LATEGLACIAL AND EARLY POSTGLACIAL ENVIRONMENTS IN PART OF THE GRAMPIAN HIGHLANDS OF SCOTLAND

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1974

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ABSTRACT

The purpose of the investigation is to present a geographical interpretation of the past environment of part of the Grampian Highlands between ca. 13,000 and 7000 B.P. The study is based principally on pollen analysis, but also draws widely on the results of sedimentological and geomorphological investigations. Six sites were selected for analysis, five of which are situated outside the presumed limits of the Loch Lomond Readvance, while the sixth site is located within those mapped limits. Detailed pollen analyses were carried out on all the profiles, and at three of the sites, organic carbon content, particle size and alkali cation percentages were also determined. Radiocarbon dates on critical horizons were obtained from two of the sites.

The pollen diagrams were divided into individual pollen assemblage zones which enabled the vegetational record at each site to be assessed independently. Correlations between the profiles showed that at the five sites outside the presumed maximal extent of Loch Lomond Readvance ice, the basal deposits were of Lateglacial age with pollen spectra indicating a milder Interstadial followed by a harsher Stadial phase. The overlying sediments were found to be Postglacial in age. At the sites within the mapped Loch Lomond Readvance limits, only Postglacial deposits were present. The combined results of pollen analyses, sedimentological and geomorphological studies suggest the following history of landscape evolution.

The Late Devensian ice-sheet, which probably reached its greatest extent 17,000 to 18,000 radiocarbon years ago, had virtually disappeared from the Grampian Highlands by ca. 13,000 B.P. The early Lateglacial pollen spectra at all the sites reflect an initial period of colonisation by open-habitat taxa on freshly-exposed substrates following ice-sheet decay. After this early phase of

vegetational development, the plant cover of that area of the Grampians to the north and west of the Ben Nevis-Lochnagar watershed was dominated by Empetrum heaths, while grassland with juniper, dwarf birch, willow and occasional copses of tree birch characterised the southern and eastern slopes. Only in the extreme south of the study area did tree birch become established in significant numbers during the Interstadial. At ca. 11,000 B. P., declining temperatures heralded the onset of colder Stadial conditions with the recrudescence of glacier ice of the Loch Lomond Readvance, and the break-up of existing plant communities through increasingly widespread solifluxion. Open-habitat and chionophilous vegetation proliferated, environmental conditions became increasingly more severe, and a tundra landscape developed. This phase was relatively short-lived however, for rapid climatic amelioration at about 10,000 B. P. saw the final disappearance of glacier ice from Scotland, the cessation of solifluxion, and the initiation of a plant succession which culminated in the establishment of climax forest over much of the area. At that time, mixed woodland covered the southern and eastern Grampian slopes, while to the north and west of the Highland watershed, the landscape was one of coniferous forest.

ACKNOWLEDGEMENTS

I am deeply indebted to my two supervisors in the Department of Geography, University of Edinburgh, for their assistance and encouragement during the preparation of this thesis. Dr. J. B. Sissons has been a never-ending source of ideas and inspiration, a willing helper in the field, and has encouraged the development of a research school which has proved to be a most stimulating environment for postgraduate study. To Dr. W. W. Newey I am particularly grateful for introducing me to the technique of pollen analysis, and for constant advice on biogeographical and botanical matters. Without the help of these two people, the project would never have been completed.

I would like to express my thanks to Clive Brooks, Roger Cornish, Murray Gray, Elspeth Insch, John Menzies and Donald Sutherland for much-needed assistance with the field work, and for many valuable discussions over the past three years.
I particularly wish to acknowledge my debt to John Lowe who gave generously of his time when I was struggling to master pollen identification, and who has always been on hand to help in the field and in the laboratory. My thanks are also due to David Agnew for his assistance with the chemical analyses, to Carson Clark and Alex Whitelaw for photo-reducing the maps and diagrams, and to Alex Bradley, Ray Harris and David Lennie for their help with the cartography and reprographics.

I am very grateful to Dr. Y. Vasari, University of Oulu, for his permission to quote recently-obtained radiocarbon dates from Scottish sites, and also to Dr. J. B. Sissons and John Lowe for making available unpublished material. I would like to thank Dr. S. Smith, Royal Scottish Museum, for identifying the shells from the Tirinie site, and Miss M. A. R. Lumsden for her competent typing of the final draft of the thesis. Finally, I am indebted to the landowners and farmers of the Grampian Highlands for allowing me access to the sampling sites.

The research was financed by grants from the Natural Environment Research Council and from the University of Edinburgh, both of which are gratefully acknowledged.

Edinburgh
September 1974.

CONTENTS

Chapter 1

INTRODUCTION AND BACKGROUND TO THE INVESTIGATION

The study of the landscape has traditionally been regarded as the preserve of the geographer. However, with the recent trend towards environmental relevance in a number of academic fields, it is becoming increasingly apparent that the most significant contributions to the understanding of the landscape are emanating from disciplines other than geography. This has been particularly marked in the analysis and reconstruction of landscapes and environments of the past where the major developments in the last decade or so have been in the sciences of botany, geology and archaeology. The geographic discipline has, on the whole, been slow to make an impact in this developing field of enquiry. This is unfortunate, for with his heritage of landscape study, and his ability to perceive the spatial relationships between discrete environmental phenomena, the geographer is ideally equipped to make a valuable contribution to palaeoenvironmental reconstruction.

It is the purpose of the present study, therefore to present a geographical interpretation of the past environment of an area of Scotland during the closing phase of the last glaciation. This time period was chosen because it afforded an opportunity to study the evolution of the landscape during a particularly dynamic period in history. The investigation is based principally on pollen analysis, but also draws widely on the results of geomorphological and sedimentological studies. The techniques employed are those of the palaeobotanist, the geomorphologist and the geologist, but the approach is that of the geographer in that the results of each particular piece of analysis are drawn together in a synthesis which aims to present an overall impression of the environment in the study area between approximately 13,000 and 7000 years before present.

The area of study comprises a large portion of the central and southeast Grampian Highlands and was selected for a number of reasons. The limits of the last glaciers in the area had been mapped in detail by Dr. J. B. Sissons, Department of Geography, University of Edinburgh, and thus the former glacial sequence was fairly well established. Moreover, a number of potential pollen sites had been located which enabled a prompt start to be made to the field work programme. Thirdly, a similar study was being carried out in the adjacent area of the Grampian Highlands to the southwest by J. J. Lowe who at the time was a research student in the Department of Geography, University of Edinburgh. Clearly, a number of advantages are inherent in essentially a joint research project of this nature. Finally, this part of the Grampians lay within a day's drive of Edinburgh, possessed a good road system which made it possible to drive into the centre of the study area, and also contained a number of pollen sites adjacent to, or within close proximity of a road. These logistical considerations are of some importance in setting up a research project of this nature, for the cumbersome pollen-sampling equipment is not easily carried long distances over rough moorland.

RELEVANT PREVIOUS WORK ON GLACIAL AND VEGETATIONAL HISTORY

In this type of project, it is not possible to consider in detail the background material to every aspect of the investigation. However, it is felt that a comprehensive review of relevant literature is needed in two specific fields. Firstly, as the period of study encompasses the closing phase of the last glaciation, it is apposite to review the sequence of events during the last glacial phase in Britain, and in Scotland in particular. Secondly, as the principal technique is pollen analysis, the development and present role of palynology in the study of vegetational history in Scotland is discussed. These two sections are important not just as background literature, but also because they bring out a number of points which were instrumental in formulating the framework for the present investigation.

THE LATE QUATERNARY IN BRITAIN

The period between <u>ca.</u> 65,000 and 10,000 years B.P. is termed the Devensian (Shotton and West 1969) after the ancient British tribe that inhabited the Cheshire Plain, a region now considered to be the type area for the stratigraphy of the last glaciation in the British Isles. The Devensian Stage is further divided into three substages:- the Early Devensian covering the period up to *ca.* 50,000 B.P., the Middle Devensian from *ca.* 50,000 to 26,000 years B.P. and the Late Devensian from *ca.* 26,000 to 10,000 years B.P. Within the Devensian Stage, only three Interstadials have been recognized in Britain, those being the Chelford, the Upton Warren, and the Allerød or Pollen Zone II, and it is on the latter that much of the present investigation is centred. Localities mentioned in the text are shown in Figures 1 and 2.

a) The Pre-Devensian Period

The majority of studies on the Pre-Devensian part of the Quaternary Era have been carried out in central England and in East Anglia in particular (see West 1968; Sparks and West 1972) and thus the sequence will not be discussed in detail here. In Scotland, there are only three known localities where deposits are thought to be of Pre-Devensian age. At Fugla Ness, Shetland, a peat layer containing fossils indicative of wooded conditions has been tentatively assigned to the Gortian Interstadial stage in Ireland (Birks and Ransom 1969). The Gortian is believed to be the equivalent of the Hoxnian Interglacial in the classic East Anglian stratigraphic sequence (Mitchell *et al.* 1973).

However, two radiocarbon dates[1] of ca. 37,000 and ca. 35,000 B.P. have been obtained from this deposit (Page 1972), although the validity of these dates is in dispute (Shotton 1972a). A second site which may also be Hoxnian in age has been discovered in the west of the Walls Peninsula in Shetland (H.J.B. Birks unpublished). Finally, in northern Lewis, stratified marine deposits are overlain and underlain by till. All the deposits contain marine shells, but the middle layer contains Sipho jeffreysianus which is only found around the coasts of southern Britain today (Baden-Powell 1938). Hence, this site too may be of interglacial age.

b) The Early Devensian Period

Thus far, only one site has been located in Britain which can be assigned to the Early Devensian period. At Chelford in Cheshire, a layer of sandy detritus beneath glacial till yielded a radiocarbon age of > 57,000 B.P. (Simpson and West 1958). Subsequent radiocarbon assays have produced finite dates for the deposit ranging from 26,000 to 60,800 years B.P., but the older

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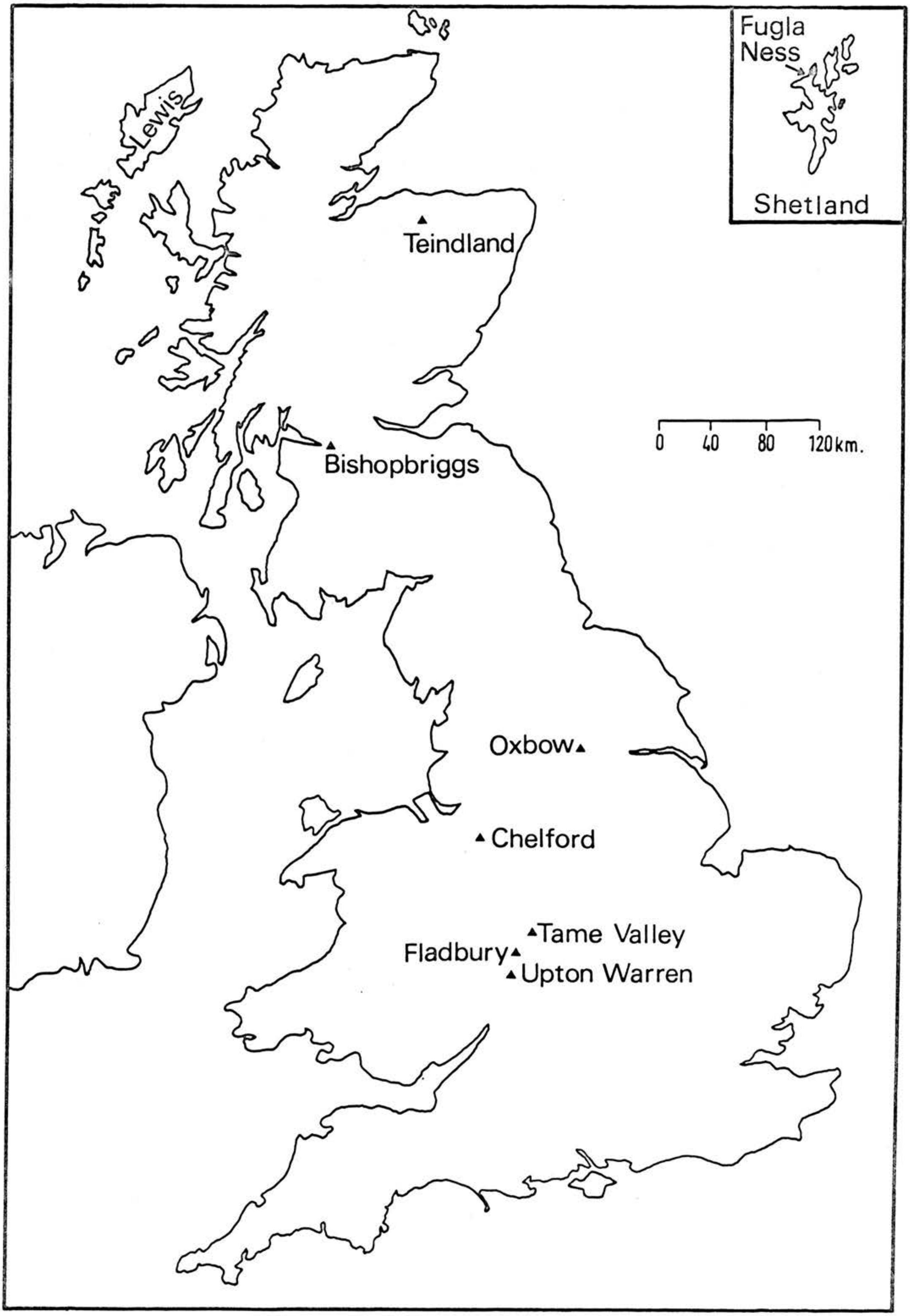
[1] Although the method of radiocarbon assay is widely recognized as a valuable tool in Quaternary research, it is clear that several sources of error are inherent in the method (see Olsson 1968 for further discussion). In recent years it has become customary to apply correction factors to dates to account for the apparent age of seawater, isotopic fractionation etc. Unfortunately, this practice is not universal and in any event, there are a large number of dates which were obtained before some of the error sources were identified, and which therefore must remain uncorrected. Thus the confusing situation has arisen whereby both corrected and uncorrected radiocarbon dates are being used for the purposes of correlation during the Late Quaternary period. In this thesis, care has been taken in the comparison of dates, particularly where the time-interval involved may be only a few hundred years. Where shell dates are used, the inner date has been quoted as this is likely to provide the most accurate date. All dates are quoted directly from original sources, and no further corrections have been made by the present writer.

FIGURE 1

Pre-, Early and Middle Devensian sites
discussed in the text.


Fugla
Ness
Shetland
Lewis
Teindland
Bishopbriggs
0 40 80 120 km.
Oxbow
Chelford
Tame Valley
Fladbury
Upton Warren

date is considered to be the most reliable (see Shotton et al. 1970 for discussion). The pollen and macroscopic plant remains indicated cool climatic conditions similar to those found in forested areas of northern Finland. While it is not possible to correlate this assemblage with any other in Britain, dates of 63,500 B.P. and 58,000-59,000 B.P. have been obtained from interstadial deposits at Amersfoort in Holland and Brörup in Denmark respectively (Haring, de Vries and de Vries 1958; van der Hammen et al. 1967; Andersen 1961). All the available evidence from Britain and adjacent areas of mainland Europe suggests that tundra conditions prevailed throughout the Early Devensian, and there is no firm evidence for the build-up of glacier ice during this period.

c) The Middle Devensian Period

The Middle Devensian too seems to have been a period of polar desert conditions, but with occasional climatic ameliorations (Mitchell 1972). The best evidence of a marked thermophilous phase comes from the assemblage at Upton Warren in Worcestershire which has been dated at 41,900 ± 800 B.P. and 41,500 ± 1200 B.P. (Coope et al. 1962). The fossil flora and fauna indicate temperate conditions as 78% of the species recorded are found in the area at the present time. The assemblage contrasts markedly with those dated at 38,700 ± 700 B.P. at Fladbury in Worcestershire (Coope 1962a), 38,600 +1720/-1420 B.P. at Oxbow near Leeds (Gaunt et al. 1970), and 32,160 +1780/-1450 B.P. in the Tame Valley, Warwickshire

(Coope and Sands 1966), all of which contain species with prominent arctic or subarctic affinities. If the radiocarbon dates are correct, these cooler assemblages indicate a return to polar desert conditions after the relatively mild climatic phase reflected in the Upton Warren deposits.

The apparent absence of glaciers during the Middle Devensian is demonstrated by the sequence of dates ranging from 30,500 ± 440 B.P. to 42,530 ± 1230 B.P. (Morgan 1973) beneath Irish Sea till in the English Midlands, and by three radiocarbon-dated sites in Scotland. On Lewis, a peat layer overlain by till has been dated at 27,330 ± 240 B.P. (von Weymarn and Edwards 1973), while at Teindland in Morayshire, a buried podzol yielded a date of 28,140 +480/-650 B.P. (Fitzpatrick 1965). Finally, a bone of Rhinoceros antiquitatis found near Bishopbriggs, Glasgow was dated at 27,550 +1370/-1680 B.P. (Rolfe 1966). As this latter site is only 80 km from the most important ice dispersal centre in the British Isles, a large area of the country must have been ice-free at that time (Sissons 1967b).

In the Middle Pleniglacial period in the Netherlands (the equivalent of the Middle Devensian in Britain), three interstadial sites have so far been discovered. These are at Moershoof'd, Hengelo and Denekamp, and have been dated at > 48,000 B.P., 38,700 ± 1100 B.P. and 29,300 ± 300 B.P. respectively (van der Hammen and Wijmstra 1971). At each site, the fossil assemblage is characterised by a marked thermophilous element, suggesting continual phases of climatic amelioration throughout the Middle Pleniglacial. It is apparent therefore, that on the continent of Europe, polar desert conditions did not persist uninterrupted throughout the entire Middle Devensian period.

d) The Late Devensian Period

After the long interstadial of the Early and Middle Devensian, the Late Devensian saw the accumulation and dispersal of great masses of glacier ice. By analogy with North America and Continental Europe, it is assumed that this ice sheet reached its maximal extent between 17,000 and 20,000 years ago (Richmond 1965, 1970). In Britain, the general sequence of events during the Late Devensian is fairly well understood, despite the existence of a number of separate ice-dispersal centres and the interaction of individual ice streams radiating from these centres of accumulation.

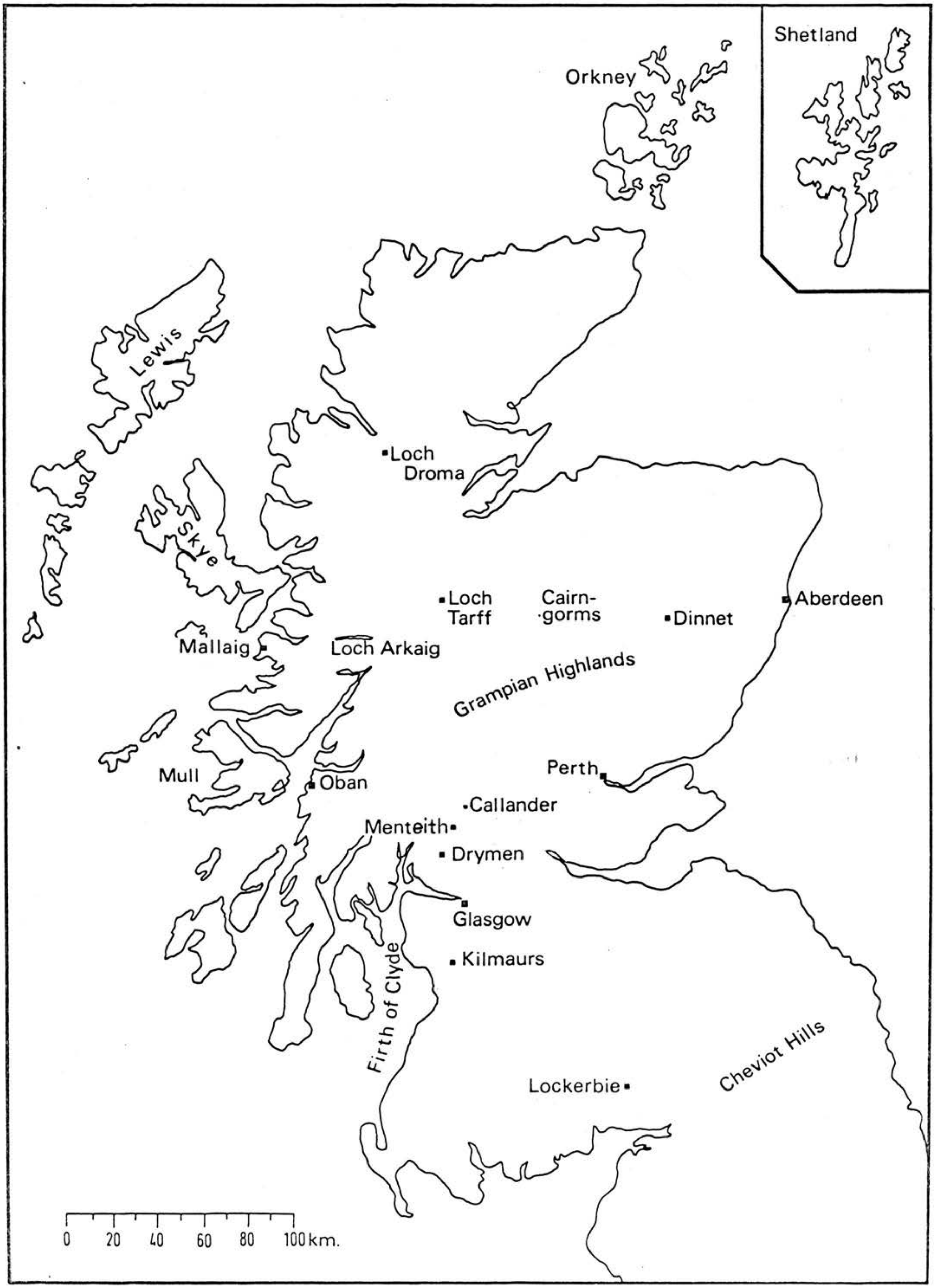
A date of 28,000 +1800/-1500 B.P. obtained from marine shells in till on the Cheshire Plain (Boulton and Worsley 1965) shows that ice moving down the Irish Sea basin crossed the English Midlands at some time after that date, while more severe constraints on this ice advance are provided by a date of <u>ca.</u> 24,000 B.P. on shell material incorporated into Irish Sea till in County Down, Eastern Ireland (Hill and Prior 1968). A possible minimum age for this ice advance is provided by a series of dates obtained from a complete "non-glacial" profile at Glen Ballyre in the Isle of Man. Three separate radiocarbon assays on a moss layer at the base of a cliff section yielded dates of 18,700 ± 500 B.P., 18,500 ± 185 B.P. and

18,400 ± 500 B.P. (Shotton and Williams 1971). However, a moss layer *beneath* glacial till at Dimlington in Yorkshire was dated at 18,240 ± 250 B.P. and 18,500 ± 400 B.P. (Penny *et al.* 1969), thus in turn providing a maximum age for the last glacial advance in Eastern England. Mitchell (1965) suggests the possibility of the Isle of Man being a nunatak during the last glaciation, but Bowen (1973) pointed to the possible "hard water effect" on the Isle of Man dates which, if taken into account would help resolve the seemingly anomalous place of this record in the glacial sequence. The precise origin of separate ice streams moving across the Irish Sea basin, and in particular, the role of ice from the Grampian Highlands does however, remain problematical (Mitchell 1972). The retreat stages of the Late Devensian ice sheet in England are more clearly understood, and radiocarbon dates show that the coast of North Wales was ice-free by 14,500 B.P. (Coope and Brophy 1972), the Isle of Man by 12,000 B.P. (Mitchell 1965), much of the Lake District by 14,000 B.P. (Pennington and Bonny 1970), and in Scotland, the Firth of Clyde by *ca.* 12,500 B.P. (Bishop and Dickson 1970; Peacock 1971).

In Scotland as a whole, however, the expansion and subsequent decay of the Late Devensian ice-sheet is still the subject of considerable debate, particularly with regard to major advance phases during the period of overall ice-sheet wastage. In south and west Scotland, a major readvance limit was recognized by Charlesworth (1926) and termed the "Lammermuir-Stranraer Moraine", while in the Aberdeen area, a succession of workers discussed the possible

FIGURE 2

Late Devensian sites in Scotland.


Shetland
Orkney
Lewis
Skye
Loch Droma
Loch Tarff
Cairngorms
Dinnet
Aberdeen
Mallaig
Loch Arkaig
Grampian Highlands
Mull
Oban
Perth
Callander
Menteith
Drymen
Glasgow
Kilmaurs
Firth of Clyde
Lockerbie
Cheviot Hills
0
20
40
60
80
100 km.

readvance limits at Dinnet in the Dee Valley and near the city of Aberdeen (Jamieson 1905; Bremner 1918, 1932; Synge 1956). The hypothesis was put forward of a major readvance of the Late Devensian ice-sheet at a relatively early stage, an event which subsequently became known as the "Aberdeen-Lammermuir Readvance". Indeed, many considered that this limit represented the maximal extent of Late Devensian ice in Scotland (Sissons 1967a). However, more recent studies have shown that the concentration of drift landforms which were generally held to mark the ice limits can be interpreted as fluvioglacial deposits resulting from progressive decay of the main ice-sheet (Sissons 1961; Clapperton and Sugden 1972). Thus, Sissons (in press) suggests that the concept of an Aberdeen-Lammermuir Readvance be rejected because of the lack of substantive geomorphic evidence.

A more recent readvance limit was recognized in the Perth area and was shown by Simpson (1933) to be quite distinct from the later readvance moraines in the Forth Valley (see below). The evidence for this readvance (later termed the Perth Readvance) lay initially in a section exposed in the valley of the Almond which revealed a basal till overlain by varved sediments which were themselves overlain by outwash sands and gravels. Synge (1956) accepted the concept of the Perth Readvance and correlated it with the limit in the Aberdeen area, while Sissons (1963, 1964) discussed the corroborating morphological evidence from the Forth and Clyde Valleys. In the Glasgow area in particular, evidence of a readvance is irrefutable as floral and faunal remains have been found in outwash gravels and sands beneath the till of the last ice advance (Coope 1962b; Macgregor and Ritchie 1940).

The date at which this readvance took place however is problematical. De Geer (1935) made a "Teleconnection" between the varves described by Simpson in the Almond Valley and the classic Swedish varve chronology, and suggested that these sediments accumulated _ca._ 13,100 years ago. A mammoth tusk from stratified deposits beneath till at Kilmaurs in Ayrshire was dated at 13,700 +1300/-1700 B.P. (Sissons 1967b), while deposits at Loch Droma (Kirk and Godwin 1963) and Lockerbie near Dumfries (Bishop 1963) showed that these areas were free of ice by 12,800 B.P. and 12,900 B.P. respectively. It was therefore suggested that the Perth Readvance culminated between 13,500 and 13,000 B.P. (Sissons 1967a, 1967b). Support for this contention is provided by recent evidence from the Clyde area where radiocarbon dates on marine shells indicate that this area of Scotland was ice-free by 12,600 B.P. (Bishop and Dickson 1970).

However, a more recent date of > 40,000 B.P. for a reindeer antler from the Kilmaurs site (Shotton _et al._ 1970) raises doubts about the validity of the date of _ca._ 13,000 B.P. on the mammoth tusk from the same site. Moreover, the date of _ca._ 27,500 B.P. (Rolfe 1966) on the rhinoceros bone from sand and gravel under till at Bishopbriggs suggests that some of the readvance evidence relates to the build-up of the ice-sheet at the beginning of the Late Devensian. Finally, the morphological evidence for a readvance in the Earn and

Tay Valleys of Perthshire has been interpreted by Paterson (1974) as resulting from gradual retreat (interspersed with occasional stillstands) of the main ice-sheet. The concept of a readvance of the Devensian ice-sheet around 13,000-14,000 B. P. must therefore be treated with some scepticism.

Evidence for a final phase of glacier activity is much less tenuous. Indeed, it was recognized more than a century ago that following the decay of the main ice-sheet, glaciers developed on a much more restricted scale in many parts of the Scottish Highlands (A. Geikie 1863). This readvance was later described by Simpson (1933), who interpreted prominent end moraines at Menteith in the Forth Valley and at Drymen to the north of Glasgow, as resulting from ice tongues moving down the Loch Lomond valley and upper Forth Valley into the marginal parts of the central lowlands. Charlesworth (1956) recognized a number of ice limits in the Scottish Highlands, and his Moraine or "M" stage was thought to correlate with the Loch Lomond Readvance.

Donner (1957, 1958) used pollen analysis and stratigraphy to date the Loch Lomond Readvance by analysing sediment which had accumulated in enclosed basins outside and inside former ice limits near Drymen, and near Oban on the west coast. Outside the presumed readvance limits, the basins contained a suite of sediments which could be correlated with the traditional pollen zones I, II, III of the

Lateglacial[2] sequence of Godwin (1940) in England and Jessen (1949) in Ireland. Inside the limit however, the lowest recognizable pollen assemblage was of pollen zone IV age. Donner therefore concluded that ice stood at the morainic limits during the cold pollen zone III and this dated the readvance to the period between 10,800 and 10,300 B.P. (Godwin and Willis 1959). The value of this technique has recently been demonstrated in the Callander area of Perthshire (Lowe unpublished), where two sites occur outside and one within a prominent end moraine. Both the outside sites lie within 2 km of the moraine and contain a complete Lateglacial sequence, while the site immediately within the moraine showed that sediment accumulation did not commence until pollen zone IV. The moraine therefore is very probably of Loch Lomond Readvance age.

In other parts of Scotland, radiocarbon dates have been instrumental in determining the Loch Lomond Readvance limits and the time at which the readvance took place. At Drymen, a date of 11,700 ± 170 B.P. was obtained from shell fragments in the end moraine complex, while at Menteith glacier-transported marine clay in the end

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[2] The term Lateglacial refers to the terminal phase of the Late Devensian period spanning the time interval from <u>ca.</u> 14,500 B.P. to 10,000 B.P. thus including pollen zones I-III (Shotton 1973). The Postglacial coincides with the start of pollen zone IV, and is virtually contemporaneous with the final temperature stage of the Flandrian which is taken to begin at 10,000 B.P. (Shotton 1973; Morner 1973).

moraine contained shells which yielded a date of 11,800 ± 170 B. P. (Sissons 1967b). These dates prove that a readvance took place after that time and presumably therefore during pollen zone III. Similar dates on shelly material of between 11,300 and 11,800 B. P. in Loch Creran near Oban, Argyllshire (Peacock 1971), and 11,330 ± 170 B. P. at Kinlochspelve on Mull (Gray and Brooks 1972) support the hypothesis that ice limits in those areas of western Scotland relate to the Loch Lomond Readvance.

In the Grampian Highlands, the limit of the Readvance is occasionally marked by end moraines, but is also often associated with the downvalley termination of a distinctive hummocky terrain (Sissons 1967a). Beyond these limits, outwash spreads and terraces can frequently be traced downvalley. The location and distribution of systems of meltwater channels, and the contrast in size of periglacial features across presumed ice limits have also been used to delimit the extent of the Loch Lomond Readvance in the Scottish Highlands (Sissons 1967a, 1967b, 1972a; Sissons and Grant 1972; Sissons et al. 1973; Thompson 1972). On the west coast of Scotalnd, outwash gravels from this readvance have been traced down the sea lochs between Oban and Mallaig (Gray 1972; McCann 1966), while in the Cheviot area of the Southern Uplands, small areas of hummocky moraine indicate the former existence of very small glaciers (Clapperton 1971). The distribution of hummocky moraine in the higher valleys of the Lake District (Manley 1959), and the small arcuate moraines in the mouths of many Snowden corries (Seddon 1957, 1962), have been cited as further evidence of a readvance at the close of the Late Devensian period.

Although the concept of the Loch Lomond Readvance is generally accepted, there remains some controversy over the pattern of glacier activity in the Scottish Highlands at the close of the Late Devensian. Manley suggested (1959) that although the English Lake District appeared to have been ice-free during the milder Allerӧd or pollen zone II, it is probable that glaciers remained active in the Scottish Highlands at that time. More recently, Sugden (1970) has argued that ice existed in the Cairngorm Mountains and adjacent areas of the Spey Valley throughout the Lateglacial period, and that the Loch Lomond Readvance is represented by a minor fluctuation around the margin of a steadily downwasting Cairngorm ice cap during pollen zone III. A similar situation is thought to have existed in the Loch Arkaig area of Inverness-shire (Peacock 1970).

An alternative explanation has been proposed by Sissons (1967a, 1972a), and Sissons and Grant (1972). It is suggested that the distinction between ice-sheet and local glacier evidence, the steep gradient of the former glaciers and the inferred relationship between these glaciers and the former upland sources, are indicative of a phase of renewed glaciation consequent on the lowering of the regional snow-line from above the mountain summits. Moreover, the radiocarbon date of 12,814 ± 155 B.P. from Loch Droma (Kirk and Godwin 1963) in association with chemical and pollen analyses from Loch Tarff near Fort Augustus which could be correlated with radiocarbon-dated profiles from the Lake District (Pennington and Lishman 1971), suggest that a large area of the Scottish Highlands was ice-free by 13,000 B. P. Such evidence of deglaciation in, or close to mountains that previously were major glacier source areas, strongly suggests that in the preceeding period of up to 2000 years, Scotland became completely free of glacier ice (Sissons, in press).

These conflicting views have been debated at some length in the recent literature (Sissons 1972b, 1973; Sugden 1972, 1973), and the relative merits of the respective arguments will not be discussed at this point. However, it is clear that the pattern of deglaciation in Scotland in general, and the status of the Loch Lomond Readvance in particular, is important in the study of the past environment of the Grampian Highlands, and thus this problem will be considered in more detail below.

PREVIOUS STUDIES ON THE VEGETATIONAL HISTORY OF SCOTLAND

The analysis of stratigraphy and of sediments has led to the reconstruction of the glacial history of the Devensian period. However, although this is an important aspect of landscape evolution, the amount of detail on climatic and environmental change which can be deduced from such studies is limited. Much more can be gained from the study of the floral and faunal record, for as life is intimately related to and dependent upon environment, so biological studies assume a place of considerable importance in the geography of the Late Quaternary period. For example, the pollen and macroscopic plant remains in the Chelford deposits are indicative of a former cool climate with a Betula-Pinus-

Picea forest as the dominant local vegetation comparable in type to the present forest of northern Finland (West 1968), while the temperate flora found in the Upton Warren site are suggestive of a climate comparable with that existing today in southern Sweden (Coope et al. 1962).

