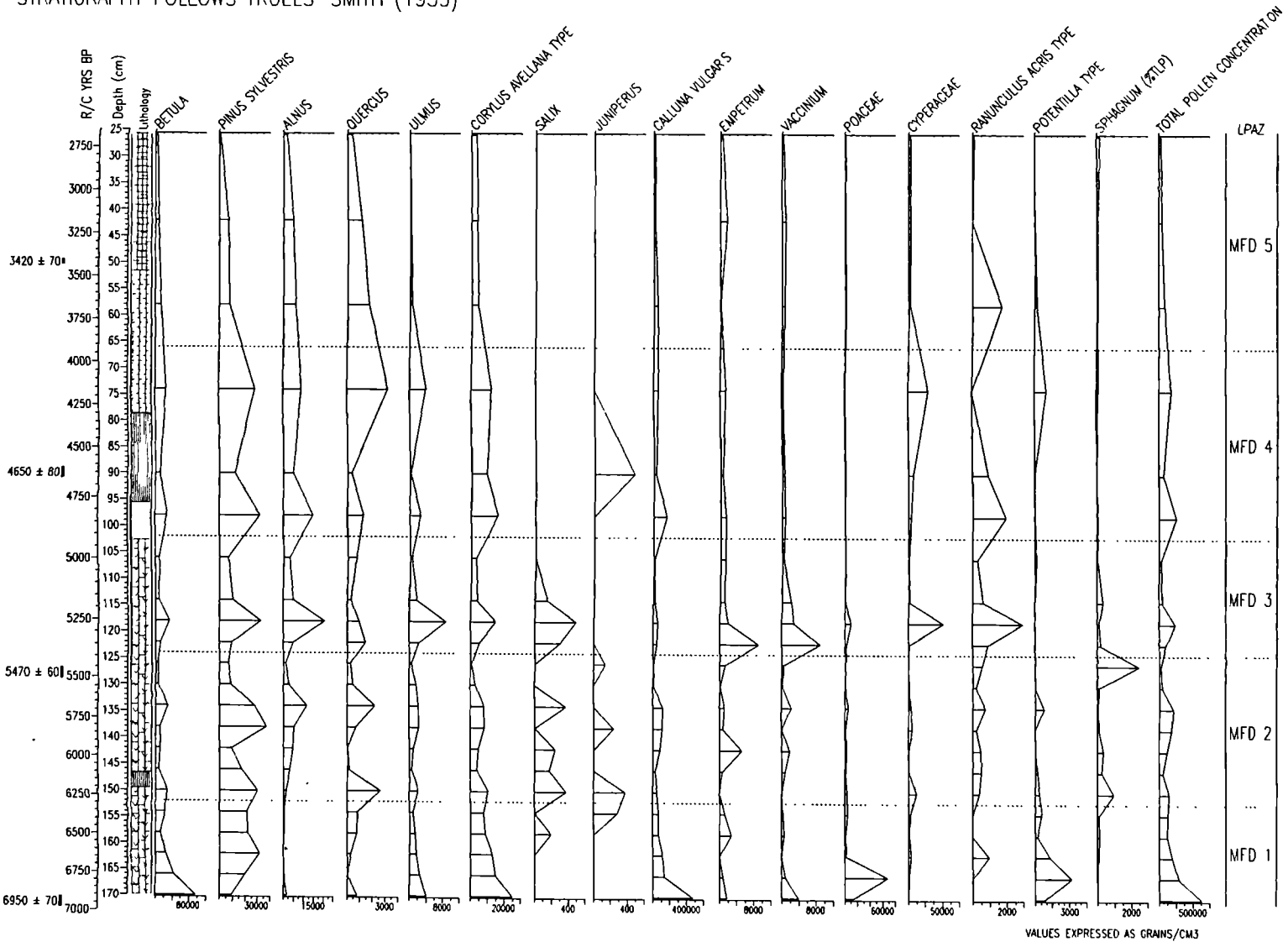


FIGURE 7.25 POLLEN INFLUX DIAGRAM FOR SITE MFD (c.500m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

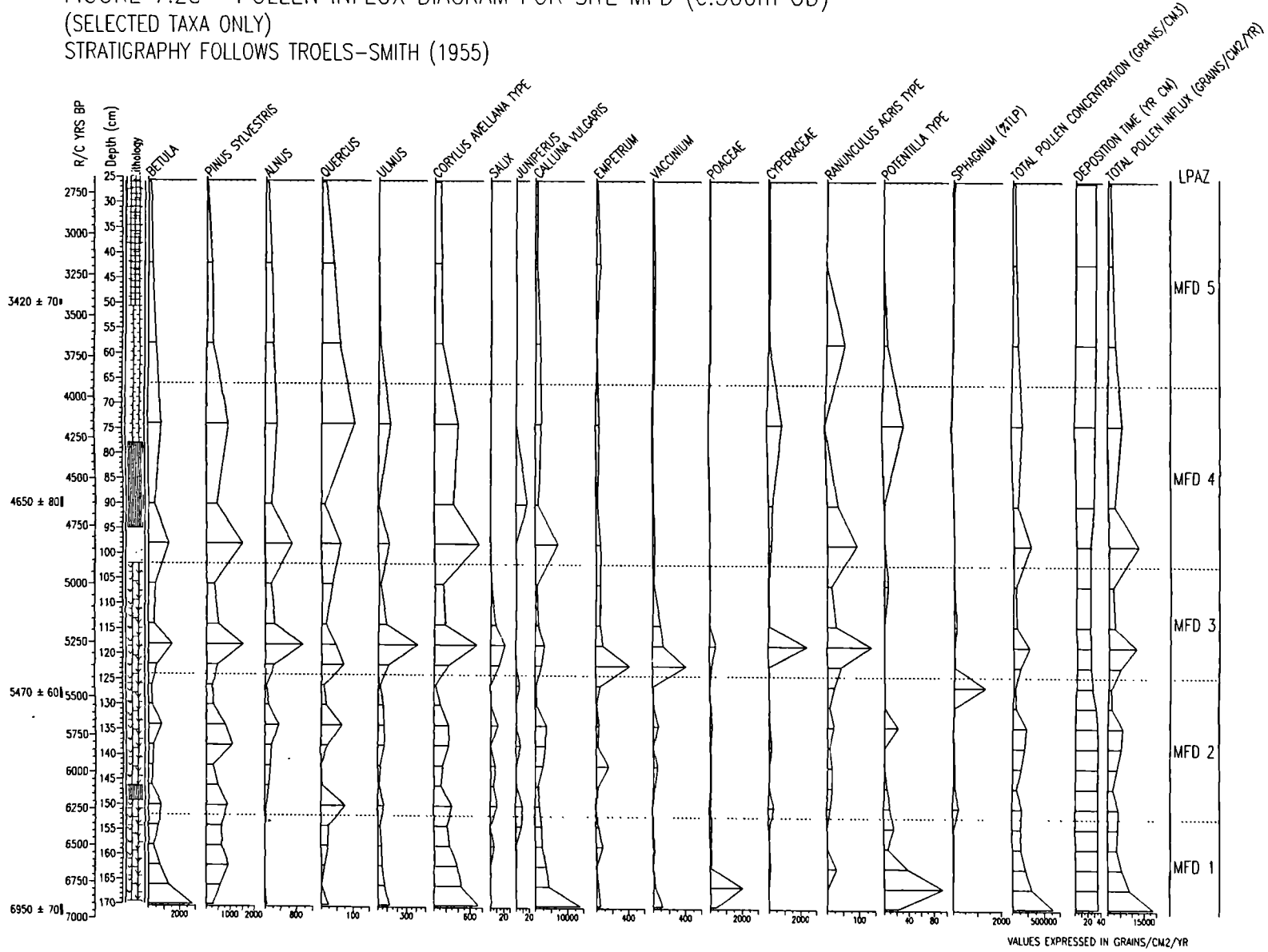
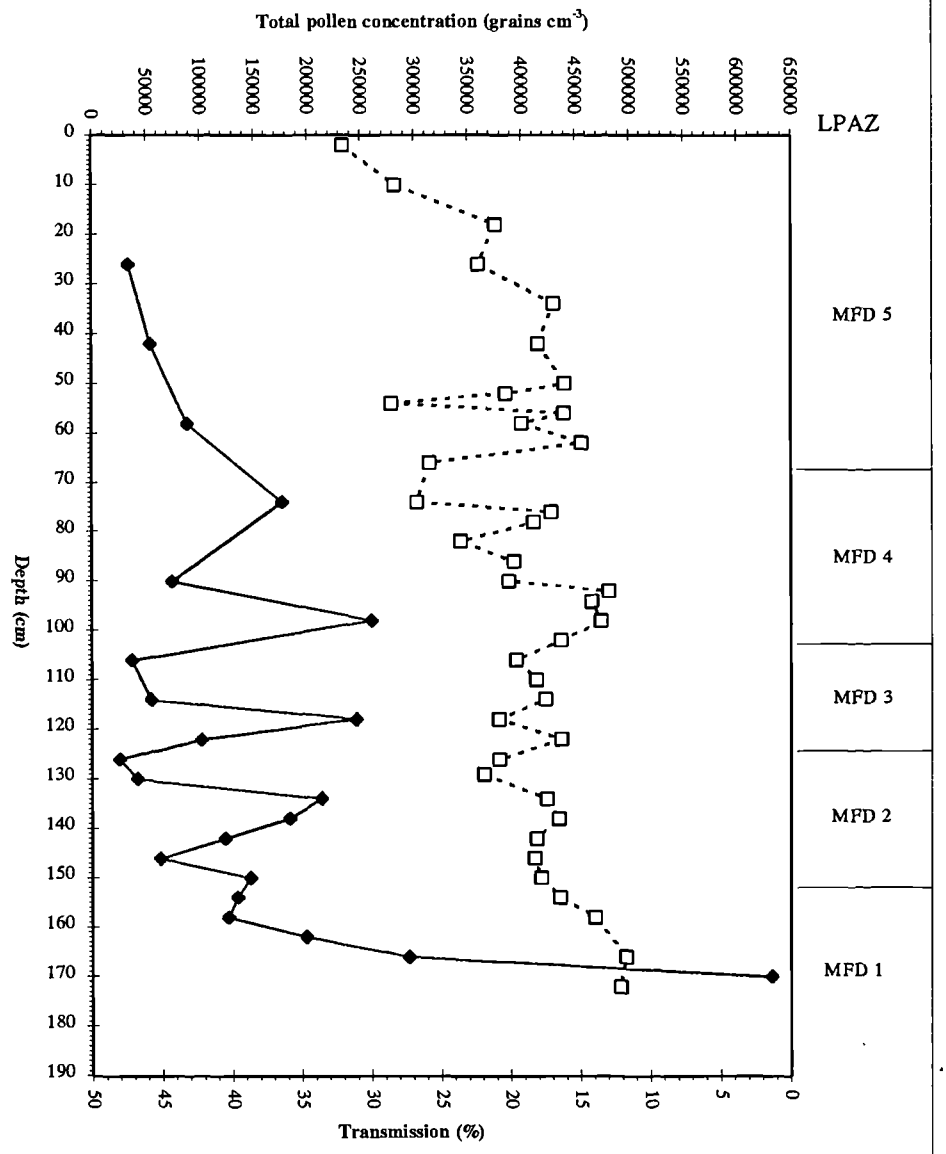


Figure 7.26.
Profile MFD - Degree of humification (expressed as the inverse of percent transmission) and total pollen concentration (expressed as grainscm^{-3}) plotted against depth (cm).



Pollen concentration (grains cm^{-3})
Transmission (%)

FIGURE 7.27 FUNGAL & ALGAL REMAINS DIAGRAM FOR SITE MFD (c.500m OD) (WITH SELECTED POLLEN AND SPORES)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TAXA AND TYPES

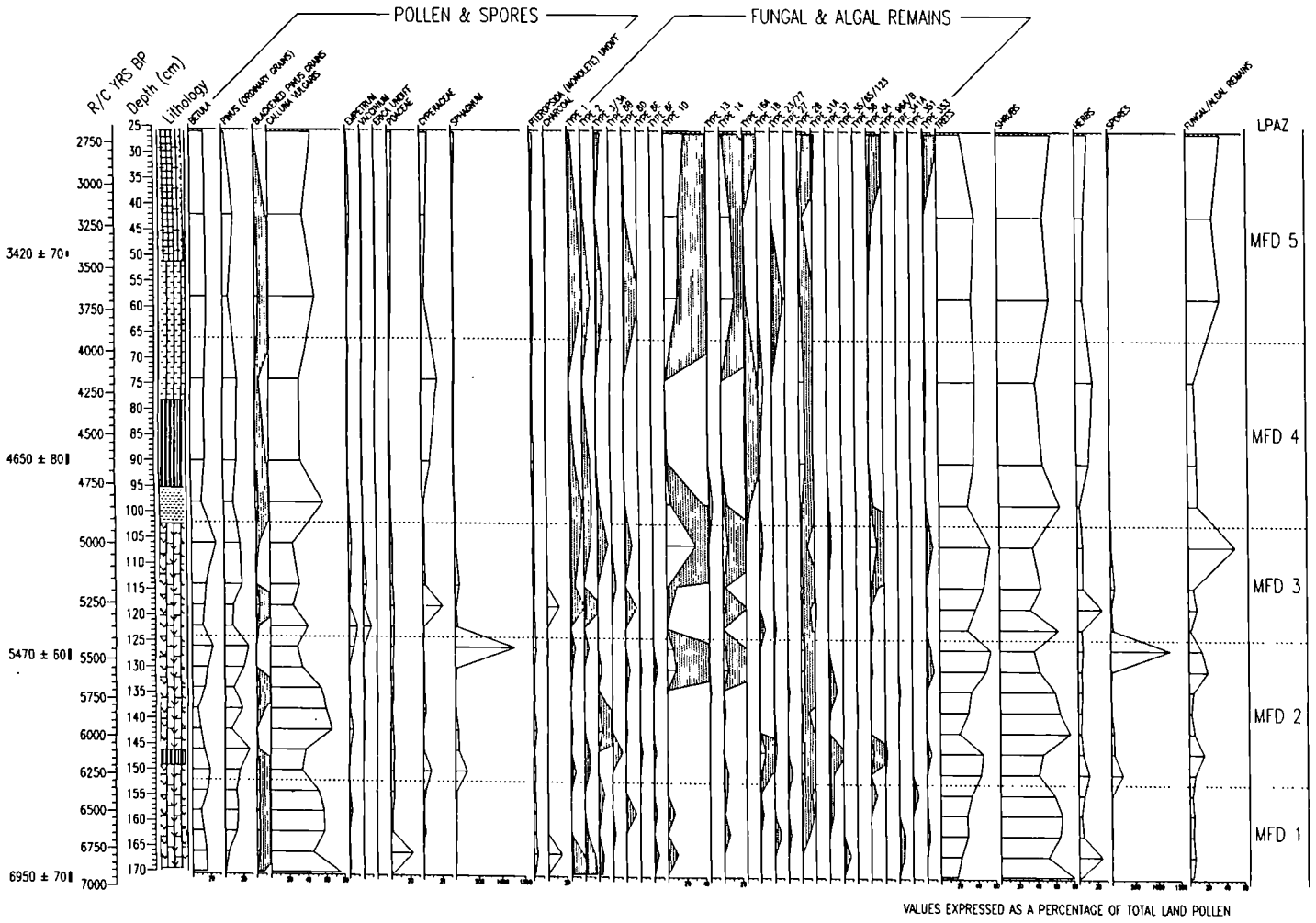


Figure 7.28
Profile MFD - Degree of humification (expressed as the inverse of percent transmission) and the frequency of blackened *Pinus* pollen grains (expressed as a percentage of total land pollen) plotted against depth (cm).

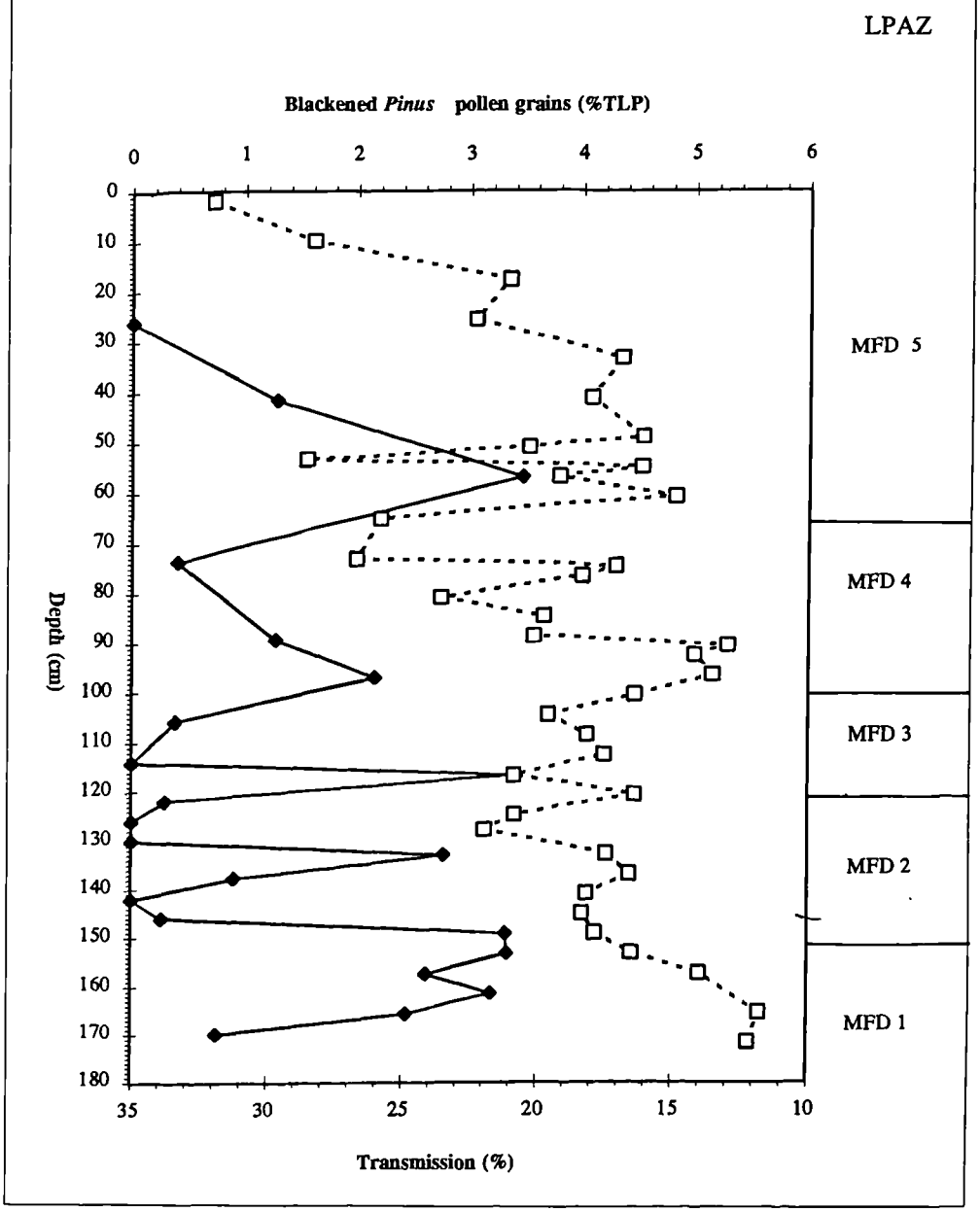
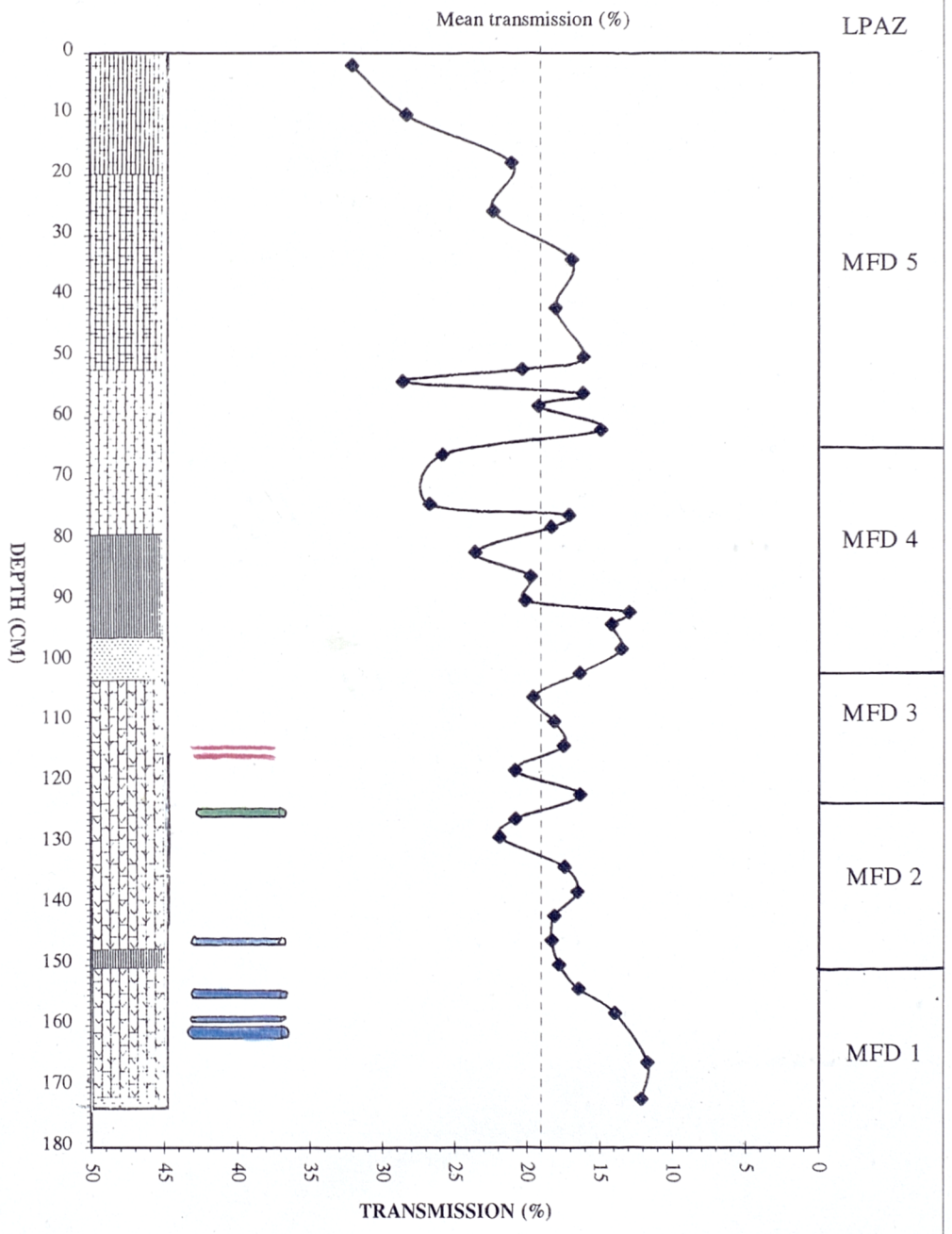


Figure 7.29.
Profile MFD - Degree of humification (expressed as the inverse of percent transmission) plotted against depth (cm). Macrofossils are represented (green = pine; blue = birch; red = Ericaceous)



woodland at lower altitudes) the pine trees may have been present as isolated trees.

The transmission values indicate a high degree of humification, particularly at the base of the zone, which is partly supported by the representation of dry-indicating fungal and algal remains.

7.3.4.2 LPAZ - MFD 2 (152-124cm) (*c.*6,290-5,390 BP)

Percentage pollen diagram

This zone is characterised by a higher frequency of *Pinus* pollen (28% at 146cm) and a low frequency of *Betula* pollen in the middle of the zone. The *Pinus* macrofossil at *c.*125cm (from within the sample column) confirms the local presence of pine at c.5,430 BP and corresponds with a *Pinus* pollen frequency of 26.5% at 126cm. However, the *Pinus* pollen frequency reaches 20% at 150cm which probably indicates the presence of pine at *c.*6,220 BP (see Section 7.5.1.1 for further discussion).

The peak in *Calluna vulgaris* pollen frequencies at 142cm (66%) corresponds with lower *Pinus* and *Betula* pollen frequencies and a rise in *Empetrum* pollen (4%). The subsequent decrease in *Calluna* pollen corresponds with the return to higher *Pinus* and *Betula* pollen frequencies and a peak in *Sphagnum* spores (*c.*1300% TLP). *Alnus* pollen frequencies rise to values consistently over 2% at 146cm (*c.*6,080 BP) (interpreted as indicative of a local, but sparse growth of alder, Huntley and Birks, 1983).

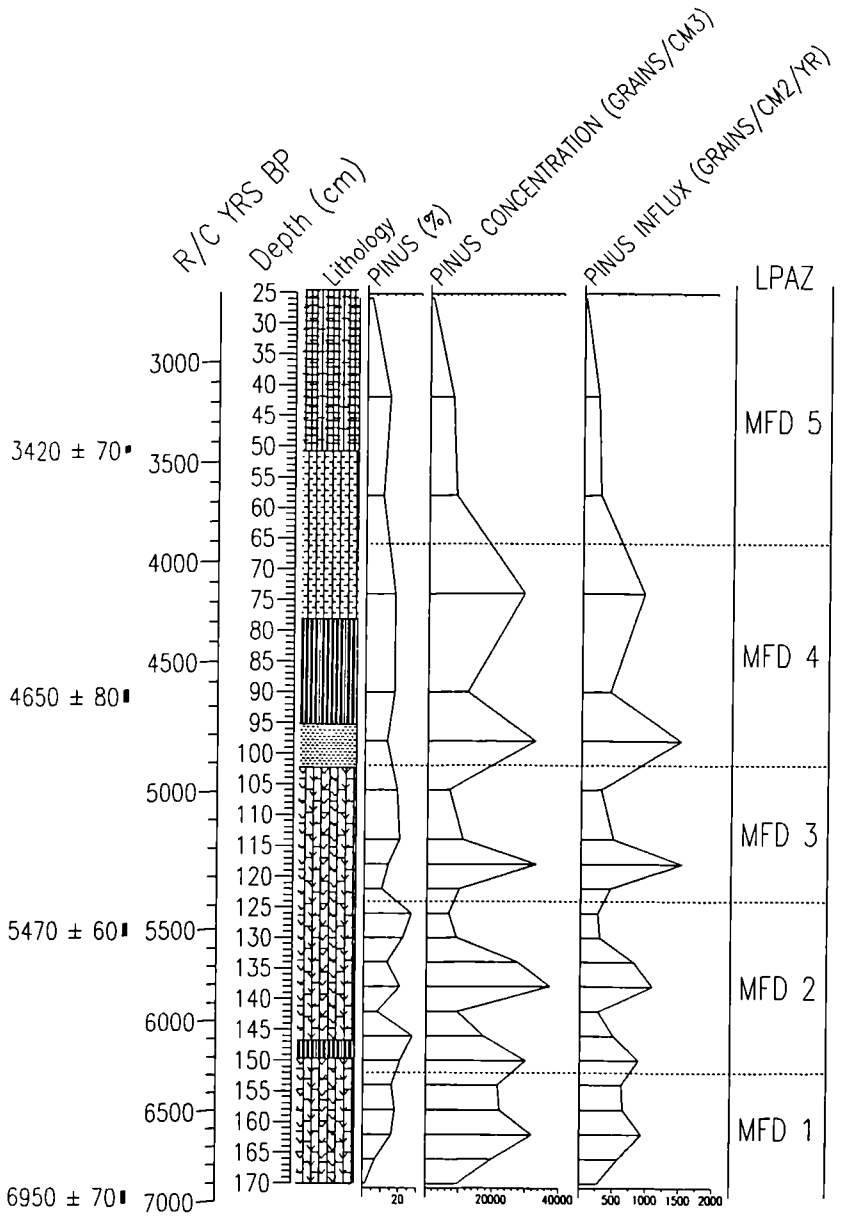
Pollen concentration and influx diagrams

There is a good correspondence between pollen concentration variations and the degree of humification in this zone (Figure 7.26). Consequently the lower *Pinus* pollen concentration and influx values at 126cm (which coincides with a relatively high *Pinus* pollen percentage) may be a reflection of the shift to a lower degree of humification at *c.*130cm (Figure 7.26 and 7.30).

Fungal and algal remains

The increase in Types 10 and 14 at the top of the zone corresponds with a decrease in *Calluna* pollen frequencies and a lower degree of humification (see below). This supports the observations of Van Geel (1978) and Blackford (1990) and in this investigation.

FIGURE 7.30
PINUS POLLEN DATA FOR SITE MFD (c.500m OD)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)



Type 28 is present at low frequencies in this zone and Type 18 (correlated with *Eriophorum vaginatum* peat, Van Geel, 1978) occurs just above the peak in Cyperaceae pollen frequencies.

The proportion of blackened *Pinus* grains corresponds well with the degree of humification in this zone (Figure 7.28).

Degree of humification

The single birch and pine macrofossils in this zone correspond with slight decreases in the degree of humification at 146cm and 125cm respectively.

Summary

The pollen evidence in this zone indicates a relatively dense pine woodland (pine colonisation at approximately 6,220 BP) with birch and an understorey of *Calluna vulgaris*. An opening of the pinewood canopy is represented at 142cm (*c.*5,950 BP) and is associated with an increase in the *Calluna* understorey and, to a lesser extent, the *Empetrum* cover. There is a general trend towards a less humified peat towards the top of the zone but this corresponds with an increase in fungal and algal remains indicative of relatively dry conditions (e.g. Types 10 and 14).

7.3.4.3 LPAZ - MFD 3 (124-102cm) (*c.*5,390-4,910 BP)

Percentage pollen diagram

This zone is characterised by decrease from the base of shrub pollen types and a gradual rise in the tree pollen types (reaching a maximum of 57%). The decrease in the representation of shrubs is largely a result of the lower *Calluna* frequencies. The higher tree pollen frequencies reflects the increase in *Betula* pollen (to 26% at the top of the zone) and an increase in *Pinus* pollen frequencies from 10% at the base of the zone to almost 20% at the top. The low representation of *Pinus* at the base of this zone corresponds with a rise of *Empetrum* and *Vaccinium* pollen frequencies.

The peak in herbaceous pollen types is largely a result in the rise in Cyperaceae pollen frequencies at 118cm.

Pollen concentration and influx diagrams

The peak in pollen concentration and influx rates at 118cm (*c.*260,000 grains cm^{-3} and *c.*11,000 grains cm^{-2} yr^{-1} respectively) corresponds to a small shift to a higher transmission value. The increase in pollen concentration/influx values may therefore represent a real increase in the pollen rain density at this time

(*c.*5,300 BP). However, the increase in pollen influx may also reflect the decrease in deposition time of the peat matrix in this zone (to *c.*22 yr cm^{-1} from *c.*34 yr cm^{-1} in the previous zone) since pollen influx is calculated by dividing the pollen concentration by the (interpolated) deposition time of the peat matrix (cf. Birks & Birks, 1980).

Fungal and algal remains

There is an increase in Types 10, 14 and 64 indicating drier conditions at the top of this zone. However, the increase in Type 64, an indicator of the local presence of *Empetrum,* does not correspond with the higher *Empetrum* pollen frequencies recorded for the base of the zone.

Degree of humification

The shift to drier conditions indicated by the fungal and algal data does not correspond with a significantly large shift to a higher degree of humification in this zone although the transmission values are generally less than the mean.

Summary

The pollen evidence in this zone indicates an open pine/birch woodland with an increase in the birch component towards the top of the zone. The increase in the proportion of birch corresponds with a reduction in the *Calluna* understorey. A slight shift towards drier conditions at the top of this zone is indicated by the humification data and corresponds with an increase of fungal/algal remains typical of drier conditions

7.3.4.4 LPAZ - MFD 4 (102-66cm) (*c.*4,910-3,910 BP)

Percentage pollen diagram

The three pollen spectra represented in this zone indicate a high proportion of *Calluna* pollen (58% at the base) and relatively low frequencies of *Betula* and *Pinus* pollen frequencies (below 16%). There is an increase in Cyperaceae pollen frequencies to 17% at 74cm.

Pollen concentration and influx diagrams

The relatively high pollen concentration and influx values at the base of this zone (*c.*260,000 grains cm^{-3} and *c.*12,000 grains cm^{-2} yr^{-1} respectively) correspond with a shift towards a higher degree of humification (Figure 7.26). This is reflected in the *Pinus* pollen data which show high concentration/influx values corresponding with a relatively low percentage values (*c.*12%) (Figure 7.30).

The peat accumulation rate decreases to 30.8 yr cm^{-1} at the top of the zone.

Fungal and algal remains

Few fungal or algal remains are recorded for this zone, the exception being the presence of Type 28 which corresponds with an increase in the Cyperaceae pollen frequencies.

Degree of humification

Relatively large fluctuations in the transmission values are recorded for this zone with a general trend to a lower degree of humification towards the top. The shift to a higher degree of humification at *c.*75-78cm corresponds with a change in lithology to from a sedge-rich peat to a dark brown detrital peat matrix.

<u>Summary</u>

The pollen evidence indicates an relatively open pine woodland with birch and an increase in the importance of the *Calluna* understorey. Cyperaceae pollen becomes more frequent towards the top of the zone, although this is not reflected in the lithology.

7.3.4.5 LPAZ - MFD 5 (66-26cm) (*c.*3,910-2,600 BP)

Percentage pollen diagram

The three pollen spectra represented in this zone indicate a high frequency of *Calluna* pollen and relatively low frequencies of *Pinus* (decreasing to 2% at 26cm). The *Betula* pollen frequency remains fairly constant (*c.*16%) but Cyperaceae pollen is less frequent in this zone. There are small increases in the taxa indicative of more open conditions towards the top of the zone, such as *Empetrum,* Poaceae, *Plantago* sp. and Pteropsida (monolete) indet..

