THE FLANDRIAN VEGETATIONAL HISTORY OF THE LOCH LOMOND AREA

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FRONTISPIECE:- Colour plate of part of Loch Lomond core LLRD1 in vertical section.

Third section from left illustrates:-

a) Post marine laminated sediment (278-305 cm). (Top of small scale rod at 278 cm).

b) Part of marine incursion sediment (305-322 cm only)

Scale - smallest division = 1 cm.
(Top of core at top left hand corner).

To my parents and brother Evan

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SUMMARY

Pollen diagrams prepared from the sediments of Loch Lomond and the Dubh Lochan have provided a general overview of the vegetational changes which have occurred in the Loch Lomond area during the Flandrian period. Progressive deforestation since 5000 B.P. and particularly during the last few centuries has been high-lighted with the period of maximum extent of mixed Quercus woodland in the Loch Lomond area having occurred between c.6000 B.P. to c.5000 B.P. The Alnus rise horizon has been demonstrated to have occurred later than expected in the Loch Lomond area.

Absolute pollen analysis has enhanced the interpretation of the relative percentage data and has shown that the pollen concentration has varied widely in the Loch Lomond sediment during the Flandrian. Pollen deposition data has been calculated from the Dubh Lochan sediments allowing a comparison to be made with deposition data from other lakes in north west England and Scotland. It has been concluded that concentration of pollen within the Dubh Lochan has occurred.

Dinoflagellate analysis has provided the first positive evidence of a marine phase in Loch Lomond's mid Flandrian history. A period of meromixis of ectogenic origin has been hypothesised to account for a laminated band following the marine sediment within which pollen and macrofossil preservation was found to be uniquely good, with pollen counting of the Loch Lomond sediment having been generally taxing. Derived Carboniferous spores were noted throughout the length of the Loch Lomond profile.

Analysis of selected terrestrial sites to compliment the picture of the status of Pinus sylvestris gained from the Loch Lomond sediments has been undertaken. The locality of the post Ulmus decline Pinus curve increase demonstrated/

demonstrated by the Loch Lomond pollen data has been traced to Glen Falloch. The Glen Falloch peat has recorded a change from Betula woodland to Pinus-Betula woodland at a time generally recognised to be one during which Pinus was in decline in Scotland and Northern Ireland. Fire attributable to man has been considered to account for the initiation of growth of Pinus on the Glen Falloch peat surface. Radiocarbon dating of Pinus wood has demonstrated the continuous presence of Pinus in Glen Falloch until c.1600 B.P., with the present day Pinus trees having been considered to be of natural origin. Data from the Ptarmigan has suggested that in at least one part of the southern Loch Lomond area more Pinus exist to-day than at any time during the last six thousand years.

1. INTRODUCTION

1.1 Scope of the thesis

The Loch Lomond area, defined as the catchment area of the loch itself, is rich in semi-natural deciduous woodland, moorland, grassland, coniferous forestation and farmland. The woodlands of the Loch Lomond area are of particular interest not only from an aesthetic and cultural aspect but also from the economic, scientific and educational points of view. Indeed the area is of interest to the ecologist as it acts as a bridge between the *Pinus* forests of north west Scotland and the mixed *Quercus* forests of central Scotland. However, in order to preserve and maintain the woodlands present in the Loch Lomond area an understanding of their development is required.

Therefore the primary concern of this project is to provide an insight into the vegetational changes which have occurred in the Loch Lomond area during the Flandrian period. This will be achieved by applying the techniques of Quaternary research to the investigation of a number of sites differing in properties such as sediment accumulation and pollen input for example. The study will also permit palaeoecological information gained from the sediments of a large lake with a large catchment area (Loch Lomond) to be compared with that from the sediments of a small lake with a small catchment area (Dubh Lochan) in close geographical proximity.

The pollen profiles from the lake sediments will provide a regional overview of the vegetational history of the Loch Lomond area. This will be complimented with a study of selected terrestrial sites in order to provide a more detailed picture of particularly interesting features (such as the status of *Pinus sylvestris*) highlighted in the regional pollen diagrams.

Before considering previous work dealing with aspects of the vegetational history of the Loch Lomond area and with the palaeoecology of lakes in general, it is worth dealing briefly with the history of vegetation in Scotland as a whole. Indeed the Loch Lomond area cannot be considered in isolation having many features in common with other areas of Scotland (and indeed Britain in general).

1.2 Lateglacial background

Absolute pollen analysis of some north western Scottish lochs (Pennington et al. 1972) show that in the early Lateglacial the pollen input from the surrounding vegetation was very low. For example, Lateglacial sub-zone Al from Loch Sionascaig suggests a treeless species rich grassland with Rumex acetosa and Lycopodium selago being important pollen and spore producers. At about 13,000 B.P. a widespread climatic amelioration occurred (Pennington and Bonny 1970, Coope and Brophy 1972, Coope 1975, Pennington et al. 1972) corresponding to a change in the lake sediments of north west Scotland to more organic material (Pennington 1977). The climatic improvement was accompanied by a vegetation change to a dwarf shrub tundra. The vegetation being dominated by Empetrum and Cyperaceae with some Juniperus. Similarly a progressive stabilisation of the landscape from about 12,800 B.P. was noted by Birks on the Isle of Skye (Birks 1973). The sites investigated show a development from a low alpine or mid alpine scrub to a Juniperus scrub. By about 11,800 B.P. Betula woodland had developed locally on Skye (e.g. Loch Meodal area).

Between 11,800 to 11,000 B.P. the maximal Lateglacial pollen productivity from Ericaceous dwarf shrub vegetation was found from the lake sediments of north west Scotland (Pennington et al. 1972, 1977). During this period a maximum in the curve for Juniperus was found at Muir Park Reservoir (Vasari and Vasari 1968) indicating both open and warmer conditions.

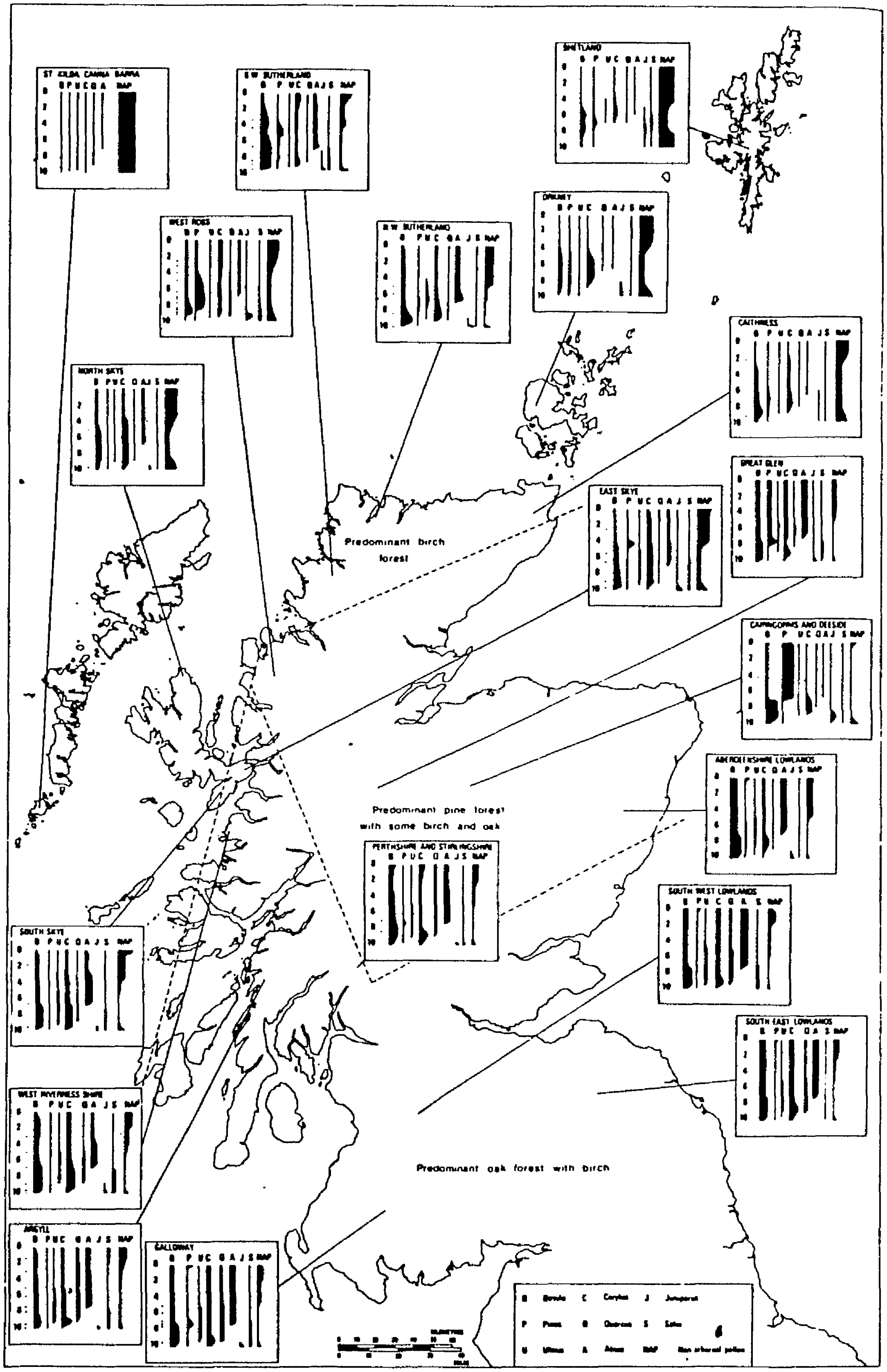
At 11,000 B.P. there was a sudden change to communities for which no modern analogues have been found. In lowland Scotland there was a decrease in Betula, Juniperus and Empetrum with a return to herb rich grassland. This Lateglacial zone (Godwin zone 111) was characterised by high values of Rumex, Gramineae and Cyperaceae pollen in lowland Scotland while Artemisia and other taxa of disturbed soils predominated in north west Scotland. Low temperatures and a more continental type of cold climate than that now found at higher lattitudes and altitudes in north west Europe may have occurred. Just before the opening of the Flandrian (10,400 to 10,000 B.P.) pollen data indicates (Pennington et al. 1972, Birks 1973) a rapid transition to closed plant communities resembling those of the preceeding interstadial.

1.3 The Flandrian forest patterns.

Scotland may be divided into four major potential vegetation regions (Figure 1), these being deducible from the existing woodland fragments (McVean and Radcliffe 1962). South of the Grampian Highlands and up the west coast as far as Skye *Quercus* forest with *Betula* would probably predominate. The principal woodlands in the central highlands would be *Pinus* with some *Betula* and *Quercus*, while in north and western Scotland *Betula* forest would be dominant. Only in very exposed coastal areas in the far north, on the smaller Hebridean islands and on Orkney and Shetland would a natural treeless landscape exist. By relating summary pollen diagrams from different areas in Scotland (Figure 1) to these potential forest areas, Birks (1977) presented a preliminary synthesis of the Flandrian forest history of Scotland. A brief description of the changing patterns of the arboreal vegetation of each of the four principle woodland areas in Scotland during the course of the Flandrian will now be given. The reader is referred to Birks (1977) for a fuller account.

Figure 1.

Major potential forest regions and summary pollen diagrams (from Birks 1977).



ST KILDA CANNA BARRA
SHETLAND
ORKNEY
WEST ROSS
NORTH SKYE
CAITHNESS
GREAT GLEN
EAST SKYE
CAIRNGORMS AND DEESIDE
ABERDEENSHIRE LOWLANDS
PERTHSHIRE AND STIRLINGSHIRE
SOUTH WEST LOWLANDS
SOUTH EAST LOWLANDS
SOUTH SKYE
WEST INVERNESS SHIRE
ARGYLL
GALLOWAY
Predominant birch forest
Predominant pine forest with some birch and oak
Predominant oak forest with birch

1. <u>Oak forest with birch region</u>.

From the available pollen data the following sequence of events can clearly be seen.

(a) An expansion of *Betula* and *Corylus* to form *Betula Corylus* woodland at about 9700 B.P.

(b) From c.8500 B.P. *Quercus* and *Ulmus* became important components of the *Betula Corylus* woodlands to form mixed deciduous forests.

(c) *Pinus* arrived from about 8000 B.P. but only occupied marginal habitats.

(d) *Alnus* replaced *Salix* on wet habitats at about 7000 B.P.

(e) General reduction in forest cover after the *Ulmus* decline (i.e. after c.5000 B.P.) accelerating during the last few centuries.

In this *Quercus* forest with *Betula* area *Pinus* only occupied marginal habitats. For example *Pinus* stumps dated between 7100 to 5000 B.P. (Birks 1975) have been found in Galloway, the trees having grown on dried peat bog surfaces. The expansion of *Alnus* has been shown to be asynchronous (Smith and Pilcher 1973) occurring in this *Quercus* forest with *Betula* area at c.7000 B.P. as compared to 7500 B.P. in north west England and as late as 6300 B.P. at Loch Sionascaig (Pennington et al. 1972). Rymer (1974) presents evidence for the local growth of *Alnus* in southern Argyllshire from about 7985 B.P. prior to its regional expansion, illustrating the complexity of the chronology and dynamics of the spread of this tree. The largely treeless nature of the area to-day is particularly due to the activities of man within the last 2000 years and especially the last few centuries. Widespread coniferous afforestation has occurred with conifer pollen being detectable in pollen diagrams which extend to the present day.

2. <u>Pine forest with some birch and oak area</u>.

In the eastern Grampian Highlands a period of herb dominance was followed by an expansion of *Juniperus* and *Betula* at about 9800 B.P. Subsequently the main expansion of *Corylus* occurred in this area at c.8000 B.P. *Pinus* probably expanded gradually into the area between 8000 and

6000 B.P. with the Alnus rise being delayed until 5500 B.P. (O'Sullivan 1975). Pinus forests survive in parts of the Cairngorm Deeside area today.

However, further east in the Aberdeenshire area Betula dominated over Pinus and Corylus after 6000 B.P. (Durno 1970). Once again forest clearance began after 5000 B.P. becoming extensive especially during the later centuries of the last two thousand years.

To the west of the Cairngorm area the situation is less clear; however Pennington (1972) has shown that after a period of Betula and Juniperus dominance, Corylus, Ulmus and Quercus expanded to form mixed deciduous woodland. Between 7800 to 6500 B.P. Pinus increased. However this increase in Pinus was probably at the higher altitudes and on poorer soils as McVean and Radcliffe (1962) regard Quercus forest (some of which is still present in the area) to have been the "natural" forest type of the Great Glen.

Further north and west in West Ross, Betula woods with some Corylus succeeded Juniperus followed by the rapid expansion of Pinus at c. 8250 B.P. (Birks 1972). Quercus woods with some Fraxinus and Ulmus were confined to areas of more favourable soil (c.f. Cairngorm area also) and were comparitively rare. Alnus expanded from 6500 B.P. and this was associated with a general degeneration of the Pinus forest in this area and at about 4200 B.P. the replacement of Pinus forest by moorland and bog reached its culmination. Indeed this decline in Pinus corresponds to a widespread spectacular decline in Pinus pollen in north west Scotland (Pennington 1972, Birks 1972, 1975). The reasons for this general decline of Pinus 4000 to 4500 years ago are far from clear; however a combination of climatic change and human activity including burning may have been causal factors. There is independent evidence from chemical analysis of lake sediments (Pennington et. al. 1972) and from peat stratigraphy to indicate a change to a more oceanic climate with strong winds and increased precipitation at that time. The demise of Pinus was not restricted to Scotland for Smith and Pilcher (1973) describe a comparable Pinus decline in north east Ireland between 4400 and 3800 B.P.

3. <u>Predominant birch forest area.</u>

The sequence of events in this area is very similar to that in the previously described *Pinus* with *Betula* area, *Betula* however being the dominant tree species. In south west Sutherland *Pinus* expanded locally about 5300 B.P., the pollen stratigraphy in north west Sutherland lacking this expansion (Birks 1977). From 5000 B.P. deforestation progressively occurred with an extensive loss of *Betula* woodland in south west Sutherland at about 1500 B.P. Some *Betula* woods still remain in ravines and on steep rocky slopes in what is an otherwise treeless landscape. According to Birks (1977) the low values of *Pinus*, *Ulmus*, *Quercus* and *Alnus* pollen indicate that no extensive closed forest ever developed in Caithness.

4. <u>Essentially treeless areas.</u>

No extensive woodland has probably existed on the Orkney or Shetland islands during the Flandrian period although *Betula* *Corylus* scrub probably developed locally in places (Moar 1969b, Jones 1975). Tall herb communities with *Rumex acetosa*, *Filipendula*, *Urtica* and *Filicales* dominated during the mid Flandrian. It is unlikely that *Quercus*, *Ulmus* or *Alnus* ever occurred on either the Orkney or the Shetland islands. The sparse pollen data from the Hebridean islands (with the exception of Skye with its close affinity to the adjacent mainland) suggests an essentially treeless landscape throughout the Flandrian.

Summary.

The major forest patterns were established in Scotland by c. 6000 B.P. The forest pattern varied over the country due to immigration rates for trees and the complex interactions between vegetation, climate and soils.

A general reduction in forestation began about 5000 B.P. becoming progressively more noticeable during the last 2000 years with increasing human impact upon the environment. Indeed the anthropogenic factor has been particularly prominent in the demise of Scottish forests during the last two or three centuries.

1.4 <u>Previous sites investigated in and around the Loch Lomond area.</u>

Ten sites have been studied in and around the Loch

Lomond area up to 1975 (for details see Figure 2). Sediments from Muir Park Reservoir and Gartmore were investigated to gain information on the Lateglacial. The Godwin zones I, II and III were only found at Muir Park Reservoir, which unlike Gartmore lay outside the moraines formed by the Loch Lomond re-advance. The re-advance occurring between 10,800 - 10,300 B.P. (Sissons 1967). The Lateglacial Flandrian interface was dated to 10,010 ± 230 B.P. by Vasari (1977) at Muir Park Reservoir.

Flanders Moss, Dubh Lochan and the two Campsie Fell diagrams provide pollen evidence of vegetational change in their respective areas during the Flandrian period. Walker's (1975) fen carr site from Dubh Lochan provides interesting comparisons with the deep water sediments from the same loch (latter results presented in this thesis), as it contains to some degree a regional element in the pollen profile. The Corylus rise has been dated to 9356 ± 165 B.P. at Dubh Lochan while the Alnus rise has been dated 6197 ± 45 B.P. at Craigbarnet Muir. Turner's pollen diagram from Flanders Moss is interesting in terms of recent forest history in relation to man.

A fuller consideration and comparison of these and other sites will be made in the relevant sections.

1.5 A consideration of the palaeoecology of lakes in General.

In studying the regional vegetational history of an area, lakes offer considerable advantages compared to other sediment types when the most informative palaeoecology data is sought. The most commonly analysed material, namely peat, suffers from the disadvantage that the separation of the regional pollen component from the local component may be difficult. Only airborne pollen and spores will be incorporated from the regional component and periods of cessation of growth or even erosion of the peat surface will complicate the picture considerably. Lastly lake sediments being more homogeneous than peats lend themselves to investigation

Figure 2.

Map showing:- A) Sites studied in and near the Loch Lomond area up to 1975.

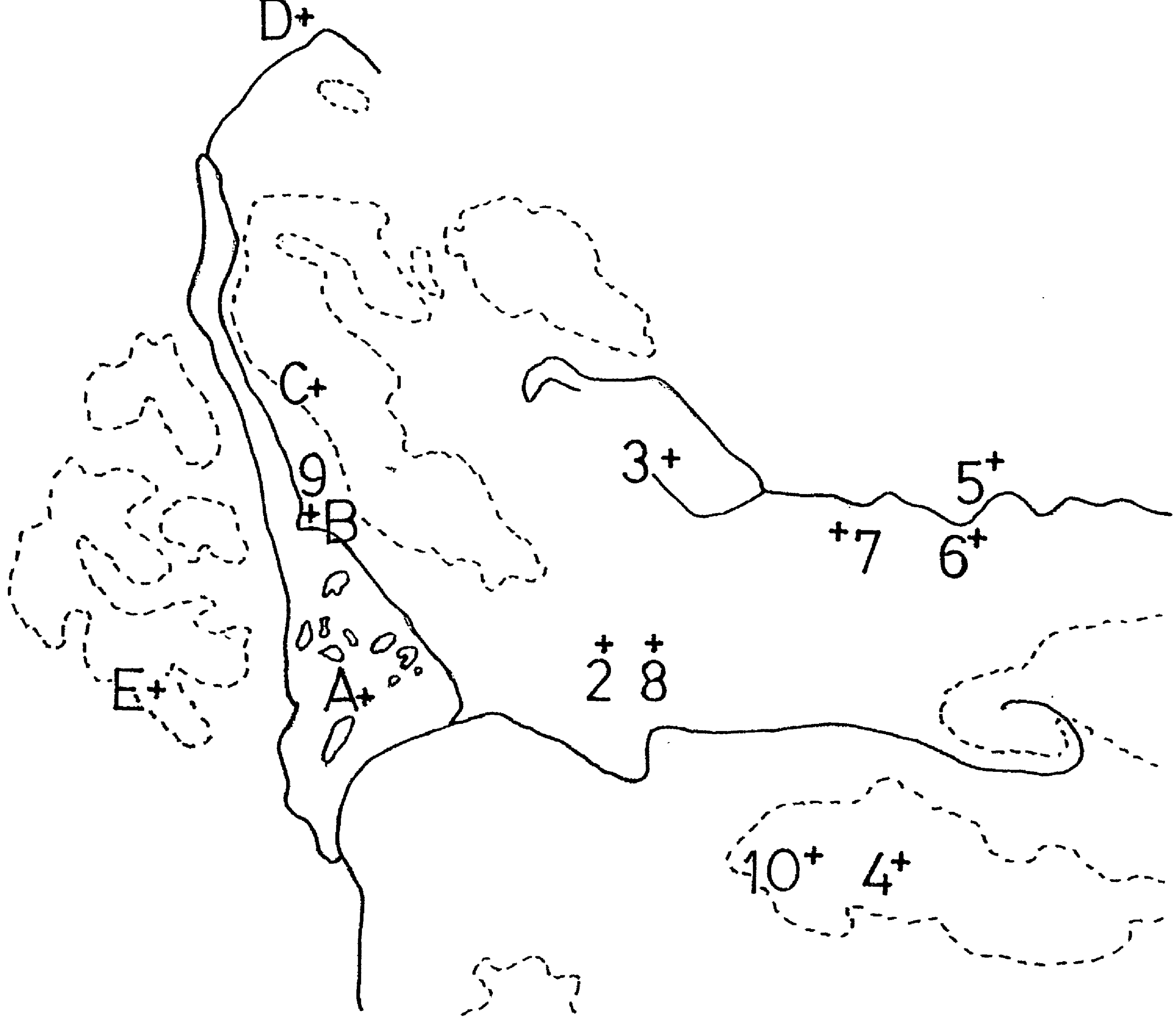
B) Sites investigated in this study.

A) Site Number/Name

Site Number/Name	Map Ref.	Workers	
1. Flanders Moss	NS 630 980	Durno, S.E.	1956
2. Muir Park Reservoir	NS 490 923	Donner, J.J.	1957
3. Gartmore	NS 500 976	Donner, J.J.	1957
4. Campsie Fells	NS 635 819	Eydt, R.	1959
5. Flanders Moss	NS 625 972	Turner, J.	1965
6. Kippen	NS 630 960	Newey, W.W.	1966
7. West Flanders Moss	NS 583 957	Newey, W.W.	1966
8. Muir Park Reservoir	NS 490 923	Vasari, Y. and Vasari, A.	1968
9. Dubh Lochan	NS 377 964	Walker, A.	1975
10. Craigbarnet Muir	NS 586 832	Stewart, D.A.	1975

B) Site Letter/Name

Site Letter/Name	Map Ref.
A. Loch Lomond Ross Dubh	NS 385 900
B. Dubh Lochan	NS 377 964
C. Ptarmigan	NS 365 015
D. Glen Falloch	NS 369 238
E. Shantron Muir	NS 328 878



D
C
9
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4

by absolute pollen analytical techniques.

There are, however, many factors which must be kept in mind both when choosing a lake site for investigation and when interpreting the results.

Choice of site.

The choice of site is very important and Faegri and Iversen (1964) consider that very large and very small lakes should be avoided as should those surrounded by extensive bogs. However, rarely can ideal sites be found. In choosing a large lake such as Loch Lomond sites should be chosen which are in fairly flat, wide basins as far as possible from islands and rivers (both entering and leaving the lake) which could upset "normal" sedimentation (e.g. due to processes such as sediment slumping). Lakes which are highly exposed to wind disturbance should be avoided as uneven sediment accumulation can occur. This latter feature has been shown by Pennington (1943, 1947, 1972) for Lateglacial sediment in Windermere and by Pennington et al. (1972) for postglacial sediments in some northern Scottish lochs such as Loch Ness.

Pollen recruitment and deposition.

Experimental work by Raynor, Ogden and Hayes (1968, 1970, 1972 a, b), theoretical work by Tauber (1965) and field investigations by workers such as Janssen (1966, 1967, 1973) all indicate that pollen deposition from the air decreases rapidly in intensity away from the vegetation source. In other words, most of the pollen recruited by air to a lake surface has probably come from the vegetation within a short distance of the lake. Indeed Anderson (1970, 1974) has shown that the dispersal distance of a high proportion of tree pollen may be as short as 30m in forest as compared to Tauber's (1965) calculated 1 km through trunk space. Raynor has also arrived at the 1 km figure for the detection of *Ambrosia* pollen released in a non forested area (Raynor et al. 1968, 1970). However in a study of the recruitment of pollen to five Lake District lakes Bonny (1976) could find no consistent relationship between the proportion of deciduous woodland within 1 km of the lakes and the percentage which tree pollen formed of the total pollen in the surface sediments. Bonny (1976) points out that deposition decreases exponentially from the pollen source which would therefore result in a dilution effect towards the centres of large lakes. However in lakes with inflowing rivers (i.e. Loch Lomond) the bulk of the annual pollen catch will be supplied by rivers and streams. Indeed Bonny (1976) suggests that of the fresh pollen entering Blelham Tarn and Ennerdale Water each year 89% and 70% respectively may be supplied by streams. The stream-borne pollen results in an increase in the percentage of degraded pollen eventually settling in the lake. By using traps Bonny (1978) noted a disparity in the proportions of degraded pollen trapped annually inside and outside the traps with 1.8% T.P. inside and 8.5% T.P. outside. Grains caught in stream traps which were not completely degraded showed signs of thinning and corrosion of the exine (Cushing 1967; Havinga 1967, 1971) as well as crumpling and breakage attributable to physical damage during transport. Although oxidation of pollen before being washed off the streamside vegetation into the water may be important. Bonny (1978) suggests that the high proportion of degraded pollen transported by water may be due to its derivation with other particulate matter from the soils of the catchment. This can result in the stratigraphic resolution of pollen diagrams from lakes being less clear than diagrams from bogs where the pollen recruited to the bog is usually incorporated almost immediately after its release into the air. This latter feature was noted by Birks (1972) when comparing pollen diagrams from Loch Dungeon and Snibe bog. The stream borne component also tends to increase the representation of pollen of plants poorly dispersed in air. To quote Bonny (1978) p 412 "Stream-borne pollen input to Blelham Tarn appears, therefore, to improve the general correspondence between the composition of the extra-local vegetation and the composition of the mid-lake sediments, both by increasing the representation of those major pollen-producing tree and shrub taxa which do not have a high efficiency of pollen dispersal in air, e.g. Alnus and Salix, and also by adding to the sediments a pollen compliment from entomophilous or low-growing herbs which do not catch the wind."

A comparison of fossil concentrations and deposition rates with annual pollen deposition per unit area of lake mud by Pennington (1973) from sites in north western Europe and America indicates some degree of concentration of pollen within lakes. Estimates of pollen deposition rates in lakes seem to be greater than average figures for deposition of pollen into traps from the air. The two main processes by which pollen may become concentrated in limmic sediments are firstly the recirculation by water currents of material already settled and its subsequent redeposition in deeper water as shown by Davis (1968, 1973) for Frains lake U.S.A. Secondly the inwash of pollen especially after floods as shown by Peck (1973). The effects of pollen inwash have also been noted by Pennington (1964) who found a steep rise in Calluna pollen after the Ulmus decline at Devoke water and by Birks (1970) at Loch Fada in the Isle of Skye.

Cushing (1967) stated that "the palaeoecology of the site of deposition should be of as much concern to the pollen analyst as the palaeoecology of the area from which the pollen came". Taking this into account Pennington (1973) has shown from studies of four lakes of contrasted size and for postglacial sediments at c. 5000 B.P. that there is a decrease in pollen deposition rates with increasing size of lake. It therefore seems that deposition rates cannot be related to the number of trees in any region but are determined by the relative efficiency of each lake as a pollen trap.

As mentioned earlier lake sediments lend themselves to investigation by absolute pollen analytical techniques. In absolute pollen analysis the relationship between the number of fossil grains to unit volume of fresh sediment (pollen concentration) is calculated. This allows a comparison of the number of grains per unit area through the length of the core. With the use of radiocarbon dating, the pollen deposition as number of grains per square centimetre per year may be calculated. It should be noted that only the deposition diagram has anything absolute about it and its absoluteness is heavily qualified by the accuracy of the estimate of sedimentation rate.

The value of absolute counts is that these procedures allow the pollen curves to be considered as independant variables as compared to interdependant percentages or proportions. Absolute pollen analysis is also a very useful tool highlighting periods of increased or decreased deposition. However there is as yet incomplete knowledge of erosion and deposition processes within large lake basins to permit a critical interpretation of absolute diagrams in relation to vegetational change. Indeed each lake has to be studied independantly from the latter point of view. That absolute pollen concentrations in lakes do not bear a direct relationship to the forest cover is due to processes such as redeposition and concentration of grains for example. Consequently Davis (1967) considers that when the deposition rate for total pollen is relatively uniform (such as during the entire postglacial at Rogers lake U.S.A.) the percentage diagram conveys almost all the information about changes in individual types contained in the deposition rate diagram.

The interpretation of the results of deposition studies must take into account the method used to calculate absolute pollen frequencies. A comparison of the four principle absolute pollen preparation techniques, namely those of Davis (1965, 1966) Mathews (1969), Jørgensen (1967) and modified Jørgensen, has been made by Peck (1974). The techniques fall into two basic categories, namely those which add "exotic" controls to the samples (i.e. Mathews) and those which sample known proportions of the total population by taking a known weight or volume of sample (i.e. Davis, Jørgensen). The method of pollen frequency determination chosen was that of Mathews (1969) and described in detail by Bonny (1972). This latter method is not as time consuming as that of Davis, the preparations and estimation of the number of grains of stock suspension taking only a few days. Thereafter the preparation time of the quantitative samples hardly exceeds that of the percentage sample. However the addition of exotic pollen introduces another variable into the calculations with the result that confidence intervals for estimates of fossil pollen concentration are wider than in the Davis method. This in turn means that the interpretation of small differences between samples is more difficult.

In the last few years palaeomagnetic studies of recent limnic sediments have been carried out. Although in its infancy this aspect of palaeomagnetic research can provide a framework for intercore comparison both within and between lakes, while aiding in time scale evaluation. Detailed palaeomagnetic studies have been carried out by Thompson (1975) on sediments from Lough Neagh and by Mackereth at Windermere. Using the techniques described by Thompson (1974) information concerning the magnetic susceptibility, intensity and declination of many lake sediments have been obtained. Susceptibility and declination changes can provide a means of correlating accurately between cores from the same lake. Work on the sediment from Lough Neagh (Thompson et. al. 1975) has shown a direct relationship between susceptibility and certain chemical and pollen analytical changes in the sediment profile. For example high susceptibility values correspond to high percentages of Gramineae, _Plantago_ and _Pteridium_ pollen as well as high concentrations of iron. A master declination curve based on observations from a number of lake district sites has been worked out by Thompson (1977). Theoretically this curve may be used to date sediments from other north British lakes. However the accuracy of this magnetic dating depends upon firstly the quality of match between the new declination data and the master curve and secondly the accuracy of the radiocarbon dating of the sediments used to plot the master cruve. Therefore when considering a new site such as Loch Lomond it must be remembered that the real extent over which the master curve is valid has not yet been determined.

2. THE ENVIRONMENTAL BACKGROUND.

2.1 Geographical location.

Loch Lomond (Lat. 56° 05'N Long 4° 35'W) which straddles the Highland Boundary Fault has the largest surface area of any lake in Great Britain. With its long axis running approximately north and south the Loch can essentially be divided into two basins. Namely north and south, the south basin being subdivided into smaller basins.

The northern basin is a deep and narrow trough (18 km long and 1.5 km at its maximum breadth) excavated in gneiss, mica schist and schistose quartzite by ice action. This basin is surrounded by mountains up to 1000m high which drop steeply giving the loch a V shaped cross section. Most of the mountains lie to the west of the loch (e.g. Ben Vorlich and Ben Arthur) while the eastern shore is dominated by Ben Lomond. The southern limit of the north basin is marked by a shallow bar formed by an outcrop of resistant Ben Ledi grits from Rowardennan on the east shore to Inverbeg on the west. The water over the bar is not more than 15m deep (Murray 1910) whereas 1 km to the north it reaches a depth of 100m. Indeed Loch Lomond is the third deepest loch in Britain being 180m deep just north of Tarbet. As the surface of the loch is only 9m above sea level most of the water in the north basin therefore lies below sea level.

The entire area south of the Inverbeg bar constitutes the southern or lower loch which has been divided into a series of basins by Slack (1954) namely the Luss, Strathcashell and Fault basins. South of the bar the loch continues on mica schist and schistose grits for another 3 km and although the loch widens slightly its maximum depth is only 66m off Ross point. Ross point itself is an outcrop of resistant grit, truncated by a fault and therefore it does not completely traverse the loch. South and west of Ross point is the Luss basin which lies in softer rocks chiefly an outcrop of Luss slate. The Luss basin contains the first group of islands which take the form of a U open to the east 1.5 km south of Ross Peninsula in an outcrop of massive pebbly grit. Slack (1954) called this area the Strathcashell basin. The whole basin from Inverbeg bar to the first group of islands, including the Strathcashell basin is referred to as the Middle or Luss basin. The remaining expanse of the loch has been referred to by Slack (1954) as the "Fault basin" and by Murray as the "Balloch basin". In this most southern area the loch reaches its maximum width of c. 7 km but does not exceed 24m in depth. The Fault basin contains the second island group, the islands lying along the line of the Highland Boundary Fault which traverses the loch from Balmaha in the north east to Arden in the south east. To the south and east of the Highland Boundary Fault the loch lies on Lower Old Redsandstone sandstones and conglomerates.

The countryside surrounding the southern part of the loch is a complete contrast to the north basin being much more open and less mountainous.

2.2 Catchment and rivers.

For the purposes of this thesis the Loch Lomond area can be defined as the catchment area of the loch, which is in total an area of c.713 km^2 (Slack 1957). The chief rivers entering the loch (Figure 3) are in the north, the River Falloch and in the south the River Endrick. The hills to the west of the loch are drained by a series of smaller rivers which are from south to north; Fruin water, Finlas water, Luss water, Douglas water and Inveruglas water. In the mountainous area north of Luss a large number of small streams cascade down the mountainsides directly into the loch on the eastern and western shores. The river Leven forms the outlet from the loch in the south west.

A brief description of the principle rivers now follows.

(a) River Falloch N S 330 204.

The River Falloch is the largest single inflow to Loch Lomond entering the loch just north of Ardlui. The river takes a right angled turn before entering Glen Falloch south of Crianlarich and in common with all the other streams and rivers inflowing from the north it flows over poorly weathering hard metamorphic rocks.

(b) Inveruglas water N S 310 092.

On the west side of the loch the Inveruglas water drains from Loch Sloy and enters the loch 5 km north of Tarbet.

(c) Douglas water N S. 340 977.

The Douglas water has a fairly large catchment area and runs through Glen Douglas where it is fed by many small streams coming off the higher blanket bog covered hills. It enters the loch on the west side of Inverbeg. The point of entry marks the boundary between the Tarbet and Luss basins.

(d) Luss water N.S 353 930.

Three burns namely Glen Mollochan, Gleann na Caoruinn and Auchengavin join to form the Luss water which has a total course of c. 9 km. The Luss water which drains the hills to the west of Luss joins the loch at the Luss basin.

(e) Finlas water N S 347 882.

The Finlas water drains from the blanket peat covered hills to the south of Luss entering the west side of the loch at Ross Park.

(f) Fruin water N.S 350 847.