In Scotland, the study of vegetational history can be divided into three major periods. The earliest investigations were concerned with the examination of macroremains preserved in peat profiles, and the implications of the fossil evidence for past changes in climate. This phase of research was later augmented by the development of the technique of pollen analysis, which was used initially to substantiate macrofossil evidence and aid in the correlation of climatic episodes between northern Britain and Scandinavia. In the post-war period, pollen analysis has been greatly refined and has become a valuable interpretative tool, as well as an additional method of dating geological and climatological events.

a) Early studies of macroremains in peat

The fact that a record of past vegetation was preserved in Scottish peat mosses was first emphasised by J. Geikie over a century ago (Geikie 1866). In a long and detailed report, Geikie pointed out the stratified nature of the peat mosses in many parts of Scotland, and attributed the stratigraphical changes to oscillations in the climate of the past. The presence of wood layers in the peats was interpreted as being indicative of former periods of climatic amelioration, while the intervening peat layers represented intervals of much cooler and humid climate. Geikie later (1895) proposed the sequence of Lower Forestian, Lower Turbarian, Upper Forestian, Upper Turbarian for the Scottish peat mosses, and a correlation was attempted between this system and the one already devised for Scandinavia.

Lewis (1905, 1906, 1907, 1911) continued Geikie's studies and substantiated many of his earlier conclusions. He was able to trace the Upper and Lower Forestian beds across the Southern Uplands and parts of the Highlands, and he also noted the occurrence of arctic plant remains between the two wood layers. These "Arctic Beds" were related to a former ice advance in the Highlands, but this hypothesis was not borne out by subsequent research. However, the presence of arctic plant layers at the base of many of the profiles was correctly referred to the period of former tundra conditions which prevailed at the close of the Ice Age. The occurrence of these basal arctic beds had already been noted by J. Geikie (1895) who had postulated that tundra conditions probably prevailed in the Lowland areas while glacier ice occupied the Scottish Highlands. Macroremains of arctic flora were also recorded in lake deposits in the Edinburgh area (Henderson 1883; Bennie 1891; Reid 1899).

Further studies on the stratigraphy of Scottish peat mosses were carried out by Sernander (1908). He noted the distinct stratigraphic changes in many of the profiles, and proposed a correlation of the Lower Forestian with the Boreal period, the Lower Turbarian with the Atlantic period, the Upper Forestian with the sub-Boreal period and the Upper Turbarian with the sub-Atlantic period. This latter system had been developed and applied in Scandinavia by Blytt and

Sernander. This correlation was later emphasised by Samuelson (1910) who interpreted the relatively mild Boreal and sub-Boreal periods as being characterised by mixed forest and dominantly pine forest respectively.

b) The early palynological studies

The investigations of Samuelson mark the end of the initial phase in the study of the history of the Scottish vegetation, for the years during and after the First World War saw the development of pollen analysis as a palaeobotanical technique. All future research employed microfossil as well as macrofossil evidence in the interpretation of past vegetation patterns.

The pioneer of palynological investigation in Scotland, and indeed in the British Isles as a whole, was Erdtman. The main emphasis of his research lay in the correlation of periods of vegetational history in the Highlands and Islands of Scotland with the sequences established for Scandinavia. These early studies (1924) were based exclusively on tree-pollen frequencies, but it was still possible to demonstrate correlations with the macrostratigraphic units of Geikie and Sernander, and subsequently with the Boreal period in Scandinavia. Later, Erdtman (1928) produced a detailed vegetational history for northern Scotland and, using the Blytt-Sernander units, was able to show the chronological order of tree immigration into Scotland. This was as follows:- Pre-Boreal - Salix and Betula; Boreal - Pinus, Ulmus, Quercus and Corylus; Boreal/Atlantic - Alnus.

Godwin (1934) used data obtained by Erdtman and coupled this with pollen analytical results from English pollen diagrams to show the pollen composition in different geographical localities through time. He thus introduced the concepts of regional parallelism and revertence in vegetational history, two hypotheses which were later discussed at length by von Post (1945). Using data obtained by Fraser from a site near Aberdeen in conjunction with pollen analysis carried out on the Continent, von Post showed that a general rise and fall in temperature during the Postglacial period could be traced in all the pollen diagrams but the actual plant response to this climatic variation changed from locality to locality.

All the available data on vegetational history in the British Isles were used by Godwin (1940) to construct vegetation maps for each of the Postglacial periods and these formed the basis of the classic system of Godwinian vegetational zones. At the time, little was known of the Lateglacial sequence in England and Wales, but Jessen (1949) later produced a scheme of Lateglacial and Postglacial pollen zones for Ireland, and this was subsequently modified to correspond with the Godwin system. This sequence of what must now be regarded as "assemblage zones" (West 1970) has been used as the basis for the division of all Scottish pollen diagrams until very recent times.

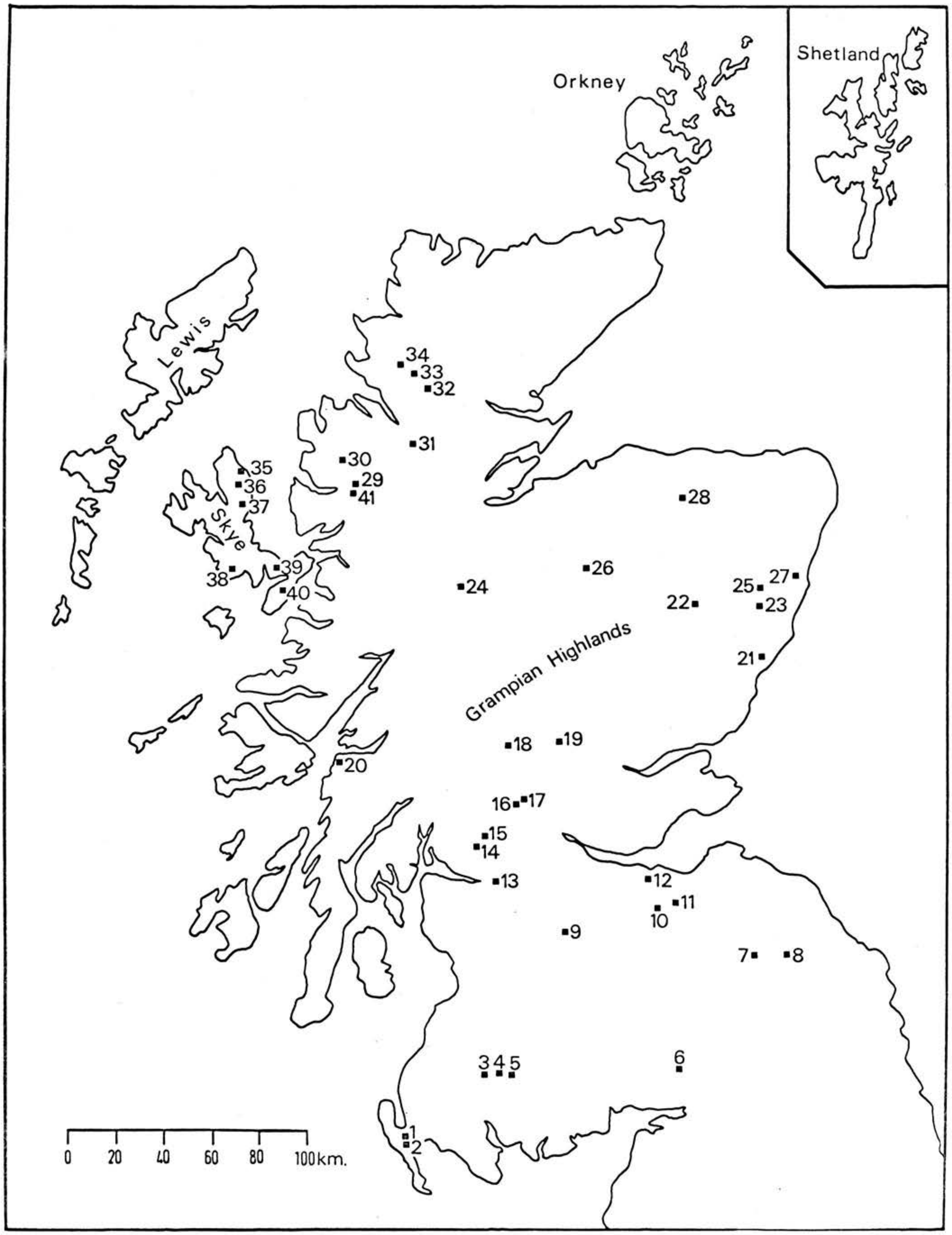
c) Modern palynological studies

Since the early investigations of Erdtman and Godwin, there has been a marked increase in the number of pollen analytical studies in Scotland. At the time of writing, over 100 pollen sites have been recorded, and although a number contain only a limited vegetational

FIGURE 3

Lateglacial and Early Postglacial pollen sites in Scotland referred to in the text.

1) Little Lochans, Wigtownshire (Moar 1969).
2) Culhorn Mains, Wigtownshire (Moar 1969).
3) Nick of Curleywee, Kirkcudbrightshire (Moar 1969).
4) Snibe Bog, Kirkcudbrightshire (H. H. Birks 1972a).
5) Loch Dungeon, Kirkcudbrightshire (H. H. Birks 1972a).
6) Bigholm Burn, Dumfriesshire (Moar 1969).
7) Whitrig Bog, Berwickshire (Mitchell 1952).
8) Din Moss, Roxburghshire (Switsur and West 1973).
9) Carnwarth Moss, Lanarkshire (Fraser and Godwin 1955).
10) Eddleston Valley, Midlothian (Newey 1968).
11) Side Moss, Midlothian (Newey 1968).
12) Corstorphine, Midlothian (Newey 1970).
13) Garscadden Mains, Lanarkshire (Mitchell 1952; Donner 1957).
14) Drymen, Stirlingshire (Donner 1957; Vasari and Vasari 1968).
15) Gartmore, Stirlingshire (Donner 1957).
16) Callander, Perthshire (Lowe unpublished).
17) Loch Mahaik, Perthshire (Donner 1957, 1958, 1962).
18) Lochan nan Cat, Perthshire (Donner 1962).
19) Loch Creagh, Perthshire (Donner 1962).
20) Oban, Argyllshire (Donner 1957).
21) Burn of Benholm, Kincardineshire (Donner 1960).
22) Loch Kinord, Aberdeenshire (Vasari and Vasari 1968).
23) Loch of Park, Aberdeenshire (Vasari and Vasari 1968).
24) Loch Tarff, Inverness-shire (Pennington _et al._ 1972).
25) Brimmond Hill, Aberdeenshire (Durno 1970).
26) Abernethy Forest, Inverness-shire (H. H. Birks 1970).
27) Strichen Moss, Aberdeenshire (Fraser and Godwin 1955).
28) Garral Hill, Banffshire (Donner 1957).
29) Beinn Eighe Nature Reserve, Wester Ross (Durno and McVean 1959).
30) Loch Maree, Wester Ross (H. H. Birks 1972b).
31) Loch Droma, Easter Ross (Kirk and Godwin 1963).
32) Loch Craggie, Wester Ross (Pennington _et al._ 1972).
33) Loch Borallan, Wester Ross (Pennington _et al._ 1972).
34) Loch Sionascaig, Wester Ross (Pennington and Lishman 1971; Pennington _et al._ 1972).
35) Loch Mealt, Inverness-shire (H. J. B. Birks 1973).
36) Loch Cuithir, Inverness-shire (Vasari and Vasari 1968).
37) Loch Fada, Inverness-shire (Vasari and Vasari 1968; H. J. B. Birks 1973).
38) Lochan Coir' a' Ghobhainn, Inverness-shire (H. J. B. Birks 1973).
39) Loch Meodal, Inverness-shire (H. J. B. Birks 1973).
40) Loch Cill Chriosd, Inverness-shire (H. J. B. Birks 1973).
41) Loch Clair, Wester Ross (Pennington _et al._ 1972).


Shetland
Orkney
Lewis
Skye
Grampian Highlands
34
33
32
31
30
29
41
35
36
37
38
39
40
28
26
24
27
25
22
23
21
18
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20
16
17
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14
13
12
11
10
9
7
8
3
4
5
6
1
2
0
20
40
60
80
100km.

record, many possess a stratigraphic profile extending back to the Lateglacial period. As the emphasis of the present study is on the Lateglacial and Early Postglacial environment of the Grampians, this final part of the review of previous research will be confined to a discussion of those sites which contain sediments deposited during that time period. Sites mentioned in the text are shown in Figure 3.

The first Lateglacial sites to be investigated in Scotland were at Whitrig Bog in Berwickshire and Garscadden Mains near Glasgow (Mitchell 1948, 1952), although deposits of Lateglacial age had already been investigated in adjacent areas of northern England (Pennington 1947). At both the Scottish sites, the threefold stratigraphic sequence of organic muds underlain and overlain by minerogenic sediment was present. Pollen diagrams were not initially published from either site, but on the basis of macrofossil content, the two minerogenic bands were assigned to the colder pollen zones I and III while the organic mud was thought to represent the milder Allerød or pollen zone II. The Whitrig Bog macrofossil assemblage was later examined by Conolly (1961), who substantiated earlier interpretations of the site and discussed the value of a number of Lateglacial species as indicators of climatic and edaphic conditions.

The Garscadden Mains site was subsequently re-investigated by Donner (1957) along with other Lateglacial sites near Oban, at Drymen, Garral Hill in Banffshire and Loch Mahaick in western Perthshire (1958). The purpose of these studies was to correlate geological events as well as climatic and vegetational phases, by investigating the stratigraphy and pollen content of lake basin sediments near the end moraines of the so-called Highland Readvance. As was discussed above, this readvance was shown to have taken place during pollen zone III and is now known as the Loch Lomond Readvance. At the five sites situated beyond the readvance limits, Donner found the characteristic Lateglacial stratigraphy of minerogenic, organic and minerogenic sediment. Pollen analysis of the organic deposits showed the former presence of a shrub tundra landscape, with *Betula* dominating the arboreal pollen and woody taxa reaching a maximum of 30% of the total land pollen sum. These organic muds were considered to be of Allerö d or pollen zone II age, and a series of radiocarbon dates from the Garral Hill site showed that this period spanned approximately 1200 years from *ca.* 12,000 B.P. to 10,800 B.P. (Godwin and Willis 1959). The overlying minerogenic deposits, which were thought to have resulted from intense solifluxion during the period of relatively unstable soil conditions during pollen zone III, were not analysed for pollen content. An additional Lateglacial site at the Burn of Benholm in Kincardinshire was also investigated by Donner (1960). Here, lenses of silty peat were found to be intercalated with a brown deposit which was interpreted by Donner as till. Pollen analysis of the peat layer indicated the former existence of tundra conditions, particularly noteworthy being the occurrence of *Köenigia islandica* which is an arctic plant and characteristic of open habitats. On the basis of comparisons with other Lateglacial sites, the Burn of Benholm peat layer was assigned to pollen zone II.

Sites occurring within the Loch Lomond Readvance limits at Gartmore and near Oban contained a suite of sediments which had accumulated in the Postglacial. These consisted of highly humified terrestrial or telmatic peats, and/or lake muds overlying clays and gravel deposits. Pollen analysis revealed an initial phase of tundra and open habitat conditions which was interpreted by Donner as representing the closing phase of pollen zone III. This then gave way to a period of birch woodland, which was in turn succeeded by *Quercus*, *Ulmus*, *Corylus*, *Pinus* and *Alnus* indicating the spread of mixed woodland in response to gradually rising temperatures leading to the Postglacial climatic optimum. In these studies, Donner found no trace of *Juniperus* pollen, yet this taxon has been an integral component of all subsequent Postglacial pollen spectra. In particular, a prominent *Juniperus* maximum has been identified in pollen zone IV at the opening of the Postglacial, and is widely regarded throughout western Europe as an important reference level indicating rising temperatures and representing a transition stage in the development towards closed forest (Iversen 1960). However, the general vegetational sequence in the Postglacial could be wholly or partially traced in other Scottish pollen diagrams produced at the time from Strichen and Carnwath Mosses (Fraser and Godwin 1955), from the Beinn Eighe Nature Reserve (Durno and McVean 1959), from Loch Mahaick, Loch Creagh and Lochan nan Cat (Donner 1962) and from a number of shallow peat profiles in the eastern Grampians and Sutherland (Durno 1956, 1957, 1958, 1959).

The first Lateglacial site to be investigated in the area of

Scotland to the north of the Great Glen was at Loch Droma in Wester Ross (Kirk and Godwin 1963). This site lies on the Highland watershed and was significant because of the radiocarbon date from the base of the section which showed the area to have been free of glacier ice by 12,800 B.P. The pollen spectra from the overlying organic sediments indicated affinities with conditions in lowland Lappland and the deposits were therefore assigned to pollen zone II. However, the date of 12,814 B.P. was considered by the authors to be too early for the classical Allerød, and the lower deposits were therefore referred to pollen zone I.

In the Dee Valley to the west of Aberdeen, two sites at Loch Kinord and Loch of Park were analysed by Vasari and Vasari (1968). Both basins contained a full suite of Lateglacial and Postglacial sediments, although a detailed study of the minerogenic deposits was not possible owing to the scarcity of microfossils present. These investigations also produced the most comprehensive macrofossil record for any site in the Scottish Highlands since the early studies of Geikie and Lewis. A further Lateglacial site in Aberdeenshire was described by Durno (1970). At Brimmond Hill near Aberdeen, a profile comprising two horizons of peat separated by layers of sand and till was uncovered during building operations. Two pollen spectra from the lower peaty stratum displayed characteristics typical of Lateglacial conditions, and this horizon was assigned to pollen zone II on the basis of comparisons with the assemblage at nearby Loch of Park.

The site at Muir Park Reservoir, Drymen, which had been previously analysed by Donner, was re-investigated by Vasari and Vasari (1968), and a complete analysis was carried out on all the sediment types. Again the characteristic open habitat conditions could be recognized, the arboreal pollen total never exceeding 20% of total land pollen at any level in the Lateglacial deposits. The diagram was notable however, for the significant percentages of Juniperus pollen in zones II and IV, an occurrence not recorded by Donner. In central Scotland, a Lateglacial site at Corstorphine near Edinburgh was described by Newey (1970). Despite the lowland situation of this particular site, tree pollen frequencies never exceeded 15% of the total land pollen even during pollen zone II. A similar phenomenon was recorded by Moar (1969) from a number of sites in apparently favoured and sheltered localities in southwest Scotland. Thus, the spread of birch woodland, widely reported during pollen zone II in many English diagrams, seems to have been somewhat restricted in its northward distribution. Moreover, the heathland communities which characterise many Highland diagrams during the Allerød period, seem to be poorly represented in these sites in central and southern Scotland. Instead, pollen zone II in these areas appears to have been a period of closed grassland (Newey 1970).

At sites where a complete Postglacial profile is preserved, notably in the Edinburgh area (Newey 1965, 1968), in the southwest of Scotland (Moar 1969), at Drymen and in the Dee Valley, the progression from open habitat conditions through to closed woodland can be traced. However, the transition from birch to mixed forest which is characteristic of the lowland pollen diagrams and, which corresponds very closely to the Godwin scheme, is not always so clearly represented in diagrams from the Highlands. Indeed, although they all zone their pollen diagrams on the basis of the Godwin-Jessen system, Donner (1957), Durno (1959) and Vasari and Vasari (1968) all express reservations over the use of this zonation scheme for Scottish pollen diagrams.

This general dissatisfaction with the traditional method of zoning pollen diagrams, not just in Scotland, but in Britain as a whole, has been reflected in the adoption in the last few years, of an assemblage zone system to divide pollen profiles from Scottish sites. In a series of papers dealing with the Postglacial history of vegetation in Scotland, H. H. Birks describes pollen sites at Abernethy Forest, Inverness-shire (1970), in the Galloway Hills (1972a) and at Loch Maree, Wester Ross (1972b). Each profile is divided into local pollen assemblage zones based on empirical analysis of the data, and these zones are then related to similar assemblages recorded in other diagrams. These studies are also of interest in that each pollen or spore type is identified to the lowest possible taxon within the British Flora. Thus, whereas before, most pollen diagrams had been constructed on the basis of plant families, genera and occasionally species, many taxa could now be discussed at the species level.

A similar approach was adopted by H. J. B. Birks (1973) in an extremely detailed study of the past and present vegetation of the Isle of Skye. He investigated five sites, four of which contained deposits of Lateglacial age. One of the Lateglacial sites, at Loch Fada, had been studied by Vasari and Vasari (1968), but only Postglacial deposits had then been found. Again an attempt was made to identify each pollen and spore type to the lowest taxon, but this proved considerably more difficult in the Lateglacial sediments owing to the poor state of preservation of many of the grains encountered. Birks also divided the profiles into local pollen assemblage zones which he was then able to correlate from one site to the next, and with which he was able to draw parallels with previously published diagrams from the Scottish mainland.

The assemblage zone system as a basis for subdivision was also employed by Pennington and other workers (Pennington and Lishman 1971; Pennington _et al._ 1972) in a series of studies on lake sediments in northern Scotland. Samples were taken from the beds of Loch Tarff near the Great Glen, and Lochs Sionascaig, Craiggie and Borallan in Sutherland. The Lateglacial sections of the cores were divided into:-

1) Pre-interstadial. Pollen Zone A.

   A _Rumex_ zone, from the lowest polleniferous sediment up to the first major expansion of woody plant pollen.

2) Interstadial. Pollen Zone B.

   The pollen spectra is characterised by woody plants, although the landscape is regarded as having been largely treeless.

3) Post-interstadial. Pollen Zone C.

   An _Artemisia_ zone containing the highest percentage of _Artemisia_ in the profile with characteristic associates.

The authors pointed to the lack of arboreal pollen in the cores and, comparing these sites with the absolute pollen diagram from Blelham Bog in the Lake District (Pennington and Bonny 1970), they interpreted the pollen spectra as produced by a locally treeless vegetation, and the tree pollen that was present as the product of long distance transport. The effect of long distance pollen on the modern pollen rain of northern Scotland has been demonstrated by recent studies in the Shetland Islands (Tyldesley 1973a, 1973b, 1973c). There, the regional pollen rain has been shown to contain significant quantities of arboreal pollen despite the treeless nature of the Shetland landscape, and it is suggested that Scandinavia is the likely source area for this tree pollen.

The low values of Ulmus and Quercus, and the virtual absence of other deciduous tree pollen in the profiles from the northern Scottish lochs during Postglacial times, led to the development of a system of regional pollen assemblage zones for the area. Six zones were distinguished, and these were subsequently dated by radiocarbon. They can thus be considered as chronozones (West 1970). Thus far, this is the only area of Scotland where a chronozone system has been developed, but dates have been published for a sequence of Flandrian assemblage zones at Din Moss in Berwickshire (Switsur and West 1973).

The studies of Pennington and others introduced to Scotland a number of techniques other than pollen analysis which had been developed and used in the Lake District. Diatom analysis was carried out and the results compared with palynological data. Chemical analysis, using the methods of Mackereth (1965, 1966) were undertaken initially on the iodine content of lake sediments as an indicator of former precipitation levels (Pennington and Lishman 1971), and subsequently on the distribution of alkali bases in the profiles (Pennington et al. 1972) which yielded information on the rate of erosion of the catchment areas of the basins through time. Thus, a number of techniques were now available to aid in the interpretation of former environmental conditions, and these recent studies represent a considerable refinement in the analysis and reconstruction of the landscape of the past.

THE FRAMEWORK OF THE INVESTIGATION

While the overall aim of this study is to present a geographical interpretation of the environment that existed in a part of the Grampian Highlands at the close of and immediately following the Late Devensian period, the results of previous research into related topics provide a number of guidelines for the project.

Firstly, although the nature and form of the Loch Lomond Readvance is still the subject of some debate, there is general agreement on the timing of the event. Moreover, Donner's method of selecting pollen sites on either side of the presumed readvance limits seems an acceptable one for the dating and delimiting of this advance. However, while it is apparent that the occurrence of a Lateglacial site beyond an end moraine is proof that Loch Lomond Readvance ice did not pass beyond that limit, the lack of Lateglacial sediments within the presumed limits does not, by itself, constitute evidence for the absence of glacier ice during the Lateglacial period. It may well be that accumulation had been delayed, or that the deepest part of a particular site had not been discovered and thus the sediments of Lateglacial age had not been found.

In the present investigation, therefore, attention is focussed on sites outside the presumed Loch Lomond Readvance limit, for the location of a number of Lateglacial sites immediately places severe areal constraints on the limit of a readvance. Moreover, the emphasis of the study is placed on the analysis of the Lateglacial environment, and hence sites that contain a sequence of Postglacial sediments only are of lesser importance.

Secondly, previous palaeobotanical studies in the Grampian Highlands have revealed that considerable variation exists in the development of the vegetation cover from one area to the next. In the Lateglacial, for example, the development of extensive heathland tracts appears to have been a phenomenon of the northern and western Grampians, while the south and east were characterised by closed grassland. In the Postglacial, the development and distribution of the ancient Caledonian pine forest seems to have been restricted to the north and west of the main Grampian watershed, while the south and east facing slopes saw the gradual expansion of mixed woodland. Thus the sites for the present project were selected at localities around the main Grampian massif in order to obtain as much information as possible on the evolution of the vegetation pattern. The aim was then to compare and contrast these results with the data already published in order to effect a regional synthesis of vegetational, and hence environmental history in the Grampian Highlands.

Thirdly, the recent literature has shown the value of analyses other than pollen as important environmental indicators. Thus far, all such investigations have been carried out on sediments obtained from large oligotrophic lake basins in the north and west of the country, and there are no detailed reports of chemical and sedimentological analyses from former small, eutrophic basins. The studies of Mackereth and Pennington have shown that a relationship appears to exist between the proportion of bases present in the sediment of a lake, and the amount of erosion that has taken place around the catchment area. Thus, during periods of intense erosion e.g. pollen zone III, quantities of relatively unleached material were washed into the basins from the surrounding slopes, and thus the quantities of alkali bases present in the sediments would be greater than during periods of relative soil stability e.g. pollen zones II and IV. This hypothesis will be tested during the course of the present study, for, if valid, it adds a further parameter to palaeoenvironmental reconstruction.

Finally, there is the problem of finding an acceptable method of zoning the pollen diagrams. Recent studies have shown that while the Godwin-Jessen system may well be applicable to diagrams from lowland sites, profiles from the Scottish Highlands cannot be zoned satisfactorily on this basis. It would appear from studies by Birks and Pennington that the system of local and regional pollen assemblage zones as discussed by West (1970) offers a more rational alternative.

This method of zonation, with some slight modification, is therefore adopted for the present study. A detailed consideration of the concepts involved is presented in Chapter 3.

Chapter 2

THE STUDY AREA

The area of investigation lies around the margins of the central and eastern Grampian Highlands of Scotland (Figure 4). It is bounded in the east by the valley of the River North Esk and in the west by the A9 Perth-Inverness road through the Pass of Drumochter. Within this region, six sites were chosen for pollen analysis, five of which contained a stratigraphical and vegetational record of the Lateglacial period. Three of the sites are located in valleys orientated approximately northwest-southeast down the southern slopes of the Grampians. These are at Blackness in Glen Esk (Nat. Grid Ref. NO/463786), Roineach Mhor in Glen Clova (Nat. Grid Ref. NO/331728) and Corrydon in Glenshee (Nat. Grid Ref. NO/132674). A fourth site on the southern side of the Grampian massif is at Tirinie in Glen Fender (Nat. Grid Ref. NN/889678). One site was selected for study on the northwest flank of the Grampians, this being by Loch Etteridge in Glen Truim (Nat. Grid Ref. NN/688929), while the only Postglacial site is situated on the col of the Drumochter Pass (Nat. Grid Ref. NN/629762) astride the main east-west Grampian watershed.

Geology

Although some controversy still surrounds the structure and stratigraphy of the Grampian Highlands, it is now possible to present a synthesis which is basically acceptable to most Highland geologists.

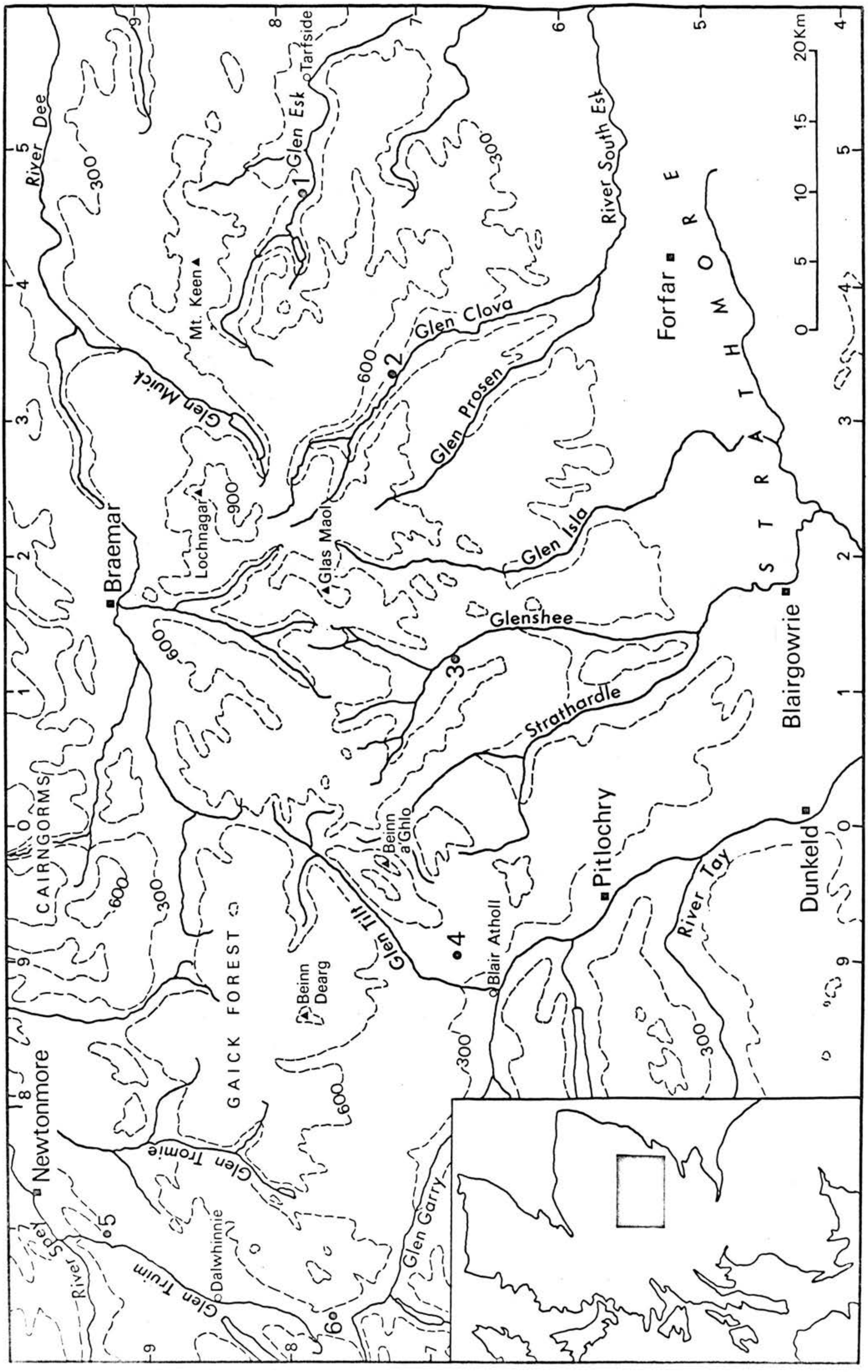
FIGURE 4

The Study Area.

Pollen sites:

1) **Blackness**
2) **Roineach Mhor**
3) **Corrydon**
4) **Tirinie**
5) **Loch Etteridge**
6) **Drumochter**

Contour interval 300 m.


River Dee
Braemar
CAIRNGORMS
GAICK FOREST
Newtonmore
River Spey
Glen Truim
Dalwhinnie
Glen Tromie
Glen Garry
Beinn Dearg
Glen Tilt
Blair Atholl
Beinn a'Ghlo
Pitlochry
River Tay
Dunkeld
Strathardle
Glenshee
Blairgowrie
Glas Maol
Lochnagar
Glen Muick
Glen Isla
Glen Prosen
Glen Clova
Mt. Keen
Glen Esk
Tarfside
River South Esk
Forfar
STRATHMORE
300
600
900
1
2
3
4
5
6
0 5 10 15 20Km

The following account has been compiled from the Memoirs of the Geological Survey written by Barrow, Wilson and Craig (1905), Barrow and Craig (1912), and Barrow, Hinxman and Craig (1913); from the British Regional Geology Handbooks by Read and McGregor (1948), and by Johnstone (1966); and from the texts by Craig (1965) and Bennison and Wright (1969).

The majority of the rocks of the central Grampians are paraschists which, together with a limited amount of other strata, represent part of a thick accumulation of sedimentary rocks deposited on the Archaean basement extending from Ireland to Scandinavia. This belt has been termed the Caledonian geosyncline, the rocks of which are made up of two contrasting facies in the Grampian area. The lower group comprises the Moine Metamorphic Assemblage and is characterised by uniformity of deposits over great vertical thicknesses, probably representing sediments deposited in shallow waters of a steadily subsiding area during an early phase of movement in the mobile belt. The sedimentary facies of the Moine Assemblage is dominantly arenaceous with a few shales. No stratigraphic succession has, as yet, been made out in them and they are mapped on a lithological basis only as psammitic granulites (metamorphosed sandstones represented by quartzites or quartz-rich rocks), pelitic schists (metamorphosed shales) and undifferentiated schists. These rocks make up most of the north, central and northeast part of the metamorphic area of the Grampians and are thought to be of late Pre-Cambrian age.