Pollen concentration and influx diagrams

The pollen concentration and pollen influx values decrease in this zone to *c.*34,000 grains cm^{-3} and *c.*1,100 grains cm^{-2} yr^{-1} respectively. This trend is shown by most of the taxa with the exception of *Erica* spp., *Prunus padus* and *Plantago* sp. which show rises in concentration and influx values in the upper half of the zone. The *Pinus* pollen percentages and *Pinus* concentration and influx values all indicate a lower representation of pine at the base of this zone (before *c.*3,650 BP) (Figure 7.30).

Fungal and algal remains

Types 10 and 14 are represented at relatively high frequencies in this zone, indicating locally dry conditions and the presence of *Calluna vulgaris* (Van Geel, 1978). The evidence for a high degree of humification in this zone generally supports the evidence provided by the three fungal/algal spectra.

Similarly, the high proportion of blackened *Pinus* grains in this zone corresponds with a relatively high degree of humification in this zone (Figure 7.28).

Degree of humification

A high degree of humification is recorded for most of this zone apart from a sharp increase in transmission values at *c.*54cm. The general decline in the degree of humification towards and above the top of the pollen zone corresponds with the presence of *Sphagnum* leaves in the peat matrix at 30cm.

Summary

The pollen evidence for this zone indicates an open *Calluna* heath with occasional birch trees and open habitat herbs. The evidence for a high degree of humification of the peat matrix for much of this zone is supplemented by fungal and algal remains indicative of relatively dry conditions.

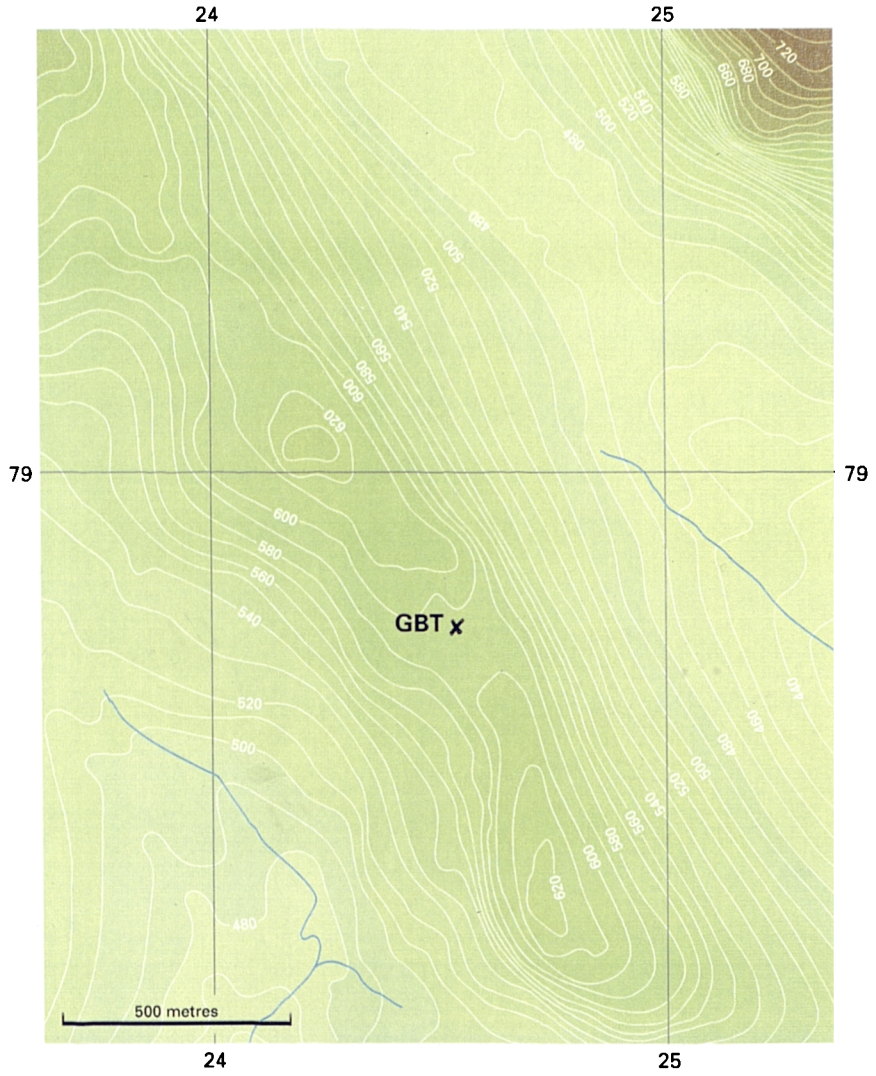


Figure 7.31: Beinn Dearg – location of sample site GBT (Grouse Butt) c.600m OD

7.4 GROUSE BUTT - SITE CODE : GBT (c.600m OD) (NGR: NH 245787)

7.4.1 SITE DESCRIPTION

This site was selected as the highest site for the Beinn Dearg transect, principally because of the deep peat profiles exposed in the erosion gulleys and, as for MFD (*c.*500m OD), since it is located in a col and is therefore a watershedding site, the humification signal is potentially more sensitive to climatic change (Chambers, 1984).

The area is heavily eroded and numerous deep peat hags were exposed. No pine stumps were located around the immediate area of this site (the upper limit identified during the reconnaissance survey of the Beinn Dearg region being *c.*490m) but occasional small birch macrofossils were identified interstratified and at the base of the peat profiles. The site area receives drainage from the higher slopes to northwest and southeast and drainage away from the site is to the southwest and northeast (Figure 7.31).

Following a preliminary survey of the area, and confirmation using a narrow gouge auger, the deepest accumulation of peat identified was approximately 2m deep. Subsequent systematic probing of the immediate area, on a 5m grid system, was undertaken to identify the deepest point. A section was excavated into an adjacent existing erosion gulley to produce a profile approximately 1m wide and 2m deep.

No large macrofossils were identified in the excavated profile, and the base of the section was wet and friable making the sampling of the basal peat difficult. This may be a result of water movement along the mineral base. The selected profile was sampled using two monolith tins from approximately 10cm above the mineral base to approximately 20cm below the current vegetated surface.

The current dominant vegetation at the site is *Vaccinium* spp., *Calluna vulgaris* (not flowering), *Empetrum nigrum,* grasses/sedges, *Eriophorum* and occasional *Betula nana.*

7.3.2 LITHOSTRATIGRAPHY

The following stratigraphy was recorded from the sampled column recovered from the monolith tins:

DATUM (0) = TOP OF UPPER MONOLITH TIN

0-24cm Dark brown, *Eriophorum* peat. H5; n2-3; Th4.

24-33cm Medium brown, *Eriophorum* peat. H4; n2; Th4.

33-61cm Dark brown detrital peat, no distinct plant remains. H7; n3; Sh4.

61-82cm Dark brown, *Eriophorum*-rich peat with *Sphagnum.* H6; n3; Th3; Tb1.

82-105cm Medium dark brown, *Sphagnum*-rich peat with *Eriophorum.* H5; n2-3; Tb3; Th1.

105-115cm Very dark brown, detrital peat with *Eriophorum* present. H6; n4; Sh3; Th1.

115-123cm Dark brown, *Eriophorum*-rich peat with Ericaceous stem fragments. Ericaceous twigs at 119-120 cm (5cm long), 117cm (2cm long) and 115cm (4cm long).
H5; n3; Th3; Tl1.

123-153cm Very dark brown, homogeneous peat with occasional *Eriophorum* remains. H7; n3-4; Sh3; Th1.

153-171cm Very dark brown to black, homogeneous peat. Occasional very small degraded twigs, e.g. 161-163cm (not identified). H8; n4; Sh3; Tl 1.

7.4.3 RADIOCARBON MEASUREMENTS

Four samples were submitted for radiocarbon analysis to Beta Analytic from profile GBT. The sampling strategy adopted is the same as for the other sites investigated at Beinn Dearg, that is at approximately 40cm depth intervals from 50cm down to the base of the profile. The radiocarbon measurements (and the quoted errors representing 1 standard deviation statistics) are shown plotted in Figure 7.32 together with the calculated sediment accumulation rates and the calibrated ages. Table 7.1 shows the laboratory details for the radiocarbon samples and the calibration ages.

A relatively slow peat deposition time of 67 yrs cm^{-1} is estimated between *c.*4,320 BP and *c.*1,640 BP compared with the preceding estimated rate of 17.0 yrs cm^{-1} and subsequent rate of 16.1yrs cm^{-1} . The pollen-stratigraphic and lithostratigraphic evidence indicate there may be a hiatus represented at *c.*125cm which might provide an explanation for the relatively slow deposition time estimated between *c.*128cm and *c.*90cm (67 yrs cm^{-1}). The implications of this will be discussed below (Section 7.4.4.3 and 7.4.4.4).

7.4.4 LOCAL POLLEN ASSEMBLAGE ZONES

7.4.4.1 LPAZ - GBT 1 (171-154cm) (*c.* 5,015-4,730 BP)

Percentage pollen diagram **(Figure 7.33).**

The high frequencies of shrubs (up to 72%) which characterise this zone largely reflect the high values for *Calluna vulgaris* pollen which rise to 63% at the top of the zone.

The most frequent tree pollen type is *Betula* which reaches a small peak of 18% in the middle of the zone but *Pinus* pollen frequencies are below 10% throughout this zone. Poaceae pollen frequencies are relatively high reaching a maximum of 13%

Figure 7.32.
GBT - Radiocarbon measurements (uncalibrated and calibrated) and interpolated peat accumulation rates (expressed in years per cm) plotted against depth (cm)

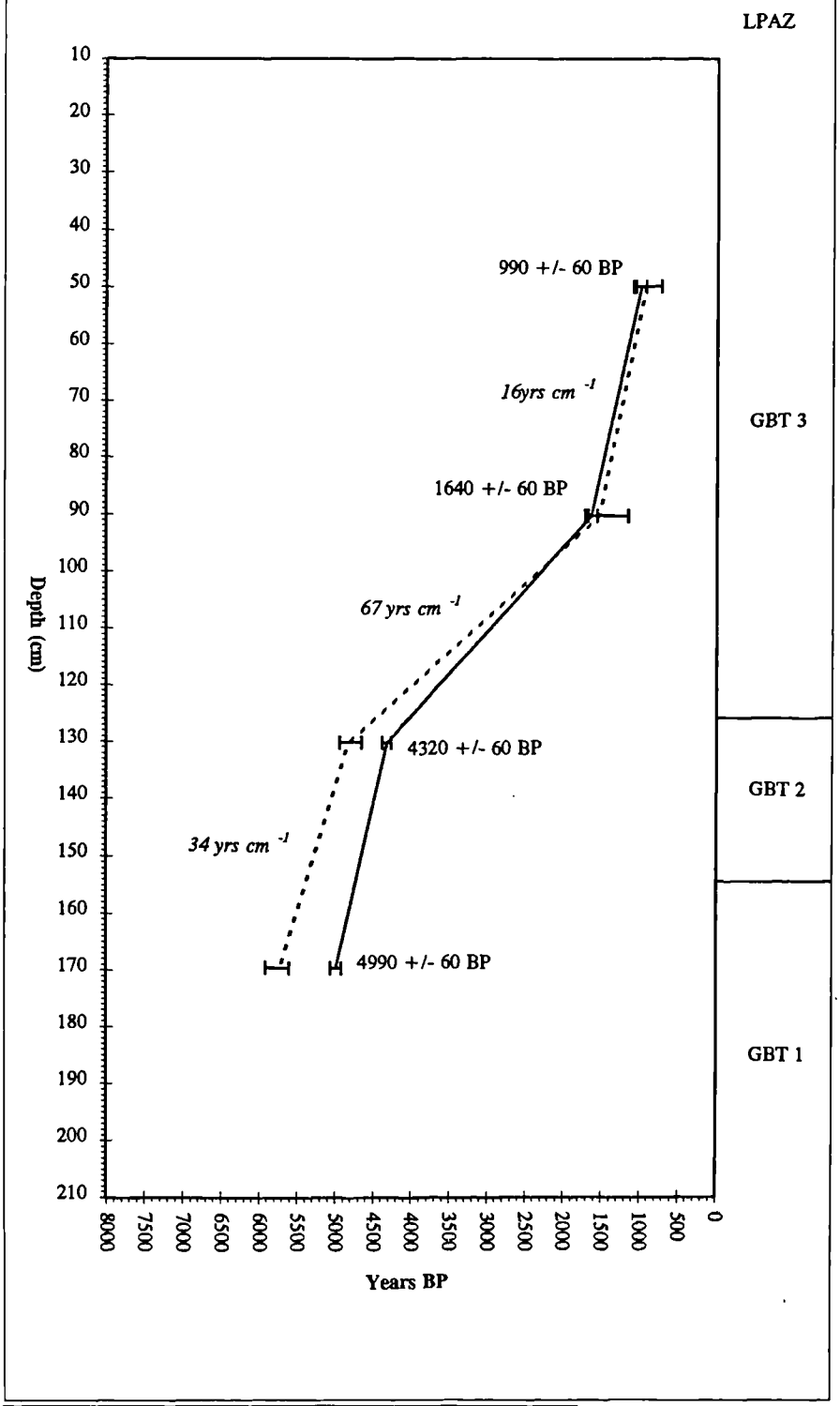
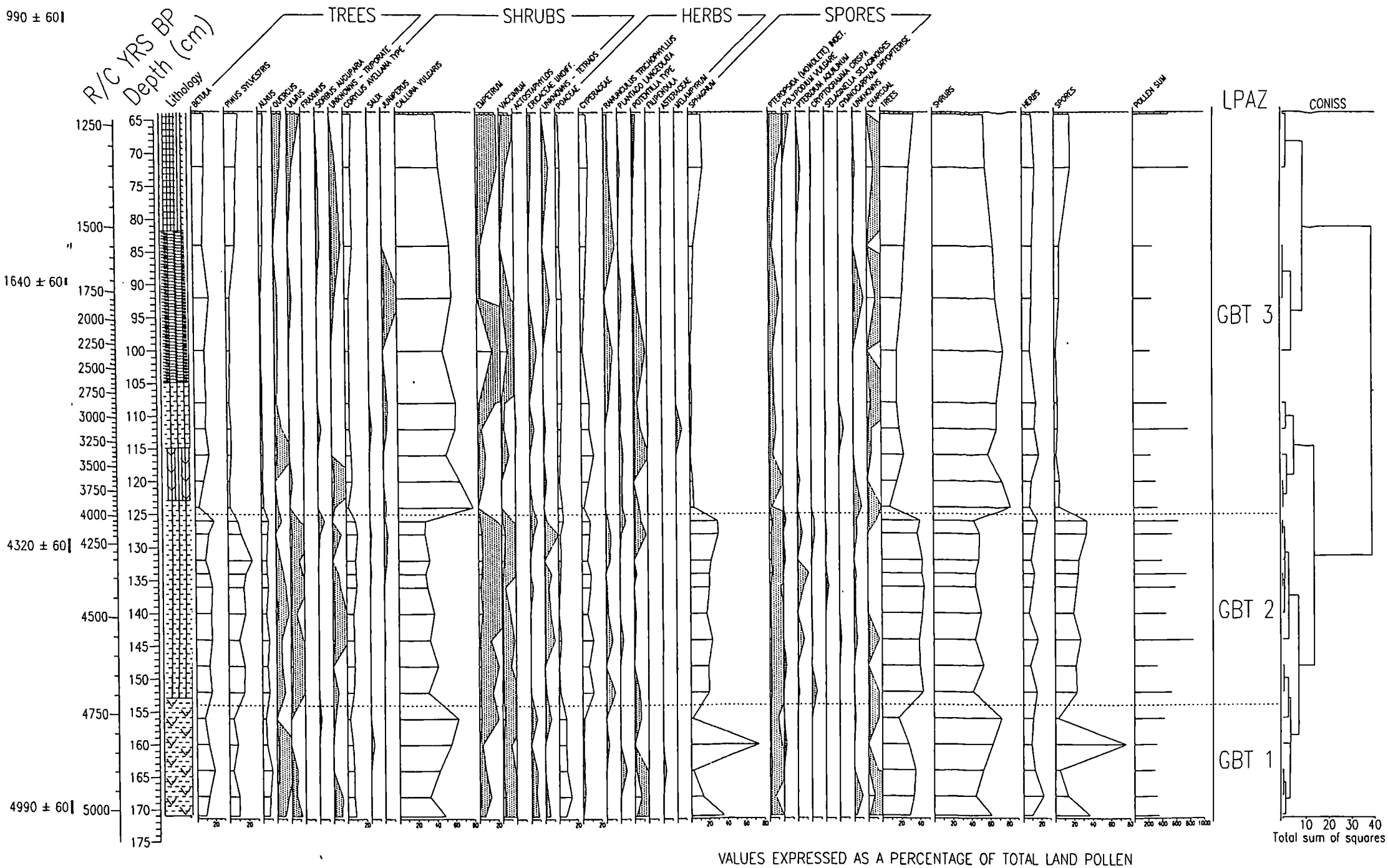


FIGURE 7.33
PERCENTAGE POLLEN AND SPORE DIAGRAM FOR SITE GBT (c.600m OD)

STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)
SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TAXA



VALUES EXPRESSED AS A PERCENTAGE OF TOTAL LAND POLLEN

at 168cm and there is a small peak in *Potentilla* type at 168cm. *Sphagnum* spores reach almost 80% (of TLP) at 160cm but this does not correspond with a *Sphagnum*-rich peat matrix.

Pollen concentration and influx diagrams **(Figures 7.34 and 7.35)**

There does not appear to be a good correspondence between the pollen concentration and degree of humification in the profile from GBT (Figure 7.36). Correspondence analysis performed on the two sets of data resulted in a score of zero.

Pollen concentration and pollen accumulation rates decrease towards the middle of the zone from maximum values at 171cm of *c.*720,000 grains cm^{-3} and *c.*43,000 grains cm^{-2} yr^{-1} respectively. The maximum values may be enhanced by the high degree of humification at the base of the zone (Figure 7.37).

The very fast rate of peat accumulation of 17 yrs cm^{-1} in this zone is likely to strongly reflect the close radiocarbon age ranges of the two dates located at 130cm and 170cm (*c.*4,320 +/- 60BP and 4,990 +/- 60 BP respectively).

Fungal and algal remains **(Figure 7.38)**

Few fungal or algal types are represented in this zone, but Type 1 and Type 13 are represented at low frequencies at 164cm. Van Geel (1972, 1980/81) observed that Type 1 is restricted to highly decomposed peat but the significance of Type 13 is not conclusive (Van Geel, 1978).

Degree of humification **(Figure 7.37)**

The basal peat at this site is highly humified (*c.*6% transmission) with a subsequent trend to a less humified peat matrix towards the top of the zone. This trend supports the evidence of fungal and algal remains which indicate relatively dry conditions (see above). The lowermost peat in this profile showed evidence of erosion by the movement of water along the minerogenic substrate; this may have caused post-depositional aeration of the basal peat and hence an increase in the degree of humification.

FIGURE 7.34 POLLEN CONCENTRATION DIAGRAM FOR SITE GBT (c.600m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

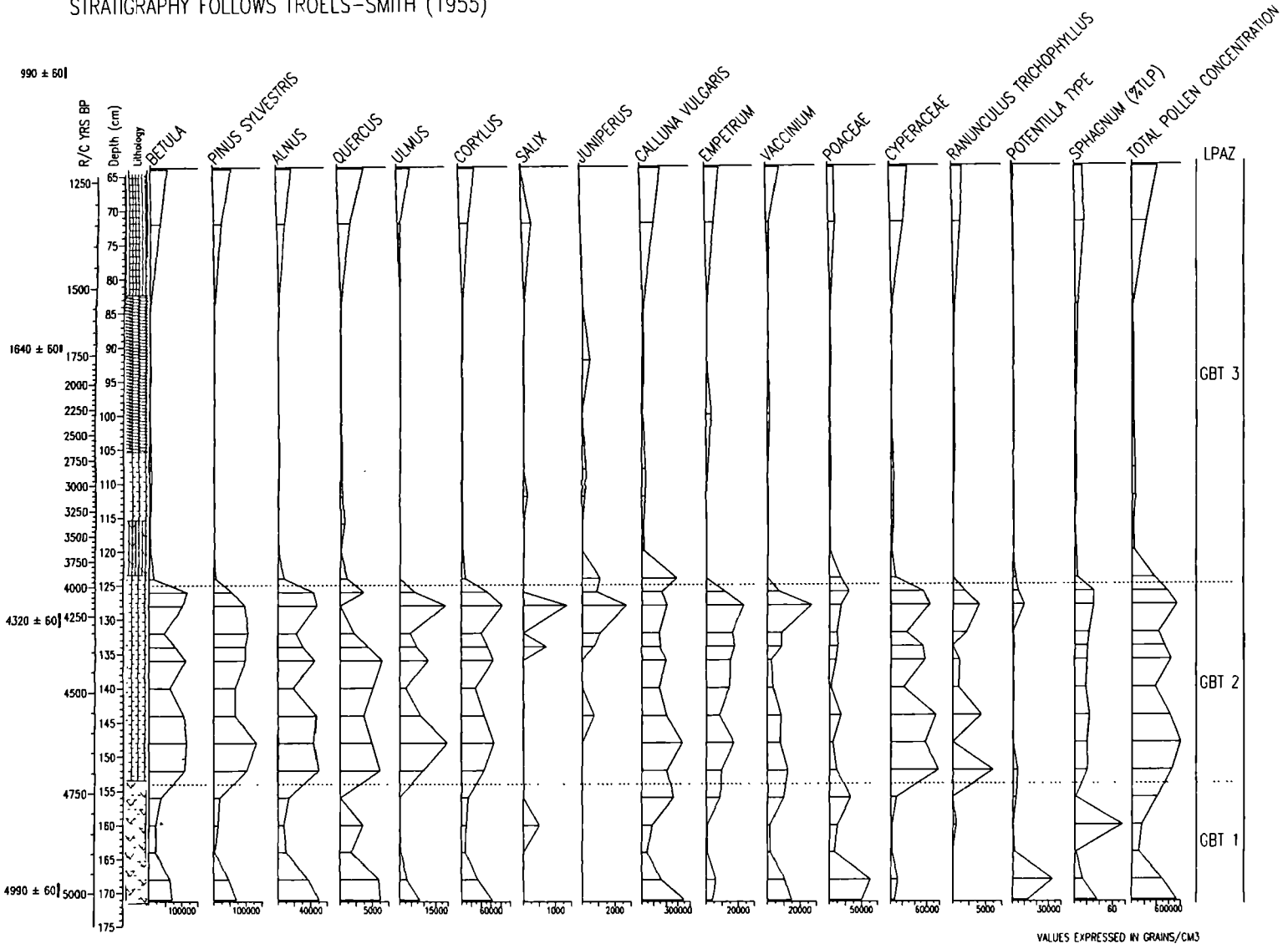


FIGURE 7.35 POLLEN INFLUX DIAGRAM FOR SITE GBT (c.600m OD)
(SELECTED TAXA ONLY)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

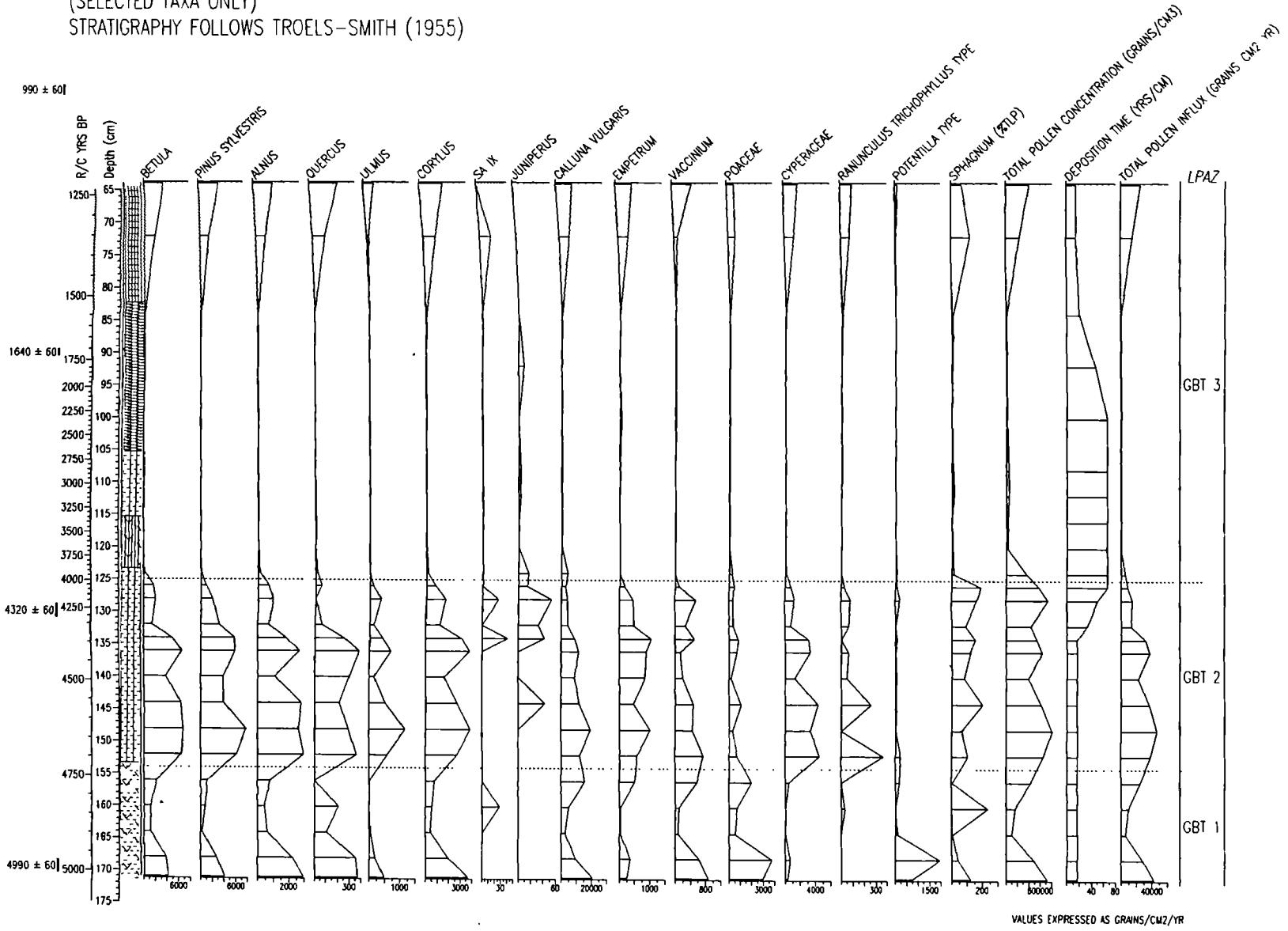
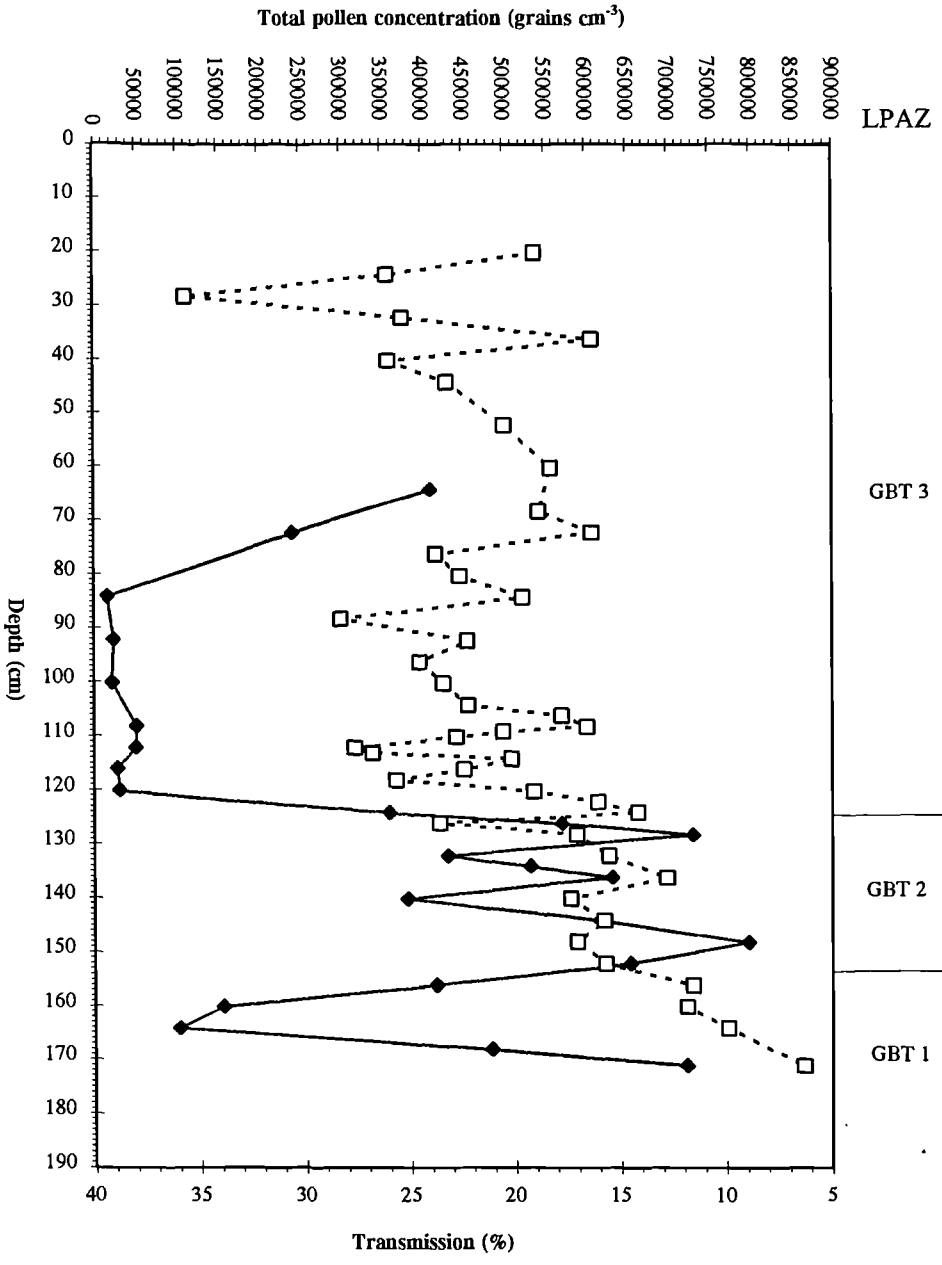


Figure 7.36.
Profile GBT - Degree of humification (expressed as the inverse of percent transmission) and total pollen concentration (expressed as grains cm^{-3}) plotted against depth (cm).