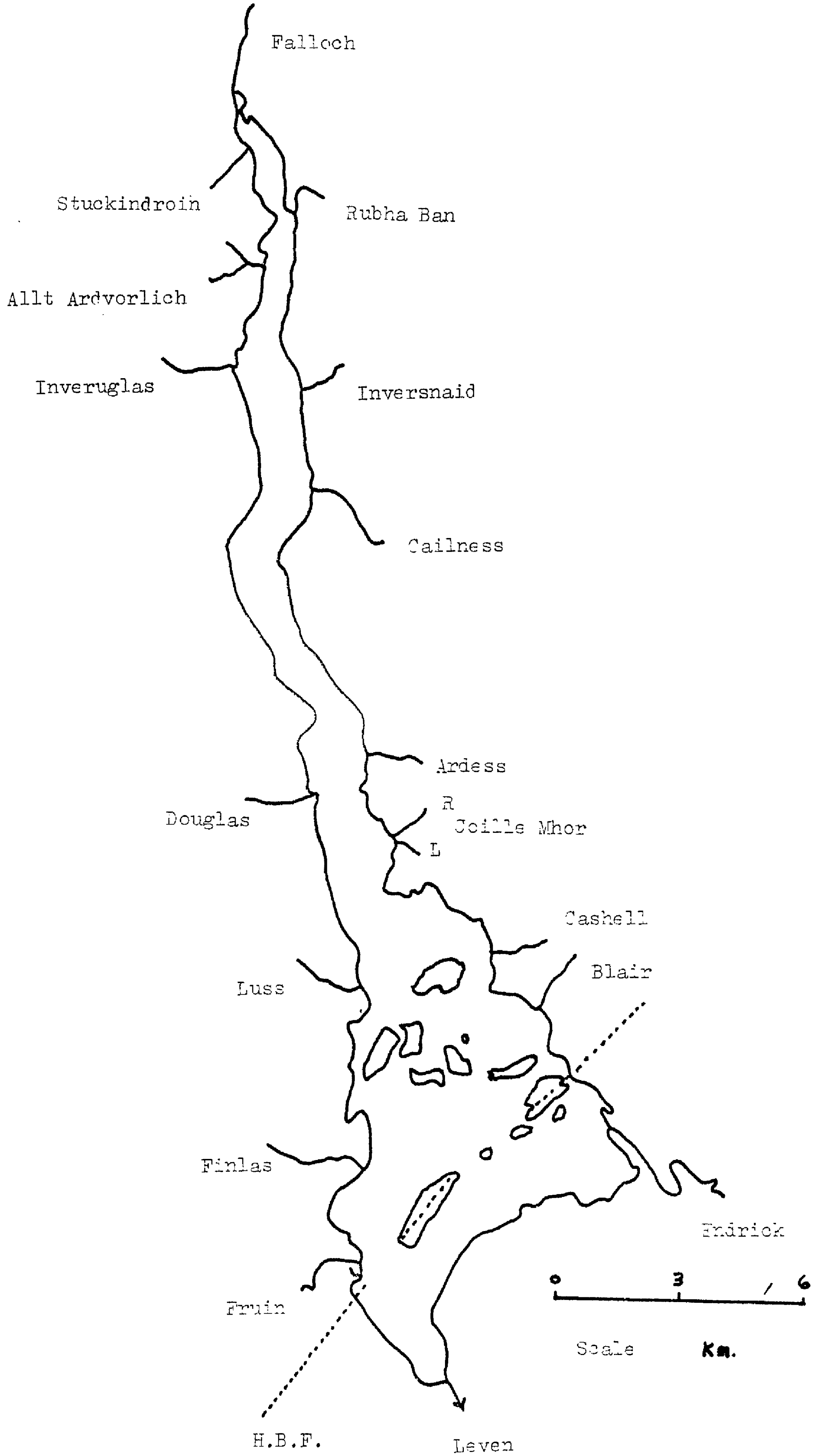
Paralleling the Finlas water the Fruin water rises in the hills above Garelochhead and enters the loch 5 km north of Balloch after passing through the fertile valley of Glen Fruin.

(g) Endrick water N S 440 880.

The Endrick water enters the loch from the south east and has the largest drainage area of all the inflows into the loch, the catchment area being about 267 km^2 (Slack 1957). The Endrick drains the Fintry and Campsie hills (both Carboniferous in age) rising at a height of just under 500 m in the Western Campsie Fells.

(h) River Leven N S 390 820.

The River Leven forms the outlet to Loch Lomond and flows southwards for 9 km through the Vale of Leven before entering the Clyde at Dumbarton.


Falloch
Stuckindroin
Rubha Ban
Allt Ardvorlich
Inveruglas
Inversnaid
Cailness
Ardess
R
Coille Mhor
L
Douglas
Cashell
Blair
Luss
Finlas
Endrick
0
3
6
Scale
Km.
Fruin
H.B.F.
Leven

2.3 Climate.

Climatically the Loch Lomond region has more affinities with the west coast oceanic regime than with the east coast continental type (Anderson and Fairbairn 1955). This results in the loch being monomictic rather than dimictic in character. The wettest months are December and January while the driest are May and June. Rainfall varies with location tending to increase in a north westerly direction and with increasing altitude. Tiltensor and Steele (1971) show the amount of rainfall on the islands to be 1524 mm as compared to 2540 mm on Ben Lomond.

The prevailing winds are from the south west; there are however no long term records of wind strength or direction available although wind speed frequently reaches gale force (i.e. force 8 or 7) in winter.

In general the climate is typical of the west coast of Scotland being rather cool, wet and with temperatures ranging from 0°C to 25°C.

2.4 Geology.

The main geological features are shown in Figure 4. Metamorphic rocks are confined to the area north west of the Highland Boundary Fault while sedimentary rocks are confined mainly to an area south east of the Fault. Most of the sedimentary rocks belong to the Old Redsandstone period and were deposited between 350 to 400 million years ago. They consist almost entirely of sandstones and conglomerates. Intrusive igneous rocks occur throughout much of the Highland part of the loch area. Indeed the Kilpatrick, Campsie and Fintry hills are the remains of Carboniferous volcanic activity. The Highland Boundary Fault which traverses the loch separates the ancient metamorphic rocks of the Highlands from the younger and more easily eroded sediments of the Midland valley.

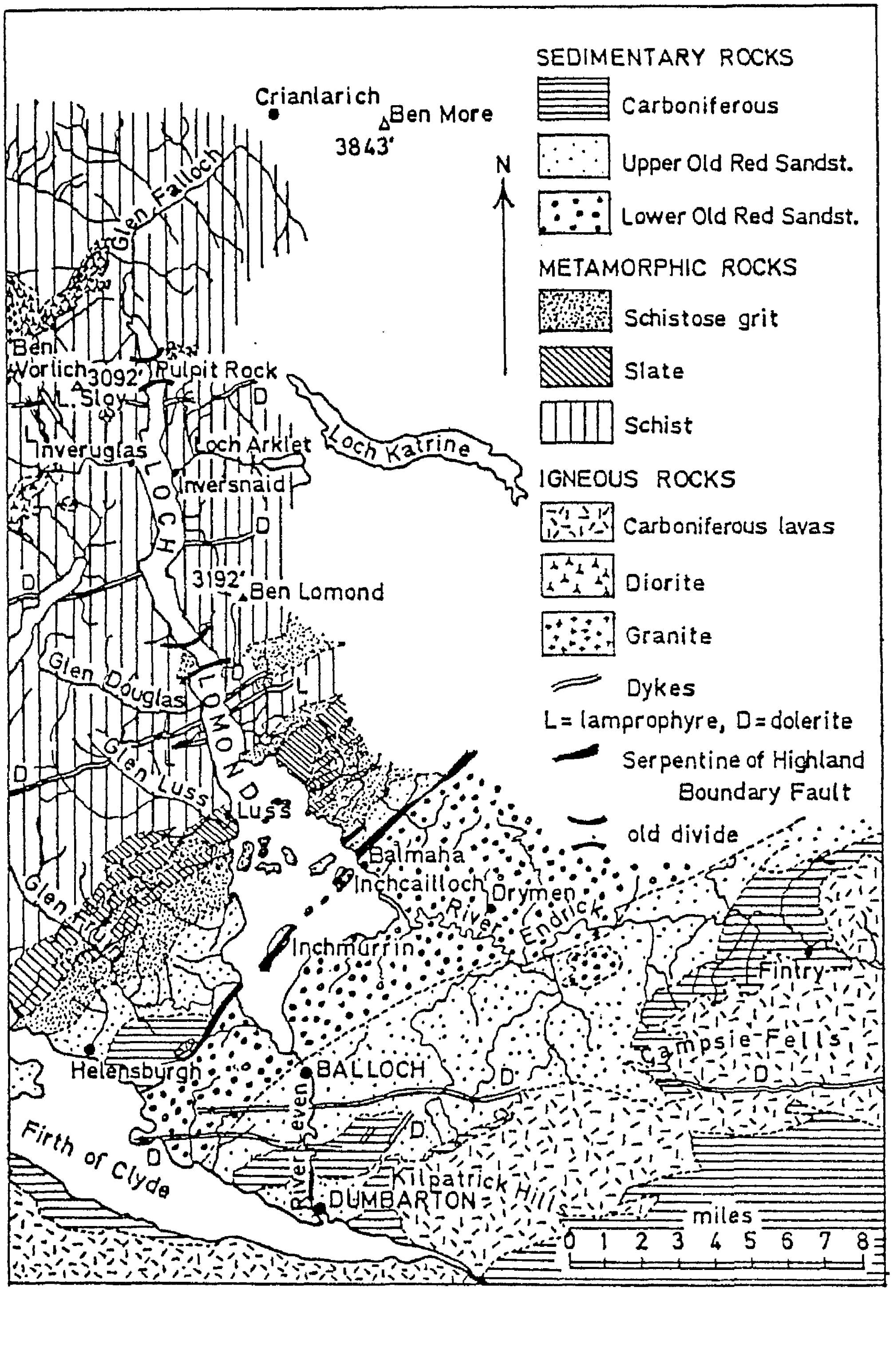
A point of note is the presence of a band of serpentine (outcropping on Inchcailloch for example) which weathers to give soils with a high base status. A

Figure 4.

Map showing the main geological features of the Loch Lomond region (from McDonald 1974).

Scale in kilometres:- 0 5 10

km



SEDIMENTARY ROCKS
Carboniferous
Upper Old Red Sandst.
Lower Old Red Sandst.
METAMORPHIC ROCKS
Schistose grit
Slate
Schist
IGNEOUS ROCKS
Carboniferous lavas
Diorite
Granite
Dykes
L= lamprophyre, D=dolerite
Serpentine of Highland Boundary Fault
old divide
N
Crianlarich
Ben More
3843'
Glen Falloch
Ben Vorlich
3092'
Pulpit Rock
L. Sloy
Inveruglas
Loch Arklet
Loch Katrine
Inversnaid
LOCH LOMOND
3192'
Ben Lomond
Glen Douglas
Glen Luss
Luss
Glen Fruin
Balmaha
Inchcailloch
Drymen
River Endrick
Inchmurrin
Fintry
Campsie Fells
Helensburgh
BALLOCH
River Leven
Firth of Clyde
Kilpatrick Hills
DUMBARTON
miles
0 1 2 3 4 5 6 7 8

fuller treatment of the geology of the Loch Lomond area is given by Gregory (1928) and McDonald (1974).

A wide range of drift deposits are to be found in the area ranging from the peats of the higher slopes to the brown earths in some of the mixed oak woodlands.

2.5 The flora and vegetation of the Loch Lomond region.

Around 540 or roughly a quarter of the species of flowering plants and ferns found in the British Isles occur in the Loch Lomond area. The flora of the area can be divided into four groups, namely:-

1) Species commonly found throughout the British Isles (e.g. *Plantago lanceolata*, *Ranunculus repens* etc.).
2) Western or Oceanic group whose distribution is probably related to high rainfall or humidity.
3) Northern group.
4) Southern group.

Some of the more notable plants from each of the above groups are listed in Table 1a. The distribution of the northern and southern groups overlap within Loch Lomondside, temperature probably being the major factor. Indeed the 10.5°C (51°F) isotherm of average minimum July temperatures passes through the southern end of the loch. Species which are unable to maintain themselves or set seed in a summer temperature of less than 10.5°C reach the northern limit of their range, hence forming the southern element in the lochside flora. Species unable to survive in temperatures in excess of 10.5°C reach the southern edge of their range and form the northern element of the lochside flora (Idle 1972)a.

Table 1b shows a comparison of the main elements of the Loch Lomond flora with Matthews'(1955) lists of the geographical elements in the British flora (Idle 1974)a. Matthews' lists do not include ferns which would increase the weighting towards western and northern species.

The vegetation of the Loch Lomond area can be divided into four main types for the purposes of description,

Table 1a and 1b.

1a. Some of the more notable plants found in plant groupings 2) to 4) in the Loch Lomond area.

1b. Comparison of the main elements of the Loch Lomond flora with Matthews' (1955) lists of the geographical elements in the British flora (from Idle 1974).

1a.

2) <u>Western or Oceanic group</u>
   Carum verticillatum
   Hymenophyllum tunbridgense
   Dryopteris aemula
   Pinguicula lusitanica
   Oenanthe crocata

3) <u>Northern group</u>
   Silene acaulis
   Cerastium alpinum
   Subularia aquatica
   Sibbaldia procumbens
   Cicuta virosa
   Lysimachia thyrsiflora

4) <u>Southern group</u>
   Bidens cernua
   Stellaria nemorum

1b.

	"Southern" species	"Western" species	"Northern" species
Loch Lomond total	13	14	50
British total	283	95	222
Loch Lomond % of British	4.5	15	22.5

namely:-

1) Upland including montane and moorland.
2) Woodland.
3) Mires.
4) Lochside or Littoral vegetation.

Each of these vegetation types contains a wide range of communities and only a few will be described here. The pattern of plant distribution induced by climate is diversified considerably due to the variety of relief and geology within the Loch Lomond area the landscape ranging from virtually sea level to 974 m.

1. Upland including montane and moorland.

The lower slopes of the hills below 650 m are characterised by a mixture of heather, moorland and grassland. The latter is commonly infested with Pteridum aquilinum. Calluna vulgaris accompanied by Erica cinerea and Vaccinium myrtillus typify the moorland vegetation. The more poorly drained sites have Erica tetralix, Trichophorum caespitosum, Narthecium ossifragum, Myrica gale and Molinia caerula, while Carex binervis and Juncus squarrosus are common in the grassland areas.

The summits and high ridges of the major hills carry a sparse close growing plant cover. This summit "heath" community is characterised by Rhacomitrium lanuginosum, Salix herbacea, Carex biglowii, Gnaphalium supinum, Galium saxatilis and Festuca ovina. Scattered in the turf are arctic-alpines including Lycopodium alpinum, Alchemilla alpina and rarely Sibbaldia procumbens. In wetter areas Polygonum viviparum, Thalictrum alpinum, Oxyria digyna, Cochleria alpina, Saxifraga stellaris and S. aizoides occur.

"Tall herb" vegetation occurs on ledges and places inaccessible to sheep, the species found being common at lower altitudes and including Luzula sylvatica, Angelica sylvestris, Trollius europaeus, and Silene dioica. Sedum rosea, Saxifraga oppositifolia, Minuartia verna, Potentilla crantzii and Draba incana are to be found in areas with sparse cliff face vegetation where the rocks are richer in minerals (Idle 1974)a.

2) Woodland plants.

The plant communities of the Loch Lomond *Quercus* woods have been described by Tittensor and Steele (1971) with the woodland vegetation of Inchcailloch having been studied in detail by Horrill et al.(1974). In total eleven community types were recognised by Tittensor and Steele (1971) each having its own characteristic physiognomic and environmental features. However only a brief description of selected community types will be given here.

In the southern mainland woods and on the islands the *Quercus* woodlands generally overly thin acidic soils, *Vaccinium myrtillus* and *Deschampsia flexuosa* being dominant with occasional *Calluna vulgaris*. Apart from *Lonicera periclymenum* shrubs are rare due to grazing by sheep, deer or cattle. However where animals are excluded *Ilex aquifolium*, *Sorbus aucuparia* and young *Betula pubescens* are the commonest shrubs. Both *Quercus robur* and *Q. petraea* are to be found. However most of the original *Q. petraea* have crossed with the introduced *Q. robur*. In places where the soils are less acid such as in the centre of Inchcailloch a plant community dominated by *Luzula sylvatica*, *Dryopteris felixmas*, *Rubus fruiticosus* agg. *Endymion non-scriptus* and *Holcus lanatus*. *Quercus* and *Betula* are the main canopy trees with *Alnus glutinosa* in more marshy areas. Indeed wherever the water content of the soil is high *Quercus* woodland is replaced by *Alnus glutinosa*, species such as *Athyrium felixfemina*, *Caltha palustris* and *Chrysosplenium oppositifolium* being characteristic. Dense growths of young *Fraxinus* reaching three to five metres in height frequently occur with the *Alnus glutinosa* (Idle 1974)a. Where the *Quercus* woods overly more base rich soil such as at Arrochymore *Ulmus glabra* and *Fraxinus excelsior* are common with a rich herb flora typified by *Allium ursinum*, *Mercurialis perennis*, *Galium odoratum* and *Sanicula europaea*.

Apart from the *Betula* woodland at the north west of Loch Lomond and the large coniferous plantations other woodland areas are limited to small areas with *Taxus baccata* on Inchlonaig being worthy of note.

3) Mires.

Typical western blanket bog of the Trichophoreto-Eriophoretum typicum association described by McVean and Ratcliffe (1962) is common in the Loch Lomond area especially on the Fintry, Campsie and Kilpatrick hills. In the hills to the east and west of Loch Lomond peat formation is mainly restricted to the hills around Luss and to the flatter plateaux north of Ben Lomond. Trichophorum cespitosum, Eriophorum vaginatum, Eriophorum angustifolium, Erica tetralix, and Calluna vulgaris are the most prominent plants with Empetrum nigrum and Rubus chamaemorus, frequently being present. Notable areas of low lying peat are to be found on Inchmoan and Inchlonaig and at Gartocharn. Marshland is mainly confined to the mouths of the rivers Falloch and Endrick (a detailed vegetation map being available for the latter area as it forms the mainland part of the Nature Conservancy Council's nature reserve) with Juncus acutifolius often being codominant with Deschampsia cespitosa.

4) Lochside and Littoral vegetation.

Three main species typify the photic zone which is usually less than five metres in depth, namely, Littorella uniflora, Isoetes lacustris and Myriophyllum alterniflorum. In contrast the vegetation higher up the shore may be rich in species such as Trollius europaeus, Rubus sexatilis, Aquilegia vulgaris and Oenanthe crocata. Notable is the presence of Rumex aquaticus at the southern end of the loch. The shores of the loch have an intermittent fringe of Alnus glutinosa sometimes with Myrica gale, which is also seen on the islands.

2.6 History and land use of the Loch Lomond area.

Mesolithic.

During the period between the lastglacial and 3000 B.C. known culturally as the mesolithic or middle stone age, Scotland would have been a sparsely populated country (Atkinson 1962, Rymer 1974). Mesolithic man was a hunter and fisher living along coastal strips, river banks and lake margins (Lacaille 1954). Man's role as an ecological factor (although only to a limited degree due to the low state of technology (Morrison 1974)) had begun by c.5000 B.C.

in the Loch Lomond area. Indeed stone implements of late mesolithic age have been found at sites near the mouth of Glen Finlas and on the island of Inchlonaig.

Neolithic.

From about 3500 B.C., the first groups of people practising agriculture and having domesticated animals arrived in Scotland. The neolithic settlers were introducing their domesticated animals into the area for the first time. The Scottish evidence mainly from animal bones discovered in chambers yielding exhumations includes domesticated ox, pig, sheep or goat and dog (Piggott 1954). Rymer (1974) points out that evidence for cereal cultivation in the Clyde-Solway cultural area is not as impressive as that for other areas in Britain. Neolithic farmers probably avoided the low lying areas and river valleys (e.g. Strathendrick valley, Vale of Leven and the lowlands around the southern end of Loch Lomond) where the soils were marshy or clayey, preferring the less densely forested hill slopes and the better drained upland soils. Remains of neolithic chambered tombs (Figure 5) can be seen on Walton Farm near Cardross and on Cameron Farm about one mile west of Balloch, both sites being between 120 m to 150m above sea level. Cairns are also present at Shiels of Gartlea, on Dumbarton Muir, and at Aucheneck on Stockie Muir.

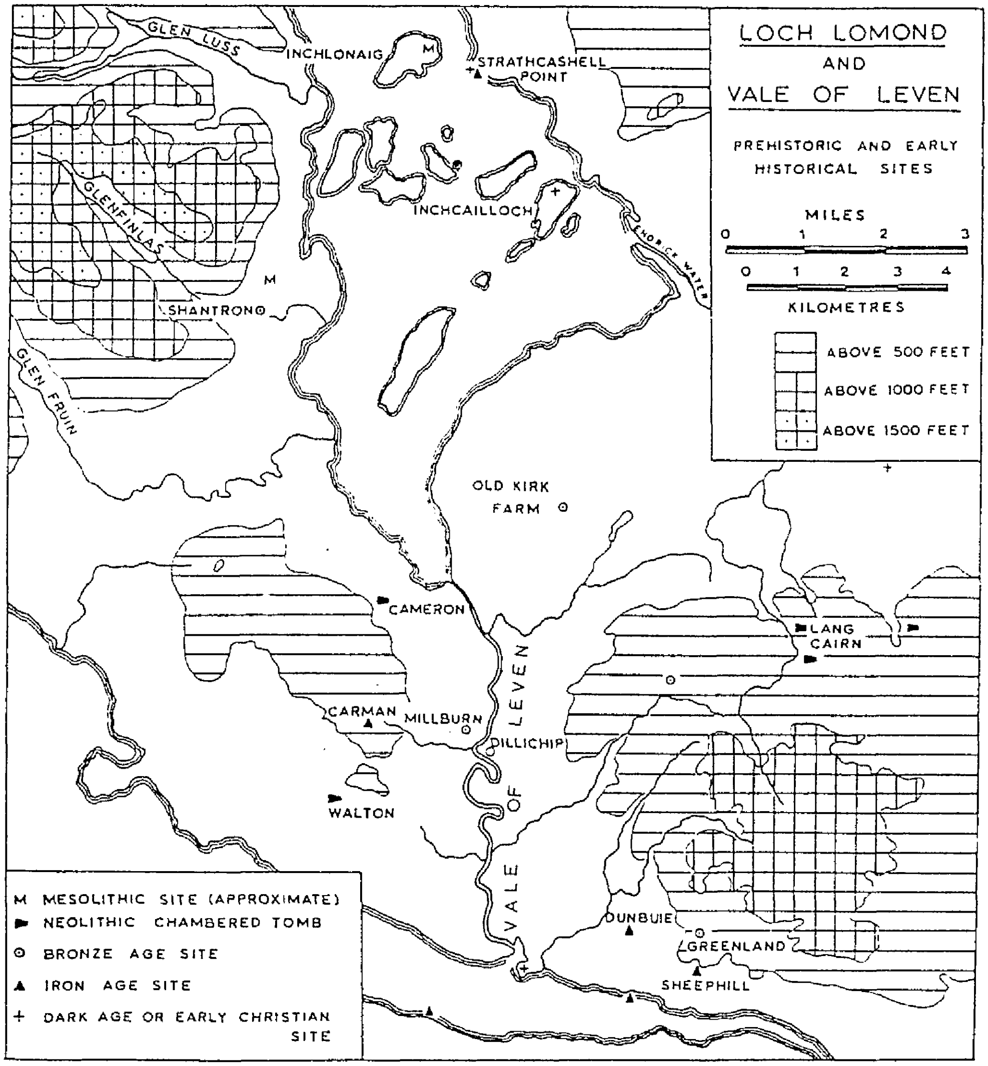
Bronze and iron ages to modern times.

Both bronze and iron age artifacts (e.g. burial cists and crannogs respectively) have been found in the Loch Lomond area. Bronze age people may have relied more on stock raising and less on arable farming than their Neolithic predecessors (Morrison 1974). Numerous cist burials of Bronze age are to be found as well as cup and ring markings, the true significance of which is not known. Evidence from other parts of Britain (i.e. enclosed settlements and small squarish fields) suggest major agricultural changes in the later Bronze age (i.e. after about 1200 B.C.).

Some time after 400 B.C. iron using people moved into Scotland. Many of the Iron age sites around Loch Lomond are

Figure 5.

Archaeological map showing prehistoric and mediaeval sites around Loch Lomond. (From Morrison 1974).


LOCH LOMOND
AND
VALE OF LEVEN
PREHISTORIC AND EARLY HISTORICAL SITES
MILES
0 1 2 3
0 1 2 3 4
KILOMETRES
ABOVE 500 FEET
ABOVE 1000 FEET
ABOVE 1500 FEET
GLEN LUSS
INCHLONAIG
STRATHCASHELL POINT
INCHCAILLOCH
ENDRICK WATER
GLENFINLAS
SHANTRON
GLEN FRUIN
OLD KIRK FARM
CAMERON
LANG CAIRN
CARMAN
MILLBURN
DILLICHIP
WALTON
VALE OF LEVEN
DUNBUIE
GREENLAND
SHEEPHILL
M MESOLITHIC SITE (APPROXIMATE)
NEOLITHIC CHAMBERED TOMB
BRONZE AGE SITE
IRON AGE SITE
+ DARK AGE OR EARLY CHRISTIAN SITE

hill forts and crannogs (such as the one just off the shore of Strathcashell point) which along with metal artifacts (i.e. weapons) suggest a warrior race. Some of the fortifications were very large such as the one at Sheep Hill above Bowling which occupied an area of 1087 square metres. While at Carman Hill above Renton there was an enclosure covering 2.4 square kilometres which may have included a settlement of some kind (Morrison 1974).

Consolidation of settlement and exploitation in the area began with the early Christianisation of Loch Lomond in the sixth and eighth centuries (Irving J. 1860, Idle 1974)b. By the twelfth century the system of infield and outfield farming was in use. The villages of Luss, Bonhill and Aber grew to cope with the increasing population. Indeed the Chronicles of the Norse raid in 1263 mention "the populous islands of Loch Lomond and the mansions on the shore" (Huxley 1964). Agriculture generally seems to have languished between the fourteenth to the seventeenth centuries.

Industrialisation in the central belt of Scotland had a considerable impact on the Loch Lomond area, especially on the *Quercus* woods which are a remnant of a more widespread natural mixed *Quercus* forest. The history and plant communities of the Loch Lomond *Quercus* woods have been well documented by Tittensor and Steele (Tittensor 1970a, 1970b, Tittensor and Steele 1971). Extensive coppicing on a 24 year rotational basis since about 1700 considerably altered the structure of the Loch Lomond *Quercus* woods, particularly bringing about a reduction in the number of tree species within the woodlands themselves. The products of the intensive woodland management of the eighteenth and nineteenth centuries were used for charcoal and in the local tanning and pyroligneous acid industries.

There is little recorded history of the Loch Lomond woodlands in the twentieth century and little management took place after 1920, many of the old estates being broken up. In 1931 the Forestry Commission began coniferous afforestation at Garadbhan, Drymen. However larch had been planted in Bonhill Parish in the sixteenth century and the Old Statistical account for Scotland (1791) states that 250 acres of "Scotch" fir and larch had been planted in the Parish. At present approximately 5180 hectares planted mostly with Larix decidua, Picea abies, Picea sitchensis some Pinus sylvestris, Pseudotsuga menziesii and Juniperus communis are held by the Forestry Commission. In order to conserve an example of the Loch Lomond woodlands which are disappearing due to clearance and underplanting with conifers, the Nature Conservancy Council established a National Nature Reserve on five of the islands in the loch and an area around the mouth of the River Endrick.

3. MATERIALS AND METHODS.

3.1 Collection of cores and storage.

(a) Limnic sediments.

With the use of the University of Edinburgh Geophysics Department's six metre Mackereth sampler sediment cores were obtained from the Loch Lomond and Dubh Lochan basins .

A series of cores were obtained from the southern basin of Loch Lomond at approximately N S 385 900 under 24 m of water (LLRD, 1-3) and at approximately N S 393 875 under 26 m of water (LLRP, 4). The cores were all over 4.70 m long. (Details of the cores are given in Table 2).

One Mackereth core 4.90 m long was obtained from the deepest part of the Dubh Lochan at N S 377 964 (Figure 6) under 11 m of water. A one metre mini-Mackereth core was also obtained from the latter site.

The six metre core tubes were cut in half horizontally along their full length, wrapped in polythene and stored in a cold room at 5^{o}C. A "cold finger" core (LLRD, CF_2). 0.8 m in length was obtained from site LLRD using the corer described by Saarnisto (1975) which consisted basically of a heavy metal tube closed and weighted at one end and open at the other. The tube was filled with dry ice and Butan-1-ol was used as the refrigerant. The corer was lowered to within one metre of the sediment surface and allowed to free fall into the sediment under its own weight. The corer was then winched aboard the boat and the outer ring of sediment removed by pouring hot water into the body of the corer. The frozen core was X-rayed by the Natural Philosophy Department of Glasgow University.

(b) Terrestrial sediments.

Three sided metal containers were used to extract monoliths of peat from suitably cleaned peat hags at each of the following sites:- Ptarmigan, Glen Falloch and Shantron Muir. (Details of sites and monoliths are given in Table 2). The samples were wrapped in polythene and stored in a cold room until used.

Table 2.

Details of a) Limnic cores a nd sites.

b) Terrestrial monoliths and sites.

a) Limnic sediments.

Site Name	Core Name	Map Reference	Water Depth	Core Length
Loch Lomond Ross Dubh	LLRD 1-3	NS 385 900	24m	c.4.70m
Loch Lomond Ross Priory	LLRP 4	NS 393 875	26m	c.4.70m
Duch Lochan	DLM 1	NS 377 964	11m	4.90m
Dubh Lochan	DLMC	NS 377 964	11m	c.1m

b) Terrestrial sediments.

Site Name	Map Reference	Monolith Length
Glen Falloch	NS 369 238	2.01m
Ptarmigan	NS 365 015	1.255m
Shantron Muir	NS 328 878	1.37m

3.2 Sampling and analysis of cores and profiles.

The terrestrial sediments were sampled to give 2 cm^3 samples which were prepared for pollen analysis by the technique summarised below:-

1) Add 10% sodium hydroxide and place in boiling water bath for 5 minutes.
2) Decant and sieve off coarse material. Stages 3) and 4) for limnic sediments only.
3) Remove silica by boiling in 40% hydrofluoric acid for up to 40 minutes or placing in cold H.F. for 3 days.
4) Remove colloidal silicates and silicafluorides by treatment with hot 10% hydrochloric acid for 15 minutes.
5) Acetolyse in boiling water bath for 3 minutes in a mixture of 9 ml acetic anhydride to 1 ml concentrated sulphuric acid.
6) Wash and neutralise.
7) Add 10 ml tertiary butyl alcohol (T.B.A.), stir, centrifuge and decant.
8) Add silicone oil of 2000 c.s. viscosity and evaporate off any remaining T.B.A. in an oven at $50^{o}c$ overnight.

Each of the above steps is separated by washing in distilled water. All samples were stained at step 6) with aqueous safranin. In the case of the limnic sediments, samples were measured (3cc for LLRD1 and 1cc for DLM1) by water displacement in a B.S. 604 Class A measuring cylinder using the method outlined by Bonny (1972). Exotic grains from a standardised stock suspension were added prior to acetolysis. The method of absolute pollen analysis chosen was that of Mathews (1969) and described in detail by Bonny (1972). Eucalyptus globulus was used as the exotic pollen, the preparation of the stock suspension being as follows; a known weight of Eucalyptus pollen was added to a 50:50 mixture of Glycerine and water and made up to a volume of 800 ml. A magnetic stirrer was used to suspend the Eucalyptus in the Glycerine, mixing continuing for at least three hours to ensure an even suspension. Samples were transferred with a pipette to a haemocytometer and the pollen concentration measured. A known volume of the stock suspension was added to each sediment sample prior to acetolysis.

The preparation procedures for the limnic samples were as outlined for the terrestrial samples; however treatment with hydrofluoric acid (stages 3) and 4) was also necessary for the removal of silicates. Dubh Lochan samples were placed in cold HF for c. 3 days while Loch Lomond samples were boiled in HF for up to 40 minutes.

Samples analysed purely for dinoflagellates were prepared by the methods described by Reid (1974) involving prolonged heating in HF.

3.3 Microscopy.

Silicone oil was used as the mounting medium in all cases and counts in excess of 150 tree grains (unless otherwise stated) were done on a Vickers Patholux microscope at a magnification of X520. Oil immersion at a magnification of X1300 was used for critical study.

3.4 Pollen and spore identifications.

Pollen and spore identifications were made with reference to the type collection in the Botany Department of Glasgow University and using the following texts:-

Andrew 1970
Birks 1973
Erdtman, Berglund and Praglowski 1961
Erdtman, Praglowski and Nilsson 1963
Faegri and Iversen 1974
Moe 1974
Punt 1976
Reitsma 1966
Sorsa 1964

Carboniferous spores were identified by Dr. A. Hibbert of Liverpool Polytechnic while exact Dinoflagellate determinations were by Dr. P. C. Reid, Institute Marine Environmental Research, Plymouth and Dr. R. Harland Institute of Geological Sciences, Leeds.

Nomenclature and conventions are after Birks (1973).

Due to the difficulty experienced in distinguishing Myrica from Corylus (especially in the Loch Lomond core with its extremely badly preserved grains), Myrica and Corylus have been put together under the category Coryloid. Unlike pollen grains or spores classified as unknown, indeterminable grains cannot be differentiated into distinct pollen or spore types. Three categories of indeterminable grains are presented namely, crumpled, concealed and corroded. The problems of spore identification due to poor preservation have been discussed by Cushing (1967).

3.5 Presentation of pollen data.

The results of the pollen analyses are presented in the pollen diagrams (some of which were drawn using the computer program Polldata MK4 kindly made available by Dr. H.J.B. Birks) enclosed with this volume. Results are expressed in one or more of the following ways:-

1) As a percentage of arboreal pollen (% A.P.), excluding Corylus and Salix.
2) As a percentage of total pollen excluding unknown and aquatic grains.
3) As either concentration (grains /cm^3) or deposition (grains /cm^2/year).

3.6 Wood Analysis.

a) Preparation.

Wood samples were prepared for identification as follows:- transverse, radial longitudinal and transverse longitudinal sections were cut using a sharp wet blade. The sections were placed on a microscope slide and stained with a fifty fifty mixture of Phloroglucinol and concentrated hydrochloric acid. Gum chloral was added and a cover slip placed on the slide. The sections were then examined at a magnification of X530.

b) Identification.

The sections of wood were identified on the basis of their anatomy by comparison with the department's reference slides and with reference to Jane (1970) and Godwin (1956 key at rear of book).

3.7 Sediment description.

Sediment description was carried out using the system of Troels-Smith (except in the case of core LLRD1) (1955).

The physical properties examined were degree of darkness (nig), Stratification (str), elasticity (elas) and dryness (sic). Munsell's colour chart was used to describe by means of a code, the colour of the sediment in each section. The nature of the contact between each lithological unit was also noted. The relative proportions of the compound elements were scored on a 5 point scale (0-4 with x indicating presence). The results of the Troels-Smith analysis are presented on the left-hand side of each pollen diagram and the symbols used to show the relative proportions of the compound elements are given in Appendix 1.

3.8 Zonation of the pollen diagrams.

To aid in the description, discussion and comparison of pollen diagrams it is useful to divide each pollen diagram into smaller units. The pollen zone is a useful sub-division of the vertical dimension of pollen diagrams. The pollen zone has been defined by Birks (1973) as:-

> "a body of sediment with a consistent and homogeneous fossil pollen and spore content that is distinguished from adjacent sediment bodies by differences in the kind and frequencies of its contained fossil pollen grains and spores".

The use of pollen zones alleviates the difficulty of applying the traditional Godwin (1940, 1956) pollen zonation scheme to Scotland (Vasari and Vasari 1968, Birks H.H. 1970). According to the American Commission on Stratigraphic Nomenclature (1961) a pollen zone as defined above is a biostratigraphic unit. Biostratigraphic units are defined without exception on the basis of their contained fossils and they carry no ecological, chronological or climatic implications. A pollen zone is usually an Assemblage zone which is defined as "a body of strata characterised by a certain assemblage of fossils without regard to their range". However according to West (1970) a pollen zone could equally well be defined as an Acme zone (a body of strata characterized by the exceptional abundance of some simple fossil group after which it is named) or in any other of the precise ways defined by the stratgraphical code. Assemblage zones are usually named after one or more of the most "abundant" taxa although the name givers need not be confined to the zone or found in every part of it. Pollen assemblage zones should whenever possible be related to units of chronostratigraphy. Indeed just as any pollen assemblage zone can be related to lithostratigraphic zones on the basis of the sediment column drawn alongside it, it can also be related to a chronozone sequence.

Regional pollen assemblage zones can be recognised and serve to delimit areas that may have shared a similar vegetational history (Birks 1970). Regional pollen zones can only be described from pollen diagrams where very local effects are excluded or at a minimum (West 1968). Local pollen zones recognised at a particular site are often but not always sub-divisions of the regional zones.

Delimitation of zones by computer.

Various numerical techniques have been devised to delimit pollen zones (e.g. Gordon and Birks 1972, Birks 1974). The advantages of numerical zonation techniques over say the purely visual method are:-

i) Consistency
ii) Criteria for zonation must be precisely defined.
iii) Speed of implementation
iv) Repeatability of results.