The upper group of geosynclinal sediments is termed the

Dalradian Metamorphic Assemblage and is characterised by considerable vertical variation of diverse rocks probably representing deposits accumulating in the later more rapidly subsiding geosyncline proper. This Assemblage is divided into Upper and Lower Dalradian, and in spite of regional lithological variations, the general stratigraphic succession can be traced throughout Scotland. In the southern Grampians, the Lower Dalradian is characterised by an upward sequence of pelites, quartzites, impure limestones, quartzites, carbonaceous schists, pelitic and calcareous schists and finally psammitic schists. The Upper Dalradian is represented in the same area by calcareous limestones, pelitic schists and psammitic grits. These rocks comprise the entire southern and southeastern part of the metamorphic area of the Grampian Highlands, and are thought to be late Pre-Cambrian to late Lower Cambrian in age. For the most part they appear to be conformable on the underlying Moine Assemblage, but the stratigraphical relationships of the two assemblages are not known with absolute certainty.

The Caledonian Orogeny folded and contorted the strata deposited in the geosyncline and the mountain chain which arose as a result was termed the Caledonides. The folding was polyphase and lasted until late Silurian times, possibly continuing until the mid Devonian. The metamorphic rocks of the Grampians form part of the Early Caledonides mountains in which the main tectonic episode was over prior to the deposition of the lower Old Red Sandstone. In the Early Caledonides, one phase of folding was characterised by recumbent folds and nappes resembling structures found in the Alps and Rocky Mountains at present.

Associated with the Caledonian Orogeny is a great suite of both intrusive and extrusive igneous rocks. In the Grampians, the representatives of this suite make up a considerable proportion of the area and comprise members which, with respect to the Early Caledonides, are pre- and early tectonic, late- and post tectonic. Syntectonic migmatites are extensively developed. The pre- and early tectonic groups are now found mainly as hornblende schists and epidiorites (e.g. in Glen Clova) and were probably basic intrusions and lavas. The syntectonic migmatite complexes now occur as granitic or granodioritic masses (e.g. Glen Clova and Glenshee), while late and post tectonic igneous activity is represented by basic or acid plutons and plutonic complexes together with minor intrusions and some lavas (e.g. Lochnagar and the Cairngorms). In some areas, igneous activity may well have extended into lower Old Red Sandstone times.

Along the Highland Border, the metamorphic and igneous rocks of the Grampian Caledonides are overlain by Old Red Sandstone sediments, derived largely from erosion of the mountain chain. These consist mainly of conglomerates and sandstones, but are also interbedded with lavas and ashes of the post-tectonic igneous activity referred to above. The Highland Boundary Fault became active at this time, throwing the sediments of lower Old Red Sandstone age down against the Schists and other rocks of the Grampians. Movement was also instituted along several other north northeast trending wrench faults, the most important one in the study area being the Loch Tay - Glen Tilt Fault.

No major faulting took place in the Grampian Highlands from Old Red Sandstone times onwards, and later movements seem to have been confined to broad folding or displacement along faults of a relatively stable block consisting of metamorphic and overlying sediments. An example of this later period of earth movement is the considerable displacement which took place along the Highland Boundary Fault during the Lower Carboniferous. Much of the later strata has since been removed during one of the long periods of erosion which took place in Old Red Sandstone times.

Physiography

The area of the Grampian Highlands included in the present study is dominated by an undulating plateau between 600 and 900 m which discordantly truncates outcrops of metamorphic and igneous strata. Occasional summits rise above the upper levels of the plateau, the most prominent being the schistose mass of Glas Maol (1075 m), the quartzite peak of Beinn a'Ghlo (1126 m), and the granitic masses of Beinn Dearg (1010 m) and Lochnagar (1154 m). Upland benches and plateaux have been recognized throughout the Scottish Highlands, and their genesis has been the subject of a protracted debate. One school of thought favours the agency of marine planation during a period of pulsed uplift (Hollingworth 1938; George 1965, 1966), while the opposing view holds that the surfaces are essentially sub-aerial in origin (Geikie 1901; Fleet 1938; Godard 1965) and may possibly have formed by a process of slope retreat (Sissons 1960). In the study area, the plateau is well developed between 600 and 850 m around the upper reaches of Glen Clova and Glen Esk, while extensive areas of plateau terrain occur between 700 and 900 m in the area known as the Gaick Forest to the east of the Pass of Drumochter (Sissons 1974).

The present drainage pattern is essentially radial, although the dominant direction of stream flow is either southwards towards Strathmore or northwards into the drainage system of the Spey. All the major valleys have been glacially overdeepened and cut back sharply into the undulating plateau. The most spectacular glacial troughs occur in the east of the study area where Glen Clova and Glen Doll are up to 700 m deep in places, while the upper reaches of Glen Lee and Glen Mark at the head of Glen Esk attain depths of 300-400 m. The western part of the study area is notable for a number of glacial breaches cutting through the east-west Grampian watershed. These include the Pass of Drumochter (Linton 1951) between Glen Garry and Glen Truim, the Loch an Dùin in the Gaick Forest, and the great fault-guided trench of Glen Tilt to the north of Blair Atholl.

The upper slopes of the glens are characterised by large areas of ice-scoured bedrock, with precipitous rock walls around the corries and trough heads. The valley floors are masked by variable thicknesses of ice-contact and fluvio-glacial sediments, with superficial deposits often terminating in a prominent drift limit along the valley sides. Away from the Highland edge, the landscape becomes less rugged as the valleys broaden out towards the Spey lowland in the north and the wide plain of Strathmore in the south.

Climate

The climate of the Grampians, in common with that of the rest of northern Britain, is governed largely by the procession of cyclonic disturbances moving eastwards from the North Atlantic. However, owing to the considerable dissection of the Scottish Highlands, and the resulting complexity of local climates, it is impossible to discuss the climate of the study area in anything but the most general terms.

A large proportion of the area lies over 600 m and land above this limit was shown by Pearsall (1950) to have a sub-arctic climate with a mean monthly temperature below freezing point for seven months of the year, and average temperatures for July of not more than 10°C: i.e. the 600 m contour corresponding approximately to the southern limit of tundra climate. At Dalnaspidal, for example, which is situated near the summit of the Pass of Drumochter, the mean January temperature is 0.4°C while the mean July temperature is only 12.5°C. Relatively milder conditions prevail in the valleys below 600 m. At Fettercairn near the mouth of Glen Esk the January and July means are 1.9°C and 13.5°C respectively, while at Blairgowrie in lower Glenshee the mean temperatures for January and July are 2.2°C and 13.6°C respectively.

Rainfall values are high throughout the Grampian Highlands, with considerable areas in the west receiving over 500 cm per year. In the central Grampians, precipitation decreases progressively from over 200 cm per year on the Gaick Plateau above the Drumochter Pass, to less than 100 cm per year in parts of Glen Esk. Most of the upland plateau receives over 150 cm each year, with more than 55% of this total falling between September and April. Around the margins of the central Grampians precipitation values are much lower, less than 75 cm being recorded in Glen Truim, while less than 60 cm per year fall in parts of Strathmore. A large percentage of the precipitation recorded in the Highland area falls as snow, and although there is no permanent snowline in the Grampians, it is clear that a slight lowering of summer temperatures or a slight increase in summit heights would bring them into the zone of permanent snow (Manley 1959).

Soils

Over most of the Grampian region, the land surface consists of soil-forming materials rather than soil proper. Apart from limited outcrops, there is a lack of calcareous parent material which, along with other processes leads to widespread acidity. Precipitation is high over much of the area which results in excessive leaching, and there is also a great deal of impeded drainage (Odell and Walton 1966). Under these conditions, the dominant soil-forming process is podzolisation. In general, highland valleys show a catena with a sequence of soil types related to slope and soil moisture status, with podzols on lower and middle slopes and blanket peats, skeletal mineral soils, and patterned mountain tundra soils on the upper slopes and plateau areas. Large expanses of frost-shattered bedrock characterise the mountain summits with limited occurrences of iron humus podzols and alpine humus soils.

In the lowlands, soils which exhibit regular profiles are normally found. Most of these are podzols of various types, but occasionally brown forest earths occur. This latter group is restricted to parent materials of a high base-status (Fitzpatrick 1964). On the flatlands bordering some of the lochs and rivers, alluvial and meadow soils occur, but where waterlogging is frequent, gley soils tend to predominate. Overall, the acid rocks of the Grampians give rise to soils with a low nutrient content, so that soils with a fertility of agricultural standards are distinctly localised, and restricted more orless solely to the lowland valleys (McVean and Lockie 1969).

Vegetation

By far the most comprehensive works on the present vegetation of Scotland are those by McVean and Ratcliffe (1962) and Burnett (1964), and the following description is based largely on those volumes.

Below 450 m in the central Grampians, heather moor is characteristic of all peaty, poorly-drained areas, while upland heaths are found on free-draining morainic terrain of all aspects. Sphagnum-Eriophorum bog occurs in badly-drained hollows and poor fens of Carex, Eriophorum and Equisetum are found where there is water movement. Above 450 m the pure heaths and heather moors give way to *Calluna-Trichophorum* communities and this transition appears to be encouraged by repeated heather burning in most areas. *Calluna-Eriophorum* bog occupies large areas of flatter ground up to 900 m in this region. On steep slopes which are difficult to burn, a tall *Vaccinium-Calluna* vegetation closely related to the woodland floor vegetation of open fire stands may develop between 300 and 800 m. The heather becomes dwarfed on exposed summits and ridges and, with other prostrate shrubs, forms a lichen-rich dwarf *Calluna* heath from about 670 m to the altitudinal limit of *Calluna* at about 970 m. In places, *Calluna* gives way to *Vaccinium myrtillus* heaths and to *Arctostaphylos* communities above 800 m, but this is largely a function of exposure with *Calluna* being more abundant on north-facing slopes.

Above the *Calluna* limit the vegetation is characterised by *Rhacomitrium* moss heath, while bogs on the high plateau belong to the *Empetrum-Eriophorum* association. Other communities of minor importance in the region are snowbed *Vaccinium* and *Vaccinium-Empetrum* heaths, *Agrostis-Festuca* grassland, alpine *Nardus* grassland, *Juncus trifidis* heaths and montane communities of springs, flushes and late snow beds.

The Glen Clova-Caenlochan-Glenshee area is atypical of the region as a whole. Here, an extensive development of floristically rich *Agrostis-Festuca*, *Nardus* and *Vaccinium* grassland occurs in the glens and on steep hill slopes due to the outcropping of calcareous rocks. Montane willow scrub, *Dryas octopetala* heaths, tall herb and dwarf herb vegetation and floristically rich montane mires are also common.

The central Grampian region occurs within the area of predominant pine forest and to a large extent, the heather moors have been derived from such forests by burning and felling, and by sheep-grazing. The process is still carried on in the Dee and Don Valleys to the east and northeast of the present study area, where pure heather moors have replaced dense pine forests, while *Calluna-Trichophorum* and *Calluna-Eriophorum* bogs probably carried more open stands of stunted trees with juniper scrub up to the forest limit at 600-800 m. Juniper is the characteristic tall shrub of the region in natural and open pine stands, and on heaths and heather moors wherever burning has been moderate. On some moors however, juniper has been confined to irrigated and grazing areas where some protection is derived from fire.

The land use of the study area varies from deer forest and hill sheep farming, with subsidiary grouse and deer interest in central areas, to grouse moors and hill farms towards the peripheral cultivation of the south and east. There are natural forests of birch and pine, with planted conifers in the Dee and Spey Valleys to the east and north. Scots pine (*Pinus sylvestris*) is used extensively in re-afforestation, along with Sitka spruce (*Picea sitchensis*), Norway spruce (*Picea abies*), European larch (*Larix decidua*) and Japanese larch (*Larix leptolis*).

Chapter 3

RESEARCH METHODS

A major aim of the project was to utilise pollen analysis to delimit and date the Loch Lomond Readvance over a large area of the Grampian Highlands, and hence it was imperative that sites should be selected which lay as close as possible to the presumed limits of that readvance. The sites by Loch Etteridge, at Roineach Mhor in Glen Clova and at Drumochter were all located by Dr. J. B. Sissons after detailed analysis of air photographs and subsequent field checking. Loch Etteridge and Roineach Mhor are situated 7-8 km and 1.5-2 km respectively from the presumed Loch Lomond Readvance limit, while the site on the col of the Drumochter Pass lies approximately 2-3 km within that limit. The sites at Blackness in Glen Esk and Corrydon in Glenshee were discovered by the "trial and error" method of driving round the area and making test bores in enclosed basins with a small Hiller type peat borer. These two sites lie approximately 3.5 km and 10 km respectively beyond the maximal extent of Loch Lomond Readvance ice. Finally, the site at Tirinie in Glen Fender was found after analysis by the writer of overlapping stereopair air photographs followed by field investigation. This site is situated approximately 8 km from the presumed Loch Lomond Readvance limit.

A site outside the presumed limit of the Loch Lomond

Readvance was considered to be suitable for pollen analysis if trial borings with the small Hiller borer (chamber length 30 cm) revealed the standard threefold Lateglacial stratigraphy of minerogenic, organic and minerogenic sediments underlying the Postglacial peats and organic lake muds. The site in Glen Clova however, was considered worthy of further analysis despite the absence of organic deposits in the basal minerogenic sediments. The location of the site in relationship to the mapped readvance limits, together with the nature of the minerogenic sediments, suggested that an oscillation may be present in the pollen spectra while not being manifest in the stratigraphy. Subsequent pollen analysis showed that this was indeed the case. Only one site within the limits of the Loch Lomond Readvance was selected for pollen analysis, and the emphasis there was placed on obtaining samples from the deepest part of the basin (Drumochter)

FIELD METHODS

Once a site had been selected for pollen analysis, the following field techniques were employed.

Trial borings were first made to determine the depth of the site, and the actual sampling was carried out at the deepest point found. Four of the sites, Blackness, Corrydon, Drumochter and Loch Etteridge were sampled using a large Hiller type borer with a 50 cm by 3 cm diameter chamber and 1.5 m alloy extension rods. A square of vegetation was removed from the surface of the site and alternate borings were made at either end of the recess between 25-30 cm apart. After the borer was raised, the chamber was cleaned and samples were taken from the inner part of the core at 5 cm intervals or, where a marked stratigraphic change occurred, at 2.5 cm intervals. Each sample was placed in a clean glass tube which was then corked, marked, and stored in a box prepared for that purpose. After the samples for pollen analysis had been removed, a field examination was made of the material in the core. Any macrofossils were noted and unidentified remains were placed in bottles and brought back to the laboratory for further examination. In order to avoid contamination, the chamber was washed and dried between borings. The samples in the tubes were sealed with paraffin wax to prevent drying out in the period between collection and analysis. Once the detailed sampling had been completed, a traverse was made across the site and the stratigraphy determined at selected points. The data were later used to construct cross-profiles of the basins investigated. However, this part of the field work was not carried out at Corrydon because of extreme difficulties encountered in penetrating the thick minerogenic layer at the base of the organic deposits.

The remaining sites at Tirinie and Roineach Mhor were sampled using a modified Dachnowski Piston Corer with 50 cm by 5 cm diameter chamber, and 1 m long extension rods. This equipment only became available during the later part of the research programme, but is obviously superior to the Hiller type borer in that cores can be removed from the site for detailed examination in the laboratory. At times however, it was impossible to force the large chamber through some of the more resistant minerogenic sediments, and thus one or both of the smaller chambers measuring 25 cm by 2.5 cm and 25 cm by 1.5 cm had to be used: e.g. in Glen Clova where the sediments often consisted of alternating layers of medium and coarse sand.

As with the sites sampled with the Hiller borer, once the exact sampling locality had been determined, a square of surface vegetation was removed, and cores were extracted alternately from holes at either end of the recess. The extension rods on the Dachnowski are graded in 20 cm intervals and some difficulty was experienced in lowering the chamber to the required depth. A solution to this problem was to employ a level and staff as follows. The closed chamber was lowered to the level at which sampling was to begin. The staff was then placed on top of the handle of the extension rods which were protruding above the bog surface, and a reading was taken with the level. The extension rods were raised until the chamber was fully opened, and the whole equipment was then forced downwards until the reading on the staff placed on the handle coincided with the first reading obtained. At this point the chamber was full. The sampler was therefore raised and the core extruded into semi-circular plastic guttering pipe which had been specially cut and labelled for the purpose. The extruded core was sealed in transparent adhesive plastic sheeting so that it was airtight. Clean water was used to wash out the chamber before the operation was repeated. Further readings on the staff ensured that an accurate stratigraphic record was maintained during the removal of successive cores.

A detailed cross-profile was not attempted at either Roineach Mhor or Tirinie owing to the difficulties encountered in penetrating the cohesive minerogenic material at the former site, and the presence of considerable areas of marsh around the actual sampling point at Tirinie.

The modified Dachnowski piston corer was also used to obtain samples for radiocarbon dating at Blackness and Loch Etteridge. At each site, the critical horizons from which samples were to be removed were first located by test bores. A square approximately 40 cm by 40 cm was then described on the ground and the surface vegetation removed to facilitate entry of the large sampling chamber. Four cores were then taken from the corners of the square, extruded into semi-circular drainpipe tubes, sealed and removed to the laboratory where they were stored in a cool room of constant temperature to await further analysis and subsequent despatch to the dating laboratory.

LABORATORY ANALYSIS

a) Analysis of cores

One of the disadvantages of the Dachnowski Piston Corer was that some of the cores tended to be compressed. Where this had happened, it was assumed that the compression factor was uniform along the length of the core and samples were then taken accordingly.

Samples for pollen analysis were removed from the centre of the cores as soon as possible after collection, the usual sampling interval being 2.5 cm or 5 cm. These samples were placed in labelled glass tubes, sealed with paraffin wax and stored ready for pollen preparation. Where pollen analysis was being carried out on cores which had been taken for radiocarbon dating, a sampling interval of 1 cm was used across critical horizons.

Once the pollen samples had been removed, the cores were cleaned and sectioned and a careful note was made of the stratigraphy. Any macrofossil remains were removed and stored at this stage. The cores were then resealed and placed in a cool room to await further analysis.

b) Preparation of pollen samples

Initially, the preparation method recommended by Godwin (1956) was used:-

1. Disintegration of the sediment by heating to 100°C in 10% KOH. Repeated sieving and washing removes humic acids and concentrates the sample in the bottom of the centrifuge tube. In minerogenic samples, the sieving removes the coarse particles from the sample.
2. Removal of silica and silicates by boiling for 5 minutes in 40-60% HF.
3. Treatment with 10% HCl to remove colloidal silicates and silicofluorides followed by repeated washing and centrifuging.

4. Acid hydrolysis of the cellulose by a mixture of 10 cc glacial acetic acid and 1 cc H_2SO_4 conc. at 100°C for up to 30 minutes, followed by repeated washing and centrifuging.

5. Mounting of the centrifugate on a slide after mixing with about 2-3 times its own bulk of safranin-stained glycerine jelly.

Where little or no organic matter was present, the acid hydrolysis stage was omitted and where the sample was purely organic, it was not necessary to boil in HF. Although this method gave fairly satisfactory results, two major modifications were made to improve the degree of pollen concentration and also the clarity of the grains.

In some minerogenic sediments, it was found that the 5 minute boiling period in HF was not sufficient to enable enough pollen to be extracted to provide a reasonably significant count from a sample of normal size. Hence, the method described by Pennington *et al.* (1972) was adopted, whereby the sample was treated for one hour in 40% HF at 95°C. Using this technique, it was often possible to count pollen in material usually classified as non-polleniferous after a normal 5 minute boil.

It was also found that the normal acetolysis method (using glacial acetic acid and H_2SO_4 conc.) was sometimes not sufficient to remove significant quantities of cellulose, nor was it effective in concentrating pollen and spores in certain types of sediment to a degree where a count could be obtained from a standard-sized sample.

Furthermore, the method tended to shrink the grains which led to problems of identification, particularly in Lateglacial sediments which required treatment with HF. Therefore the method of acetolysis recommended by Erdtman (1960) and outlined in Faegri and Iversen (1964) was adopted.

This procedure may be summarised as follows:-

1. Deflocculation and KOH treatment followed by sieving and washing.
2. Dehydration with glacial acetic acid.
3. Treatment with a fresh mixture of 9 parts anhydride acetic acid and one part H_2SO_4 conc. at 100°C for 1 to 1.5 minutes.
4. Washing with glacial acetic acid to prevent reprecipitation of cellulose acetate.
5. Washing and centrifuging.
6. Mounting in the usual manner.

Although this method requires great care, only a little experimentation was needed before satisfactory results were obtained. Not only was the degree of concentration of pollen and spores considerably increased, but the slight swelling induced in the grains by this treatment greatly facilitated identification.

The site at Tirinie contained a suite of sediments rich in calcium carbonate, and it was therefore necessary to pretreat samples from this site in cold 5-10% HCl before commencing the standard preparation.

c) Determination of organic carbon content

The organic carbon content of samples taken from the cores from Tirinie, Roineach Mhor and Loch Etteridge was determined by the absorptiometric method (Walkley and Black 1934) as modified by Metson (1961). In this procedure, the finely-ground sample is treated with $Na_2Cr_2O_7$ solution followed by H_2SO_4 conc. The solution is then diluted with water and left to stand for 4 to 6 hours, after which time it is centrifuged and its absorption is measured on a stable photoelectric absorptiometer. The organic carbon content is then read from standard graphs. A sample size of 0.5 gm of sediment was used in each case.

d) Determination of the cations K, Na, Mg, Ca

The determination of the alkali cations K, Na, Mg and Ca was made on 10 gm of air-dried sample from each of the Tirinie, Roineach Mhor and Loch Etteridge cores. The samples were leached with a solution of ammonium acetate, pH 7, and glacial acetic acid, and the cation determinations made using an EEL 100 Flame Photometer for K and Na, and an EEL 140 Atomic Absorption Spectrophotometer for the Ca and Mg. The Flame Photometer operates on the principle that a metallic salt drawn into a non-luminous flame ionises and emits light of a characteristic wavelength, while the Atomic Absorption Spectrophotometer determines the concentration of an element by its capacity to absorb light of its characteristic resonance while in an atomic state. In each case, the galvanometer readings were related to a graph constructed from standard samples, and the results are expressed in milliequivalents per 100 gm of sediment (Buchman and Brady 1969).

e) Determination of total carbonate content

Laboratory observations of the cores from Tirinie revealed that much of the sediment was rich in calcium carbonate, and an assessment of the amount of carbonate present at each level was made using the Collins Calcimeter. This instrument determines the percentage of carbonate contained in a sample by measuring the amount of gas released by the reaction between the sample and 10 cc of concentrated HCl. A sample size of 0.2 gm was used for samples from levels rich in carbonates, while 2.0 gm of sediment was needed from horizons with a low carbonate content.

f) Particle size analysis

Particle size analysis was carried out on samples from Loch Etteridge, Tirinie and Roineach Mhor. The results of the analysis were to be used primarily to aid in the interpretation of the cation data, for the concentration of metallic bases in a body of sediment will be determined, at least in part, by the amount of colloidal material present (Buckman and Brady 1969). Thus it was of some importance to obtain a quantitative assessment of the proportion of the sediment which lay in the fine silt and clay category.

The pipette method (Krumbein and Pettijohn 1938) was used because it was considered to be the most accurate means of particle size determination. A sample size of 20 gm of dry sediment was used and the relative proportions of sand (> 0.02 mm), medium silt (0.02-0.006 mm), fine silt (0.006-0.002 mm) and clay (< 0.002 mm) were determined. Sodium hexametaphosphate (calgon) was used as the dispersing agent, but in spite of the relatively high degree of buffering (4%), some flocculation of colloids appeared to take place in the carbonate-rich samples from Tirinie. Hence the results obtained from those cores should be interpreted with caution.

g) Preparation of samples for radiocarbon assay

Once the main pollen diagrams had been constructed, further visits were made to the sites at Blackness and Loch Etteridge to obtain samples from critical horizons for radiocarbon assay. A rapid count of 100 grains per level was then carried out to locate precisely the points in the core from which the radiocarbon samples were to be taken. In each case, the pollen fluctuations to be dated coincided with, or could be related to a marked stratigraphic change. A slice of sediment 1.5 cm in thickness was then removed from the same horizon in four separate but identical cores, carefully cleaned, and placed in a labelled polythene bag. At least 100 gm wet weight of material was obtained in this manner and this was considered to be adequate for dating purposes. The basal sample from the Loch Etteridge core was highly minerogenic, and over 200 gm of material was therefore removed, the individual slices varying from 1.5 cm to 3 cm in thickness. The upper sample from the same site was obtained by removing a 4 cm slice from a single core, as a close inspection revealed that in the other cores a "corkscrew" effect had occurred and as a result, the critical horizons could not be located.

Three samples of material from Blackness were sent to the Radiocarbon Laboratory at the University of Hanover, while four samples from Loch Etteridge were despatched to the Scottish Universities Radiocarbon Laboratory at East Kilbride near Glasgow.

POLLEN ANALYSIS

Pollen and spores were counted using a Baker Patholette microscope with a x 40 microplan objective (numerical aperture x 0.7) and x 10 Complan binocular eyepiece tubes. Critical examinations were made under oil with a x 80 Microplan oil-immersion objective (effective numerical aperture x 1.32). Later analysis was carried out using a Vickers M15c microscope with x 10 Complan eyepieces and a x 40 Microplan objective (numerical aperture x 0.7). This microscope possessed a slightly more powerful oil-immersion objective with a magnification of x 100 (effective numerical aperture x 1.25).

Identification of pollen and spores was made with the aid of a reference set of type slides which had been prepared using similar methods to those outlined above. Photographs, drawings and keys in various publications further aided identification. In particular Erdtman, Berglund and Praglowski (1961) and Erdtman, Praglowski and Nilsson (1963) proved to be of great value, while Erdtman (1943), Hyde and Adams (1958) and Kapp (1969) were also of use.

In identifying pollen and spores no attempt was made to go beyond the list of taxa in the keys of Faegri and Iversen (1964). Indeed, the poor state of preservation of many grains, especially in Lateglacial sediments often prevented identification down to this level. However, the following categories require special mention:-

i) *Betula*. No attempt was made to separate *Betula nana* from tree birch on a quantitative basis as the HF treatment obviously altered many of the grains. Thus the pore morphology and characteristic grain size discussed by Terasmae (1951) and Birks (1968) could not be used as diagnostic criteria. However, where a positive identification of *Betula nana* was made, a note was taken, and the occurrence recorded on the pollen diagram.

ii) *Salix*. The writer experienced considerable difficulty in distinguishing between various species of *Salix* and hence no quantitative separation was attempted. However, occasional grains were encountered which could be tentatively identified as *Salix* cf. *herbacea* using the key of Faegri and Iversen (1964) and a type slide. These occurrences were also recorded in the pollen diagrams.

iii) *Corylus-Myrica*. As differentiation between these taxa is dubious even at the electron microscope level (Birks 1973), no attempt at separation was made in this study.

iv) Gramineae and Cyperaceae. No attempt was made to further subdivide these families in spite of the availability of special keys.

v) Filicales. On the diagrams, Filicales represents the total of naked Polypodiaceae spores together with Polypodium (cf. Pennington et al. 1972).

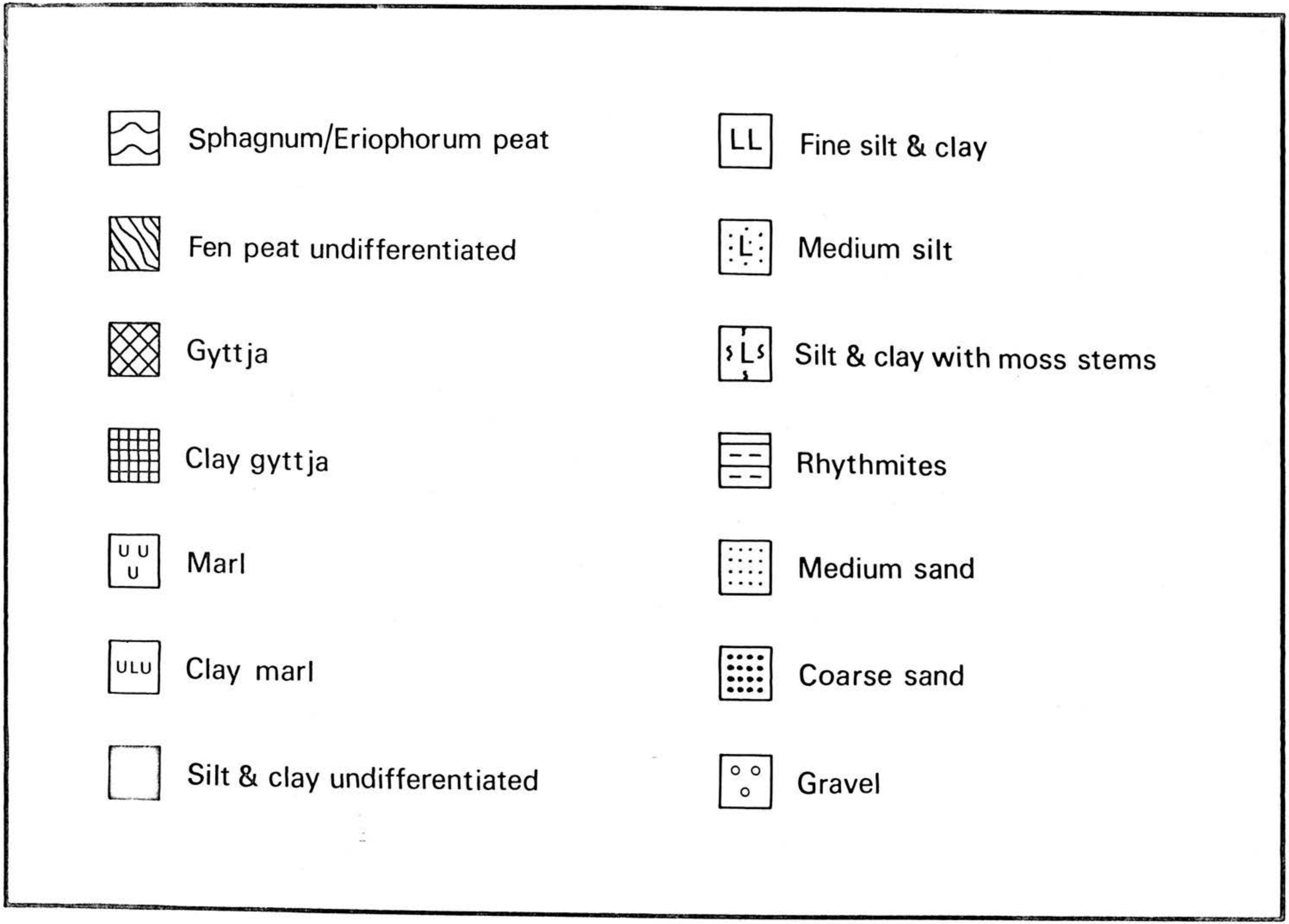
Pollen counts were based on 150 arboreal pollen (excluding aquatics and spores) in Postglacial samples, and 300 land pollen (excluding aquatics and spores) in samples of Lateglacial age. These pollen sums were attained at most levels, although in some Lateglacial horizons where pollen was extremely sparse, a pollen sum of 100 land pollen was used. However, the significance of the counts at these levels is obviously lower, and subsequent interpretation of the former vegetation pattern therefore less reliable. At some levels, less than 10 grains per slide were recorded in spite of repeated preparations. For the purposes of this study, such levels were regarded as non-polleniferous and are indicated as such on the pollen diagrams.

THE POLLEN DIAGRAMS

The results of analyses are presented in the form of pollen diagrams and a similar format is maintained throughout to facilitate comparison. The sediment symbols were devised by Faegri and Gams (1937) and are listed in Faegri and Iversen (1964), but it was found to be necessary to slightly modify the original symbols at times and even to devise new ones e.g. the symbol for rhythmites used at Roineach Mhor (Figure 5). The same sediment symbols are used in the diagrams of cross-profiles of the sites. An estimate of pollen concentration at

FIGURE 5

Sediment and peat symbols used in the present study (modified after Faegri and Gams 1937).


Sphagnum/Eriophorum peat
Fen peat undifferentiated
Gyttja
Clay gyttja
Marl
Clay marl
Silt & clay undifferentiated
Fine silt & clay
Medium silt
Silt & clay with moss stems
Rhythmites
Medium sand
Coarse sand
Gravel

each level is provided by a curve depicting the number of slides taken to complete a pollen count. Where isolated grains occur, these are represented by letters on the diagrams and not as parts of individual pollen curves.

DIVISION OF THE PROFILES

All the diagrams were divided on the basis of biostratigraphic criteria and not on lithostratigraphy as had been common in some of the earlier Scottish pollen diagrams (e.g. Donner 1957). However, a biostratigraphic boundary often coincided with a marked stratigraphic change, but this in no way influenced the placing of the boundary line. Thus the diagrams are divided into a series of biozones, each reflecting a particular assemblage of plants at a particular time period.

It has long been customary to divide all British pollen diagrams into a series of zones based on the concept that climatic change is reflected in broadly synchronous changes in vegetation patterns (Godwin 1940, 1956; Jessen 1949). The division was first attempted in Scandinavia by von Post (Munthe, Hede and von Post 1925), who related pollen curves to the Blytt-Sernander sequence of climatic episodes. In so doing, he described a series of pollen assemblage zones which were then ascribed to a particular time period. An assemblage zone is defined as "a body of strata characterised by a certain assemblage of fossils without regard to their ranges" (Cushing 1967). The problem with a series of such zones is obviously one of correlation, for with differing vegetational development in different geographical localities, there is often no sound basis for comparison. Regional parallelism was put forward by Godwin (1934) and von Post (1945) as a basis for broad correlations, but recent work from the Scottish Highlands has shown this concept to be far from satisfactory.

West (1970) advocated the use of chronozones to serve as the basis for wider correlations and, while this must be considered a valid alternative, it does require a large number of radiocarbon dates on critical horizons at type sites throughout the country. The difficulties inherent in this scheme are therefore considerable. In Scotland for example, there are only two sites which could be considered as type sites. These are at Loch Sionascaig in Sutherland (Pennington et al. 1972), and Din Moss in Berwickshire (Switsur and West 1973). However, as each is supposed to be representative of a limited area only, neither site can be used as a reference site for the development of a chronozone system in the Grampian Highlands.