Pollen concentration (grains cm^{-3})
Transmission (%)

Figure 7.37.
Profile GBT - Degree of humification (expressed as the inverse of percent transmission) plotted against depth (cm). Macrofossils are represented (green = pine; blue = birch; red = Ericaceous)

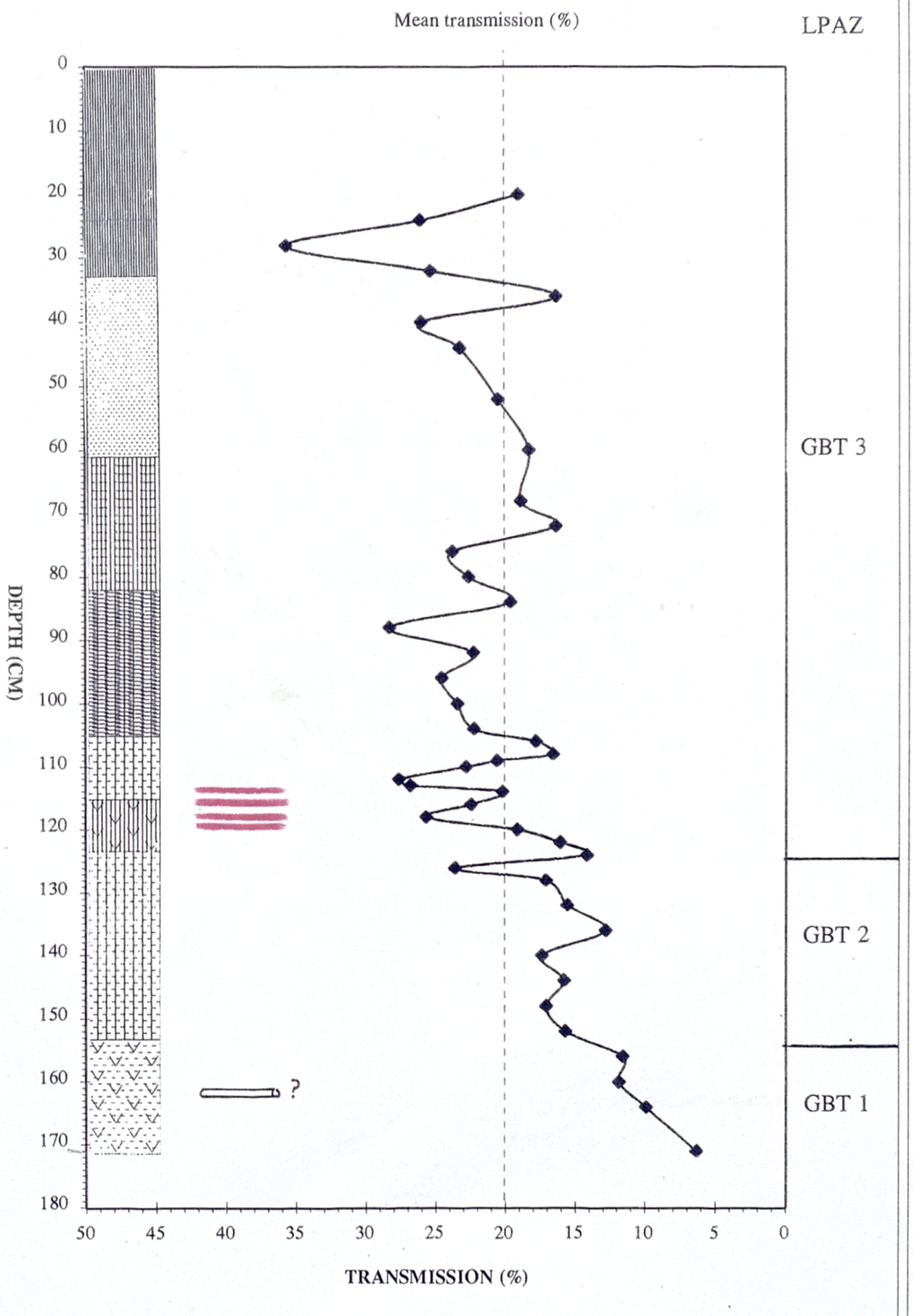
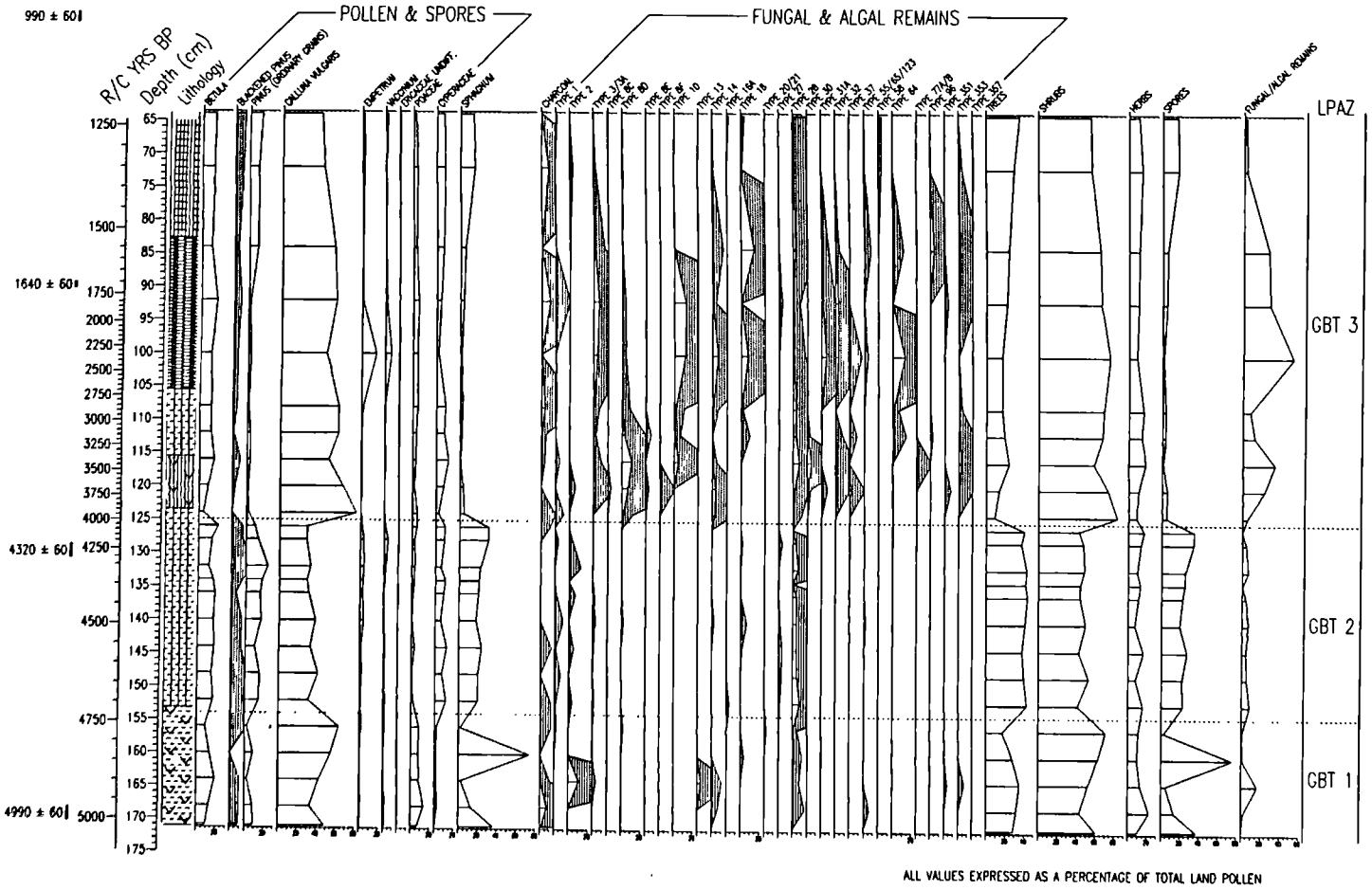


FIGURE 7.38 FUNGAL AND ALGAL REMAINS DIAGRAM FOR SITE GBT (c.600m OD)
(WITH SELECTED POLLEN AND SPORES)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)
SHADING REPRESENTS AN EXAGGERATION OF X10 FOR MINOR TAXA AND TYPES



Summary

The pollen evidence indicates that this zone represents a *Calluna* dominated heath with grasses and possibly isolated stands of birch. The relatively high degree of humification of the peat matrix is only partially supported by the fungal and algal remains evidence.

7.4.4.2 LPAZ - GBT2 (154-125cm) (*c.*4,730-4,000 BP)

Percentage pollen diagram

This zone is characterised by a reduction in the representation of the shrub pollen types (*c.*45%) and an increase in tree pollen types (to over 40%).

The *Pinus* pollen frequencies are relatively high in this zone, reaching a maximum of 25% at 132cm which corresponds with slightly lower *Betula* pollen frequencies. Although there is no macrofossil evidence for the presence of pine at this site the rise in the pine pollen frequencies indicate pine did reach this site during this period.

The major feature of the shrub pollen types is the decrease in *Calluna vulgaris* pollen frequencies to a minimum of 29% at the top of the zone. *Empetrum* pollen frequencies show a small rise between *c.*140cm and 125cm.

The proportion of Cyperaceae pollen rises in this zone to an average of approximately 10%.

Pollen concentration and influx diagrams

This zone is characterised by relatively high pollen concentration and influx values, rising to *c.*800,000 grains cm^{-3} and *c.*39,000 grains $cm^{-2}\ yr^{-1}$ respectively at 148cm. Pollen concentration and humification values do not appear to be strongly related (Figure 7.36) but the decrease of the influx values towards the top of the zone corresponds to an increase in the deposition time (or decrease in the peat accumulation rate) from 17.0 to 67.0 yr cm^{-1}. As suggested for MFD 3 (Section 7.3.4.3) the decrease in influx values may therefore reflect the change in the rate of peat accumulation (and therefore may also be a reflection of the radiocarbon age estimates and/or the possibility of a hiatus in the stratigraphy proposed at *c.*125 cm).

Maximum values for pollen concentration and influx values are found for most taxa in this zone with the exception of Poaceae which shows a decrease in values (as

indicated by the percentage pollen diagram). *Calluna vulgaris* and *Pinus sylvestris* show the highest pollen concentration values (*c.*329,000 grains cm^{-3} and *c.*133,000 grains cm^{-3} respectively) despite the decrease in the relative frequency of the former.

The *Pinus* pollen data (percentage, concentration and influx values) are shown on an age depth axis in Figure 7.39. There is strong pollen evidence for the local presence of pine at 132cm (*c.*4,350 BP) and the concentration/influx data indicates an additional phase of local pine growth between 148cm and 152cm (*c.*4,650 BP). The *Pinus* pollen data also show a marked decline in the representation of *Pinus* pollen at the top of this zone.

Fungal and algal remains

Very few fungal and algal remains are represented in this zone, with the exception of Type 28 which corresponds to a rise in Cyperaceae pollen frequencies.

Although blackened *Pinus* pollen grains were recorded for this site there does not appear to be a strong positive relationship with the degree of humification (Figure 7.40). This may be related to the relatively low frequencies of *Pinus* grains represented and the generally low degree of peat humification in this profile (the GBT profiles has the highest mean transmission value for the Beinn Dearg transect of 20%).

Degree of humification

With the exception of the uppermost measurement, the transmission values in this zone signify a higher than average degree of humification.

<u>Summary</u>

The pollen evidence suggests that this zone represents a relatively open pine/birch woodland with an understorey dominated by *Calluna* but with some *Empetrum* an *Vaccinium* stands. Although the relative pollen data indicates a reduced *Calluna* cover during this zone, the pollen concentration and influx data indicates that *Calluna* remains an important component of the understorey.

The transmission values indicate a relatively well humified peat in this zone and the relatively low representation of fungal and algal remains may be related to this high degree of humification (poorly preserved).

FIGURE 7.39
PINUS POLLEN DATA FOR SITE GBT (c.600m OD)
STRATIGRAPHY FOLLOWS TROELS-SMITH (1955)

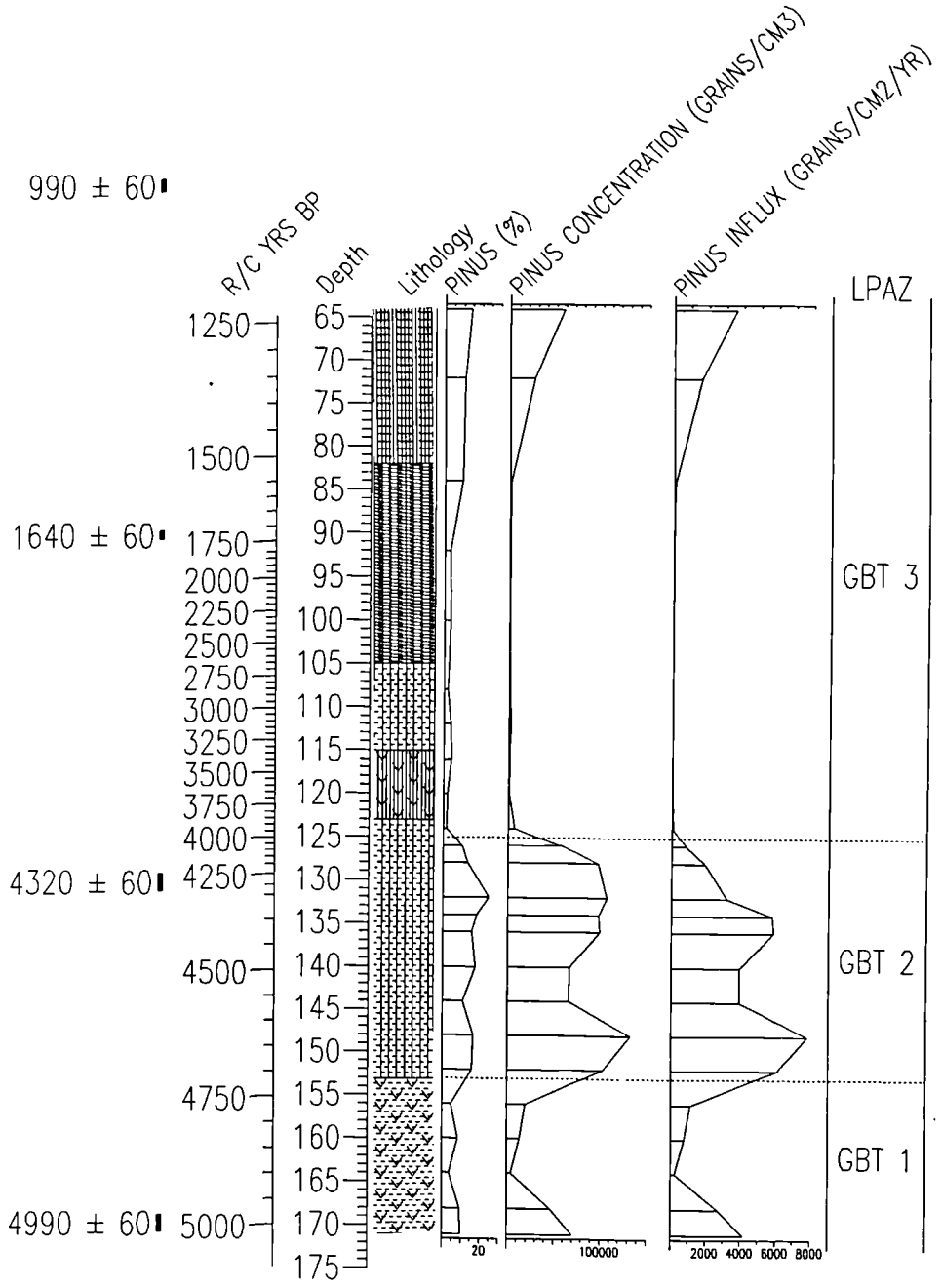
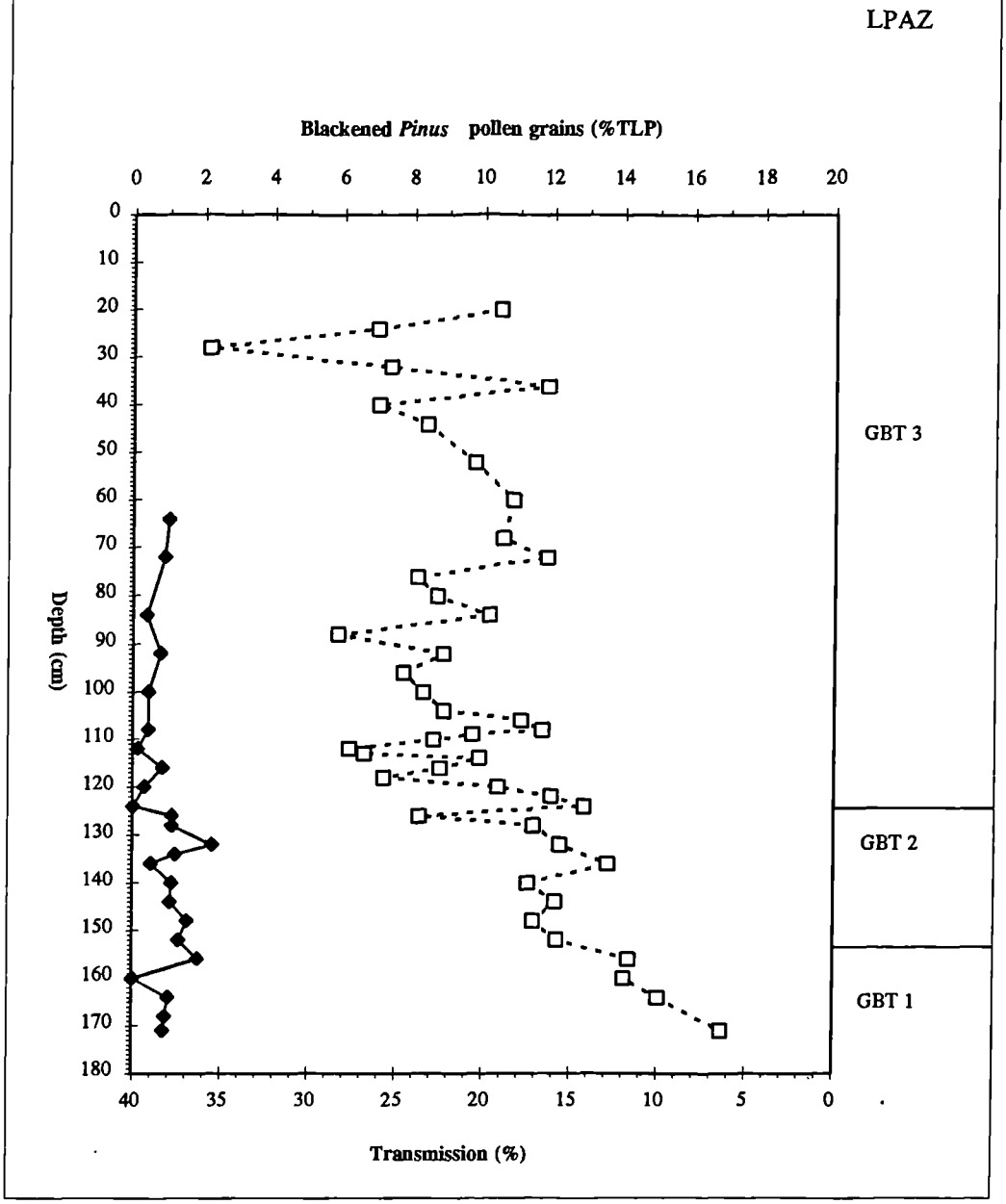


Figure 7.40.
Profile GBT - Degree of humification (expressed as the inverse of percent transmission) and the frequency of blackened *Pinus* pollen grains (expressed as a percentage of total land pollen) plotted against depth (cm).



As with the highest site at Gleann Einich (MNM), since no pine macrofossils were located at GBT there is no direct and conclusive evidence for the establishment of pine at GBT. *Pinus* pollen reaches 25% at 132cm (*c.*4,350 BP) and since the *Calluna* pollen values remain relatively high throughout this profile, the *Pinus* pollen is probably not over-represented (as at the highest site investigated at Gleann Einich, MNM). Therefore, it is concluded that pine did reach this high altitude site, at least at *c.*4,350 BP, but was probably present as isolated stands or trees from the time represented at the base of this zone (*c.*4,690 BP).

7.4.4.3 LPAZ - GBT 3 (125-64cm) (*c.*4,000-1,220 BP)

Percentage pollen diagram

This zone is characterised by a decrease in the proportion of tree pollen types and a corresponding increase in shrub pollen frequencies (to 82%). *Betula, Pinus* and *Alnus* pollen frequencies decrease and *Calluna vulgaris* pollen frequencies show a sharp rise to 80% at the base of the zone. The proportion of *Sphagnum* spores falls to 4% (%TLP) despite the rise in *Sphagnum* leaves in the peat matrix (*c.*75% at 90cm). There is a small rise in *Empetrum* and *Vaccinium* pollen frequencies at 100cm and Poaceae pollen is present in low frequencies throughout the zone.

Pollen concentration and influx diagrams

The decrease in pollen concentration and influx values at the base of this zone (to *c.*30,000 grains cm^{-3} and *c.*450 grains cm^{-2} yr^{-1} respectively) corresponds with a change in lithology to an *Eriophorum* and *Sphagnum*-rich peat matrix.

However, the decrease in pollen concentration and influx values coincides with a lower accumulation rate of the peat (deposition time = 67 yr cm^{-1} which was discussed in Section 7.4.4.2) but also with a change in lithology to a fresher *Sphagnum*-rich peat. The decrease in pollen concentration values could therefore be explained by one or more of the following:

i) A real decrease in pollen influx to the site
ii) An anomalous radiocarbon date, probably the 1640 BP date
iii) A hiatus in the stratigraphy

The subsequent lower deposition time of 16.1 yr cm^{-1} between *c.*95cm to 80cm corresponds to a decrease in the proportion of *Sphagnum* leaves in the peat and a trend towards a more humified peat (see below).

The *Pinus* pollen percentage, concentration and influx values (Figure 7.39) all indicate a decline in the representation of pine at the base of this zone (*c.*4,000 BP).

Fungal and algal remains

This zone is characterised by an increase in the variety and frequency of fungal and algal remains.

Between 120cm and 112cm types indicative of relatively wet conditions are present at high frequencies (e.g. Type 8d, possibly associated with *Eriophorum vaginatum,* Van Geel, 1972 and Type 28, associated with higher Cyperaceae pollen frequencies in this study). These wetter indicators correspond with a generally lower degree of humification (see below) and a sedge-rich peat matrix.

At *c.*100cm there is an increase in Types 3/3a, 10, 14 and 64 (indicating drier conditions, Van Geel, 1972, 1978) but there is a corresponding rise in Types 31a and 32 which are indicative of wetter conditions (Van Geel, 1972, 1978, 1980/81) and Type 18 which Van Geel correlated with *Eriophorum vaginatum* (Van Geel, 1978).

The rise in Type 18 frequencies coincides with the increase in *Eriophorum* remains in the peat matrix but paradoxically with very low Cyperaceae pollen frequencies (at 100cm). The transmission values indicate a relatively low degree of humification which contrasts with the rise in the frequencies of Types 3/3a, 10, 14 and 64. However, the peak in Type 64 at 100cm coincides with the peak in *Empetrum* pollen frequencies and therefore supports the association proposed by Van Geel (e.g. 1978) and indicates the local growth of *Empetrum* in a *Sphagnum*-rich environment (as shown by the high proportion of *Sphagnum* leaves in the peat matrix).

The frequency of blackened *Pinus* grains in this zone shows evidence of exhibiting an inverse relationship with the degree of humification, which is in contrast to the relationship observed at the other sites. The blackened *Pinus* grains represented at GBT appear to corresponds more closely with the *Calluna* pollen frequencies (Figure 7.40).

Degree of humification

There are large fluctuations in the transmission values represented in this zone but there is a trend to a lower degree of humification (between *c.*105 and 75cm) which

is associated with the *Sphagnum* and *Eriophorum*-rich peat matrix. The location of the macrofossils (unidentified) between *c.*115-20cm corresponds with a low degree of humification.

The relationship between the degree of humification and the fungal and algal types is not a simple one. The presence of Types 8D and 28 between 120cm and 112cm corresponds with a generally lower degree of humification and a sedge-rich peat matrix. However, types indicative of relatively dry conditions at *c.*100cm are recorded together with types indicative of wetter conditions in a less humified, *Sphagnum*-rich peat matrix.

Summary

The pollen evidence in this zone indicates a *Calluna*-dominated heathland possibly with occasional isolated birch trees. The pollen-stratigraphic data at the top of the zone shows evidence for a return to higher *Pinus* pollen frequencies which may represent a regional increase of pine at lower altitudes.

Fungal and algal remains indicative of both wet and dry conditions are recorded in the less humified, *Sphagnum*-rich peat between *c.*105 and 80cm. Above *c.*70cm there is a general trend towards a less humified peat above.

The marked change in lithology, pollen-stratigraphy and the Types of fungal and algal remains at the base of this zone suggests that the boundary between GBT2 and GBT1 may represent a hiatus in the stratigraphy. This interpretation is supported by the analysis of the radiocarbon age estimates (Figure 7.32) which demonstrates the non-linear relationship between the radiocarbon dates and depth. The hiatus may represent a temporary cessation of peat accumulation at *c.*4,000 BP or erosion of an unknown quantity of peat represented above 125cm.

7.5 SUMMARY OF BEINN DEARG RESULTS

The results from the analyses of the Beinn Dearg sites will be discussed under the same sub-headings used for the Gleann Einich results (see Section 6.5). A comparison of the results from both study areas will be discussed in Chapter 8.

7.5.1 POLLEN-STRATIGRAPHIC EVIDENCE

Figure 7.41 presents a schematic summary of the local pollen assemblage zones as described for Beinn Dearg, plotted on a temporal scale (radiocarbon years BP). The pollen-stratigraphic evidence will be discussed with particular reference to the history of pine in the region. The pollen stratigraphic evidence at the base of the lower three sites indicate the local presence of *Calluna* heath. Therefore the inception of peat accumulation at all the sites investigated at Beinn Dearg pre-dates the local colonisation of pine.

7.5.1.1 THE COLONISATION OF PINE AT BEINN DEARG

Figure 7.42 shows the pine pollen frequencies (%TLP) for each site at Beinn Dearg plotted on temporal scales (radiocarbon years BP). As with the interpretation of the sites at Gleann Einich, in the absence of radiocarbon dated pine macrofossils, an assessment of the presence or absence of pine at a particular time is based on the pollen-stratigraphic evidence. Pine macrofossils confirm that pine was present at a site at some time in the past, but whether these are contemporaneous with peaks in pine pollen percentages needs to be tested by direct dating of both.

Only one pine macrofossil was identified from within the sampled columns of the sites investigated at Beinn Dearg, which was from the profile at MFD (*c.*500m OD). The corresponding pine pollen frequency adjacent to this macrofossil is 26.5% (TLP) but again, without the aid of direct radiocarbon dating, contemporaneity of the macro- and microfossil evidence cannot be confirmed.

Since the average pine pollen frequencies for each of the sites at Beinn Dearg are less than those from the sites investigated at Gleann Einich, it is likely that a lower threshold figure than that adopted for the Gleann Einich data (30% TLP) would be appropriate as an indication of the presence/absence of pine.

A comparison of the relative timing of the colonisation of pine using two different semi-arbitrary threshold frequencies (15% and 20% total land pollen) is given below.

FIGURE 7.41. SUMMARY OF LOCAL POLLEN ASSEMBLAGE ZONES FOR THE SITES INVESTIGATED AT BEINN DEARG (RADIOCARBON YEARS BP)

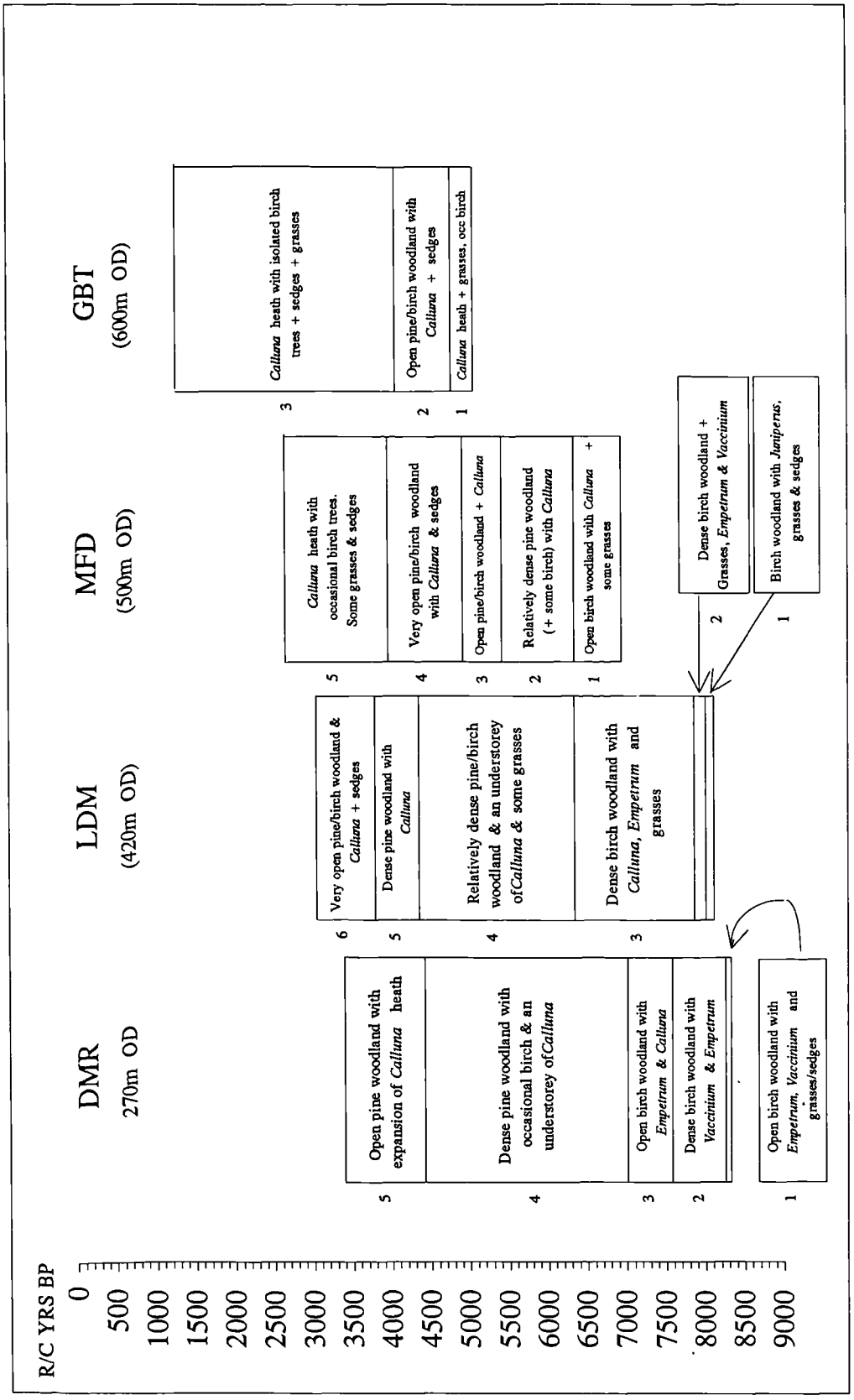


FIGURE 7.42. *PINUS* POLLEN FREQUENCIES FOR SITES INVESTIGATED AT BEINN DEARG PLOTTED ON AGE AXES (RADIOCARBON YEARS BP)

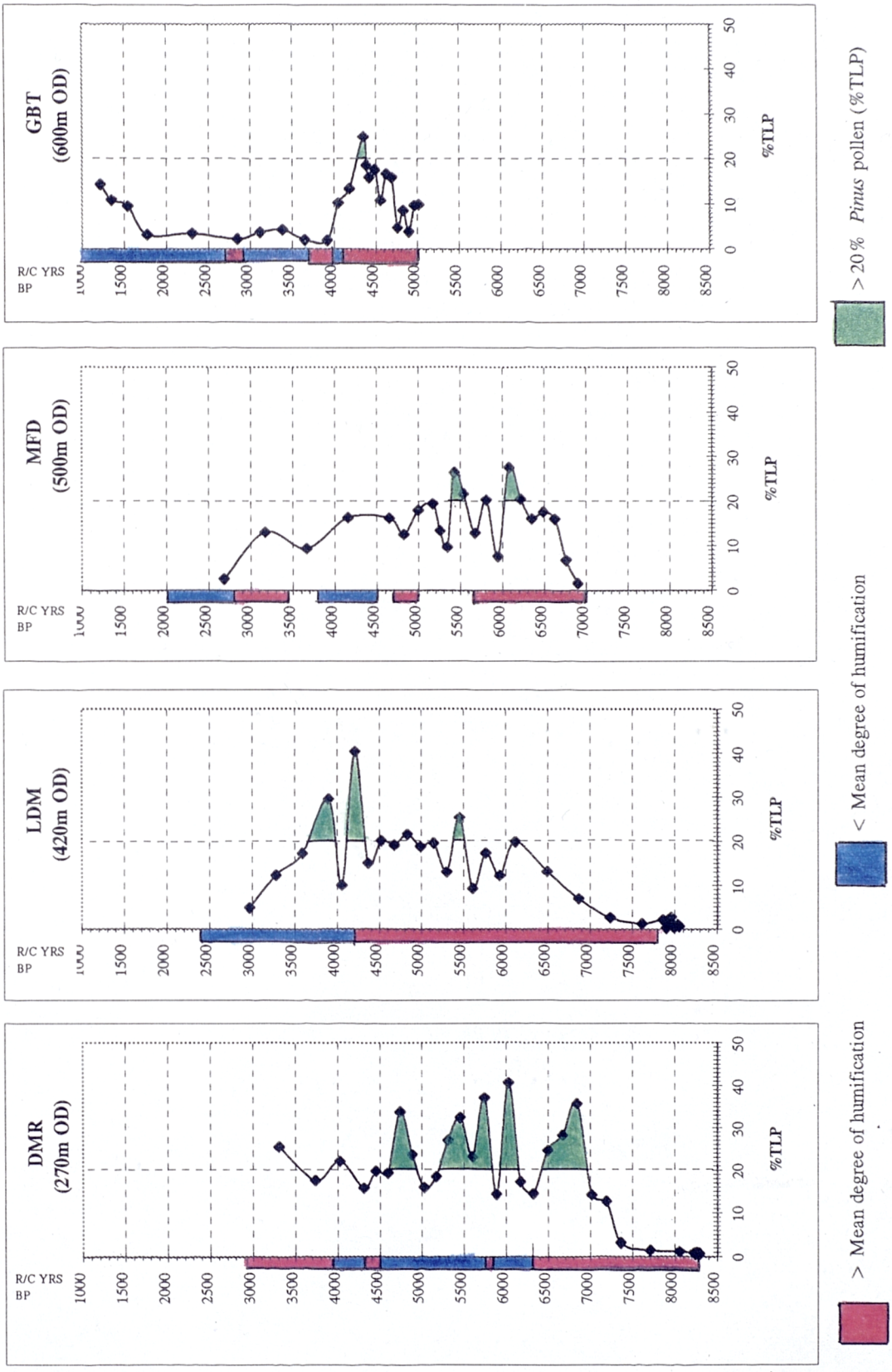


TABLE 7.2 Beinn Dearg - comparison of radiocarbon age estimates for the colonisation of pine using two threshold frequencies of *Pinus* pollen frequencies (%TLP)

SITE	ALTITUDE	(15% TLP)	(20% TLP)
GBT	600m OD	4,690 BP	4,350 BP
MFD	500m OD	6,630 BP	6,220 BP
LDM	420m OD	6,110 BP	6,110 BP
DMR	270m OD	6,840 BP	6,840 BP

Both threshold figures (15% and 20%) indicate pine colonised the higher site MFD (500m OD) before colonising the site of LDM situated at 420m OD. Due to the close geographical proximity of these two sites (*c.*1,000m apart) it is difficult to imagine a scenario where pine would migrate to MFD before reaching LDM (perhaps from a separate source of seed dispersal).

Alternatively, the apparent late colonisation of pine at LDM (in comparison to MFD) may be a result of one of the features of relative pollen data (as indicated at some of the Gleann Einich sites), i.e. that of the suppression of *Pinus* pollen frequencies by profuse pollen producers such as *Calluna.* However, at the time of pine colonisation at LDM the corresponding *Calluna* pollen frequencies and concentration values are higher at MFD than at LDM. So if pine pollen frequencies are suppressed by high *Calluna* pollen frequencies it is more likely to be reflected in the relative pollen stratigraphy of MFD than at LDM.

As described in Section 7.2.3, the two lower radiocarbon measurements at LDM produce close age estimates (8,050 +/- 70 at *c.*175cm and 7,850 +/- 60 at *c.*133cm). Although these estimates pre-date the estimated pine colonisation at this site, the interpolation of the dates may distort the age-depth plots. If the lowermost date is omitted and linear interpolation is performed with the three remaining age estimates, an even earlier date for pine colonisation date is implied (*c.*6,000 BP). So, without additional radiocarbon measurements, the relative timing of the colonisation of pine at the Beinn Dearg sites cannot be ascertained with confidence.