In a comparison of five numerical zonation methods (applied to two Flandrian profiles in England and Wales) Birks (1974) was able to demonstrate not only consistency between the different techniques used but also a general agreement with the conventional Godwin zonation scheme.

The pollen diagrams presented here have been divided into local pollen zones using the numerical techniques devised by Gordon and Birks (1972). A computer program called Conslink was used to aid in the determination of local pollen zones. Conslink utilises constrained agglomerative procedures. These require that the levels amalgamated must be adjacent or the groups of levels are not separated by any level which is not in either group. The pollen data was supplied to the computer starting at level 1 and giving the total pollen count for each taxon at that level. This information was given for all sample levels in stratigraphic order. The computer examined the levels and put the two levels which were most similar together. An amalgamation value h was determined which represented the difference between the two levels. The values of h given were plotted against the stratigraphic sequence and a dendrogram was constructed. Levels were placed in groups determined by the value of h, each group containing more levels the larger h became. A value of h was selected which permitted the levels to be split into groups each group constituting a zone.

Results of the Conslink analyses were additionally compared to the results of two divisive techniques called Splints F and Splints Q incorporated in the same program. In the divisive procedures the computer compared variance between successive levels. The two methods used are very similar but use a different definition of divergence. Divisions become apparent where variance is large.

The numerical analyses were based on all pollen and spore types of vascular plants (excluding aquatics) which attained at least 5% or more of the basic pollen sum chosen in at least one level. According to Birks (1972) pollen and spore values of less than 5% need not be considered in the computations as they are of little importance in biostratigraphy. However they may be of considerable value in the interpretation of the diagram itself.

The results of the zonation procedures are presented at the righthand side of each pollen diagram and in the relevant sections discussing each diagram.

4. REGIONAL VEGETATIONAL HISTORY.

4.1 Sites Investigated.

Two loch sediment cores were investigated by pollen analysis to provide a regional picture of the vegetational history of the Loch Lomond area. Namely core DLM from the Dubh Lochan and core LLRD1 from Loch Lomond. The Dubh Lochan site was chosen as a fen carr diagram from the side of the loch (Walker 1975) already existed hence allowing a comparison between deep water and marginal pollen profiles. The comparison between the Dubh Lochan pollen profile and the profile from Loch Lomond also has many interesting aspects due to the different nature of the pollen recruitment areas. The pollen profile from the Dubh Lochan sediment aids in the understanding and interpretation of the Loch Lomond profile. Indeed the Dubh Lochan information suffers none of the difficulties of interpretation imposed upon the Loch Lomond data by for example:-

a) Poorly preserved pollen and spores
b) Very low organic carbon content of the sediment ruling out accurate radiocarbon dating
c) Very large pollen recruitment area
d) Marine transgression during the "mid" Flandrian.
e) Large rivers entering and leaving the loch.

There now follows a description of the sedimentary and pollen stratigraphy of both the Loch Lomond and Dubh Lochan cores. Details of the environmental background and flora and vegetation will only be given for the Dubh Lochan (Figure 6) as in the case of Loch Lomond they have already received comprehensive treatment in Chapter 2.

Loch Lomond.

4.2.1 Sediment stratigraphy.

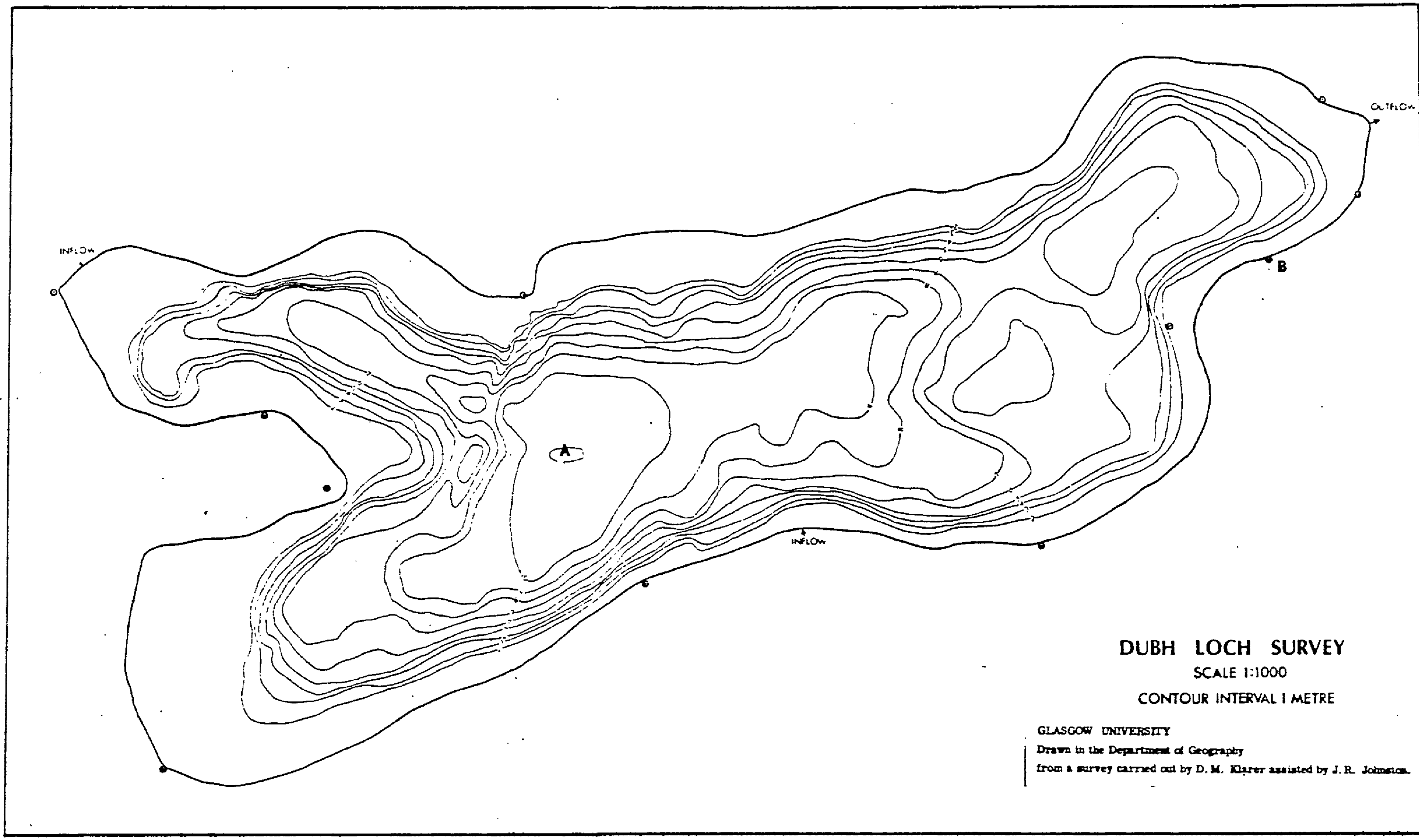
From a series of cores (Table 2) obtained from the southern basin of Loch Lomond core LLRD1 was chosen for study. The symbols

Figure 6.

Survey map of the Dubh Loch (kindly provided by D. M. Klarer).

A - Site DLM

B - Walker's fen carr site.



OUTFLOW
INFLOW
INFLOW
A
B
DUBH LOCH SURVEY
SCALE 1:1000
CONTOUR INTERVAL 1 METRE
GLASGOW UNIVERSITY
Drawn in the Department of Geography
from a survey carried out by D. M. Klarer assisted by J. R. Johnston.

used to represent each lithological unit are shown in Figure 12. The sedimentary profile is presented on the left-hand side of the LLRD 1 pollen diagrams. The top of the core is taken to be 0 cm. The frontispiece shows a colour photograph of the core.

0 - 278 cm	Brown silty clay
278 - 305 cm	Finely banded clay
305 - 375 cm	Black silty clay
375 - 390 cm	Brown silty clay
390 - 392 cm	Grey clay
392 - 470 cm	Brown silty clay
470 - 490 cm	Grey clay

4.2.2 Pollen Stratigraphy.

For convenience the sediments between 420 cm and 0 cm at site LLRD 1 are divided into five biostratigraphic intervals based upon the pollen and spore content of all land plants with values of 5% or more total pollen. The local pollen zones are numbered from the base upwards and are prefixed LLRD 1. The results of the zonation procedures (outlined in 3.8) are presented at the righthand side of the % T.P. diagram (Figure 11) and in Figure 7. All figures are based on ≤T.P. (sum total pollen excluding aquatics, mosses, crumpled corroded and derived pollen and spores.

Local pollen zones LLRD 1:-

LLRD 1-A (420 - 355 cm).

This zone is characterised by high values of *Pinus* (14-62%) and Filicales (12 - 22%) pollen and spores respectively. *Betula* values are very low only rising above 5% towards the upper end of the zone. The highest value of derived spores is found at the base of the zone (12%).

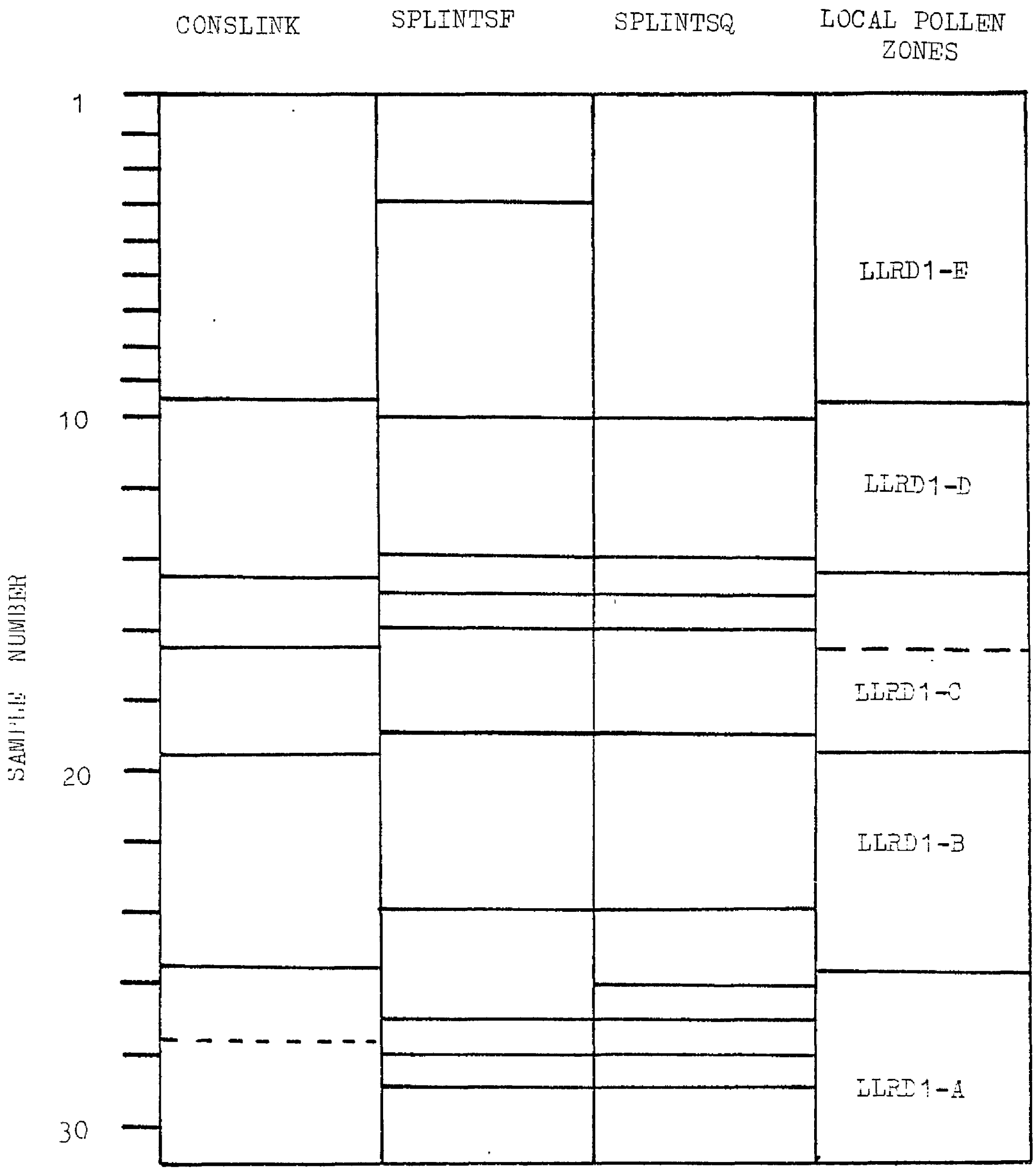
LLRD 1-B (355 - 302.5 cm).

This zone is characterised by high values of arboreal pollen. The *Alnus* curve rises to 19% while *Betula* and *Ulmus* reach their highest values of 19% and 7% respectively. *Pinus* values fall rapidly while the spores of freshwater aquatic plants are conspicuously absent. Marine dinoflagellate cysts are present throughout.

LLRD 1-C (302.5 - 250 cm).

This zone can be divided into two subzones, namely a and b.

LLRD 1



9/10 - 170 cm
14/15 - 250 cm
19/20 - 302.5 cm
25/26 - 355 cm

LLRD 1-C subzone A (302.5 - 275 cm)
LLRD 1-C subzone B (275 - 250 cm)

Subzone A is characterised by high values of Quercus (up to 20%), Alnus (up to 30%) and Coryloid pollen (up to 39%). Gramineae increases to 5% while the first Plantago lanceolata pollen is noted.

Subzone B is characterised by a peak in Pinus pollen of 9%. Arboreal pollen values decline. Cyperaceae pollen is present for the first time.

LLRD 1-D (250 - 170 cm).

A general reduction in arboreal pollen typifies this zone. Quercus declines from 16% to 2%. Coryloid and Alnus values are lower than in the previous zone. Gramineae values are consistently above 7% reaching 11% at the top of the zone. Pteridium rises from 14% at the base to 21% in the middle of the zone before falling gently to less than 4%. Plantago lanceolata is continuously present except in the lowest sample, the lower part of the zone being comparatively herb rich. However no herb taxon reaches more than 1%. Isoetes reaches a maximum value of 8%.

LLRD 1-E (170 - 0 cm).

This zone is characterised by fairly high Gramineae values which remain fairly steady (15-25%) throughout the zone. Calluna values rise above 5% reaching a maximum of 13% at the top of the zone. Arboreal pollen values are lower than in previous zones. Alnus values remain fairly constant at c.25% only decreasing at the top of the zone. A profusion of herbs also typifies this zone, only Plantago and Filipendula reaching 1%. The curve for Sphagnum rises towards the top of the zone.

4.2.3 Macrofossils.

The only plant macrofossil found was a twig of Alnus within the laminated layer at a depth of 282 cm.

4.2.4 Radiocarbon dates.

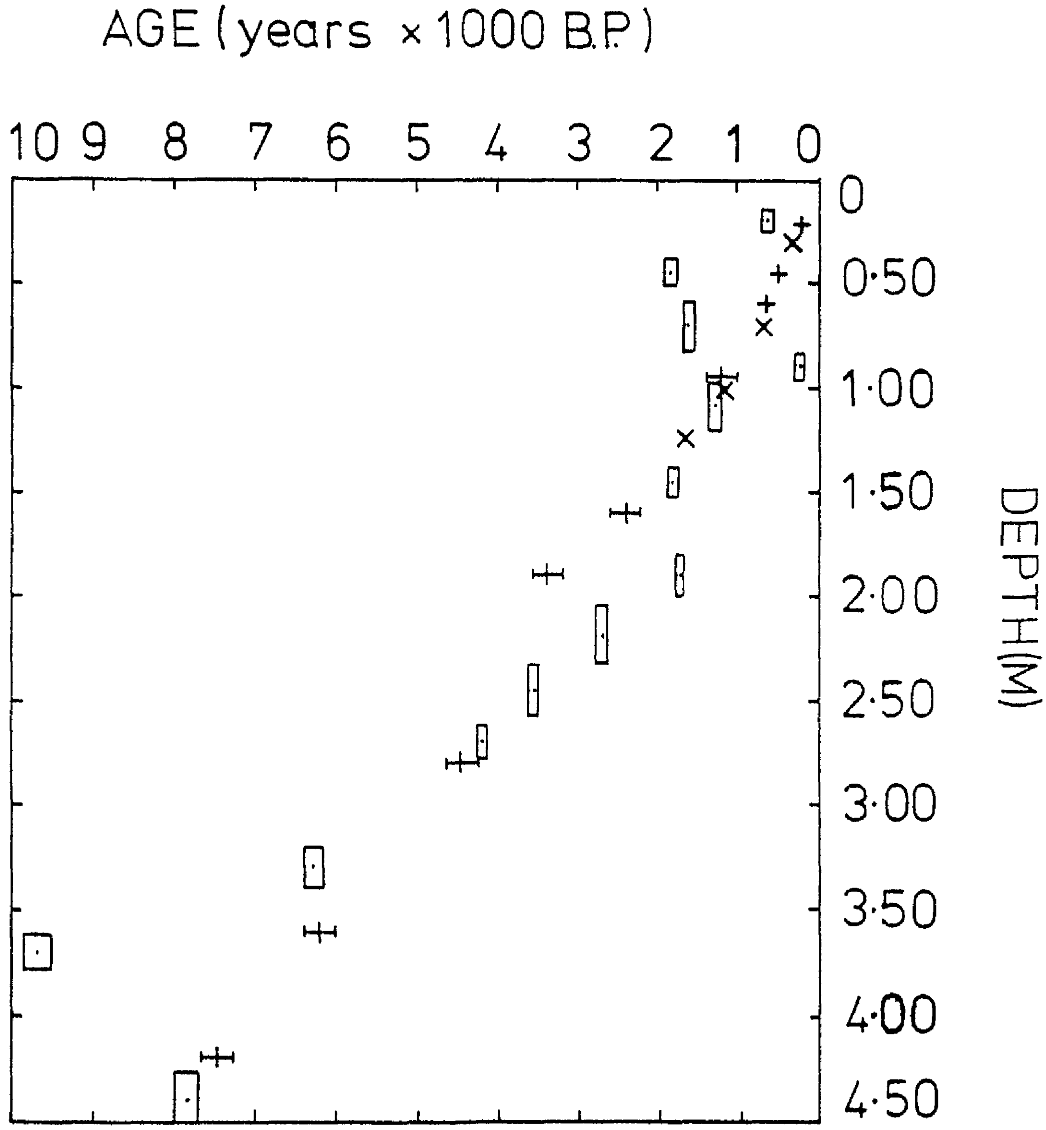
Thirteen radiocarbon dates (Table 3 and Figure 8) were provided by the Radiochemistry section of Glasgow University. A full discussion of the dates is given in Appendix 2 only the most important details being described here. Due to a low organic carbon content (1.5% freshwater

LAB NO.	DEPTH/WIDTH OF SAMPLE	DATE (AGE$\pm$1σ YEARS B.P.
G.U. 900	15-25 cm	643$\pm$52
G.U. 901	38-52 cm	1815$\pm$78
G.U. 902	58-82 cm	1627$\pm$51
G.U. 903	83-97 cm	231$\pm$55
G.U. 904	97-119 cm	1294$\pm$69
G.U. 905	138-152 cm	1838$\pm$59
G.U. 906	180-200 cm	1730$\pm$59
G.U. 907	205-233 cm	2712$\pm$78
G.U. 908	233-257 cm	3542$\pm$55
G.U. 909	262-278 cm	4205$\pm$59
G.U. 910	320-340 cm	6293$\pm$102
G.U. 911	362-378 cm	9694$\pm$156
G.U. 912	426-454 cm	7832$\pm$131

Figure 8.

Age plotted against depth for core LLRD1. Boxes represent radiocarbon dates, with widths corresponding to the ± 1σ error intervals (based on statistical counting uncertainties only) and heights corresponding to depth sampled. Upright and diagonal crosses define palaeomagnetic dates from observatory and archaeomagnetic declination and inclination records respectively. Horizontal bars represent correlations with Windermere radiocarbon dates at declination turning points and include ± 1σ radiocarbon counting errors.

(From Dickson et al. 1978. Appendix 2).


AGE (years ×1000 B.P)
10 9 8 7 6 5 4 3 2 1 0
0
0·50
1·00
1·50
2·00
2·50
3·00
3·50
4·00
4·50
DEPTH(M)

sediment, 5% marine sediment) relatively long depth increments of half cores were used for ^{14}C dating. The long core lengths used reduced the accuracy of the dates. Furthermore the plot of ^{14}C age against depth (Figure 8) shows marked deviations at 370 cm and above 190 cm "from the linearity which would be expected in a constant sedimentary regime" (Dickson et. al 1978, see Appendix 2). The abnormal course of the radiocarbon curve above 190 cm may be due to the inwash of older terrestric sediments into the lake as noted by Jøhansen (1977) for Lake Saksunarvatn, Faeroe Islands.

4.2.5 Palaeomagnetic analysis.

The results of the palaeomagnetic analysis by the University of Edinburgh Geophysics Department are presented in Figure 8 along with the radiocarbon dates. The palaeomagnetic results are described concisely by Thompson in Appendix 2 (Dickson et. al. 1978).

4.3 Dubh Lochan.

4.3.1 Location, geology and vegetation.

The Dubh Lochan is a small loch on the eastern shore of Loch Lomond at map reference N.S 377.963. Details of the lochs morphometry are as follows:-

a) Surface area 7.06×10^4 metres^2
b) Total volume 3.88×10^5 metres^3
c) Maximum depth 11.1 metres
d) Average depth 4.8 metres
e) Length 550 metres
f) Mean breadth 128 metres
g) Catchment area 1.1 kilometres^2

The two inflow burns (Figure 6) have an intermittent inflow with negligible surface water inflow during much of the spring and summer.

The Dubh Lochan lies in an area of schist and schistose grits which have been metamorphosed from Pre Cambrian or Cambrian sedimentary rocks of the Dalradian series during the Carboniferous period (Anderson 1947).

The Dubh Lochan has a rich aquatic macrophyte flora with a well developed fringe of Phragmites communis and Carex rostrata. Nuphar lutea, Nymphaea alba (both especially at the eastern end of the loch), Hippuris vulgaris, Equisetum fluviatile, Juncus bulbosus, Sphagnum section Palustria, Myriophyllum alterniflorum, Lobelia dortmanna, Fontinalis antipyretica, Litorella uniflora and Isoetes lacustris are all commonly present in the loch.

The loch is surrounded by semi-natural deciduous woodland of Quercus hybrids (Q. robur x Q. petraea), Betula pubescens, Sorbus aucuparia, Larix decidua, Fagus sylvatica, Fraxinus excelsior, Populus tremula (growing sparsely at the edge of the loch), Ilex aquifolium, Hedera helix, Rhododendron ponticum and Lonicera periclymenum. The ground flora is composed of Pteridium aquilinum Vaccinium myrtillus, Deschampsia flexuosa, Anthoxanthum odoratum, Dryopteris spp. and Blechnum spicant while the most conspicuous herbs are Potentilla erecta, Melampyrum pratense and Oxalis acetosella. (For a fuller floristic list the reader is referred to Tittensor and Steele 1971).

Above the Dubh Lochan are several conifer plantations mainly of Picea abies, P. sitchensis, Larix decidua, Larix leptolysis with some Pinus sylvestris and Pinus contorta having been planted locally.

Beyond the forest is wet moorland with Calluna vulgaris, Myrica gale and Molinea caerula, the Calluna replacing Pteridium aqulinum as the altitude increases. Still higher there is a Molinia-Anthoxanthum-Agrostis zone followed by in places a zone of blanket bog dominated by Sphagnum and Eriophorum vaginatum. Rhacomitrium heath is present in places at the highest altitudes often being replaced by short turf dominated by Nardus stricta and Festuca ovina with various arctic-alpine plants in association (Idle 1974).

4.3.2 Sediment Stratigraphy.

A Troels-Smith sedimentary description of core DLM now follows the symbols used to represent the stratigraphy being given in Appendix 1. The results are presented on the left hand side of the Dubh Lochan diagrams.

10-257 cm	Dark brown organic mud, Nig 2, strf 0, elas 2, sicc 2, lim 0. Colour 7.5 YR 3/2 dark brown, humo 3. $Ld^3 2$ Dh 2 Ga+ (LSO+). Transition very gradual. Bands of clay at 70,77,191 and 218 cm. (Ag + As) 4 (LSO+).
257-263 cm	Organic mud, Nig 2, strf 0, elas 2, sicc 2, lim 3. Colour 10 RR3/2 very dark greyish brown, humo 2. Sharp lower boundary. $Ld^2 1$ Dh2 Gal (LSO+).
263-265 cm	Homogeneous clay, Nig 1, strf 0, elas 2, sicc 2, lim 3. Colour 2.5 Y 5/4 light olive brown. Transition sharp (As + Ag) 4.
265-383 cm	Mud gyttja, Nig 3, strf 0, elas 2, sicc 2, lim 2. Colour 5 YR 2.5/2 dark reddish brown, humo 2. Clear lower boundary. Lhl $Ld^2 1$ Dh2 (LSO+).
383-408 cm	Mud + clay bands, Nig 3, strf 3, elas 2, sicc 2. Colour 10 YR 3/1 very dark grey, humo 2. Lhl $Ld^2 1$ Dhl Gal (LSO+). Pale clay bands at 383, 388 and 394 cm, plus a series between 405-408 cm (c.14 bands) (LSO+).
408-411 cm	Grey clay, Nig 2, strf 0, elas 3, sicc 2, lim 3. Colour 5 Y 5/2 olive grey. Lower boundary sharp (As + Ag) 4.
411-444 cm	Homogeneous mud, Nig 3, strf 0, elas 2, sicc 2, lim 1. Colour 10 YR 3/2 very dark greyish brown, humo 2. Lhl Dhl Ga2 (LSO+). Clay band at 477 cm.
444-449 cm	Thinly banded clays. 10 YR 4/1 dark grey. Lhl Ldl Dhl Gal (LSO+).
449-490 cm	Mud gyttja, Nig 3, strf 0, elas 3, sicc 2. Colour 5 YR 2.5 dark reddish brown, humo 2. $Ld^2 1$ Lhl Dhl Gal (LSO+).

4.3.3 Pollen Stratigraphy.

The sediments between 490 and 10 cm have been divided into five local pollen zones. The division is based upon the pollen and spore content of all land plants with values of 5% or more total pollen using the numerical methods described in Chapter 3. The local pollen zones are numbered from the base upwards and are prefixed DLM ("Dubh

Lochan Mackereth" core not to be confused with the DL designation given by Walker (1975) to her fen carr site). The results of the zonation procedures are presented at the right hand side of the pollen diagrams (Figures 14 and 15) and in Figure 9. All figures quoted are based on ≤TP (excluding aquatics, mosses, crumpled, corroded and concealed pollen and spores).

Local pollen zones DLM:-

DLM-1 (490-425 cm).

This zone is characterised by values of Coryloid pollen in excess of 40% and *Betula* in excess of 18%. *Quercus*, *Ulmus* and *Alnus* are minor components in the pollen spectrum. Filicales values are fairly high reaching 11%. *Pteridium* values reach 2.5% while Gramineae reaches 3-4% in the lower half of the zone. *Isoetes* spores are absent.

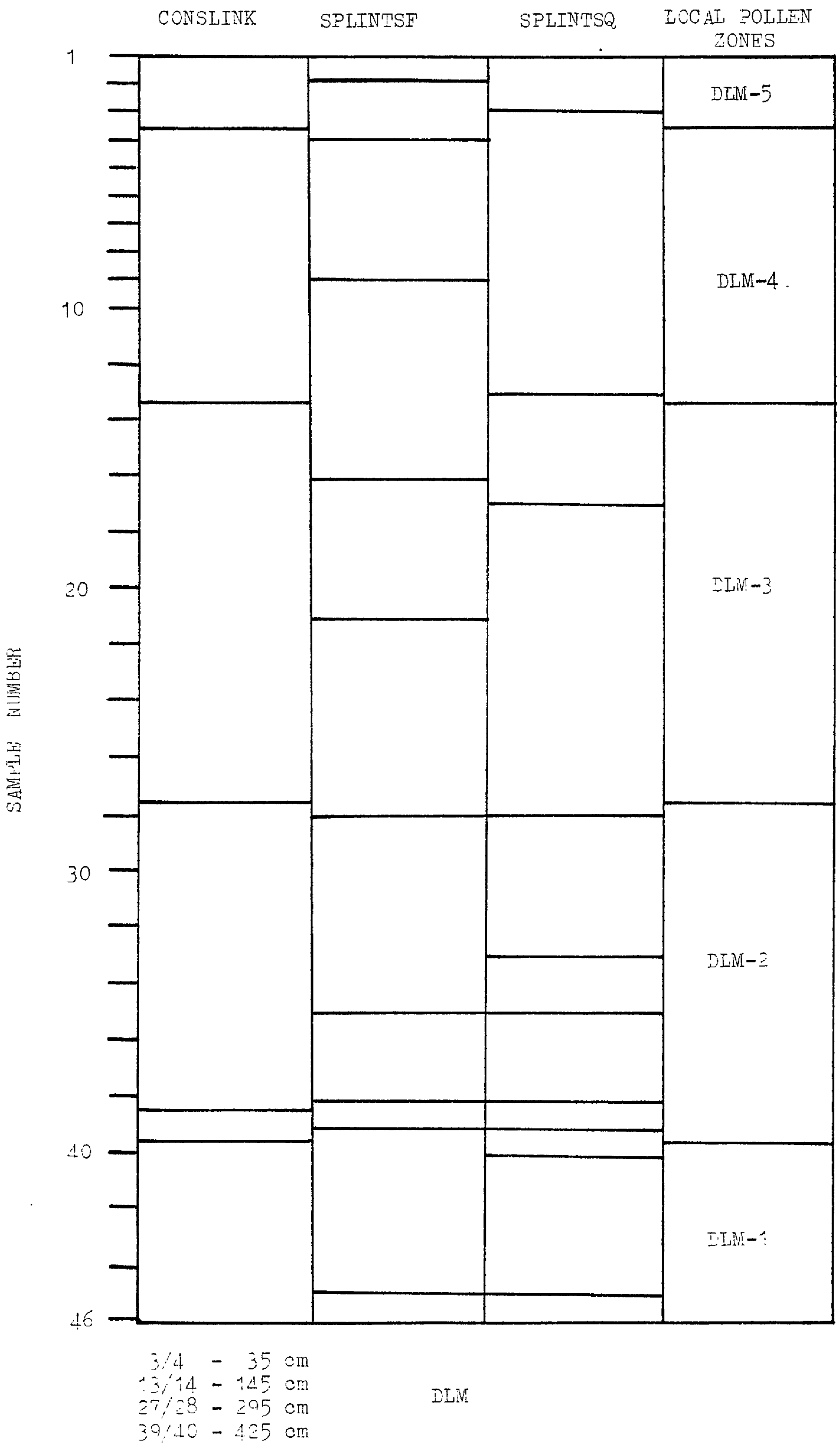
DLM-2 (425-295 cm).

High arboreal pollen values characterise this zone. The *Alnus* curve rises very steeply at the opening of the zone and the maximum value for this taxon of 30% is found within this zone. *Quercus* values rise to a maximum of 22% a value of 10% being more common. A peak in *Pinus* pollen of 19% occurs at the base of the zone, the normal value being 2% or less. *Betula* and Coryloid values both fall slightly while the first *Fraxinus* pollen is noted. *Ulmus* declines to less than 1% at the top of this zone being high (c.10%) throughout the zone. Filicales values fluctuate being consistently above 9% during the top 20 cm of the zone. The first presence of *Isoetes* is noted at the top of the zone.

DLM-3 (295-145 cm).

High arboreal and Coryloid pollen values tipify this zone. *Quercus* ranges from 8% to 24% while Coryloid pollen values are between 20-38%. The first presence of *Tilia* is noted.

Herb pollen values begin to increase slightly only Rosaceae undiff. reaching 1%. The first *Plantago lanceolata* pollen is found, its presence being discontinuous.


CONSLINK
SPLINTSF
SPLINTSQ
LOCAL POLLEN ZONES
DLM-5
DLM-4
DLM-3
DLM-2
DLM-1
SAMPLE NUMBER
1
10
20
30
40
46
3/4 - 35 cm
13/14 - 145 cm
27/28 - 295 cm
39/40 - 425 cm
DLM

Filicales spores reach a peak of 10% in the middle of the zone values generally being c.5% or less. The highest values of Isoetes spores in the profile are found (3-5%) in the lower half of the zone being absent in the upper half.

DLM-4 (145-35 cm).

This zone is characterised by an increase in the herb component. Gramineae drops from 13% at the base of the zone maintaining values of c.6% before rising to over 11% at the top of the zone. The maximum Cyperaceae pollen value of 5% is found. Calluna values of 2% are common rising to 5% at the close of the zone. Plantago lanceolata is continuously represented but never reaches 1%.

DLM-5 (35-10 cm).

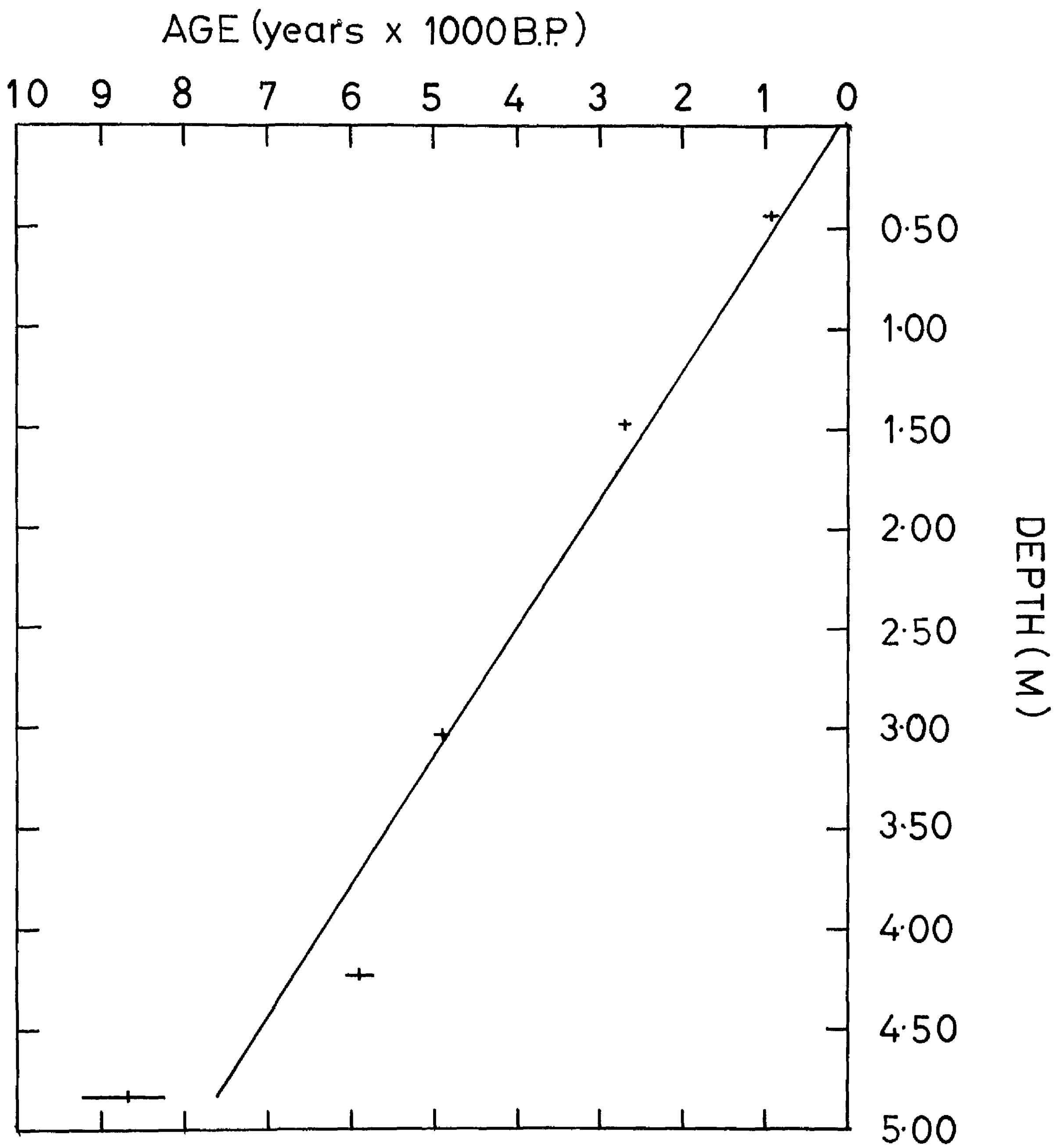
The continued increase of herb pollen at the expense of arboreal pollen is typical of this zone. Betula (5-10%) Quercus (3-11%) and Alnus (12-17%) decline while Ulmus is absent from the profile. Calluna rises from 9% to 19% before declining to 13%. Both Plantago lanceolata and Pteridium have peaks at the base of the zone (2.6% and 12% respectively). The majority of herbs never reach 1%.