The most satisfactory approach thus far encountered in the division of Highland profiles is the one advocated by Pennington et al. They suggest that as the Godwin-Jessen scheme is not applicable to large areas of Scotland, pollen zones should be defined in terms of biostratigraphic units, but wherever possible, the profiles should be divided into time units (chronozones) and changes discussed in relation to periods of time rather than zones of any kind. In the present study, the lack of radiocarbon dates, particularly for the Postglacial period, prevented the establishment of a chronozone system, and hence it became necessary to divide the diagrams into broad assemblage zones. In the Lateglacial profiles, however, it was often possible to distinguish time periods both on the basis of dates obtained from the present sites and also from sites in adjacent areas. In either case, the method differs from the Godwin-Jessen scheme in that the approach to the zonation system is essentially an inductive one. Each site is studied in isolation and pollen assemblages identified before a broader assemblage zone scheme for this area of the Grampian Highlands is drawn up. Once these broad assemblages had been established, it was then possible to make comparisons with similar assemblages in other parts of Scotland and northern England.

a) Division of the Lateglacial profiles

Under the traditional system, the Lateglacial period was seen as an initial cold phase (pollen zone I), a mild period (pollen zone II/Allerød) and a colder pollen zone III. On this scheme, the I/II boundary is dated at ca. 12,000 B.P. Using sites in western and central Britain, Coope and others (Coope, Morgan and Osborne 1971; Coope and Brophy 1972; Harmsworth 1968; Osborne 1972) have concluded from Coleoptera and Cladocera studies that the period of maximum warmth was reached during the later part of pollen zone I, while Pennington and others (Pennington 1970; Pennington and Bonny 1970; Pennington and Lishman 1971; Pennington et al. 1972) have concluded from pollen, chemical and diatom analysis that milder interstadial conditions began perhaps 1000 years before the onset of classical pollen zone II. The following table lists the radiocarbon dates from sites in northwest Britain which lend credence to this hypothesis of early warming in Lateglacial times.

Table 1

Date	Locality	Material	Reference
12,810 ± 180 B.P.	St. Bees, Cumberland	Detritus mud in sand	Godwin and Willis (1959)
12,510 ± 170 B.P.	St. Bees, Cumberland	Basal organic mud in cliff section	Shotton and Williams (1973)
12,750 ± 120 B.P.	Callander	Basal gyttja in kettle hole	Lowe (unpublished)
12,814 ± 155 B.P.	Loch Droma	Basal organic mud in monolith	Kirk and Godwin (1963)
12,940 ± 250 B.P.*	Lockerbie	Organic layer in folded till	Bishop (1963)
12,150 ± 120 B.P.	Isle of Man	Gyttja - base of "zone II"	Dickson et al. (1970)
14,330 ± 230 B.P. 14,280 ± 230 B.P.	Blelham Bog	Lowest organic mud in kettle hole	Pennington and Bonny (1970)
14,468 ± 300 B.P.	Glanllynau	Moss layer at base of Lateglacial sequence	Coope and Brophy (1972)

* A second radiocarbon assay on material from this site yielded a date of 3847 ± 60 B.P. (Shotton et al. 1967).

Moreover, recent studies on the microfauna of the ocean bed sediments in the North Atlantic have revealed that the early deglacial warming of the North Atlantic waters had begun before 13,000 B.P. and that by 12,500 B.P. the flow of temperate waters along the coast of Western Europe had become well established (Ruddiman and McIntyre 1973). It is therefore advisable to abandon the classical pollen zone I/II/III scheme and to consider the Lateglacial period in terms of a cold Stadial (previously termed pollen zone III) preceded by a milder Interstadial[3]. In the study area, it is possible to recognize the following generally-defined pollen assemblage zones based on this concept:-

a) A zone characterised by woody taxa, notably Betula, Juniperus and Empetrum, indicative of generally mild conditions which prevailed in the study area during the Lateglacial Interstadial. The early part of the zone (conventionally interpreted as pollen zone I) is represented by a pollen assemblage suggestive of a pioneer vegetation characterised by Rumex and Salix cf. herbacea. The presence of Artemisia in small quantities is indicative of an initial period of soil instability.

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[3] The term Stadial refers to a climatic episode within a glaciation during which a secondary advance of glaciers took place (American Commission on Stratigraphic Nomenclature 1961, p. 660). The term Interstadial is commonly accepted as a short milder phase within a glacial period (Sparks and West 1972), during which forestation did not reach the current level (Luttig 1965), and during which a secondary recession or stillstand of glaciers took place (American Commission on Stratigraphic Nomenclature 1961, p. 660).

b) A zone dominated by herbaceous pollen, notably *Artemisia*, with significant percentages of Caryophyllaceae, *Rumex* and Saxifragaceae. This assemblage often coincides with minerogenic sediments that accumulated in the basins during the relatively harsh period of the Lateglacial Stadial. This *Artemisia* assemblage has been widely recognized in pollen diagrams from Highland Britain.

c) An early Postglacial *Betula-Juniperus* zone which characterises the early Flandrian at every site investigated and is marked by a prominent *Juniperus* peak with significant percentages of *Betula*, *Salix* and *Empetrum*. This assemblage has been widely reported in pollen profiles from northwest Europe and is indicative of rising temperatures and a transition from the open-habitat of the Lateglacial period to the closed forest of the Postglacial Climatic Optimum (Iversen 1960).

b) Division of the Postglacial profiles

The difficulties of applying the Godwin-Jessen zonation system to Postgalcial profiles from the Scottish Highlands have already been demonstrated, and thus a series of regional pollen assemblage zones were devised based on pollen assemblages at individual sites. These are:-

a) Betula-Juniperus zone. This zone is characterised by values of up to 100% arboreal pollen (A.P.) for *Juniperus*, while *Betula* is the dominant tree pollen. *Pinus* values remain low throughout the zone and Corylus-Myrica appears near the upper contact.

b) Betula-Corylus-Myrica zone. Betula remains the dominant tree pollen while Corylus-Myrica rises to a maximum at all the sites. Pinus values are still low, but percentages of Ulmus and Quercus rise throughout the zone.

c) Closed forest zone. Pinus dominates the pollen spectrum at Drumochter and Loch Etteridge where it exceeds 60% A.P. Betula and Alnus are present in significant amounts, while Ulmus and Quercus are recorded throughout the zone. At Corrydon, the dominant tree pollen is of Betula, although Pinus, Alnus, Ulmus and Quercus are present in significant quantities.

d) Betula-Pinus-Ericales zone. This zone is only present in the Drumochter diagram, where Betula and Pinus exceed 45% A.P. while Ericales attain values of 40% A.P.

INTERPRETATION OF THE POLLEN DIAGRAMS

The interpretation of pollen figures depicted in the profiles is undoubtedly the most difficult part of the whole palynological process, for a variety of problems relating to pollen deposition and preservation have to be taken into account when palaeoecological inferences are being made.

No attempt was made to process the pollen data in any way to account for the differing pollen productivity of different plants. Recent studies in Europe (Andersen 1966, 1970, 1973) have shown that of the trees, Betula, Pinus, Alnus and to some extent Quercus are all high pollen producers, while *Ulmus*, *Tilia* and *Fraxinus* are considerably less prolific. Thus, in the comparison of tree species, it is necessary to remember that *Ulmus* for example will be constantly underrepresented in pollen profiles. As yet there are no detailed analyses on the relationship between arboreal and non-arboreal pollen production, and thus at present there is no numerical basis upon which the A.P./N.A.P. ratios can be expressed (Pennington *et al.* 1972). In any event, Oldfield (1970) has pointed out a number of the problems involved in applying "correction factors" to fossil pollen spectra (e.g. Davis 1963), for often little is known on the scale and complexity of former pollen transfer. With regard to the latter point, the presence of pollen which is clearly the result of long distance transport has been recognized in many Lateglacial pollen diagrams, and it is usually possible to isolate these grains on an intuitive basis.

A number of potential error sources in the interpretation of pollen profiles are related to the accumulation and preservation of pollen grains in lake or peat sediments. Studies on differential pollen preservation (Sangster and Dale 1964) have shown that certain pollen types are less well-preserved in lake and pond sediments, and may thus be underrepresented in the pollen spectrum. *Pinus* and *Betula* for example, were found to suffer very little degradation, while *Populus* was almost entirely destroyed. Fortunately, the results seem to demonstrate that the major elements in the pollen rain undergo little change, and thus errors from this source should be minimal.

A more serious problem in the interpretation of fossil pollen figures results from the inwash and redeposition of pollen grains from around the lake catchment (Cushing 1964; H. J. B. Birks 1970). In general, these grains tend to be highly degraded and as such may often be identified. Where large numbers of degraded pollen grains were encountered, a record was kept, but no attempt was made to separate out corroded and amorphous pollen on a quantitative basis.

It has also been shown (Pennington 1947, 1964; Franks and Pennington 1961) that certain pollen grains e.g. Alnus are present in greater quantity near the lake or pond margins, while other grains such as Pinus are found in greater numbers in central rather than in littoral deposits. In the present study, all samples were obtained from as near to the deepest point in the basin as was possible in order to make the results from the different sites comparable. Also, no absolute pollen analysis (Davis 1965; Bonny 1972) was carried out, and therefore reliable estimates of pollen influx could not be determined. However, a record was kept of the number of slides needed to complete a standard pollen count and thus an index (albeit relatively crude) of pollen concentration was obtained

Finally, no attempt was made to interpret the past vegetation of the study area in quantitative terms. Criticism has been levelled in the past at the essentially intuitive approach of European palaeoecologists (Livingstone 1968), but as has been pointed out (Pennington et al. 1972), changes in the percentage composition of the pollen spectra must clearly reflect changes in environmental parameters, and the value of pollen analysis lies not solely in a technique for detailed reconstruction of past vegetation patterns, but also as a tool for isolating and identifying palaeoenvironmental changes.

Chapter 4

SITES INVESTIGATED

This chapter describes the nature and stratigraphy of each of the six sites studied, and presents the results of palynological and sedimentological analyses. The vegetational record is divided into local pollen assemblage zones, and the criteria for the selection of these zones are put forward. A brief description is also given of the stratigraphical and sedimentological record from zone to zone, and of the type of landscape inferred from the pollen spectra in each assemblage zone. No attempt is made at this stage to compare and contrast vegetational and sedimentological changes in the different sites, nor to discuss the overall environmental implications of the data, as a detailed consideration of these factors constitutes the essence of the following three chapters. Finally, a section is included on the implications of the stratigraphic and pollen record in each of the basins for the glacial sequence in areas of the Grampians around the sites.

1. BLACKNESS

Blackness (Nat. Grid Ref. NO/463786) is situated in Glen Esk, Angus, approximately 3 km west of the hamlet of Tarfside, and

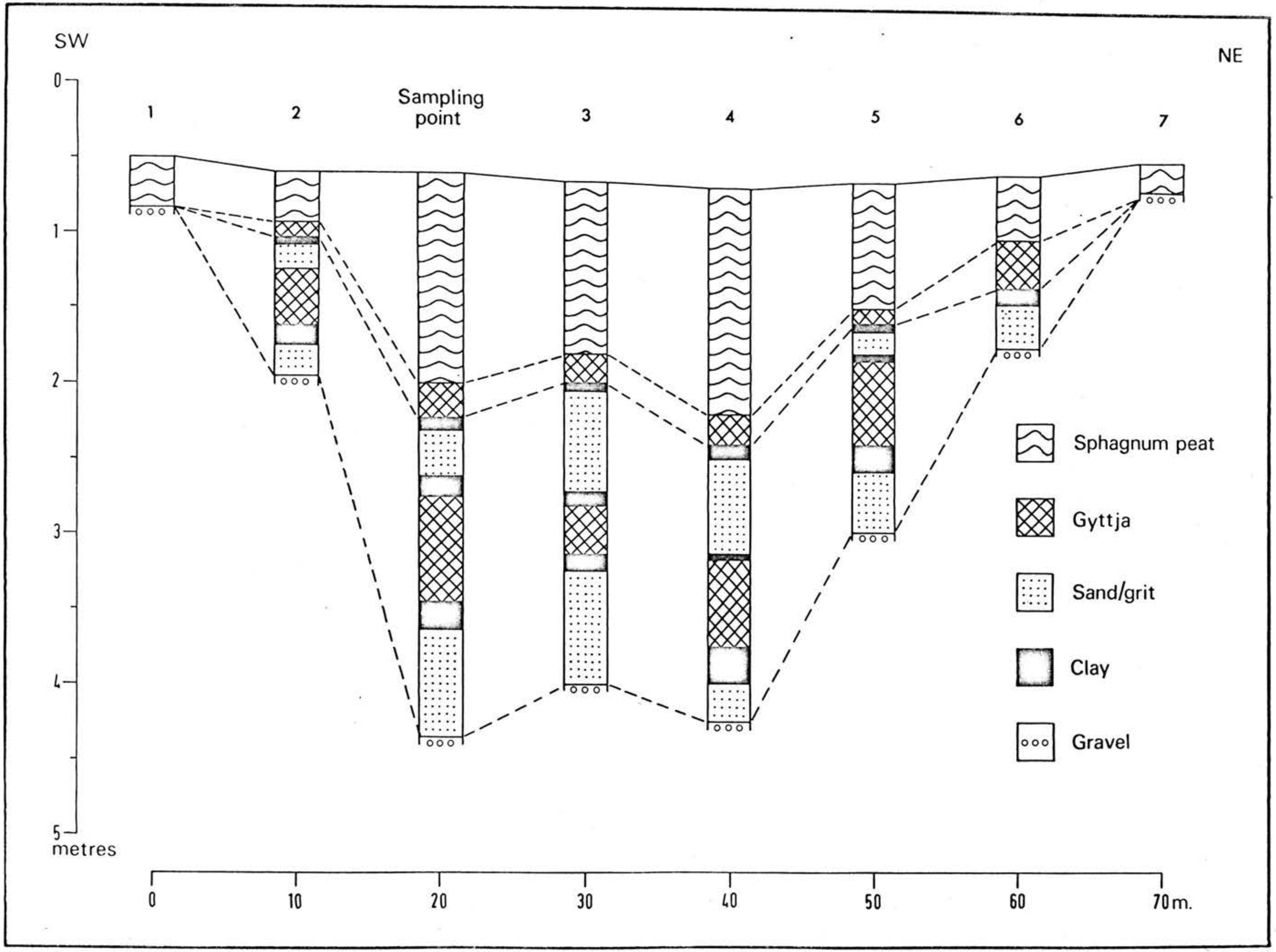
28 km north of Forfar (Figure 4). It lies at 227 m O.D. in an area of undulating topography on the north bank of the River North Esk. The site is a small kettle hole surrounded by ice-contact and fluvio-glacial deposits, and is about 50 m in diameter at the widest point. The surface of the bog is comparatively dry and supports a number of trees of *Betula* spp. with a locally dense understorey of *Myrica gale*. The ground layer is characterised by *Calluna vulgaris*, *Erica tetralix*, *Erica cinerea*, *Festuca ovina* and *Polytrichum* spp., while *Juncus* and *Carex* are found around occasional small pools. *Sphagnum* spp. is also an important element in the vegetation cover.

A series of test bores across the basin revealed a clear stratigraphic sequence in the sediments: basal minerogenic deposits, organic muds, minerogenic material, surface organic layer of lake muds and peats (Figure 6). The deepest point in the site was found to be 370 cm and samples for pollen analysis were therefore taken at that locality. A general description of the stratigraphy at the sampling site is as follows:-

0- 64 cm	Surface sample. Roots and poorly-humified *Sphagnum*-*Eriophorum* peat.
64-138 cm	Very wet, more highly-humified pale brown *Sphagnum*-*Eriophorum* peat. Humification increasing with depth. Seeds of *Betula* and *Potamogeton*, leaf of *Betula*, stems of *Carex* and *Calluna*, and wood possibly of *Betula*.

FIGURE 6

Diagrammatic cross section
showing the stratigraphy of the deposits at Blackness.


SW
NE
Sampling point
1
2
3
4
5
6
7
0
1
2
3
4
5
metres
0
10
20
30
40
50
60
70m.
Sphagnum peat
Gyttja
Sand/grit
Clay
Gravel

138-163 cm	Dark brown organic mud - gyttja, becoming slightly coarser in texture with depth. Very highly humified.
163-170 cm	Fine to medium grey silt/clay, becoming coarser and more micaceous with depth.
170-202 cm	Very coarse micaceous grit. Leaf of *Betula nana*.
202-214 cm	Fine to medium grey silt/clay.
214-283 cm	Very highly humified dark brown gyttja. Leaf of *Salix*, seeds of *Potamogeton* and *Carex*.
283-299 cm	Medium silt, becoming coarser and less organic with depth.
299-369 cm	Very coarse micaceous grit.
370 cm	Gravel.

Six separate pollen assemblage zones were identified in the diagrams (Figures 7 and 8) and the Lateglacial-Postglacial boundary was placed between the upper two assemblage zones. This boundary corresponds very closely with the marked stratigraphical change from minerogenic to organic sediment at 163 cm.

A second visit was made to the site after the initial analysis had been carried out, and eight cores were removed from above and below the uppermost minerogenic stratum for the purpose of obtaining radiocarbon dates from critical horizons. A partial pollen diagram was then drawn up after a rapid count of 100 grains on samples removed

FIGURE 7

Blackness: pollen diagram 1.

BLACKNESS

Diagram 1.

NATIONAL GRID REFERENCE NO 463786 ALTITUDE 227m. O.D.

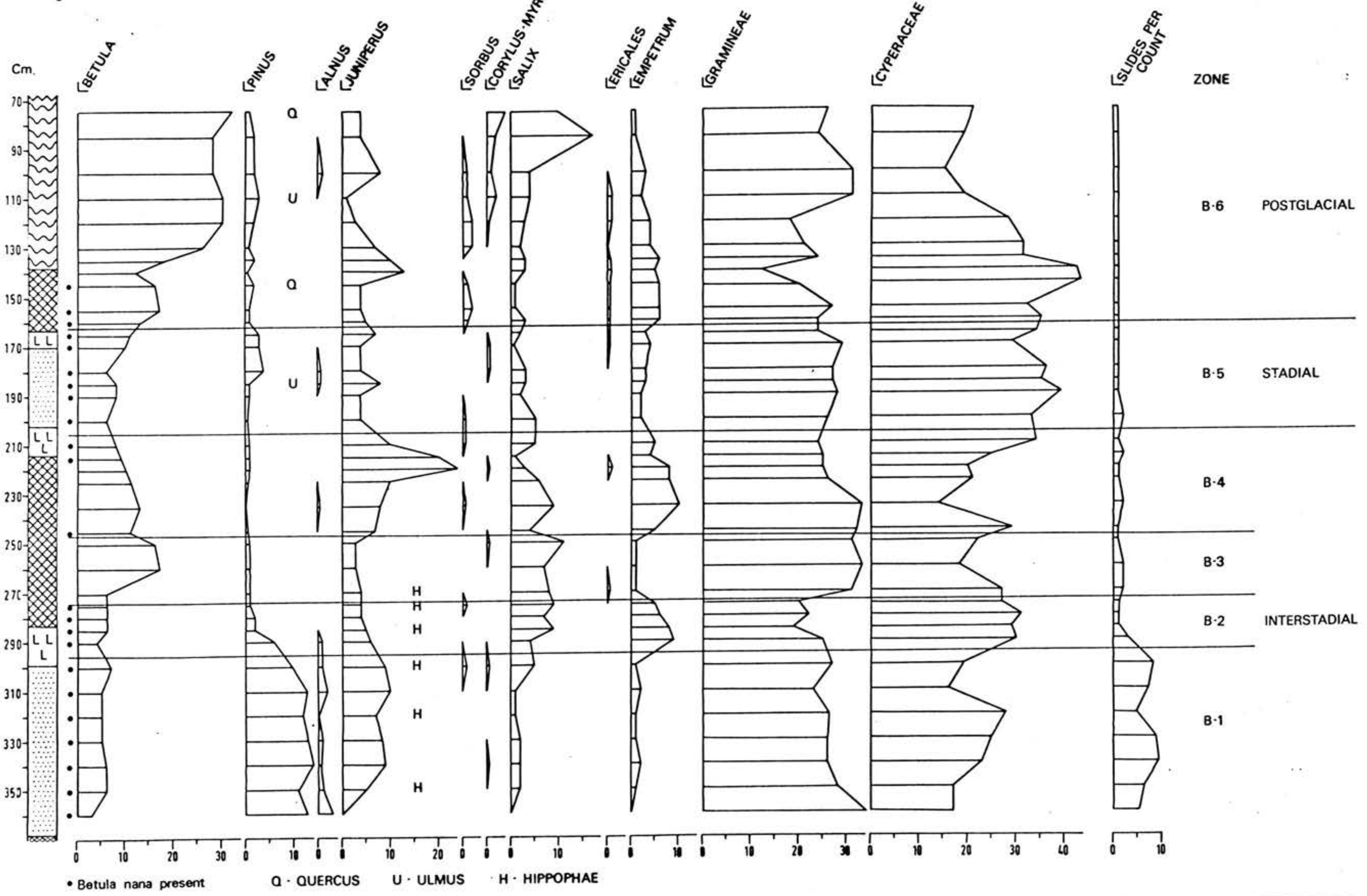


FIGURE 8

Blackness: pollen diagram 2.

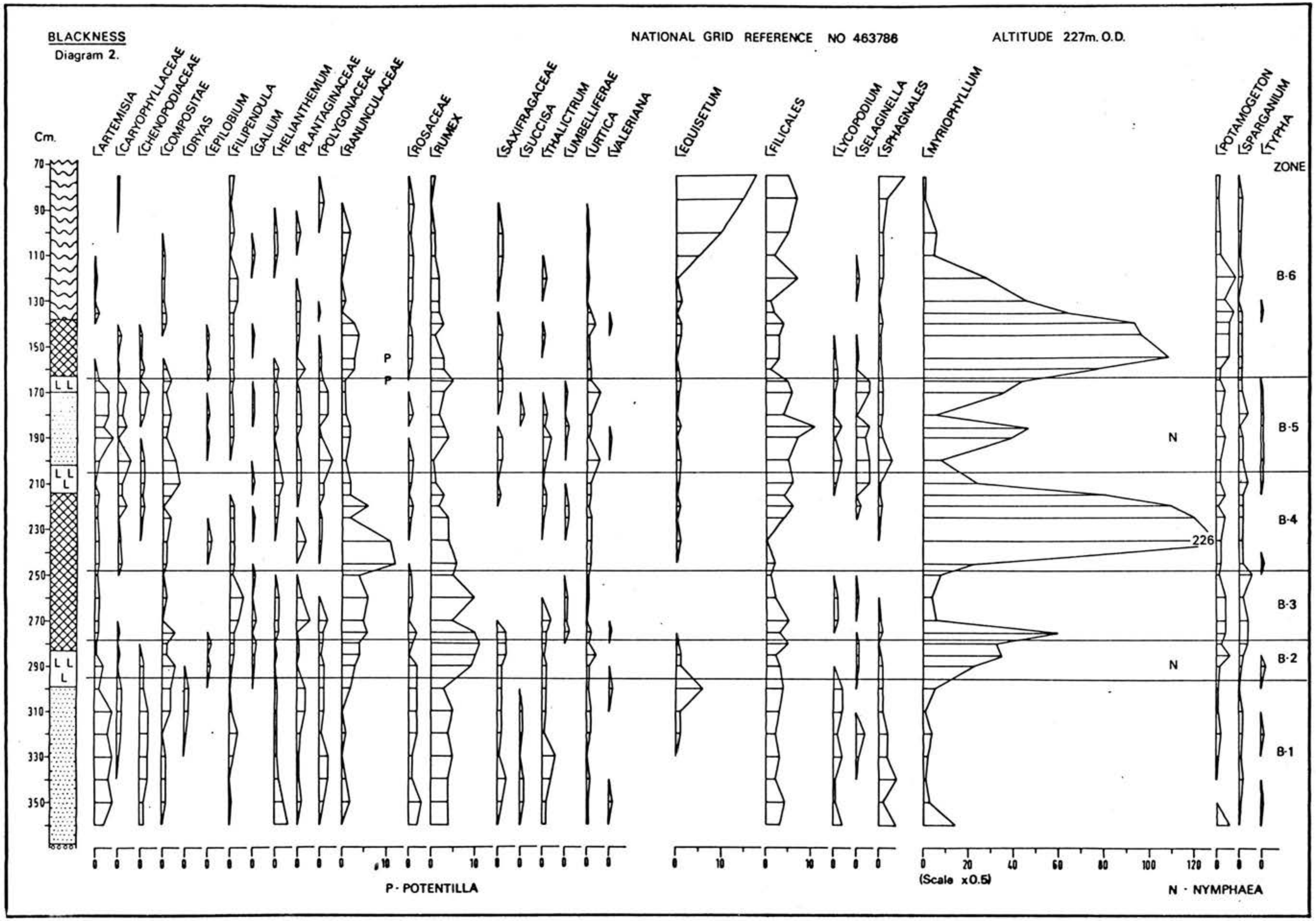
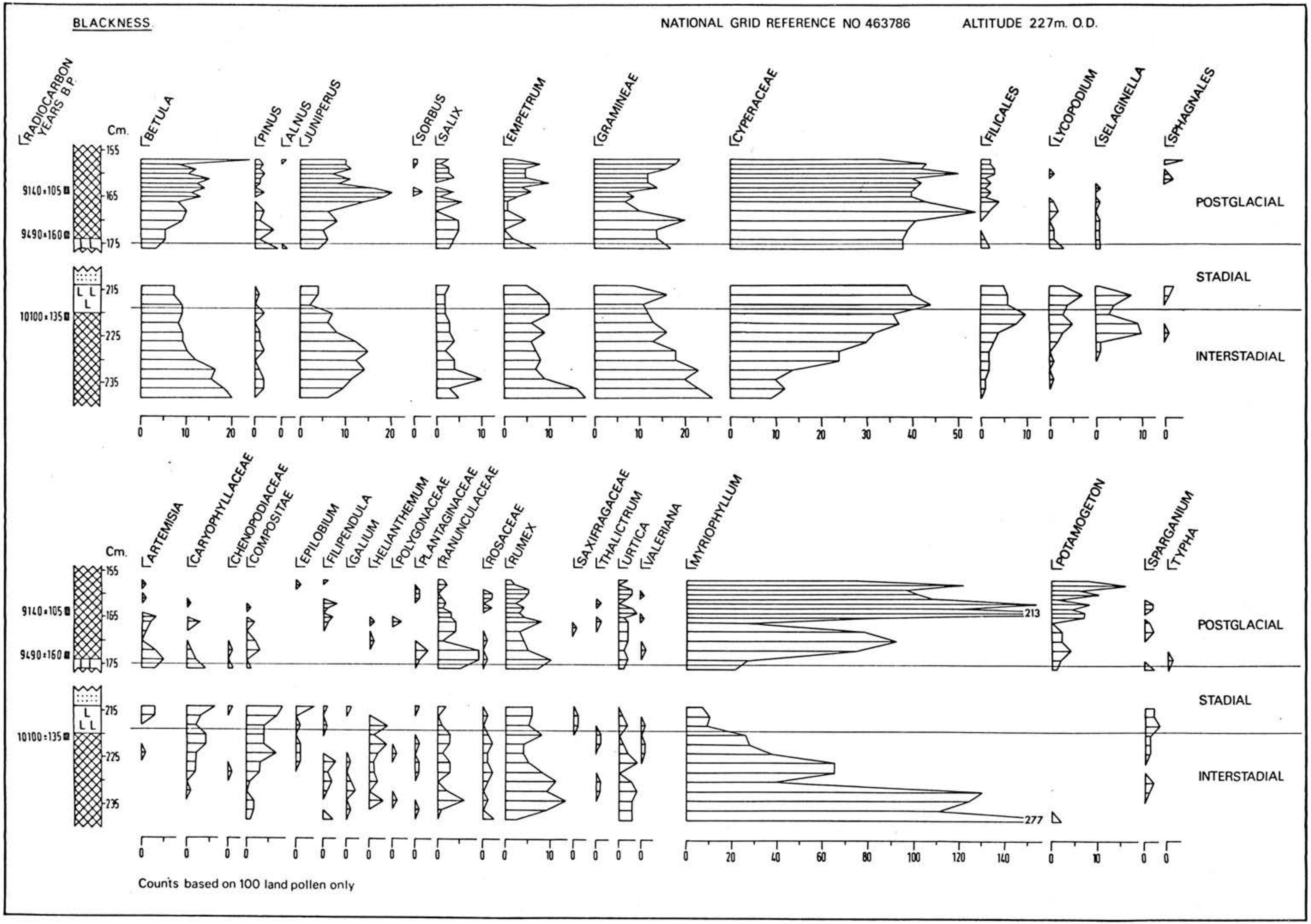

BLACKNESS
Diagram 2.
NATIONAL GRID REFERENCE NO 463786
ALTITUDE 227m. O.D.
Cm.
ARTEMISIA
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITAE
DRYAS
EPILOBIUM
FILIPENDULA
GALIUM
HELIANTHEMUM
PLANTAGINACEAE
POLYGONACEAE
RANUNCULACEAE
ROSACEAE
RUMEX
SAXIFRAGACEAE
SUCCISA
THALICTRUM
UMBELLIFERAE
URTICA
VALERIANA
EQUISETUM
FILICALES
LYCOPODIUM
SELAGINELLA
SPHAGNALES
MYRIOPHYLLUM
POTAMOGETON
SPARGANIUM
TYPHA
ZONE
70
90
110
130
150
170
190
210
230
250
270
290
310
330
350
B-6
B-5
B-4
B-3
B-2
B-1
P
P
N
N
226
0
10
20
40
60
80
100
120
(Scale x0.5)
P - POTENTILLA
N - NYMPHAEA

FIGURE 9

Blackness: partial pollen diagram
and radiocarbon dates.


BLACKNESS.
NATIONAL GRID REFERENCE NO 463786
ALTITUDE 227m. O.D.
RADIOCARBON YEARS B.P.
Cm.
155
165
175
215
225
235
9140±105
9490±160
10100±135
BETULA
PINUS
ALNUS
JUNIPERUS
SORBUS
SALIX
EMPETRUM
GRAMINEAE
CYPERACEAE
FILICALES
LYCOPODIUM
SELAGINELLA
SPHAGNALES
POSTGLACIAL
STADIAL
INTERSTADIAL
0
10
20
30
40
50
ARTEMISIA
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITAE
EPILOBIUM
FILIPENDULA
GALIUM
HELIANTHEMUM
POLYGONACEAE
PLANTAGINACEAE
RANUNCULACEAE
ROSACEAE
RUMEX
SAXIFRAGACEAE
THALICTRUM
URTICA
VALERIANA
MYRIOPHYLLUM
POTAMOGETON
SPARGANIUM
TYPHA
213
277
60
80
100
120
140
Counts based on 100 land pollen only

at 1 and 2 cm intervals from two of the cores. This partial diagram, and the radiocarbon-dated horizons are shown in Figure 9.

Gramineae-Rumex assemblage zone

Zone B-1 370-295 cm

This is the basal pollen assemblage zone in the site and is characterised by high values for Gramineae and Cyperaceae, with significant percentages of *Rumex* and *Artemisia*. The zone coincides with the lower layer of coarse minerogenic detritus which has resulted from the weathering and erosion of the surrounding mica-schists. The presence of these sediments at the base of the stratigraphic sequence suggests a period of landscape instability following the retreat of the Devensian ice-sheet. The pollen spectrum reflects an open environment, with *Artemisia* and associated taxa indicative of disturbed soils coinciding with the virtual absence of pollen of solifluxion-intolerant woody plants. The sparseness of the local pollen rain during this period is demonstrated by the fact that in order to obtain a sum of 300 land pollen, it was often necessary to count five or six slides. The presence of *Betula* and *Pinus* seems to be anomalous, and it is possible that these taxa are the product of long-distance transport (see Chapter 5 for further discussion). The boundary of the zone is placed at the rise in the curves for *Empetrum* and *Myriophyllum* and the decline in values for *Pinus* and *Betula*.

Empetrum-Rumex assemblage zone

Zone B-2 295-270 cm

This zone spans the stratigraphic transition from coarse minerogenic sediment through a band of silty-clay to the beginning of the gyttja deposits. The pollen spectrum is characterised by significantly higher values for woody plants which are thought to be of local origin notably *Salix* and *Empetrum*, by a rising *Rumex* curve, and by a marked increase in aquatic pollen - especially *Myriophyllum* cf. *alterniflorum*, and to a lesser extent *Potamogeton*. The gradual extinction of taxa associated with disturbed soils, the spread of heathland plants and the transition from minerogenic to organic sediment, reflects the closing of the vegetation cover and the stabilisation of the landscape. The high values for Cyperaceae, and the rising curves for pollen of marshland plants - notably Ranunculaceae (mainly *Caltha* cf. *palustris*) and to a lesser extent Filipendula, suggests the formation of a floristically-rich littoral marsh and reed swamp, while the advent of aquatic pollen in considerable quantities may be a reflection of milder environmental conditions. The upper boundary of the zone is placed at the decline in the curve for *Empetrum* to very low levels and the rise in the curve for Gramineae.

Betula-Salix-Gramineae assemblage zone

Zone B-3 270-245 cm

Betula rises to 17% of total land pollen in this zone, while *Salix* and Gramineae maxima exceed 10% and 35% respectively. Some of the Betula is undoubtedly of tree birch which may be of local origin, possibly reflecting the development of birch groves in sheltered localities around the site (see Chapter 5). Although the values for Cyperaceae fall at the beginning of the zone, the high values for Gramineae may indicate the spread of the littoral reed swamp and marsh, and a marked contraction in areas of open water. The sharp drop in Myriophyllum percentages after a peak at the beginning of the zone may thus be a result of this hydroseral succession. The zone is floristically-rich and is characterised by high values for marsh-land taxa. The upper contact is placed at the fall in the curve for Betula, and an initial rise in the curves for Juniperus and Empetrum.

Betula-Juniperus assemblage zone

Zone B-4 245-205 cm

This zone spans the transition from the rich organic gyttja through a band of silty-clay to the upper layer of coarse minerogenic sediment. The zone is characterised by a prominent Juniperus peak (24%), and significant percentages of Betula, Empetrum and Gramineae. Again, a number of the birch pollen resemble tree birch, but the high Juniperus values show that open-heath conditions prevailed in the area at that time. Gramineae values decline towards the upper contact of the zone, and the sharp rise in the curve for Myriophyllum to very high values (224%) may reflect an interruption in the hydroseral sequence and a revertence to open-water conditions. The subsequent fall in values for this taxon towards the upper contact of the zone is probably a function of declining environmental conditions, for the renewed inwash of minerogenic debris at this level coincides with the reappearance of taxa indicative of disturbed soils and open habitats. A radiocarbon date of 10,100 ± 135 B.P. (HV-5642) was obtained from the stratigraphic transition from organic to minerogenic material. The upper boundary of the zone is marked by falling values for woody plants, notably *Juniperus* and *Empetrum*.