However, a comparison of the age estimate for the colonisation of pine at the lowest site, DMR, with published estimates in other parts of Northwest Scotland is worthwhile. Pennington *et al.* (1972) suggest a pine colonisation date of *c.*8,000 BP at Loch Scionascaig (at approximately sea-level, about 30km to the northwest of Beinn Dearg) and *c.*8,250 BP at Loch Maree (about 30km towards the west) (Birks, 1972). As discussed in Section 2.1.2, the source of the early arrival of pine at Loch Maree and Loch Scionascaig is unknown (Kinloch *et al.*, 1986, Birks, 1989) but biochemical evidence indicates a unique history, possibly through glacial survival or jump dispersal. The colonisation of pine at Beinn Dearg is likely to be derived from a similar migration source, and a later colonisation date than that estimated

for Loch Maree and Loch Scionascaig (both approximately at sea-level) might be expected. These dates produce a mean migration rate (or geographical spread rate) of *c.*26 m yr^{-1} from Loch Scionascaig and 21 m yr^{-1} from Loch Maree which compares with a rate of 60-100 m yr^{-1} during a similar period in Wales (Birks, 1989).

As for the sites at Gleann Einich (see Section 6.5.5.1), the pine migration rates between the sites at Beinn Dearg can be estimated and are shown below:

TABLE 7.3 Estimation of migration rates of pine between the sites investigated at Beinn Dearg

From	To	Horizontal distance (m)	15% threshold	20% threshold	Altitudinal difference (m)
DMR	**LDM**	1500m	2.07 m yr^{-1}	2.07 m yr^{-1}	150 m
DMR	**MFD**	2650m	12.44 m yr^{-1}	4.26 m yr^{-1}	230m
LDM	**MFD**	1000m	-1.95 m yr^{-1}	-9.71 m yr^{-1}	80 m
MFD	**GBT**	1300 m	0.67 m yr^{-1}	0.70 m yr^{-1}	100 m
DMR	**GBT**	3950m	1.84 m yr^{-1}	1.56 m yr^{-1}	330 m

If the site of LDM is omitted (due to the problems outlined above) the migration rates of pine decrease with altitude, from 4.26 m yr^{-1} between DMR and MFD compared to 0.70 m yr^{-1} between MFD and GBT. This, of course, assumes that pine colonised the highest site of GBT, although no pine macrofossils were identified to confirm this.

The average migration rate for pine at Beinn Dearg (from DMR to GBT) of 1.56 m yr^{-1} (using the 20% threshold frequency) compares with an average rate of 3.3 m yr^{-1} at Gleann Einich. Since Beinn Dearg is near the northern limit of the distribution of pine in Scotland (McVean & Ratcliffe, 1962) slower migration rates for both the geographical spread from Loch Scionascaig or Loch Maree and altitudinal spread at Beinn Dearg might be expected..

7.5.1.2 TREE-LINE DYNAMICS

Figure 7.42 shows the *Pinus* pollen frequencies plotted on common temporal scales (radiocarbon years BP) of the four sites investigated at Beinn Dearg with phases of higher and lower than mean degree of humification indicated.

In Section 7.5.5.1 the semi-arbitrary figure of 20% *Pinus* pollen was adopted as indicative for the local colonisation of pine at a site (a threshold figure used by Bennett (1984) in assessing the present/absence of pine in Britain during the Holocene). For the same reasons, significant deviations from the value of 20% *Pinus* pollen will be used as a guide of the changing density of pine stands at each site (and hence help identify significant changes in

the altitude of the tree-line). Frequencies greater than 20% *Pinus* pollen indicate an increase in the density of the pine woodland canopy and frequencies of less than 20% indicate a change to an open canopy.

Using the 20% threshold figure of *Pinus* pollen frequencies, the estimated age ranges of growth of relatively dense pine woodland at each of the four sites are as follows:-

i) Relatively dense pinewood canopy at DMR between *c.*6,840 BP and *c.*4,740 BP
ii) Relatively dense pinewood canopy at LDM between *c.*6,100 BP and *c.*3,900 BP
iii) Relatively dense pinewood canopy at MFD between *c.*6,200 BP and *c.*5,400 BP
iv) Relatively dense pinewood canopy at GBT between *c.*4,400 BP and *c.*4,300 BP.
v) Short-term reduction in the density of the pinewood canopy at DMR between *c.*6,400 BP and *c.*6,200 BP and possibly a reduction at MFD at *c.*6,400 BP.
vi) Dense pine woodland canopy at DMR, LDM and MFD at *c.*6,100 BP.
vii) Reduction in pinewood density at DMR, LDM and MFD at *c.*5,900 BP.
viii) Dense pinewood canopy at DMR, LDM and MFD at *c.*5,500 BP.
ix) Reduction in pinewood density at LDM and MFD at *c.*5,400 BP.
x) Increase in density of pine woodland (but remaining relatively open) at LDM and MFD at *c.*5,000 BP
xi) Dense pine woodland at LDM at *c.*4,200 and *c.*3,900 BP.
xii) Dense pine wood canopy and relatively high tree-line (shown at GBT) between *c.*4,400 BP and *c.*4,300 BP.

For the Gleann Einich sites, the evidence of lower *Pinus* pollen frequencies used to indicate a relatively open pine woodland canopy was supplemented by an increase in *Empetrum* pollen frequencies. However, at Beinn Dearg, following the colonisation of pine at the two lower sites (DMR and LDM), *Empetrum* pollen is recorded at very low frequencies. At MFD, high *Empetrum* pollen frequencies do correspond with lower pine pollen frequencies but paradoxically at GBT, high *Empetrum* pollen frequencies correspond with high pine pollen frequencies. Therefore, the *Empetrum* pollen data cannot be used to supplement the *Pinus* pollen evidence of an opening of the pinewood canopy because of the inconsistent relationship between the datasets.

Figure 7.43 shows the pine pollen concentration data for the Beinn Dearg profiles. Of particular interest is the high concentration values represented at GBT (a maximum of *c.*132,000 grains cm^{-3}) in comparison to LDM and MFD. A similar trend is observed in the total pollen concentration variations at the four sites (Figure 7.44). Although pollen concentration has been shown to correspond with a relatively high degree of humification (as at APB, section 6.1.4.1) this does not appear to be the case at GBT (Section 7.4.4.1 and Figure 7.37).

FIGURE 7.43. *PINUS* POLLEN CONCENTATION VALUES (EXPRESSED AS GRAINS PER CM^3) FOR SITES INVESTIGATED AT BEINN DEARG PLOTTED ON AGE AXES (RADIOCARBON YEARS BP)

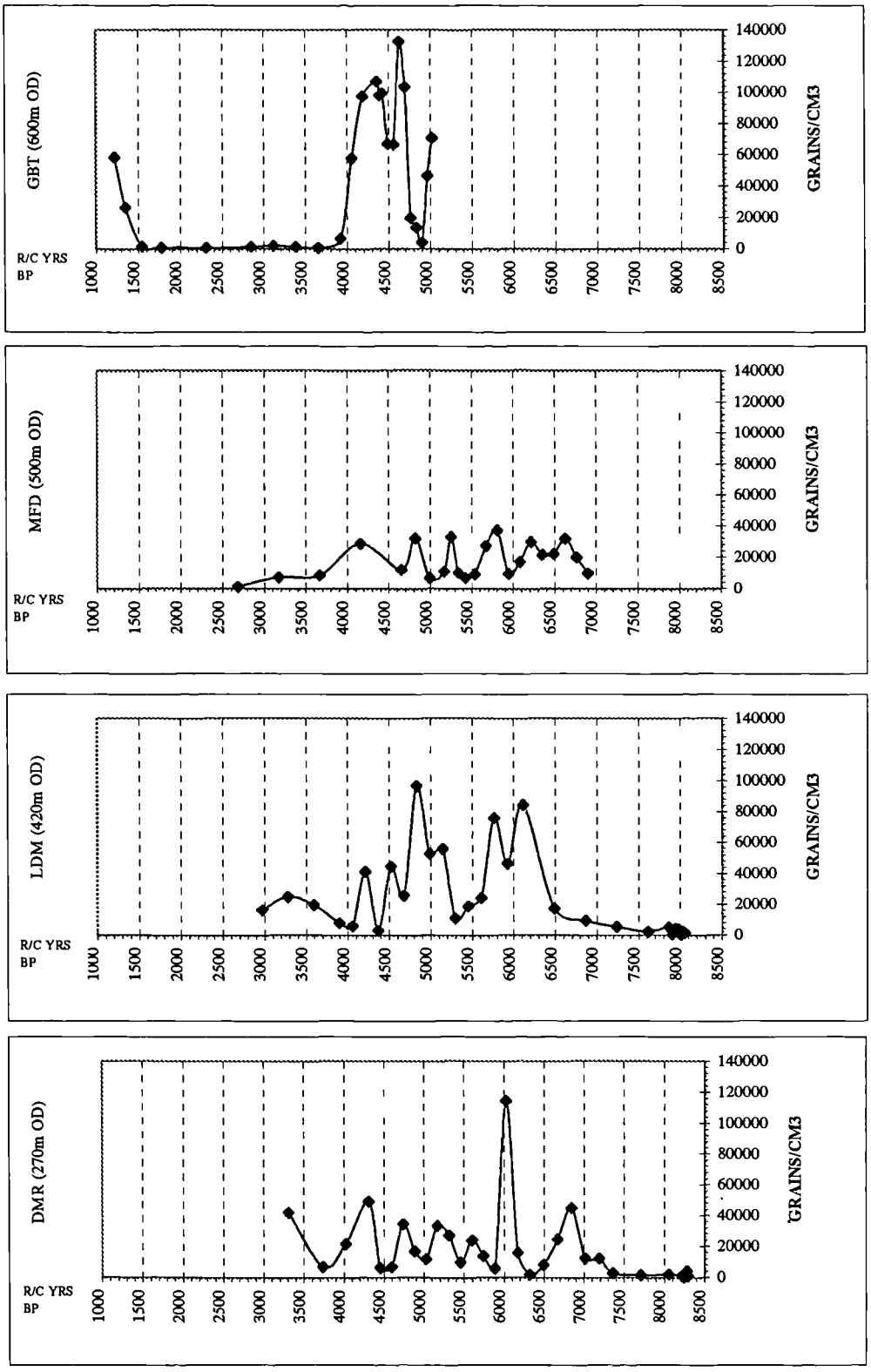
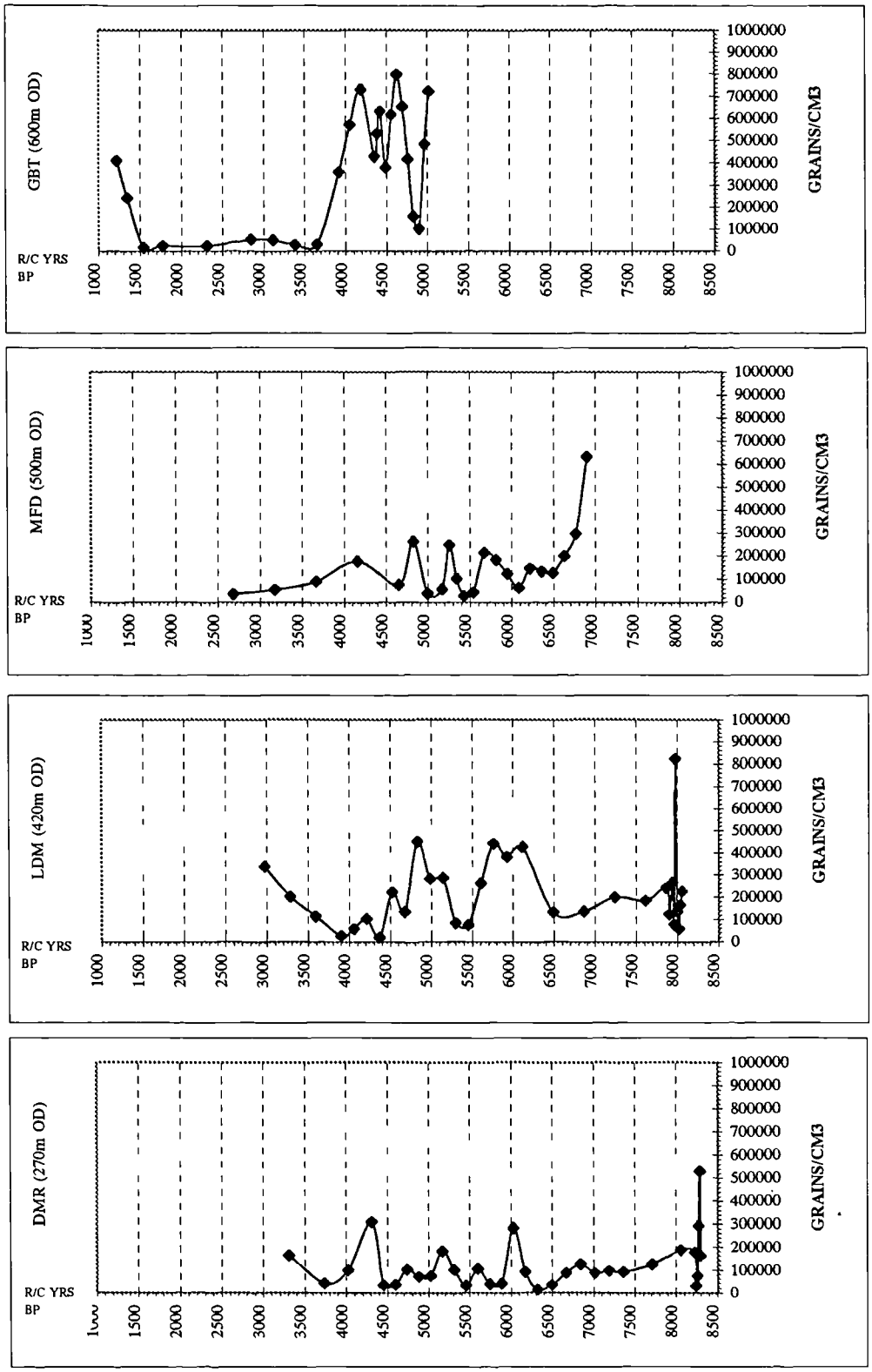


FIGURE 7.44. TOTAL POLLEN CONCENTRATION VALUES (EXPRESSED AS GRAINS PER CM^3) FOR THE SITES INVESTIGATED AT BEINN DEARG ON AGE AXES (RADIOCARBON YEARS BP)



Therefore, it is reasonable to assume that the high pollen concentration and influx values observed in GBT2 (between *c.*4,730 and *c.*4,000 BP) represent a real increase in pollen influx to the site. Since low pollen concentration values are represented at MFD and LDM during this period it is unlikely that the pollen rain at GBT is derived from these lower sites. It is also difficult to envisage a scenario where the density of the pine woodland is greater at higher altitudes (e.g. GBT) than at lower altitudes (e.g. MFD and LDM) unless the woodland at lower altitudes was affected by anthropogenic activities, such as felling and clearing.

However, modern pollen samples collected from known communities in Papua New Guinea (Williams *et al*, 1978) showed a significant representation of *Nothofagus* (beech) pollen at altitudes higher than the limit of the beech forest. Similarly, Hicks (1993) found a high representation of *Pinus* pollen above the tree-line in Northern Finland (see Section 4.4) which may partly explain the high pollen concentration and influx values recorded at GBT, but does not fully explain the large increase in the order of magnitude of the values at this site (compared to, for example MFD). However, Tauber (1977) and Prentice (1985) found that the highest annual pollen influx (from modern pollen rain investigations) was recorded in the pine forest and the lowest on the bare mountain tops. Fossitt (1994) investigated the modern pollen rain in three areas in the northwest of the British Isles (from lake sediments in small lakes) and found a low representation of *Pinus* on Shetland and the Western Isles (1.1% and 1.0% respectively). However, since these islands are largely unforested today, and the prevailing winds are from south to west, the estimates are not directly comparable to the Beinn Dearg region.

An explanation for the high pollen concentration values represented at GBT is therefore not straightforward and probably involves a combination of a variety of factors, such as pollen provenance and recruitment into the peat matrix. The pollen may be derived from the adjacent valley to the northwest (Allt Leacachain catchment) where pine stumps were located to an altitude of *c.*500m OD. This would provide an explanation for the higher *Pinus* pollen concentration at GBT between *c.*4,700 BP and *c.*4,050 BP and may also partly explain why high *Empetrum* pollen frequencies correspond to the higher *Pinus* pollen frequencies.

As for MNM (the highest Gleann Einich profile), since no macrofossils were located at GBT, there is no conclusive evidence that pine colonised GBT during the time represented in the peat profile. The significant contrast between the pollen-stratigraphic evidence from GBT and MNM is that a relatively high proportion of *Calluna vulgaris* is represented at GBT. The *Pinus* pollen frequencies at GBT, therefore, are unlikely to be over-represented because of the paucity of profuse pollen producing taxa contributing to the pollen sum.

An additional problem is that there may be a hiatus in the stratigraphy at GBT at about *c.*4,000 BP (base of GBT 3), and therefore the high pollen concentration values in GBT 3 may be a result of reworking of the peat matrix.

However, the peak in *Pinus* pollen frequencies between *c.*4,400 BP and *c.*4,300 BP at GBT (and similarly at *c.*4,200 BP and *c.*3,900 BP at LDM)corresponds with evidence for a short-term expansion of pine in the far north and west of Scotland at about 4,400 BP at Lochstrathy (Gear and Huntley, 1990), Loch Assynt (Birks, H.H. i, 1973-4 in Birks, 1980), Cross Lochs (Charman, 1994) and Loch Ashik, Isle of Skye (Birks and Williams, 1983). Therefore, if the pollen-stratigraphic evidence at GBT is representative of an increase in the altitudinal limits of pine at Beinn Dearg this corresponds very well with the evidence for a synchronous expansion of the northern, geographical, limit of pine.

7.5.1.3 THE DECLINE OF PINE AT BEINN DEARG

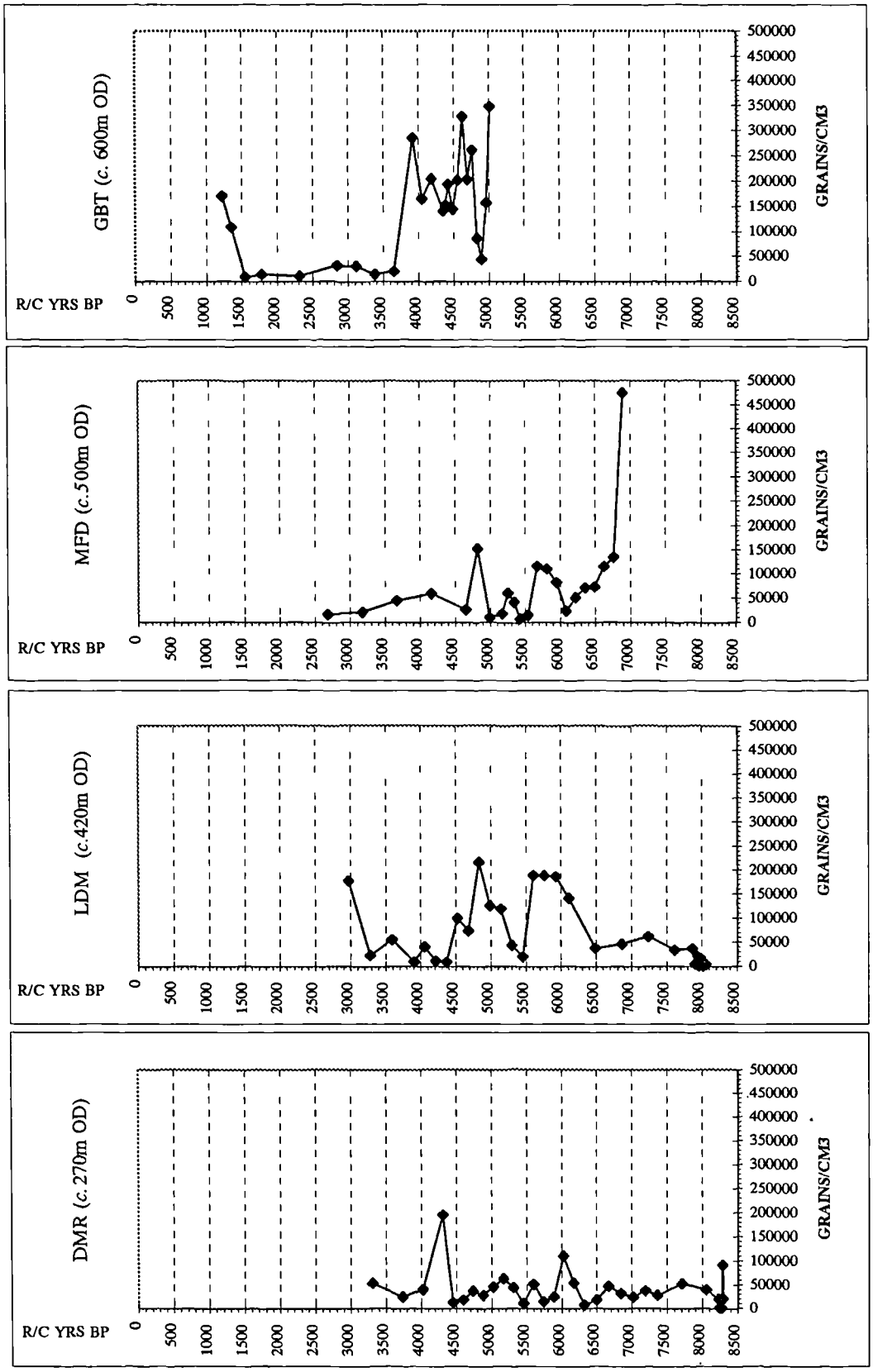
The widespread decline of pine pollen frequencies observed in northern Scotland (*cf.* Bennett, 1984) at approximately 4,000 BP is not apparent at all of the four sites under investigation at Beinn Dearg. At suggested in the preceding section, the end of the main phase of pine woodland establishment at each of the sites is:- *c.*4,740 BP at DMR, *c.*3,900 BP at LDM, *c.*5,400 BP at MFD, and *c.*4,300 BP at GBT (see Figure 7.42).

At DMR, it is likely that pine was present after 4,740 BP since a pine stump is located above the sampled profile, at the current ground surface. The trend towards an increase in *Pinus* pollen frequencies after *c.*3,500 BP also supports the notion of continued presence of pine and it is suggested that the blanket peat at DMR may have been cut. There does not appear to have been an abrupt decline of pine, therefore, at DMR.

There is a relatively sharp decrease in pine pollen frequencies at LDM (420m OD) at *c.*3,670 BP. The pine pollen frequencies just prior to this date show two high values, indicating a relatively dense pine woodland cover at a period when DMR (270m OD) and MFD (500m OD) indicate the dominance of *Calluna* heath or open pine woodland. However, the pine pollen concentration values at LDM (Figures 7.14 and 7.43) indicate a corresponding open pine woodland at *c.*4,000 BP, so the pine pollen frequencies may be enhanced by the low *Calluna* pollen concentration values (Figure 7.45). Therefore the pine woodland may have been more open than the relative pollen diagram indicates for LDM 5 (LPAZ) and the evidence for a decline of pine at this site is not straightforward.

Following the decline of pine pollen frequencies shortly after *c.*5,500 BP at MFD the pine woodland canopy remained relatively open. However, there is a trend towards a decrease in the pine pollen frequencies after *c.*4,150 BP (Figure 7.42) which is supported by the pine pollen concentration values (Figure 7.43).

FIGURE 7.45. *CALLUNA VULGARIS* POLLEN CONCENTRATION VALUES FOR SITES INVESTIGATED AT BEINN DEARG (EXPRESSED AS GRAINS PER CM^3) PLOTTED ON AGE AXES (RADIOCARBON YEARS BP)



As explained in the previous sections, although there is no conclusive (macrofossil) evidence for the colonisation of pine at GBT, the high pine pollen frequencies and concentration values indicate that it did reach this site for a relatively short period just before 4,300 BP (see 7.5.1.2) followed by a fairly rapid decline. Minimum pine pollen frequencies are represented at this site shortly after 4,000 BP which corresponds with the decline in pine other parts of Northwest Scotland (i.e. *c.*4,250 BP at Loch Scionascaig (Pennington *et al.*, 1972) and Loch Maree (Birks,1972) and in Caithness (Gear and Huntley, 1990). However, as mentioned above, there is a possibility that there is a hiatus in the peat profile at *c.*4,000 BP which might explain the sharp decline in pine pollen frequencies. The hiatus might also be a result of the tree cover, however, due to the increased erosion by wind and exposure and/or an increase in the run-off of water from the surrounding higher ground.

In summary, the pollen stratigraphy represented in the profiles at LDM and GBT show evidence to support the notion of 4,000 BP pine decline, but MFD shows a reduction of dense pine woodland at *c.*5,500 BP and DMR shows a continuation of pine woodland cover after *c.*3,500 BP (Figure 7.42).

7.5.2 SITE HYDROLOGY

7.5.2.1 DEGREE OF PEAT HUMIFICATION

The results of the humification analyses of the profiles from Beinn Dearg are plotted on temporal axes in Figure 7.46. The average transmission values are shown (as dashed lines) to facilitate the identification of shifts towards a higher or lower degree of humification. The transmission values are plotted on a reverse scale (because of the inverse relationship to the degree of humification).

As with the sites at Gleann Einich, to simplify the humification signals at the sites, synchronous shifts in transmission values at two or more sites are identified (Tables 7.4 and 7.5) and the significance of these shifts will then be discussed.

FIGURE 7.46. DEGREE OF HUMIFICATION FOR THE SITES INVESTIGATED AT BEINN DEARG, SHOWING DEVIATIONS FROM THE MEAN TRANSMISSION VALUES FOR EACH SITE AND COMPARISON WITH "PLUVIALS" IDENTIFIED BY DUBOIS AND FERGUSON (1985)

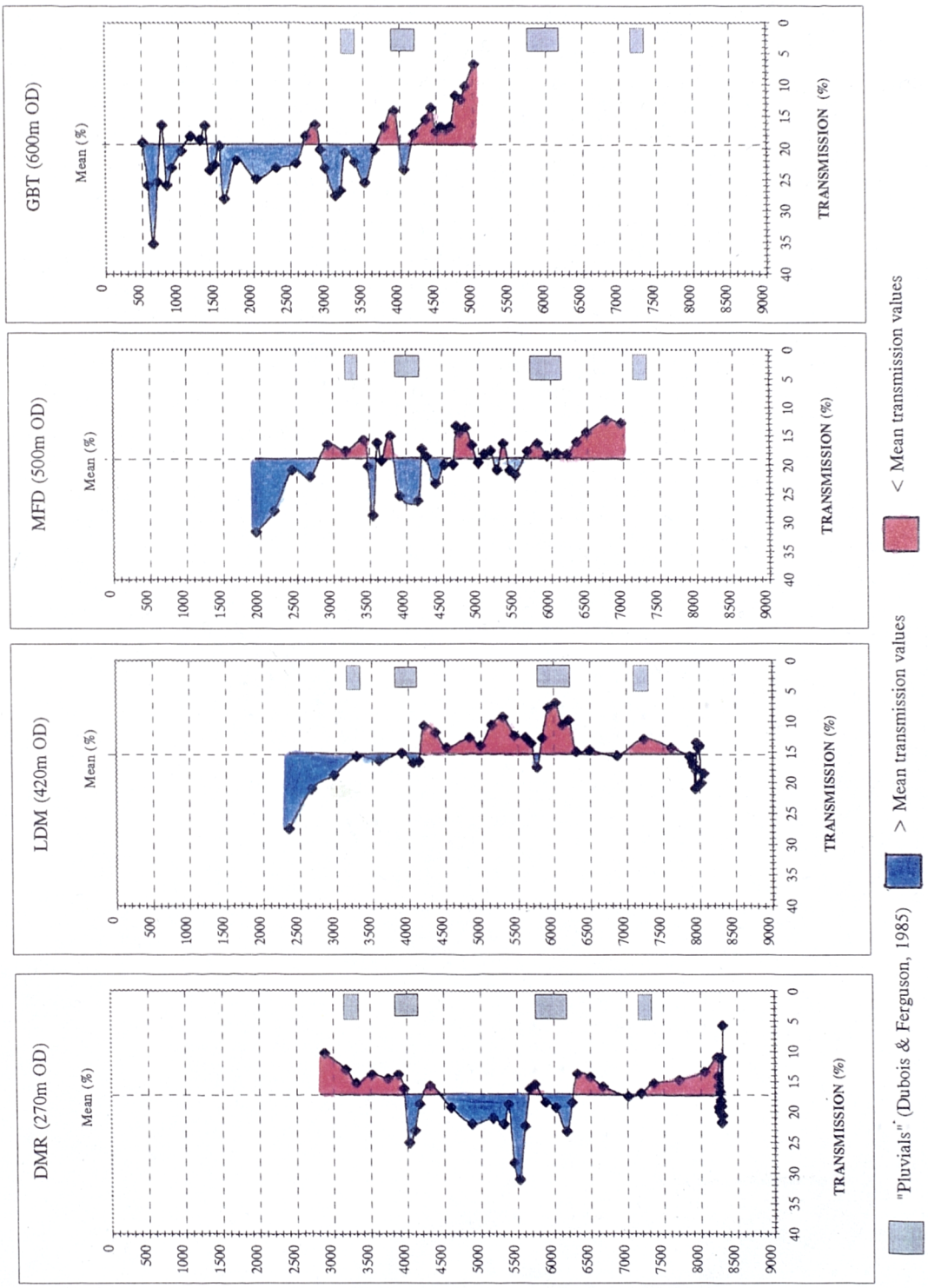


TABLE 7.4 Synchronous shifts to a lower than mean degree of humification (wet shifts) for the Beinn Dearg profiles (synchronous shifts registered by 3 or more sites denoted in bold: (XXX = no transmission measurements)

1,944-2,315 BP	XXX		MFD	GBT
2,315-2,578 BP	**XXX**	**LDM**	**MFD**	**GBT**
2,578-2,682 BP	XXX	LDM	MFD	
2,913-3,482 BP		LDM		GBT
3,482-3,512 BP		**LDM**	**MFD**	**GBT**
3,512-3,543 BP		LDM	MFD	
3,666 BP		LDM	MFD	
3,912-4,025 BP		LDM	MFD	
4,025-4,135 BP	**DMR**	**LDM**	**MFD**	**GBT**
4,135-4,158 BP	DMR		MFD	
4,597-4,650 BP	DMR		MFD	
4,995 BP	DMR		MFD	
5,254 BP	DMR		MFD	XXX
5,427-5,504 BP	DMR		MFD	XXX

The strongest signals for a regional shift towards less humified peat are between 2,315-2,578 BP, 3,482-3,512 BP, and 4,025-4,135 BP. The latter corresponds with a 'pluvial' episode identified by Dubois & Ferguson (1985) in the Cairngorms between c.4,200-3940 BP. All four sites also show a subsequent shift towards a higher degree of humification after *c.*4,100 BP (see below), although it is not so clearly demonstrated at LDM. The other 'pluvial' episodes of Dubois & Ferguson (*c.*3,300 BP, *c.*6,200-5,800 BP and *c.*7,300 BP) are not so well represented by the humification data at Beinn Dearg. However, the 3,300 BP 'pluvial' episode might be represented by a lower than average degree of humification at LDM and GBT and the 6,200-5,800 BP 'pluvial' episode corresponds with the less humified peat at DMR and a trend towards a lower degree of humification at MFD.

TABLE 7.5 Synchronous shifts to a higher than mean degree of humification (dry shifts) for the Beinn Dearg profiles (synchronous shifts registered by 3 or more sites denoted in bold: **(XXX** = no transmission measurements)

2,682-1,600	XXX	(LDM)	(MFD)	GBT
3,420-2,897	DMR		MFD	
3,605	DMR		MFD	
3,789	**DMR**		**MFD**	**GBT**
3,918-3,650	DMR	LDM?		GBT
4,220-4,212		LDM		GBT
4,281-4,220		**LDM**	**MFD**	**GBT**
4,311	**DMR**	**LDM**		**GBT**
4,909-4,693		**LDM**	**MFD**	**GBT**
5,015-4,909		LDM		GBT
5,168-5,082		LDM	MFD	XXX
5,341		LDM	MFD	XXX
5,743-5,674	DMR		MFD	XXX
6,323-5,841		LDM	MFD	XXX
6,490-6,323	**DMR**	**LDM**	**MFD**	**XXX**
6,967-6,490	DMR		MFD	XXX
7,240	DMR	LDM	XXX	XXX
7,999-7,961	DMR	LDM	XXX	XXX

The strongest evidence for synchronous shifts towards more humified peat occur between 6,490-6,323 BP, 4,909-4,693 BP, 4,311 BP, 4,281-4,220 BP, 3,918-3,650 BP and 3,789 BP.

The phases of higher and lower than average degree of humification are shown plotted to the left of the pine pollen frequencies in Figure 7.42. Less humified peat generally corresponds with higher pine pollen frequencies at Gleann Einich (Figure 6.41) but the relationship is not so clear at Beinn Dearg. However, the results from Beinn Dearg do suggest that episodes of pine colonisation at each of the sites coincides with a shift in the nature of the peat to a higher degree of humification (see Figure 7.42). This suggests that warmer and/or drier conditions are more favourable for the colonisation of pine and where pine stumps are present, (e.g. at DMR), they are found to correspond with the upper part of a phase of relatively well humified peat. The lack of a consistent correspondence between episodes of less humified peat and high pine pollen frequencies may be related to the density of the pine woodland. If, as suggested at Glean Einich (Section 6.5.2.1) the dense pine woodland canopy causes an increase in the local humidity at the ground surface, then this argument cannot be extended to Beinn Dearg. However, since the pine pollen frequencies and concentration values are generally lower at the Beinn Dearg profiles, this might indicate that

the pine woodland canopy was relatively more open. In this is the case, then a more open pine woodland canopy might not effectively increase the local humidity of the ground surface at the Beinn Dearg sites.