4.3.4 Radiocarbon dates.

Five sediment samples were subject to radiocarbon analysis and the results are presented in Table 4 and Figure 10.

Table 4 DLM Radiocarbon dates.

Reference No.	Depth (cm)	Radiocarbon years B.P.
SRR-1217	41-46	917 ± 105
SRR-1218	145-150	2707 ± 70
SRR-1219	300-305	4913 ± 85
SRR-1220	420-425	5909 ± 170
SRR-1221	480-485	8732^{+510}_{-480}



AGE (years x 1000 B.P.)
10
9
8
7
6
5
4
3
2
1
0
0·50
1·00
1·50
2·00
2·50
3·00
3·50
4·00
4·50
5·00
DEPTH (M)

Regression analysis shows the mean sedimentation rate to be 0.63 mm/yr for the whole profile. However between 490 and 420 cm the sedimentation rate is estimated to be 0.2 mm/yr and between 300-420 cm to be 1.2 mm/yr. By comparison with the Loch Lomond radiocarbon profile the Dubh Lochan (DLM) dates provide a more accurate base upon which to calculate pollen influx values.

4.4 Regional pollen assemblage zones.

Using the pollen profiles from sites LLRD 1 and DLM a series of regional pollen assemblage zones has been constructed for the Loch Lomond area. The recommendations of the "Code of Stratigraphic Nomenclature (1961) and the "International Subcommission on Stratigraphic Nomenclature" (1972) have been followed. The regional pollen assemblage zones are used as a basis for describing both sites LLRD 1 and DLM and are informal in the sense of the code.

As the Loch Lomond pollen diagram provides a pollen profile taken to be representative of the region its local pollen zones suggest themselves to be used as the regional pollen assemblage zones. When a comparison with the pollen zones of other sites of regional significance namely Dubh Lochan (Walker 1975) and DLM the validity of this assumption is strengthened.

Regional pollen assemblage zones are defined from the LLRD 1 profile with one exception, namely the Betula - Coryloid assemblage zone which is not recognised at site LLRD 1 due to factors such as differential preservation for example. All values are ≤T.P. (sum of total pollen excluding aquatics, mosses, crumpled, corroded, concealed and derived pollen and spores).

1. Betula-Coryloid.

Assemblage zone.

Type locality and section.

Dubh Lochan (Stewart) Core DLM.

Zone DLM-1 490-425 cm.

Description.

Coryloid pollen is 40% or more of total pollen while *Betula* is 18% or more of total pollen. *Quercus* and *Pinus* are less than 10% while Filicales spores attain values of 10% or more.

Contacts.

The upper boundary is placed where *Alnus* pollen values rise above 10%, namely the *Alnus* rise. The lower boundary is the base of the profile with Coryloid in excess of 65%.

Subdivisions.

The following subzone is recognised:-

Pinus assemblage subzone. The subzone is recognised at site Dubh Lochan (Walker 1975) DL. Total tree pollen is over 90% ≤P + S while *Pinus* pollen reaches its highest level of 20% total arboreal pollen in this subzone. The upper boundary is the *Alnus* rise with an associated decrease in *Pinus* pollen values. The lower boundary is where *Pinus* pollen values exceed 5% ≤P + S.

Other Occurences.

The assemblage zone occurs at the following sites in and near the Loch Lomond area:-

Flanders Moss East zones V AND VI (c.240 cm thick) (Durno 1956).

Muir Park Reservoir (Drymen) zones V and VI (c.150 cm thick) (Donner 1957).

Gartmore zones V and VI (c.60 cm thick) (Donner 1957)

Muirpark Reservoir zone V/VI (c.100 cm thick) (Vasari and Vasari 1968).

Dubh Lochan (Walker) zone DL2 (c.60 cm thick) (Walker 1975).

As broadly defined above the assemblage zone can also be recognised in many pollen diagrams from sites in northern and western Britain. For example it shows similarities to the following:-

a) Chronozones N.W.S. III and IV at Loch Clair in north west Scotland - Birch - Hazel assemblage zone (part of Pine/ Birch assemblage zone) (Pennington 1973).

b) Betula-Corylus assemblage zone at Loch Cill Chriosd, Isle of Skye zone LCC-7 (Birks 1973).

c) The Betula-Corylus/Myrica assemblage zone at Cooran Lane, Kirkcudbrightshire (zones CL2-CL3) (Birks H.H. 1972).

d) Similarities to zones V and VI at many of the Lake district sites such as Seathwaite Tarn (Pennington 1964).

Age.

The radiocarbon profile (Figure 11) for core DLM shows that this assemblage zone began c.9000 B.P. and ended c.5909 B.P.

2. Betula-Quercus-Alnus (with Ulmus).

Assemblage zone.

Type locality and section.

Loch Lomond core LLRD 1.

Zone LLRD 1-B 355-302.5 cm.

Description.

Tree pollen is over 70% T.P. Alnus values are 10% or more while Quercus values exceed 10%. Ulmus frequencies reach 7%.

Contacts.

The lower boundary is where Alnus values exceed 10%, namely the Alnus rise, while the upper boundary is where the value of Ulmus pollen falls below 2%.

Other Occurrences.

This assemblage zone can clearly be seen from all the sites studied in the Loch Lomond area (Figure 2) and also from site DLM zone DLM 2) and corresponds to the Godwin zone VIIa.

As broadly defined above the assemblage zone can be recognised at many sites in the Lake district such as Seathwaite Tarn and Devoke water (both zone VIIa) (Pennington 1964).

Age.

The Alnus rise which marks the beginning of this assemblage zone has been dated to 5909±170 B.P. at site DLM, while the upper boundary is the Ulmus decline at 5000 B.P.

3. Quercus-Alnus.

Assemblage zone.

Type locality and section.

Loch Lomond core LLRD 1 zone LLRD 1-C and LLRD 1-D 302.5-170 cm.

Description.

Alnus pollen values generally 20% and over. Quercus pollen values up to 20% (2-20%). Ulmus pollen values low, 3% to +. Fraxinus present. Gramineae values are between 5-10% while Pteridium varies between 5-15%. Continuous representation of *Calluna*, Cyperaceae and *Plantago lanceolata*.

Contacts.

The lower boundary is where *Ulmus* pollen values fall below 2% namely the *Ulmus* decline, while the upper boundary is where Gramineae exceeds 10%.

Sub-divisions.

The following subzones are recognised at site LLRD 1 namely:-

a) *Pinus* assemblage subzone characterised by a rise in *Pinus* pollen to 9%. The lower boundary is the *Ulmus* decline while the upper boundary is where *Pinus* pollen declines below 5%.

b) *Pteridium* assemblage subzone. *Pteridium* values commonly between 10-20%. The lower boundary is where *Pteridium* exceeds 10% while the upper boundary is where Gramineae values rise above 10%.

Other occurrences.

This assemblage zone is clearly recognisable from sites DLM and DL (Walker 1975) corresponding closely to zones DLM3 and DL5 respectively. It can also be recognised with variations at all of the other sites studied in the area (Figure 2) corresponding closely to Godwin zone VIIb.

Age.

The lower boundary is the *Ulmus* decline c.5000 B.P. while the upper boundary dates c.1700 B.P. by interpolation between dates from the LLRD 1 radiocarbon date profile.

4. *Calluna* - Gramineae.

Assemblage zone.

Type locality and section.

Loch Lomond core LLRD 1 zone LLRD 1-E. 170-0 cm.

Description.

Gramineae values consistently between 10-20% T.P. while *Calluna* values reach 12%. *Alnus* pollen values are fairly constant at c.22% while *Quercus* values are below 11%. *Pinus* increases to 5% at the top of the assemblage zone. A wide variety of herb taxa are present (generally not exceeding 1%).

Contacts.

The lower boundary is where the curve for Gramineae exceeds 10% while the upper boundary is at the top of the profile.

Sub-divisions.

None.

Other occurrences.

As broadly defined above this assemblage zone can be seen at both of the Dubh Lochan sites DLM and DL corresponding to zones DLM4 and DLM5 (especially the latter) and DL6 respectively.

Age.

From the LLRD 1 radiocarbon profile (Figure 8) the lower boundary of the assemblage zone is seen to be c.1700 B.P. while the upper boundary is the present day.

5. DISCUSSION OF SITES LLRD1 and DLM.

5.1 Site LLRD1 - % T.P. diagram Figure 11.

The findings from site LLRD1 are conveniently discussed using the regional pollen assemblage zones set out in Chapter 4.4 and by reference to the relevant diagrams mentioned in the text. (All values quoted are percentage total pollen unless otherwise stated).

Zone LLRD1-A. 420-355 cm.

No comparable zones are to be found.

Very little can be inferred as to the nature of the vegetation of the Loch Lomond region from zone LLRD1-A. This is due to differential preservation of pollen and spores making a sensible reconstruction of the vegetation exceedingly difficult. Although the general state of pollen preservation in core LLRD1 was very bad with counting at all levels generally very difficult, zone LLRD1-A proved particularly taxing. The factors which point to differential preservation are:-

1) Exceedingly high *Pinus* values (up to 60% T.P.) in association with high fern values (c.23%), high values of derived spores, and *Isoetes* spores (up to 30%).
2) Low *Betula* and Coryloid values with visible degradation of these grains.

3) Badly corroded _Quercus_ and _Ulmus_ pollen.

4) A large number of indeterminable corroded grains.

High _Pinus_ values were found by Murray (1975) in the Ochtertyre Moss carse clay, while Godwin (1956) points to similar high _Pinus_ values in esturine clays stratified between peat layers in the English Fenland and also in clays of the Dutch and north west German coasts. Among proposed explanations of this phenomenon are long distance wind transport, surface drifting, differential destruction and the incorporation of secondary pollen by erosion of _Pinus_ wood peat. At individual sites any one or a combination of the latter processes may have been in operation. _Pinus_, Filicales, derived and _Isoetes_ spores are overpresented due to the fact that even when badly corroded their morphological characteristics are unmistakable. _Pinus_ (_P. sylvestris_) was probably growing on the higher slopes around Loch Lomond and on the Campsie fells prior to the Alnus rise. Godwin (1975) puts the whole region into the 10-20% isopol for _Pinus_ in zone VI (including Corylus). However a consideration of a number of sites in the Loch Lomond region (Table 13) shows the true picture for _Pinus_ to be more complex than the isopol data suggest. In general the higher the altitude of the site the higher the percentage of _Pinus_ pollen. Therefore if as generally supposed the climate became warmer and wetter between c.6-7000 B.P., _Pinus_ may have expanded occupying the poorer soils mainly at higher altitudes and also in more isolated "boggy" areas at lower altitudes. On the richer soils however _Pinus_,which characteristically competes poorly with trees of the deciduous forest, would have been few in numbers. However due to differential preservation little can be said concerning the history of Pinus below 350 cm from site LLRD 1.

The low values of Betula (45% during most of the zone) do not make sense when a comparison is made with other diagrams from the Loch Lomond region. For example both sites DL (Walker 1975) and DLM from the Dubh Lochan have Betula values always in excess of 20% T.P. during Godwin zone VI. Indeed Betula was a major component of the vegetation in the Loch Lomond region during zone VI (LLRD 1-A).

The sediment of Loch Lomond is unusual if not unique among British Flandrian sediments in containing throughout its length derived Carboniferous spores. Trilete spores of the genera Vallatisporites, Lycospora, and Punctatisporites have been recognised. As there are no Carboniferous rocks north of the Highland Boundary Fault the most likely origin of the derived spores is the Carboniferous rocks which lie around the western edges of the Campsie fells (Figure 4) and through which the Endrick water flows. A study of the distribution of these derived spores might provide an insight into the "migration" of pollen and spores within the loch itself with perhaps a concentration gradient in a south (high numbers) north (low numbers) direction.

Along with Filicales and Isoetes, derived spores have their maximum percentage values in pollen zone LLRD 1-A. From a consideration of the pollen concentration/percentage diagram (Figure 12) it would appear that the picture presented by the percentage diagram for Isoetes, derived and Filicales spores is plainly artificial. Indeed the great advantage of the concentration diagram, namely that each taxon is considered independently becomes clear in trying to interpret zone LLRD 1-A. A consideration of the Isoetes curve will serve to demonstrate the false picture shown by the percentage diagram for zone LLRD 1-A. Isoetes has 13-34% T.P. in this zone compared to later values of c.5% (excluding marine phase). However the concentration curve shows that the highest values of Isoetes spores of 9×10^3 - 11×10^3 grains/cm^3 are not in zone LLRD 1-A but in zones D and E (c.f. 2.5×10^3 - 6.5×10^3 grains/cm^3 for zone A). The values of Filicales and derived spores also show a similar picture. From this evidence it would appear that the maxima of Isoetes, Filicales and derived spores in the percentage diagram during zone LLRD 1-A do not reflect a true picture of the vegetation but are a consequence of differential preservation in favour of these grains.

Betula-Quercus-Alnus (with Ulmus).

Assemblage zone. LLRD 1-B 355-302.5 cm.

This assemblage zone is characterised by high values of arboreal pollen often in excess of 80% T.P. (Interpretation is simplified due to the absence of differential preservation to the extent shown in zone LLRD 1-A). The pollen spectrum during zone LLRD 1-B suggests a period of mixed deciduous forest in those parts of the catchment area suitable for its support.

Alnus pollen values rise very rapidly at the beginning of this zone reaching a maximum of 19%. This represents the expansion of Alnus within the Loch Lomond catchment area. From Figure 8 showing the radiocarbon dates the Alnus rise can be roughly dated (ignoring date GU911) to between 6300-6500 B.P. This is fairly reasonable considering the problems associated with the radiocarbon dating of the Loch Lomond sediment as a date of 5909 ± 170 B.P. has been obtained from the Dubh Lochan (site DLM) sediment (Figure 10) and a date of 6197 ± 45 B.P. (SRR 985) from Craigbarnet Muir peat in the western Campsie fells (Stewart 1975). The event occurs some one thousand years later in the Loch Lomond region than in north western England. Indeed the time transgressive nature of the Alnus rise horizon has been clearly shown by Smith and Pilcher (1973) who considered all the radiocarbon dated Alnus rise profiles in the British Isles up to 1972. The Alnus rise took place in the Loch Lomond area a little later than it did in north western Scotland, Pennington (1972) providing dates of 6300±140 B.P. at Loch Sionascaig and 6570±145 at Loch Clair for the *Alnus* rise. Therefore at around 6000 B.P. *Alnus* established itself as a lakeside and streamside tree in the Loch Lomond region.

Ulmus values rise to a maximum of 7% (at 320 cm) just before the well known *Ulmus* decline event occurs. As *Ulmus* is known to be one of the poorer pollen producers (Faegri and Iversen 1974) it will with the latter value probably have been a fairly common member of the mixed *Quercus* forest (especially on richer soils) represented by this assemblage zone.

Pollen values for *Quercus* in zone LLRD 1-B are similar to those from other Scottish and northern English sites in the equivalent regional pollen assemblage zone at 10-20% T.P. (Godwin and Deacon 1974). This contrasts with *Quercus* values of between 20-35% for site DL (Dubh Lochan Walker 1975) which may have been due to purely local factors.

Although *Pinus* decreases from c14 to 5% T.P. the latter value suggests that *Pinus* was probably present locally in the Loch Lomond area. Indeed Walker (1975) found a *Pinus* needle at site D.L. in local pollen zone DL4 which is equivalent to this regional pollen assemblage zone.

Filicales values decrease gradually from 15 to 10% while *Pteridium* values are the lowest in the sequence being a mere presence. The low values of *Pteridium* and high Filicales values can be interpreted as a consequence of the region being under almost complete tree cover apart from the highest altitudes and areas where the soil was unsuitable for tree growth. The values for herb pollen are also low during this assemblage zone, this being due to the pollen produced by the heavy tree cover swamping the herb pollen produced mainly from the margins of the forest.

Very noticeable is the absence of spores of the freshwater pteridophyte *Isoetes lacustris* which is entirely absent during this assemblage zone due to the effects of the marine incursion (5.4.2), indicating the intolerance of *Isoetes* to water of high salinity.

The *Ulmus* decline.

The *Ulmus* decline horizon which begins within this *Betula*-*Quercus*-*Alnus* (with *Ulmus*) regional pollen assemblage zone between c.315 to 300 cm merits special consideration.

The decline in the *Ulmus* pollen percentage has been noted from many sites in north west Europe and a review concerning the possible causes of the event at the Atlantic-Sub-boreal transition has been given by Ten Hove (1968). Indeed six possible explanations are given:- climate, competition, edaphic factors, human influence, disease and selective pollen filtering. Ten Hove leans heavily towards an anthropogenic cause for the *Ulmus* decline possibly in combination and interaction with any of the other explanations referred to above. Many of the sites investigated in north western England show signs of intensified human activity at the time of the *Ulmus* decline. Indeed in the case of the Lake district sites (e.g. Blea Tarn) signs of human activity can be related to patterns of early Neolithic occupation as revealed by artefacts (Pennington 1975). Therefore careful scrutiny of all sites for signs of human activity at the *Ulmus* decline is required especially where evidence of Neolithic occupation is present. As at other sites in the Loch Lomond area none of the usual pollen indicators of cereal cultivation (e.g. cereal grains, *Artemisia*) occur at the *Ulmus* decline at site LLRD 1. As noted when dealing with the historical ecology of the Loch Lomond area (section 2.6) evidence for cereal cultivation by Neolithic man in the Clyde-Solway cultural area is not "as impressive as in other areas in Britain".

However at sites LLRD 1, DLM and DL there is an increase in the curve for Gramineae along with the first presence of *Plantago lanceolata* at the *Ulmus* decline horizon. Indeed a similar situation occurs at Craigbarnet

Muir (Stewart 1975). This along with the archaeological evidence (e.g. chambered tombs) would suggest that Neolithic man was beginning to have a noticeable effect upon the vegetation in the Loch Lomond region from c.5000 B.P. (Ulmus decline dated 4913±85 B.P. at site DLM). Furthermore the increase in the Pteridium spore curve from 280 cm (Figure 12 and Figure 14) at LLRD 1, to a maximum of 20% at 220 cm indicates considerable clearance operations within the Loch Lomond catchment area. The clearances may possibly have been in connection with Neolithic livestock raising practices of the type envisaged by J. Troels-Smith (Iversen 1973) with the use of Ulmus leaves for fodder.

Quercus-Alnus.

Assemblage zone.	LLRD 1-C and LLRD 1-D.
a) Pinus subzone	302.5 cm to 250 cm.
b) Pteridium subzone	250 cm to 170 cm.

a) Pinus subzone.

The values of Pinus (14% T.P.) Polypodium (8%) and Filicales (28%) pollen and spores at 270 cm although indicating a correct trend towards increasing percentages may be exaggerated on the high side. This may be due to the low pollen count of only 212 grains at 270 cm along with slight (probably persistent throughout the profile) differential preservation which would as already noted when dealing with zone LLRD 1-A tend to increase the percentages of these particular grains.

The general pattern of the Pinus curve is particularly interesting showing a rise from 280 cm (even taking account of the extra high value at 270 cm noted above) corresponding to a radiocarbon date of 4205±79 B.P. between 262 and 278 cm (G.U. 909). This LLRD 1 Pinus rise corresponds to the post Ulmus decline Pinus increase at Glen Falloch which (as will be discussed when dealing with the Glen Falloch site) has been dated to 4310±50 B.P. from peat in Glen Falloch. It would appear that the Loch Lomond sediments in the southern basin are recording the expansion of Pinus in the Glen Falloch area, the river

Falloch being the major inflow into the loch.

Alnus *Quercus* and Coryloid values continue to rise slightly at the base of the subzone thereafter showing a general decline towards the top of this *Pinus* subzone.

b) *Pteridium* subzone.

During the *Pteridium* subzone (local pollen zone LLRD 1-D) *Pinus* values decline although a small peak of 3.5% occurs at 200 cm. *Quercus* values decline markedly from a height of c.14% to only 2% at the top of the subzone. *Betula* increases from c.10% to 14% while Coryloid values also show a slight upward trend. These latter changes in pollen frequency point towards a decrease in the forested nature of the Loch Lomond catchment area with a trend towards more open conditions. This trend towards more open environments is emphasised by Gramineae values up to 10% with pollen of Cyperaceae, *Calluna* and *Plantago lanceolata* (from 230 cm) being present throughout the subzone.

The major feature of this subzone is, of course, the increase in *Pteridium* from c.5% (in the previous *Pinus* subzone) to between 14-20% in the middle of this *Pteridium* subzone. These high values of *Pteridium* may indicate a protracted phase of forest clearance possibly by man in certain areas of the lakes catchment. The high *Pteridium* values are associated with high values of crumpled, derived and *Isoetes* spores. As noted by Bonny (1976) *Isoetes* spores may be transported from lake margins and re-deposited in the deeper basins of the lakes. Indeed in this case *Isoetes* is a good indicator of lateral transport and possibly erosion of marginal sediments. Furthermore, unlike the high percentage values of derived, *Isoetes* and crumpled pollen and spores in zone LLRD 1 the high values of these microfossils in this *Pteridium* subzone LLRD 1-D are probably not solely a result of differential preservation. The latter high values taken along with the general increase in herb pollen taxa, appear to indicate an increase in allochthonous input to the sediments of Loch Lomond from the pollen catchment area. It is possible to speculate that during this *Pteridium* subzone a large proportion of the increase in herb pollen may have originated from the catchment of the Endrick Water, it being the main source of the derived Carboniferous spores which attain their maximum concentration values (Figure 12) in this subzone. Therefore during this Quercus-Alnus regional pollen assemblage zone (as clearly shown by summary diagrams Figures 13 and 17) there is a decrease in the arboreal component of the vegetation of the Loch Lomond catchment associated with an increase in herb and pteridophyte (particularly Pteridium) pollen and spores. High values of Isoetes spores probably indicate re-deposition and lateral transport of an increased input of pollen probably from the soils of the lochs catchment area. This latter feature may have been connected with human activities especially in the catchment of the Endrick water as indicated by the increase in both the percentage and the concentration values (Figure 12) of derived Carboniferous spores. However why this postulated increase in pollen input (which is most clearly shown by consideration of the summary concentration diagram Figure 18 where total concentration rises from c.47 x 10^3 grains/cm^3 at 240 cm to 211 x 10^3 grains/cm^3 at 160 cm) has not affected the sedimentation rate remains a problem. (However problems with LLRD 1 radiocarbon dates must be remembered).

Calluna Gramineae.

Assemblage zone. LLRD 1-E 170-0 cm.

The highest values of non arboreal pollen are found in this zone indicating the continued reduction in woodland during the last c.2000 years represented by this zone. Below 120 cm Pteridium values reach 10% while Gramineae values have increased from 10% to 18-23% which both indicate open conditions especially at the higher altitudes.

Towards the top of the zone (i.e. above 80 cm) Calluna increases to c.12% indicating the expansion of blanket bog peat at higher altitudes. This assemblage zone also has the greatest diversity of herb pollen taxa in the profile emphasising the trend towards more open conditions with tall herbs such as Filipendula ulmaria being present.

Figure 13.

Summary pollen diagrams from core LLRD1 and core DLM. Pollen sum for LLRD1 is trees, tall shrubs, agriculture indicator plants (Gramineae, *Plantago lanceolata*, *Pteridium*), bog plants (*Calluna*, Cyperaceae, *Sphagnum*) and derived Carboniferous spores. Pollen sum for DLM is identical but there were no derived spores.

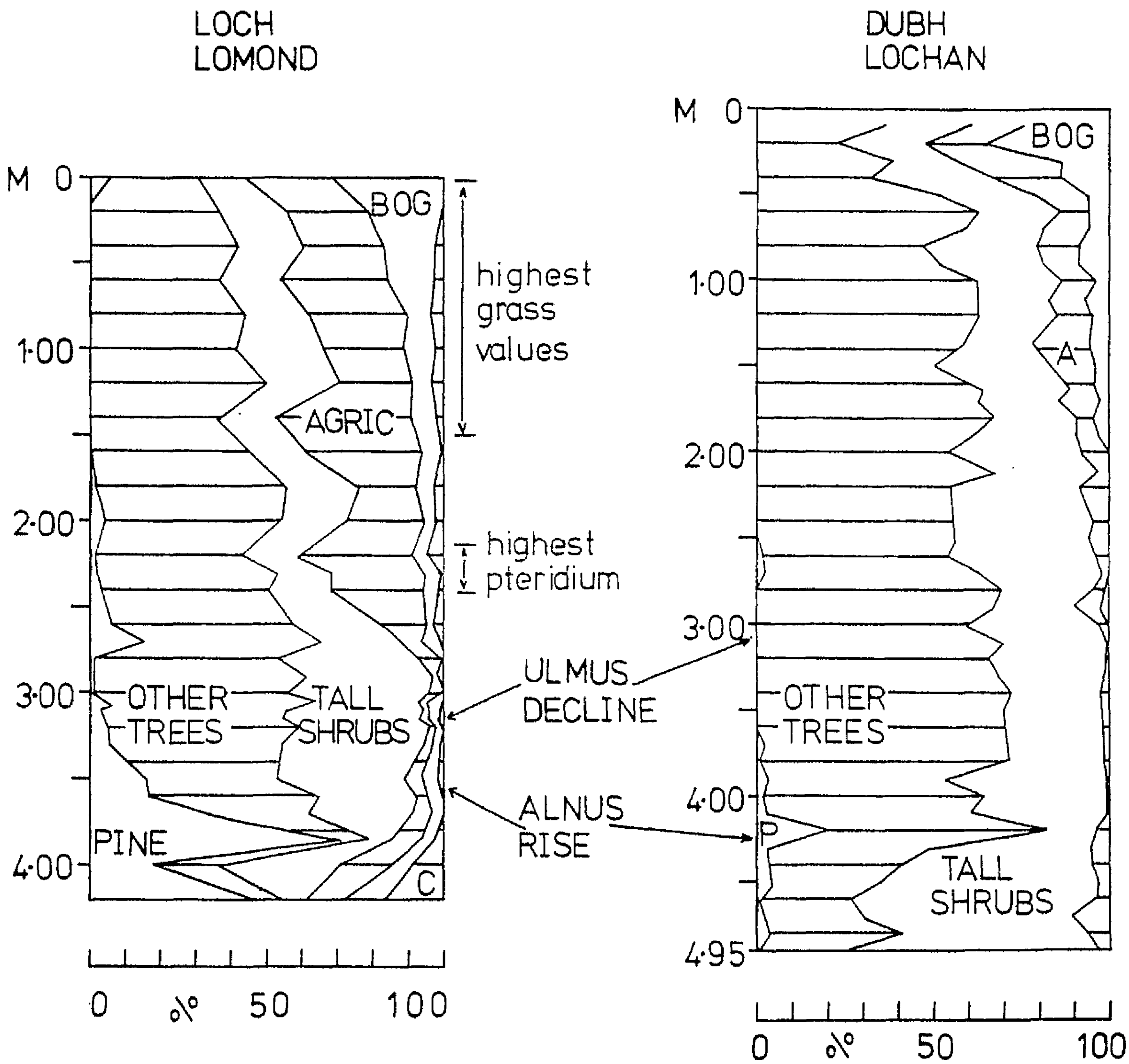
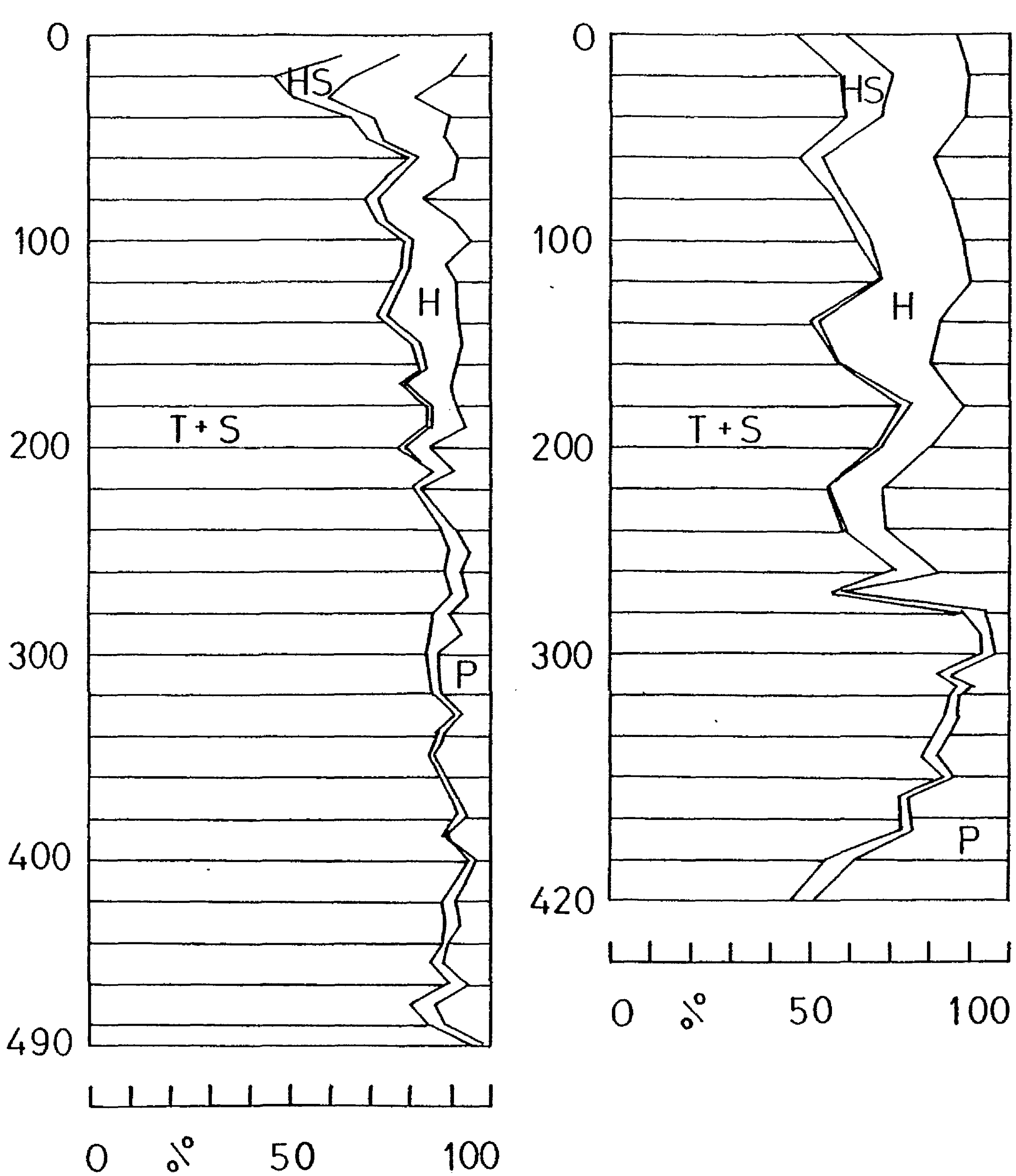

LOCH
LOMOND
DUBH
LOCHAN
M 0
1·00
2·00
3·00
4·00
4·95
BOG
AGRIC
highest
grass
values
highest
pteridium
OTHER
TREES
TALL
SHRUBS
PINE
C
ULMUS
DECLINE
ALNUS
RISE
A
P
0
%
50
100

Figure 17.

Summary diagrams from core LLRD1 and core DLM based on sum of total pollen excluding crumpled, corroded, concealed and derived pollen and spores.



TREES + SHRUBS- T+S

HEATHS- HS

HERBS- H

PTERIDOPHYTES- P

FIGURE 17

Selaginella selaginoides, Botrychium lunaria and Lycopodium sp all pteridophytes indicative of open environments are to be found within this zone. Betula declines from 12% to 7% while with the exception of the topmost sample Pinus is a mere presence. Quercus declines from 14% at 80 cm to 1% at 20 cm probably due to removal by man.

The final level of this assemblage zone probably lies within the last 150 years with both Pinus and Quercus values rising to 5%. This latter feature is probably due to the modern planting of these two trees by man.

5.2 Site DLM % T.P. diagram Figure 14.

The results of the analysis of core DLM can be conveniently discussed using the regional pollen assemblage zones described in Chapter 4.4. All values quoted are percentage total pollen unless otherwise stated. (ΣT.P. = sum total pollen excluding aquatics, mosses, crumpled and unidentified pollen and spores).

Betula-Corylus.

Assemblage zone. Zone DLM-1 490-425 cm.

This assemblage zone represents a Betula-Corylus woodland period spanning c.3100 years (between c.9000 B.P. and 5900 B.P. see Figure 10). According to Walker (1975) this Betula-Corylus woodland type was probably similar to the Betula pulescens/Cirsium heterophyllum association found in the Isle of Skye to-day. Characteristic of this latter association is an abundance of tall herbs (Birks 1973). However the pollen of very few herb taxa have been found in this assemblage zone which may be due to the mechanisms of pollen input into the loch.

At the close of this assemblage zone there is a sudden and dramatic increase in the percentage of Pinus pollen from c.2.5% to 20%. This is represented by an increase from 2415 grains/cm^3 at 430 cm to over 48000 grains/cm^3 at 420 cm (Figure 15). This "Pinus increase" is often found in diagrams from Scotland and northern England, usually occurring at or just before the Alnus rise. Pinus remained an important member of the forest at this latitude for a comparatively short time, the surge in Pinus pollen at this site representing only about 500 years of sedimentation (430-415 cm). Unlike Walker's (1975) fen carr diagram the pre-Alnus rise Pinus peak is only represented by a single sample at site DLM (Figure 14). This appears to conflict with the well developed Pinus curve from the fen carr pollen spectrum. It may be that before the Alnus rise the Betula-Corylus wood acted as a barrier to the introduction into the loch of wind dispersed Pinus pollen from the higher slopes. The main source of Pinus pollen input at that time being by way of run off water into the loch. As Pinus pollen grains are light and float easily they may have been concentrated around the edges of the loch at for example the fen carr site. This would account for a marked rise in Pinus pollen taking place earlier at the fen carr site. The actual Pinus maxima at both sites DLM and DL (Walker) are very similar at c.20% and one can envisage Pinus growing very close to the loch at the time of the maximum percentages.

Betula-Quercus-Alnus (with Ulmus).

Assemblage zone. 425-295 cm zone DLM-2.

This zone represents a period of mixed Quercus forest spanning c.1000 years. Alnus pollen percentages increase very rapidly at the beginning of the assemblage zone. The radiocarbon date at 422.5 cm shows the Alnus rise to have occurred at 5909±170 B.P. which is in general agreement with other sites in the area for this horizon (i.e. Campsie fells 6197±45 B.P. Stewart 1975). As noted when dealing with the LLRD 1 Alnus rise the expansion of Alnus took place at site DLM some one thousand years later than in the north west of England. This fits with the general pattern that the horizon occurs later and later the further north the latitude of the site. However the Dubh Lochan Alnus rise date is surprisingly younger than that from Loch Maree where the Alnus rise has been dated to 6500 B.P. (Birks H.H. 1972)b. It might have been expected that Alnus would have expanded in central Scotland before it did so in the north west. However much more needs to be known about the chronology and dynamics of the spread of this tree. As shown by the absolute diagram (Figure 15) at the time of the Alnus rise the pollen concentration rose from c.2000 to over 40,000 grains/cm^3 within a period of c.340 years. From 5900 B.P. Alnus has remained an important element both in the pollen spectrum and in the local vegetation surrounding the Dubh Lochan.

The mixed nature of the forest during this assemblage zone is emphasised by values of Ulmus pollen up to 12% and the presence of Fraxinus which first appears at 380 cm or roughly 5500 B.P. Both Ulmus and Fraxinus will have been important elements of the mixed woodland around the loch especially on richer soils.

Quercus pollen values rise to between 10-20% which is typical for the region (i.e. Donner 1957, Stewart 1975, Turner 1965) but lower than that found at the adjacent fen carr site. This difference between the two sites may again be due to properties of pollen input into the loch sediment. Another interesting difference between the marginal fen carr site (Figure 16) pollen spectrum and that from the deep water sediment is the occurrence of 20% Isoetes spores at the former site. In comparison Isoetes is only present once during this assemblage zone at site DLM with a value of less than one per cent. The difference may be due to conditions for growth of Isoetes only being suitable at the marginal fen carr site during this zone in association with a concentration of the spores at the sides of the loch. As Isoetes still grows in the loch to-day a study of the deposition of its spores in relation to the distance from the loch margin could be made.

The assemblage zone ends with the Ulmus decline where the Ulmus pollen frequency drops from c.10% to a mere presence. The Ulmus decline has been dated at this site to 4913$\pm$85 B.P. which is in general agreement with many radiocarbon dates from numerous sites in north western Europe which all show the event to have occurred close to 5000 B.P. As at other sites in the Loch Lomond region there is a noticeable absence of pollen of plants taken as indicators of human activity associated with the Ulmus decline at site DLM.

Quercus-Alnus.

Assemblage zone. Zone DLM3 295-145 cm.