Gramineae-Cyperaceae assemblage zone

Zone B-5 205-160 cm

The zone spans the upper layer of micaceous sediment which most probably accumulated in the basin during a period of intense solifluxion under severe periglacial conditions (see below). The pollen spectrum is dominated by Gramineae and Cyperaceae, but the significantly increased percentages of *Artemisia*, Caryophyllaceae, *Rumex* and *Selaginella* which are all indicative of open habitats suggest the former existence of an unstable tundra landscape. Although values for woody taxa are generally low, and much of the *Pinus* and *Betula* is most likely the product of long distance transport, the discovery of a leaf of *Betula nana* at *ca.* 190 cm indicates that some dwarf birch were present in the area at the time. The upper contact of the zone is placed at the sudden disappearance of open-habitat taxa at about 165 cm, coupled with the rise in values for woody plant pollen. A radiocarbon date of 9490 ± 160 B.P. (HV-5649) was obtained from immediately above the stratigraphic change from minerogenic to organic sediment at the upper contact of this zone. This boundary is taken to represent the division between the Lateglacial and Postglacial periods.

Betula-Juniperus-Empetrum assemblage zone

Zone B-6 160-70 cm

This is the uppermost assemblage zone in the site, and covers the transition from the organic lake muds to the accumulation of terrestrial peats. The zone is characterised by significantly higher values for Empetrum, Juniperus and Betula, and reflects the closing of the vegetation cover and the development of closed woodland. The Juniperus maximum was dated at 9140 ± 105 B.P. (HV-5648). The appearance of Corylus-Myrica in the upper levels probably presages the spread of deciduous forest into the area, but the accumulation of sediment in the basin had ceased before this event occurred. The stages in the Postglacial hydrosere are clearly represented in the pollen record, with successive peaks in Myriophyllum, Cyperaceae, Equisetum and finally the rise in the Sphagnum curve. The succession reflects the gradual expansion of the littoral fen into the remaining areas of open water and the final build-up of Sphagnum peat. The high Salix values in the uppermost two counts probably reflect the spread of willows into the site during the final stages of the hydrosere.

Implications for the glacial sequence

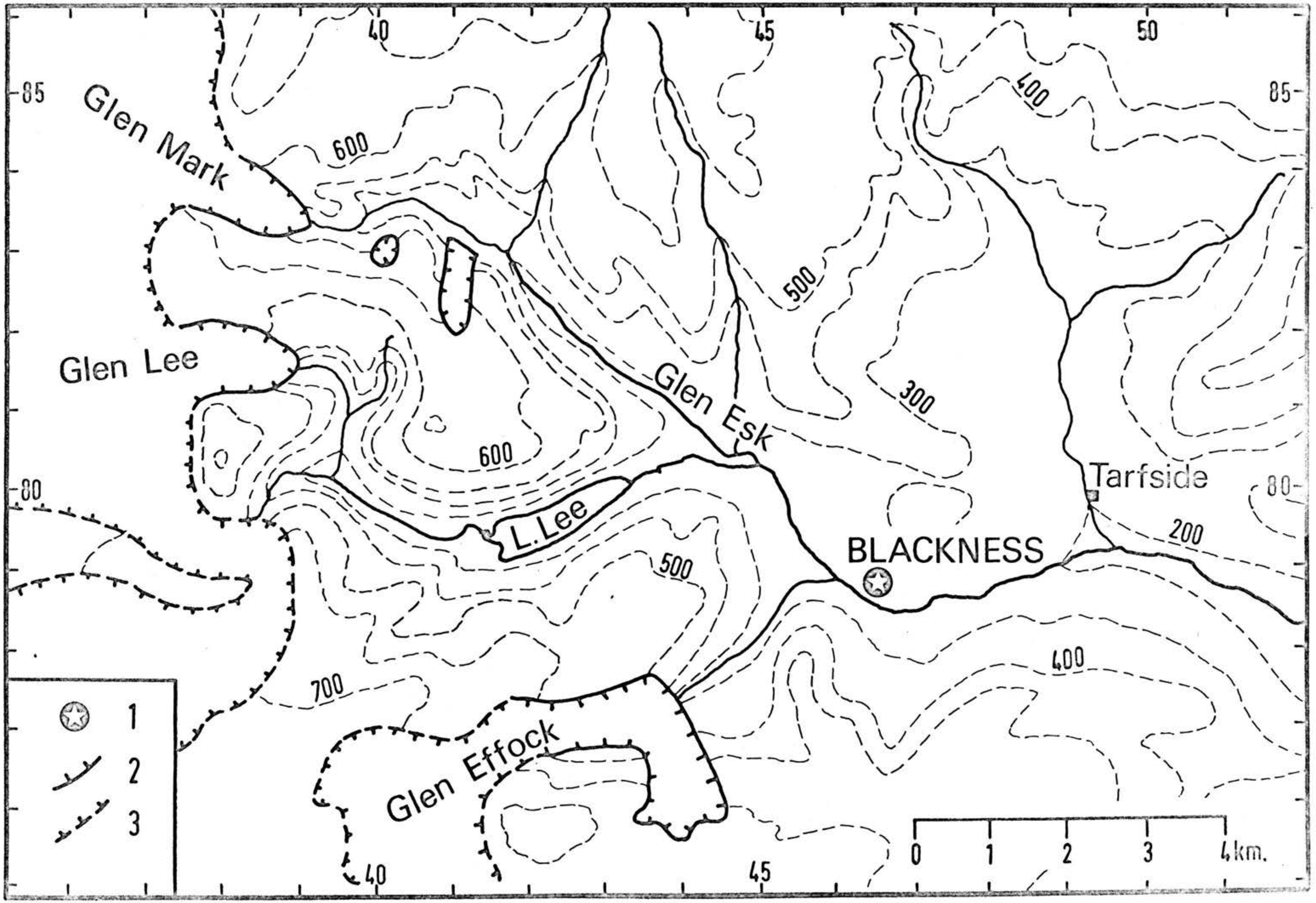
The stratigraphical and vegetational record preserved in the Blackness site is comparable with the Lateglacial sequence

FIGURE 10

The site at Blackness in relation to
Loch Lomond Readvance glacier limits
(after Sissons 1972).

1) Pollen site.
2) Probable glacier limits.
3) Possible glacier limits.

Contour interval 100 m.


40
45
50
85
85
Glen Mark
600
400
500
Glen Lee
300
Glen Esk
600
Tarfside
80
80
L.Lee
BLACKNESS
200
500
400
700
1
2
3
Glen Effock
0
1
2
3
4km.
40
45

observed at other sites in the Scottish Highlands although there is a clear discrepancy between the radiocarbon dates and those obtained from other Scottish sites (see below). The ice-contact deposits around the site must have resulted from the decay of the Late-Devensian ice-sheet, for the site was ice-free at the time of the Loch Lomond Readvance. A series of former ice limits has been identified by Sissons (1972) in upper Glen Effock approximately 3 km southwest of the site, and in upper Glen Lee and Glen Mark respectively approximately 7 km west and northwest of the site (Figure 10). In Glen Effock, a low boulder moraine occurs on the valley floor behind an outwash terrace and this limit is then continued southwards for several hundred metres by a low terminal moraine. On the south side of Glen Lee, a small lake named Carlochy in a corrie-like embayment is surrounded by a gently-curving terminal moraine a few metres high, while in Glen Mark there is a set of almost identical features. As these landforms represent readvance limits (see Chapter 1) and not merely stillstand positions during ice-sheet decay, it is logical to assume that they mark the maximal extent of the Loch Lomond Readvance in this area of the Grampians.

2. ROINEACH MHOR

The site named Roineach Mhor (Nat. Grid Ref. NO/331728) is situated in Glen Clova, Angus, about 0.5 km southeast of the hamlet of Clova, and about 25 km northwest of Forfar (Figure 4). It lies at

228 m O.D. in a depression between two large eskers which are part of a complex system of ice-contact features that cover the valley floor at this point. The basin is roughly oval in shape, and is approximately 70 m in length and 50 m across at the widest point. The bog surface is wet and is characterised by stands of Juncus spp. and Carex spp., with extensive areas of Sphagnum moss. Near the drier margins, Calluna vulgaris and Erica tetralix are common, while stands of Betula spp. are found on the esker sides.

This site, along with a number of adjacent basins, was investigated at an early stage in the research programme, when test bores showed that less than 2 m of sediment were underlain by a coarse minerogenic stratum. This resistant layer appeared to be impenetrable and was thought to be the basal material in the site. In view of the apparent absence of Lateglacial sediment, the site was abandoned as unsuitable for further study. However, the steep-sided nature of the basin suggested that an infill of much more than 2 m should be present and this, coupled with the location of the presumed Loch Lomond Readvance limit near the site (Sissons 1972), prompted a second visit to the area in an attempt to penetrate the coarse layer at approximately 2 m depth. In spite of initial difficulty, this aim was achieved and a further 3 m of sediment was discovered. The stratigraphy at the sampling site was as follows:-

0-150 cm	Surface sample. Poorly humified Sphagnum peat and rootlets.
150-170 cm	Moderately humified Sphagnum peat.

170-187 cm	Dark brown gyttja, very highly humified, stems of *Carex* and a leaf of *Betula nana*.
187-195 cm	Very coarse grit.
195-202 cm	Medium sand.
202-208 cm	Fine sand.
208-218 cm	Silty clay with some sand layers.
218-220 cm	Medium coarse sandy grit.
220-238 cm	Medium silt/sand. Quantities of organic debris - very highly decomposed stems and rootlets. Identification impossible.
238-287 cm	Fine grey silt/clay with occasional layers of fine sand.
287-306 cm	Fine grey silt/clay.
306-348 cm	Alternating layers of sand and silt/clay. Bands of varying thickness - 53 rhythmites counted.
348-354 cm	Fine sand.
354-368 cm	Alternating layers of sand and silt/clay. Bands of varying thickness - 12 rhythmites counted.
368-373 cm	Fine grey silty-clay.
373-386 cm	Alternating layers of sand and silt/clay. Bands of varying thickness - 13 rhythmites counted.
386-430 cm	Fine grey silt/clay with occasional sand lenses.
430-449 cm	Fine grey silty-clay.
449-452 cm	Medium sand.
452-455 cm	Fine grey silty-clay.

FIGURE 11

Roineach Mhor: pollen diagram 1.

ROINEACH MHOR

Diagram 1.

NATIONAL GRID REFERENCE NO 326729 ALTITUDE 228m. O.D.

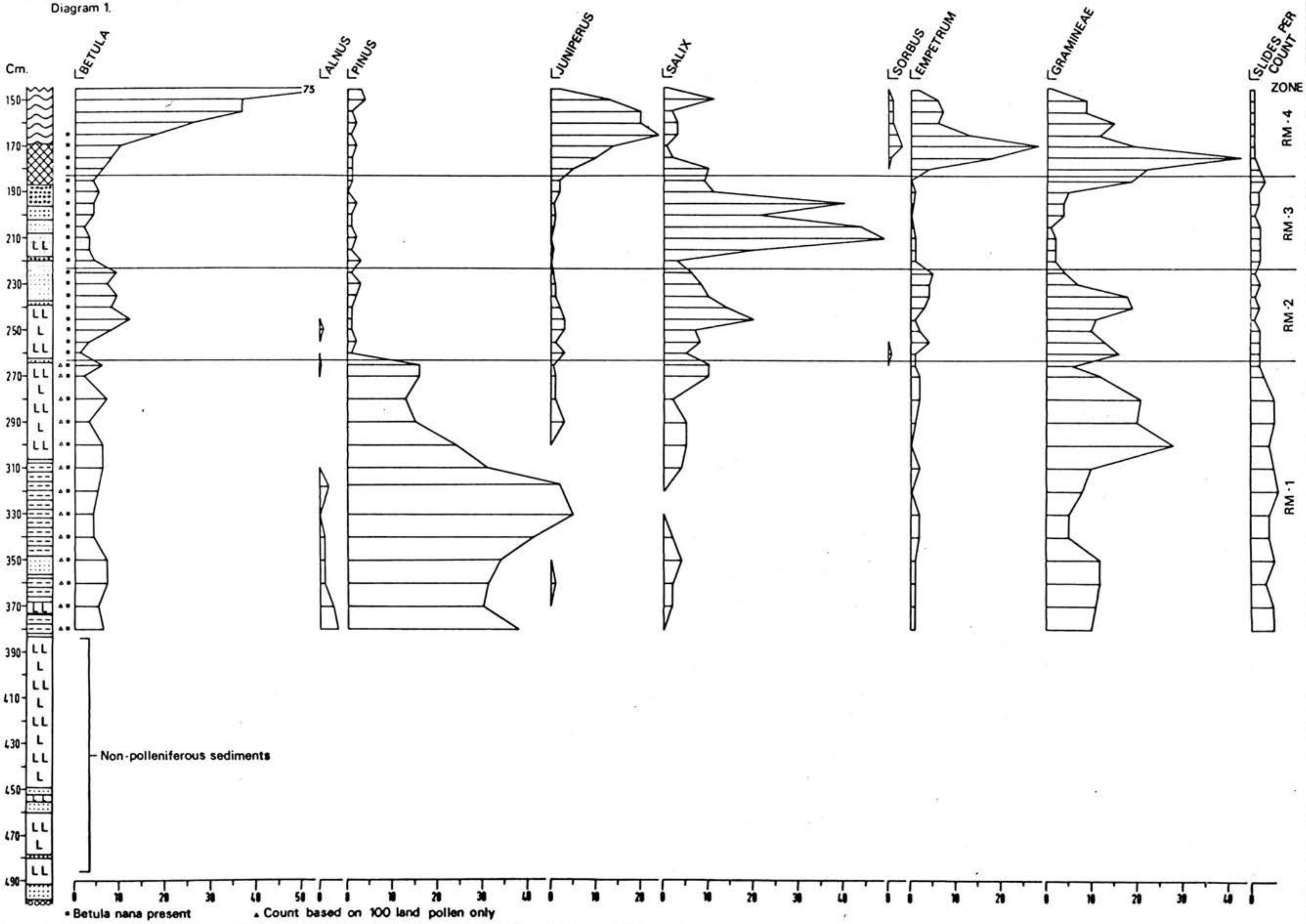
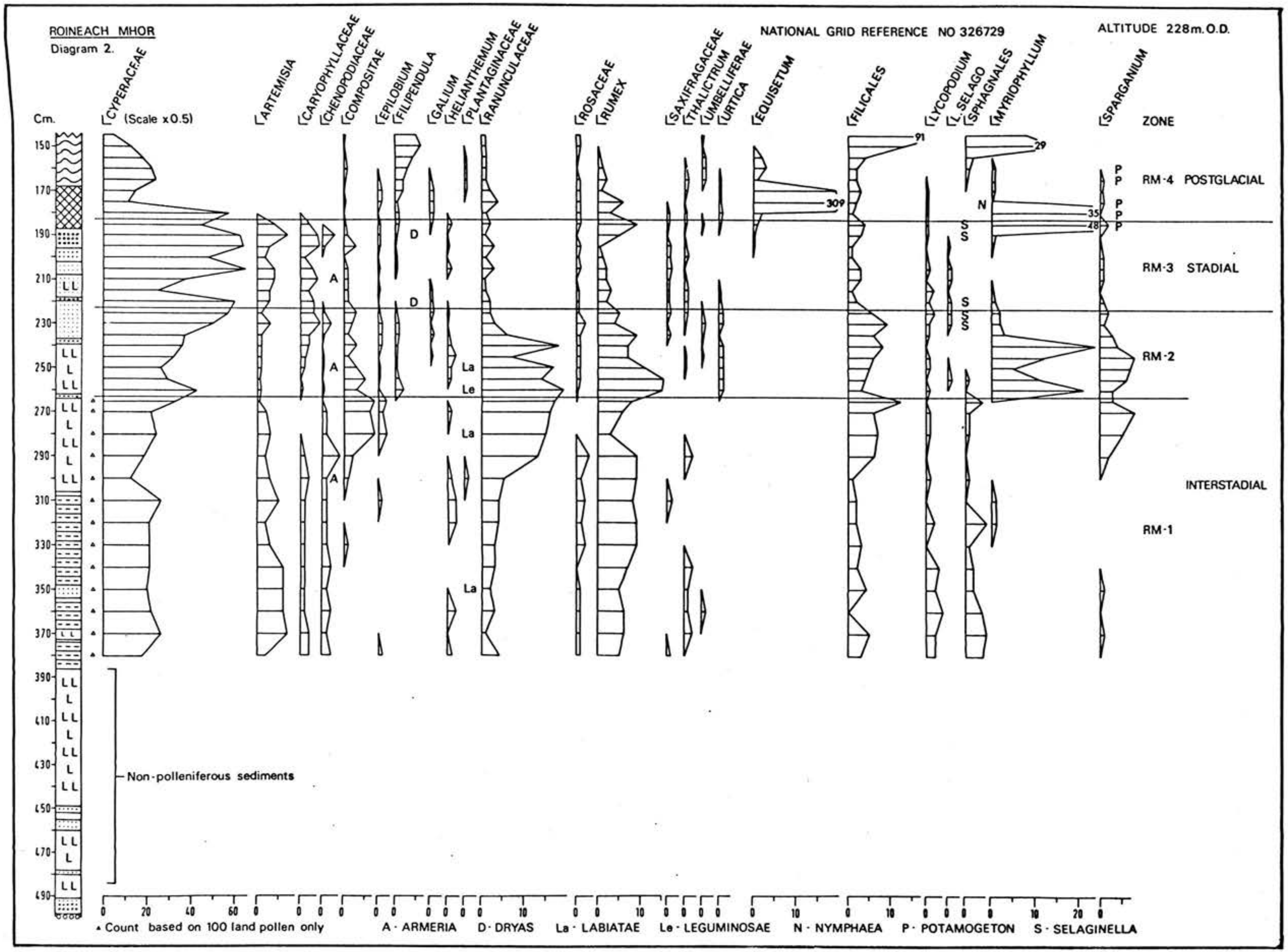


FIGURE 12

Roineach Mhor: pollen diagram 2.

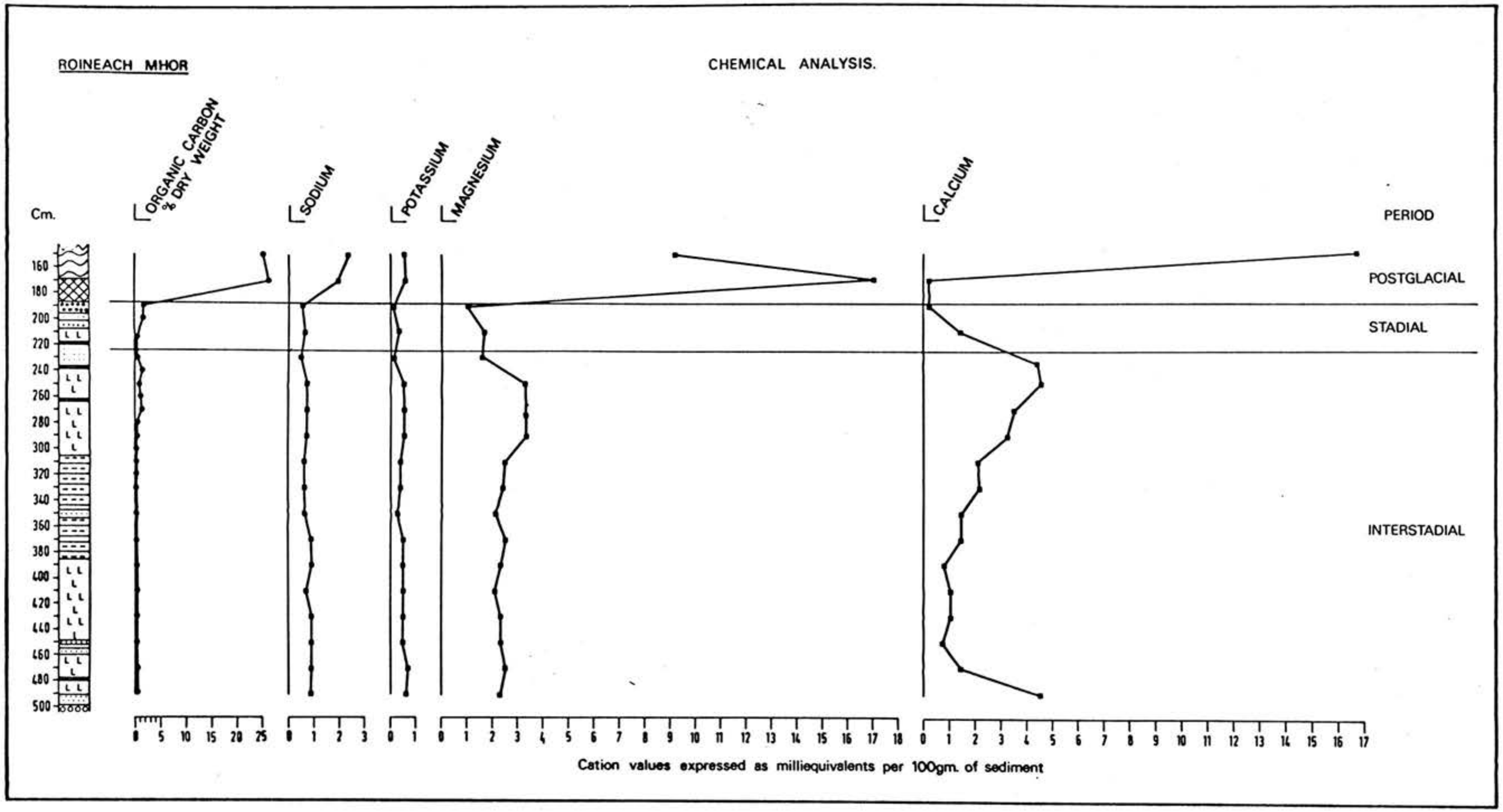


ROINEACH MHOR
Diagram 2.

▲ Count based on 100 land pollen only
A · ARMERIA
D · DRYAS
La · LABIATAE
Le · LEGUMINOSAE
N · NYMPHAEA
P · POTAMOGETON
S · SELAGINELLA

<u>FIGURE 13</u>

Roineach Mhor: chemical diagram.


ROINEACH MHOR
CHEMICAL ANALYSIS.
Cm.
ORGANIC CARBON % DRY WEIGHT
SODIUM
POTASSIUM
MAGNESIUM
CALCIUM
PERIOD
POSTGLACIAL
STADIAL
INTERSTADIAL
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
0 5 10 15 20 25
0 1 2 3
0 1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Cation values expressed as milliequivalents per 100gm. of sediment

455-460 cm	Medium sand.
460-478 cm	Fine grey silty-clay.
478-480 cm	Medium sand.
480-491 cm	Fine grey silty-clay.
491-499 cm	Sand, increasingly coarse with depth.
499 cm	Gravel.

The basal 120 cm of sediment were found to contain insufficient pollen for analysis on the basis of criteria outlined in the previous chapter. The lowest acceptable pollen count was made at 380 cm but only 100 land pollen were counted at each level between that depth and 260 cm because of the low pollen content of the sediment. Four different pollen assamblage zones were identified in the pollen diagrams (Figures 11 and 12), and the Lateglacial-Postglacial boundary was placed between the upper two zones. This boundary closely coincided with the transition from minerogenic to organic sediment that occurred at 187 cm.

Rumex-Artemisia-Gramineae assemblage zone

Zone RM-1 380-260 cm

This zone is characterised by high values for *Rumex*, *Artemisia* and Gramineae, with a rising curve for Ranunculaceae, and higher values for *Rumex* and Compositae near the upper contact. The very high *Pinus* values are thought to be due to long-distance transport and are emphasised by the relative sparseness of pollen in the sediments. (It was often necessary to count five or six slides in order to obtain a pollen sum of only 100 land pollen from a sample of standard size.) This is probably a function of the impoverished nature of the local vegetation at the time, but may also be due in part to the rapid rate of sedimentation in the basin as suggested by the presence of rhythmites below 302 cm (see below). In addition to *Pinus* pollen, *Betula*, *Alnus* and the isolated grain of *Tilia* at 320 cm are also most likely the product of long-distance transport. The organic carbon content of the sediment is uniformly low, as are values for Na and K. After an initial decline, the curve for Ca rises towards the upper contact of the zone, while percentages of Mg remain almost constant throughout. The boundary between zones RM-1 and RM-2 is placed at the sharp decline in *Pinus* between 265 and 260 cm which is taken to indicate the burgeoning of the local pollen rain, and which coincides with a marked rise in the curve for *Myriophyllum*.

Betula-Salix-Rumex assemblage zone

Zone RM-2 260-220 cm

This zone is floristically richer than its predecessor and is characterised by values of up to 20% for *Salix* and 15% for *Betula*, with significant percentages of *Rumex*, Gramineae and Ranunculaceae. *Empetrum* is present in small quantities throughout the zone but reaches a maximum near the upper contact. This zone reflects the closing of the vegetation cover after the open-habitat conditions of zone RM-1, and is indicative of a trend towards stabilisation of the soils around the catchment area. However, the occurrence of occasional lenses of coarser material in the sediment solumn indicates that this process is still not complete. The zone is characterised by a marked increase in values for aquatic pollen, notably Myriophyllum cf. alterniflorum, while the appearance of Filipendula and the high values for Ranunculaceae (many of which resemble Caltha palustris) probably reflect the development of a fairly rich marsh flora. Percentages of aquatic pollen decrease markedly below the upper contact of the zone, this decline being probably due to an increasing trend towards harsher environmental conditions, as it precedes the decrease in values for woody taxa, and heralds the return of the open-habitat plants. Organic carbon values fluctuate between 1 and 2%, while after attaining high values, the curves for Ca and Mg decline towards the upper contact of the zone. The boundary of the zone is placed at the decline in Empetrum and Betula.

Salix-Cyperaceae assemblage zone

Zone RM-3 220-185 cm

This zone coincides with alternating layers of coarse and medium-coarse grit (between 55-60% of the sediment lies in the greater than 0.02 mm size range), with the most resistant layers situated near the top and bottom of the zone. The upper 10 cm spans the transition from extremely coarse grit to organic mud. The zone is characterised by very high values for Salix and Cyperaceae, with significant percentages of Artemisia and Caryophyllaceae. Almost all the pollen grains were heavily corroded and identification was often difficult. The overall pollen spectrum however, is indicative of an extremely harsh environment, and many of the Salix grains resemble Salix herbacea, a chionophilous species characteristic of snowbed vegetation. There is a virtual absence of other woody plants and aquatics. The unstable nature of the regolith at this time is reflected in the very coarse nature of the sediment in the basin which most probably resulted from a period of intense solifluxion. The significant quantities of Artemisia and associates further emphasise the unstable nature of the landscape. The values for organic carbon rise towards the upper levels of the zone, but this is probably due to organic matter from above becoming lodged in the top 5-10 cm of the grit. The curves for alkali cations fall to very low values during this zone. The upper contact is placed at the sudden decline in chionophilous and disturbed soil taxa and the initial rise in values for Empetrum and Juniperus.

Juniperus-Empetrum-Betula assemblage zone

Zone RM-4 185-145 cm

This zone spans the transition from organic lake muds to terrestrial Sphagnum peat. It is characterised by successive peaks in the pollen curves for Rumex, Gramineae, Empetrum, Juniperus and Betula which reflect the closing of the vegetation cover and the establishment of birch woodland after the harsh tundra conditions which appear to have prevailed during zone RM-3. There is no record in the site of the arrival of Corylus-Myrica or deciduous forest in the area, and thus sediment accumulation must have ceased at an early stage in the Postglacial period. As at Blackness, the progression of the hydrosere can be traced in the pollen record from the peak in the Myriophyllum curve through the spread of the fringing fen to the final build-up of Sphagnum peat. There is a marked rise in the organic carbon curve at the transition from minerogenic to organic sediment at 187 cm, and this is accompanied by a similar upward trend in the alkali cations Mg, K and Na, while Ca rises sharply towards the upper levels of the zone.

Implications for the glacial sequence

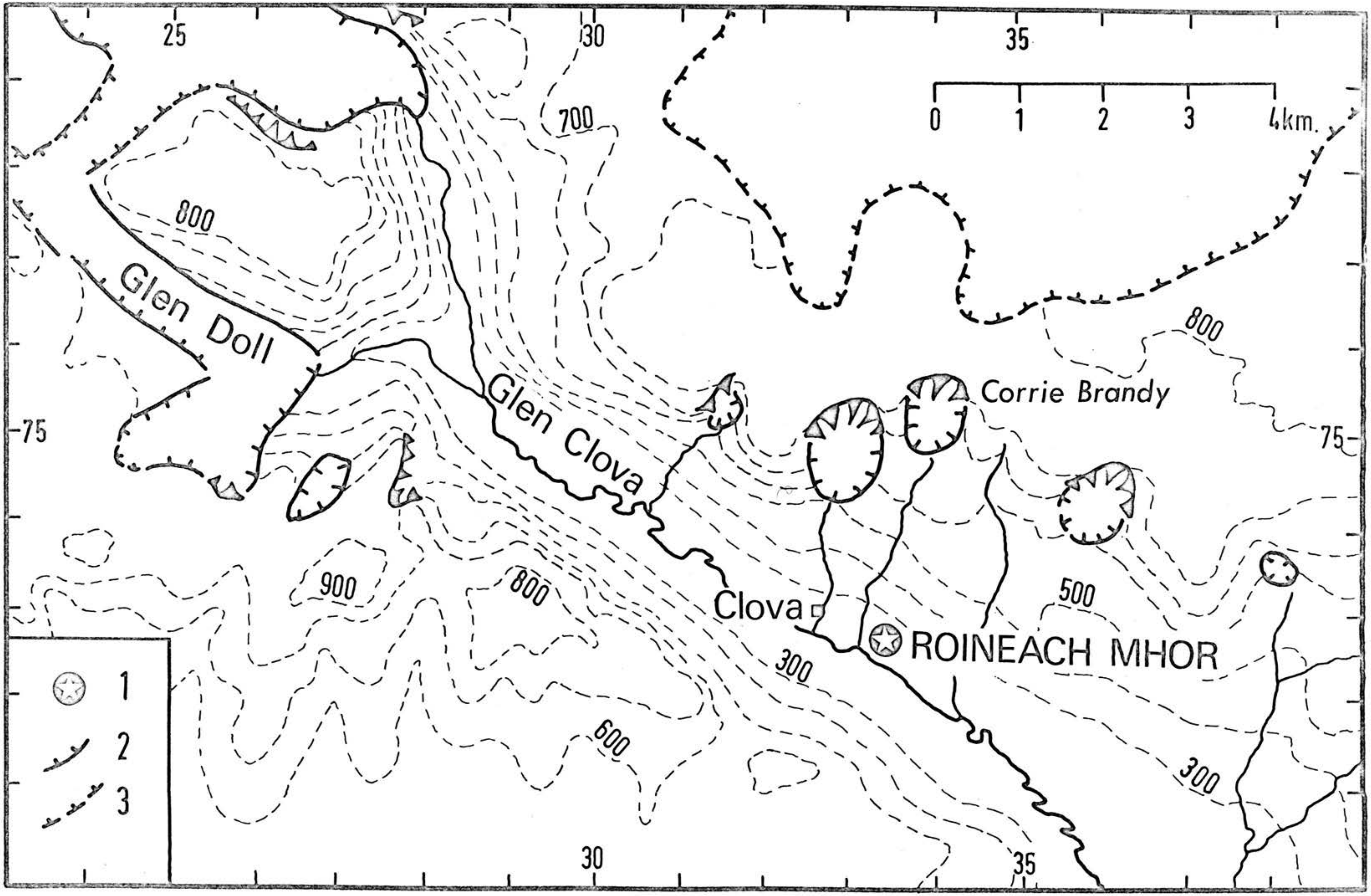
Although the standard Lateglacial stratigraphy is not present in this basin, there is a marked oscillation in the vegetational record. The harsh environmental conditions of the Stadial are represented by the disturbed soil and chionophilous flora of zone RM-3, while before this zone there is clear evidence of a milder climatic episode. Thus, a Lateglacial record appears to be preserved in the site. The surrounding ice-contact landforms must therefore be related to the decay of the Late Devensian ice-sheet. However, five former corrie glaciers on the north side of Glen Clova have been identified by Sissons (1972), the best evidence being in Corrie Brandy only 1.5 km to the north of the pollen site (Figure 14). There a prominent end moraine 700 m in length and up to 10 m in height follows the lip of the corrie. To the west of the site, on the plateau above the head of Glen Clova, the limits of a former ice-cap have been inferred.

FIGURE 14

The site at Roineach Mhor in relation to Loch Lomond Readvance glacier limits (after Sissons 1972).

1) Pollen site.
2) Probable glacier limits.
3) Possible glacier limits.

Contour interval 100 m.


25
30
35
0
1
2
3
4km.
700
800
Glen Doll
Glen Clova
Corrie Brandy
75
75
800
900
800
500
Clova
ROINEACH MHOR
300
600
300
30
35
1
2
3

As the site at Roineach Mhor is Lateglacial in age, it is highly probable that these mapped limits relate to the Loch Lomond Readvance in this area of the Grampian Highlands.

3. CORRYDON

Corrydon (Nat. Grid Ref. NO/132674) is situated in Glenshee, Perthshire, approximately 3.5 km southeast of the Spittal of Glenshee, and 23 km north of Blairgowrie (Figure 4). It lies at 333 m O. D. in a large kettle hole by the west side of the A93 Perth-Braemar road. The basin is roughly circular in shape and is about 250 m in diameter. The surface is dry and supports a grass vegetation dominated by Nardus stricta, with Calluna vulgaris and occasional stands of Carex nigra and Juncus spp. Sphagnum is present in the damper hollows while isolated trees of Betula are scattered around the margins of the site.