In addition, the mean degree of humification at Beinn Dearg is, on average generally higher than the mean values represented for the sites at Gleann Einich. This was a little surprising, as the Northwest Highlands were selected to provide an "oceanic" transect to compare with the relatively "continental" Cairngorms. The evidence for a generally higher degree of humification at Beinn Dearg is supported by the very low occurrence of *Sphagnum* leaves preserved in the peat matrix. The exception to this trend is found at the highest site, GBT, where the fungal and algal remains data also suggest a generally wetter (less humified) peat profile. This will be discussed further in the following section.

7.5.2.2 FUNGAL AND ALGAL REMAINS

The fungal and algal remains represented in the Beinn Dearg profiles supports the inferences drawn from humification evidence proposed above, i.e. that these sites are generally dry, since relatively low frequencies of wet-indicating types are recorded.

At DMR (Figure 7.8) there are virtually no fungal/algal remains indicative of wet mire surface conditions, such at Types 30 and 31A, but there are indicators of dry conditions such as Types 10 and 14. Very few Type 28 remains were recorded, which supports the observation proposed in this investigation that Type 28 is associated with Cyperaceae.

Extremely low frequencies of fungal and algal remains indicative of wet conditions are represented at LDM (Figure 7.17), which supports the notion that this profile is possibly the driest of the Beinn Dearg sites according to the low mean transmission values (15%). The few fungal/algal remains recorded are indicative of dry conditions such as Types 1, 2, 10 and 14. It is interesting to note that the fungal/algal remains are most frequent in the local pollen assemblage zone LDM 5, which exhibits evidence for a shift towards a lower degree of humification. The fungal and algal remains may therefore be subject to similar conditions favourable for preservation, as are macrofossils. The highest preservation potential appears to coincide with shifts towards a lower degree of humification. The fungal and algal remains recorded in significant frequencies in LDM1, LDM 2 and LDM 3 are Types 64 (associated with *Empetrum*) and Type 28 (associated with higher Cyperaceae pollen frequencies). However, there is a lack of a consistent correspondence between Type 10 and *Calluna vulgaris* pollen frequencies at LDM, despite the circumstantial evidence that *Calluna* is probably the host plant (Van Geel, 1972). Blackford (1990) similarly found an inconsistent correlation between Calluna and Type 10 and suggests that the extremely dry conditions which favour Calluna growth are beyond the optimal conditions of Type 10. Type 10 might therefore be expected to be found where Calluna pollen frequencies are high but the degree

of humification (as an indication of dryness of the peat matrix) is below the tolerance threshold of Type 10. However, Blackford (1990) also suggests that low Type 10 frequencies corresponding to high *Calluna* pollen frequencies might indicate a distal source for the pollen.

MFD also shows little evidence for fungal/algal remains indicative of relatively wet conditions (Figure 7.27), the exception being Type 28 which, again, rises with the Cyperaceae pollen frequencies. Types 10 and 14 are the most frequent fungal and algal remains represented, but the rise in Type 10 towards the top of the sample profile does not correspond with a higher degree of humification.

The site showing the largest variety of fungal and algal remains is the highest site, GBT (Figure 7.38). This site has the highest average transmission (20%) indicating a generally lower degree of humification (indicative of colder and/or wetter conditions). Significantly, this site is the only one of the Beinn Dearg profiles where Types 31a and 32 (wet indicators) are represented at high frequencies, increasing in frequency during GBT3 which corresponds with the decrease in the degree of humification and a *Sphagnum*-rich peat matrix.

If the fungal and algal data are to be used to supplement the humification data, bias in the preservation potential of the remains needs to be considered. Presumably, during phases of a high degree of humification, some of the fungal and algal remains will be subject to degradation, as are pollen grains, spores and wood remains. So if a decrease in the representation of dry indicating fungal and algal remains is recorded, as at LDM, which corresponds to a higher degree of humification it may reflect that the remains were not preserved due the humification process. Therefore, a low frequency of Type 10 corresponding to a high frequency of *Calluna* pollen might indicate an increase in the regional pollen signal, but may also indicate that the fungal and algal remains failed to become incorporated into the fossil record. Therefore, the humification evidence should be assessed *in tandem* with the pollen-stratigraphic and fungal and algal remains data. Therefore further research is justified to investigate the hydrological, edaphic and plant community interactions in terms of the depositional environment and live plant/acrotelm processes.

7.5.2.3 BLACKENED *PINUS* POLLEN GRAINS

This feature was observed at all the sites at Beinn Dearg, even in the profile from the relatively less well humified, and highest site, GBT (unlike MNM at Gleann Einich). However, the correspondence between blackened *Pinus* grains and the degree of humification does not appear to be as strong at the sites investigated at Beinn Dearg (in comparison to the observations at Gleann Einich). The relationship between blackened *Pinus* and the degree of humification needs further consideration. Factors such as the

"mean residence time" of the upper layers of the peat with in the acrotelm, the depth of the peat profile in relation to the "mean age" (or length of time the *Pinus* grains have resided in the catotelm) and the vegetation colonising the mire surface (since there is evidence for a greater density of *Calluna* cover at the Beinn Dearg sites) need to be assessed. Since the blackened *Pinus* grains were discussed in Section 6.5.2.3 for the Gleann Einich profiles it will be beneficial to assess the factors mentioned above by comparing the evidence from both regional transects. Therefore the blackened *Pinus* grains will be discussed further in the following chapter (Section 8.7).

7.5.2.4 THE PRESENCE OF MACROFOSSILS

The general trend of macrofossil preservation in the profiles investigated at Beinn Dearg is that wood macrofossils are more frequent in the less humified peat matrix (see Figures 7.9, 7.18, 7.37). To test this relationship more transmission values are required from the peat profiles, at smaller sampling intervals (contiguous sampling is ideal). However, it is possible to draw some general conclusions.

Pine macrofossil presentation at DMR, LDM and MFD occurs towards the top of phases of relatively well-humified peat which supports the hypothesis of Birks (1975) that pine colonisation and establishment on mire surfaces is largely controlled by the local environmental factors, such as the relative dryness of the mire.

However, in comparison to the Gleann Einich site profiles, the Beinn Dearg profiles contain a low proportion of *Sphagnum* leaves preserved in the peat matrix. This corresponds with the generally higher mean degree of humification recorded for the Beinn Dearg profiles and the comparatively low representation of wet-indicating fungal and algal remains. Therefore, it is not possible to critically assess whether a subsequent increase in peat accumulation rates (as is often associated with a relatively fresh *Sphagnum*-rich peat matrix) is related to the preservation of the pine macrofossil (cf. Birks, 1975). The only stratigraphic evidence indicative of a return to wetter conditions of the mire surface is the degree of humification data.

The exception to the trend for low representation of *Sphagnum* leaves is the highest site at Beinn Dearg, GBT (*c.*600m OD) (see lithostratigraphic description, Section 7.4.2) where a *Sphagnum*-rich peat is present between 82cm and 105cm (and corresponds with a relatively low degree of humification). Since pine macrofossils are not present in the profile at GBT it is not possible to interpret the preservation potential of the peat matrix in terms of pine macrofossil representation (as for the Gleann Einich sites where a *Sphagnum*-rich peat matrix often overlies pine macrofossils). However, the site at GBT is comparable to the highest altitude site of the Gleann Einich transect (MNM) where there is also pollen-stratigraphic evidence for the local presence of pine but no supporting macrofossil evidence.

Since there is strong pollen-stratigraphic evidence for the local presence of pine establishment at GBT, a similar conclusion is reached regarding the local colonisation of pine, i.e. that pine was present in the region of this site but the mire surface was too wet for the growth of pine.

7.5.2.5 SUMMARY OF THE BEINN DEARG RESULTS

The biostratigraphic evidence at Beinn Dearg indicates that several site-specific factors may be affecting the pollen-stratigraphic evidence for the local history of pine in the area. These include close radiocarbon age estimates for samples recovered from the lower part of the profiles at DMR and LDM, very high pollen concentration and influx values at the highest site on the transect (GBT), and a generally high representation of profuse pollen producers within the shrub layer (e.g. *Calluna vulgaris*) which may be causing an under-representation of *Pinus* pollen frequencies.

The mean degree of humification of the profiles is surprisingly high (in comparison with the Gleann Einich sites) and is thought to be related to the dominance of *Calluna* at the understorey layer in the region. This is supported by the evidence of a low proportion of *Sphagnum* leaves preserved in the peat profiles (with the exception of GBT) and, in comparison to the Gleann Einich profiles, a low representation of wet-indicating fungal and algal remains.

The results will discussed further in the following chapter, where both the evidence from Beinn Dearg and Gleann Einich will be compared and assessed.

CHAPTER 8.0 DISCUSSION AND SYNTHESIS OF RESULTS

8.1 INTRODUCTION

The principal aim of this thesis was to assess the potential of the palaeo-environmental evidence preserved in blanket peats from two areas of northern Scotland for reconstructing tree-line variations during the Holocene. The primary source of evidence is that of the palaeobotanical record (pollen and macrofossils), but an interpretation of these data also requires careful consideration of the site-specific factors which may affect these records in a number of inter-related ways.

The main site specific factors are:
- local vegetation cover
- site topography and drainage characteristics
- duration and rate of peat accumulation
- degree of humification of peat
- palaeoclimatic changes
- distance from migration centres or "fronts" of certain plants

In this chapter, an analysis of the local factors influencing the palaeo-ecological records will be presented first, with a view to establishing what general conclusions can be drawn about the local and regional changes affecting the history of pine. In the final section, the various lines of evidence will be synthesised to construct a model for Holocene environmental change at Beinn Dearg and Gleann Einich followed by a comparison with existing palaeo-environmental evidence and climatic models proposed for other areas of Scotland and Northwest Europe.

8.2 PEAT INITIATION

The origin and development of blanket mires (or peat initiation) has been interpreted as resulting from deforestation (Moore, 1973), progressive paludification (Taylor and Smith, 1980) and climatic deterioration (Godwin, 1946). Peat initiation and formation is also strongly controlled by site topography and the effective rainfall (precipitation/evaporation ratio) which is supported by the wide variety of radiocarbon age estimates obtained for peat initiation in the South Pennines (Tallis, 1991), Mid Wales (Smith and Taylor, 1989) and Northwest Scotland (Moore *et al.*, 1984).

The influence of site topography on the initiation of blanket mire formation at the sites investigated at Beinn Dearg and Gleann Einich, is perhaps reflected in the wide range of dates obtained from the basal sediments. The variety of site types investigated in this study (basin mire, valleyside mire and saddle mire types) enables an assessment of topographic control on blanket peat formation and proposals as to which type of site topography is likely to form peat first. Moore *et al.* (1984) and Edwards and Hirons (1982) propose that plateau

and basin sites are more prone to waterlogging and hence form peat first, with a subsequent spread of blanket peat to more marginal areas, such as slopes. Similarly, Tallis (1991) investigated a range of sites in different topographic situations in the South Pennine uplands and demonstrated that peat initiation was found to occur earlier at water-collecting situations followed by subsequent spread to water-shedding situations. Kaland (1988) suggests that heavy precipitation is the primary reason for ombrotrophic mire-formation around the alpine forest limit of western Norway, and that an anthropogenic factor is only important for peat initiation where there is a relatively low precipitation.

Tables 8.1a and 8.1b present the physiographic context for each of the sites at Beinn Dearg and Gleann Einich, together with a summary of the interpretation of the basal fossil pollen assemblage, degree of humification, fungal and algal remains represented and the peat accumulation rates. Figure 8.1 shows the basal radiocarbon date of each of the sites plotted by altitude.

With the exception of site LOD in the Gleann Einich group, which will be discussed below, peat initiation commences at all sites at a progressively later date with increasing altitude. Since one of the major factors governing peat inception is high humidity (precipitation/ evaporation ratio) one would expect blanket peat accumulation to commence earlier at higher altitudes sites (since there is generally an increase in precipitation and decrease in temperatures at higher altitudes). The fact that this is not the case at the Beinn Dearg and Gleann Einich transects suggests that, aside from local site topography, the altitudinal trend may reflect the increasing degree of wind exposure at higher altitudes, and/or the importance of downslope water flow to the lower altitude sites which "feeds" peat initiation.

Since LOD is a basin mire type site (hence a water-collecting situation) the relatively early radiocarbon age estimate for the basal sediments from this site supports the suggestions of Tallis (1991), Moore *et al.* (1984) and Edwards and Hirons (1982) that these sites are likely to form the early foci of peat formation. The other characteristic difference in the basal sediments from LOD compared to the other sites investigated at Gleann Einich (and also at Beinn Dearg) is the relatively low degree of humification (Tables 8.1a and 8.1b). The basal sediments at LOD indicate that peat formed in a prevailing waterlogged environment, possibly at the edge of the lochan, as demonstrated by the representation of aquatic pollen types, such as *Potamogeton* spp.

The humification evidence from the other sites shows relatively highly humified basal peats but very few fungal and algal remains were represented to supplement this. This might indicate that the fungal and algal remains may be more susceptible to disintegration in highly humified peats (in comparison to pollen grains) and that aeration may have been caused by through flow of water at the mineral surface.

TABLE 8.1a Summary of physiographic context, basal radiocarbon dates, accumulation rates and basal biostratigraphic interpretations of Gleann Einich profiles

GLEANN EINICH

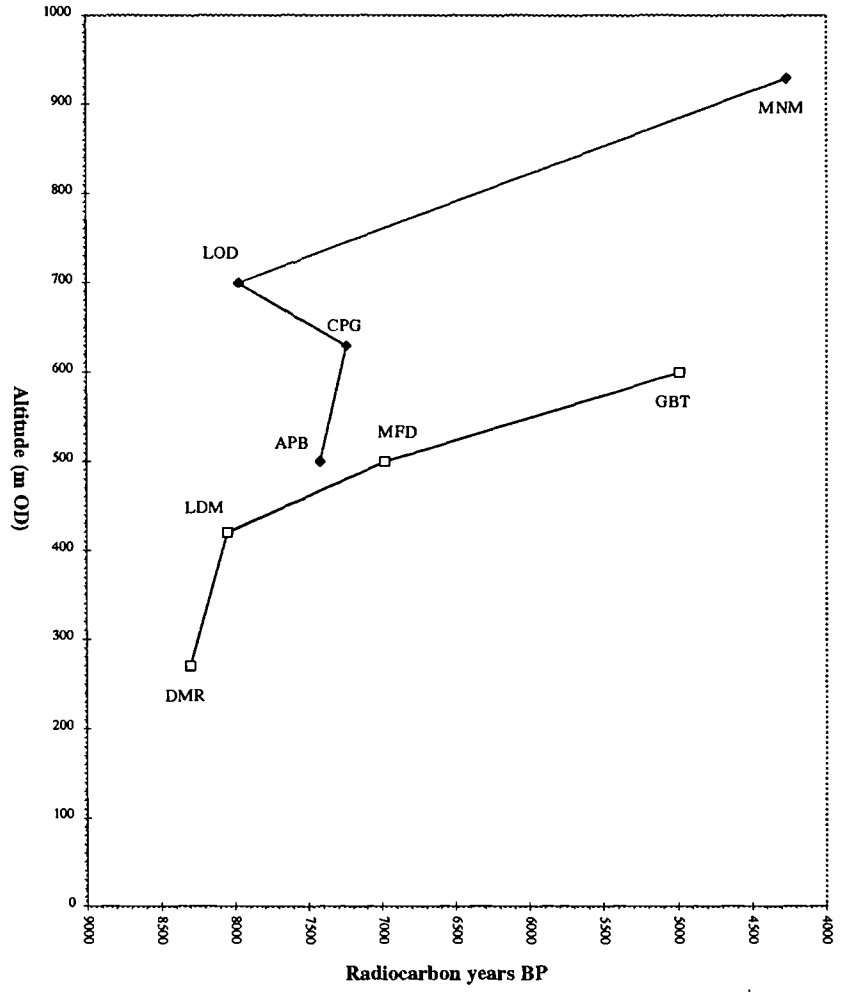
SITE CODE	Altitude (m OD)	Basal date (^{14}C years BP)	Type of site	Depth of profile (cm)	Basal accum rates (cm/100 yr)	Mean Peat Accum rates (cm/100 yr)	Basal Sediment description	Basal pollen assemblage	Basal woody macro fossils?	Basal Humification	Fungal/ algal evidence?
APB	500	7420 +/- 80	Valleyside mire (with some saddle mire characteristics)	260cm	2.5	4.1	Black peat with minerogenic incl	*Calluna* + pine	Birch & pine twigs	High	None
CPG	630	7240 +/- 80	Valleyside mire	175cm	1.2	3.1	Black peat (1.5cm above coarse sand)	*Calluna* + birch, some sedges & Filicales	No	High	Small amount Type 18
LOD	700	7970 +/- 60	Valleyside/basin mire	250cm	7.6	5.2	Dark brown fibrous peat (2cm above fine sand)	Birch with sedges & grasses (some aquatics)	No	High to Low	Types 3/3a
MNM	930	4270 +/- 70	Valleyside mire	147cm	4.3	14.2	Dark brown sedge peat (bottom 10cm missing on coarse gravels)	Sedges & some grasses (occasional *Sphagnum* leaves)	No	High	Type 28 & 64

TABLE 8.1b Summary of physiographic context, basal radiocarbon dates, accumulation rates and basal biostratigraphic interpretations of Beinn Dearg profiles

BEINN DEARG

SITE	Altitude (m OD)	Basal date (^{14}C years BP)	Type of site	Depth of profile	Basal accum rates (cm/100 yr)	Mean Peat Accum rates (cm/100 yr)	Basal Sediment description	Basal pollen assemblage	Basal woody macro fossils?	Basal Humification	Fungal/ algal evidence?
DMR	270	8300 +/- 130	Valleyside mire/rheotrophic	205cm	53.8	2.9	Minerogenic-rich peat	Birch with *Empetrum*, *Vacciniinium*, grasses and sedges	Birch (decomposed)	High	None
LDM	420	8050 +/- 70	Valleyside mire	177cm	20.8	2.6	Black peat with minerogenic inclusions	Birch with Juniper, grasses, sedges & Filicales (just below *Sphagnum* spore peak)	Birch	Lowish	None
MFD	500	6950 +/- 70	Saddle mire	208cm	2.9	3.5	Black peat with minerogenic inclusions	*Calluna* with some birch	Birch	High	None
GBT	600	4990 +/- 60	Saddle mire	191cm	5.9	4.1	Black homogeneous peat	*Calluna* with some sedges (& *Sphagnum* spores)	Ericaceous? twigs	High	None

FIGURE 8.1. BASAL RADIOCARBON AGE ESTIMATES FOR THE PROFILES INVESTIGATED AT GLEANN EINICH AND BEINN DEARG PLOTTED ON AN ALTITUDINAL AXIS (m OD)



A brief interpretation of the basal pollen assemblages recorded for each site is also shown on Tables 8.1a and 8.1b. There does not appear to be any strong indication of vegetation types conducive to, or typical of, environmental conditions favouring peat formation although there is evidence for the presence of birch at the base of the profiles from the two lower sites of each transect. Similarly, birch macrofossils are often preserved at the base of the profiles. However, this may merely reflect the relatively early date for peat initiation at lower altitudes, i.e. before the arrival of pine.

The basal peat accumulation rates show no significant pattern in relation to altitude or geographic location. The sites of DMR and LDM (Beinn Dearg) show very high basal accumulation rates but this reflects the close radiocarbon dates recorded at the base of these profiles (as discussed in Sections 7.1.3 and 7.2.3). LOD shows a relatively high basal accumulation rate (7.6 cm $100yrs^{-1}$) in comparison with the other profiles at Gleann Einich. This is likely to be related to low humification and prevailing waterlogged conditions suggested by the evidence from the base of this profile (discussed above)

To summarise, the conclusions to be drawn from the various lines of evidence for the initiation of peat accumulation at Beinn Dearg and Gleann Einich are:

1. Peat initiation generally occurred first at the lowest sites and last at the highest sites
2. The relatively early peat accumulation recorded at LOD in Gleann Einich (700m OD) supports the suggestions of Tallis (1991), Moore *et al.* (1984) and Edwards and Hirons (1982) that basin mire sites are more susceptible to waterlogging and hence peat accumulation should commence relatively early in such topographic settings
3. A high degree of humification is recorded at the base of the peat profiles (with exception of LOD which shows evidence a low degree of humification). This indicates that the basal peat layers were relatively well oxygenated and the anaerobic catotelm zone had probably not formed

8.3 PEAT ACCUMULATION RATES

The mean peat accumulation rates (peat-growth rates) for each of the sites are shown in Tables 8.1a and 8.1b. These figures represent the overall mean peat accumulation rates calculated for profiles based on linear interpolation of the radiocarbon age estimates and extrapolation to the uppermost pollen sampling depth. The high basal accumulation rates calculated for DMR and LDM are probably erroneous (discussed above) and have therefore been excluded from the estimates of the mean accumulation rates. The figures in Tables 8.1a and 8.1b are shown in 'cm 100 $years^{-1}$' to facilitate comparison with the data presented by Birks (1975), Pears (1975), and Chambers (1984).

The mean total peat accumulation rates for the sites investigated at Beinn Dearg and Gleann Einich are significantly greater than those proposed by Pears (1975) for the Cairngorms (2.0-3.0 cm 100 yrs^{-1}) and by Birks (1975) at Loch Einich (2.0 cm 100 yrs^{-1}). Chambers investigated the peat accumulation rates of sites in upland South Wales (Chambers, 1984) and demonstrated that higher rates were represented at moist-receiving basin sites (*c.*5 cm 100 yrs^{-1}) in comparison to moisture-shedding sites (*c.*2.0-2.3 cm 100yrs^{-1}).

The general conclusions to be drawn from the peat accumulation rates at the sites investigated at Beinn Dearg and Gleann Einich are:

GLEANN EINICH

1. A general increase in peat accumulation rates at higher altitudes. MNM shows the fastest rate of 14.2 cm 100yrs^{-1} (the lower rate for CPG will be discussed below)
2. The basal accumulation rates are generally lower than the total mean accumulation rates, with the exception of the basin site, LOD, which shows a basal accumulation rate of 7.6 cm 100yrs^{-1} and a total mean accumulation rate of 5.2 cm 100yrs^{-1}. This is presumably related to the prevailing waterlogged conditions at the base of the profile at LOD being more favourable for peat accumulation (and/or there may be less autocompaction due to the high water content).

BEINN DEARG

1. The fastest accumulation rates are shown at the highest site GBT (mean accumulation rate of 4.1 cm 100yrs^{-1}).
2. The mean accumulation rates for the saddle mire type sites MFD and GBT are not lower than the valleyside mire type sites DMR and LDM which therefore does not support the observations of Chambers (1984) that moisture shedding sites (such as saddle mires) accumulate at slower rates than moisture collecting sites (such as valleyside mires).

In general, therefore, the highest sites at each transect show the highest mean accumulation rates but relatively later dates for peat initiation. When the threshold for peat formation is crossed at these sites, peat tends to accumulate relatively quickly. Therefore, if mean peat accumulation rates can be shown to increase with altitude, then presumably a factor to be considered regarding the degree of humification at these sites is the "mean residence time" of the upper layers of the peat stratigraphy within the active acrotelm (where the humification process is thought to occur (cf. Clymo,1978)).

The mean accumulation rates at the sites investigated at Beinn Dearg are more in line with previous observations, such as Birks (1975) and Chambers (1984). This will be discussed further in Section 8.4.

When interpreting the mean accumulation rates for blanket peats it is important to consider the various factors which govern the net balance of peat growth. These are:

1. Rate of production and decay of peat-forming vegetation (Coulson and Butterfield, 1978)
2. The decomposition of plant material which is largely controlled by the water content of the peat matrix (Swift *et al.*, 1979)
3. Degree of aerobic decomposition (humification) and autocompaction following incorporation into the anaerobic zone (catotelm) of the peat profile (Clymo, 1978)
4. Vegetation community colonising the mire surface and forming the peat matrix. *Eriophorum* spp. tend to decompose relatively slowly (hence a high accumulation rate) (Coulson and Butterfield, 1978) while heath-dominated mires generally accumulate more slowly (Chambers, 1984).

Factor 3, the degree of humification, can be directly compared with the mean accumulation rates for the sites at Beinn Dearg and Gleann Einich, whereas factors 1 and 2 are more difficult to assess. Factor 4 will be discussed later in this section.

The table below (Table 8.2) shows the relationship between the mean degree of humification (mean transmission values) and the mean peat accumulation rates. This data is plotted on an altitudinal axis in Figure 8.2.

TABLE 8.2 Relationship between the mean degree of humification (mean transmission values) and the mean peat accumulation rates for the sites investigated at Gleann Einich and Beinn Dearg.

GLEANN EINICH

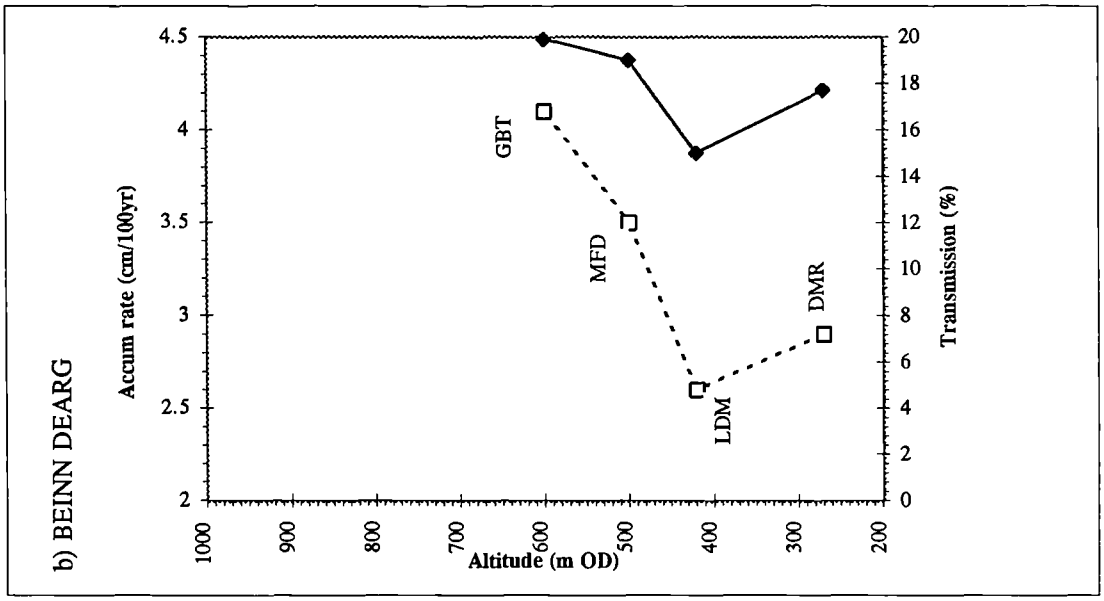
SITE	Altitude (m OD)	Mean Trans (%)	Mean accum (cm 100yr^{-1})
APB	500	23.0	4.1
CPG	630	15.0	3.1
LOD	700	24.1	5.2
MNM	930	29.5	14.2

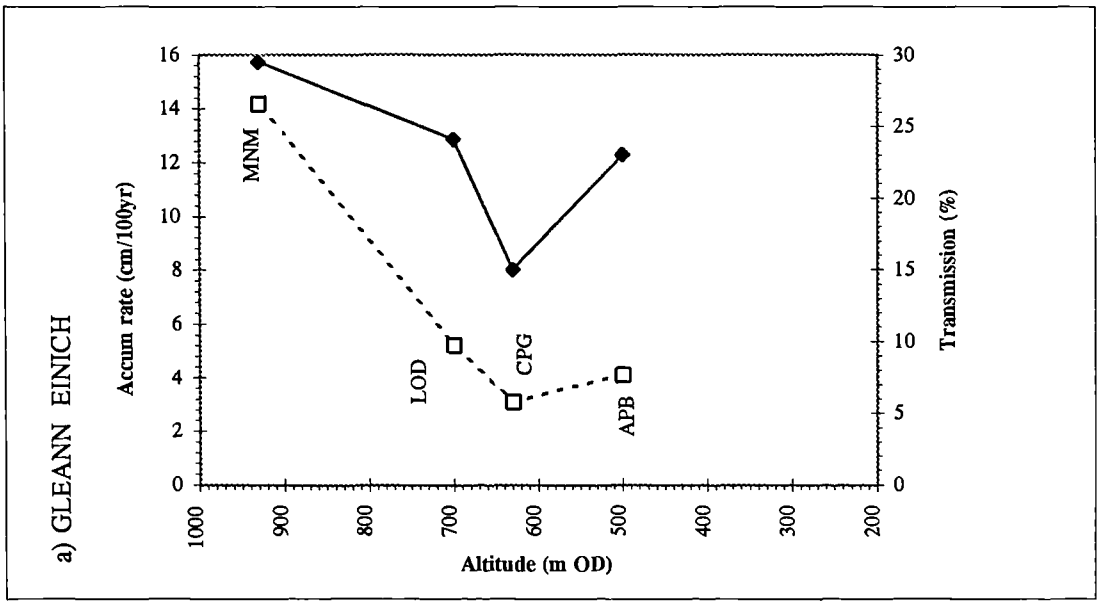
BEINN DEARG

SITE	Altitude (m OD)	Mean Trans (%)	Mean accum (cm 100yr^{-1})
DMR	270	17.7	2.9
LDM	420	15.0	2.6
MFD	500	19.0	3.5
GBT	600	19.9	4.1

It is interesting to note the generally lower mean peat accumulation rates shown by the sites investigated at Beinn Dearg. This may be related to the vegetation community colonising the mire surface (Factor 4, above) and forming the peat matrix, since in general, higher frequencies of *Calluna vulgaris* pollen are represented at the Beinn Dearg sites (Figure 8.3) This supports the hypothesis proposed by Chambers (1984) that peat growth is likely to be slower under a heath-dominated community. This might also provide an explanation for the higher mean degree of humification value represented at the Beinn Dearg sites (supposedly the wetter, more "oceanic" transect as indicated by the present climatological data) (Table 5.1).

FIGURE 8.2. RELATIONSHIP BETWEEN THE MEAN DEGREE OF HUMIFICATION (% TRANSMISSION) AND MEAN PEAT ACCUMULATION RATES (CM /100 YEARS) OF SAMPLE PROFILES AT a) GLEANN EINICH AND b) BEINN DEARG ON AN ALTIDUNAL AXES (m OD)

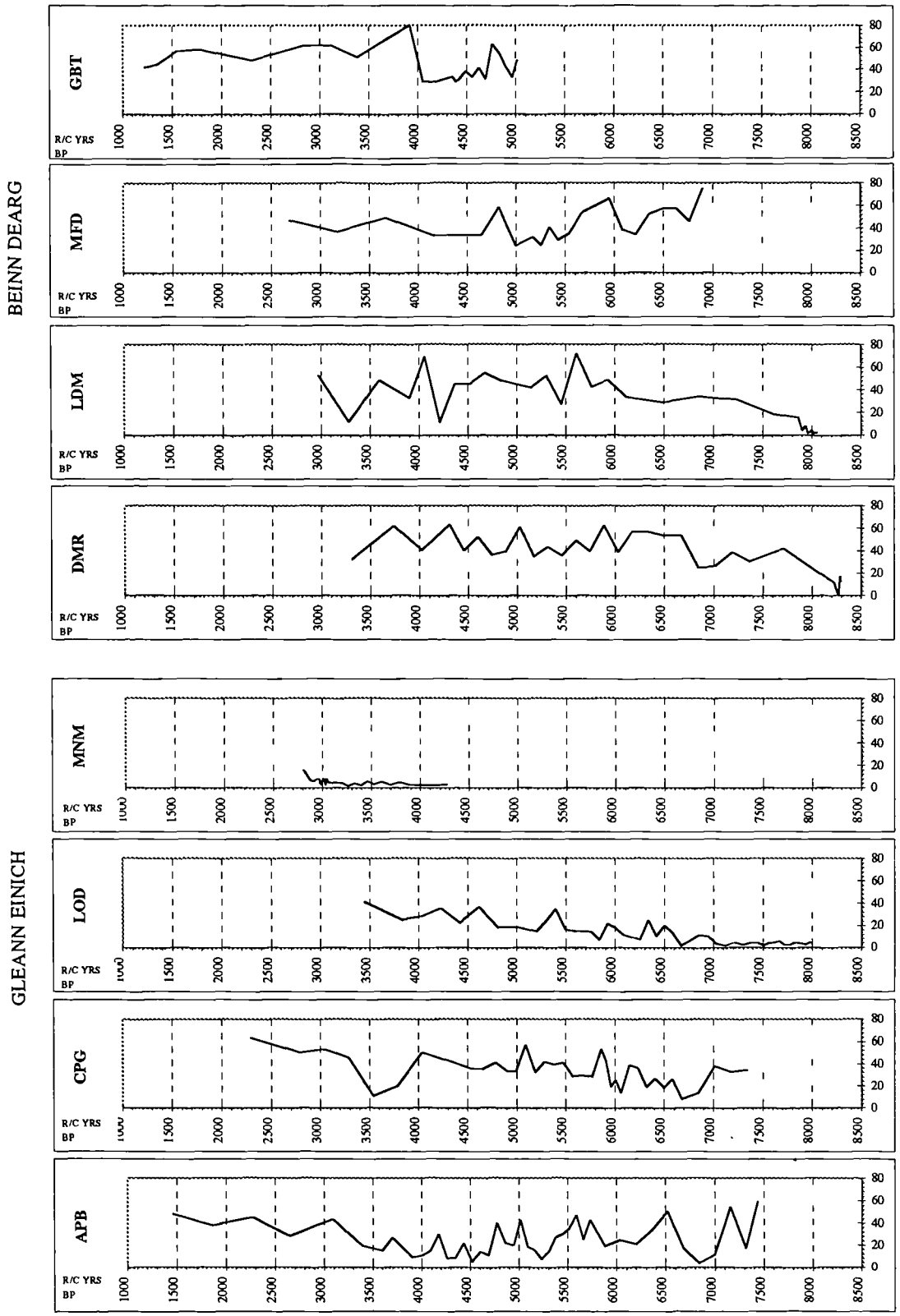




Mean transmission value (%)

Mean peat accumulation rate (cm/100yr)

FIGURE 8.3. *CALLUNA VULGARIS* POLLEN FREQUENCIES (%TLP)
FOR SITES INVESTIGATED AT GLEANN EINICH AND BEINN DEARG
PLOTTED ON COMMON AGE AXES (RADIOCARBON YEARS BP)



Whilst it is useful, and interesting, to compare the mean peat accumulation rates at these sites, it is important to remember that these values are the mean values of the overall peat accumulation rates. Not only are the figures dependent upon the accuracy of the radiocarbon age estimates but also, as shown by the humification evidence, the peat accumulation rate through a profile is likely to show short-term oscillations. Similarly, since a number of factors govern the net accumulation rate of peat (Clymo, 1978), these figures are presented merely as a guide to the relative magnitude of the rate of peat accumulation of the sites investigated and enable a comparison between the transects.