The Gramineae curve begins to rise slowly from the time of the Ulmus decline but is not associated with the presence of indicators of arable agricultural activity. This would suggest local clearance operations and a progression to a slightly more open forest. The rise in Gramineae values is associated with the continuous presence of Calluna, Cyperaceae and Sphagnum pollen and spores, although with values of <1%. This may indicate the beginnings of peat growth on the higher hillsides around the loch. However the summary diagram (Figure 13) shows that the indicators of peaty, boggy conditions do not show a consistent increase until 200 cm (c.3400 B.P. by interpolation from Figure 10).

The first Plantago lanceolata pollen occurs at 280 cm, although the curve is discontinuous. It is only from 190 cm (c.3250 B.P.) that the curve for this indicator of human activity is continuously present. Indeed from 180 cm Plantago lanceolata is associated with other indicators of open and disturbed conditions such as Rumex sp. Urtica and Succisa pratensis. As in the case of the fen carr site (Walker 1975) no cereal pollen was found within the pollen profile. This simply indicates the lack of local growth of cereals in the area of the loch.

The values of Salix are low not only within this zone but throughout the profile. This is not unexpected as Salix is insect pollinated and is therefore poorly dispersed. However Salix values of up to 20% (T.P.) were found at the loch margin site. As shown clearly in both the pollen (Figure 16) and macrofossil diagrams from the fen carr site there is a local hydroseral succession from open water to a Salix carr during zone DL5. In the case of the fen carr site Salix catkins were deposited directly into the sediment. However in the deep water sediment

Salix input will have been low and further masked by the input of arboreal pollen. This therefore highlights the greater suitability of loch sediments in providing a more accurate picture of the regional vegetation than the marginal sediments where the situation is complicated by purely local factors.

Calluna-Gramineae.

Assemblage zone. Zones DLM4 and DLM5 145-10 cm.

The Calluna-Gramineae zone covers the period between (interpolation between and extrapolation from dates on Figure 10) approximately 2500 B.P. (c.500 B.C.) to c.160 B.P. (c.1800 A.D.). That is from the Iron age to the end of the eighteenth century. In keeping with a period during which the impact of man upon the environment would be expected to have increased, the pollen profile shows an increase in actual percentages and in numbers of pollen taxa indicative of disturbed and more open conditions during this assemblage zone.

Periods of forest clearance at 150 cm and 80 cm are suggested by a decrease in the arboreal pollen percentage and associated increase in agricultural and bog related pollen as shown in the summary diagram (Figure 13). (Bog includes Sphagnum, Calluna and Cyperaceae while agriculture includes Plantago lanceolata, Urtica, Rumex and Gramineae pollen).

The peak of agriculturally related pollen at 140 cm (Figure 13) includes the highest Gramineae value in the whole pollen profile of 13% and may reflect local clearance during the Iron age period. The agricultural component decreases slightly after 140 cm with the arboreal component recovering slightly. Evidently Iron age man did not have a large long lasting effect on the vegetation around the Dubh Lochan itself. However the full effect of the change in vegetation may not have been recorded by the Dubh Lochan sediments due to a swamping effect by the high pollen input from the still dense deciduous woodland on the immediate lochside. This peak in agriculturally related pollen at 140 cm in core DLM may correspond to that recorded from core LLRD 1 in Loch Lomond at 140 cm (Figure 13) which appears to show a rapid increase in human activity within the Loch Lomond region c.2000 years ago. Unfortunately due to the complexity of the Loch Lomond radiocarbon date picture direct comparison between sites is difficult.

The period of forest clearance between 100 cm and 60 cm corresponds to a slight increase in both bog and agricultural pollen indicators with Pteridium reaching 3.5%. This second clearance phase occurred between c.1600 B.P. and c.950 B.P. (by interpolation from Figure 10). This is only slightly later than the first extensive clearance noted by Turner (1965) at Flanders Moss which occurred between c.150-250 A.D. with continued clearance activities being noted from that time onwards.

As shown by both the deposition and percentage diagrams (Figures 14 and 15) there is a considerable increase in agricultural and bog derived pollen from c.50 cm or c.800 B.P. (c.1150 A.D.) with a parallel decline in arboreal pollen. This may represent the period of vigorous farming activity based on the infield and outfield system from the twelfth century (Morrison 1974). From c.50 cm the Calluna curve rises to 18% while Sphagnum and Cyperaceae also increase indicating the spread of blanket peat and moorland conditions in the higher areas around the Dubh Lochan and possibly around the edges of the lochan itself to a limited extent.

The trend towards deforestation appears to have been reversed from 20 cm upwards. (The top of this assemblage zone is not the present about 10 cm of sediment being absent due to drying out and crumbling). The arboreal curve (Figure 13) increases rapidly at the expense of both the agricultural and bog related pollen during the period estimated from the radiocarbon data to be between c.320 B.P. to c.160 B.P. The pollen profile may be reflecting the beginnings of more conservative forestry practices which came into use in the Loch Lomond area from about 1600 A.D. onwards, developing into the coppicing system widely practiced in the Buchanan Quercus woods. (Idle 1974, Tittensor 1970).

It would appear therefore that the Calluna-Gramineae assemblage zone at site DLM contains a great deal of valuable information concerning the effects of man upon the vegetation in the locality of the Dubh Lochan. Closer sampling and more detailed radiocarbon dating of the top 150 cm of the Dubh Lochan lake sediment would probably prove to be very rewarding in attempting to assess man's role in the development of the present day vegetation around the Dubh Lochan.

5.3 A comparison between sites.

5.3.1 Comparison between sites DLM and DL (Walker 1975).

Even within close proximity sites can provide pollen spectra which reflect different pictures of the vegetation under study. Spectra ranging from purely local to regional in nature may result due to differences in processes such as sediment accumulation and pollen deposition for example. A comparison between the pollen profiles from sites DLM and DL (Walker 1975) serves to illustrate the importance in choice of site, the fen carr site DL having a more local flavour in its pollen spectrum while the deep water site having a more regional character (and as such will later be compared to site LLRD 1).

Although the summary diagrams (Figure 16 and Figure 17) from both DLM and DL show a striking resemblance, with both having tree and shrub pollen accounting for over 70% T.P. for most of the Postglacial, a number of differences between the actual pollen diagrams is apparent. The principle contrasting features will now be dealt with.

As evidenced by the presence of a Lateglacial like facies (not actually Lateglacial due to Loch Lomond re-advance) and the inclusion of the Corylus rise (dated to 9356$\pm$165 B.P. at DL) the fen carr site DL provides a longer and older sequence than site DLM. This may simply be due to the Mackereth corer not having penetrated to the bed of the loch with subsequent loss of historical data only highlighted by the study of site DL.

During the *Betula*-*Quercus*-*Alnus* (+ *Ulmus*) assemblage zone (local pollen zone DL4) conditions appear to have been very favourable for the growth of *Isoetes lacustris* at the loch margin site (perhaps the water depth becoming suitable as the loch edge "moved forward"). *Isoetes* values often between 10-40% ($\lesssim$P + S) with a peak in excess of 60% are found in this regional pollen assemblage zone. Meanwhile during the same regional pollen assemblage zone (local pollen zone DLM 3) at the deep water site DLM, *Isoetes* values never reach 1% T.P. the spores only being recorded in one sample. *Isoetes* spores would therefore appear to be concentrated in the shallows at the edge of the loch around the site of liberation. This being the case *Isoetes* spores provide a good marker grain and would appear to indicate that during the period between the *Alnus* rise and the *Ulmus* decline (c.1000 years) little pollen was transported from the edge to the deepest part of the Dubh Lochan. Bonny (1976) in a study of the recruitment of pollen to lake sediments has demonstrated that at Ennerdale lake *Isoetes* spores in littoral surface mud constituted 70% of total pollen and spores at a depth of 1.5 m. At a water depth of 40 m *Isoetes* accounted for only 6% ($\lesssim$P + S) hence illustrating evidence for limited translocation of *Isoetes* spores from shallow to deep water. A similar situation as regards transportation of *Isoetes* spores seen to be occurring from "present day" Ennerdale sediments would appear to have occurred during the *Quercus*-*Alnus* regional pollen assemblage zone (local pollen zone DLM 3) in the Dubh Lochan. During this post *Ulmus* decline period *Isoetes* spores attain values of 5% T.P. which would suggest transportation of those spores from the margin to the deepest part of the loch just after the *Ulmus* decline horizon. To explain why transport of *Isoetes* spores should be at a maximum during local pollen zone DLM 3 requires further investigation into the physical and chemical nature of the loch's sediments.

Evidence from both the micro (Figure 16) and macrofossil (Walker 1975) diagrams implies strongly that the sediments from site DL are recording a hydroseral succession from open

open water, through shallow water (as illustrated by high Isoetes values in local pollen zone DL 4) to a Salix carr. Salix thereafter being replaced by Myrica as the dominant pollen producer. The deep water site DLM certainly did not record the increase in Salix during the Quercus-Alnus regional pollen assemblage zone with Salix only once attaining a value of 1% T.P. during the assemblage zone.

As Myrica has not been separated from Corylus at the deep water site little can be said concerning the final stages of the hydroseral succession shown in local pollen zone DL 6 at the marginal site. (See Godwin 1975 p.248 for details of controversy over separation of Myrica and Corylus. I personally feel that most of the Coryloid pollen is in fact Corylus and not Myrica in the upper part of the DLM profile). As there is no observable rise in Coryloid pollen during the Calluna-Gramineae regional pollen assemblage zone this suggests that the deep water sediment was not recording the Myrica expansion around the fringe of the Dubh Lochan. Nevertheless it may be argued that a change in the composition of the Coryloid pollen spectrum in favour of Myrica may have occurred during the latter assemblage zone at site DLM.

In the case of Salix the marginal site, unlike the deep water site, recorded the Salix expansion through the direct incorporation of catkins (Walker 1975) into the sediment.

Consideration of the previous few paragraphs suggest the deep water site DLM as being the most useful for comparison with the Loch Lomond deep water core LLRD 1, many of the purely local hydroseral events noted at the fen carr site being absent from the pollen profile.

5.3.2. Comparison between sites DLM and LLRD 1.

Having compared two pollen diagrams from within what is essentially a small lochan lying within a heavily wooded local and extra local (i.e. vegetation within 1 km sensu Bonny 1976) vegetation belt, comparison will now be made between deep water core DLM (Dubh Lochan) and deep water core LLRD 1 (Loch Lomond). Before embarking on this comparison a mental adjustment must be made due to the different nature of the sites under comparison. In particular it must be remembered that Loch Lomond differs from the Dubh Lochan in being by comparison an inland sea with a vastly greater catchment area which contains a much more highly varied vegetation. The coring sites themselves differ in both depth (LLRD 1, 26m cf. DLM, 11m) and distance from the margin of the respective lakes (or nearest islands in the case of LLRD 1), both being greater in the case of the Loch Lomond site.

As illustrated by Figure 17 tree pollen is between 70-90% T.P. at site DLM for most of the Postglacial until c.917$\pm$105 B.P. when the tree curve begins to decline to 45% T.P. However during the upper 250 cm of core LLRD 1 (the only part of the profile which can safely be compared due to differential preservation and the presence of a marine and a laminated layer which will be discussed in 5.4.2) the arboreal component is lower varying between 47 to 72% T.P. with values generally below 60% T.P. The higher arboreal pollen component at site DLM may be due to the more heavily wooded and more limited nature of the Dubh Lochan catchment area. It is interesting that during the marine and laminated layers the tree values at LLRD 1 (Figure 17) match more closely to those commonly found at DLM.

The summary diagrams presented in Figure 13 highlight certain components of the pollen profile. Namely <u>Pinus</u>, other trees, tall shrubs, agriculturally related pollen (i.e. <u>Plantago</u> <u>lanceolata</u>, Gramineae, <u>Pteridium</u>) and bog plants (i.e. <u>Calluna</u> Cyperaceae and <u>Sphagnum</u>). In the <u>Calluna</u> Gramineae regional pollen assemblage zone at site DLM a rise can clearly be seen in the values of bog related plants from 50 cm both in the summary and full pollen diagrams (Figures 13 and 14) before declining again between 20-10 cm. The LLRD 1 pollen diagrams show a similar increase in bog pollen indicators from c.80 cm but without the subsequent reduction in values found at DLM. From this data it is tempting to imply an increase in the erosion of blanket bog peats in the Loch Lomond area during roughly the last twelve hundred years. Perhaps due to climatic or anthropogenic factors or both a deterioration in the upland environment occurred in the Loch Lomond area during the last millenium accelerating particularly during the last few hundred years. In other words, the increase in the bog component at DLM probably represents the inwash of pollen from higher altitudes around the loch rather than being solely attributable to a local increase in the bog flora around parts of the loch shore.

That the decrease in the bog spectrum (Figure 13) from 20 cm at site DLM does not occur at LLRD 1 may simply be due to woodland management practices during the last three hundred years (i.e. coppicing from c.1700 A.D.) around the Dubh Lochan in particular. As the Loch Lomond catchment includes a proportionately much larger area of blanket peats (e.g. Campsie fells, Luss hills etc.) the increased input in erroded bog pollen (especially during the period of afforestation being considered at DLM) may have concealed the increase in the tree component in certain areas of the lochs catchment. However the increase in the <u>Pinus</u> curve from c.20 cm at LLRD 1 (Figure 13) may be a function of the increased peat erosion just mentioned. Although the latter increase in <u>Pinus</u> at LLRD 1 may be due to the planting of <u>Pinus</u> in the Loch Lomond area in recent centuries it may also be reflecting an increase in peat erosion and hence the <u>Pinus</u> pollen it contained in for example the Glen Falloch area (to be discussed in Chapter 6.

Continuing with the <u>Pinus</u> curve (Figure 13) the post <u>Ulmus</u> decline <u>Pinus</u> "peak" shown clearly between 280 and 160 cm in the LLRD 1 profile is only represented by a small increase in <u>Pinus</u> pollen at DLM (Figure 13) between 250-270 cm. The increase at site DLM may be due to the local growth of <u>Pinus</u> around the Lochan itself. Indeed taking the <u>Ulmus</u> decline at Walkers (1975) fen carr (Figure 16) site to be at c.350 cm a small post <u>Ulmus</u> decline <u>Pinus</u> peak is indeed present. If the <u>Pinus</u> peak at DLM and DL (post <u>Ulmus</u> decline) is regional in nature a source other than that to be postulated later (namely Glen Falloch) for the Pinus pollen found at site LLRD 1 will have to be sought.

Finally an increase in the agricultural component in the DLM and LLRD 1 summary pollen diagrams (Figure 13) occurs in both cases a few hundred years after the Ulmus decline. Unfortunately direct comparison between the two sites under discussion is in this instance extremely difficult due to the nature of the radiocarbon dates from the upper part of the LLRD 1 profile.

5.4 Absolute data from core LLRD 1 (Figure 12).

Interpretation of the results of the absolute pollen analysis of Loch Lomond core LLRD 1 is complicated by a number of factors namely:-

5.4.1) Differential preservation below 355 cm
5.4.2) Marine transgression period
5.4.3) Post Marine laminated layer
5.4.4) Deviations from linearity shown by some radiocarbon dates.

Consideration of each of the above factors is necessary to allow an evaluation of the usefulness of the absolute data in interpreting vegetational changes in the Loch Lomond area.

5.4.1 Differential preservation.

This has been dealt with during the discussion of the relative data(Section 5.1). However to re-emphasise, below 355 cm differential preservation is in operation resulting in a pollen spectrum with high concentrations of pollen and spores which show a low susceptibility to oxidation such as Pinus (Havinga 1967).

5.4.2 Marine transgression period (305-375 cm).

As demonstrated by the presence of cysts of planktonic marine dinoflagellates the sediments between 305 cm and 375 cm are marine in nature. Geologists have long suspected a marine phase within Loch Lomonds Flandrian period. However the dinoflagellate cysts provide the first positive evidence of the marine phase. The dinoflagellate cysts found are strictly marine and include:- *Operculodinium centrocarpum* (Defl. and Cooks), Wall, *Bitectatodinium tepikiense* Wilson, probably two species of *Spiniferites* and an abundance of *Lingulodinium machaerophorum* (Defl. and Cooks) Wall (the resting cyst of *Gonyaulax polyedra*). The cysts noted resemble recent assemblages from the eastern coast of the Irish sea (Reid pers. comm.). They are indicative of reduced salinity (<33%) and shallow turbid conditions. The concentration curve for dinoflagellate cysts (Figure 12) is bi-phasic, suggesting a decrease in "marinity" within the incursion (c.340 cm). Table 5 shows the results (in percentage terms) of two slides counted in detail (Dr. R. Harland I.G.S.) and the results presented in percentage terms. The sample at 370 cm can be interpreted as indicative of less than fully marine salinity as *L. machaerophorum* is well known to "prefer" less saline nearshore environments. Meanwhile the assemblage at 320 cm may be interpreted in relation to the older as possibly indicative of a more fully marine salinity as evidenced by the incursion of *O. centrocarpum* an oceanic to nearshore species. Harland (pers comm.) warns however that the latter species is ubiquitous and caution is needed in any interpretation. The concentration curve therefore may be displaying the initiation and primary peak followed by a decrease, subsequent increase and finally the decline of marine influence within the marine layer.

Although the remains of freshwater ~~macrophytes~~ plants such as *Littorella*, *Nuphar*, *Myriophyllum* and *Pediastrum* are generally poorly represented within the core the spores of the freshwater pteridophyte *Isoetes lacustris* are well represented. That is except between 280 cm and 375 cm. The interesting correlation between the presence of Dinoflagellate cysts and *Isoetes* spores can be seen clearly from Figure 12. The absence of *Isoetes* spores during a marine period and their appearance after such a period is clearly seen from other diagrams in north western Europe (especially north Norway) where changes in sea/land levels have been studied (e.g. Donner et. al 1977, Sønstegaard 1977). Indeed *Isoetes* is not known to

Table 5.

Dinoflagellate counts from core LLRD 1
Marine layer at 372 cm and 320 cm.
(Counting by R. Harland, Institute of
Geological S~~ervi~~ces).
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Dinoflagellate percentage counts at 372 cm and 320 cm.

372 cm — Count of 205 specimens

Lingulodinium machaerophorum (Deflandre & Cookson) Wall 1967	96.10 %
Spiniferites cf. *ramosus* (Ehrenberg) Mantell sensu Harland 1977 *S.* cf. *bulloideus* (Deflandre & Cookson) Sarjeant sensu Reid 1974	3.41 %
Operculodinium centrocarpum (Deflandre & Cookson) Wall 1967	0.49 %

320 cm — Count of 230 specimens

Operculodinium centrocarpum	52.17 %
Lingulodinium machaerophorum	45.65 %
Bitectatodinium tepikiense Wilson 1973	1.30 %
Spiniferites cf. *ramosus*	0.87 %

tolerate saline conditions. The recovery of Isoetes values is fairly slow, reappearing at 280 cm. This suggests that conditions did not become suitable for the growth of Isoetes until five to eight hundred years after the end of the incursion itself. (This may have been due to the processes involved during the next factor 8.4.3, to be discussed).

A single valve of the Mollusc Macoma calcarea was found at 330 cm and had been bored into by the predatory prosobranch Natica sp. Although commonly found in the Clyde beds (e.g. at Lochgilphead) (Peacock et. al. 1977) and with a record from clays at Inchlonaig (Brady et. al. 1874), Macoma calcarea is now extinct in the British Isles. It has a high boreal distribution with an outlying Danish occurrence. A likely explanation for the presence of the Macoma valve is that it may be derived from the late Devensian clayey silts around the loch. These clayey silts were extensively eroded during the Flandrian transgression. However Molluscsrelated to the Flandrian transgression were recorded last century from Rossarden near Luss (Brady et. al. 1874) and include Mytilus edulis, Hydrobia ulva, Macoma balthica and Littorina sp. This shell bed should not be confused with the older arctic beds (Clyde beds) and is younger. ~~in nature~~.

As judged from core LLRD 1 the marine transgression lasted some 1,450 years beginning about 6,900 B.P. and ending about 5,450 B.P. The event therefore began some 1,400 years later than the corresponding transgression in the upper Forth valley (Sissons 1974). The lateness of the Loch Lomond transgression may have been due to the time required to submerge the "substantial barrier" across the Vale of Leven (Dickson et. al. 1978, Appendix 2). Apart from a reduction in Isoetes spores and the presence of marine dinoflagellates the marine incursion would appear to have had little effect on the process of pollen accumulation within the loch. However due to differential preservation immediately before the marine sediment and the presence of laminated sediment with triple the pollen concentration "usual" for the LLRD 1 profile immediately following the marine layer, no comparison with adjacent pollen samples can be made. Therefore it is difficult to draw valid conclusions as to the effect of the incursion on the pollen concentration during the marine phase.

5.4.3 Post Marine Laminated Sediment 278-305 cm.

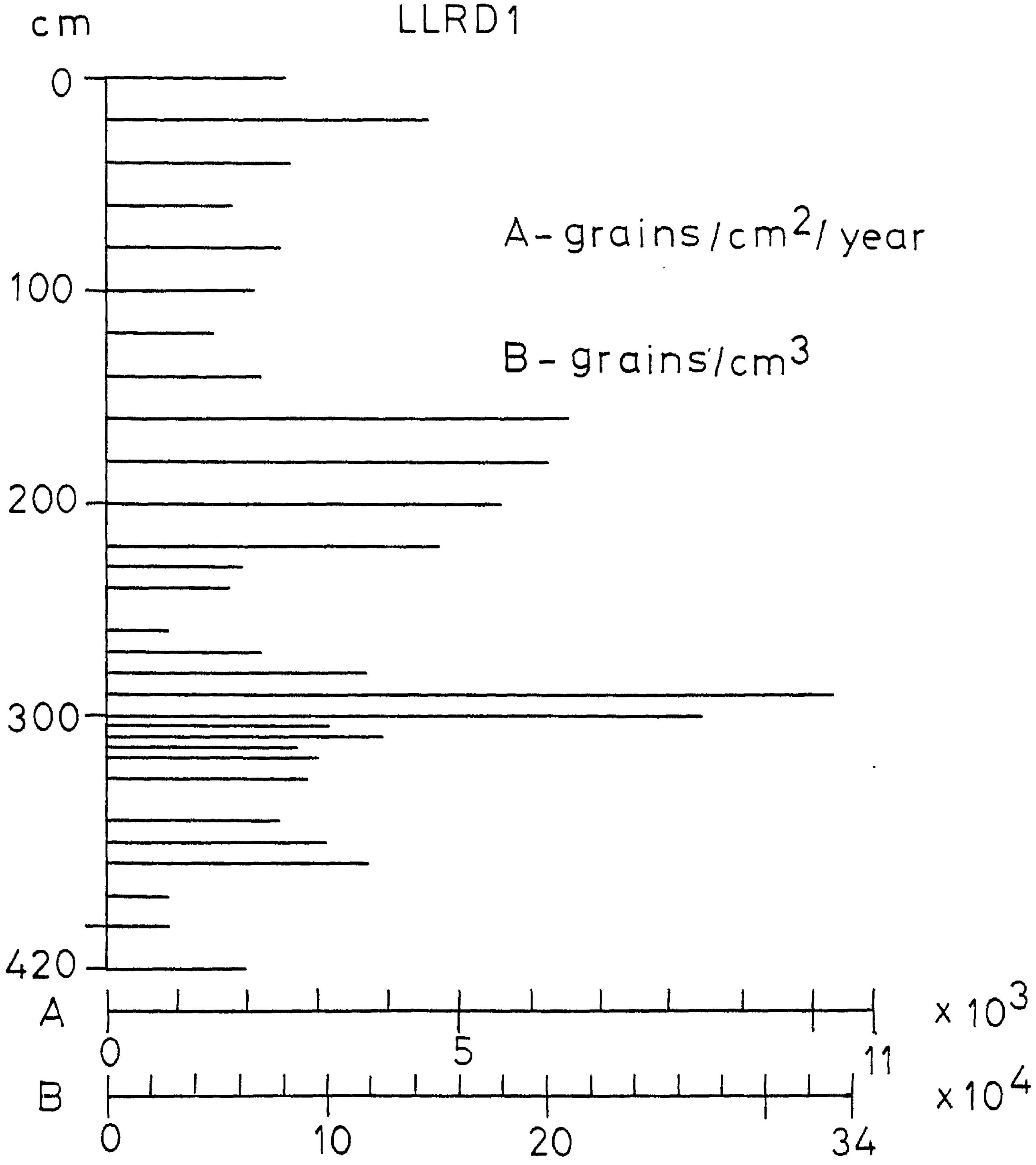
As mentioned in the introduction a considerable advantage of absolute over percentage diagrams is that changes in the amounts of individual taxa can clearly be seen. Indeed changes in pollen concentration (grains/cm^3) are fully highlighted using absolute pollen analysis. This advantage of absolute over percentage diagrams is clearly displayed in Figure 12 where between 278 cm and 305 cm the sediment is finely laminated. Unlike the percentage data the absolute values show that there is a massive increase in pollen concentration within this immediate post marine layer. In the laminated layer the total pollen concentration increases dramatically from an average of 100,000 grains/cm^3 (c.305 cm) to 331,000 grains/cm^3 before dropping again to below 100,000 grains/cm^3 (Figure 18). This represents a tripling of the pollen concentration within a period of c.160 years (calculated from radiocarbon profile).

Associated with the increase in concentration of microspores within the laminated layer is a considerable improvement in the preservation of all grains. At 300 cm no corroded category grains were recorded. The only plant macrofossil found within the whole core (LLRD 1) was a twig of Alnus glutinosa at 282 cm. Both the qualitative and quantitative changes in the fossil content suggest that conditions were less oxidizing during this laminated layer.

Due to the concentration of almost all taxa increasing it is difficult to envisage this change in pollen concentration between 278 cm and 305 cm as a reflection of an actual vegetational change. In other words as yet no

Figure 18.

Total, Concentration and Deposition diagram for core LLRD1.



cm
LLRD1
0
100
200
300
420
A- grains/cm2/ year
B - grains/cm3
A
0
5
11
x 10^3
B
0
10
20
34
x 10^4

However, the exposure of the extensive south basin tends to prevent stratification.

viable hypothesis is available to explain such a pollen spectrum solely in terms of changing vegetation and its concomitant pollen concentration. A change in the sedimentation rate caused by an input of soil from the catchment area and hence the contained pollen is difficult to postulate. Such an event would contradict the radiocarbon evidence which shows a stable sedimentation rate throughout the laminated layer of sediment. One possible explanation (and the only one seriously considered here) may be that a period of meromixis occurred immediately after the incursion.

Meromixis is the condition "in which some water remains partly or wholly unmixed with the main water mass at the circulation periods" (Hutchison 1957). This must be contrasted with the present monomictic status of the loch which means that the temperature does not drop below 4°C and it stratifies directly in the summer (Hutchison 1957, Wetzel 1978). As circulation occurs throughout the entire water column it is also a Holomictic lake (it might be expected to be Dimictic - circulating freely twice a year - at this latitude where the lake would be directly stratified in summer and indirectly stratified in winter) due to the oceanicity of the climate.

The type of meromixis envisaged would be ectogenic in nature whereby an external event (in this case the marine transgression) brings salt water into the basin (a fairly full account of meromixis is given by Frey 1967). Once a stratum of dense salt water had become established, an anoxic layer would probably have been set up. This layer would have been ideal for the preservation of pollen grains and spores and hence may possibly be responsible for the high pollen concentration values found in the laminated layer. If meromixis alone explains the increase in pollen concentration it would imply that only during the period of the laminated sediment are the true pollen concentration values being seen in Loch Lomond. Hence at all other times the concentration values will be abnormal due to processes such as oxidation for example. Also redeposition of marginal sediment and concentration at the deeper parts of the loch may have been occurring through fluctuations in the level of the loch. Unfortunately a good indicator of transport and redeposition namely *Isoetes* spores is absent. However between 140 cm to 220 cm pollen concentration values again show very high values for this sediment with a peak of 211,110 grains/cm^3 at 160 cm. This is associated with high values of Filicales Carboniferous and *Isoetes* spores which would indeed strongly suggest redeposition or lateral transport of sediment within Loch Lomond (between 140 cm to 220 cm) possibly along with differential preservation in favour of these grains due to the lack of meromictic conditions found in the laminated layer. A great deal of further investigation into the nature of the laminated layer is required to clarify the situation.

If meromixis occurred between 278-305 cm it would appear to have lasted c.800 years (assessed from the radiocarbon profile). This is entirely feasible considering that salt water is still detectable in Lake Tokke southern Norway after 6000 years (Strom 1961).

5.4.4 Deviations from linearity shown by some radiocarbon dates.

As already noted when considering the radiocarbon dates from core LLRD 1 there are a number of deviations from linearity in the resultant profile. The anomalously old date at 370 cm (Figure 8) and the quasi vertical or negative gradient trends above 190 cm make the calculation of pollen deposition (grains/cm^2/year) data only feasible between 330 cm and 190 cm. The determination of pollen deposition rates relies upon the accurate calculation of sediment accumulation rates. Therefore errors involved in estimating pollen deposition include the inherent errors in radiocarbon dating which in the case of the LLRD 1 dates are considerable (i.e. due to the low organic carbon content and width of sediment dated - Appendix 2). By interpolation between dates the LLRD 1 Alnus rise is c.6640 B.P. However the Dubh Lochan DLM Alnus rise has been accurately dated to 4913±85 B.P. (Table 4) showing the LLRD 1 radiocarbon profile to be c.600 years in error at the Alnus rise horizon.

Until considerably smaller samples can be used to calculate more accurate dates calculation of pollen deposition rates from core LLRD 1 will not be very informative exercise. However Figure 18 includes a pollen deposition scale based upon the 0.31mm/year sedimentation rate shown by regression analysis for the profile between 190 and 330 cm. It must be stressed that this scale should only be used for that part of the core between c.1700 B.P. and c.6300 B.P., and even then with considerable caution.

5.4.5. Appraisal of the LLRD 1 absolute data.

Interpretation of the absolute data from core LLRD 1 in relation to changes in the vegetation cover of the Loch Lomond area would appear to be a meaningless exercise considering the problems caused by factors 5.4.1 to 5.4.4. above. Indeed the relative percentage diagram would appear to be more useful in this instance. However the absolute data has shown clearly that the amount of pollen trapped and retained by the Loch Lomond sediments has varied widely at different times during the course of the Flandrian period. In the case of the postulated phase of meromixis an internal cause may be sought to explain the variation in pollen concentration. At other times especially during the top c.200 cm of the diagram the variation in pollen concentration may be due to external processes such as increased soil erosion for example.

5.5 Absolute data from core DLM (Figure 15).

Interpretation of the Dubh Lochan DLM absolute data is not hampered by any of the special problems (factors 5.4.1 to 5.4.4) associated with the Loch Lomond sediment profile. Indeed unlike the situation with core LLRD 1 radiocarbon dating permits calculation of deposition figures from the concentration data.

Linear regression analysis (Figure 10) of the radiocarbon dates from site DLM provides a mean sedimentation rate of 0.63 mm/year or 15.9 years/cm^2. The deviations from the closest fit of points at 422.5 cm and 482.5 cm may be considered to be minor when account is taken of:-

1) the large standard error at both 482.5 cm (i.e. 2σ is c.1000 years) and 422.5 cm (i.e. 2σ is c.340 years).
2) radiocarbon dating of lake sediments itself is influenced by a large number of variable factors highlighted by for example the low carbon content and fossil carbon content of the Loch Lomond core described in the last Chapter.

Baxter (in Dickson et. al. 1978 Appendix 2) concludes that a much greater although non quantifiable uncertainty is attached to the dating of lake sediments than the counting error(s) (i.e. σ) alone suggest.

Taking the above factors into consideration a sedimentation rate of 0.63 mm/year has been used to calculate the deposition (grains/cm2/year) data from the concentration values at site DLM.

Figure 15 includes a summary of total deposition figures for each sample level while Table 6 provides details of the maximum and minimum deposition values, plus the mean deposition value for each of the regional pollen assemblage zones at site DLM.

During the Betula-Quercus-Alnus (with Ulmus) regional pollen assemblage zone there is approximately a tripling of the mean pollen deposition rate from 10×10^3 grains/cm^2/year in the previous Betula-Coryloid regional pollen assemblage zone to 3.0×10^4 grains/cm2/ year. This increase in pollen deposition can be seen (Figure 15) to have occurred at around the time of the Alnus rise horizon (i.e. c.6000 B.P.). It may reflect an increased input of pollen to the loch sediment from the expanding arboreal vegetation of the loch's catchment, corresponding with perhaps an increase in oceanicity in climate

Table 6.

Maximum and minimum, plus mean deposition values for each regional pollen assemblage zone at site DLM.

Table 6.

Regional pollen assemblage zone	Local pollen zone	No. of grains/cm^2/year Min.		No. of grains/cm^2/year Max.	Mean No. of grains/cm^2/year
Betula-Coryloid	DLM 1	6×10^3	to	1.4×10^4	1.0×10^4
Betula-Quercus-Alnus (with Ulmus)	DLM 2	1.5×10^4	to	5.5×10^4	3.0×10^4
Quercus-Alnus	DLM 3	9×10^3	to	5.7×10^4	2.9×10^4
Calluna-Gramineae	DLM 4 & 5	1.4×10^4	to	6.0×10^4	2.6×10^4

referred to in previous sections. As no major change in sedimentation rate is seen to occur the increase in pollen deposition values would appear to reflect both a qualitative and quantitative change in the vegetational "pattern" around the Dubh Lochan at the time of the Alnus rise.

Mean deposition values drop slightly after the Ulmus decline to c.2.5 x 10^4 grains/cm^2/year during the Quercus-Alnus regional pollen assemblage zone (excluding values at 160 and 170 cm). Deposition values begin to rise again towards the top of the profile perhaps associated with intensified human activity in recent centuries.

From Table 7 it can be seen that the Dubh Lochan sediment has very high pollen deposition rates which on a consideration of figures from present day pollen traps (i.e. Blelham Tarn) indicates a massive concentration of pollen within the sediments of the Dubh Lochan (also clearly shown by Pennington for other north British sites, Table 7 and Pennington 1973). Unfortunately no comparative values are available for pollen deposition into either suspended traps or surface mud at DLM to allow comparison with other sites. (Deposition values from site LLRD 1 at c.5000 B.P. compare more closely to these from lake sediment traps i.e. Blelham Tarn).

The very high pollen deposition values at site DLM are probably due to the heavily wooded catchment area combined with the loch's size, enclosed nature and possibly considerable redeposition of grains within the basins. (Davis 1967, Pennington 1973, Bonny 1976). Indeed the high values of Isoetes spores between 350 cm to 150 cm suggest (as already noted when considering the percentage data) a considerable transport of pollen from the edges of the loch to the deepest part associated with a concentration of the grains (Pennington 1972). As noted by Hyvarinen (1976) "high pollen deposition values may be due to high allochthonous contribution to sediments or to other characteristics of the sedimentary regime, rather than to

Table 7.

Deposition values for selected Scottish and north English lochs and lakes at c.5000 B.P., compared to present day surface mud and suspended pollen trap samples (Pennington 1973).

Table 7.

	Site	Deposition grains/cm^2/year
a)	Mixed *Quercus* forest of N.W. England and Loch Lomond area.	
	Windermere (south basin)	1.6 to 2 x 10^3
	Blea Tarn	1.5 x 10^4
	Dubh Lochan DLM	3 x 10^4
	LLRD 1	3.9 x 10^3
b)	Area of *Pinus*-*Betula* forest	
	Loch a Chroisg	5 x 10^3
	Loch Clair	1.5 x 10^4
c)	Compare above figures with figures for present N.W. England.	
	Windermere surface mud	6.75 x 10^3
	Blelhan Tarn	4.8 x 10^4
d)	Pollen traps	
	Blelhan Tarn floating trap	3 x 10^3

high pollen productivity of the surrounding vegetation." Considering this point Craig (1978) warns that comparisons of deposition rates must be done cautiously unless the nature of the sites is also compared. Craig further concludes that pollen concentration may provide more information than pollen deposition when corresponding zones at different sites are compared.

6. THE VEGETATIONAL HISTORY OF PINUS IN THE LOCH LOMOND AREA.

6.1 Ecology of Pinus sylvestris and the distribution of stumps in peat.

During the discussion of the regional pollen diagrams LLRD 1 and DLM many references were made to the vegetational history of *Pinus* in the Loch Lomond area. The latter area is particularly interesting as it lies between the *Pinus* forests of the north west and the mixed *Quercus* forests of central Scotland. Figure 19 (from Birks H.H. 1975) shows the distribution of *Pinus* stumps in peat. Excluding those found in Galloway it can be seen that the Glen Falloch area represents the most south western extent of the Caledonian *Pinus* forests. Therefore it is an ideal area to study the behaviour of *Pinus* at its ecological limits. In order to investigate more thoroughly the status of *Pinus* in the Loch Lomond area and to attempt to find the locality of the expansion of *Pinus* shown by the LLRD 1 pollen profile, three sites were studied, namely, Glen Falloch, Ptarmigan and Shantron Muir.

Before describing each of the above sites and discussing the resultant data a brief consideration of *Pinus* stumps in peat and of the growth of *Pinus* on peat will be given.