Test bores with the small Hiller borer revealed the presence of predominantly minerogenic sediments below 8 m, and a rapid pollen count of samples taken from these deposits showed that a Lateglacial vegetational record was preserved in the basin. A further visit was therefore made to the site and detailed sampling carried out. The minerogenic sediments proved to be extremely difficult to penetrate even with the large Hiller borer, and thus it was impossible to find the deepest point in the site with any accuracy. However, a locality was found where almost 11 m of sediment had accumulated and this was considered to be adequate for sampling purposes. The stratigraphy was as follows:-

0- 446 cm	Not sampled.
446- 495 cm	Highly humified *Sphagnum-Eriophorum* peat with some wood fragments.
495- 544 cm	More highly humified *Sphagnum-Eriophorum* peat.
544- 594 cm	Very highly decomposed *Sphagnum* peat. Leaf and seed of *Betula*.
595- 646 cm	Very highly humified lake mud - gyttja.
646- 782 cm	Brown-black gyttja.
783- 783 cm	Grey silt/clay.
784- 864 cm	Brown-black gyttja.
864- 865 cm	Grey silt/clay.
865- 880 cm	Green-brown gyttja, becoming more micaceous with depth.
880- 950 cm	Fine grey silt/clay.
950- 995 cm	Coarser silt with some sand layers.
995-1025 cm	Dark grey detrital mud.
1025-1029 cm	Green-grey organic mud.
1029-1052 cm	Dark grey detrital mud.
1052-1064 cm	Green-grey organic mud.
1064-1080 cm	Fine grey silt/clay, becoming increasingly micaceous near base.
1080 cm	Gravel.

FIGURE 15

Corrydon: Lateglacial pollen diagram 1.

CORRYDON

Diagram 1.

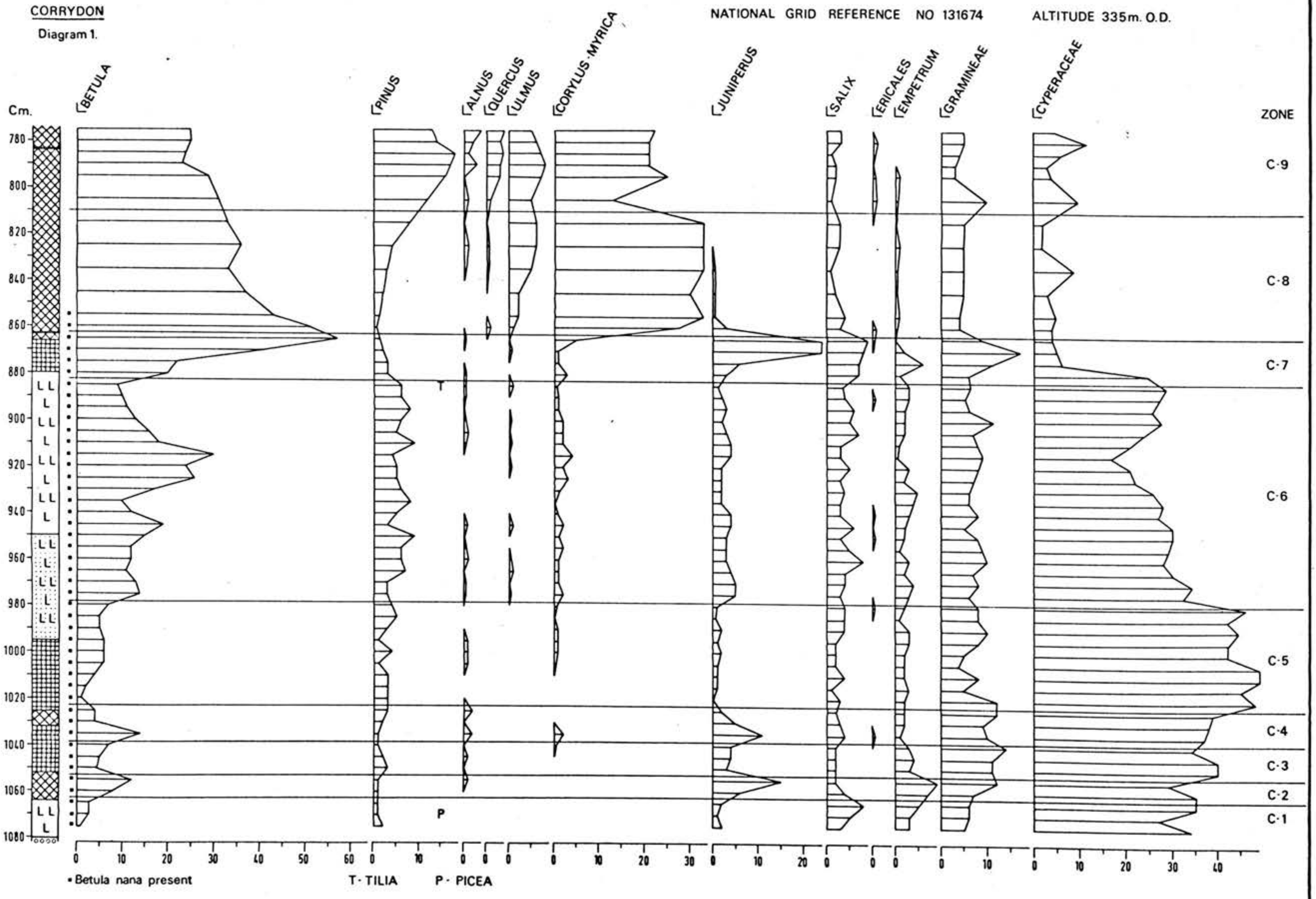
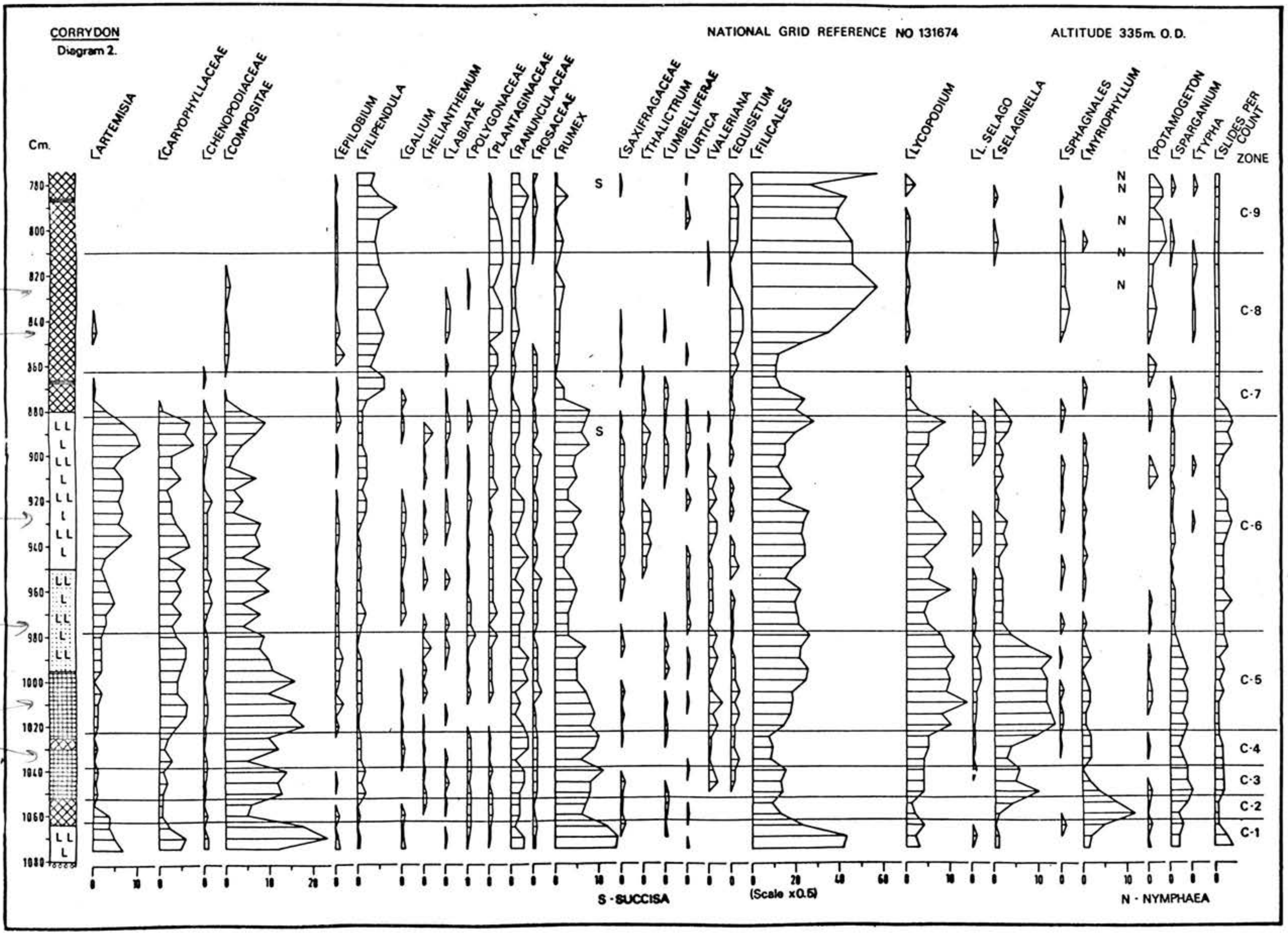


FIGURE 16

Corrydon: Lateglacial pollen diagram 2.



CORRYDON
Diagram 2.

NATIONAL GRID REFERENCE NO 131674

ALTITUDE 335m. O.D.

Gyttja

Fine Silt & clay

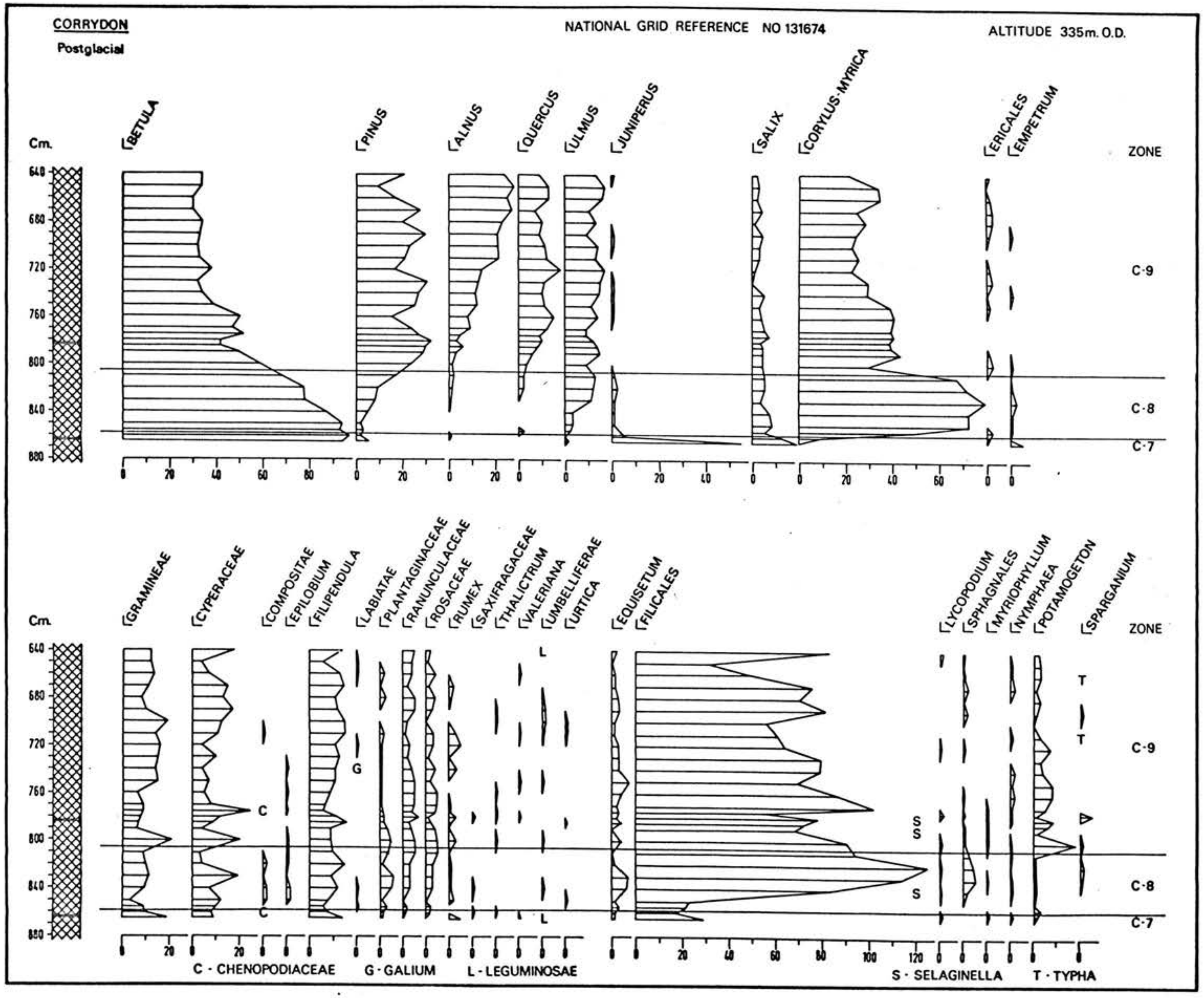
Med silt.

clay

gyttja

FIGURE 17

Corrydon: Postglacial pollen diagram.


CORRYDON
Postglacial
NATIONAL GRID REFERENCE NO 131674
ALTITUDE 335m. O.D.
Cm.
640
680
720
760
800
840
880
BETULA
PINUS
ALNUS
QUERCUS
ULMUS
JUNIPERUS
SALIX
CORYLUS-MYRICA
ERICALES
EMPETRUM
ZONE
C·9
C·8
C·7
0 20 40 60 80
0 20
0 20
0
0
0 20 40
0
0 20 40 60
0
0
Cm.
640
680
720
760
800
840
880
GRAMINEAE
CYPERACEAE
COMPOSITAE
EPILOBIUM
FILIPENDULA
LABIATAE
PLANTAGINACEAE
RANUNCULACEAE
ROSACEAE
RUMEX
SAXIFRAGACEAE
THALICTRUM
VALERIANA
UMBELLIFERAE
URTICA
EQUISETUM
FILICALES
LYCOPODIUM
SPHAGNALES
MYRIOPHYLLUM
NYMPHAEA
POTAMOGETON
SPARGANIUM
ZONE
C·9
C·8
C·7
C
C
G
L
L
S
S
S
T
T
0 20
0 20
0 20 40 60 80 100 120
C - CHENOPODIACEAE
G - GALIUM
L - LEGUMINOSAE
S - SELAGINELLA
T - TYPHA

Nine separate pollen assemblage zones were recognized in the pollen diagrams (Figures 15, 16 and 17), and the Lateglacial-Postglacial boundary was placed between the sixth and seventh of these zones. This boundary coincides with the marked stratigraphic change from minerogenic to organic sediment at 880 cm.

Rumex-Compositae-Filicales assemblage zone

Zone C-1 1075-1062.5 cm

This is the basal assemblage zone and is characterised by very high values for Filicales, and significant percentages of Cyperaceae, Rumex, Compositae and Artemisia. Pollen of woody plants is scarce, much of the Salix resembling Salix herbacea, although the rise in the Salix curve towards the upper contact of the zone may reflect the expansion of shrub willows into the area. The overall picture is of an open-habitat landscape with soil instability being widespread. The upper boundary of the zone is placed at the rise in woody plants, particularly Betula and Juniperus, and the complementary decline in open-habitat species, especially Compositae and Rumex.

Betula-Juniperus-Empetrum assemblage zone

Zone C-2 1062.5-1052.5 cm

This zone spans the lowest band of organic mud or gyttja and reflects the expansion of shrub vegetation into the area. Juniperus attains a maximum value of 15% of the total land pollen, while Betula and Empetrum are also significant elements in the pollen spectrum.

Almost all the birch pollen seem to be of *Betula nana*, although some grains which are undoubtedly of tree birch are present. Values for open-habitat herbaceous taxa are lower in this zone, and it appears that the assemblage represents a transition stage in the closing of the vegetation cover. The zone is also noteworthy for the higher percentages of *Myriophyllum* cf. *alterniflorum* which may be indicative of more temperate conditions. The upper boundary of the zone is placed at the simultaneous decline in the curves for *Betula*, *Juniperus* and *Empetrum*.

Rumex-Selaginella assemblage zone

Zone C-3 1052.5-1032.5 cm

Values for pollen of woody plants are relatively lower in this zone and there is an increase in open-habitat species. *Rumex*, Caryophyllaceae, Gramineae, *Selaginella* and Filicales are all present in significant quantities, but values for *Artemisia* remain low. Thus, in spite of the decline in percentages of shrub and heathland pollen, the spectrum does not appear to reflect a return to the unstable open landscape of zone C-1. Instead, the area appears to have been characterised by closed grassland with taxa of pronounced steppe, rather than tundra affinities. The renewed expansion of *Betula* and *Juniperus* marks the upper limit of this zone.

Betula-Juniperus assemblage zone

Zone C-4 1032.5-1025 cm

This zone spans the transition from detritus mud to the upper band of green-grey gyttja. Peaks in the *Betula* and *Juniperus* curves indicate the renewed expansion of shrub vegetation in the area, although taxa indicative of open grassland still dominate the pollen spectrum. Again the majority of the birch pollen appears to be of *Betula nana*, although some tree birch is present. *Myriophyllum* values rise at the beginning of the zone, but percentages are considerably lower than in zone C-2. The upper boundary is placed at the decline in values for *Betula* and *Juniperus* to very low levels, and the rise in the curves for *Selaginella* and *Lycopodium*.

Lycopodium-Selaginella assemblage zone

Zone C-5 1025-980 cm

Lycopodium and *Selaginella* reach 10% of total land pollen while *Rumex*, Caryophyllaceae, Compositae, Filicales and Cyperaceae are present in significant quantities. The pollen spectrum is again characterised by open-habitat taxa, with very low values for pollen of woody plants, and the lower percentages of thermophilous taxa indicate progressive climatic deterioration. *Artemisia* is present throughout the zone, but is not yet a major element in the pollen record. The zone spans the transition from detrital muds to the beginning of coarse silt deposits at 995 cm. The latter sediments are thought to be the result of inwash of coarse material following the break-up of the vegetation cover and the onset of solifluxion processes. The upper boundary of the zone is placed at the decline in values for *Selaginella* to low levels, and the complementary fall in the percentages of *Lycopodium*.

Artemisia-Filicales assemblage zone

Zone C-6 980-880 cm

This zone covers the transition from coarse to medium-fine minerogenic sediment and is characterised by increasingly significant percentages of *Artemisia*, with Caryophyllaceae, *Lycopodium*, Filicales and Cyperaceae being well represented in the pollen spectrum. Again, an open-habitat tundra landscape is envisaged, with a sparse vegetation cover and an increasing trend towards soil instability. The impoverished nature of the local vegetation at the time is reflected in the fact that it was often necessary to count four or five slides in order to obtain a sum of 300 land pollen. Many of the *Salix* grains resemble *Salix herbacea* which probably grew locally at the time, but the quantities of *Pinus* pollen present are most likely the result of the long-distance effect. The very high quantities of *Betula* pollen seem anomalous in the type of landscape suggested above, and possible explanations for this phenomenon are discussed in the following chapter. The upper boundary of the zone is placed at the marked decline in open-habitat taxa, notably *Artemisia*, Caryophyllaceae, *Lycopodium* and *Selaginella*, and the beginning of the rise in values for pollen of woody plants.

Betula-Juniperus assemblage zone

Zone C-7 880-862.5 cm

This is the earliest Postglacial pollen assemblage zone and is characterised by successive peaks in the curves for *Empetrum*, *Juniperus* and *Betula*. The assemblage reflects the transition from the unstable tundra landscape of zone C-6 to the closed birch woodland of the Postglacial. Notably thermophilous taxa such as *Filipendula* rise towards the upper levels of the zone, although there is no marked increase in values for aquatic pollen. *Corylus-Myrica* appears in significant quantities near the upper contact of the zone. The sediments consist almost entirely of organic muds or gyttja, but a thin band of silty-clay occurs at 863 cm. The upper boundary is placed at the simultaneous decline in values for *Betula* and Juniperus, and the complementary rise in *Corylus-Myrica*.

Betula-Corylus-Myrica assemblage zone

Zone C-8 862.5-810 cm

Corylus-Myrica and *Betula* dominate the pollen spectrum, but *Betula* declines progressively throughout the zone. *Ulmus* and *Pinus* both rise towards the upper contact from initially low values, while *Alnus* and *Quercus* are present in small quantities. Filicales values are high throughout, the majority of the spores resembling *Dryopteris filix-mas*. This zone reflects a wooded landscape, with high Filicales and *Corylus-Myrica* values reflecting the growth of of a rich understorey. The upper contact of the zone is placed at the steep decline in values for *Corylus-Myrica*.

Betula-Pinus-Ulmus assemblage zone

Zone C-9 810-640 cm

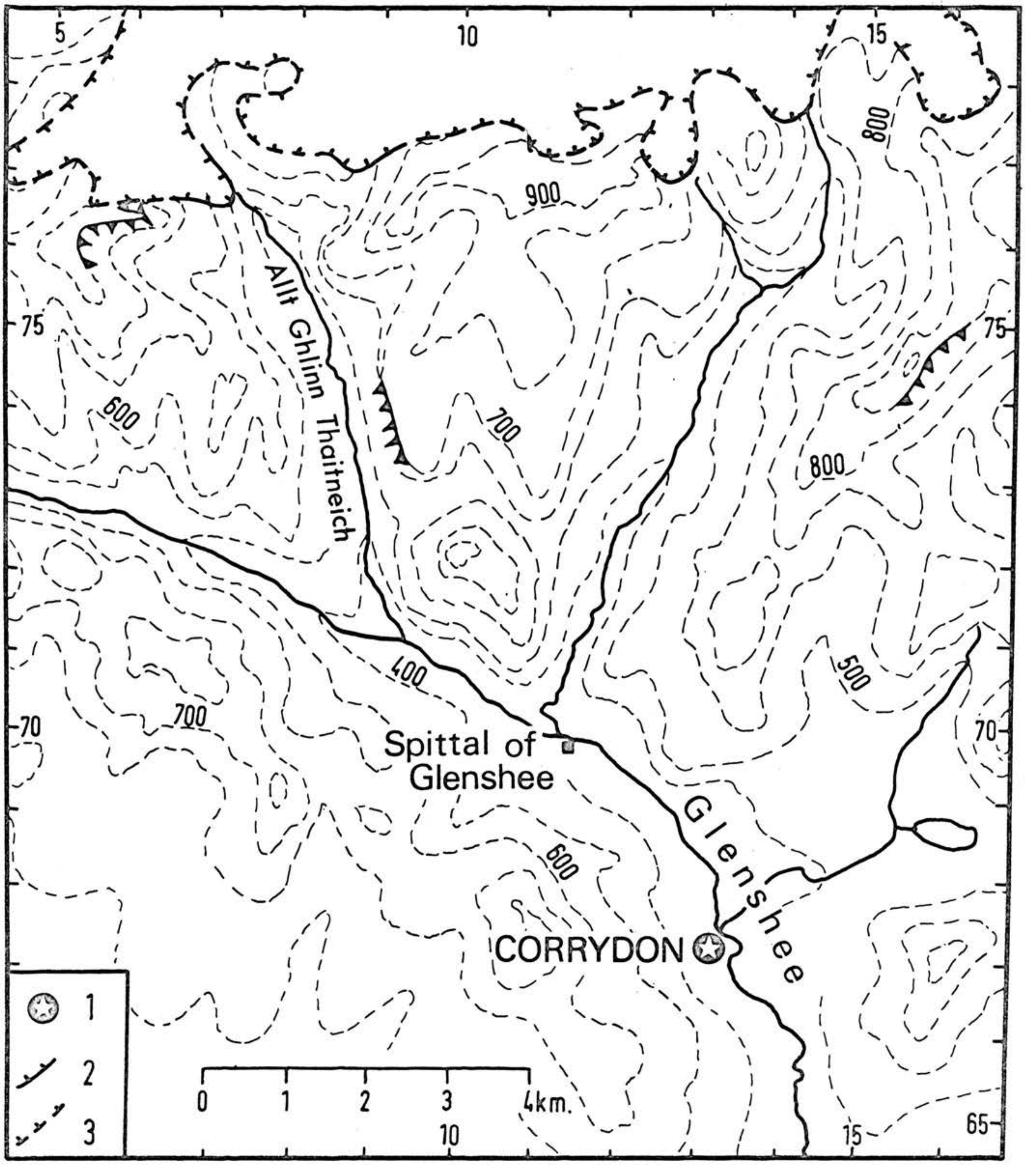
This zone is characterised by high values for *Betula*,

FIGURE 18

The site at Corrydon in relation to
Loch Lomond Readvance glacier limits
(after Sissons unpublished).

1) Pollen site.
2) Probable glacier limits.
3) Possible glacier limits.

Contour interval 100 m.


5
10
15
900
800
Allt Ghlinn Thaitneich
75
75
600
700
800
500
400
70
70
700
Spittal of Glenshee
600
Glenshee
CORRYDON
1
2
3
0
1
2
3
4km.
10
15
65

Ulmus, and Pinus. The curves for Quercus and Alnus rise throughout the zone, while Corylus-Myrica and Filicales remain as important contributors to the pollen spectrum. This assemblage reflects the final establishment of mixed woodland in this area of the Grampian Highlands. The sediment consists entirely of highly humified organic mud but there is a thin band of silty-clay at 783 cm. The occurrence of these minerogenic layers in the sediment column will be discussed more fully in Chapter 6.

Implications for the glacial sequence

As this site contains a stratigraphical and vegetational record of the Lateglacial period, the surrounding ice-contact landforms must be related to the wastage and decay of the Late-Devensian ice-sheet. However, at the head of Allt Ghlinn Thaitneich, approximately 10 km to the north of the site (Figure 18), there is a marked downvalley termination of a series of morainic mounds which have been inferred to be a glacier readvance limit (Sissons unpublished). As the site at Corrydon is of Lateglacial age, it is therefore logical to assume that this mapped limit relates to the Loch Lomond Readvance.

4. TIRINIE

The site is situated near Tirinie farmhouse (Nat. Grid Ref. NN/889678) in Glen Fender, Perthshire, approximately 3 km northeast of Blair Atholl (Figure 4). It lies at 337 m O.D. in

p 35

a westward-sloping depression which appears to be an abandoned channel cut into ice-contact and fluvioglacial deposits. The depression contains three separate basins, all of which are extremely marshy, with large areas of standing water. The middle basin of the three proved to be the most accessible and was therefore selected for detailed investigation. It is roughly oval in shape with a long axis of approximately 80 m and is almost 30 m across at the widest point. The surface vegetation is reed swamp dominated by *Carex* spp. and *Juncus* spp. with areas of *Sphagnum* moss around the margins of the basin.

The site is relatively shallow, being only 4.25 m at the deepest point found, but test bores revealed the presence of a clear stratigraphic oscillation in the basal sediments. The stratigraphy at the sampling site was as follows:-

0-141 cm	Surface sample. Very wet, poorly humified roots and stems.
141-215 cm	Poorly humified fen peat.
215-277 cm	More highly humified fen peat.
277-350 cm	Light grey-white marl. Abundant shells of *Lymnaea peregra* (spiral) and *Pisidium* spp.
350-389 cm	Dark grey silty-clay.
389-392 cm	Medium-coarse silt.
392-396 cm	Light grey silty clay.
396-399 cm	Light grey-white marl.
399-404 cm	Dark grey clay marl.

FIGURE 19

Tirinie: Lateglacial pollen diagram.

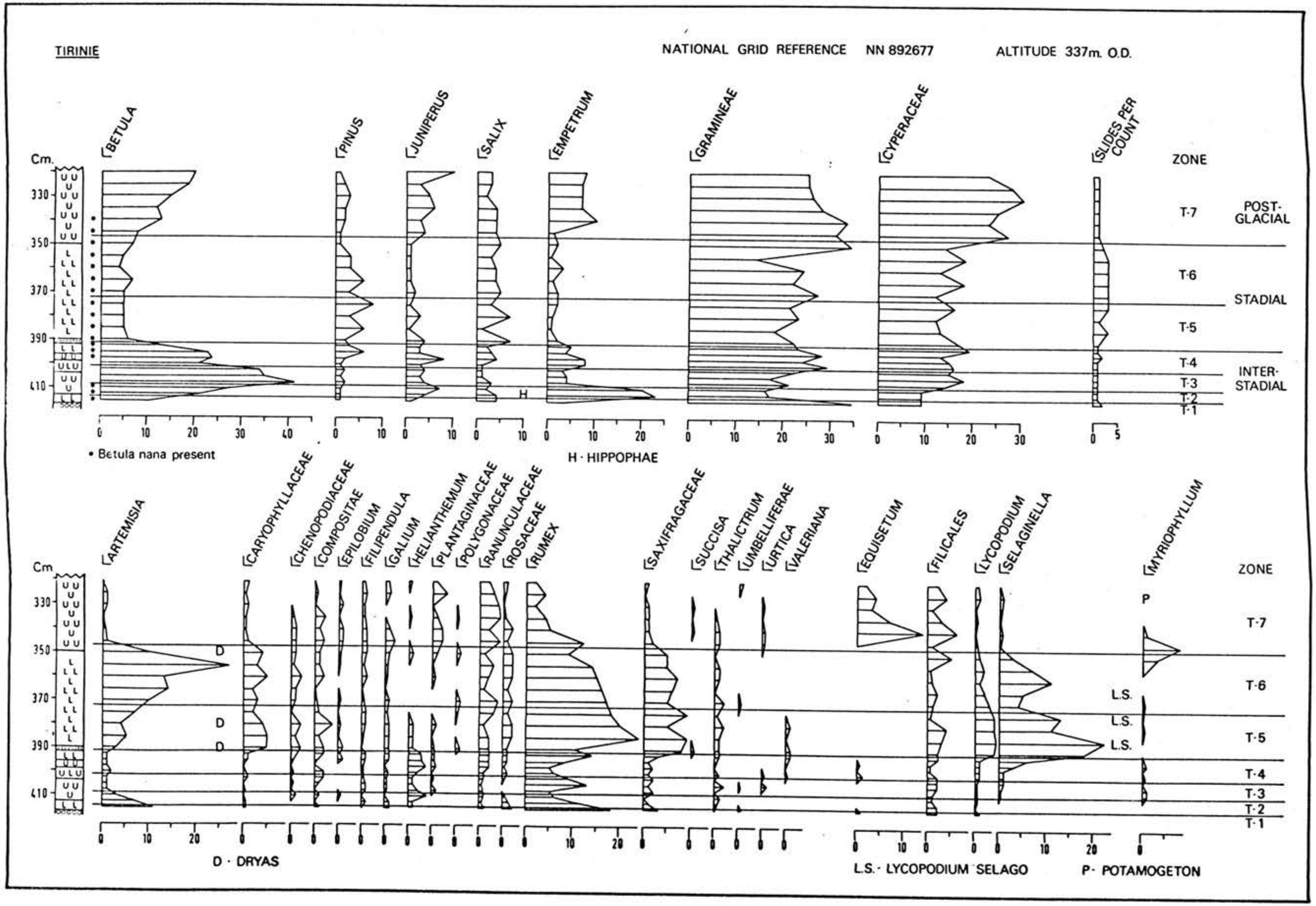
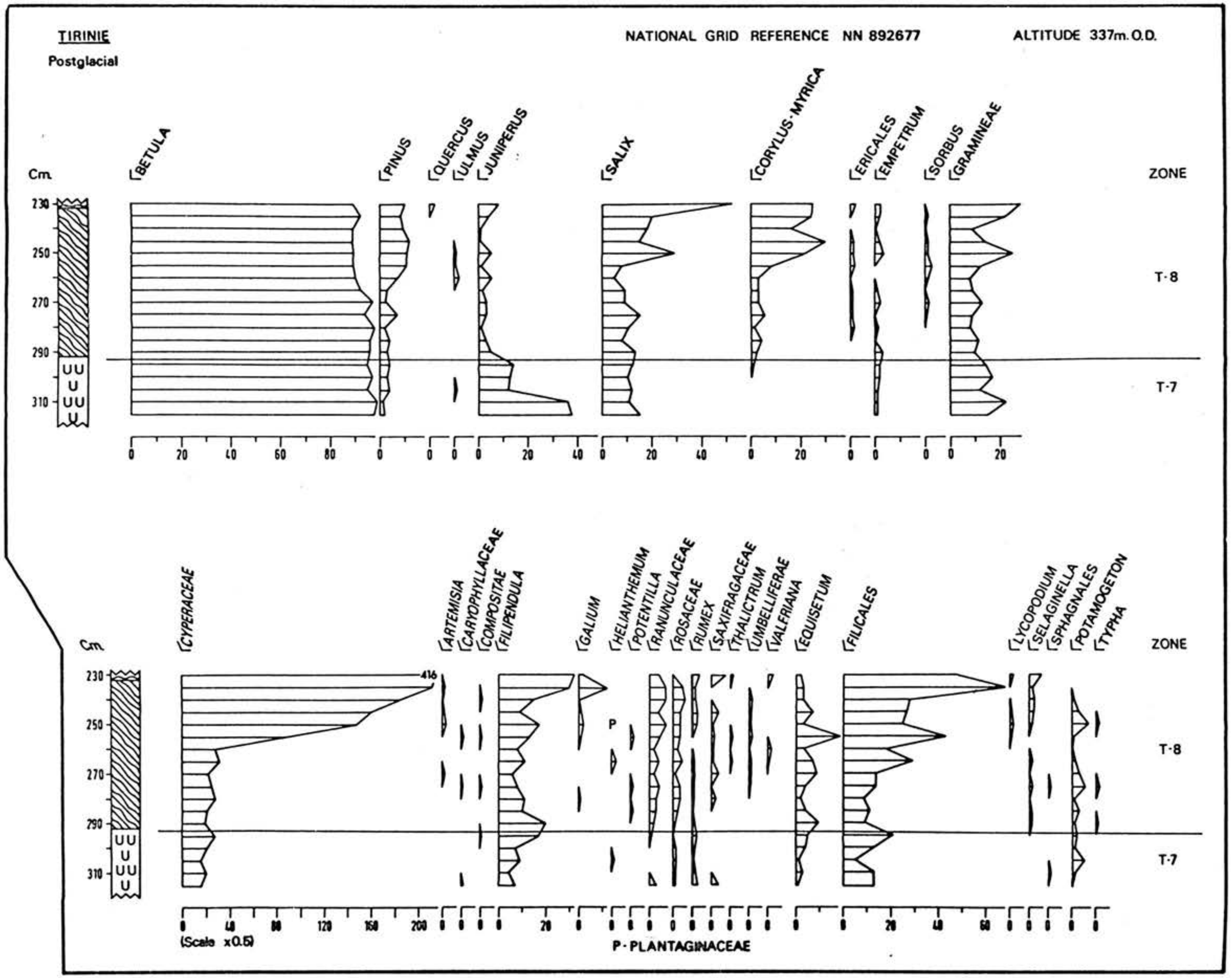

TIRINIE
NATIONAL GRID REFERENCE NN 892677
ALTITUDE 337m. O.D.
Cm.
330
350
370
390
410
BETULA
PINUS
JUNIPERUS
SALIX
EMPETRUM
GRAMINEAE
CYPERACEAE
SLIDES PER COUNT
ZONE
T·7
T·6
T·5
T·4
T·3
T·2
T·1
POST-GLACIAL
STADIAL
INTER-STADIAL
H
• Betula nana present
H · HIPPOPHAE
ARTEMISIA
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITAE
EPILOBIUM
FILIPENDULA
GALIUM
HELIANTHEMUM
PLANTAGINACEAE
POLYGONACEAE
RANUNCULACEAE
ROSACEAE
RUMEX
SAXIFRAGACEAE
SUCCISA
THALICTRUM
UMBELLIFERAE
URTICA
VALERIANA
EQUISETUM
FILICALES
LYCOPODIUM
SELAGINELLA
MYRIOPHYLLUM
D
P
L.S.
D · DRYAS
L.S. · LYCOPODIUM SELAGO
P · POTAMOGETON

FIGURE 20

Tirinie: Postglacial pollen diagram.