8.4 DEGREE OF PEAT HUMIFICATION

Figure 8.4 shows the results of the humification analyses from the set of four sites at both Beinn Dearg and Gleann Einich plotted on a common temporal scale (radiocarbon years BP), with less than mean transmission values for each site shaded in red (higher degree of humification) and greater than mean transmission values in blue (lower degree of humification). Further comparison is provided in Figure 8.4 by illustrating the Beinn Dearg and Gleann Einich trends in relation to the "pluvials" inferred by Dubois and Ferguson (1985) and the Main Recurrence Surface (MRS) inferred by Barber (1982).

As discussed in Section 5.2.6, since the humification analysis was not performed on contiguous samples (due to the large number of samples this would entail) the shading is simply a visual aid for the identification of shifts to a higher or lower degree of peat humification for each profile. Obviously, an assumption has been made by interpolating between the transmission values but this does not prevent some general conclusions being drawn.

All the transmission values are measured using distilled water as a standard so there is some value in comparing the relative magnitudes of the mean, maximum and minimum transmission values obtained for each site investigated. These are shown in Figure 8.5.

The general trends are summarised below in Table 8.3:

TABLE 8.3 Maximum degree of humification (minimum percent transmission values) for sites investigated at Gleann Einich and Beinn Dearg

GLEANN EINICH	BEINN DEARG
	DMR (270m OD) (5.6%)
	GBT (600m OD) (6.4%)
	LDM (420m OD) (6.9%)
CPG (630m OD (7.5%)	
LOD (700m OD) (9.7%)	
	MFD (500m OD) (11.8%)
APB (500m OD) (11.9%)	
MNM (930m OD) (18.6%)	

Figure 8.4 Degree of humification (percent transmission) for the sites investigated at Gleann Einich and Beinn Dearg plotted on common age axes (radiocarbon years BP) and comparison with existing climate models. (Lower than mean transmission values shown in red and higher than mean transmission values shown in blue)

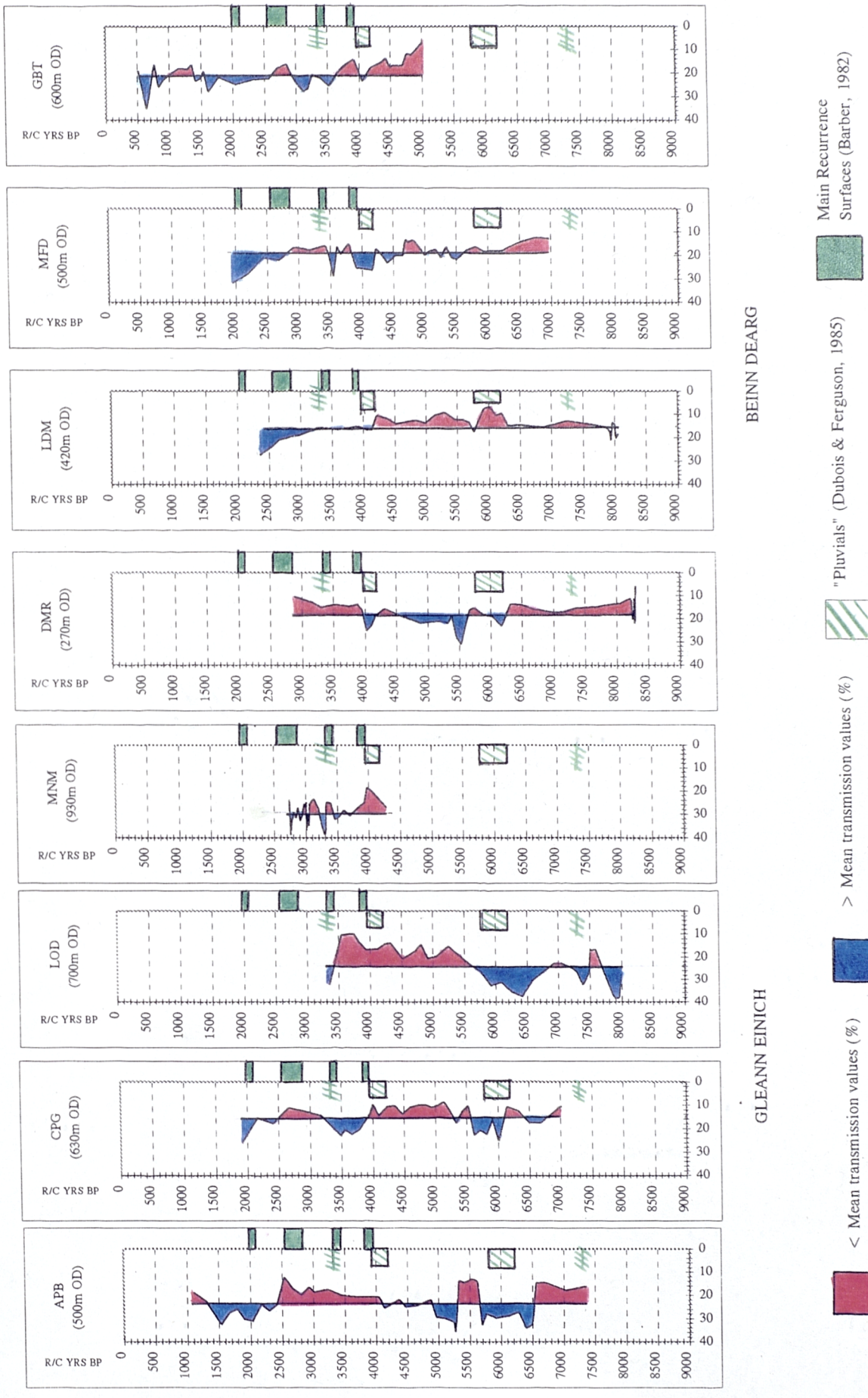
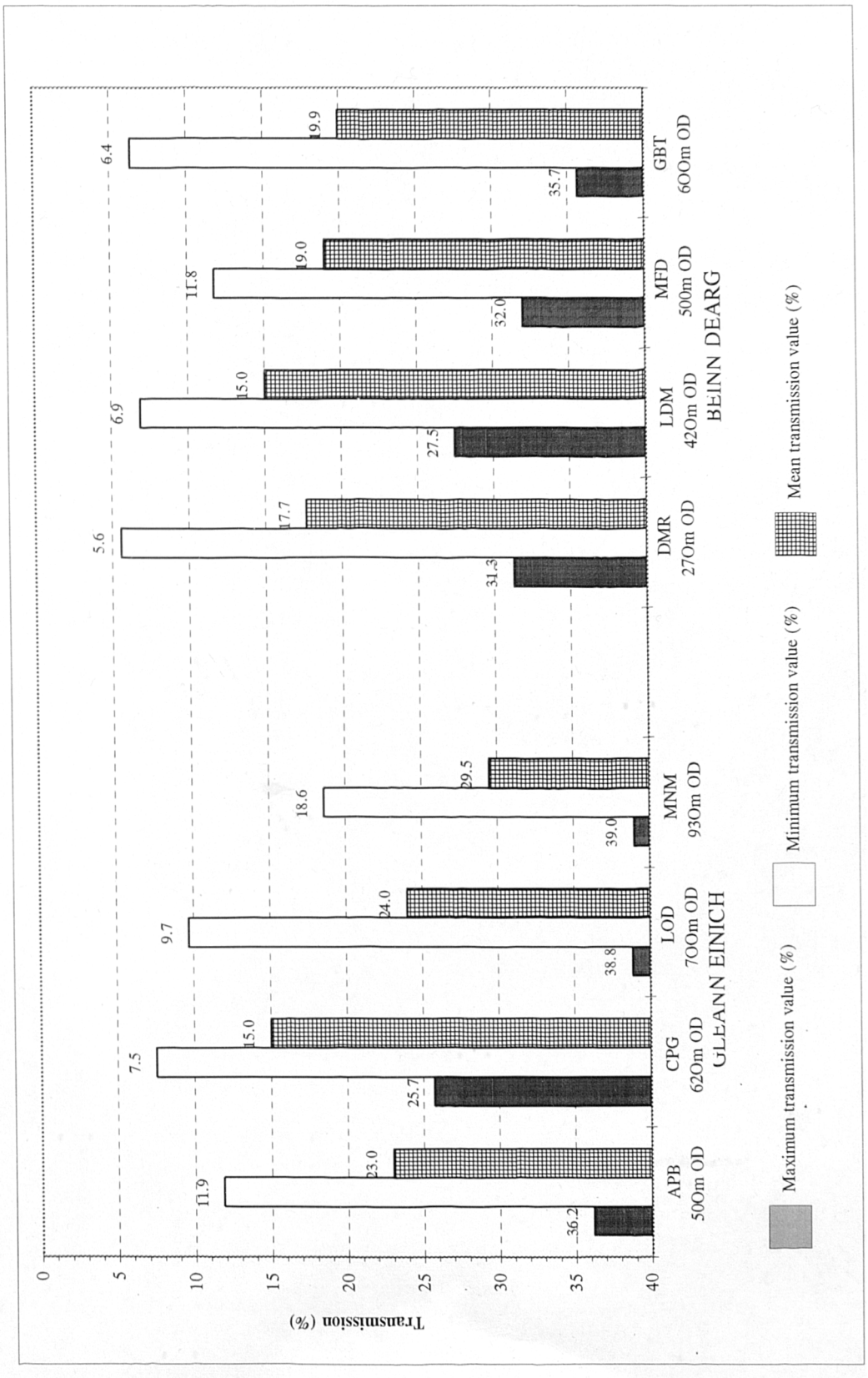


FIGURE 8.5. HUMIFICATION VARIATIONS (EXPRESSED AS MAXIMUM, MINIMUM AND MEAN TRANSMISSION VALUES) FOR ALL SITES INVESTIGATED, ILLUSTRATING BETWEEN-SITE, AND INTER-AREA VARIATIONS AND RELATIONSHIPS OF HUMIFICATION TO ALTITUDE.



The Beinn Dearg sites (with the exception of MFD) generally show lower minimum transmission values than those for the Gleann Einich sites. This indicates that the peat profiles sampled from Beinn Dearg are relatively more humified (show higher extremes of humification) than those from Gleann Einich. As mentioned in Section 7.5.2 this is somewhat surprising, since Beinn Dearg was selected to provide a relatively "oceanic" sampling transect to compare with the relatively "continental" transect at Gleann Einich.

TABLE 8.4 Minimum degree of humification (maximum percent transmission values) for sites investigated at Gleann Einich and Beinn Dearg

GLEANN EINICH	BEINN DEARG
MNM (930m OD) (39.0%)	
LOD (700 m OD) (38.8%)	
APB (500m OD) (36.2%)	
	GBT (600m OD) (35.7%)
	MFD (500m OD) (32.0%)
	DMR (270m OD) (31.3%)
	LDM (420m OD) (27.5%)
CPG (630m OD) (25.8%)	

With the exception of CPG, therefore, the Glean Einich profiles show the highest maximum transmission values indicating that the Gleann Einich sites are generally less humified than the Beinn Dearg sites. It is also interesting to note that the highest altitude sites on both transects show the lowest minimum degree of humification.

TABLE 8.5 Mean degree of humification (mean percent transmission values) for sites investigated at Gleann Einich and Beinn Dearg

GLEANN EINICH	BEINN DEARG
CPG (630m OD) (15.0%)	LDM (420m OD) (15.0%)
	DMR (270m OD) (17.7%)
	MFD (500m OD) (19.0%)
	GBT (600m OD) (19.9%)
APB (500m OD) (23.0%)	
LOD (700m OD) (24.1%)	
MNM (930m OD) (29.5%)	

Again, in general, with the exception of CPG (Gleann Einich) the Beinn Dearg sites show a higher mean degree of humification.

Similarly, the transmission values from the Gleann Einich sites show a greater variation about the mean than the Beinn Dearg sites (see Figure 8.5). The exception to this trend at Gleann Einich is CPG which shows a higher mean degree of humification and a lower variance than the other sites investigated on this transect. Therefore the CPG transmission values show a similarity with the character of transmission values from the sites investigated at Beinn Dearg. The transmission values for CPG (mean value of 15%, maximum of 26% and minimum transmission of 7.5%) are similar to LDM (15%, 27.5% and 6.9% respectively).

As discussed above (Section 8.3) this is considered to be related to the dominant vegetation community colonising the site at CPG. CPG shows a relatively high representation of *Calluna* pollen (Figure 8.3) in comparison with the other Gleann Einich sites. The *Calluna* pollen frequencies at CPG are of a similar magnitude to those at the Beinn Dearg sites and the peat growth rates are therefore probably slower under the heath-dominated community (*cf.* Chambers, 1984). This is supported by the evidence of the higher annual mass loss of *Calluna* (25.6%), relative to Sphagna (16.2%) (Coulson and Butterfield, 1978) (see Section 5.2.6). This slower accumulation rate would be reflected as higher degree of humification since the upper peat layers would have a longer "mean residence time" within the acrotelm (term introduced in Section 8.3). The lower mean transmission values at CPG and at the Beinn Dearg sites are therefore related to the vegetation community colonising the mire surface and may not indicate generally drier climatic conditions.

So, in summary, the general characteristics of the relatively "oceanic" Beinn Dearg sites are:

i) higher minimum degree of humification
ii) higher maximum degree of humification
iii) higher mean degree of humification
iv) lower variability about the mean (Beinn Dearg sites are more humified but show lower extremes in values than the Gleann Einich sites).

The generally higher degree of humification recorded at the Beinn Dearg sites needs to be explained and three suggestions are:

1. The prevailing warm westerlies at Beinn Dearg and generally lower altitudes result in higher mean January temperatures (3.0°C) than for Gleann Einich (2.5°C) However, the mean July temperatures at Beinn Dearg (13.5°C) are lower than those for Gleann Einich (14.0°C). Since humification is a factor of temperature as well as relative humidity, the higher mean January temperatures at Beinn Dearg might provide an explanation for the higher mean and maximum degree of humification recorded at Beinn Dearg.

   Supporting evidence for the generally lower degree of humification (and probably wetter conditions) indicated from the peat profiles at the Gleann Einich sites transect is:

   i) the higher proportion of *Sphagnum* leaves preserved in the peat matrix
   ii) high frequency of wet indicating fungal and algal remains

2. Higher altitude of the Gleann Einich sites. MNM and LOD (930m and 700m OD respectively) are higher than the highest Beinn Dearg site. This would again be related to the affect of temperature on the degree of humification (since there is reduction in temperatures at higher altitudes). However, two of the Beinn Dearg sites with comparable altitudes to Gleann Einich (MFD at 500m OD and GBT at 600m OD) do not show

comparable transmission characteristics (i.e. maximum, mean and minimum) which would indicate that sites from similar altitudes from different transects cannot be compared.

3. The dominant vegetation community colonising the mire surface. As mentioned above, *Calluna* pollen is generally more frequent at the Beinn Dearg sites and at one site on the Gleann Einich transect (that of CPG). Therefore, since heathlands tend to accumulate more slowly than sedge or *Sphagnum* dominated mires then this may be affecting the humification values (*cf.* Chambers, 1984). Since humification is also a function of the length of time the peat matrix remains in the acrotelm of the profile, higher humification can be expected to be associated with heathland dominated mires.

Barber (1982) suggests that some lowland raised bogs, such as Bolton Fell Moss near Carlisle, may be particularly sensitive to climatic fluctuations since they are situated between areas "where conditions are so wet that only the peaks of surface dryness may be reflected in an otherwise 'wet' stratigraphy (e.g. bogs in Western Ireland) whereas others, in a drier zone, may reflect only large shifts to greater surface wetness (e.g. bogs in central Germany)".

This potential for reflecting shifts in the prevailing climatic conditions might explain the lower variation about the mean transmission values recorded at Beinn Dearg (in comparison to Gleann Einich). If the generally higher degree of humification recorded at Beinn Dearg is a factor of the dominant mire vegetation community (as suggested above) rather than a factor of a relatively drier climate, then the wet shifts recorded in the peat stratigraphy (as indicated by lower humification values) might be expected to be less extreme if the prevailing climate is already wet. Since the Cairngorms are more continental in terms of climate (greater extremes in winter/summer temperatures and a generally lower annual precipitation of *c.*1,000 to 1,600 mm yr^{-1} compared to *c.*1,600 mm yr^{-1} at Beinn Dearg) the Gleann Einich sites might be expected to show these shifts to wetter or drier climatic conditions more extremely. Hence the greater variation about the mean transmission values recorded at the Gleann Einich sites. Therefore, the parameters discussed above (prevailing climate, altitude and vegetation colonising mire surface) might provide a method for assessing the suitability of a peat profile to record environmental change. This will be discussed further in Section 8.11.

To test the reliability of transmission values as indicators of drier or wetter climatic conditions, the data from Beinn Dearg and Gleann Einich can be compared with other regional climate models.

Recurrence Surfaces are horizons in a peat profile where there is a change from a relatively well-humified dark peat matrix to a relatively poorly humified light-coloured *Sphagnum* peat

(Barber, 1982) (see Section 3.5.4). The opposite change in stratigraphy, to a relatively well-humified peat cannot be used as a fixed reference point between sites since it may merely represent an increase in humification due to the build up of the mire surface (under drying or constant moisture conditions) above the recurrence surface 'wet datum' (Barber, 1982).

Barber (1982) summarises the various lines of evidence for climatic change in the later prehistoric period derived from peat-stratigraphic data (generally lowland raised bogs) and concludes that the following significant wet shifts (Recurrence Surfaces) can be identified:

1. Probable climatic deterioration at *c.*3,950-3,850 BP (may have been minor in nature)
2. More pronounced climatic decline at *c.*3,450-3,350 BP
3. Catastrophic decline to a cooler and/or wetter climate around *c.*2,850-2,550 BP (known as the Grenzhorizont)
4. Some evidence for a further decline around 2,050 BP.

Although, Haslam (1987) demonstrated a wide spread of dates for the Recurrence Surface thought to correspond to the Grenzhorizont in mires from Ireland to Poland, studies of many mires have produced evidence for changes to wetter conditions in the period 2,800-2,200 BP (Blackford, 1993). This provides a reference humification signal against which the data from Beinn Dearg and Gleann Einich can be further tested.

As shown in Figure 8.4 (transmission values for all eight sites on age axes) the Beinn Dearg profiles show evidence for the wet shifts outlined above, particularly between 2,850-2,500 BP. The Gleann Einich sites (APB and CPG) show evidence for less humified conditions after 2,500 BP which corresponds with the more conservative age range for the Grenzhorizont summarised by Blackford (1993). Since all of the profiles investigated (which extend into the period represented after *c.*3,000 BP) show shifts towards less humified peat at or just before *c.*2,500 BP, this suggests that the method adopted here for investigating the degree of humification of the peat matrix provides meaningful results. In addition, this indicates that the mire surface of the sites investigated in this study were sufficiently sensitive to reflect the deterioration of climatic conditions between *c.*2,850-2200 BP as a shift to a lower degree of humification. Therefore the changes to a lower degree of humification identified lower in each of the profiles probably also represent shifts to wetter conditions.

Additional evidence for wetter climatic conditions has been proposed by Dubois and Ferguson (1985) from isotopic analysis of sub-fossil wood obtained from peat in the Cairngorms (termed "pluvials"). The "pluvial" periods are shown schematically (as oblique blue lines) to the right of the humification curves on Figure 8.4.

TABLE 8.6 Humification evidence from profiles investigated at Gleann Einich and Beinn Dearg and correspondence with "pluvials" inferred by Dubois & Ferguson (1985) for the Cairngorms. XXX = predates peat accumulation for site.

R/C YRS BP	APB	CPG	LOD	MNM	DMR	LDM	MFD	GBT
*c.*3,300 BP	NO	YES	YES	YES	NO	NO	NO	YES
4,200-3,950 BP	NO?	NO	NO	NO	YES	YES?	YES	YES?
5,800-6,200 BP	YES	YES	YES	XXX	YES	NO	NO	XXX
*c.*7,300 BP	NO	XXX	YES	XXX	NO	NO	XXX	XXX

It appears from the data presented here that the "pluvials" identified in the Cairngorms by Dubois and Ferguson (1985) do not correspond precisely with episodes of lower degree of humification at the Gleann Einich sites. The best correspondence appears to be the "pluvial" estimated to have occurred at *c.*5,800-6,200 BP which coincides with a lower degree of humification at all of the sites at Gleann Dearg with the exception of MNM where the peat accumulation post-dates this period.

It is interesting to note that the shift to wetter conditions inferred between *c.*4,200-3,800 BP (Dubois and Ferguson, 1985) in the Cairngorms coincides with a shift to slightly higher transmission values by all of the Beinn Dearg sites (hence indicating a lower degree of humification). In contrast, the only Gleann Einich site to reflect a change to less humified conditions during this period is CPG, which as indicated above, appears to show similar characteristics in transmission values to the Beinn Dearg sites rather than the Cairngorms sites. Birks (1972) interprets the major decline of pine in the Northwest Highlands between *c.*4,250 and 4,000 BP as a response to increased "oceanicity" and moisture which resulted in pine being restricted to better drained slopes where blanket peat could not develop. The results of the humification analyses from the Beinn Dearg profiles supports this hypothesis.

To summarise, there is evidence for a synchronous shift to a lower degree of humification at Gleann Einich between *c.*6,200-5,600 BP which corresponds well with the "pluvial" identified between *c.*6,200-5,800 BP (Dubois and Ferguson, 1985). This "pluvial" however, is not indicated by the transmission values from the profiles at Beinn Dearg. Beinn Dearg shows evidence for a synchronous shift to slightly less humified conditions at *c.*4,000 BP which corresponds with the "pluvial" identified between 4,200-3,950 BP.

Beinn Dearg and Gleann Einich both show evidence for a shift to a lower degree of humification after *c.*2,500 BP which corresponds with the Grenzhorizont identified across Northwest Europe between 2,800-2,200 BP (Blackford, 1993).

Since there are several episodes of synchroneity in the humification records from Beinn Dearg and at Gleann Einich, particularly the representation of the main recurrence surface after *c.*2,800 BP, it is concluded that valleyside blanket mire types (moisture-collecting sites such as APB and LDM) can provide significantly useful palaeohydrological evidence as can saddle mire types (water-shedding sites such as LDM and MFD).

8.5 POLLEN CONCENTRATION AND DEGREE OF HUMIFICATION

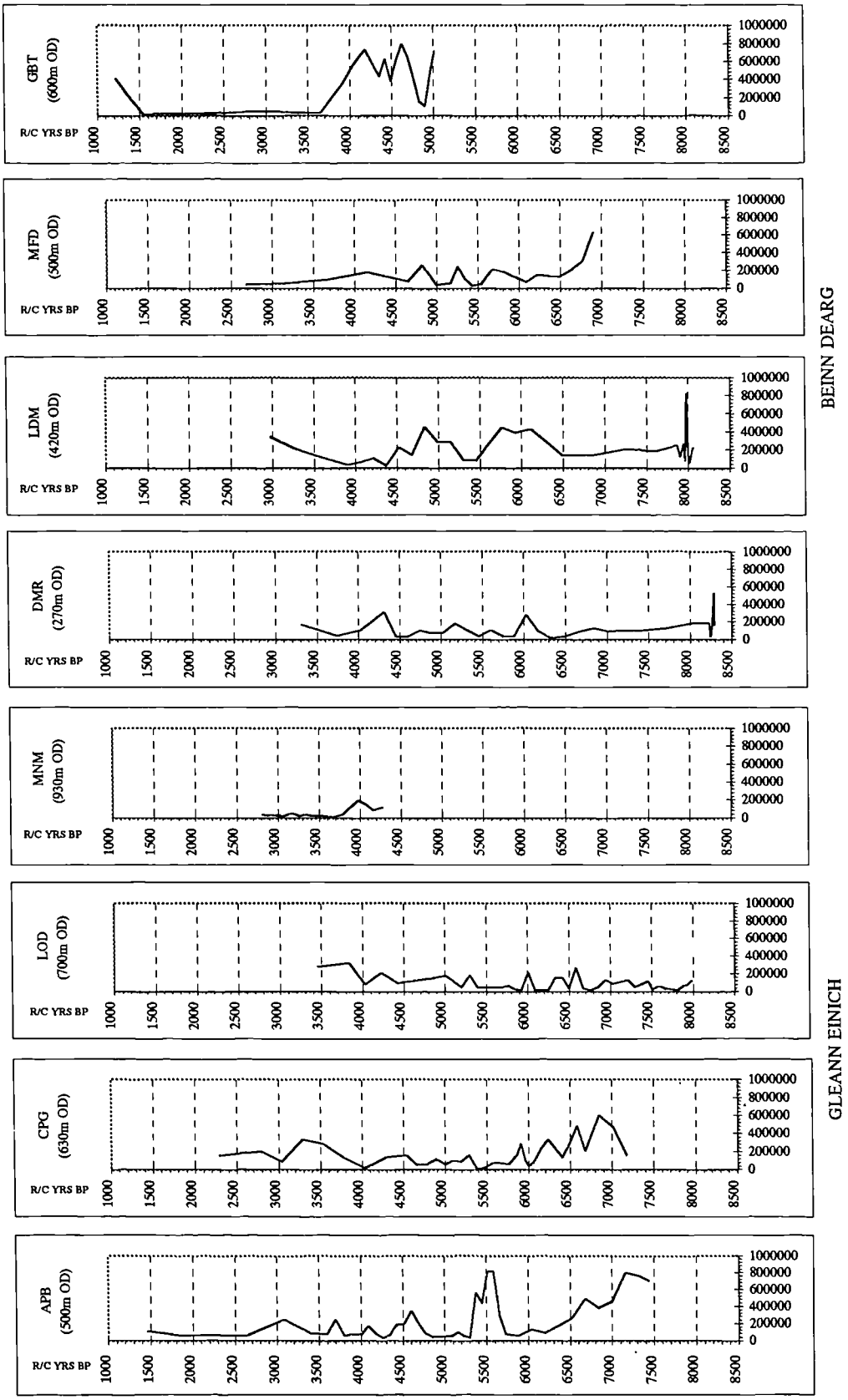
The trend towards generally lower total pollen concentration values with increasing altitude observed in the profiles from the Gleann Einich transect is not shown at Beinn Dearg. Paradoxically, the highest site investigated at Beinn Dearg (GBT) shows considerably higher pollen concentration values (Section 7.5.1.2). The total pollen concentrations from all site on both transects are shown plotted to common age axes (radiocarbon years BP) in Figure 8.6. The identification of synchronous episodes of high or low pollen concentration values is not considered worthwhile since pollen concentration has been shown to often correspond with the degree of humification. However, the fact that the GBT profile exhibits the lowest mean degree of humification of the Beinn Dearg sites but relatively high total pollen concentration values, indicates that the pollen recruitment and preservation at this site is not straightforward. Further investigation is required at a site intermediate in altitude between MFD and GBT or at a similar altitude to GBT in the adjacent valley before fuller interpretation of the pollen concentration anomaly can be made.

This investigation highlights the necessity for supplementary humification evidence from peat profiles for the full elucidation and interpretation of pollen concentration and influx data. The relationship also needs to be tested statistically. Correspondence analysis was undertaken on the datasets from the eight profiles investigated in this study, but since i) the depth of sampling intervals for humification and pollen analysis was not identical, and ii) often only portions of the profile plots (visually) indicated a degree of correspondence between the datasets, the resultant correlation coefficients revealed a differential pattern between pollen concentration and degree of humification (as a function of depth).

8.6 ENVIRONMENTAL CONDITIONS FAVOURABLE FOR THE PRESERVATION OF WOOD MACROFOSSILS

The results from this investigation support the hypothesis of Birks (1975) and Pears (1975, 1988) that the presence of pine macrofossils (pine stumps) is a factor of the local environment rather than an indication of the former density of the pine woodland. Pine stumps were recorded in the peat profiles at APB, CPG, DMR, and LDM and in all cases the stumps coincide with a high degree of humification of the peat matrix, and are generally located towards the upper part of a phase of relatively well humified peat. Since one of the original objectives of this project was to investigate the relationship between the upper limit

FIGURE 8.6. TOTAL POLLEN CONCENTRATION VALUES FOR THE SITES INVESTIGATED AT GLEANN EINICH AND BEINN DEARG PLOTTED ON AGE AXES (RADIOCARBON YEARS BP)



of preservation of pine stumps along an altitudinal transect, this coincidence with the degree of humification indicates that a minimum degree of humification is necessary for the establishment of pine on the mire surface and its subsequent preservation within the peat matrix as shown in Table 8.7.

TABLE 8.7 Pine stump preservation and degree of humification at Gleann Einich and Beinn Dearg sites

SITE	Altitude	Estimated age (R/C years BP)	Transmission values
<u>Gleann Einich</u>			
APB	500m OD	2,500-3,000 BP	20-12%
CPG	620m OD	6,500-6,000 BP	11-16% (intermediate 25.5%)
		4,400-4,700 BP	9-9% (intermediate of 12%)
<u>Beinn Dearg</u>			
DMR	270m OD	7,100-6,100 BP	17.5-11%
		>3,200 BP	13-10%
LDM	400m OD	*c.*4,500 BP	15%
		6,500-6,250 BP	15%

Although the preservation of pine stumps depends on the local presence of pine trees on the mire surface it appears from these data that the maximum transmission values which correspond to the preservation of pine stumps are *c.*25% at Gleann Einich and *c.*15% at Beinn Dearg. This may indicate that pine trees were able to colonise a wetter mire surface (less humified peat matrix) in the Cairngorms than at Beinn Dearg. However, the establishment of pine trees on a wetter substrate at Gleann Einich may also be related to the density of the surrounding woodland. If, as the higher pine pollen frequencies indicate, Gleann Einich supported a denser woodland than Beinn Dearg, there would presumably have been a greater production of seeds in the vicinity of the site and therefore a greater chance of pine establishment on the mire surface.

If there is a minimum humification value for the establishment of pine on the mire surface, as indicated above, the problem still remains as to whether the absence of pine macrofossils at a site is indicative of the absence of pine trees in the area. This problem is further exacerbated where relatively high pine pollen frequencies are recorded as for the highest two sites on each transect (over 40% at MNM and over 20% at GBT) which can be interpreted as the local establishment of pine for each of the two site areas.

8.7 FUNGAL/ALGAL REMAINS

The record of fungal and algal remains provides important supplementary independent proxy evidence to test and strengthen the interpretation of the humification data as indicated by the transmission values. As stated in Section 8.4, since a shift to a higher degree of humification may also reflect the build up of the mire surface above the "wet datum" of the recurrence surface of raised mires (Barber, 1982), the less humified episodes will be tested against the fungal and algal evidence.

The fungal and algal remains which have been shown to indicate wetter conditions are the Types 31a and 32 (e.g. Van Geel, 1978; Aaby and Tauber, 1975). These types are the remains of the rhizopods *Amphitrema flavum* and *Assulinea* spp (Types 31a and 32 respectively) and are relatively easy to identify (particularly Type 31a) and therefore reduce the possibility of misidentification.

Figure 8.7 shows the humification evidence of all eight sites investigated on an age axis (radiocarbon years BP) and the bars to the right the representation of Types 31a and 32 in the stratigraphy.

There is generally a good correspondence with significant shifts to less humified peat and the presence of Types 31a and 32. This is shown particularly well at the Gleann Einich sites APB, LOD and MNM and at the Beinn Dearg sites DMR and GBT. The supplementary evidence of the rhizopod evidence at these sites therefore strengthens the evidence for shifts to less humified peat, and might indicate that the less humified peat is primarily related to wetness (rather than coolness). However, the relative importance of temperature *versus* humidity cannot be resolved since higher temperatures may lead to an increase in the rate of evapotranspiration which would similarly result in a increase in the degree of humification.

The absence of Types 31a and 32 at CPG and very low representation of Types 31a at LDM and MFD (Type 32 is absent) is also significant, since the mean transmission values indicate that these sites are relatively well humified (and therefore probably dry). In general, the low frequency of Types 31a and 32 at the Beinn Dearg sites indicates that the profiles on this transect are relatively dry compared to the Gleann Einich profiles. This is again surprising since, as stated above, Beinn Dearg was selected as the warmer and wetter "oceanic" site but this may be related to the greater *Calluna* cover at these sites (as discussed in Section 8.4).

The table below summarises the frequencies of Types 31a and 32 from the Beinn Dearg and Gleann Einich sites.