F. J. Lewis (1905-7,1911) studied the stratigraphy of "forest beds" in Scottish peat bogs, peat layers being taken to indicate glacial periods and stump layers interglacial periods. Earlier Blytt and Sernander had used stumps in peat to develop hypotheses concerning past climates in Norway and Sweden respectively (Birks H.H. 1975). The resultant Blytt and Sernander climatic scheme indicated that the forest beds belonged to dry periods such as the Boreal and Sub-Boreal while the intervening peat belonged to wet periods such as the Atlantic and Sub-Atlantic. However a consideration of *Pinus* stump dates (Birks H.H. 1975) clearly indicates lack of synchroneity of occurrence of stumps with the climatic scheme put

Figure 19.

The distribution of *Pinus* stumps in peat at the present day, and the probable limit of native *Pinus* had man not been active. *Pinus* stump record in a 10 km x 10 km grid square;

(From Birks, H.H. 1975).

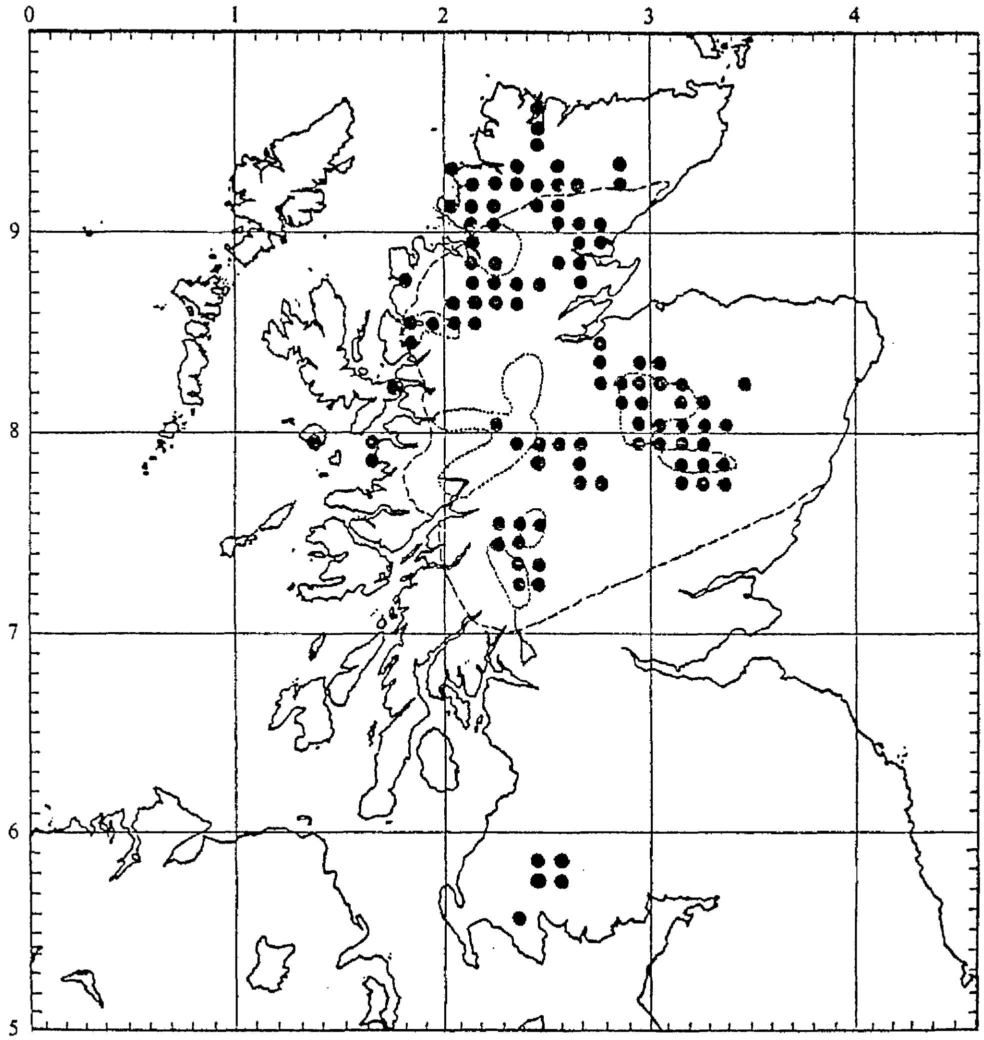


FIGURE 1. The distribution of pine stumps in peat, of native pine at the present day, and the probable limit of native pine had not man been active. ●, Pine stump record in a 10 km × 10 km grid square; ...., present limit; ----, probable limit.

forward by Blytt and Sernander.

The period of major Pinus immigration and expansion in the highlands of Scotland occurred between 8000-6500 B.P. Subsequently the Pinus forests of western Scotland were largely destroyed by widespread blanket bog development from c.4000 B.P. (O'Sullivan 1977). Therefore it is interesting to note the post Ulmus decline Pinus peak in the LLRD1 pollen diagrams (Figures 11 and 13) which suggests the expansion of Pinus somewhere within the Loch Lomond region at c.4200 B.P.

Birks has suitably reviewed the problem of the growth of Pinus on peat, only the most important details being described here (Birks, H.H. 1975).

Peat type is important. Trichophorum caespitosum or Molinia caerula peat is acutely deficient in phosphorus while Calluna vulgaris peat is very deficient in nitrogen (McVean a, b, 1963). McVean further demonstrated that mycorrhizal association improved nutrient uptake on nutrient deficient peat. However fibrous peat contained a mycorrhizal inhibitor produced by Calluna (Harley 1959) which can be destroyed by a hot burn. In nature maximum establishment of Pinus seedlings occurs between three to six years after a hot burn. Waterlogging retards older seedlings (McVean 1963b) and may cause death. However with aeration retarded seedlings may recommence growth and set seed in conditions unsuitable for further seedling establishment. Indeed waterlogging may explain the eastern distribution of Pinus to-day, the colonization of the western bogs being inhibited by waterlogging whereas periods of drought in the east allow the upper layers of peat to become aerated encouraging Pinus growth.

Like the stumps examined by Birks, H.H. (1975) all the stumps examined in this study were found to be upright in the peat. In the light of the present ecological conditions for growth of Pinus on peat outlined briefly above, Birks (Birks, H.H. 1975) considered that the upper layers of peat were anaerobic as evidenced by the growth of the stumps, their preservation indicating subsequent wetter conditions.

Further details of the ecology and biology of *Pinus sylvestris* in Scotland which may be useful when considering the evidence presented in this thesis for the trees' growth on peat are presented in Table 8.

6.2 Glen Falloch.

6.2.1 Site description and stratigraphy.

Glen Falloch is located in the parish of Killin, Perthshire at latitude 56° 22′N, longitude 4° 39′W. The site (Figure 20) studied is situated between the Glasgow-Oban road and railway line at N S 369 238. The woodland which is not a true pinewood community but consists merely of scattered trees on the south east slopes, is on quartzose mica schists of the Dalradian series. The soils are podsolised or peat covered. Rainfall is c.1905 mm. The site is at 150 m O.D., most of the *Pinus* being found between 150-210 m O.D. The field layer communities are not characteristic of native pinewoods due to the open nature of the woodland and intense grazing by sheep. The area is grass moorland. Table 9 shows the results of a 5 x 5 m quadrat directly above the sampling site. There is no natural regeneration of *Pinus* in Glen Falloch. According to Stephen and Carlisle (1959) no early historical information has been found concerning the Glen Falloch *Pinus* trees. However Balfour (1932) considered them to be native and natural. The status of the present day *Pinus* trees will subsequently be considered in the light of the vegetational history of the area.

At the site of study the peat is on average c.1 m deep, being deeply erroded by channels exposing numerous *Pinus* stumps. A description of the stratigraphy described using the system of Troels-Smith (1955) now follows:-

0-4 cm Trichophorum-Hypnum cupressiforme peat. Nig. 3, strf. 0, elas. 3, sicc. 3, lim. 1, humo. 0.
Colour 10R 2.5/1 reddish black.
Composition:- $Th^{o}3$ $Tb^{o}1$.
Relatively unhumified peat.

4-22 cm — Trichophorum-Eriophorum peat.
Nig. 3, strf. 0, elas. 2, sicc. 2, lim. 0, humo 2.
Colour 10R 2.5/1 reddish black.
Composition:- $Th^{2}3$ Sh1 Tl^{2} + anth +.

22-55 cm — Eriophorum-Trichophorum-Calluna peat.
Nig. 3, strf. 0, elas. 2, sicc. 2, lim. 0, humo. 2.
Colour 10R 2.5/1 reddish black.
Composition:- $Th^{2}3$ $Tl^{2}1$ Sh. + anth. +.

55-90 cm — Highly humified peat.
Nig. 3, strf. 0, elas. 1, sicc. 2, lim. 0, humo. 3.
Colour 5YR 2.5/1 black.
Composition $Th^{3}3$ Sh1 anth. +.

90-125 cm — Highly humified Betula wood peat.
Nig. 3, strf. 0, elas. 2, sicc. 2, lim. 0, humo. 3.
Colour 2.5YR 2.5/2 very dusky red.
Composition $Th^{3}2$ Dl1 Sh1 anth. +.

Pinus wood was present at 36 cm and Betula wood was present at 112 cm.

The upper 4 cm consisted of fairly unhumified Trichophorum caespitosum peat with abundant leaves and stems of Hypnum cupressiforme and very few leaves of Sphagnum section Sphagnum.

Between 4 cm to 22 cm the Trichophorum-Eriophorum peat contained abundant Cyperaceae rootlets mainly of T. caespitosum, the spindles of Eriophorum being present but in very low numbers. Small pieces of Pinus wood were present. Sphagnum imbricatum leaves were abundant at 10 cm while charcoal was present at 10 cm and 20 cm.

Within the Eriophorum-Trichophorum-Calluna peat, Calluna rootlets were present throughout. Eriophorum rootlets and spindles were present from 50 cm upwards being most abundant at 40 cm. A small piece of Pinus wood was noted at 30 cm and charcoal fragments were abundant at 55 cm.

From 55 cm to 90 cm the peat was highly humified with many small pieces of herbaceous rootlets and stems. Charcoal was present at 60, 70, 85 and 90 cm while

Table 8.

Selected details of the ecology and biology of *Pinus sylvestris* L. in Scotland.

(Mainly extracted from McVean 1963).

1. Altitudinal distribution varies from sea level in the north west to 625 m in Cairngorm mountains.

2. *Pinus* mainly on north-facing slopes with *Betula* and *Quercus* dominating south-facing slopes.

3. Light demanding (intolerant of heavy shade).

4. Highly competitive on many nutrient deficient sites where it can be the climax vegetation.

5. Most *Pinus* trees less than 200 years old, the oldest stump ring count being 395 years from Arkaig (Steven and Carlisle 1959).

6. Seed may be set on trees as young as 6 years.

7. Female inflorescence develops mid May to early June.

8. Male flowers appear at the base of current year's shoots in early spring with anthesis in June.

9. Susceptible to fire.

Table 9.

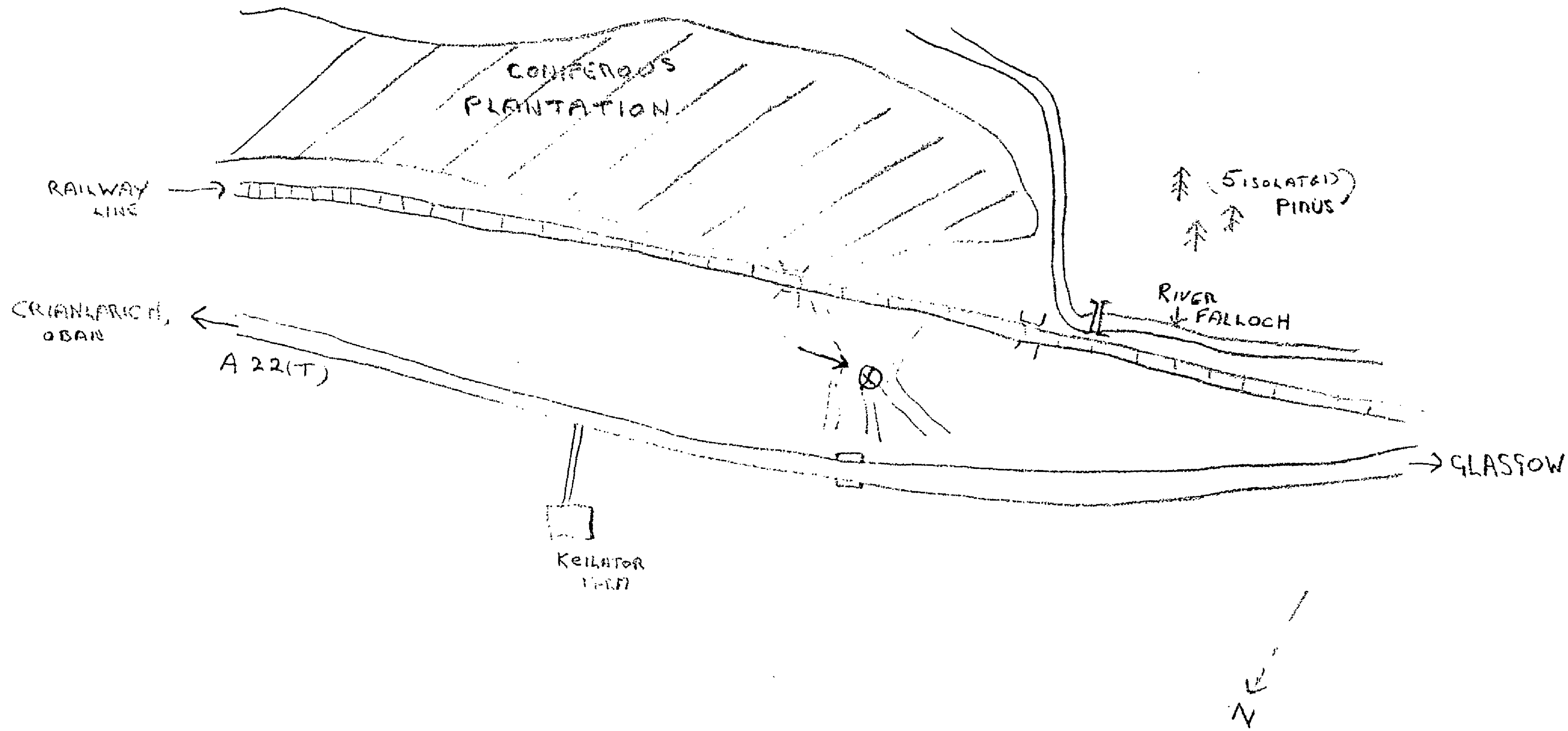
Results of a 5 x 5 m quadrat taken directly above the site of study.

Table 9.

Taxon	Domin Scale Value
Trichophorum caespitosum	8
Molinia caerulea	4
Deschampsia flexuosa	4
Anthoxanthum odoratum	4
Potentilla erecta	3
Galium saxatile	3
Vaccinium myrtillus	3
Narthecium ossifragum	+
Cerastium holosteoides	+
Polytrichum commune	3
Rhytidiadelphus squarrosus	4
Hypnum cupressiforme	4

Figure 20.

Copy of sketch map from field notes showing the location of the Glen Falloch site. (ⓧ marks position of site).


CONIFEROUS
PLANTATION
RAILWAY
LINE
(5 ISOLATED
PINUS)
RIVER
FALLOCH
CRIANLARICH,
OBAN
A 22(T)
GLASGOW
KEILATOR
FARM
N

sclerotia of Cenococcum geophilum were present at 85 and 90 cm.

Betula bark and twigs were abundant in the highly humified peat from 90 cm downwards while numerous sclerotia of Cenococcum geophilum were present throughout. Charcoal was noted at 100, 103, 105, 111, 120 and 120-125 cm.

6.2.2. Radiocarbon dates.

Details of the two radiocarbon dates from Glen Falloch are given in Table 10. Peat from 95 cm gave a date of 4310±50 B.P. while the Pinus stump from the upper 40 cm of the profile provided a date of 1620±50 B.P.

The Pinus stump date shows that about fifteen hundred years of the peat profile is absent and that the pollen diagram does not reach the present day.

6.2.3. Glen Falloch local pollen zones.

The Glen Falloch pollen diagrams (Figure 21, trees as a percentage total arboreal pollen, A.P., and Figure 22, all taxa as a percentage total pollen, T.P. ≤T.P. excluding Sphagnum, crumpled corroded concealed and unidentified), have been divided into two local pollen zones using the methods outlined in the materials and methods section. The zones designated GF1 and GF2 are drawn on Figures 21 and 22 and separately in Figure 23.

GF1-125cm - 92.5cm. (See Figure 24 for summary diagram).

Tree pollen dominated by Betula (25-44% T.P.) varies between 41-67% total pollen being usually in excess of 50% T.P. Alnus values never exceed 12% T.P. (20% A.P.) while Quercus never exceeds 5% T.P. (10% A.P.) and Ulmus is always less than 3% T.P. (c.6% A.P.). Tilia is present at 110 cm. Coryloid (Corylus) values vary between 9-25% T.P. The highest Salix values are found in this zone but never attain more than 3.5% T.P. Calluna drops from c.15% T.P. to less than 1% T.P. at 110 cm, rising again to c.10% T.P. at 95 cm while Gramineae values drop from 15% T.P. at 120 cm to c.2% T.P. for the remainder of the zone.

G.U. - 1061:- Sample of peat taken at a depth of 95 cm, from a peat face 125.5 cm in depth.

a) Humic acid fraction.

$-413.6 \pm 5.3^{o}/oo$ $-28.8^{o}/oo$ 4290±75 years

b) Residue.

$-416.8 \pm 5.1^{o}/oo$ $-28.5^{o}/oo$ 4330±70 years

c) Average.

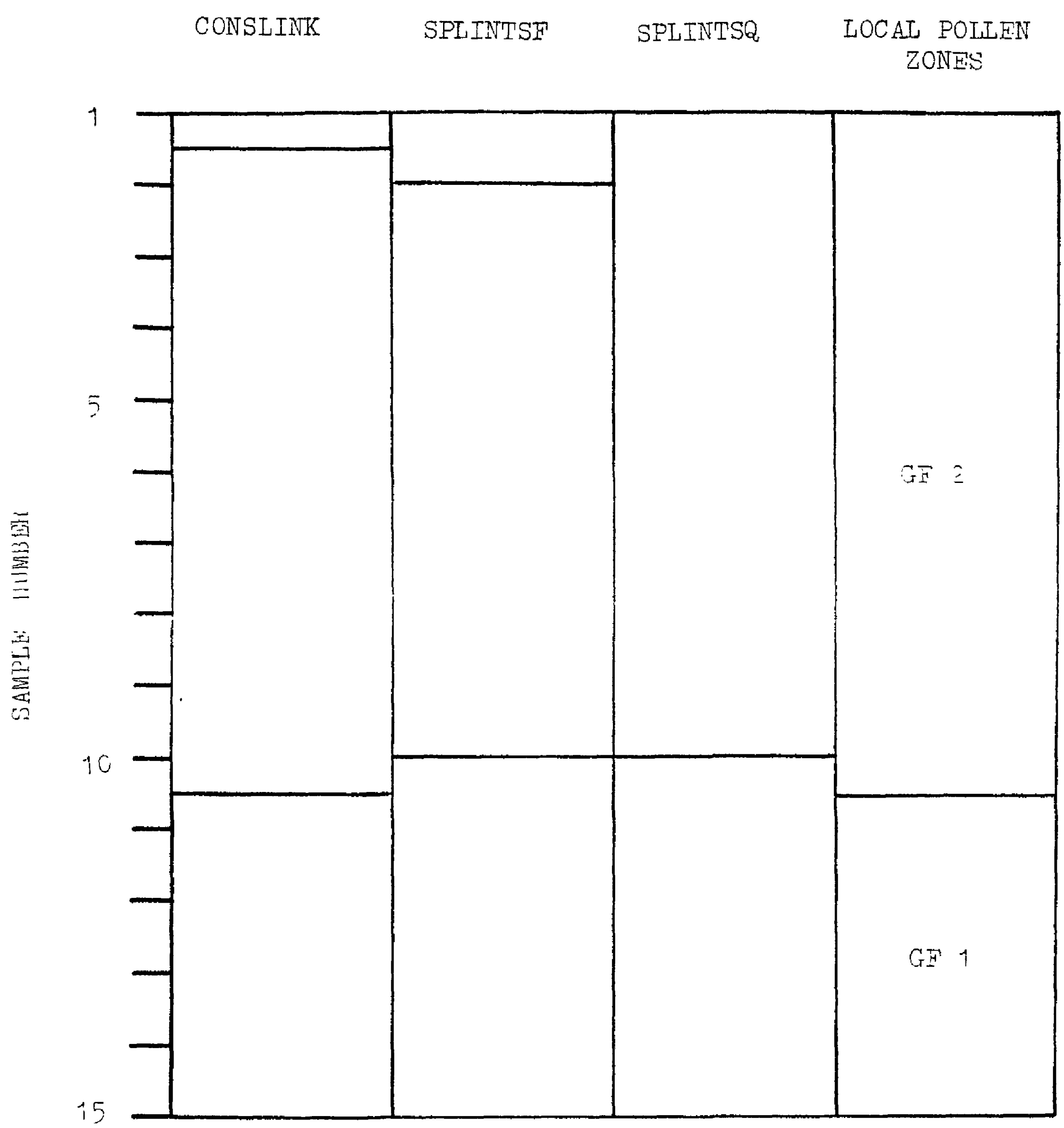
$-415.2 \pm 3.7^{o}/oo$ 4310±50 years

G.U. - 1062:- *Pinus sylvestris* wood stump.

Cellulose fraction

$-182.7 \pm 5.3^{o}/oo$ $-23.4^{o}/oo$ 1620±50 years

GLEN FALLOCH



10/11 - 92.5 cm

Figure 24.

Summary diagrams for Glen Falloch, Ptarmigan and Shantron Muir. Pollen sum based on sum of all pollen and spores excluding crumpled and corroded.

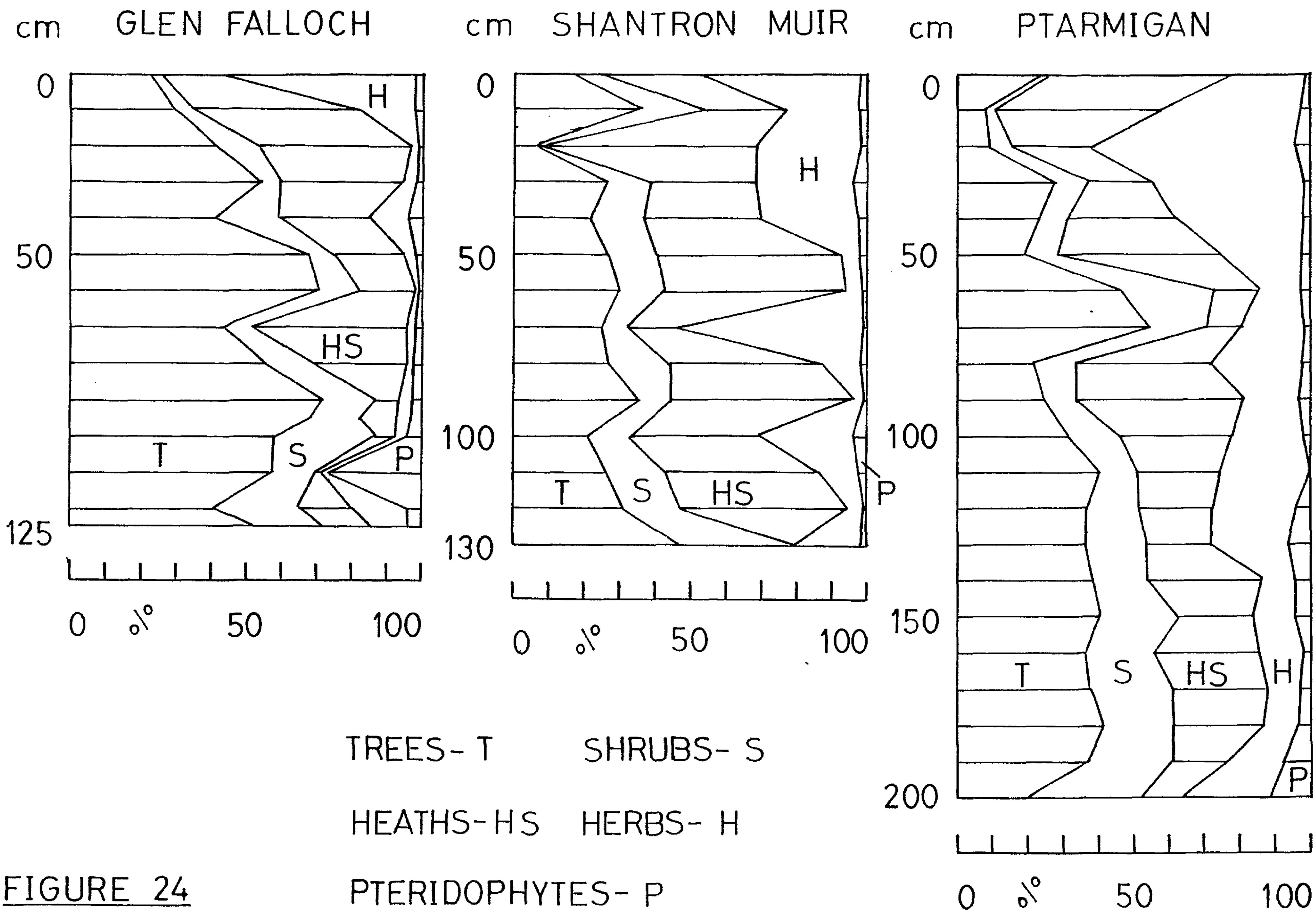

cm GLEN FALLOCH
cm SHANTRON MUIR
cm PTARMIGAN
0
50
100
125
130
150
200
0 % 50 100
T
S
HS
H
P
TREES- T
SHRUBS- S
HEATHS-HS
HERBS- H
PTERIDOPHYTES- P

FIGURE 24

Filicales reaches a peak of 25% T.P. at 110 cm before declining rapidly to values of less than 3% T.P.

Sphagnum values never exceed 12% T.P. the curve rising rapidly at the top of the zone.

GF2-92.5 cm-0 cm.

Tree pollen values are generally in excess of 50% T.P. dropping to c.20% T.P. at 0 cm. Betula values decline at the base of the zone to less than 30% T.P. with values ranging between 9-27% T.P. (16 to 45% A.P.). Pinus percentages vary between 6-47% T.P. (c.25%-75% A.P.) with a peak of 47% T.P. (75% A.P.) at 20 cm.

Alnus values decline continuously from a maximum of 11% T.P. at 90 cm to less than 2% T.P. at 0 cm.

Quercus never exceeds 3% T.P. (c.7% A.P.) while Ulmus is always less than 1% T.P. Fraxinus is continuously present from 40 cm (less than 1% T.P.). Coryloid values vary between 3% to 19% T.P., Salix always being less than 2% T.P.

Calluna values fluctuate rising from 5% T.P. to 42% T.P. at 70 cm then declining to 14% T.P. at 60 cm before rising again to a maximum of 46% T.P. at 10 cm.

Vaccinium is present during most of the zone, values never exceeding 2.5% T.P.

The curve for Cyperaceae rises steeply from 0% at 20 cm to 14% T.P. at 0 cm. Gramineae values also show a marked increase from 2% at 20 cm to 40% T.P. at 0 cm. Unlike Cyperaceae, Gramineae is continuously present during this pollen zone.

A wide range of herb pollen is present especially in the upper 20 cm of the profile. However apart from Rosaceae undiff. and Plantago lanceolata no other herb taxon exceeds 1% T.P. Those present include Galium, Potentilla, Rumex and Urtica.

Pteridium values only once exceed 1% T.P. with a value of 3.6% T.P. at 40 cm.

The *Sphagnum* curve behaves erratically with for example a peak of 300% T.P. at 40 cm and 104% T.P. at 80 cm, values normally being less than 60% T.P.

6.2.4 Discussion of the Glen Falloch data (Figures 21 and 22).

As indicated by the ^{14}C date at 95 cm and the low values of *Ulmus* pollen (>6% A.P.) zone GF1 began after the *Ulmus* decline horizon (dated 4913±85 B.P. at site DLM) and ended at c.4310 B.P. During that period of time Glen Falloch by inference from the pollen spectra and the macro stratigraphy was occupied by *Betula* woodland. As shown by the *Betula* bark and wood in the peat *Betula* trees grew directly on the site investigated, the woodland probably being of the type in existence at the north west end of Loch Lomond. From the low values of all other tree taxa *Betula* would appear to have been dominant in the area.

Values for *Pinus* in zone GF1 are exceedingly low (>5% A.P.) and can be accounted for solely by wind-borne pollen. Therefore it would appear that the woodland contained little or no *Pinus* in marked contrast to the next zone. The low values of *Pinus* pollen must be explained in the light of the fact that *Pinus* forest was probably fairly extensive in the Tyndrum area a few miles to the north. The values of *Pinus* may be very low in zone GF1 perhaps due to a filtering effect of the type envisaged by Tauber (1965) caused by the dense *Betula* woodland. Such a process may also help to explain the very low values of *Alnus* pollen during this zone which can be equated to the early part of Godwin zone V11b. Consideration of Table 11 showing *Alnus* values during early zone V11b from many sites in the Loch Lomond area illustrates that the *Alnus* values at Glen Falloch are fairly low for the Loch Lomond region. Indeed *Alnus* might have been expected to have occupied the stream sides in particular in Glen Falloch with the River Falloch being only a few hundred metres from the site studied.

As will be considered later evidence of numerous burns in the form of charcoal is found throughout the

Table 11.

Comparison of the Glen Falloch Alnus data with that from other sites in the Loch Lomond area during early Godwin zone V1lb. Values, as % A.P., showing approximate range (details of sites given in Figure 2 and Table 2).

Site	*Alnus* Value (% A.P.)
Glen Falloch	c. 10-20%
Ptarmigan	c. 25-50%
Shantron Muir	c. 20-60%
LLRD1	c. 25-55%
DLM	c. 30-45%
Flanders Moss (Turner)	c. 45-60%
Flanders Moss (Durno)	c. 40-50%
Craigbarnet Muir	c. 35-50%
Campsie Fells	c. 30-50%
Muir Park Reservoir (Donner)	c. 50-70%

Betula woodland period. Unfortunately the profile does not extend to or beyond the *Ulmus* decline horizon and therefore no information regarding the vegetational history of *Pinus* at for example the time of the *Alnus* rise can be gained.

The opening of zone GF2 at 4310±50 B.P. is marked by a drammatic increase in the curve for *Pinus* at the expense of *Betula*, *Ulmus*, *Quercus* and Coryloid pollen values. In fact *Betula* values fall from c.65% A.P. to c.40% A.P. while *Pinus* values rise from c.10% to over 40% A.P. This increase in *Pinus* at 95 cm probably represents the immigration and establishment of *Pinus* in the Glen Falloch area particularly on the valley slopes from c.4300 B.P. From that time until at least 1620±50 B.P. *Pinus* persisted in Glen Falloch and a mixed *Pinus*-*Betula* woodland existed. Unlike the present day scattered *Pinus* trees in Glen Falloch the field layer communities were probably more typical of western *Pinus* woods where *Betula* is frequent or codominant, with *Vaccinium myrtillus*, *Calluna vulgaris*, *Deschampsia flexuosa* and *Molinia caerula* as prominent members of the field layer.

By 1600 B.P. *Pinus* occupied the valley peat at the site of study with Cyperaceae becoming more prominent especially in the upper 40 cm of the profile. Although *Pinus* appears to decrease at the top of the zone (profile) the situation regarding the upper part of the pollen profile is complicated due to the loss of the upper c.1500 years of peat accumulation (i.e. truncated profile) either through erosion or removal by man.

The *Pinus* increase in Glen Falloch is clearly recorded by lake sediments (core LLRD1) in the south of Loch Lomond which indeed provides a similar date c.4200 B.P. for the beginning of the expansion, hence removing any doubts about the representability of the one site studied in Glen Falloch.

The most important question is why *Pinus* should spread in the Glen Falloch area at 4300 B.P. when in many other western areas it disappeared between 4500-4000 B.P.

(Pennington 1972, Birks, H.H. 1972b, 1975) with a corresponding decline in north east Ireland between 4,400 to 3,800 B.P. (Smith and Pilcher 1973). Reasons for the general decline have been attributed to factors such as a climatic change to more oceanic (wet, windy) conditions possibly in combination with human activity such as burning.

Presumably the peat which was oligotrophic in nature (i.e. lack of mesotrophic indicators) was sufficiently dry for the growth of Pinus seedlings. However the Pinus stump beside the monolith of peat studied was rooted firmly in fibrous Calluna peat, which as noted earlier is unfavourable for seedling establishment. Durno and McVean (1959) consider that fire has been a dominant factor in the development of vegetation in the Beinn Eighe area since Boreal times (and hence probably so in many other areas). The numerous finds of charcoal throughout the profile probably indicate deliberate burning of the vegetation by man (i.e. Neolithic onwards) after 5000 B.P. in the Glen Falloch area. In my opinion it would be hard to attribute the numerous fires indicated by the charcoal finds to natural fires alone. Burning of the peat surface may therefore have permitted the establishment and maturation of Pinus on the Glen Falloch peat. (Indeed inspection of the peat from below a Pinus stump selected at random contained numerous fragments of charcoal). Both the presence of the charcoal and the Pinus stumps themselves suggest that the peat was fairly dry and well aerated when Pinus finally arrived at this site. However if the spread of Pinus into Glen Falloch and its ultimate establishment on the peat on the valley floor itself were (as hypothesised here) to have been enhanced by fire the dry nature of the surface peat would appear to contradict the postulated increase in oceanicity and wetness for c.4500 B.P. already mentioned. Perhaps due to localised favourable conditions, Pinus may have colonized Glen Falloch while declining in the more exposed areas such as Rannoch moor. Establishment of Pinus further south may have been effectively blocked by competition from deciduous trees on the more favourable soils south of Glen Falloch while at higher altitudes around Glen Falloch paludification may have been too great to permit seedling establishment. The effects of man on the spread of *Pinus* in what must surely have been a natural pass way to the north west remain as yet unquantifiable.

Therefore this investigation of a single site in Glen Falloch (despite its problem of an incomplete sequence) has demonstrated that in at least one area of western Scotland the Caledonian *Pinus* forest was spreading around 4300 B.P. This latter feature is contrary to all other findings known in the west of Scotland. A more detailed study of the Glen Falloch and Tyndrum areas with perhaps a limnic core from Loch Tulla might help to elucidate the behaviour of *Pinus* at the most southerly limit of the Caledonian *Pinus* forest.

Lastly whether or not *Pinus* woodland has survived continuously in Glen Falloch since 4300 B.P. to the present day cannot be determined from the pollen diagram due to the truncated nature of the profile. The presence of woodland in Glen Falloch is shown on Roy's map (1746) of the area, which does not unfortunately distinguish between coniferous and deciduous trees, although it is represented in usual fashion for natural woodland. However from an advertisement in 1808 concerning the sale of about five thousand "Scots firs" from an estate near the head of Loch Lomond, Anderson (1967) considers that the present day *Pinus* trees are remnants of the latter early nineteenth century woodland.

Other factors which must be noted when considering whether *Pinus* survived through to the present day from 4300 B.P. in Glen Falloch include:-

a) The lack of many of the normal plant associates.

b) Narrow age (size) class distribution((a) and (b) Dr. D. C. Malcolm pers. comm.)

c) The survival of the wood so close to a main highway into the highlands when the *Quercus* woods a few miles to the south are known to have been managed for 250 years with at least some introduction of plants.

The lack of normal plant associates may be due to the rich geology and intensity of grazing. Associated species occur more abundantly in the stream ravine. Morphological work on cones by Dr. Malcolm and his associates (at Edinburgh University Department of Forestry and Natural Resources) places them within the Scottish population, while the form of the trees suggest that they were members of the lower canopy, one or two looking as though they had begun life in a denser stand. (Dr. D. C. Malcolm pers. comm.).

Therefore it seems probable that the remaining trees in Glen Falloch are a remnant of the Caledonian Pinus forest. Nevertheless a complete sequence of peat must be sought to clarify the problem of the status of the present day Pinus trees in Glen Falloch.

Having shown beyond reasonable doubt that Pinus became established in Glen Falloch at 4300 B.P. it was decided to investigate two sites further south to determine the behaviour of Pinus just beyond the limit of the Caledonian Pinus forest. Two sites were chosen. The first was on the Ptarmigan (6.3) which adjoins Ben Lomond some nineteen kilometres south of Glen Falloch on the eastern side of Loch Lomond. This high altitude site (c.500 metres O.D.) was chosen in order to be clearly above the Quercus forest which as shown from the regional study (Diagrams LLRD1, DL and DLM) has existed on the east of Loch Lomond during at least the last six thousand years.

The second site was on the western side of Loch Lomond (at c. 350 metres O.D.) on Shantron Muir some thirty five kilometres south of Glen Falloch.