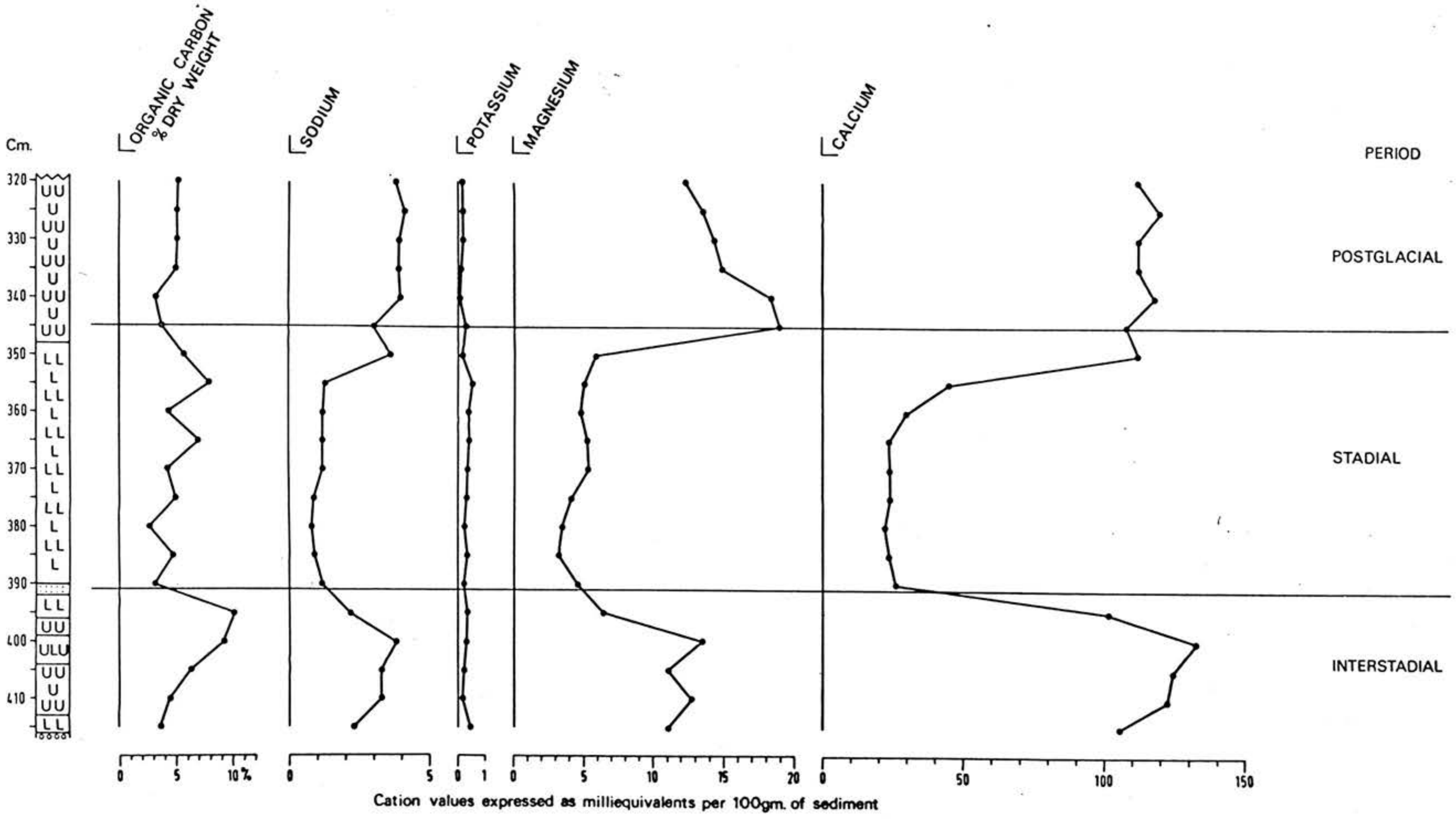

TIRINIE
Postglacial
NATIONAL GRID REFERENCE NN 892677
ALTITUDE 337m. O.D.
Cm.
230
250
270
290
310
BETULA
PINUS
QUERCUS
ULMUS
JUNIPERUS
SALIX
CORYLUS·MYRICA
ERICALES
EMPETRUM
SORBUS
GRAMINEAE
ZONE
T·8
T·7
0
20
40
60
80
CYPERACEAE
ARTEMISIA
CARYOPHYLLACEAE
COMPOSITAE
FILIPENDULA
GALIUM
HELIANTHEMUM
POTENTILLA
RANUNCULACEAE
ROSACEAE
RUMEX
SAXIFRAGACEAE
THALICTRUM
UMBELLIFERAE
VALERIANA
EQUISETUM
FILICALES
LYCOPODIUM
SELAGINELLA
SPHAGNALES
POTAMOGETON
TYPHA
416
P
120
160
200
(Scale x0.5)
P - PLANTAGINACEAE

<ins>FIGURE 21</ins>

Tirinie: chemical diagram.

TIRINIE

CHEMICAL ANALYSIS.



404-413 cm	Cream-coloured shell marl. Very high concentration of shells of *Lymnaea peregra* and *Pisidium* spp.
413-417 cm	Light grey silty-clay.
417 cm	Gravel.

Eight distinct pollen assemblage zones were identified in the pollen diagrams (Figures 19 and 20) and the Lateglacial-Postglacial boundary was placed between the sixth and seventh of these zones. This assemblage zone boundary corresponds very closely with the pronounced stratigraphic change from grey silty-clay to shell marl at 350 cm.

Rumex-Artemisia assemblage zone

Zone T-1 417-413 cm

Although this assemblage contains only one count, it is considered that there is sufficient difference in the pollen spectra to justify the separation of this zone from the succeeding one. This basal assemblage is characterised by high values for *Rumex*, *Artemisia* and Gramineae, with significant percentages of Saxifragaceae. Levels for pollen of woody and thermophilous taxa are uniformly low. The zone corresponds with the basal layer of light grey clay, the upper boundary coinciding with the transition from clay to marl deposits. The lithological and palynological evidence suggests an open steppe-type of landscape with a relatively sparse vegetation cover and unstable soils. The upper contact of the zone is placed at the rapid increase in *Empetrum* and *Betula* percentages, and the complementary decline in the curves for *Rumex* and *Artemisia*.

Empetrum-Betula assemblage zone

Zone T-2 413-408 cm

Empetrum and *Betula* each exceed 20% of the land pollen total in this zone, while both Gramineae and *Juniperus* are significant contributors to the pollen spectrum. Values for taxa of open-habitats, notably *Artemisia* and *Rumex* decline steadily throughout the zone, but there is an increase in values for *Helianthemum*. The sediment consists entirely of a fine clay marl which is rich in shells. The curve for organic carbon content rises steadily throughout the zone, while there are significantly increased values for the alkali cations Na, Ca and Mg. The curve for K however, declines from zone T-1. This assemblage zone reflects the stabilisation of the landscape and the expansion of heathland plants into the area. Most of the birch pollen is of *Betula nana*, but percentages of tree birch tend to rise near the upper contact of the zone. The boundary of the zone is placed at the sharp fall in values for *Empetrum* and *Juniperus* and the sharp rise in the curve for *Betula*.

Betula assemblage zone

Zone T-3 408-401 cm

This zone is characterised by very high values for *Betula* (over 30% of total land pollen), with significant quantities of *Rumex* and Gramineae. Values for *Salix*, *Empetrum* and *Juniperus* are much lower during this zone. Myriophyllum cf. alterniflorum is present in small amounts as in the previous zone, but pollen of other aquatic plants are absent. A large proportion of the Betula pollen appear to be of tree birch, and in view of the apparently rich pollen rain during this zone, it seems unlikely that these grains are the produce of long-distance transport. Most of the tree birch is therefore probably of local origin, but values are not sufficiently high to postulate the existence of birch woodland in the area at this time. The zone spans the transition from pure shell marl (carbonate content over 60%), to a silty-clay marl at 402 cm. The curve for organic carbon values continues to rise through the zone, and there is a continued upward trend in the curves for the alkali cations Na and Ca. The upper boundary of the zone is placed at the marked fall in values for Betula and the complementary rise in the curve for Empetrum.

Betula-Juniperus-Empetrum assemblage zone

Zone T-4 401-391 cm

Betula, Juniperus and Empetrum, together with Salix and Gramineae are the dominant elements in the pollen spectrum, but lower values for each taxon are recorded towards the upper levels of the zone. Rumex, Selaginella, Lycopodium and Saxifragaceae become increasingly more significant towards the upper contact. The grey clay marl at the base of the zone grades upwards into a thin layer of pure shell marl (carbonate content over 78%). This in turn gives way to a thin band of fine grey clay, which is finally succeeded by a narrow band of medium-coarse grit. The organic carbon curve reaches a maximum of 9.25% at 400 cm, but thereafter declines to 3.1% at 390 cm. The curves for alkali cations fall throughout the zone, and the carbonate content drops to only 1.3% near the upper contact. The zone reflects the transition from heathland to open steppe, with an increasing trend towards soil instability. The boundary of the zone is placed at the marked drop in Betula and Empetrum values and the simultaneous rise in the curves for Lycopodium, Selaginella and Saxifragaceae.

Rumex-Selaginella assemblage zone

Zone T-5 390-370 cm

This zone is characterised by high values for Rumex and Selaginella, with significant percentages of Saxifragaceae, Lycopodium and Caryophyllaceae. Artemisia increases in value towards the top of the zone. The pollen rain is relatively sparse compared with the previous three zones, and the percentages of Pinus and Betula may well be the product of the long-distance effect. The sediment is a grey, silty-clay with a uniformly low carbonate content compared with the overlying and underlying marl. The organic carbon curve fluctuates throughout the zone but remains generally low, and there are significantly reduced values for Na, Ca and Mg when compared with the previous zone. The pollen spectrum is dominated by taxa indicative of open steppe conditions, but the rising Artemisia curve and the increasingly minerogenic nature of the basin sediments heralds the onset of solifluxion processes under a harsh tundra environment. The upper contact of the zone is placed at the decline in values for Selaginella and Lycopodium.

Artemisia-Rumex assemblage zone

Zone T-6 370-347 cm

Artemisia dominates the pollen spectrum while Rumex and Gramineae are present in significant quantities. Caryophyllaceae, Selaginella and Saxifragaceae are still important elements in the landscape, although Lycopodium decreases progressively throughout the zone. Values for woody and thermophilous taxa are uniformly low, but there is a slight increase in values for Betula near the upper contact of the zone. Myriophyllum also appears at this level in association with the transition from fine, silty clay to shell marl. The organic carbon content fluctuates but remains generally low, while there is a marked upward trend in the curves for alkali cations Na, Ca and Mg at, or near the upper contact of the zone. The pollen spectrum reflects a harsh, tundra landscape with disturbed soils and a sparse vegetation cover. The upper boundary of the zone is placed at the sharp decline in taxa characteristic of open habitats, and the rise in the curves for pollen of woody plants.

Betula-Juniperus-Empetrum assemblage zone

Zone T-7 347-290 cm

This is the basal Postglacial assemblage zone and is characterised by successive peaks in the curves for Rumex, Gramineae, Empetrum, Juniperus and Betula, once again reflecting the transition from open tundra to closed woodland. The zone spans the upper deposit of light-coloured marl which is extremely rich in shells. Total carbonate values rise to 84% while organic carbon levels rise slightly after an initial decline. However, they remain surprisingly low when compared with the percentages in the Lateglacial deposits. The alkali cations Na, Ca and Mg are significantly higher than in zone T-6. The initial stages in the Postglacial hydrosere can be traced in the pollen record, with successive maxima in values for Myriophyllum, Equisetum and Cyperaceae reflecting the gradual contraction in areas of open water with the expansion of the littoral fen. The upper boundary of the zone is placed at the final decline in the Juniperus curve, and the appearance of Corylus-Myrica.

Betula-Corylus-Myrica assemblage zone

Zone T-8 290-230 cm

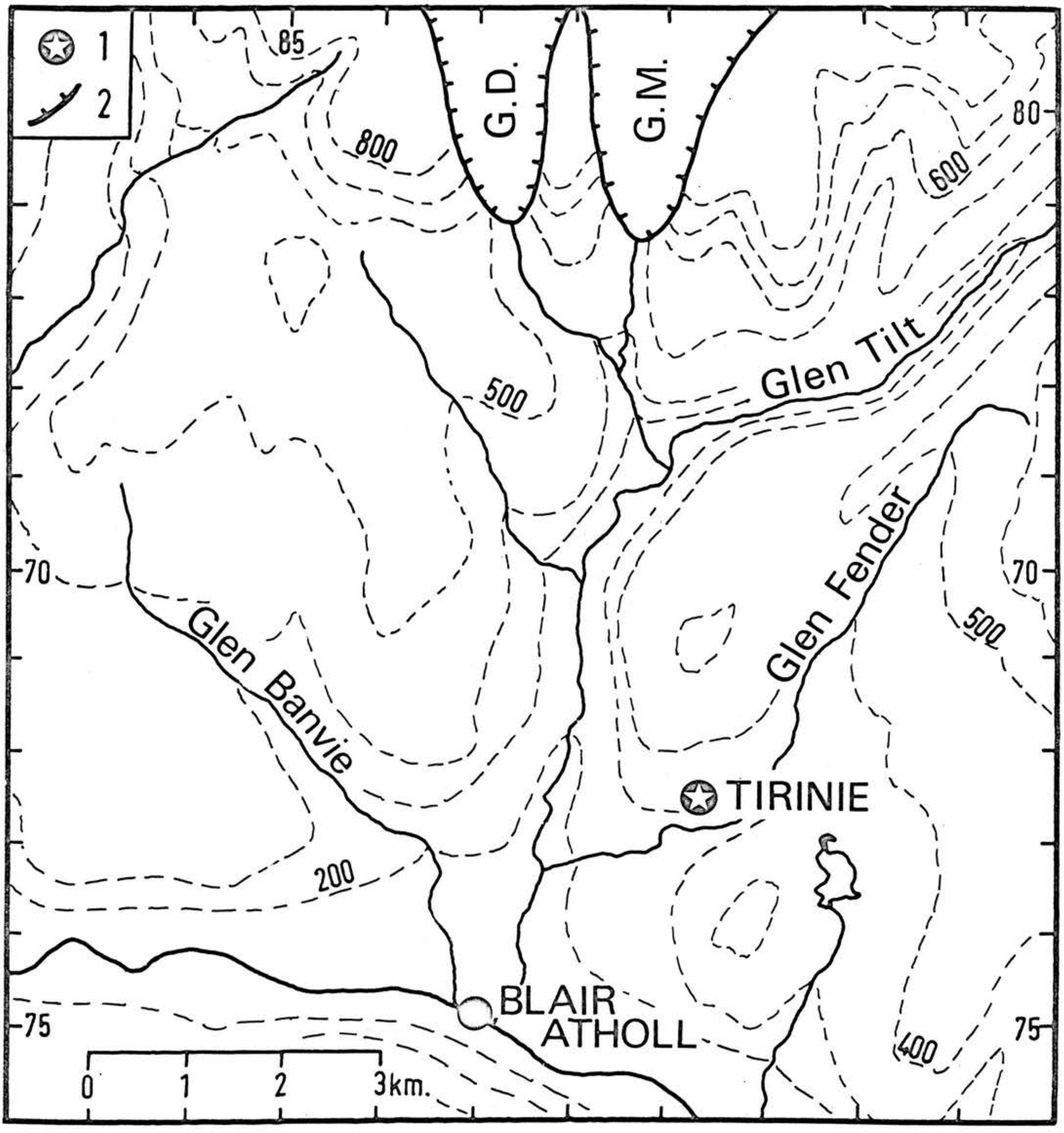
This zone contains high values for Betula and increasing quantities of Salix, Pinus and Corylus-Myrica. Values for Juniperus and Empetrum are low. The rapid rise in values for Cyperaceae between 260 and 250 cm reflects the encroachment of the marginal fen, while the significant increases in Filipendula and to a lesser extent Ranunculaceae cf. Caltha palustris are indicative of the development of a rich marsh flora. The higher values for Salix in the upper 20 cm probably reflects the spread of shrub willow into the margins of the site. The pollen spectrum reveals the establishment of birch woodland, with the gradual expansion of Corylus-Myrica,

FIGURE 22

The site at Tirinie in relation to
Loch Lomond Readvance glacier limits
(after Sissons 1974).

1) Pollen site.
2) Probable glacier limits.
G.D. Gleann Diridh.
G.M. Gleann Mhaire.

Contour interval 100 m.


1
2
85
800
G.D.
G.M.
80
600
500
Glen Tilt
Glen Fender
70
70
500
Glen Banvie
TIRINIE
200
BLAIR
ATHOLL
75
75
400
0
1
2
3km.

probably initially as an understorey shrub. The occasional grains of *Quercus* and *Ulmus*, in association with the rising *Pinus* curve presages the spread of mixed forest into the area.

Implications for the glacial sequence

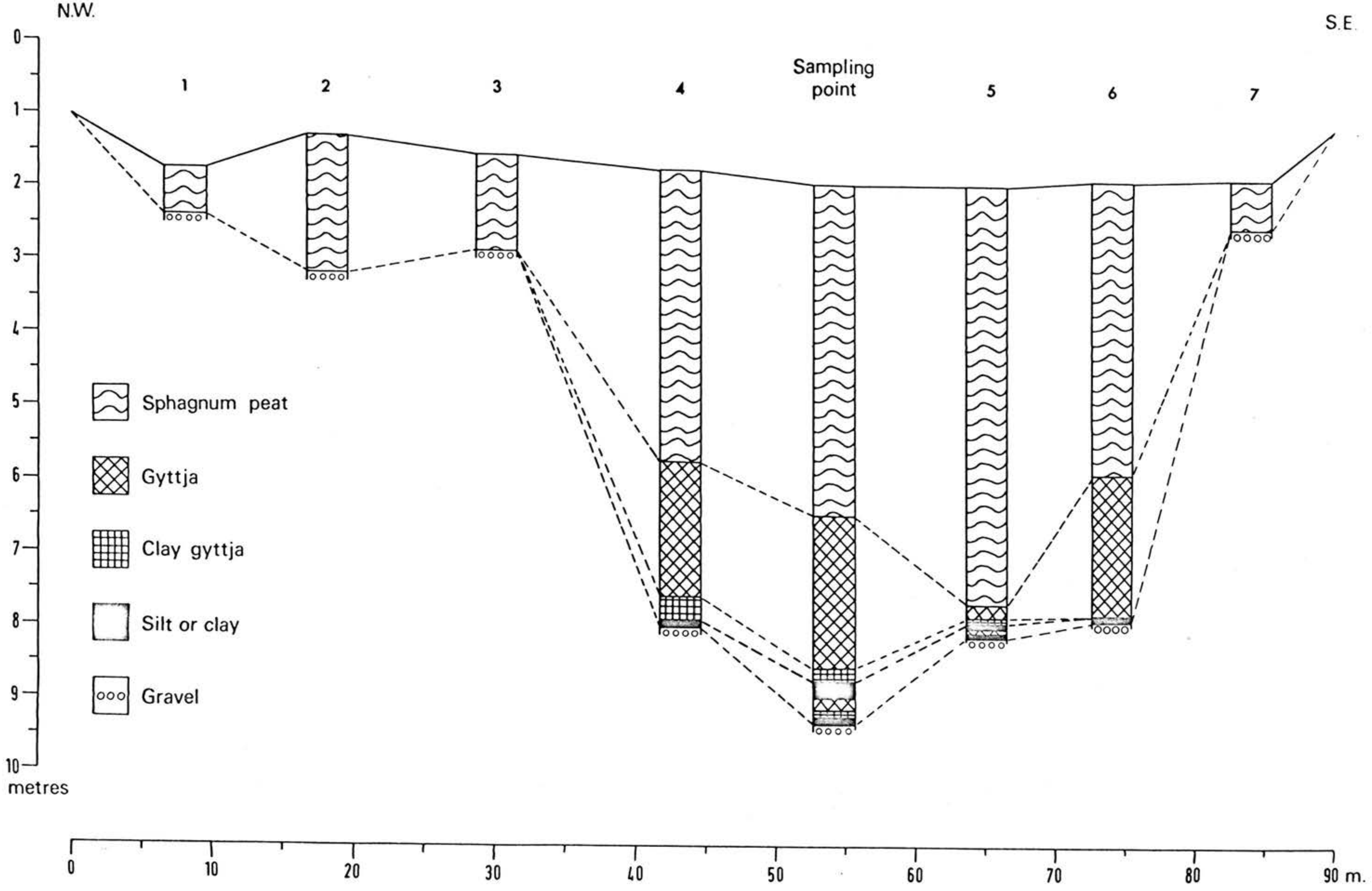
As this site contains a complete stratigraphical and vegetational record of the Lateglacial period, the surrounding ice-contact landforms must be related to the wastage of the Late-Devensian ice-sheet. In Gleann Mhaire and Gleann Diridh, some 7 km to the north of the site (Figure 22), a series of hummocky moraines terminate downvalley in outwash terraces. These have been recognized as readvance limits by Sissons (1974), and are thought to mark the maximal extent of outlet glaciers from a former ice-cap on the Gaick Plateau to the north. As the site at Tirinie is Lateglacial in age, these mapped limits most probably relate to the Loch Lomond Readvance.

5. LOCH ETTERIDGE

Loch Etteridge (Nat. Grid Ref. NN/688929) is situated in Glen Truim, Inverness-shire, approximately 10 km northeast of Dalwhinnie and 7.5 km southwest of Newtonmore (Figure 4). (p.36) The loch lies at 295 m O.D. in a large dead-ice hollow surrounded by a complex system of kames, kame terraces and eskers. A small embayment at the southwest end of the loch has been infilled, and pollen analytical investigations were centred on this locality.

FIGURE 23

Diagrammatic cross-section showing the stratigraphy of the deposits at Loch Etteridge.


N.W.
S.E.
Sampling point
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7
8
9
10
metres
Sphagnum peat
Gyttja
Clay gyttja
Silt or clay
Gravel
0
10
20
30
40
50
60
70
80
90 m.

The embayment is approximately 70 m in width and over 200 m along its long axis. The surface is relatively dry and supports a rich flora of *Myrica gale*, *Calluna vulgaris* and *Erica tetralix*, with small stands of *Salix* spp. and *Betula nana*. *Festuca ovina* and *Agrostis* spp. are the dominant grasses, while *Polytrichum communis* and *Polytrichum alpinum* are the main moss species. A small stream flows southwest-northeast across the site and is fringed with *Juncus effusus* and *Juncus articulatis* in conjunction with stands of *Eriophorum vaginatum* and *Eriophorum angustifolium*. *Potamogeton* spp. grows extensively in the stream.

A transect of test bores across the site revealed the presence of a pronounced stratigraphic oscillation in the basal deposits (Figure 23) which was best developed alongside the small stream in the centre of the basin. The stratigraphy at this point was as follows:-

0-405 cm	Not sampled.
405-475 cm	Highly humified *Sphagnum* peat. Seeds of *Menyanthes* and wood possibly of *Betula*.
475-540 cm	Very highly humified organic gyttja. Stems of *Carex* and *Phragmites*. Occasional wood fragments.
540-674 cm	Dark brown gyttja.
674-687 cm	Green grey clay gyttja.
687-701 cm	Light grey silty-clay.
701-720 cm	Green-brown gyttja.

720-730 cm	Grey-green clay gyttja, more micaceous near base.
730-742 cm	Very fine grey silty-clay, wet and difficult to obtain uncontaminated samples with the Hiller borer. More sandy near the base.
743 cm	Gravel.

The basal 15 cm were found to contain insufficient pollen for analysis, and were therefore classed as "non-polleniferous" on the basis of criteria outlined in Chapter 3. The lowest level analysed was 727.5 cm, but pollen was still sparse, and consequently only 100 pollen were counted from that sample. In all the other samples, a total of 300 land pollen was used as the pollen sum. Eight distinct pollen assemblage zones were recognized and the Late-glacial-Postglacial boundary was placed between the fifth and sixth of these zones at 682.5 cm, approximately 9 cm above the stratigraphic transition from fine grey clay to organic clay gyttja.

A second visit was made to the site after the initial analysis had been carried out, and four cores were removed from the basal deposits near the original sampling point for the purpose of obtaining radiocarbon dates from critical horizons. A further pollen diagram was then drawn up after a rapid pollen count of 100 grains on samples removed at 2.5 cm intervals from one of the cores. The material in that core was then used for sedimentological analysis. The stratigraphy of the core is as follows:-

FIGURE 24

Loch Etteridge: Lateglacial pollen diagram 1.

LOCH ETTERIDGE

Diagram 1.

NATIONAL GRID REFERENCE NN 688929 ALTITUDE 295m.O.D.

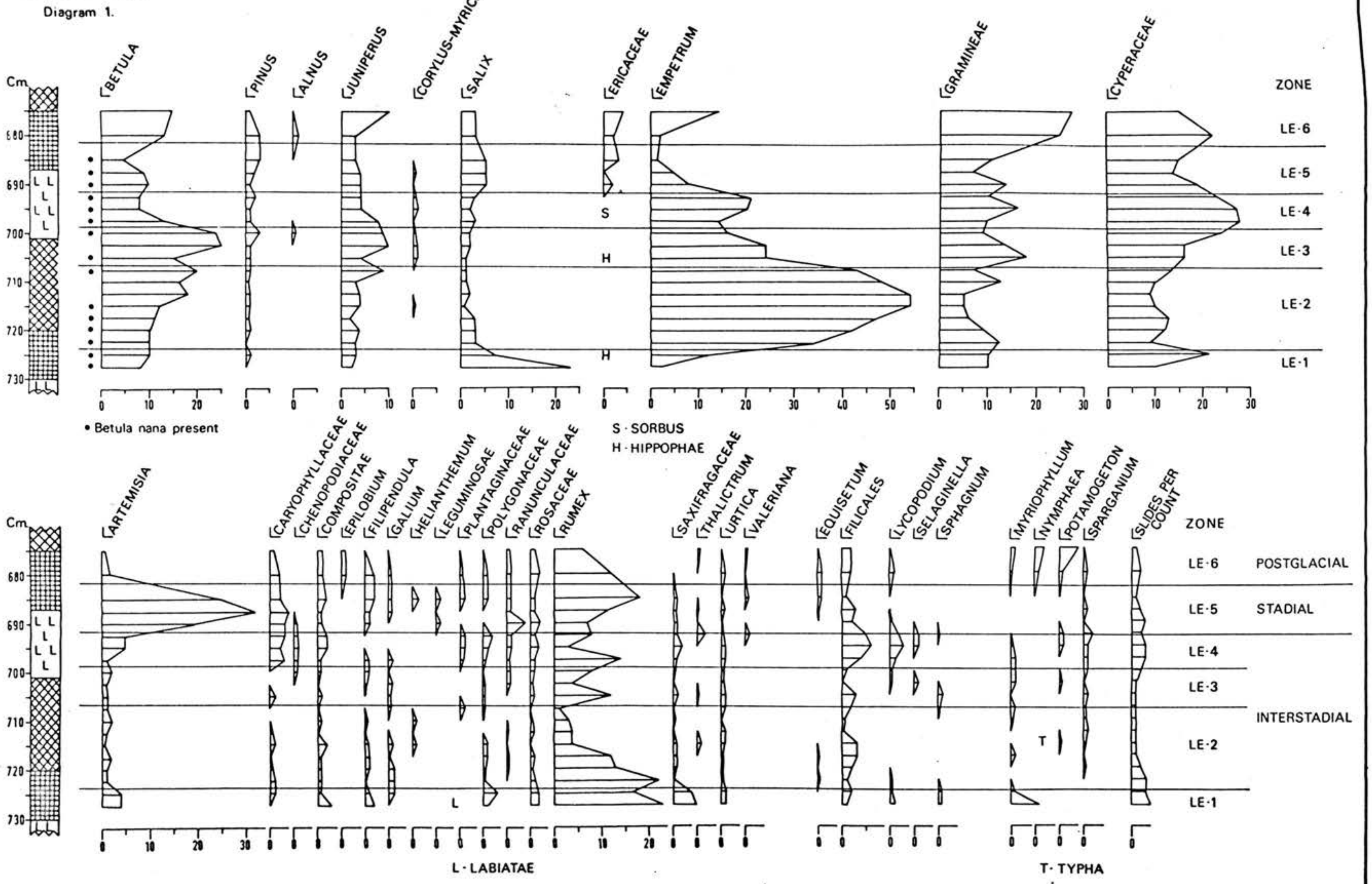


FIGURE 25

Loch Etteridge: Lateglacial pollen diagram 2.

LOCH ETTERIDGE

Diagram 2.

NATIONAL GRID REFERENCE NN 688929 ALTITUDE 295m. O.D.

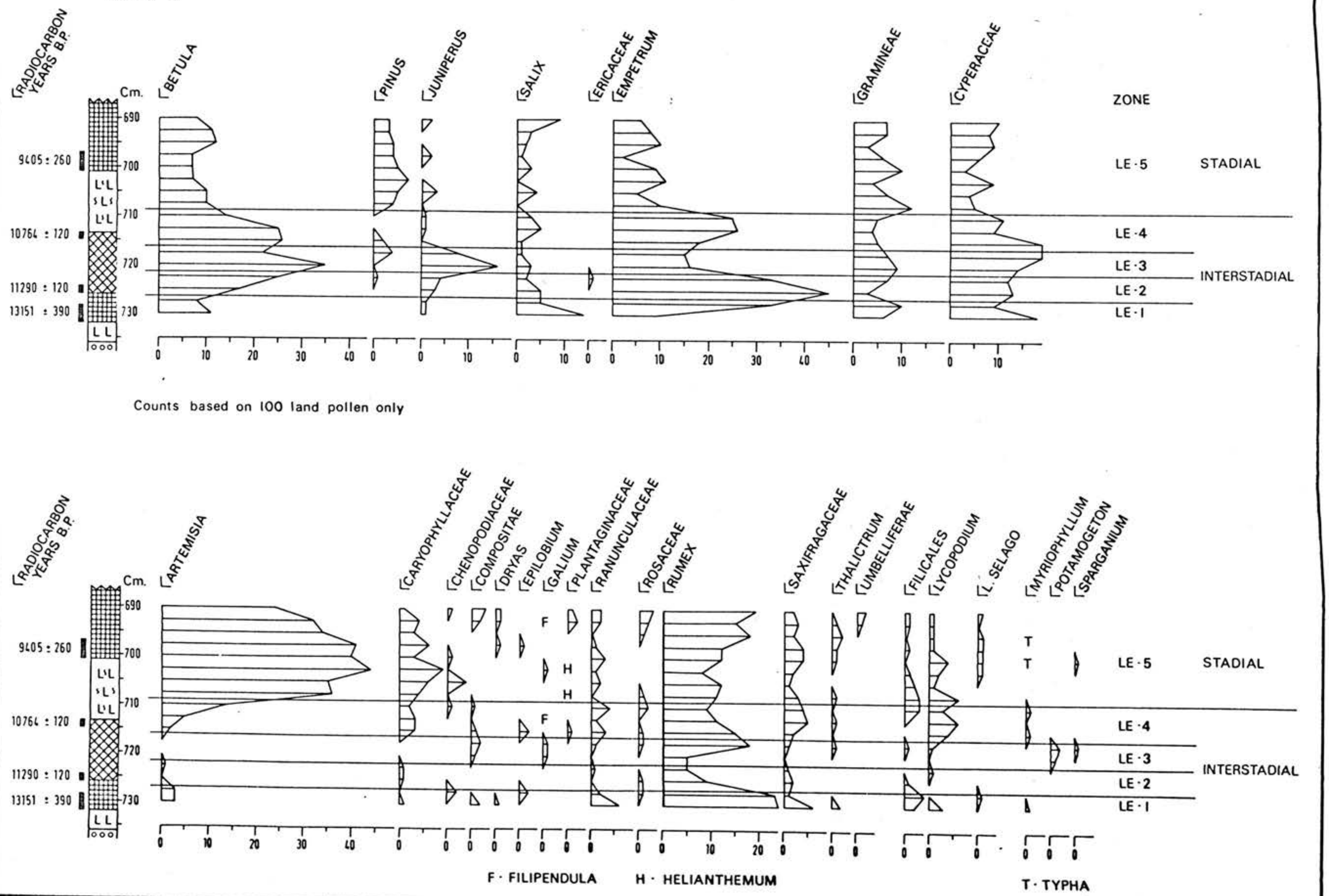


FIGURE 26

Loch Etteridge: Postglacial pollen diagram.