FIGURE 8.7. DEGREE OF HUMIFICATION (% TRANSMISSION) OF SITES INVESTIGATED AT GLEANN EINICH AND BEINN DEARG, PLOTTED ON AGE AXES (RADIOCARBON YEARS BP) (SHOWING PRESENCE OF WET-INDICATING FUNGAL/ALGAL REMAINS)

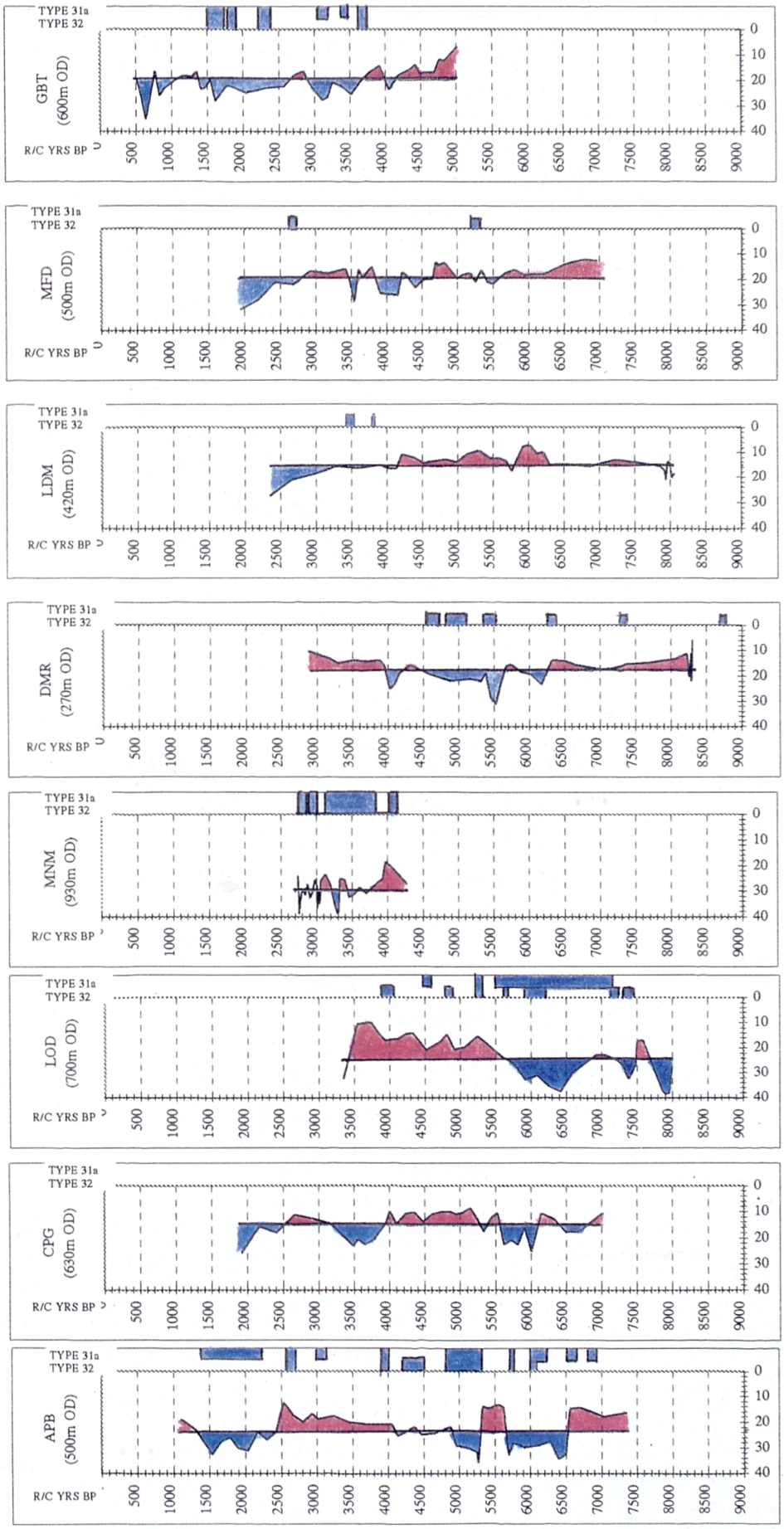


TABLE 8.8. Summary of transmission data and representation of Types 31a and 32 for Gleann Einich and Beinn Dearg transects.

GLEANN EINICH

	Mean Trans	Min Trans	Max Trans	Type 31a	Type 32
APB	23.0%	11.9%	36.2%	<42%	<6%
CPG	15.0%	7.5%	25.8%	Absent	Absent
LOD	24.1%	9.7%	38.8%	<132%	<10%
MNM	29.5%	18.6%	39.0%	<14%	<17%

BEINN DEARG

	Mean Trans	Min Trans	Max Trans	Type 31a	Type 32
DMR	17.7%	5.6%	31.3%	Absent	<1.2%
LDM	15.0%	6.9%	27.5%	<1.1% (top 2)	Absent
MFD	19.0%	11.8%	32.0%	<0.3%	Absent
GBT	19.9%	6.4%	35.7%	<5.1%	<3.4%

The higher frequencies of Types 31a and 32 often correspond with the sites with a high mean transmission value (and are hence generally less humified). Therefore, this evidence confirms the observation that the Gleann Einich sites were generally wetter, or less humified than the Beinn Dearg sites, with the exception of CPG, which again shows a similarity with the Beinn Dearg sites (as suggested in the discussion of the humification results, Section 8.4).

In summary, the sites which favour the presence of Types 31a and 32 are:

1. Minimum degree of humification values >32% (transmission) (i.e. extremely fresh peat)
2. Mean degree of humification >*c.*19% (transmission) (i.e. not highly humified)

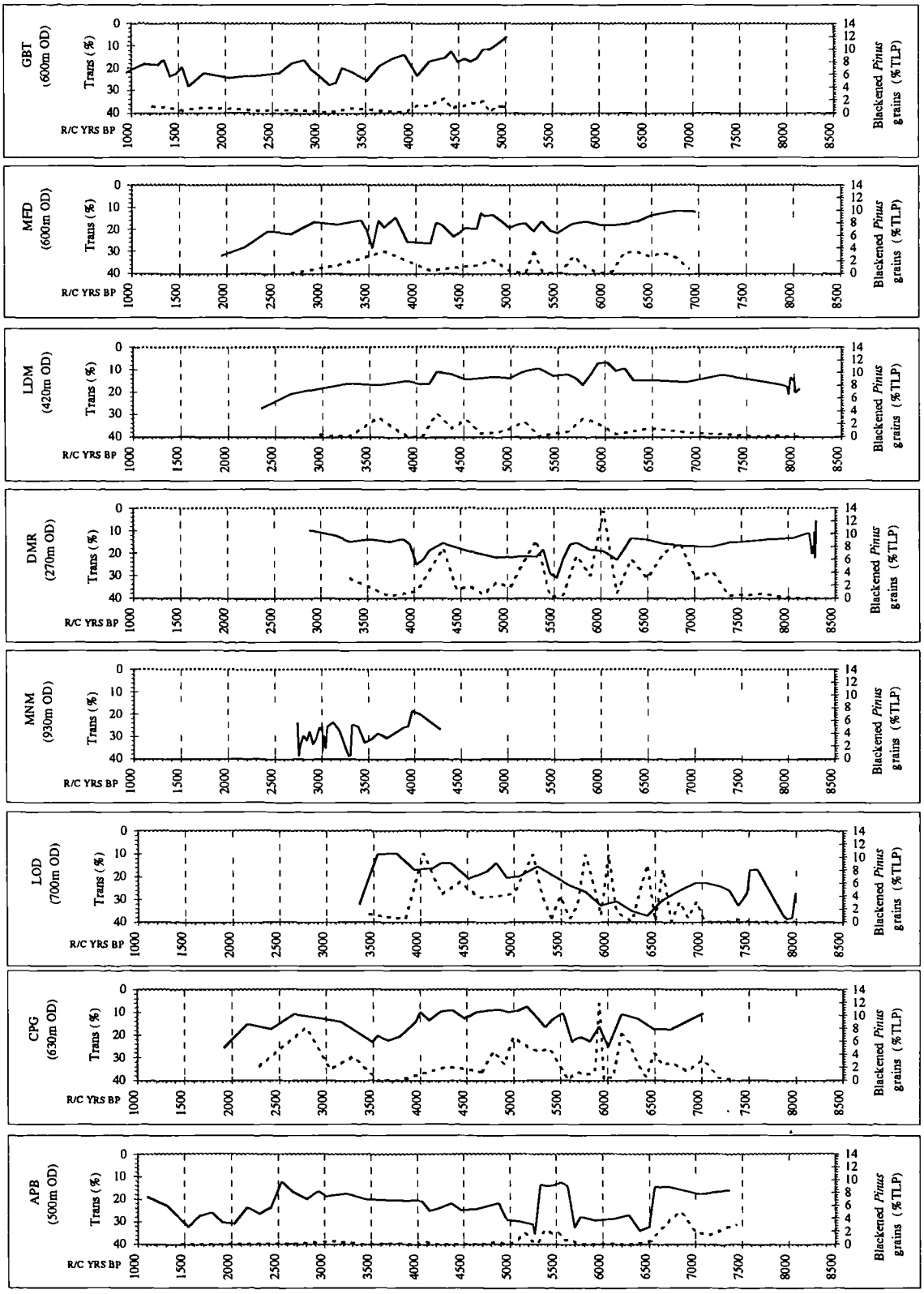
This study therefore highlights the fundamental importance of the employment of multi-proxy independent evidence for the reconstruction of environmental change and provides an insight into the diversity of the potential palaeoecological data available from blanket peats.

8.8 BLACKENED PINUS GRAINS

The frequency of blackened *Pinus* pollen grains recorded during routine pollen analysis indicate that their abundance is related to the degree of humification of the peat matrix. However, there is no consistent correspondence with highly humified peat and other factors need to be considered such as dominant vegetation cover and pollen provenance.

Figure 8.8 shows the relationship between the degree of humification (% transmission) and the frequency of blackened *Pinus* grains (%TLP) plotted on age axes for the eight sites investigated. There is a generally a good correspondence between low transmission values

FIGURE 8.8. THE DEGREE OF HUMIFICATION (EXPRESSED AS % TRANSMISSION) AND FREQUENCY OF BLACKENED *PINUS* GRAINS (%TLP) PLOTTED ON COMMON AGE AXES (RADIOCARBON YEARS BP)



——— Degree of humification (Transmission values %)

- - - - - - - - - Blackened *Pinus* grains (%TLP)

(high degree of humification) and an increase in the frequency of blackened *Pinus* pollen grains. This suggests that the formation of blackened *Pinus* grains is an on-site process and is related to the relative wetness of the mire surface at the time of pollen deposition.

One of the significant features of Figure 8.8 is the absence of blackened *Pinus* grains represented at MNM and the very low frequencies represented at GBT, both of which are the highest site on each transect (930m and 600m OD respectively). The mean transmission values for these sites are the highest for each transect (29.5% for MNM and 19.9% for GBT) and there may, therefore, be a minimum threshold of degree of humification for the blackening of the *Pinus* grains to occur. MNM and GBT also have the highest total mean peat accumulation rates for both transects (14.2 cm100yr^{-1} and 4.1 cm 100yr^{-1}), therefore if the blackening of the *Pinus* grains is an on-site process this suggests that it may be related to the mean residence time the *Pinus* grains remain in the acrotelm of the peat matrix (and therefore related to the degree of humification).

However in addition, the relationship between a higher degree of humification and the frequency of blackened *Pinus* grains may also be linked to the relative "age" of the profile. The proportion of blackened *Pinus* grains is often greater in the lower portion of the profiles (for example APB, DMR and GBT). Bearing in mind that this is also a reflection of the greater density of pine woodland establishment during the periods represented lower down the profile (and hence higher *Pinus* pollen frequencies) it may also be an indication that the process which causes the blackening of the grains continues after the peat matrix becomes incorporated in the catotelm. If this is so, the frequency of blackened *Pinus* grains might indicate that humification occurs within the acrotelm and that a "secondary" humification occurs (probably at a much lower rate) within the catotelm (however this would be very difficult to test).

8.9 TREE-LINE DYNAMICS

In the light of the assessment of the site-specific factors considered in the preceding sections of this chapter, an attempt will be made in this section to assess the pollen-stratigraphic evidence for changes in the relative position of the tree-line, or probably more realistically, changes in the relative density of the pine woodland canopy.

The problems associated with the identification of tree-line changes from pollen-stratigraphic data encountered in this investigation are the following:

1. *Pinus* pollen percentages are often dependent on the vegetation forming the understorey layer and colonising the mire surface
2. Pollen concentration and influx data may be affected by the degree of humification of the peat matrix

3. Identification of synchronous changes of pollen-stratigraphic data is dependent on accurate radiocarbon age estimates and the interpolation between these ages.

With these limitations in mind, additional methods for the identification of tree-line changes from pollen-stratigraphic evidence were considered:

1. *Pinus/Calluna* pollen ratio <1 as an indication of an opening of the pinewood canopy (cf Jennifer McConnell, personal communication). Since some of the sites investigated are located at or above the altitudinal limit of *Calluna vulgaris,* this ratio cannot be adopted as an index in all cases.
2. Increase in the pollen frequency of species indicative of the zone above the tree-line, for example, *Empetrum* spp. This provides a supplementary guide for the identification of lower tree-lines but cannot be used as a primary source of evidence, because of the low *Empetrum* frequencies recorded, particularly in the Beinn Dearg profiles.

Although the first method has limited potential for some of the sites investigated (since some of the sites lie above the present altitudinal limit of *Calluna*), both of the above indices were assessed in parallel with the *Pinus* pollen data to determine episodes of dense and open pine woodland cover, and hence tree-line fluctuations. Figure 8.9 shows the *Pinus* pollen frequencies represented at all eight sites investigated plotted to a common age axis (radiocarbon years BP). Time periods when *Pinus* pollen frequencies exceed thesholds of >20% (TLP) and >30% (TLP) are also shown.

The table below (Table 8.9) assess the supplementary evidence of increases in *Calluna vulgaris* and *Empetrum* pollen frequencies to identify synchronous episodes of lower tree-lines (or a decrease in the relative density of the pine woodland canopy.

TABLE 8.9 Increase of *Calluna vulgaris/Empetrum* and decrease in *Pinus* pollen frequencies. Evidence for lower tree-lines/open pinewood canopy (R/C years BP):

ABP	CPG	LOD	MNM	DMR	LDM	MFD	GBT
6,500	**6,400**	**6,500**		**6,300**		**6,350?**	
	5,900					5,900	
5,600	**5,400**	**5,400**		**5,200**	**5,300**	**5,400**	
4,000		**4,000**			**3,800**		**4,200**
			3,000?				

FIGURE 8.9. *PINUS* POLLEN FREQUENCIES (%TLP) FOR SITES INVESTIGATED AT GLEANN EINICH AND BEINN DEARG PLOTTED ON COMMON AGE AXES (RADIOCARBON YEARS BP)

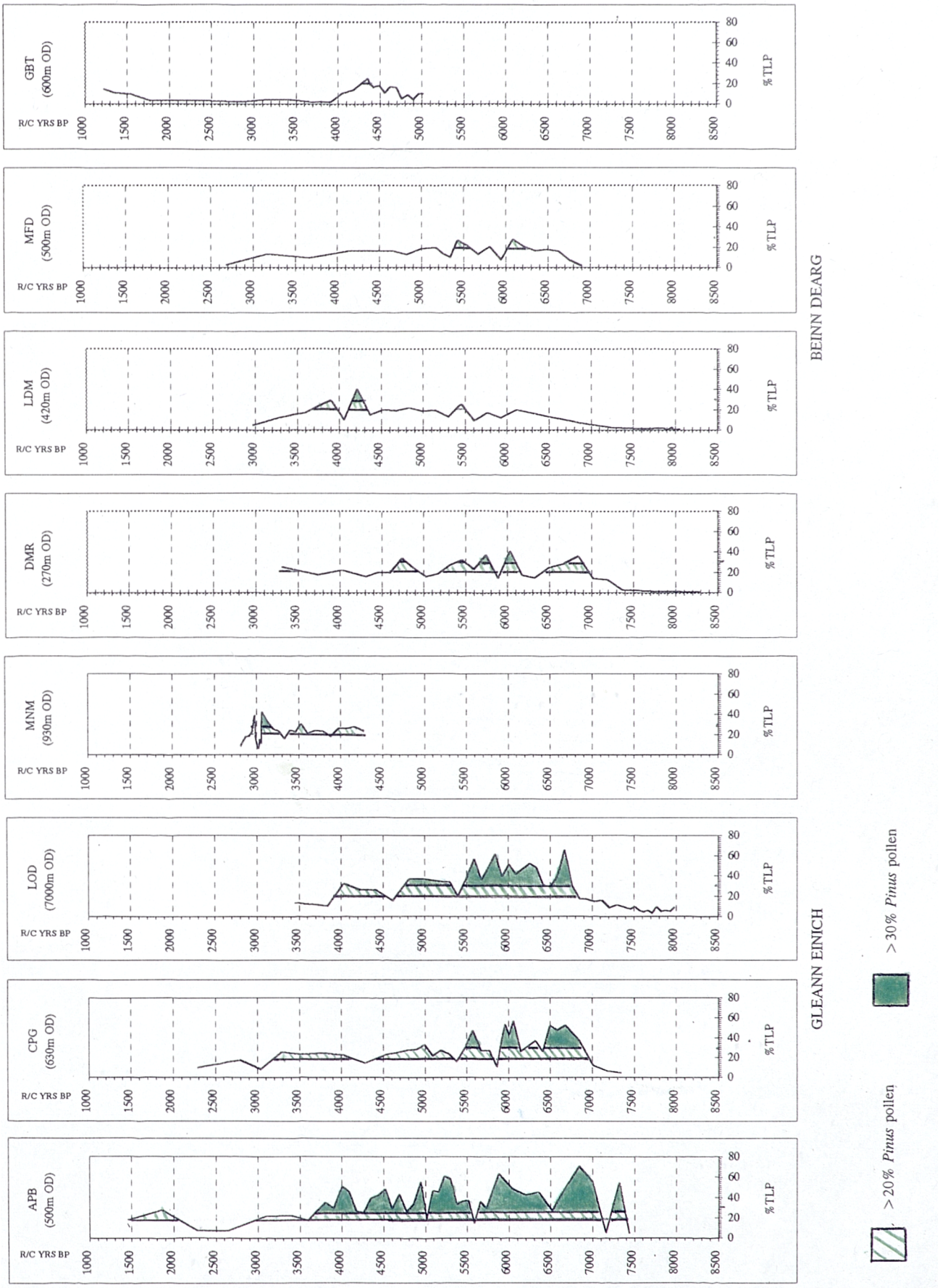


TABLE 8.10 Decrease of *Calluna vulgaris/Empetrum* and increase in *Pinus* pollen frequencies. Evidence for higher tree-lines/dense pinewood canopy (R/C years BP):

APB	CPG	LOD	MNM	DMR	LDM	MFD	GBT
7,250	6,750	6,750		6,750			
6,000	6,000	6,000		6,000	6,100?	6,100	
5,900	5,600	5,600		5,500	5,500	5,500	
4,900	5,000	5,000					
4,100		4,100			4250		4,400
			3,100				

Although this sequence of events appears somewhat complicated the broad trends to be identified are:

1. High tree-lines (relatively dense pinewood canopy) following colonisation of pine in both areas.
2. Opening of the pinewood canopy at *c.*6,400 BP at Gleann Einich and possibly at *c.*6,300 BP at Beinn Dearg.
3. High tree-lines (relatively dense pinewood canopy) between *c.*6,250 and *c.*5,500 BP at Gleann Einich and possibly between *c.*6,100 and *c.*5,400 BP at Beinn Dearg.
4. Lower tree-lines (opening of the pinewood canopy) at *c.*5,400 at Gleann Einich and *c.*5,300 BP at Beinn Dearg.
5. Higher tree-line at Gleann Einich at *c.*5,000 BP.
6. Higher tree-line (dense pinewood canopy) between *c.*4,200-4,000 BP at Gleann Einich and *c.*4,300-4,200 BP at Beinn Dearg.

The denser pine woodland canopy identified before *c.*6,400 BP and before *c.*4,000 BP in this investigation correspond with the results of Bridge *et al.* (1990) for higher pine pollen frequencies between *c.*6,800-6,600 BP and *c.*4,870-4,660 BP at Rannoch Moor which are interpreted as indicative of high tree-lines. The results from Rannoch Moor, together with a general summary of the results from this investigation, are shown in Figure 8.10. Tree-line dynamics will be discussed further in Section 8.11.

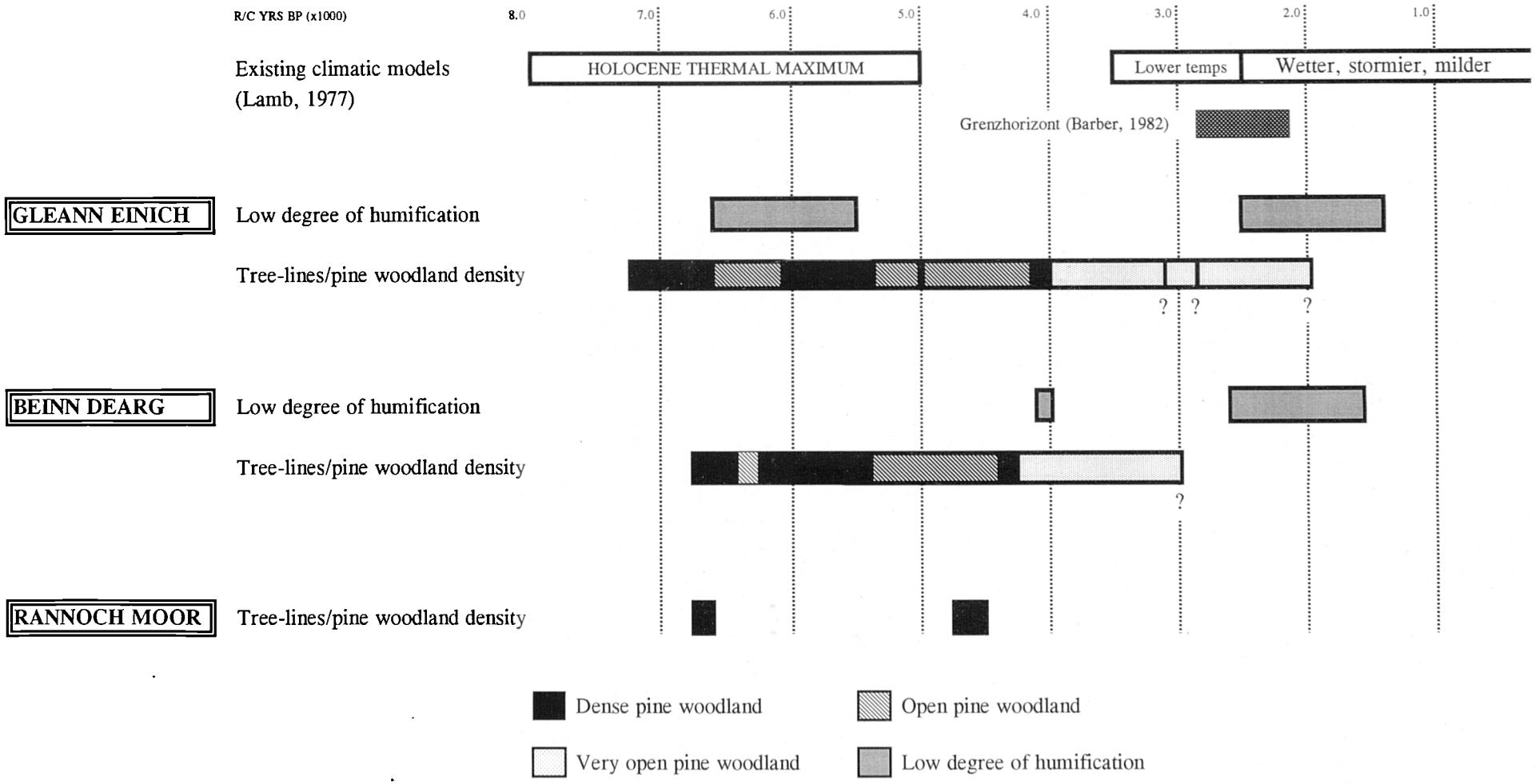


FIGURE 8.10 SUMMARY OF RESULTS FROM GLEANN EINICH AND BEINN DEARG TRANSECTS (WITH COMPARISON OF TREE-LINE CHANGES INTERPRETED AT RANNOCH MOOR (WARD *et al.*, 1987))

8.10 PINE MIGRATION RATES

The generally slower migration rates calculated between the Beinn Dearg sites might also be related to the existing vegetation cover into which pine migrates (as discussed for Gleann Einich, Section 6.5.1.1). At the time of pine colonisation at the sites at Beinn Dearg, *Calluna vulgaris* pollen frequencies and concentration values are generally high in comparison to Gleann Einich.

TABLE 8.11 *Calluna* pollen frequency and concentration at estimated time of pine colonisation for the sites at Gleann Einich

SITE	*CALLUNA* POLLEN %	*CALLUNA* POLLEN (CONC)	PINE MIGRATION RATE (TO NEXT HIGHEST SITE)
APB	60%	400,000 grains/cm^{-3}	1.3 m yr^{-1}
CPG	40%	180,000 grains/cm^{-3}	8.3 m yr^{-1}
LOD	10%	<1,000 grains/cm^{-3}	
MNM	<5%	4,000 grains/cm^{-3}	

TABLE 8.12 *Calluna* pollen frequency and concentration at estimated time of pine colonisation for the sites at Beinn Dearg

SITE	*CALLUNA* POLLEN %	*CALLUNA* POLLEN (CONC)	PINE MIGRATION RATE (TO NEXT HIGHEST SITE)
DMR	40%	50,000 grains/cm^{-3}	2.07m yr^{-1}
LDM	35%	200,000 grains/cm^{-3}	-9.71m yr^{-1}
MFD	60%	50,000 grains/cm^{-3}	0.7m yr^{-1}
GBT	40%	150,000 grains/cm^{-3}	

The slowest pine migration rate at Gleann Einich is between APB and CPG which has a relatively dense *Calluna* understorey at the time of pine colonisation. The generally dense *Calluna* cover at the Beinn Dearg sites at the time of pine colonisation may be an additional reason for slower migration rates. As suggested in Section 6.5.1.1 a relatively dense *Calluna* cover may inhibit the establishment and growth of pine seedlings and therefore effectively reduce the migration rate of pine.

8.11 SYNTHESIS OF POLLEN-STRATIGRAPHIC, HUMIFICATION AND FUNGAL/ALGAL REMAINS DATA AND COMPARISON WITH EXISTING MODELS FOR HOLOCENE CLIMATE CHANGE

Figure 8.10 shows the summary of the results from the analyses undertaken at Beinn Dearg and Gleann Einich together with the pollen evidence for higher tree-lines at Rannoch Moor inferred by Bridge *et al.* (1990). The phases of a low degree of humification are based on the evidence of the transmission measurements from the peat profiles supplemented by the fungal and algal remains data. The tree-line changes are inferred from the pollen stratigraphic data.

The main points are the high tree-lines, or relatively dense pine woodland, interpreted from the pollen stratigraphic evidence for both transects up to *c.*5,400 BP followed by a relatively open pine woodland canopy until shortly before *c.*4,000 BP. At about *c.*4,200 BP at Gleann Einich and *c.*4,400 BP at Beinn Dearg, there is evidence for a short-term re-establishment of pine at higher altitudes and a corresponding increase in the density of the pine woodland canopy at lower altitudes (this will be discussed further below). There is a general decline in the density of pine woodland at *c.*4,000 BP at Gleann Einich and at *c.*4,300 BP at Beinn Dearg. However, the pollen-stratigraphic evidence from the highest site on the Gleann Einich transect (MNM at *c.*930m OD) there is evidence for a short-term establishment of (probably) isolated stands of pine at *c.*3,100 BP and *c.*2,900 BP, but there is no macrofossil evidence to support the hypothesis that pine reached this site area. However, Pears (1968) has located isolated pine stumps up to an altitude of *c.*914m in the Cairngorms, which strengthens the argument that pine was able to colonise the better drained substrates around Moine Mhor.

The pollen-stratigraphic data indicates that pine colonised the lowest site at Gleann Einich (APB, *c.*500m OD) at, or before, the period represented at the base of the profile (*c.*7,250 BP) which compares with the estimate of *c.*6,800 BP at Beinn Dearg. The age estimates for the colonisation of pine at Gleann Einich correspond fairly well with previously published estimates. Birks (1975) suggests that conditions were favourable for the establishment of pine on the mire surface at her Loch Einich site (*c.*500m OD) at *c.*6,000 BP (based on a radiocarbon age estimate of a pine stump) but the pollen evidence shows a rise in *Pinus* pollen frequencies below the corresponding stratigraphic depth of the stump. Similarly, at Allt na Feith Sheilich (595m OD) Birks (1975) infers a minimum age estimate for pine colonisation of *c.*7,000 BP (based on an age determination of pine stumps) which compares with a colonisation estimate of *c.*7,100 BP interpolated by Birks and Mathewes (1978) from O'Sullivan's (1975) results at Loch Pityoulish. The slightly earlier colonisation age estimate for APB (*c.*7250 BP) may reflect that this estimate is based on the interpolated pollen-stratigraphic evidence rather than direct dating of pine stumps. Since this investigation has

shown that macrofossil preservation is often closely linked to the establishment conditions and preservation potential of the individual mires, colonisation estimates based on pollen-stratigraphic evidence are probably more realistic and accurate.

The colonisation of pine at Beinn Dearg was discussed in Section 7.5.1.1, and the slightly later age estimate for this region (*c.*6,800 BP), in comparison to the evidence from Loch Maree and Loch Scionascaig (8,250 BP and 8,000 BP respectively) is interpreted as reflecting the migrational time lag from a dispersal origin from the direction of Loch Maree and/or Loch Scionascaig (approximately 30km distance to the West and Northwest respectively).

The decrease in the density of the pine woodland canopy proposed between *c.*6,400 BP and *c.*6,200 BP at Beinn Dearg and *c.*6,600 BP and *c.*6,100 BP at Gleann Einich compares well with the evidence from Rannoch Moor, where Ward *et al.* (1987) infer a lowering of the altitudinal limit of pine to below 293m shortly after *c.*6,500 BP (see Section 2.2.3). There therefore appears to be a regional decrease in the density of pine woodland cover, and a lowering of the tree-line, commencing between *c.*6,600 BP to 6,500 BP. Birks (1972) infers that pine began to decline from about 6,500 BP at Loch Maree, which may reflect the response of pine to a regional deterioration in climate. However, at Loch Maree, if, as the pollen-stratigraphic data indicates, pine failed to become re-established to its former density in this region, this suggests that the subsequent environmental conditions were not favourable for the growth of pine in marginal habitats and locations.

The pollen-stratigraphic evidence from both Gleann Einich and Beinn Dearg suggest a reduction of the pine woodland canopy shortly after *c.*5,400 BP (which was not identified at Rannoch Moor by Ward *et al.* (1987)) and an explanation for which, based on existing climatic hypotheses cannot be proposed at this stage. It may reflect the theoretical expectations for a decrease in summer solar radiation in the Northern hemisphere following *c.*6,000 BP and a change to reduced seasonality (Imbrie & Imbrie, 1979; Kutzbach & Guetter, 1986).

There is evidence for a return to higher tree-lines shortly before *c.*4,000 BP at both the Gleann Einich profiles (*c.*4,200 to *c.*4,000 BP) and the Beinn Dearg profiles (*c.*4,300 BP and *c.*4,200 BP) which compares with evidence for rise in the altitudinal limit of pine at Rannoch Moor (Ward *et al.*, 1987) at *c.*4,700 BP. This is also comparable to the extension of the northern range limit of pine (in Caithness) inferred by Gear and Huntley (1991) and Charman (1994) shortly before *c.*4,000 BP. Therefore, the evidence from this study indicates that both the altitudinal and latitudinal limit of pine in Northern Scotland responded to a regional change in climate shortly before *c.*4,000 BP. However, the evidence from the highest site investigated at Gleann Einich (MNM, *c.*930m OD) indicate that isolated stands of pine trees

were present in the local region shortly before *c.*3,100 BP. If this evidence is correct, then this suggests that the reduction of pine woodland cover at lower altitudes at this time may not only be a response to regional climate change. MNM is extremely remote (see Figure 5.1) and the survival of pine after the decline at lower altitudes may be related to anthropogenic woodland reduction and clearance at lower altitudes. Further sites need to be investigated, both at altitudes between *c.*700m (LOD) and *c.*930m OD (MNM) and from deeper peat profiles (to obtain a longer time sequence than that represented in the MNM profile) before further conclusions can be reached.

If regional changes in the density of pine woodland canopy can be identified across Northern Scotland it is worthwhile comparing the data with the evidence from other parts of Northern Europe. As outlined in Section 2.3, maximum spread of pine in northernmost Fennoscandia occurred between *c.*7,500 BP and *c.*5,000 BP (Hyvären, 1976) followed by a decline in pine pollen values shortly after *c.*5,000 BP. In the Swedish Scandes, there was a fall in the altitudinal limit of pine from about 4,000 BP (Eronen and Huttunen, 1993) and Kullman (1990) suggests that the decline may have commenced at about 6,000 BP. Kullman (1992) concludes that the steady decline in the altitudinal limit of pine is probably a response to the continuous cooling and change of seasonality caused by a decrease in radiation towards the mid-Holocene (Kutzbach and Gallimore, 1988). However, the published palaeobotanical data from Scandinavia does not show evidence for an increase in the altitudinal and latitudinal (or northern) limits of pine shortly before *c.*4,000 BP as suggested for Northern Scotland (e.g. Gear and Huntley, 1990). This may reflect that the expansion in Northern Scotland of the limits of pine growth was a response to a change in maritime (or oceanicity) influences or weather patterns.