6.3 Ptarmigan.

6.3.1 Site description and stratigraphy.

The Ptarmigan site is situated at map reference N S. 365 015 on the south east of the mountain at a height of c.500 m O.D. The schistose rocks are covered with blanket bog eroded in places by streams. The blanket bog surface vegetation consists of varying proportions of Calluna vulgaris and Eriophorum vaginatun with Erica tetralix and Vaccinium myrtillus as major components (Table 12). Betula sp. and Sorbus aucuparia are present in the steep gully stream sides 50 to 100 m below the site, while the nearest Quercus trees are roughly 400 m below the site. The surrounding area is heavily grazed by both sheep and red deer. Rainfall is heavy with 2540 mm being recorded on Ben Lomond itself (Tittensor and Steele 1971). The site studied was located at the side of a small stream, the peat being 2.01 metres in depth.

A Troels-Smith description of the stratigraphy which is presented at the left hand side of the relevant pollen diagrams now follows:-

0-155 cm	Highly humified blanket peat. Nig 3, strf 0, elas 2, sicc 2, lim 0, humo 3. Colour 5YR 2.5/1 black Composition $Th^{3}2$ Sh2 Tl+
155-199 cm	Highly humified peat. Nig 4, strf 0, elas 2, sicc 2, lim 0, humo 3. Colour 5YR 2.5/1 black Composition $Th^{3}1$ Sh3.
199-201 cm	Highly humified mineral peat. Nig 3, strf 0, elas 2, sicc 2, lim 0, humo 3. Colour 2.5YR 2.5/2 very dusky red. Composition $Th^{3}+$ Sh3 Ga1.

Little in the way of plant macrofossils were found in the highly humified peat although Eriophorum spindles were present down to c.170 cm. Sclerotia of Cenococcum geophilum were present throughout the profile apart from the mineral peat. Large pieces of Betula wood were noted at the site at a depth of 192 cm.

6.3.2. Ptarmigan local pollen zones.

The Ptarmigan pollen diagrams (Figure 25 - trees as a percentage arboreal pollen excluding Coryloid and Salix, and Figure 26 - all taxa as a percentage of total pollen excluding Sphagnum, crumpled, corroded and concealed)

Table 12.

Results of a 5 x 5 m quadrat taken in the vicinity of the Ptarmigan site. (The surface vegetation corresponds loosely to the Calluneto-Eriophoretum typinum association (Pennine blanket bog) described by McVean and Ratcliffe (1962)).

Taxon	Domin scale value
Calluna vulgaris	7
Erica tetralix	4
Vaccinium myrtillus	4
Eriophorum vaginatum	7
Deschampsia flexuosa	3
Molinia caerulea	3
Sphagnum sp.	4
Hypnum cupressiforme	3
Potentilla erecta	2

have been divided into four local pollen zones. The zones designated P1 to P4 are drawn in Figures 25 and 26 and separately in Figure 27.

Zone P1 201-185 cm.

Tree pollen varies between 20-38%T.P. (Figure 24), Betula being the principal arboreal producer with a value of 16% T.P. (76% A.P.) at the base of the zone. Alnus values increase from less than 2% T.P. (7% A.P.) to over 10% T.P. (<25% A.P.) at the close of the zone. Ulmus values rise slightly from c.1.5% T.P. (6% A.P.) to c.5% T.P. (10% A.P.) during the zone. Pinus values have a maximum of 4% T.P. (11.5% A.P.) at 190 cm dropping below 2% T.P. (c.5% A.P.) at 185 cm. Quercus values rise from an initial low of <1% T.P. (2% A.P.) at 200 cm to over 5% T.P. (12% A.P.).

Calluna values exceed 11% T.P. while Gramineae values are 8% T.P. during most of this zone. From an initial high value of 14% T.P. Cyperaceae frequencies drop to less than 1% T.P. at 190 cm.

A large number of herb taxa including Succisa pratensis, Filipendula, Urtica, Solidago type, Taraxacum type, Potentilla and Galium sp. characterise this basal zone. Only Succisa, Filipendula and Potentilla exceed 1% T.P.

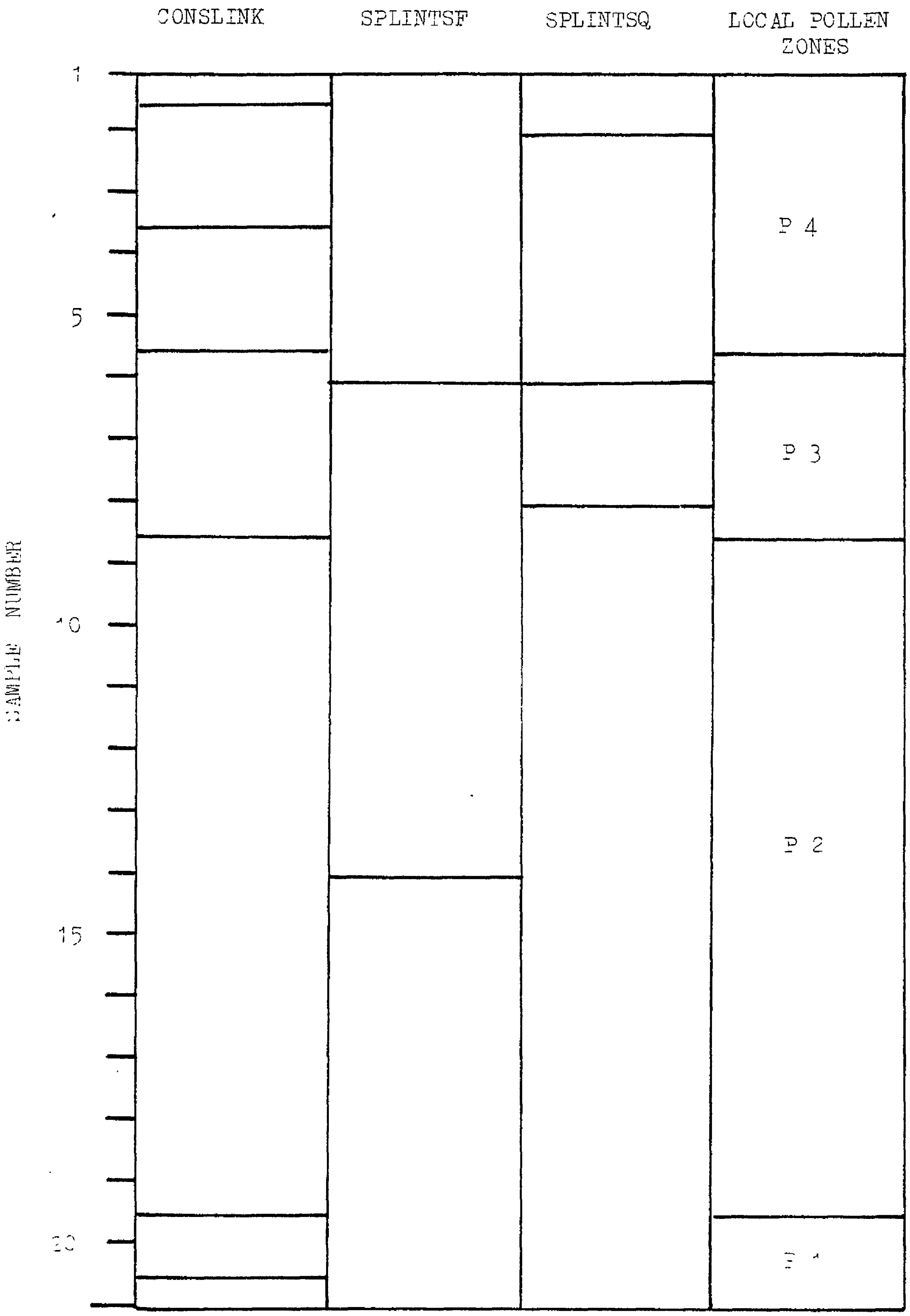
Filicales values decrease from 10% T.P. at 200 cm to less than 5% T.P. at the close of the zone, while Sphagnum frequencies fluctuate between 6-18% T.P.

The bottom of zone P1 is the base of the profile while the P1/P2 boundary is where Alnus values rise above 15% T.P. (c.35% A.P.).

Zone P2 185-75 cm.

Total tree pollen declines gradually from 42% T.P. at 180 cm to 22% T.P. at 80 cm (although it rises sharply towards the end of the zone) with values being over 30% T.P. for most of the zone (Figure 24). Betula values remain

PTARMIGAN



5/6 - 45 cm
8/9 - 75 cm
19/20 - 125 cm

fairly steady at c.12% T.P. (32% A.P.) with a peak of 18% T.P. (45% A.P.) at 110 cm while Pinus values never exceed 3% T.P. (5% A.P.) being mainly below 1% T.P. Quercus values rise from 6% T.P. (14% A.P.) to 10% T.P. (25% A.P.) at 150 cm before declining very gradually to less than 2% T.P. (7% A.P.) at 80 cm. Alnus values average 15% T.P. (35% A.P.) for most of the zone dropping to less than 7% T.P. (25% A.P.) after 110 cm. Ulmus values decline from 4% T.P. (10% A.P.) at 180 cm to 1% T.P. (3% A.P.) at 170 cm rising again to 2% T.P. (6% A.P.) at 160 cm. Above 130 cm Ulmus values are less than 1% (c.2% A.P.). Fraxinus is discontinuously present from 150 cm values never reaching 1% T.P. (2% A.P.).

Calluna values are continuously above 18% T.P. with a maximum of 47% T.P. at 90 cm, while Gramineae values average c.5% T.P. for most of the zone. Cyperaceae frequencies reach a maximum of 22% T.P. at 140 cm. Herb pollen is less frequent than in zone P1 with only Plantago lanceolata and Filipendula exceeding 1% T.P.

The P2/P3 boundary is where Betula values rise above 22% T.P. (58% A.P.).

Zone P3 75-45 cm.

Total tree pollen rises sharply from the base of the zone to a peak of 55% T.P. at 70 cm subsequently falling to 20% T.P. at 50 cm, Betula being the principal component. Betula reaches 35% T.P. (63% A.P.) at 70 cm before declining to 10% T.P. (55% A.P.) at the end of the zone. Only at 70 cm do the values of Pinus and Fraxinus exceed 1% T.P., Pinus having a value of 2.3% T.P. (4% A.P.) while Fraxinus has a value of 2% T.P. (c.4% A.P.). Ulmus values are always less than 1% T.P. (<1% A.P.). Alnus increases from c.7% T.P. (25% A.P.) at the beginning of the zone to 13% T.P. (27% A.P.) at 60 cm before declining again to 5% T.P. (23% A.P.) at 50 cm.

Coryloid values reach 22% T.P. at 60 cm before declining again to c.5% T.P. at the top of the zone. Hedera helix is present at 80 cm.

Calluna decreases from c.30% T.P. at the base of the zone to 13% T.P. at 60 cm before rising again to 45% T.P. at 50 cm. Cyperaceae frequencies follow a similar trend declining from c.15% T.P. at the beginning of the zone to 4% T.P. at 70 cm before increasing to c.20% T.P. at the close of the zone. Gramineae values reach 8% at 50 cm.

Herb pollen is fairly sparse with only *Plantago lanceolata* reaching 1% T.P. at 70 cm. *Sphagnum* values are fairly low only rising above 20% T.P. at the end of the zone.

The P3/P4 boundary is where *Calluna* values rise above 20% T.P.

Zone P4 45-0 cm.

During this upper zone tree pollen reaches its lowest value of 7% T.P. at 10 cm, having fallen from 29% T.P. at 30 cm (Figure 24). Total arboreal pollen values increase again towards the top of the profile with an ultimate value of 24% T.P. at 0 cm. *Betula* decreases to 3% T.P. (41% A.P.) at 10 cm from 10% T.P. (55% A.P.) at the opening of the zone, finally having a value of 10% T.P. (42% A.P.) at 0 cm. *Pinus* frequencies increase from less than 1% T.P. (9% A.P.) at 10 cm to 5% T.P. (20% A.P.) at 0 cm. *Quercus* values never exceed 5% T.P. (17% A.P.) while *Ulmus* values never exceed 1% T.P. (2% A.P.). *Alnus glutinosa* has a maximum value of 10% T.P. (35% A.P.) at 30 cm and a minimum value of 2% T.P. (22% A.P. - not the minimum A.P. value which is at 0 cm) at 20 cm before increasing to 4% T.P. (17% A.P.) at 0 cm.

High *Calluna* and Cyperaceae values characterise this zone. *Calluna* values are highest at the top and base of the zone while Cyperaceae values are highest at the centre of the zone. *Calluna* increases to 51% T.P. at 0 cm from 18% T.P. at 30 cm while Cyperaceae declines from a maximum for the whole profile of 48% T.P. at 20 cm to 4% T.P. at 0 cm.

Plantago lanceolata has a maximum value of 2.5% T.P. at

10 cm being above 1% T.P. for most of the zone. Sphagnum values fluctuate being absent at 30 cm and having a maximum value of 39% at 40 cm.

The top of zone P4 is the top of the profile.

6.3.3. Discussion of the Ptarmigan data.

Discussion of the Ptarmigan pollen profile is to some extent hindered by the lack of a well defined time-scale, no radiocarbon dates being available. Also major pollen horizons such as the Ulmus decline and Alnus rise cannot be assigned to the profile with absolute certainty. Therefore the interpretation of the pollen diagrams (Figures 25 and 26) must not be regarded as final in terms of estimated ages and may be subject to modification with the subsequent provision of radiocarbon dates.

The position of the site at a high altitude and with Ben Lomond in close proximity introduces many factors (e.g. rainfall, drainage and wind patterns) which may have been purely local in nature with a concommitant production of a vegetational pattern peculiar to the area. Therefore comparison with other diagrams from the Loch Lomond area is difficult especially since sites like DLM and DL are at a much lower altitude and are surrounded by deciduous trees. Comparison with the Campsie fell diagrams of Stewart (1975) and Eydt (1957) is also difficult due to differences in bedrock, altitude/climate and peat type for example.

Zone P1 200-185cm.

The basal zone of the pollen profile probably begins at the Alnus rise horizon where Alnus values rise to continuously high values (here in excess of 10% A.P.). The fairly high values of Ulmus (up to 10% A.P.) further suggests that zone P1 is pre-Ulmus decline in age. Considering the above evidence the base of the profile (201 cm) is probably just over six thousand years old (i.e. DLM Alnus rise 5909$\pm$170 B.P. Craigbarnet Muir 6197$\pm$45 (Stewart 1975))and therefore on an age basis local pollen zone P1 may be assigned to the Betula-

Quercus-Alnus(with Ulmus) regional pollen assemblage zone put forward in this thesis.

In vegetational terms zone P1 represents a period of fairly open Betula woodland with some Salix and Corylus. Indeed the base of the peat profile contained fairly large pieces of Betula wood, indicating that Betula grew directly on the site during zone P1. A whole suite of herbs suggestive of incomplete woodland cover such as Succisa, Saussurea, Potentilla and especially tall herbs such as Filipendula and Solidago are present. The open nature of the Betula woodland is further stressed by the presence of Pteridophytes such as Selaginella selaginoides, Lycopodium clavatum (and Lycopodium sp.) which all tend to indicate a mountain, moorland environment.

Ulmus values of up to 10% A.P. suggest that the tree was growing fairly high up the mountain.

Zone P2.

From the base of zone P2 up to c.70 cm Alnus shows a continuous expansion. The Alnus frequencies are very similar to those commonly found in the Loch Lomond region at immediate post Alnus rise times (see Table 11). Whether or not Alnus grew in the area of the site is problematical as no Alnus wood was found in the peat. To-day there is no evidence that Alnus sets viable seed above c.300 m although there are relict Alnus woods surviving above that height (McVean 1955). As further shown by McVean's ecological studies Alnus is adversely affected by many environmental factors. Namely strong winds during the flowering season, late frost in the early stages of seedling establishment, as well as by leaching, podsolization and ombrogenous bog formation. As most of these factors would have prevailed or have been initiated by the time of the Alnus rise the tree probably did not grow at or above the present limit. However values of Alnus pollen (25-50% A.P.) suggest that the altitudinal limit must have been fairly high at the time of the climatic optimum. Indeed Pears (1969) has shown that in the Cairngorm region at least the altitudinal tree limit was c.716 m at the climatic optimum. Therefore Alnus may well have grown near the site in the mosaic of vegetation caused by the local environmental conditions already noted.

Between 180 cm and 170 cm Ulmus drops from 10% A.P. to less than 3% A.P. This drop in the Ulmus curve is taken to be the Ulmus decline which is followed by a slight rise and subsequent decline to very low values as at most sites in the Loch Lomond area. Therefore c.175 cm should provide a radiocarbon date of c.5000 B.P.

Agriculturally related pollen is very sparse (as might be expected due to the altitude of the site) with Artemisia occurring at 180 cm while the first Plantago lanceolata occurs at 170 cm. Indeed the Gramineae curve actually declines slightly associated with an increase in pollen of plants indicative of bog communities such as Calluna and Sphagnum. Pteridium reaches 1% T.P. at 170 cm again emphasising the open nature of the area around the site and in particular the higher slopes of the mountain itself. Although only having a value of 1% T.P. this probably still indicates a considerable covering of Pteridium on the steep hill slopes above the woodland limit (i.e. c.170 m). Pteridium is only 1% T.P. at 0 cm in what is essentially a surface sample, large areas of the rough grazing on the steep slopes below the site being Pteridium infested. However as Pteridium is not tolerant of exposure it has probably never grown on the site analysed.

Above 170 cm Alnus values decline slightly while the Quercus curve increases in keeping with the change to dryer conditions proposed by Blytt and Sernander during this Sub-Boreal period of the Post glacial. At 150 cm Quercus reaches a peak of 25% A.P. while values are generally higher in this zone than in subsequent zones. This latter feature may indicate that during most of zone P2 the altitudinal limit of Quercus was higher than at the present day.

From 125 cm Cyperaceae and Calluna values increase illustrating the continuous development of ombrogenous peat forming vegetation.

Zone P3 75-45 cm.

During zone P3 there is a resurgence in arboreal and shrub pollen (clearly shown in Figure 24) and a corresponding reduction in Calluna Cyperaceae and Sphagnum spores. Open Betula woodland may have therefore encroached on the area of the site during this zone as illustrated by the increase in Betula to a peak of 34% T.P. at 70 cm. However arboreal pollen values decline again from 70 cm associated with an increase in herb pollen (Figure 24).

Zone P4 45-0 cm.

Zone P4 represents the continuous development of heath moorland with a slight increase in Gramineae during the upper 10 cm perhaps associated with increased grazing pressure in the area during the last few centuries.

Pinus values increase during the upper 20 cm of the zone reaching 20% A.P. at the top of the pollen profile. This increase in Pinus pollen will have been the result of forestry practices in the Loch Lomond area during the last three centuries.

Consideration of Pinus.

Pinus values are very low throughout the profile with the (postulated) Alnus rise Pinus peak only reaching 12% A.P. Table 13 shows values of Pinus from other sites in the Loch Lomond area at around the time of the Alnus rise (c. Godwin Vl/Vlla boundary). The table illustrates that the Ptarmigan Pinus values would in fact be among the lowest in the Loch Lomond area and

Table 13.

Pinus peaks at the Alnus rise horizon for selected sites in and around the Loch Lomond area.

	Site	Height above sea level/m	% Total tree pollen (excluding *Corylus*)
1.	Ptarmigan (Profile may not contain *Pinus* peak)	c.500m	12%
2.	Craigbarnet Muir	416m	55%
3.	Campsies (Muir Toll)	367m	40%
4.	Drymen	234m	60%
5.	Flanders Moss East	17m	20%) no peak
6.	Flanders Moss West	17m	25%) no peak
7.	Dubh Lochan (Walker)	17m	32%
8.	Dubh Lochan (Stewart)	6m	19%

would not bear out the general trend that the higher the altitude of the site the higher the *Pinus* value during the period in question.

The absence of high *Pinus* values at the *Alnus* rise horizon at the Ptarmigan site may be due to several factors such as:-

a) The profile may not extend far enough back in time to include the *Alnus* rise *Pinus* peak.

b) The position of the site in relation to the surrounding topography may have affected the transfer of *Pinus* pollen from lower altitudes (such as around the Dubh Lochan).

c) High level *Betula* woodland may have had a filtering effect on *Pinus* pollen from the lower slopes of the Ptarmigan despite the area probably not being heavily wooded.

d) *Pinus* may have been restricted mainly to areas north of the Ptarmigan with only a few at lower altitudes and those mostly further south.

When considering the above factors it is interesting to compare the upper 10 cm of zone P4 which has *Pinus* values up to 20% A.P. with the peak of 12% A.P. in zone P1. This latter feature may indicate that the number of *Pinus* trees in the pollen catchment area of the Ptarmigan site was lower in zone P1 than to-day.

Noteably there is no indication of the increase in *Pinus* values at 4300 B.P. shown by the Glen Falloch site which once again may have been due to any of the factors a) to d) already mentioned in this section.

6.4 Shantron Muir.

6.4.1 Site description and stratigraphy.

Shantron Muir lies in the parish of Luss, Dumbartonshire at latitude 56° 02' N, longitude 4° 41' W. The site of study is at map reference NS 328 878 at an altitude of c.350 m O.D. and on a slope of 8° facing northwards towards Rossdhu House.

The area which consists mainly of schistose metamorphic rocks is covered by heavily grazed blanket peat. The surface vegetation corresponds fairly closely to the Trichophoreto-Eriophoretum typicum association (western blanket bog) of the type described by McVean and Ratcliffe (1962). Table 14 shows the results of a 5 x 5 m quadrat from directly above the site of study.

A Troels-Smith description of the sediment which is included at the left hand side of the pollen diagrams (Figures 28 and 29) now follows:-

0-128 cm	Highly humified Eriophorum-Calluna peat. Nig 3, strf 0, elas 2, sicc 2, lim 0, humo 3. Colour 5YR 2.5/1 black. Composition $Th^{3}2$ Sh2 $Tl^{3}+$.
128-130 cm	Highly humified herbaceous rootlet peat. Nig 2, strf 0, elas 2, sicc 2, lim 0, humo 3. Colour 2.5YR 2.5/2 very dark red. Composition $Th^{3}1$ Sh^{2} Gal.

The highly humified sediment contained little in the way of macrofossil remains. Eriophorum spindles were present from 120 cm upwards.

6.4.2 Zonation of the Shantron Muir pollen profile.

Although subjected to the zonation procedures described in the materials and methods section, the results of which can be seen in Figure 30, it was decided not to adopt the resultant zones. Use of the zones would have defeated the primary objective of the procedure, namely to provide a useful framework for ease of discussion. The profile has been considered to consist of essentially one local pollen zone namely SM1 which is kept in order to provide continuity of profile description.

Zone SM1 130-0 cm.

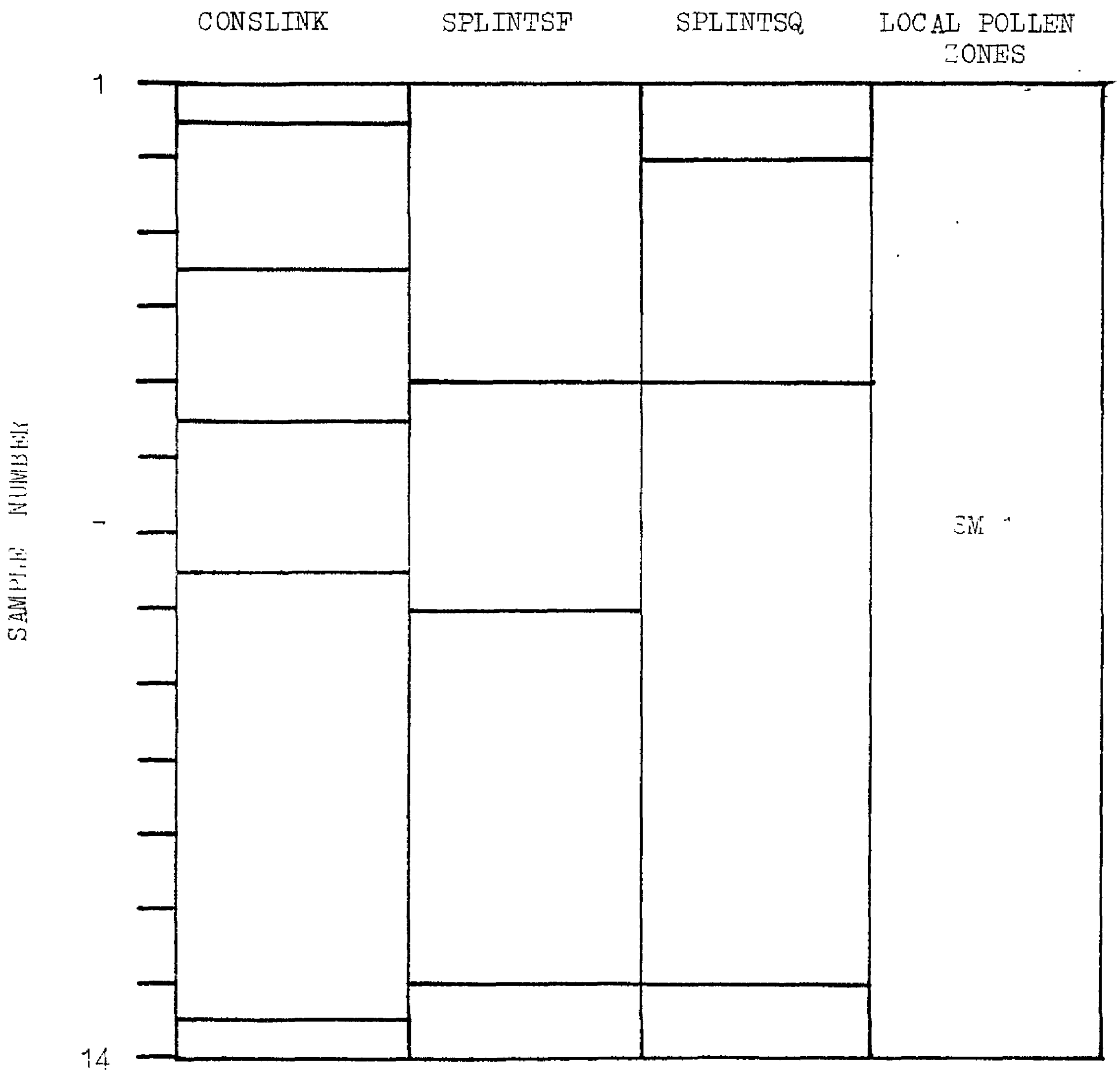
Total tree pollen values never exceed 46% T.P. (Figure 24) being on average c.25% T.P. for most of the

Table 14.

Results of a 5 x 5 m quadrat taken directly above the site of study. (Shantron Muir).

Taxon	Domin scale value
Calluna vulgaris	4
Eriophorum vaginatum	5
Eriophorum angustifolium	4
Trichophorum caespitosum	5
Erica tetralix	4
Vaccinium myrtillus	3
Molinia caerula	4
Deschampsia flexuosa	4
Potentilla erecta	3
Polytrichum commune	6
Sphagnum sp.	4
Hypnum cupressiforme	2
Cladonia sp.	1

SHANTRON MUIR



profile. High frequencies of heath pollen characterise this zone rising from <1% T.P. at 130 cm to 47% T.P. at 120 cm, thereafter having values usually between 30% to 50% T.P. (notable exceptions being 70 cm with 3.6% and 20 cm with 60% T.P.) up to 20 cm when values drop below 30% T.P.

Betula values decline between 130 cm to 100 cm from 25% T.P. (53% A.P.) to 4% T.P. (24% A.P.) subsequent values lying in the range 8-14% T.P. (30-60% A.P.). Alnus values remain fairly steady throughout the profile, frequencies ranging from 6% to 18% T.P. (22-45% A.P.). Similarly Quercus values show little variation with a typical value of c.5% T.P. (c.15% A.P.). Ulmus never exceeds 1.5% T.P. (3% A.P.) while Pinus frequencies only rise above 1% T.P. (i.e. 9% A.P. at 0 cm) from 10 cm upwards. Fraxinus is present throughout while Sorbus is intermittently present.

Coryloid values average c.12% T.P. with Salix never reaching 1% T.P.

Calluna values rise dramatically from <1% T.P. at 130 cm to 48% T.P. at 120 cm with subsequent values remaining above 30% T.P. (apart from a low value of 13.% T.P. at 70 cm corresponding to a high Gramineae value of 47%). Gramineae values decline from 24% T.P. at 130 cm to 3% T.P. at 120 cm. Above 120 cm Gramineae values average 4% T.P., excluding the peak of 47% T.P. at 70 cm and the increase in values from 20 cm to reach 25% T.P. at 0 cm. Between 130 cm and 50 cm Cyperaceae values only exceed 5% T.P. at 100 cm where a value of 17% is found. Apart from a value of 7% T.P. at 10 cm Cyperaceae values above 50 cm lie between 18% and 22% T.P.

Generally herb taxa are poorly represented both in terms of the numbers of taxa found and in the level of pollen frequency attained, only Plantago lanceolata and Rumex exceeding 1% T.P.

In the case of Pteridophytes only Pteridium aquilinum exceeds 1% T.P. with a maximum value of 4% T.P. at 110 cm. Sphagnum spore values fluctuate although a trend towards stable values (c.3% T.P.) occurs between 110 cm and 80 cm.

6.4.3. Discussion of the Shantron Muir data (Figures 28 and 29).

As the Shantron Muir profile is of limited value in terms of the elucidation of the history of Pinus in the Loch Lomond area, discussion of the site will be kept to a minimum.

The pollen record would appear to indicate the continuous development of blanket peat on the site. Without a radiocarbon date the age of the initiation of peat growth on the site can only be speculated about. However the following features allow a highly provisional estimation of the age of the base of the profile (e.g. useful to the radiochemist):-

a) Ulmus values never exceed 3% A.P. (therefore post Ulmus decline).

b) Continuous Plantago lanceolata from 120 cm upwards (c.f. DLM and LLRD1 have continuous Plantago since c.3500 B.P.).

c) Evidence of Neolithic and especially Iron age occupation of the area has been noted in Chapter 2 (2.6).

Features a) to c) suggest that the peat may have begun to form around three and a half thousand years ago perhaps due to the influence of human activity in the area. (However further work of the detail done by Moore (Moore 1968, and Moore and Chater 1969) in Wales could be done to examine the latter possibility).

The fairly stable values of tree pollen indicate that the surrounding area has probably remained in a state of dynamic equilibrium as regards trees during the time of the profile. Indeed Alnus, Betula and Sorbus were probably restricted to the lower slopes and stream sides (perhaps due to grazing pressures) as they are to-day.

Pinus values are negligible throughout the profile, only increasing during the last c.25 cm probably due to modern planting of Pinus within the Loch Lomond area with Picea also being noted at 0 cm. Therefore the Shantron Muir site provides very little information of value as regards the history of Pinus. However the value of the site would be enhanced by the provision of a radiocarbon date from the base of the profile which would permit a comparison of the Shantron Muir and Glen Falloch diagrams to see if they overlap in time to any extent.

6.5 General discussion of Pinus in the Loch Lomond area and conclusions.

Considering all the sites studied in this thesis together a provisional picture of the vegetational history of Pinus sylvestris in the Loch Lomond area can be built up.

The Pinus peaks at or around the time of the Alnus rise shown by the Dubh Lochan and other diagrams in the Loch Lomond area (Table 13) suggest that Pinus was fairly widely established in the Loch Lomond area although details of the exact extent of Pinus woodland still requires further investigation. Indeed the interpretation of Pinus pollen values in general is complicated by problems associated with the production and distribution of Pinus pollen itself. Godwin (1975) indicates that many workers have noted high Pinus values in surface samples at locations where no Pinus exist and conversely low Pinus values may be found where there is ample evidence for the existence of Pinus. An occurrence of the latter phenomenon has been noted at Drumbow (NS 828 695) in Lanarkshire (Dickson, pers. comm.) where a site containing three Pinus stumps dated to c.3000 B.P. has an associated Pinus value of only c.10% A.P. Therefore small stands of Pinus which may have once existed in the Loch Lomond region may have left low Pinus values (perhaps due to the Pinus pollen being swamped by the pollen rain from the surrounding vegetation).

The Glen Falloch site has shown that the Caledonian

Pinus forest extended down to the north end of Loch Lomond at c.4300 B.P., while core LLRD1 has shown that the pollen produced from this latter woodland is detectable in the sediment at the southern end of Loch Lomond. That Glen Falloch was occupied by *Pinus* woodland between 4300 and 1600 B.P. is now certain. However why *Pinus* woodland should have developed in Glen Falloch at a time generally recognised to be one during which *Pinus* woodland was in decline in many areas of Scotland and Ireland remains unclear.

Further study is required to provide data concerning the status of *Pinus sylvestris* both pre 4300 B.P. and post 1600 B.P. in this most northerly part of the Loch Lomond area.

The situation as regards the status of *Pinus* south of Glen Falloch is unclear. The Ptarmigan site provides no evidence of a post *Ulmus* decline, *Pinus* increase comparable to that which occurred in Glen Falloch. The dominance of *Quercus* woodland clearly shown in this thesis may have severely restricted the establishment of *Pinus* woodland to the south of Glen Falloch.

7. GENERAL DISCUSSION AND CONCLUSIONS.

In keeping with the aims of this thesis presented in the introduction, pollen analysis of limnic and terrestrial sediments has provided a wide variety of information concerning changes in the vegetation of the Loch Lomond area during the Flandrian period. The analysis of sediments from Loch Lomond and the Dubh Lochan which differ completely in morphometry and catchment size but lie within close proximity, has shown the validity of using large lakes in providing information about gross changes in the vegetation of a region.

The main sequence of events found can be outlined as follows:-

a) Presence of a lateglacial like facies with high Betula, Empetrum, Gramineae, Cyperaceae, Artemisia, Rumex, Filipendula and two saxifrages S. aizoides and S. oppositifolia. This represents a brief pioneer phase after the melting of the Loch Lomond glacier and is seen only in Walker's (1975) fen carr diagram (Figure 16).

b) Betula Corylus woodland period with many tall herbs in association between c.9000 B.P. and c.6000 B.P. The Corylus rise horizon has been dated to 9356±165 B.P. at Walker's fen carr site.

c) A period of mixed Quercus woodland between c.6000 B.P. and c.5000 B.P. with Ulmus and Fraxinus being important forest community members. This mixed Quercus woodland period began with a rapid increase in the pollen of Alnus representing the establishment of the tree in the Loch Lomond area. The Alnus rise horizon has been dated to 5909±170 B.P. at site DLM.

d) Apart from an increase in Pinus woodland in the Glen Falloch area at 4300 B.P. a general decline in mixed Quercus woodland since the Ulmus decline is seen to occur. Pollen of plants typical of open forest, bog, moorland/

moorland, grassland and those plants normally associated with the presence of man become increasingly important towards the present day especially during the last few centuries.

The Loch Lomond core LLRD1 has emphasised the usefulness of the absolute counting method providing evidence that the pollen concentration has varied widely during the Flandrian. The establishment of a mid Flandrian marine transgression in Loch Lomond between c.6900 B.P. and 5450 B.P. will hopefully be of value in understanding land and sea level changes in the west of Scotland as well as other phenomena connected with such events. The hypothesised period of meromixis immediately after the marine transgression suggests that only during the stable period of meromixis are the true pollen concentration values for the Loch Lomond sediment being seen. The presence of Carboniferous spores may provide a suitable marker for studies of the transport and distribution of pollen and sediment within Loch Lomond to be made. Radiocarbon dates of a more accurate nature than those obtained from the Loch Lomond sediments have permitted the calculation of pollen deposition values (grains/cm^2/year) from the Dubh Lochan data and their comparison with other British lake deposition values. The data produced from the latter study has served to emphasise the difficulty of equating pollen deposition values with actual quantities of vegetation in the surrounding pollen catchment area.

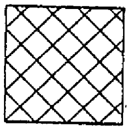
Comparison of deep water site DLM with marginal site D.L. (Walker 1975) has demonstrated how critical the choice of site can be with the marginal site as expected having a much more local flavour with the hydroseral component of site DL being absent from site DLM.

The expansion of *Pinus* sylvestris within the Loch Lomond area at c.4300 B.P. suggested by the post *Ulmus* decline *Pinus* curve from core LLRD1 has been verified by the analysis of peat from Glen Falloch and the Ptarmigan. The Glen Falloch data illustrates that in at least one part of the Loch Lomond area *Pinus* forest was expanding at 4310 ± 50 B.P. and that *Pinus* has remained in Glen Falloch continuously until at least 1620 ± 50 B.P. The influence of human activity in the form of peat burning as evidenced by the many charcoal finds in the Glen Falloch peat has been considered to have been a major factor in the establishment of *Pinus* on the Glen Falloch peat. Indeed it would appear most likely that the present day *Pinus* trees in Glen Falloch are remnants of the forests recorded in the Glen Falloch peat. No evidence of *Pinus* forests after the *Ulmus* decline has been found south of Glen Falloch with the Ptarmigan pollen profile suggesting that more *Pinus* trees exist to-day in the pollen catchment area of the site than at any time during the last six thousand years. Finally it is hoped that this study will provide stimulus for further research in a variety of fields in connection with the Loch Lomond area.