As outlined above, the pollen-stratigraphic data from Gleann Einich and Beinn Dearg suggests that there was a regional decline in the altitudinal limit at about 5,400 BP. This also corresponds to the thermal deterioration which is thought to have occurred at the end of the Atlantic period (*c.*5,000-5,500 BP) followed by a partial recovery (Lamb, 1977; Ballantyne and Harris, 1994). Therefore, the evidence for an increase in the density of pine woodland at CPG (*c.*630m OD) and LOD (*c.*700m OD) at 5,000 BP may reflect a response to this partial reversion to warmer summer conditions. The fact that there is no evidence for this elevation of the regional tree-line at *c.*5,000 BP in the pollen-stratigraphic data from Beinn Dearg might indicate that the threshold for the re-establishment of pine at higher altitudes in this locality was not crossed. Moe (1979) and Karlén (1976) suggest that there is evidence for a short-term increase in the tree-line at *c.*5,000 BP in Scandinavia, which supports the interpretation that a climatic amelioration at this time favoured pine growth in the more "continental" regions (and hence is found at the Gleann Einich profiles).

The evidence for a lower degree of humification at the profiles investigated at Gleann Einich between *c.*6,500 and *c.*5,600 BP is not reflected in the evidence from the profiles at Beinn Dearg sites. In contrast, the lower degree of humification identified in the profiles from Beinn Dearg shortly before *c.*4,000 BP is not represented in the Glenn Einich profiles. The deuterium isotope analyses of pine macrofossils in the Cairngorm Mountains (Dubois and Ferguson, 1985) suggest particularly wet conditions prevailed between 4,200-3,940 BP. The evidence that this "pluvial" episode corresponds to a synchronous shift to a lower degree of humification at all of the Beinn Dearg profiles and only two of the Gleann Einich profiles (CPG and MNM) indicates that each site may have a unique and individual "humification threshold". If, as the evidence of the mean degree of humification values, the types of fungal and algal remains, and the *Sphagnum* macrofossil evidence suggest, the Gleann Einich peat profiles are generally wetter (or less humified) than the Beinn Dearg profiles, the shift to wetter conditions at *c.*4,200-3,940 BP, as identified by Dubois & Ferguson (1985), might not have been sufficiently great, or intense enough, to cause a shift to a lower degree of humification at the majority of the Gleann Einich profiles. In contrast, since the Beinn Dearg profiles show evidence for a higher mean degree of humification, these generally drier (or more humified profiles) may have lower site-specific humification thresholds for responding to wetter conditions. Hence, the Beinn Dearg profiles show evidence for a synchronous shift to a lower degree of humification between *c.*4,200-3,940 BP. Significantly, the exception to the trend at the Gleann Einich sites is CPG, the profile with the highest mean degree of humification and palaeobotanical evidence suggesting generally drier conditions. This profile is inferred as exhibiting humification characteristics similar to the Beinn Dearg profiles (see Section 8.4) and therefore is likely to have a lower humification threshold for responding to a shift to wetter climatic conditions. MNM (*c.*930m OD) at Gleann Einich, also shows evidence for a shift to a lower degree of humification at *c.*4,000 BP but this period is represented at the base of the profile, where the humification is generally relatively high for all of the profiles. The shift to a lower degree of humification may therefore represent the basal accumulation of peat and the formation of the acrotelm.

The evidence for a synchronous shift to lower degree of humification at Beinn Dearg commencing at *c.*2,750 BP is matched by a lower degree of humification at the Gleann Einich sites of APB and CPG at a slightly later date of *c.*2,500 BP (the upper part of the profiles at LOD and MNM are not represented during this period). This corresponds well with a major recurrence surface recognised at many sites across northwest Europe between *c.*2,800-2,200 BP (known as the Grenzhorizont) (Barber, 1982) and the thermal deterioration which is thought to have occurred at around 2,500 BP (Lamb, 1977) when temperatures were approximately 2°C lower than those of the Holocene climatic optimum (*c.*8,000-5,000). The recognition of this major recurrence surface therefore indicates that the method adopted to assess the degree of humification in this investigation is sound. The evidence for synchronous shifts in the degree of humification of profiles from different site types (with

different topographic characteristics) provides an important base for future peat stratigraphic investigations.

In general, the humification evidence supports the proposal of Birks (1975) and Pears(1975, 1988) that the establishment and subsequent preservation of pine stumps is partly controlled by mire surface conditions. The stratigraphic position of the pine stumps in this investigate generally corresponds with the top of a phase of well humified peat indicating that relatively dry mire surface conditions are required for the establishment of pine trees. Since topography has been shown to be an important factor controlling mire surface conditions this provides an explanation for i) the wide range of radiocarbon dates of pine stumps from within peat stratigraphies (cf. Birks, 1975) and ii) situations where pollen-stratigraphic evidence conflicts with macro-fossil evidence for the local presence (or absence) of pine.

CHAPTER 9.0 CONCLUSIONS

This final chapter will draw conclusions on some of the palaeoecological information available from upland blanket mire stratigraphies and future research needs. At the outset of this study, the principal aim was to investigate variations in the upper altitudinal limits of pine woodland in Northern Scotland, and to assess these variations in terms of palaeoclimatic signals. But as with all research, this strategy was adapted slightly as new data became available which might have important implications for palaeoenvironmental reconstructions.

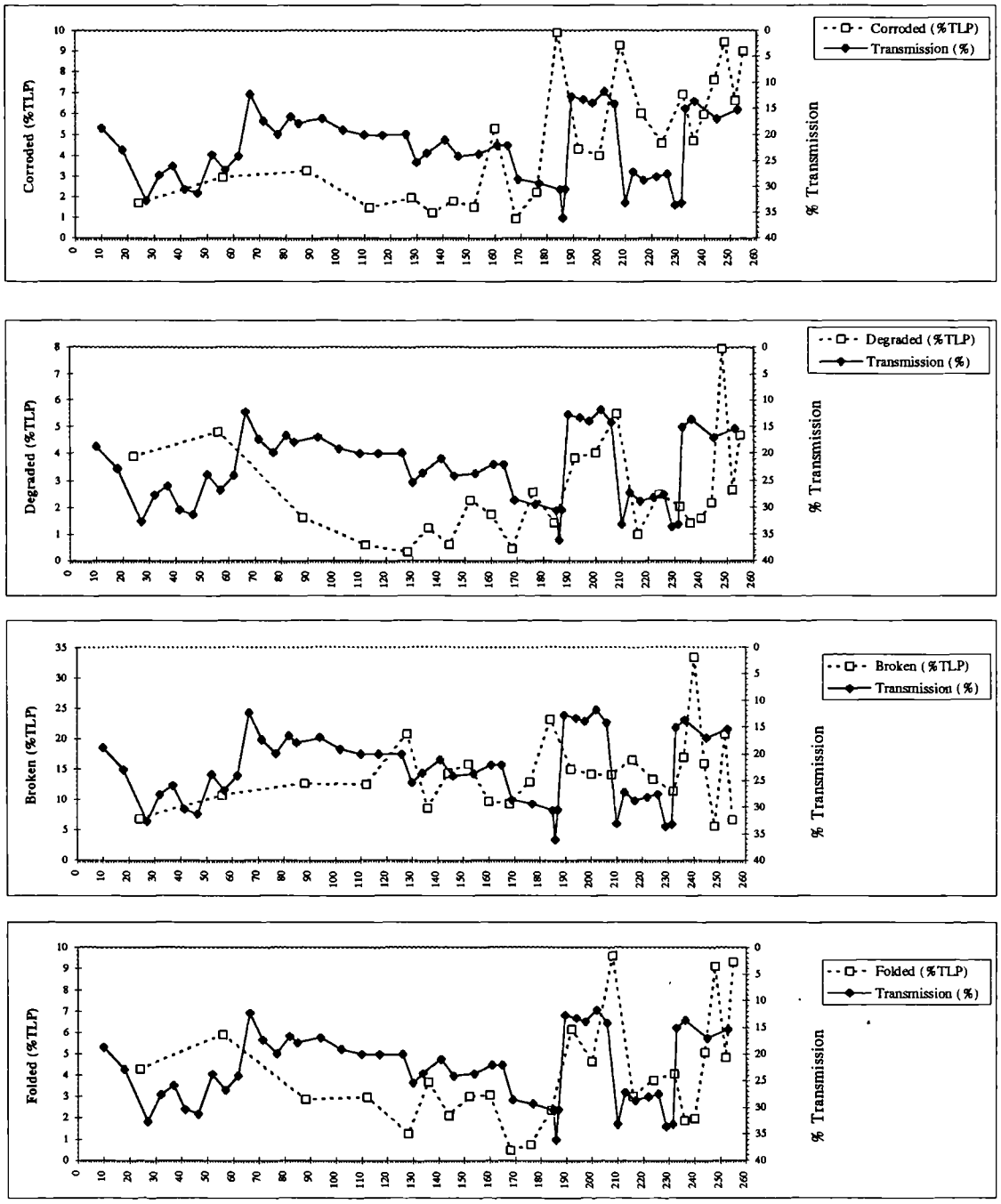
The assessment of the degree of humification of the peat profiles was initially carried out to assess the palaeoenvironmental conditions which favoured the establishment (and subsequent burial) of pine trees on mire surfaces. However, comparison with the pollen-stratigraphic evidence, and in particular the pollen concentration values, indicates that the degree of humification appears to directly, or indirectly, influence the pollen concentration values. A high degree of humification often corresponds with high pollen concentration values and *vice versa*. Aaby (1988) also observed a similar phases of correspondence between pollen influx values and degree of humification at Holmegaard Bog, an ombrotrophic mire complex in southern Denmark. The results presented in this thesis highlight the necessity of the adoption of an objective assessment of the degree of humification when interpreting pollen concentration and influx data from peat profiles. Before a 'degree of humification' correction factor can be considered, or applied, to pollen concentration and influx data, a thorough investigation needs to be undertaken at close sampling intervals of the relationship between the datasets. Pollen influx investigations are heavily dependent upon peat accumulation rates (or deposition times) so to minimise this potential source of error, more radiocarbon dates are required than those available for this study (and ideally AMS dates). The relationship between pollen concentration/influx values and the degree of humification can then be tested statistically with, for example, correspondence analysis.

A second important source of palaeoenvironmental information which was not envisaged at the start of this investigation is the evidence of the fungal and algal remains data. Not only can the fungal and algal types often supplement the pollen-stratigraphic data (and in the absence of plant macrofossils may provide information regarding the likely pollen source area of some species, as found, for example with Type 10 and *Calluna vulgaris* pollen frequencies) but they can provide an additional proxy-indication of the local mire surface hydrological conditions, to supplement the humification data. Most of the previous investigations of fungal and algal remains are from lowland ombrotophic mires (e.g. Van Geel, 1978, 1980/81) so this investigation has demonstrated the importance of fungal and algal remains data from upland blanket mires as a source palaeoenvironmental information.

Given the opportunity of multi-site palaeoenvironmental reconstructions, the methodological approach adopted in this investigation is obviously ideal. The combined evidence of pollen stratigraphy, humification, fungal and algal remains and the macrofossil record allows an assessment of which sites are "sensitive" and which are "complacent" to climatic oscillations (*sensu* Lowe, 1991). Initially, the upper limit of pine stump preservation formed a basis for where the altitudinal sampling transect should cross but it was not until detailed analyses of the palaeobotanical data had been undertaken that it was clear which sites would provide a sensitive record. Even the choice of transect areas provide surprising results. Beinn Dearg, the wetter "oceanic" transect, proved to be relatively well humified (which is supported by the fungal and algal remains evidence) compared to the drier "continental" transect at Gleann Einich. This was shown to be related to the dominant vegetation cover on the mire surface, where the *Calluna vulgaris* cover at Beinn Dearg sites appears to be more dense than at the Gleann Einich sites. On this basis, the reasons why the humification data from the Beinn Dearg profiles show clear evidence for the *c.*4,200 to 3,950 BP "pluvial" (inferred for the Cairngorms by Dubois and Ferguson (1985)) in comparison to the Gleann Einich profiles which do not appear to reflect this event, can be better understood. The conditions at the Gleann Einich sites, as shown by the lower mean degree of humification values, were generally wetter, and the mire surface did not respond significantly to a shift to wetter conditions (in terms of a shift to less humified peat). Significantly, the only site to show convincing evidence for a shift to a low degree of humification during the period representing this "pluvial" for the Gleann Einich profiles is CPG (600m), which is relatively well humified compared to other sites on the transect. In this sense, these results and interpretations are similar to the work of Barber (1982) who proposes a "climatic hingeline" exists across Britain and Ireland. Very wet lowland bogs, such as those found in Ireland, do not show evidence for a response to a shift to wetter conditions because the prevailing conditions are already extremely wet. Therefore, since a degree of "sensitivity" and "complacency" has also been identified in peat profiles along altitudinal transects taken from upland blanket mires in two climatically contrasting areas on Northern Scotland, this provides an important basis for future palaeoclimatic reconstructions.

The lowest mean degree of humification recorded at Beinn Dearg and Gleann Einich is represented in the peat profiles recovered from the highest site for each transect. Since humification is a function of temperature and relative humidity this would be expected. However, presumably humification is not a year-round process and would be reduced to a minimum during periods of freezing of the mire surface and when under snow cover. Since the Gleann Einich sites would be subjected to colder winter temperatures (see Table 5.1) and longer periods of temperatures below 0°C, this may provide an additional explanation for the lower mean degree of humification for the Gleann Einich profiles (and similarly why the lowest mean degree of humification is recorded at the highest altitudes). Therefore, the

Figure 9.1
Deterioration of pollen grains at profile APB (Gleann Einich) plotted against degree of humification (percent transmission) on a depth axis (cm)



proportion of the year when humification occurs (i.e. "humification days") is likely to represent an important factor governing the degree of humification for each site profile.

The results from this investigations have provided a better understanding of factors which govern humification of a mire profile, such as dominant mire vegetation cover, mean residence time within the acrotelm, density of woodland canopy (as found with the Gleann Einich profiles where a low degree of humification corresponds with evidence for a relatively dense pine woodland canopy) and altitude.

As outlined in Section 5.2.3.2, the state of preservation of the pollen grains was assessed based on a classification scheme originally proposed by Cushing (1964, 1967). The relationship between the different types of deterioration and the degree of humification (inverse of percent transmission) is shown on a depth axis for profile APB (500m OD) (Gleann Einich) in Figure 9.1. The lower part of the profile, especially between *c.*190cm and *c.*210cm where the peat is highly humified, indicates that the deterioration of the pollen grains is partially caused by on-site processes such as the degree of humification of the peat matrix. The correspondence is particularly good for degraded pollen grains which suggests that this feature is caused by oxidation within the acrotelm, or microbial attack. Cushing (1964) and Birks (1970) propose that the degraded form of pollen deterioration results from physical abrasion, or mechanical damage. However, Lowe (1982) suggests that degraded pollen grains may also result from chemical modifications, which is supported by the evidence shown from the profile located APB (Figure 9.1). Further investigation of the relationship between the degree of humification and pollen deterioration is required, perhaps together with an assessment of the correspondence with the frequency of blackened *Pinus* pollen grains (which as indicated in the results presented in this thesis is also closely linked to the degree of humification).

As shown in Appendix 5.3, the dendrochronological investigations of two of the pine stumps recovered from the site areas investigated show evidence for a cross-matching chronology, which is supported by radiocarbon dating, for the site of LOD (*c.*700m OD) at Gleann Einich. This initial assessment of the tree-rings represents one of the few examples of cross-matching of sub-fossil pine stumps in the Scottish Highlands and indicates the potential palaeoenvironmental information that further investigations might provide.

The assessment comparison of the palaeobotanical and hydrological data from each of the profiles depends on accurate radiocarbon age assessments and interpolations between these estimates. Two sites, DMR and LDM (Beinn Dearg) were investigated for tephra (based on the method proposed by Hall *et al.* (1994) but initial observations found no tephra shards. However, if tephra is identified and assigned to an existing tephrochronlogy this would

provide a method to test the accuracy of the radiocarbon age estimates and hence test the inferred synchroneity of palaeoenvironmental "events".

The summary of the palaeoenvironmental data obtained from Beinn Dearg and Gleann Einich in Figure 8.10 indicates that the methodology used in this investigation has the potential for future similar investigations. The evidence for a high tree-line at 6000 BP corresponds well with the climatic values obtained by computer simulation of the global climate (Kutzbach *et al.* 1996). Bennett (1996) presents the climate variables for the grid square that includes the Cairngorms which shows that 6000 years ago the July temperatures were 2°C greater than today. This corresponds well with the data both from Gleann Einich and Beinn Dearg for high tree-lines inferred at this period. The identification of fluctuations in the upper limit of pine during the Holocene at both transect areas supports the upper limit of macro-fossil representation for a tree-line gradient across Northern Scotland. Pine reached altitudes of up to *c.*930m OD in the Cairngorms (as indicated by the MNM profile at Gleann Einich) and *c.*600m OD (for a short period) at Beinn Dearg. It should therefore be possible to estimate the upper limit of pine, or tree-line at intermediate areas, such as Glen Affric, based on the results from Beinn Dearg and Gleann Einich. The upper limit of pine stump preservation at Glen Affric was identified as *c.*530m (Section 5.1.3.4, Figure 2.1) but the tree-line gradient based on pollen-stratigraphic data from Gleann Einich and Beinn Dearg indicates the maximum Holocene tree-line for pine at Glen Affric is likely to be in the region of 750m OD.

When consideration is made of the number of different local factors which influence the representation of palaeobotanical and hydrological evidence preserved within blanket peat profiles, the evidence for synchronous regional and extra-regional shifts in the altitude of tree-lines and the relative degree of humification supports the validity of the adopted methodology. This investigation has therefore demonstrated the potential of upland blanket peat profiles as a source of a wide variety of information from which interpretations can be made regarding local and regional environmental change during the Holocene.

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APPENDIX 5.1 Description and published palaeoecological interpretations of the more frequent fungal and algal remains encountered in the investigations of the profiles from Beinn Dearg and Gleann Einich.

Types 1 & 2 *Gelasinospora* spec. (*Gelasinospora* undifferentiated) Fungi.

Type 1 Hyaline pits c. micron wide (round) spore surface almost black, evenly ornamented. Fossil Type 1 spores probably not characteristic enough to identify them to the species (Van Geel, 1978). Mainly fumicolous but also carbonicolous and lignicolous (Lundquist, 1972). Reaches highest frequencies in charcoal layers, may indicate carbonicolous but may just prefer dry conditions. Found on a lichen occurring in peat bogs (*Ladonia arbuscule)*. Restricted to peaty part, in particular to the amorphic, highly decomposed peat (Van Geel *et al.,* 1980/81).

Type 2 - Fungi.

Spore surface dark brown, ornamented with 2-4 micron wide hyaline pits (Van Geel, 1978). Shows maxima similar to Type 1. Modern - soil isolates - *Calluna* heath.
Restricted to peaty part, in particular to the amorphic, highly decomposed peat (Van Geel, 1980/81).

Type 3/3A - fungi

Ascospores - brown, many transverse and longitudinal septa, strongly flattened. Low frequency throughout the section. Found especially in layers formed under very dry conditions in the ombrotrophic peat. (Van Geel, 1978)

Type 8A Fungal fruit bodies

Fruit bodies small and circular in outline. Several macroscopic remains of plants bore Type 8A, on *Eriophorum vaginatum* they were found attached to a superficial, septate mycelium and also connected with the fruit bodies of 8B type. On a leaf of *Sphagnum* sect *Cymbifolia* they occurred together with Type 8D fruit bodies.(Van Geel, 1978)

Type 10 - Fungi

2-7 celled spores. Especially in highly humified peat (possibly). Conidia of *Trichocladium opacum* - a saprophyte (Van Geel, 1972).

Conidia or chlamydospores. Found in organic connection with thin root fragments of Ericales. Form partly inside the outermost cell-layer of the roots. Levels with high frequency show a relatively high frequency of roots of Ericales. Circumstantial evidence suggest they are *Calluna vulgaris* is probably the host plant. Good indicator of locally dry conditions in raised bog peat (Van Geel, 1972).

Type 13 - Sporangia - fungus

Probably haustoria as they occur on parasitic fungi. No clear relation with peat forming vegetation or humification (Van Geel, 1972).

Entophlyctis lobata (Van Geel, 1978). Restricted to the most oligotrophic part of the *Sphagnum* peat, to the period preceding the birch carr (Van Geel *et al.* 1980/81).

Type 14 - *Meliola* cf *niessleana* Winter Fungi

Ascospores - 3-septate inequilateral (one side almost straight), slightly constricted at the septa. Septa thickened around the pore. *Meliola* cf *niessleana* - ascospores. Obligate and rather oligophagous parasites on green plants. Associated with *Vaccinium vitis-idaea*. However, in Van Geel's samples the only Ericales he found associated with Type 14 fungus is *Calluna vulgaris* and mycelium attached to *C. vulgaris* leaves. Probably a common parasite on *C. vulgaris* in peat bogs during the Atlantic to Subatlantic period. Found no Type 14 at a level which showed charred remains of *C. vulgaris*, possible indicating that the fungus does not occur on *Calluna* growing on mineral soils (Van Geel, 1978).

Type 16A Fungi

Conidia of *Curvularia tuberculata*. This type has a very characteristic shape and only occurs in some samples. No clear relation with peat forming vegetation or humification (Van Geel, 1972).

Type 16A - spores - 3 chambered (3-spetate), constricted in middle. Some mycologists suggest Type 16a represent ascospores and not the conidia of *Curvularia subterculata* Jain as suggested previously. Wietermarshcher Moor III - not correlated with certain phenomena (but the macrofossil analysis was rather primitive. Occur in levels where Gramineae are present in the local vegetation e.g. *Molinia coerulea* peat and lower part of peat formation starts. There the percentage of Gramineae pollen rises, although graminaceous macrofossils were not observed. (Van Geel, 1978).

Disturbed conditions in continental bogs, among others in *Molinia*-peat. Associated with "disturbance" layers) - *Sphagnum imbricatum* layer in the *Narthecium* root peat (Van Geel, 1988).

Type 16b

Prefers mesotrophopic conditions in *Sphagnum* peat. Coincide with relatively dry phases. During the relatively moist and oligotrophic phases in which *Amphitrema flavum (Type 31a)* shows maxima Type 16A occurs less frequently or is totally absent (Van Geel *et al.*, 1980/81).

Type 18 Fungi

Eriophorum peat (Van Geel, 1972). One-septate, bigger than 19. Pores at both ends - 0.8 microns. Septum often not there. Rather pale. Ascospores. Correlated with *Eriophorum vaginatum* peat. Fruit bodies immersed in host tissue, possibly leaf fragments or rootlets of *E. vaginatum*. Only found with
E. vaginatum directly where the roots penetrated lower levels, so do not exactly indicate the position of the surface. If the Type fungus occurred on leaves of *E vaginatum,* it is likely that the levels containing the Type 18 fungal remains will not exactly correspond with the somewhat deeper levels of the macroscopic remains (Van Geel, 1978).

Type 19 Fungal

No clear relation with peat forming vegetation or humification (Van Geel, 1972). Smaller than 18. At both ends the wall becomes very thin and forms a pore of c. 0.5 microns. One cell slightly broader than the other (not so in 18). Often found grouped together. Only found in the *Sphagnum papillosum-S imbricatum* peat (Van Geel, 1978).

Type 27 Fungi *Tilletia sphagni*

Correlation with reliably identified *Sphagnum* species cannot be made because of identification problems, mainly due to the degree of decomposition of the macroscopic *Sphagnum* remains, but the levels where the Type 27 spore curve shows maxima often coincide with transitions from drier vegetation types to wet *Scheuchzeria* vegetation. Change from drier to wetter sediment (Van Geel, 1978).

Type 28 Spermatophore of *Canthocamptus* (Copepoda)

No clear relation with peat forming vegetation or humification (Van Geel, 1972).

Probably representing the spermatophores of different species. Absent in the mineral subsoil and lowest 20cm of peat section. Rather scarce, represent the (temporary) presence of open water (Van Geel, 1978). *Spermatophores of Copepoda* - temporary increase in *Narthecium* root peat. Might indicate predominance of inundated conditions just after deposition of small stones. Absent in peat dominated by *Sphagnum magellanicum* (Van Geel, 1988).

Type 30 Fungi *Helicosporium? Helicoon pluriseptatum*

No clear relation with peat forming vegetation or humification (Van Geel, 1972).
Multi-septate, coiled conidia gradually tapering to a narrow point. The spores appear singly or in groups of two or three, just above the water film adhering to the leaf. Mature conidia formed on the decaying plant material. No indications about special conditions or substrates, only that it is absent in the lowest minerotrophic peat and the *Molinia* peat (Van Geel, 1978). Preference for the *Sphagnum papillosum*-peat which may indicate preference for relatively wet conditions (Van Geel, 1988).

Type 31A Rhizopod *Amphitrema flavum*

Fresh peat (Van Geel, 1972). Shell of *Amphitrema flavum* is not destroyed by acetolysis. The curve of *A. flavum* provides reliable information about locally moist conditions (Van Geel, 1978).
A.. flavum occurs in the more oligotrophic and wet parts of the sections. In these parts there are more macroscopic remains of *Sphagnum,* probably because there is less decomposition (Van Geel, *et al.*,1980/81).

Type 32 Rhizopod *Assulinea muscorum, A. seminulum*

Rhizopods are restricted to *Sphagnum* peat (Van Geel, 1978).

Assulina is present in nearly all samples apart from *Narthecium* root peat (compare with contemporaneous decline if *Amphitrema flavum*). Rise of *Assulina* in *Sphagnum papillosum* peat and presence in the *S. magellanicum* dominated upper peat layer indicates that the genus *Assulina* has a wider ecological amplitude than *Amphitrema flavum* (Van Geel, 1978).

Type 64 *Phaengellina empetri* (Phill.) Dennis

Correlated with the presence of macroscopic remains of *Empetrum nigrum.* So far it has not become clear whether this coincidence reflects a host-parasite or symbiotic relation, or is simply due to similar ecological requirements (Van Geel, 1978).

APPENDIX 5.2 Method adopted for the assessment of the degree of humification (based on Blackford (1990) and Blackford and Chambers (1993)).

1. Dry sample in crucible for approximately 12 hours at 105°C.
2. Grind with pestle and mortar, cutting the more fibrous fragments with scissors.
3. Dry at 105°C overnight.
4. Weigh 0.2g of dried sample and place in 150ml conical flask.
5. Make up 8% NaOH solution (120mg of NaOH and 1500ml of distilled water).
6. Add 100ml of NaOH solution to each sample and note time.
7. Place conical flasks on hot plate and bring solution up to the boil
8. Simmer for approximately one hour.
9. Poor solution into 250ml measuring cylinder and make up to 200ml with distilled water.
10. Wrap top of cylinder with "Parafilm" and shake thoroughly
11. Filter through Qualtitative Grade 1 filter paper to the 25ml mark of a 100ml measuring cylinder*.
12. Make up to 50ml mark with distilled water.
13. Cover top with "Parafilm" and shake thoroughly
14. Switch on Spectrophotometer (Phillips Pye Unicam PU 8600 UV/VIS) and change wavelength to 540µm (it needs one hour to stabilise).
15. Standardise spectrophotomer with distilled water.
16. Measure transmission (%) at 4 hours from Point 7 as possible. Note time and repeat 3 times for each sample (more, if values vary considerably).
17. Standardise spectrophotometer with distilled water before measuring each sample.

APPENDIX 5.3 DENDROCHRONOLOGICAL REPORT ON PINE *P. sylvestris* STUMP SAMPLES (AN INITIAL INVESTIGATION)

A.K.Moir, 4th November 1996

Methods

Generally samples over 80 years in length were selected in the field for dendrochronological analysis, these were then cut by hand with a bow saw. On returned to the laboratories the dendrochronological samples were air dried and sanded to allow ring counting.

A number of procedures and methods are commonly used in most dendrochronological studies at present. The software was written and developed by Ian Tyers of the Museum of London. The "t" values quoted in matches refer to the Students t-test which is used as a significance test on the correlation coefficients. Generally a t-value of 3.5 or over represents a match, provided that the visual comparison is acceptable. The program (Baillie & Pilcher, 1973) measures the amount of correlation between two ring sequences at each position of overlap, all the t-values quoted in this report are Cros73 values. Mean sensitivity is a measure of the variation between successive years of tree-ring widths: it ranges from 0.0 to 1.0, larger values indicating greater variability.

Initial measurement of radii, revealed the majority of samples of an adequate length to crossmatch, but also revealed a number of problems commonly seen of pine:-

i) Crossmatched radii from the same sample we found to be affected by locally missing rings (i.e. those visible around only part of the circumference), and between samples, totally missing rings. Comparison of several radii from the same sample was necessary to obtain an entire ring sequence, this was not always possible where early rings were missing due to the poor preservation of some areas of samples.

ii) The measurement of extreme narrow ring width, was actually alleviated by a characteristic often seen as a problem in measuring conifers. The variability in width of a single ring around the circumference of a tree often called "lobate growth" (Ward *et al.*, 1987) allowed narrow or partly "missing" rings to be measured on a number of radii from a single section. After several measured radii from a section were compared missing rings could be identified where the entire section was available.
Longer continuous length samples are useful in the initial construction of individual tree series means greatly enhancing there initial accuracy; which in turn increases the chances of cross-matching between samples.

Results

Summary information (Sample code/Length in years/Species/ Mean width/Sen) for the 44 samples taken during the course of this investigation may be seen in the Table:- Dendro Samples.

Site:- APB
The 5 samples collected from this site, ranged from between 87 years and 257 years in length. No significant intra- or inter-site cross-matching was established with any of the samples from this site.

Site:- CPG
Four samples were collected from this site, these ranged from between 96 years and 260 years in length. No significant intra- or inter-site cross-matching was established with any of the samples from this site.

Site:- DMR
The 15 samples collected from this site, ranged from between 31 years and 242 years in length. No significant intra- or inter-site cross-matching was established with any of the samples from this site.

Site:- LDM
Three samples were collected from this site, these ranged from between 119 years and 176 years in length. No significant intra- or inter-site cross-matching was established with any of the samples from this site.

Site:-LOD
The 7 samples collected from this site, ranged from between 96 years and 151 years in length. Five of the samples (LOD001, LOD002, LOD003, LOD004, LOD006) significantly cross-matched against each other and were combined into a 161 year site chronology (LOD). The LOD chronology has an mean growth rate of 0.70mm per year and sensitivity of 0.26. There was significant intra-site cross match at this site, but no inter-site cross-matching was established with the samples.

Dating
The LOD site chronology cannot be reliably cross-dated with any available established chronologies at present. However two radiocarbon dates were made upon the outer ring of two separate *P. sylvestris* stumps (LOD004 and LOD006) which were cross-matched in the LOD site chronology. The outer rings of LOD004 and LOD006 yield radiocarbon dates of 6,270 +/- 80 years and 6,440 +/- 70 years respectively. The samples LOD004 and LOD006 are confidently cross-matched relative to each other at 11 to 161 years and 1 to 137 years respectively in the LOD site mean chronology.

NB. The conflicting pine macro-fossil dates may indicate contamination of the peat samples by humic acids from overlying younger sediments. Pine macro-fossils are notoriously difficult to date by means of biostratigraphic correlation and radiocarbon dating is essential to prevent serious mistakes in interpretation being made (Pears, 1970).

Discussion
Daniell (Unpublished) describes of pine stump sites from the N. Scotland region as tending to span a period of approximately 350-400 years between 4,413 and 3,833 B.P. Variations in a general *P. sylvestris* extinction period (Gear, Unpublished) within regions was explained by either the factors limiting growth varying locally and therefore critical thresholds will be crossed at different times: or that the lag between climatic change and the resultant change in local environmental conditions being different at each site depending upon topography, soil type and underlying substrate.

Unfortunately in this study a level of replication 25-30 trees (Dewitt & Ames, 1978) is not achieved and the small sample size of the sites examined place limitations on these results and conclusions. The nature of sub-fossil roots can also give an indication of depth of water table at different sites, although again unfortunately no record of tap-root development was taken on the pine samples taken for dendrochronological analysis in this study. The sample taken from the LOD is also to small to recognise or to make inference on causes of *P. sylvestris* extinction at this site.

It would also normally be expected that *P. sylvestris* sample series over 100 years would significantly cross-match if they were contemporaneous in date. The lack of cross-matching of samples over 100 years old within these sites may be explained by two hypothesis:-

1. Missing rings may account for the lack of cross-matching between samples in which case this problem may be resolved by increasing the number of samples taken from sites. Which may indicate that pine in some localities is unsuitable for dendrochronological study since the climatic signal may be overridden by other factors affecting growth creating locally missing rings.

2. The samples do not have any significant periods of overlap and are therefore not contemporaneous in age. This is supported by evidence at a number of sites, where there are observable different horizons of pine.

Previous radiocarbon dated pine stumps in northern Scotland have yielded dates of between 3,976 and 4,393 BP (Gear, Unpublished) and 3815 - 4405 BP (Daniell, Unpublished), suggesting that they are approximately synchronous. What this study does show is that pine horizon used to create the site chronology LOD is anchored by two radiocarbon dates at 7178 BP (LOD004) and 7325 BP (LOD006) (calibrated) and clearly represents an earlier phase of pine growth and preservation. This conclusion supports the second hypothesis

Studies on the pine at Rannoch Moor (Bridge *et al*, 1990) indicate some of the problems of the dendrochronological study of pine in northern Scotland. Samples taken from 8 sites scattered in N. Scotland suggests that pine occupied different sites from between 120 and 349 years. This study combined with work undertaken by the author at Farlary (north west Scotland) further demonstrates that sufficient sampling, of suitable length pine stumps, at a single horizon level can enable the creation of pine chronologies by standard dendrochronological techniques. Modern dendrochronological studies have indicated the importance of site factors, the carefully selection of sites must play a vital role in the possible building a pine chronology for Northern Scotland.