APPENDIX 1.

Symbols used to show the relative proportions of the compound elements in the Troels-Smith sediment descriptions used in this thesis.

1) DUBH LOCHAN.



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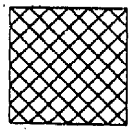
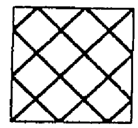
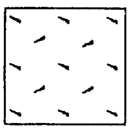


$Ld^{3}2$



Lh1



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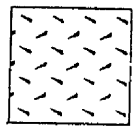

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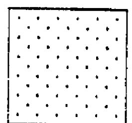
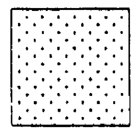
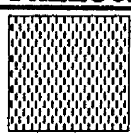


Ga1

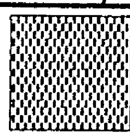


Ga2

2) GLEN FALLOCH, PTARMIGAN, SHANTRON MUIR.



$Th^{3}2$



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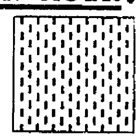

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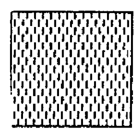

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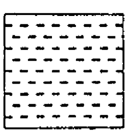
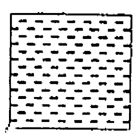


Sh1



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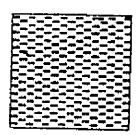

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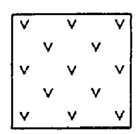

$Tl^{2}1$

Gal

APPENDIX 2.

Palynology, palaeomagnetism and radiometric dating of Flandrian marine and freshwater sediments of Loch Lomond.

An article by Dickson, J.H. and Stewart, D.A. et al. published in nature 274, 548-553 1978.

Article consisting of six unnumbered pages now follows.

APPENDIX 3. Selected abbreviations used in the text.

% A.P.	-	percentage of arboreal pollen
% T.P.	-	percentage of total pollen
P + S	-	sum of pollen and spore
B.P.	-	radiocarbon years before present, present being taken as 1950.

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FIGURE 11 a LOCH LOMOND ROSSDHU CORE LLRD1 ANAL. D.A.STEWART

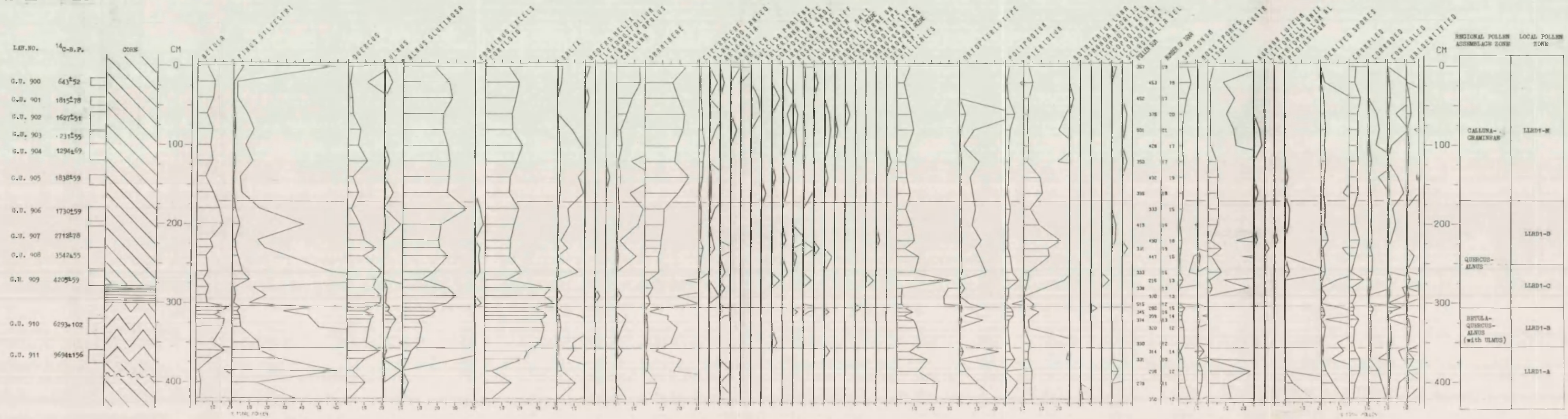


FIGURE 11b

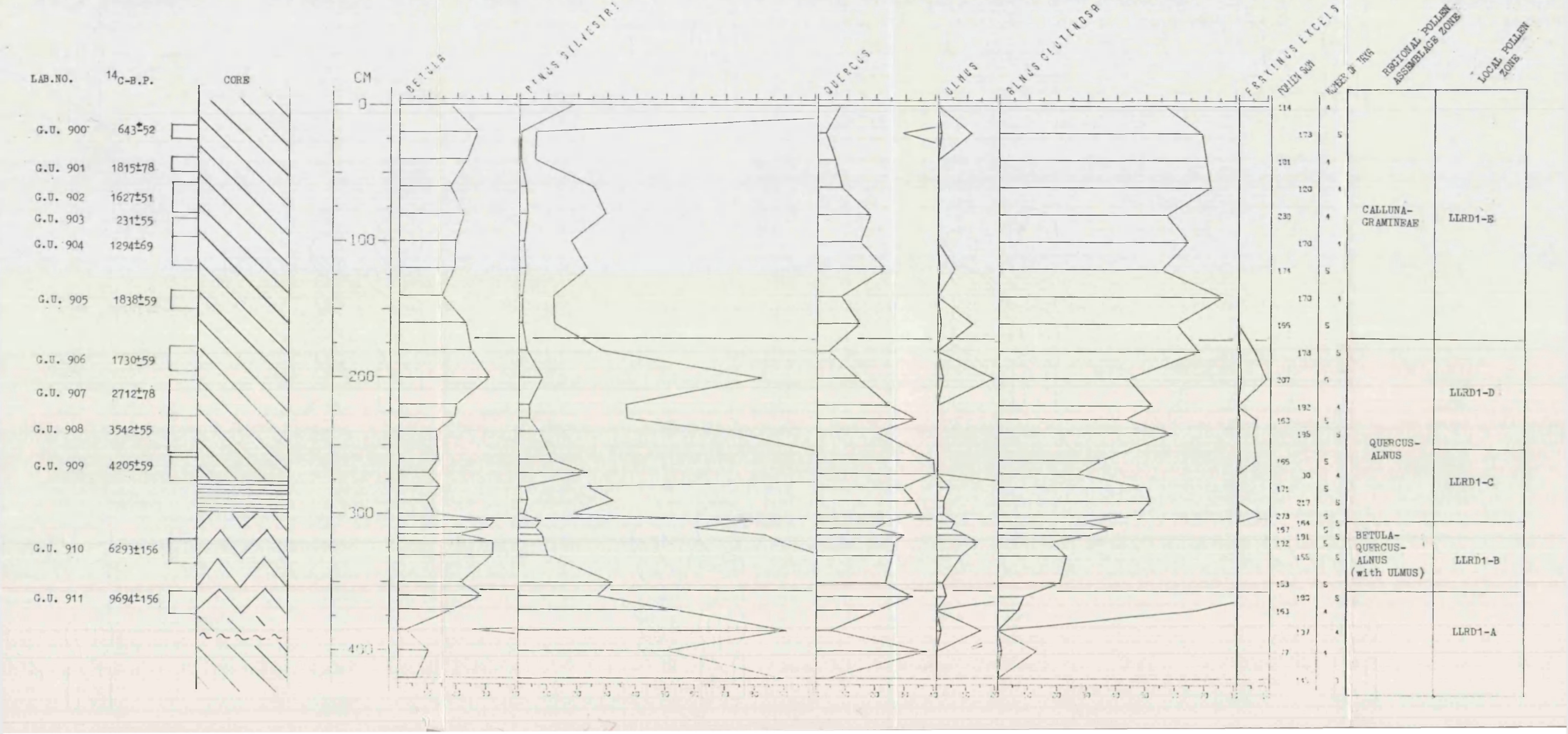

LOCH LOMOND ROSSDHU CORE LLRD1 %AP
LAB.NO.
^{14}C-B.P.
CORE
CM
BETULA
PINUS SILVESTRIS
QUERCUS
ULMUS
ALNUS GLUTINOSA
FRAXINUS EXCELS
POLLEN SUM
NUMBER OF TAXA
REGIONAL POLLEN ASSEMBLAGE ZONE
LOCAL POLLEN ZONE
G.U. 900 643±52
G.U. 901 1815±78
G.U. 902 1627±51
G.U. 903 231±55
G.U. 904 1294±69
G.U. 905 1838±59
G.U. 906 1730±59
G.U. 907 2712±78
G.U. 908 3542±55
G.U. 909 4205±59
G.U. 910 6293±156
G.U. 911 9694±156
0
100
200
300
400
CALLUNA-GRAMINEAE
QUERCUS-ALNUS
BETULA-QUERCUS-ALNUS (with ULMUS)
LLRD1-E
LLRD1-D
LLRD1-C
LLRD1-B
LLRD1-A

FIGURE 14a   DUBH LOCHAN CORE DLM ANAL D. A.STEWART

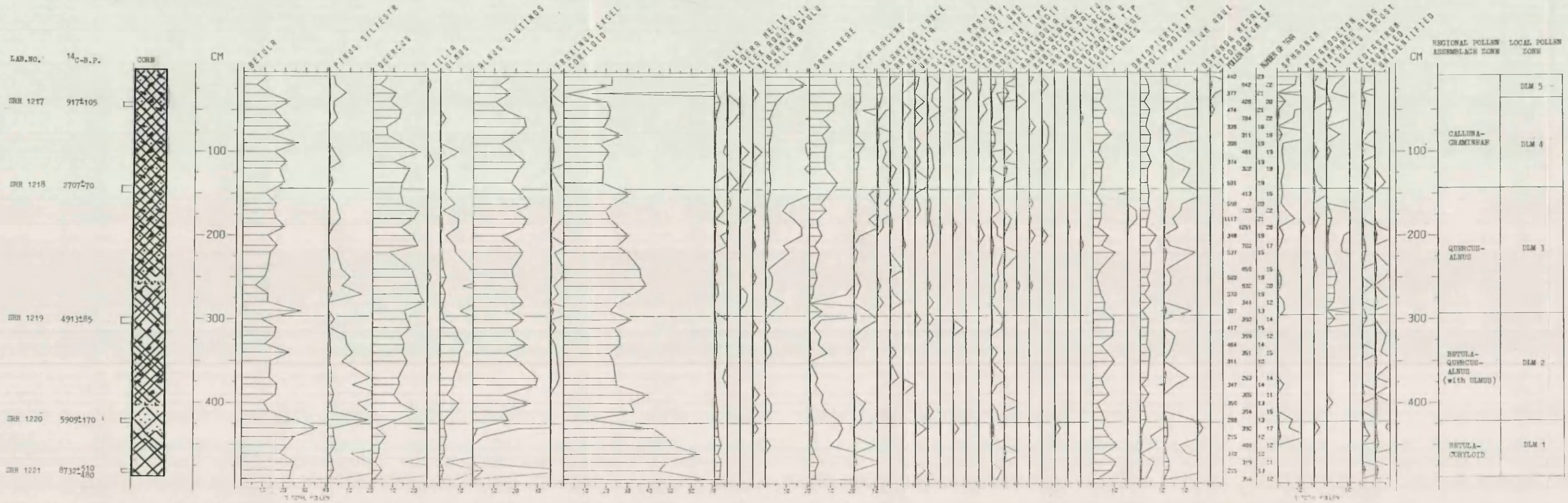


FIGURE 14b DUBH LOCHAN AP (STEWART)

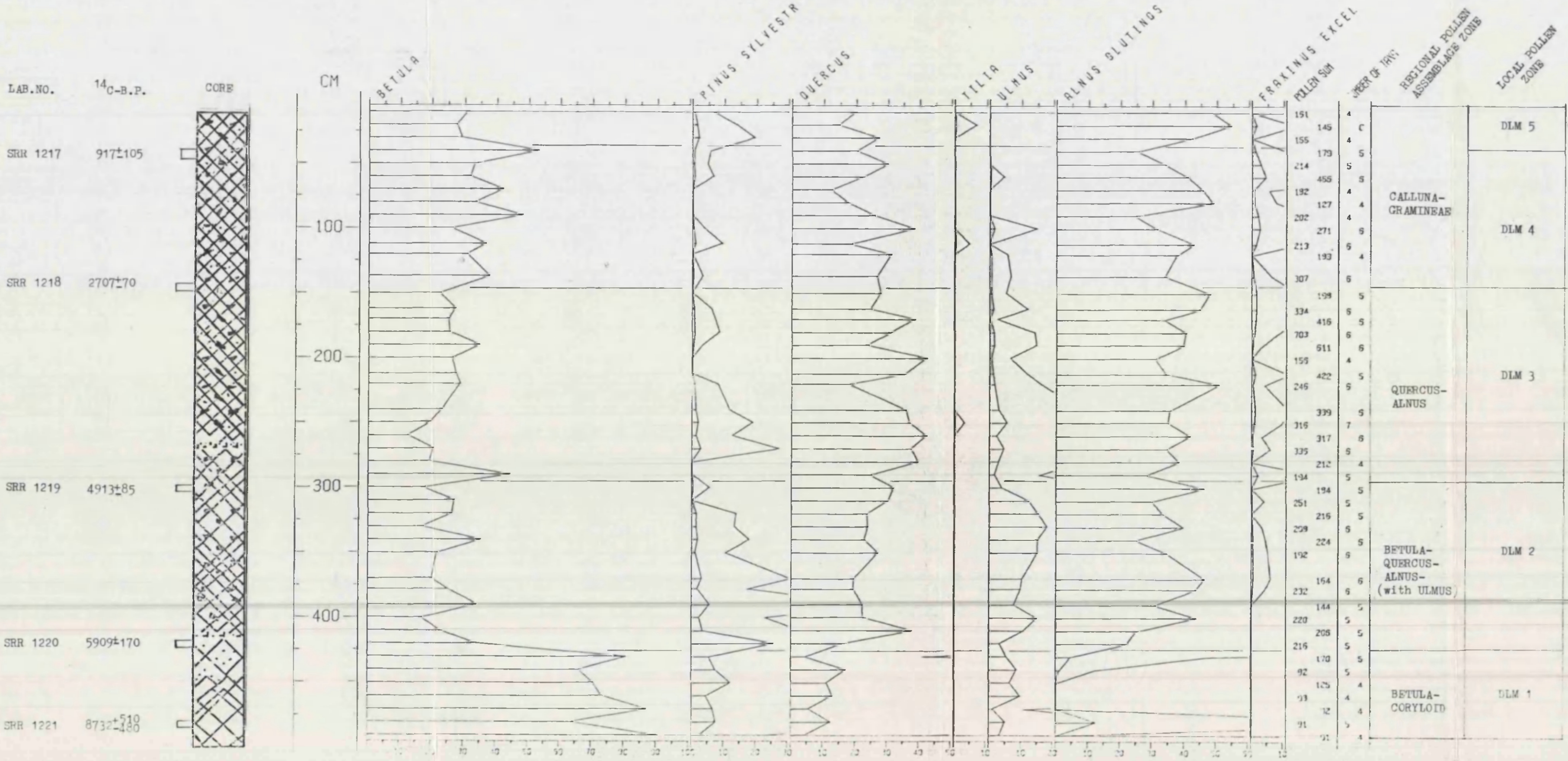


FIGURE 16
(WALKER 1975)

POLLEN DIAGRAM - DUBH LOCHAN

FIGURE 21 GLEN FALLOCH AP.

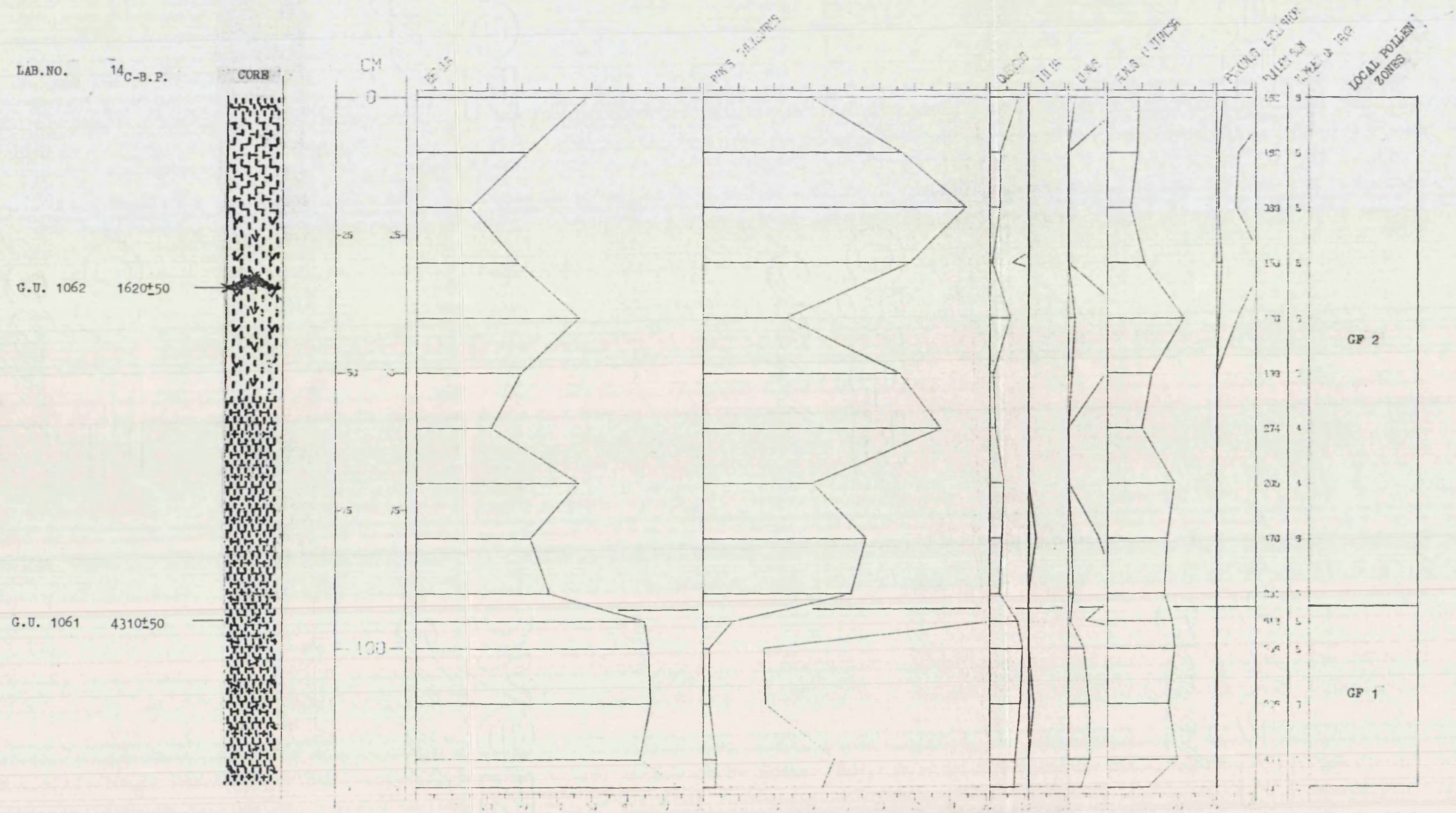


FIGURE 22 GLEN FALLOCH ANAL D. A. STEWART

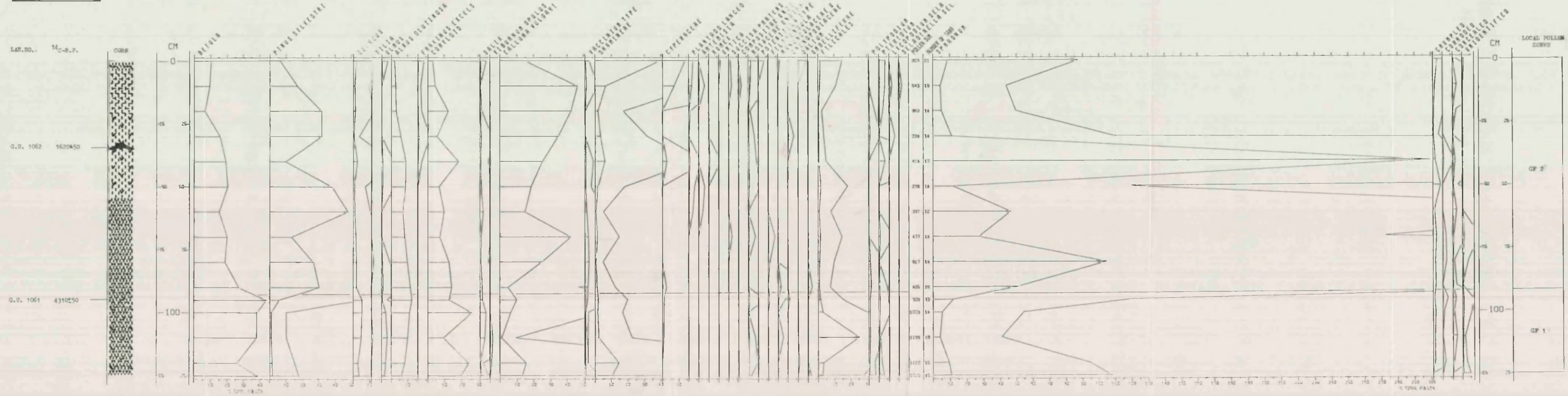


FIGURE 25 PTARMIGAN AP

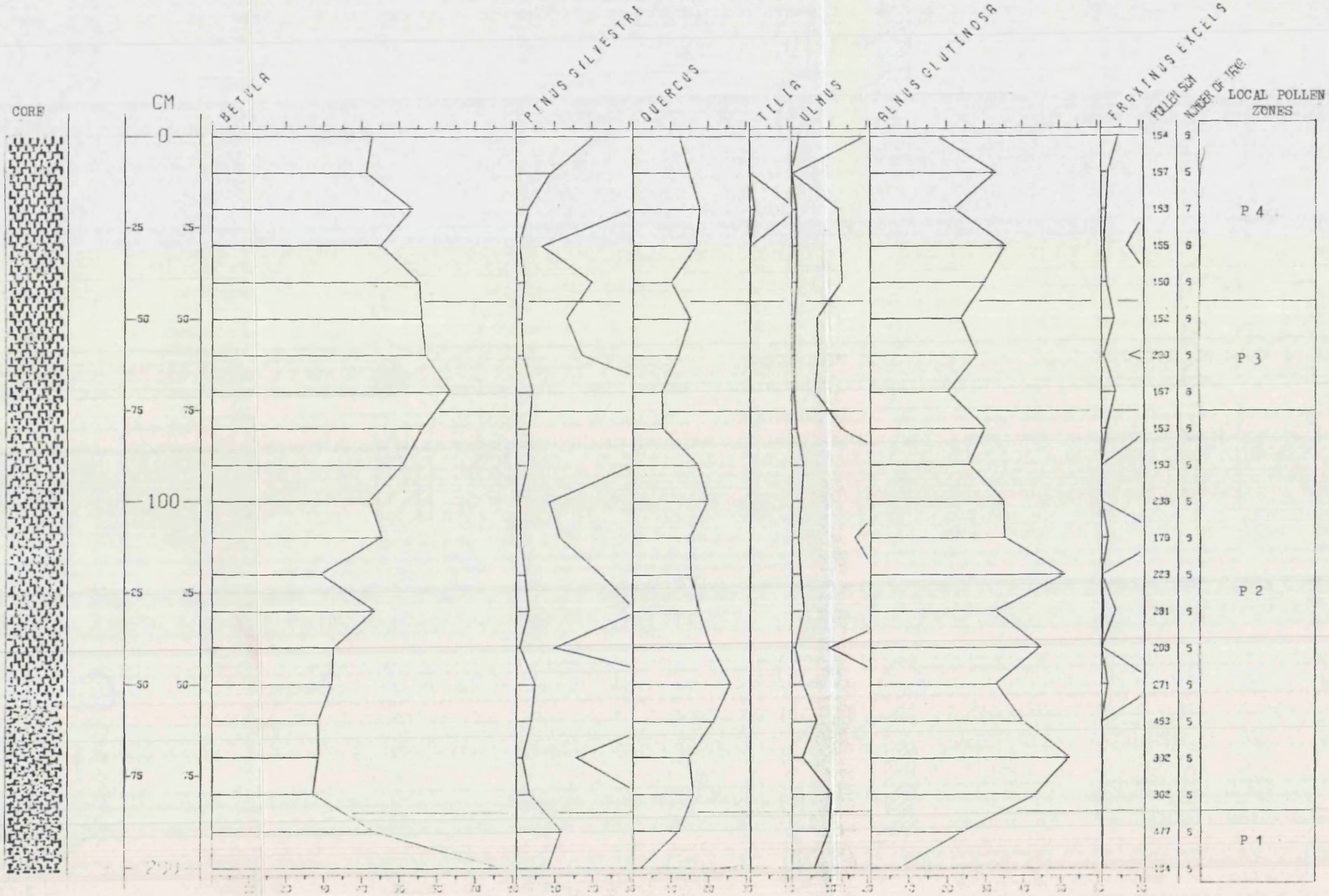


FIGURE 26 PTARMIGAN

ANAL. D.A.STEWART

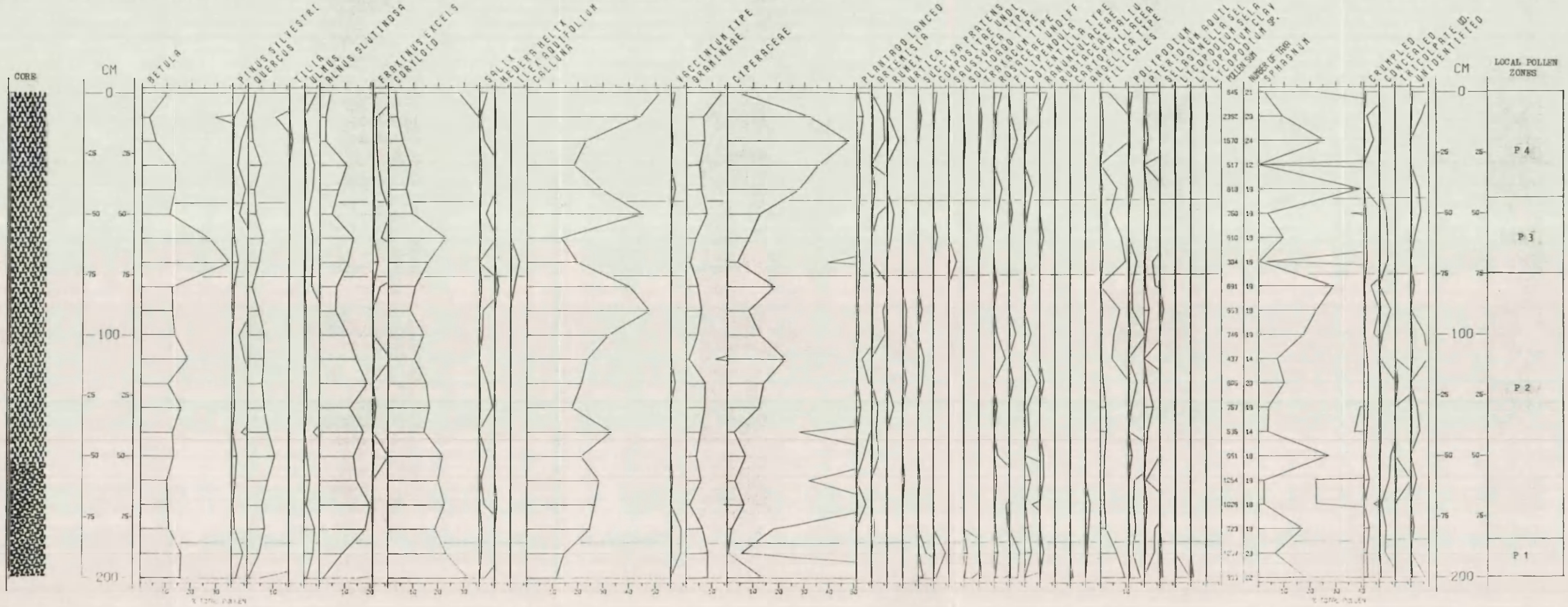


FIGURE 28 SHANTRON MUIR AP

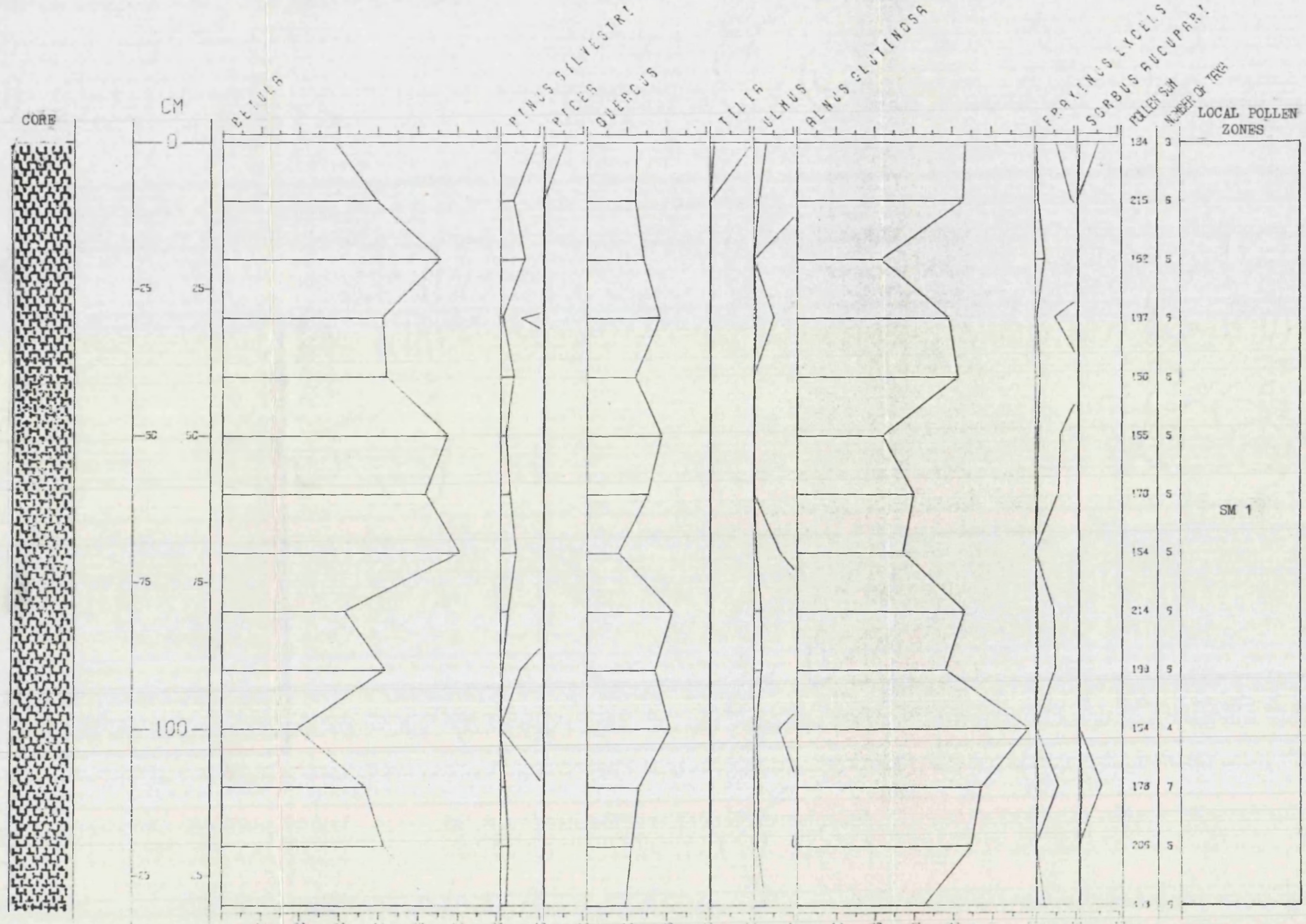
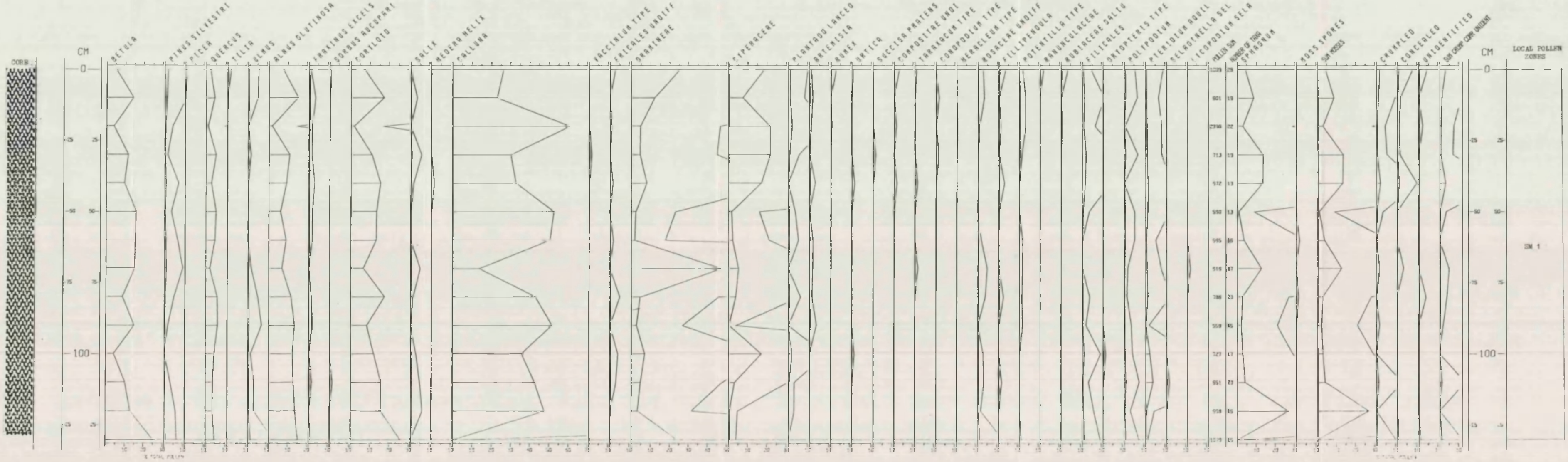


FIGURE 29 SHANTRON MUIR



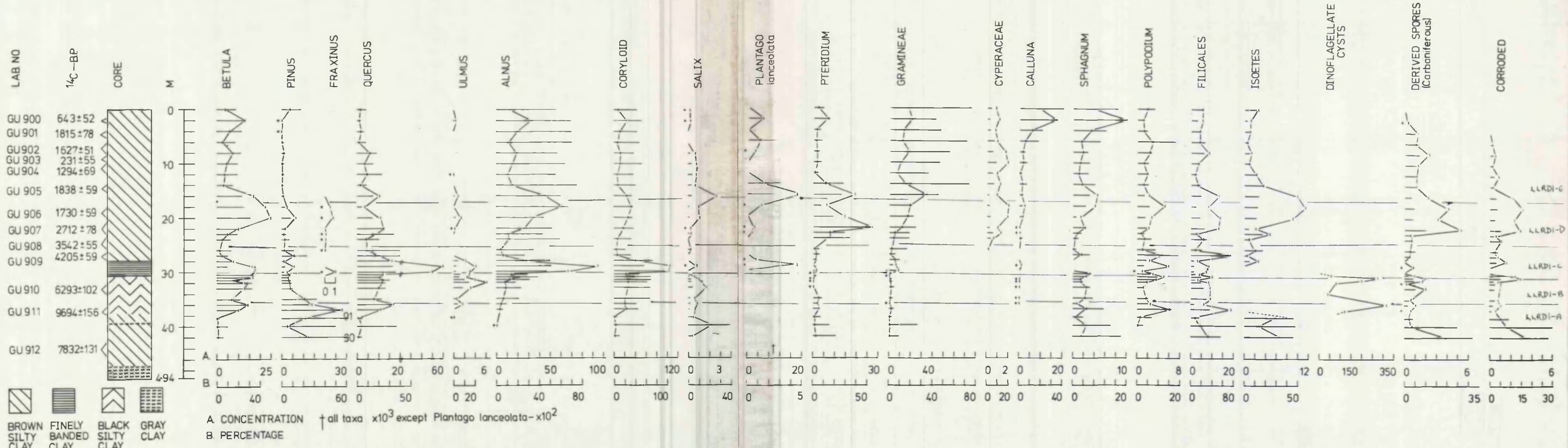


FIGURE 12. A - VERTICAL BARS B - HORIZONTAL LINES

DLM - DUBH LOCH CORE ABSOLUTE DATA

FIGURE 15

STRATIGRAPHIC SYMBOLS - APPENDIX 1

A - CONCENTRATION - grains/cm^3 ALL VALUES x10^3 (TILIA x1)

B - DEPOSITION - grains/cm^2/year ALL VALUES x10^3 or marked as x10^2