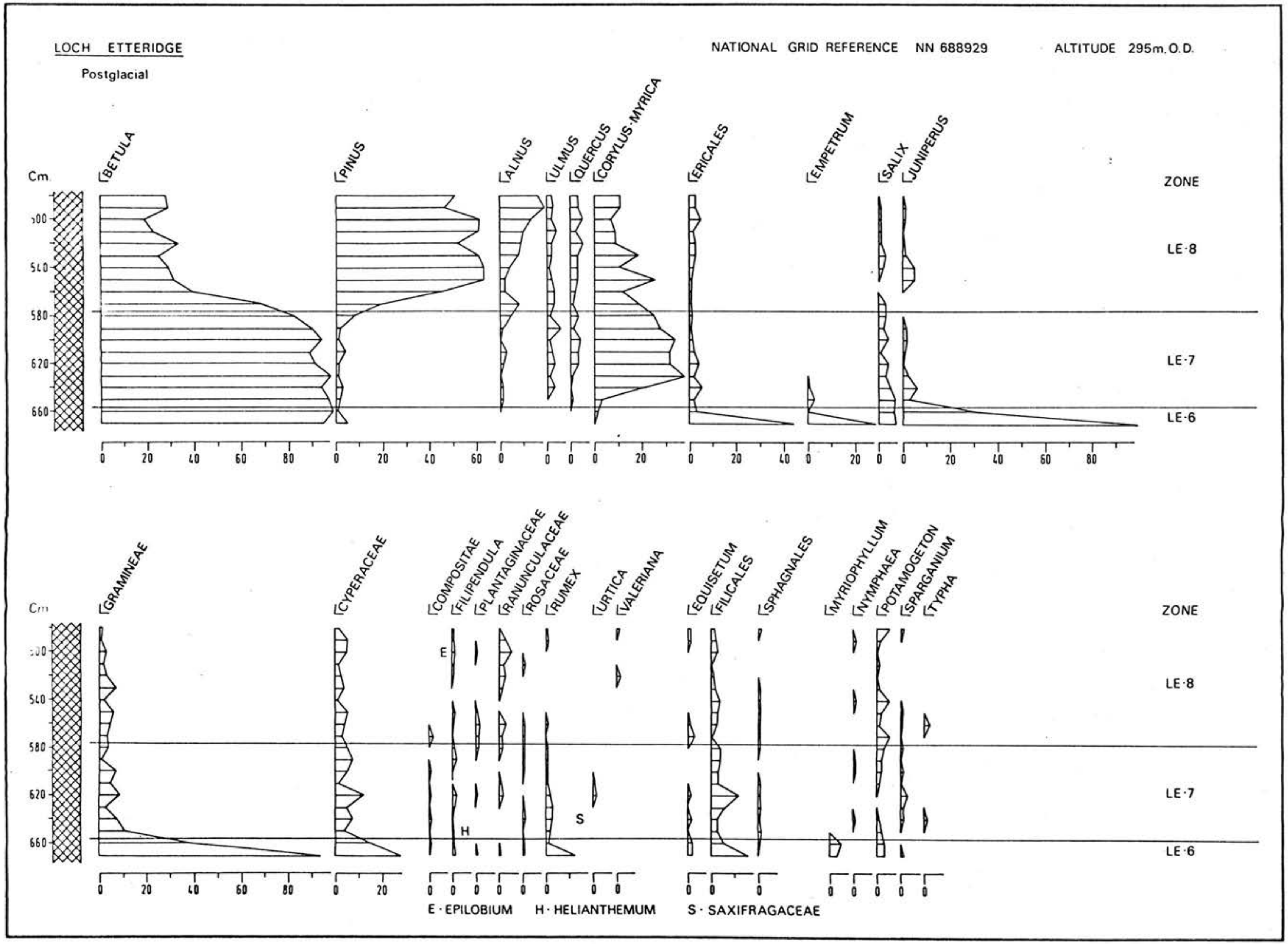
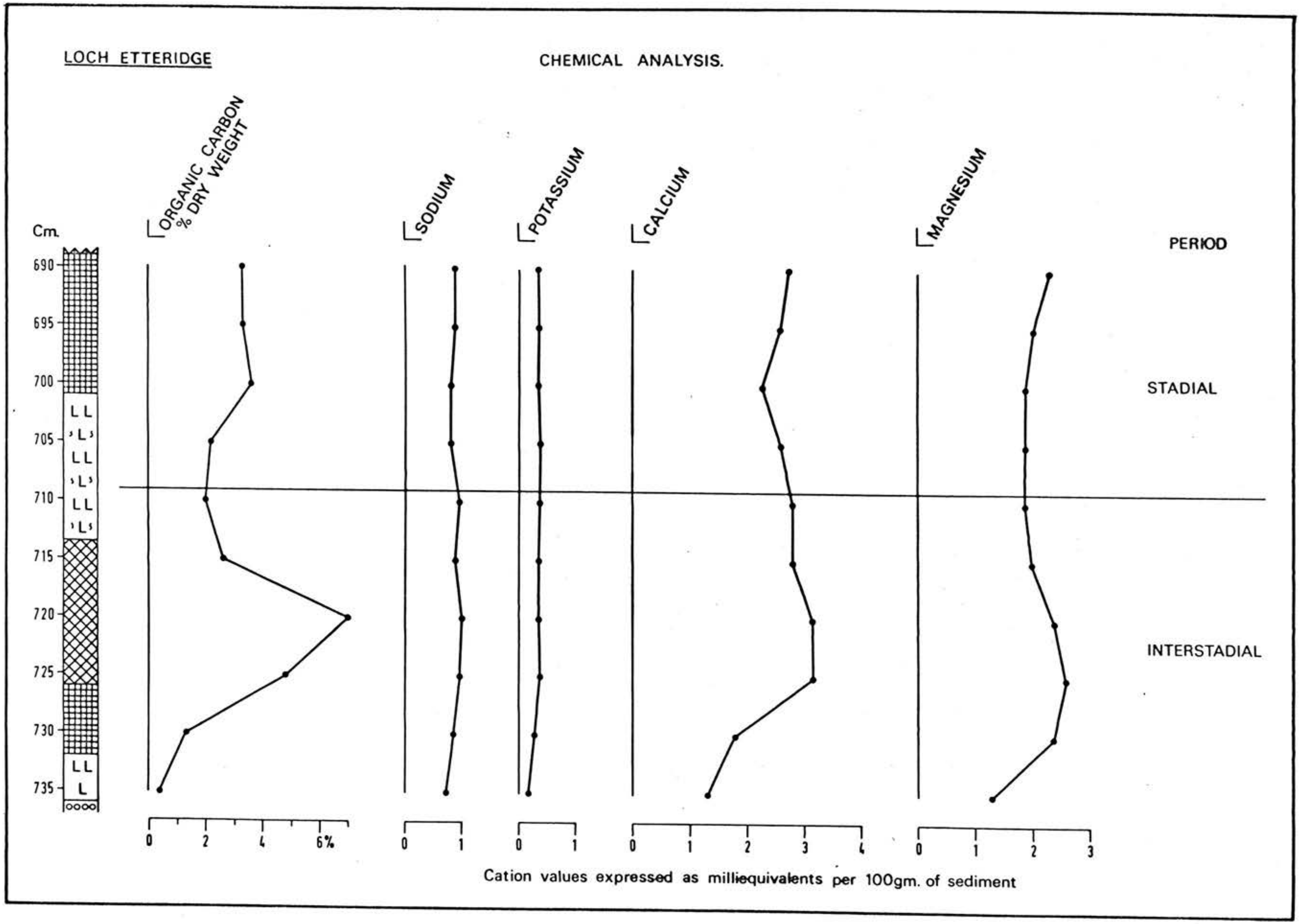

LOCH ETTERIDGE
Postglacial
NATIONAL GRID REFERENCE NN 688929
ALTITUDE 295m. O.D.
Cm
BETULA
PINUS
ALNUS
ULMUS
QUERCUS
CORYLUS-MYRICA
ERICALES
EMPETRUM
SALIX
JUNIPERUS
ZONE
LE·8
LE·7
LE·6
500
540
580
620
660
0
20
40
60
80
GRAMINEAE
CYPERACEAE
COMPOSITAE
FILIPENDULA
PLANTAGINACEAE
RANUNCULACEAE
ROSACEAE
RUMEX
URTICA
VALERIANA
EQUISETUM
FILICALES
SPHAGNALES
MYRIOPHYLLUM
NYMPHAEA
POTAMOGETON
SPARGANIUM
TYPHA
E
H
S
E · EPILOBIUM
H · HELIANTHEMUM
S · SAXIFRAGACEAE

FIGURE 27

Loch Etteridge: chemical diagram.


LOCH ETTERIDGE
CHEMICAL ANALYSIS.
ORGANIC CARBON % DRY WEIGHT
SODIUM
POTASSIUM
CALCIUM
MAGNESIUM
PERIOD
STADIAL
INTERSTADIAL
Cm.
690
695
700
705
710
715
720
725
730
735
L L
L
0
2
4
6%
0
1
0
1
0
1
2
3
4
0
1
2
3
Cation values expressed as milliequivalents per 100gm. of sediment

690-701 cm	Green-brown organic clay gyttja. Very fine sediment with no identifiable macrofossils.
701-713 cm	Fine grey silty-clay with stems and moss fibres.
714-726 cm	Green-brown organic clay gyttja with three distinct highly organic bands.
726-732 cm	Clay gyttja, becoming increasingly coarser near the base.
732-736 cm	Grey silty clay becoming more sandy near the base.
736 cm	Gravel.

The basal 9 cm of sediment were classed as "non-polleniferous" and the lowest level analysed was 730 cm. Five separate pollen assemblage zones were identified and these were comparable with the five lowest assemblage zones recognized in the original diagram. Detailed differences in stratigraphy and pollen totals between the two diagrams are thought to be due largely to differential compression in the cores obtained with the Dachnowski piston corer. Henceforth, the original diagram will be referred to as Loch Etteridge I (Figures 24 and 26) and the diagram from the cores will be termed Loch Etteridge II (Figure 25).

Rumex-Salix assemblage zone

Zone LE-1 Below 724 cm - Loch Etteridge I
Below 728 cm - Loch Etteridge II

This is the basal pollen assemblage zone in the site, and

is characterised by high values for Rumex (over 20% of total land pollen at most levels), and Salix, with significant percentages of Gramineae, Saxifragaceae and Artemisia. Most of the Salix grains resemble Salix herbacea, while the majority of the birch pollen seems to be of Betula nana. Empetrum rises throughout the zone indicating the gradual transition to an open steppe-type of landscape with a sparse vegetation cover to a closed heathland. This change is also reflected in the sediment column, as the zone spans the transition from basal minerogenic sediments to clay gyttja.
The lower 3-4 cm of clay gyttja at Loch Etteridge II yielded a radiocarbon date of 13,151 ± 390 B. P. (SRR-304). The organic carbon curve rises throughout the zone, and there is a similar upward trend in the curves for Ca and Mg with a very slight rise in the values of Na and K. The upper contact of the zone is placed at the sharp increase in percentages of Empetrum and the decline in values for Artemisia, Rumex (in Loch Etteridge II) and Salix.

Empetrum assemblage zone

Zone LE-2 724-706 cm - Loch Etteridge I
728-722 cm - Loch Etteridge II

Empetrum dominates the pollen spectrum in this zone, reaching 54% of total land pollen in the diagram from Loch Etteridge I. Betula and Juniperus are present in significant percentages, while Rumex declines towards the upper contact. Again, the majority of birch pollen resemble Betula nana, and there is no firm evidence for the arrival of tree birch in the area during this zone. Values for organic carbon and the alkali cations Ca and Mg continue to rise and there is a change in the sediment column from clay gyttja near the base, to almost pure organic mud near the top of the zone. A date of 11,290 ± 165 B.P. (SRR-303) was obtained from the transition between these two sediment types at 725-726 cm in Loch Etteridge II. The upper contact of the zone is placed at the sharp decline in values for Empetrum.

Betula-Juniperus assemblage zone

Zone LE-3 706-698 cm - Loch Etteridge I
724-716 cm - Loch Etteridge II

This zone is characterised by high values for Betula which exceed 30% of the total land pollen in the diagram from Loch Etteridge II. Juniperus, Rumex and Empetrum are also significant in the pollen spectrum. Values for aquatic pollen continue to be very low, but the rise in the Cyperaceae pollen curve may be a reflection of the expansion of the littoral fen into the shallower parts of the basin. Tree birches appear to be present in larger quantities, but the majority of the pollen of this genus is still Betula nana. The pollen spectrum reflects a shrub-heath landscape with occasional copses of tree birch. The organic carbon curve reaches a maximum during this zone, as do the curves for the alkali cations Ca and Mg, although with the exception of Na and K there is a definite decline in the chemical curves towards the top of the zone. The upper contact is placed at the decline in Betula and Juniperus and the renewed upward trend in the curve for Empetrum.

Betula-Empetrum assemblage zone

Zone LE-4 698-692 cm - Loch Etteridge I

716-709 cm - Loch Etteridge II

Empetrum is again dominant in the pollen spectrum along with Betula and Rumex. However, the decrease in values for these taxa throughout the zone, in association with the gradual upward trend in the curves for Artemisia, Lycopodium, Saxifragaceae and Filicales reflect the transition from a closed heathland vegetation to an open tundra flora. The sediment consists largely of a fine grey clay indicating renewed inwash of material consequent on the thinning of the vegetation cover. However, the lower 2 cm of the zone in the diagram from Loch Etteridge II span the transition from the underlying organic muds to the grey silty-clays. A sediment sample from this horizon yielded a radiocarbon date of 10,764 ± 120 B. P. (SRR-302). The curve for organic carbon drops sharply towards the upper contact of the zone, and there is also a gradual decline in values for Ca. The upper boundary of the zone is placed at the drop in Empetrum percentages and the complementary rise in the curve for Artemisia.

Artemisia assemblage zone

Zone LE-5 692-682 cm - Loch Etteridge I

Above 709 cm - Loch Etteridge II

This zone is characterised by high values for Artemisia which exceeds 40% of the total land pollen in the diagram from Loch

Etteridge II. Rumex, Caryophyllaceae and Saxifragaceae are also present in significant quantities, while values for woody taxa are uniformly low. The Pinus pollen is probably the produce of long-distance transport. The pollen spectrum reflects an open tundra environment with a predominance of taxa indicative of unstable soils. There is a gradual change in the sediment column from pure minerogenic deposits to clay gyttja which is probably a result of a gradual trend towards soil stability. Values for organic carbon however remain low and there are commensurately low values for the alkali cations, although there is a slight rise in the curves for Ca and Mg near the top of the zone. A date of 9405 ± 260 B.P. (SRR-301) was obtained from 3.5 cm of the clay gyttja above 701 cm in Loch Etteridge II. The upper boundary of the zone is placed at the very sharp drop in Artemisia on the diagrams from Loch Etteridge I. This contact also represents the boundary between Lateglacial and Postglacial sediments.

Betula-Juniperus-Empetrum assemblage zone

Zone LE-6 682-655 cm - Loch Etteridge I

This is the basal Postglacial pollen assemblage zone, and is characterised by successive peaks in the curves for Rumex, Gramineae, Empetrum, Juniperus and Betula. The zone represents the transition from the tundra landscape of zone LE-5 through the gradual expansion of heathland to the final establishment of birch forest. Myriophyllum cf. alterniflorum is present in small quantities but, as in previous zones, the overall aquatic pollen content is low. The zone also spans the stratigraphic transition from clay gyttja to pure organic mud, and the upper contact is placed at the decline in values for Juniperus and the rise in the curve for Corylus-Myrica.

Betula-Corylus-Myrica assemblage zone

Zone LE-7 655-575 cm - Loch Etteridge I

Corylus-Myrica rises steadily to a peak in the early part of the zone, and thereafter declines progressively towards the upper boundary. Betula remains the dominant tree pollen, while Ulmus, Quercus and Alnus are all present in small quantities. Pinus rises gradually near the upper limit of the zone. The pollen spectrum reflects the continued dominance of birch woodland in the landscape, but the rise in the Corylus-Myrica percentages indicates the development of a shrub understorey. Moreover, the occurrence of Pinus and deciduous tree pollen in small quantities herald the spread of mixed forest to the area. The upper boundary of the zone is placed at the rise in the curve for Pinus, and the decline in values for Betula and Corylus-Myrica.

Pinus assemblage zone

Zone LE-8 575-450 cm - Loch Etteridge I

The pollen spectrum is dominated by Pinus which exceeds 60% of the total arboreal pollen, although Betula and Corylus-Myrica are still present in significant quantities. Ulmus and Quercus occur throughout the zone, while Alnus rises progressively towards the upper contact. The rise in the Alnus curve, in association with the slight increase in values for Ericaceae may be indicative of a trend towards moister environmental conditions. The zone reflects a landscape of coniferous forest, with occasional stands of deciduous woodland and isolated areas of open heathland.

Implications for the glacial sequence

The stratigraphical and vegetational record preserved in the site by Loch Etteridge is comparable with the Lateglacial sequence observed at many other sites in the Scottish Highlands. The surrounding fluvioglacial landforms must therefore be the product of the decay of the Late-Devensian ice-sheet. If the basal radiocarbon date is correct, a minimum age for the disappearance of this ice from the area must be about 13,000 B.P. To the south and east of the site readvance limits have been recognized by Sissons (1974) relating to outlet glaciers from an ice-cap which developed on the Gaick Plateau. The most clearly-defined of these limits occurs in upper Glen Truim approximately 13 km south of Loch Etteridge (Figure 28). There, a series of hummocky moraines which can be traced southwards through the Pass of Drumochter over a distance of 14 km, terminates abruptly and is succeeded by outwash. As the site by Loch Etteridge is Lateglacial in age, it is reasonable to assume that these mapped limits relate to the Loch Lomond Readvance.

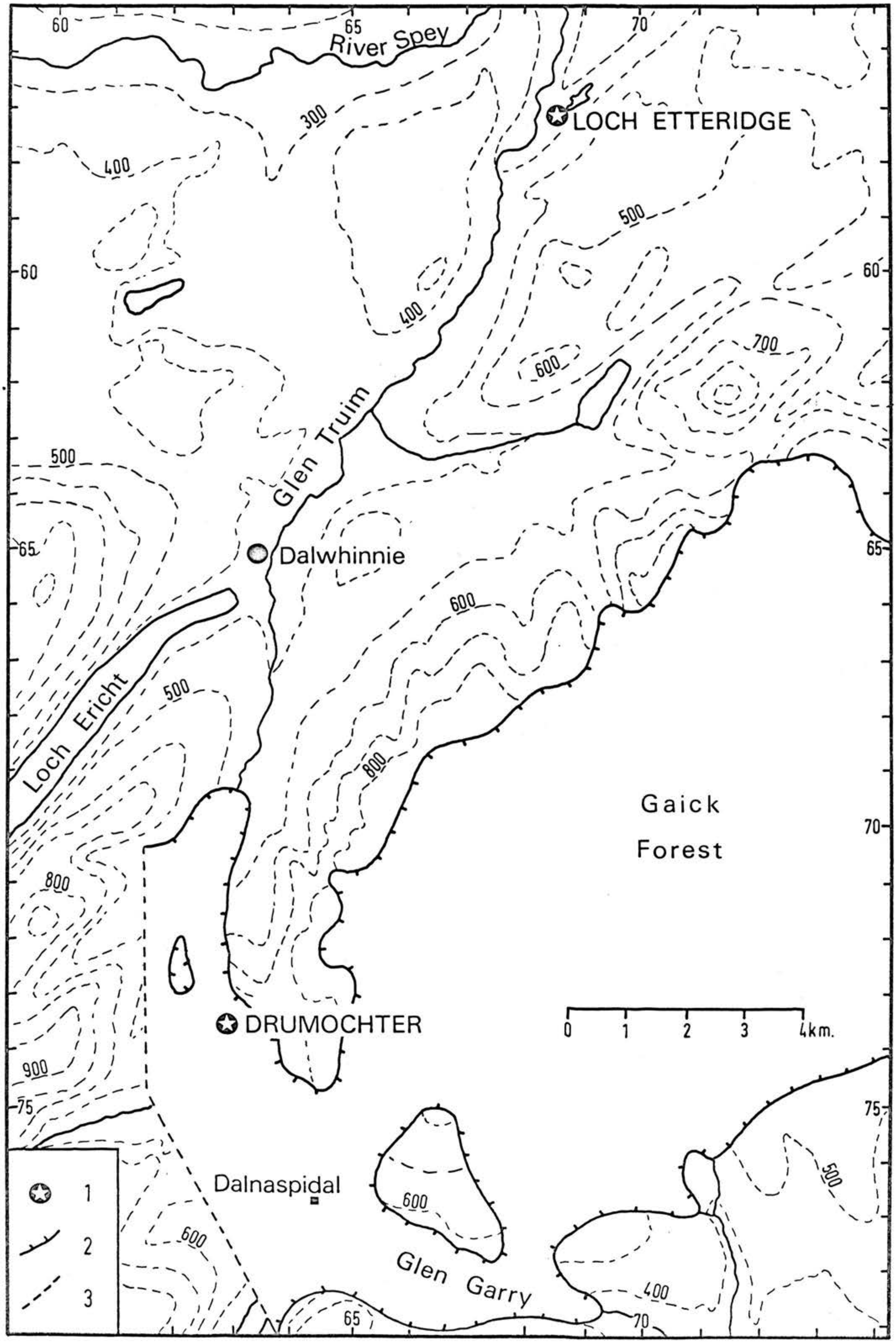
It has been suggested that ice remained in the Cairngorm Mountains, and in at least a considerable part of the Spey Valley

FIGURE 28

The sites at Loch Etteridge and Drumochter in **relation to**
Loch Lomond **Readvance glacier** limits
(after Sissons **1974).**

1) **Pollen** sites.
2) **Probable glacier limits.**
3) **Limit of mapped area.**

Contour interval 100 **m.**


River Spey
LOCH ETTERIDGE
Glen Truim
Dalwhinnie
Loch Ericht
Gaick
Forest
DRUMOCHTER
Dalnaspidal
Glen Garry
0 1 2 3 4km.
1
2
3
60
65
70
75
300
400
500
600
700
800
900

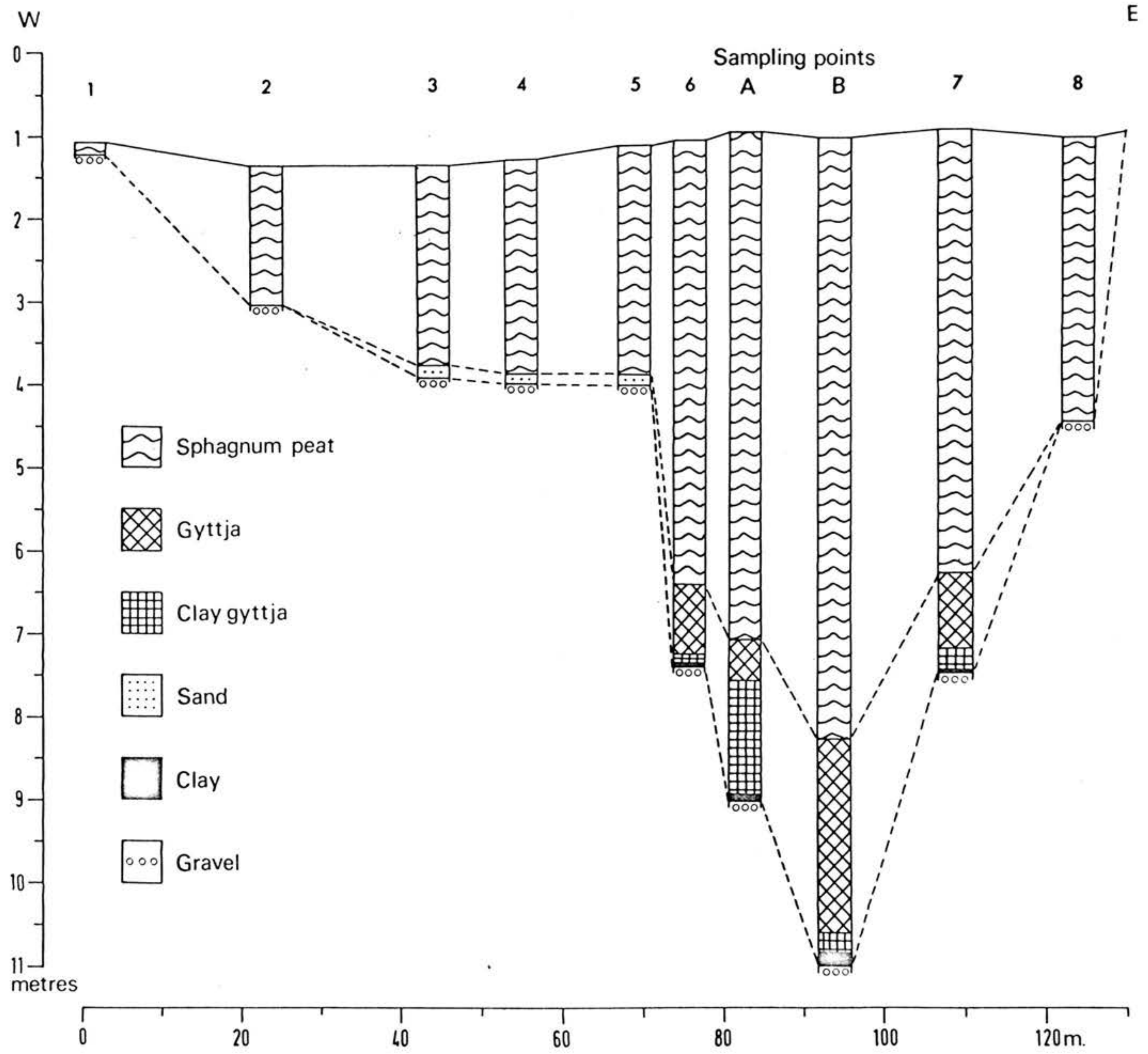
throughout the Lateglacial period (Sugden 1970). However, the presence of sediments in the Loch Etteridge site which have been shown by pollen analysis and radiocarbon assay to be of Lateglacial age casts doubt on this hypothesis, for it is difficult to conceive of an ice mass with its margins rising to the south and west (as indicated by Sugden) existing in the Spey Valley, if adjacent areas of Glen Truim were ice-free at the time. Moreover, as there is clear evidence in the Grampian Highlands to support the hypothesis of a glacial readvance during the Lateglacial Stadial or pollen zone III (see Chapter 1), and as it has been demonstrated that this time period was of sufficient duration to allow the complete build-up of an ice-cap on the Gaick Plateau (Sissons 1974), then the concept of a steadily downwasting ice-cap in the Cairngorm Mountains persisting throughout the Lateglacial period becomes increasingly more suspect.

6. DRUMOCHTER

The site (Nat. Grid Ref. NN/629762) is situated on the col of the Drumochter Pass, Inverness-shire, approximately 8 km south of Dalwhinnie, and 27 km northwest of Blair Atholl (Figure 4). It lies at 449 m O. D. in a large dead-ice hollow between the A9 Perth-Inverness road and the railway, and is surrounded by a distinctive hummocky morainic topography. The depression is almost 1 km in length and is approximately 130 m across at the

FIGURE 29

Diagrammatic cross-section showing the stratigraphy of the deposits at Drumochter.


W
E
Sampling points
1
2
3
4
5
6
A
B
7
8
Sphagnum peat
Gyttja
Clay gyttja
Sand
Clay
Gravel
0
1
2
3
4
5
6
7
8
9
10
11
metres
0
20
40
60
80
100
120 m.

sampling point. The surface is relatively dry, and supports a vegetation of *Myrica gale*, *Calluna vulgaris* and and *Erica tetralix* with *Ulex* spp. on drier areas. *Eriophorum vaginatum*, *Eriophorum angustifolium*, *Juncus squarrosus* and *Sphagnum* spp. are found round the wetter hollows, while *Molinia caerulea* and *Polytrichum communis* are also present.

The site lies within the presumed Loch Lomond Readvance limits and therefore attention was centred on finding the deepest point in the basin. A rapid transect of test bores showed that over 800 cm of sediment had accumulated near the centre of the bog, and as this was thought to be the deepest point, the entire profile was sampled at this locality (Figure 29). The stratigraphy was as follows:-

0- 30 cm	Fibrous roots and poorly humified *Sphagnum-Eriophorum* peat.
31-165 cm	*Sphagnum-Eriophorum* peat. Fragments of birch wood, seeds of *Menyanthes* and stems of *Calluna*.
165-380 cm	*Sphagnum* peat, becoming more highly humified with depth. Wood of *Betula*, stems of *Calluna*, *Phragmites* and *Carex*.
380-460 cm	Much wetter *Sphagnum* peat. Twig of *Betula*, wood possibly of *Pinus*, seeds of *Menyanthes*.
460-570 cm	*Sphagnum* peat, more highly humified. Wood fragments of *Pinus* and stems of *Calluna*.

570-619 cm	Yellow-brown *Sphagnum* peat. Seeds of *Menyanthes* and stems of *Phragmites* and *Carex*.
619-668 cm	Fibrous lake mud with seeds of *Menyanthes*.
668-770 cm	Green-grey clay gyttja, becoming more micaceous near base.
770-812 cm	Clay gyttja - minerogenic content increasing.
812-819 cm	Fine grey silty-clay, becoming sandy near the base.
820 cm	Gravel.

Subsequent investigation revealed the presence of a deeper point in the basin, roughly 10 m to the east of the original sampling point, and a further set of samples was taken from the basal 2.4 m of sediment at this locality. The stratigraphy there was as follows:-

760-809 cm	Dark brown fibrous lake mud - very highly humified.
809-951 cm	Green-grey clay gyttja, becoming more micaceous with depth.
951-979 cm	Fine grey silty clay, becoming coarser near the base.
979-991 cm	Medium-coarse sand.
992 cm	Gravel.

The original pollen diagram is hereafter referred to as Drumochter I (Figures 30 and 31) and the diagram from the basal sediments only is termed Drumochter II (Figure 32). Four separate pollen assemblage zones were identified in the diagrams, the

FIGURE 30

Drumochter: pollen diagram 1a.

DRUMOCHTER

Diagram 1a.

NATIONAL GRID REFERENCE NN 629762

ALTITUDE 449m. O.D.

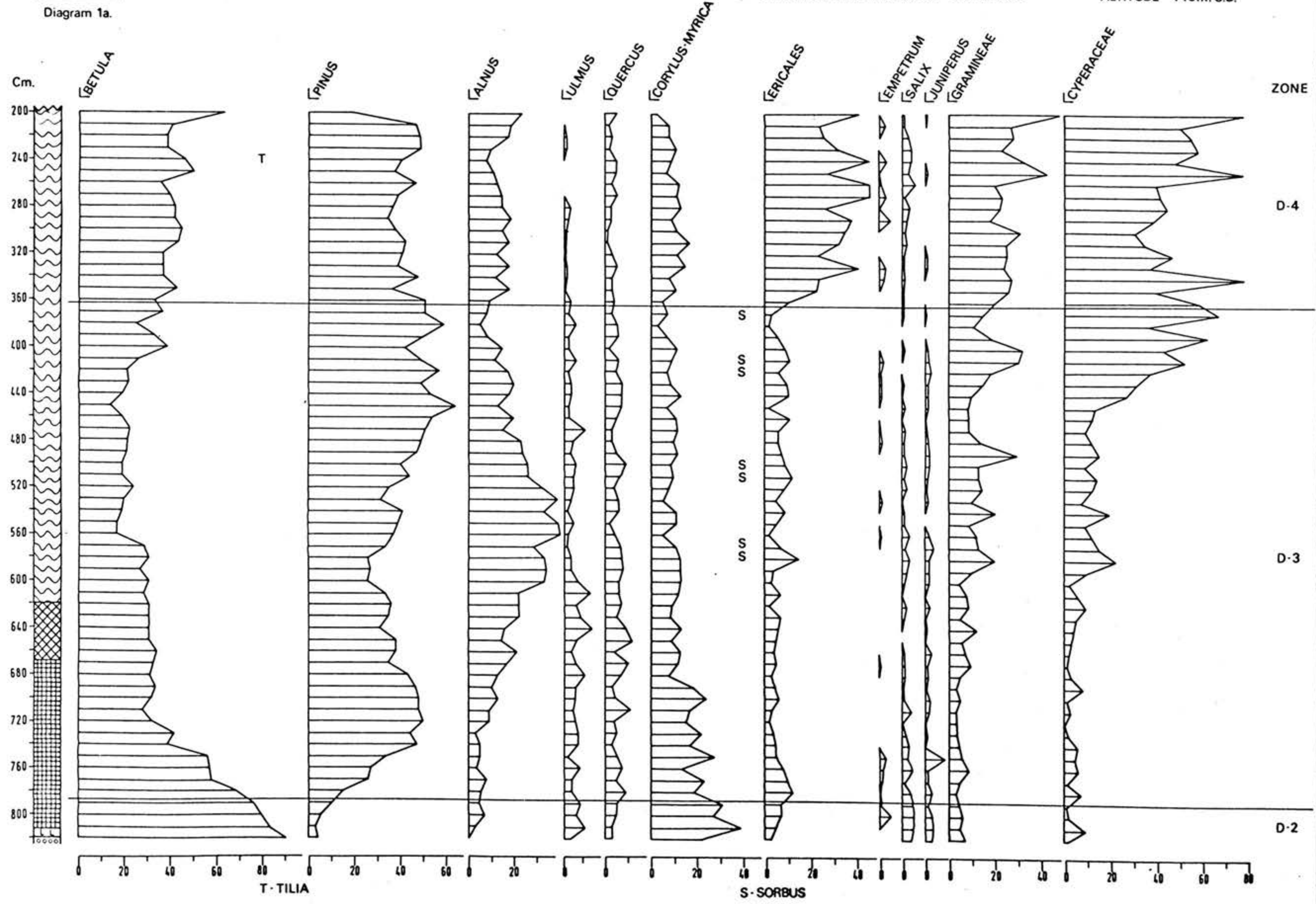


FIGURE 31

Drumochter: pollen diagram 1b.

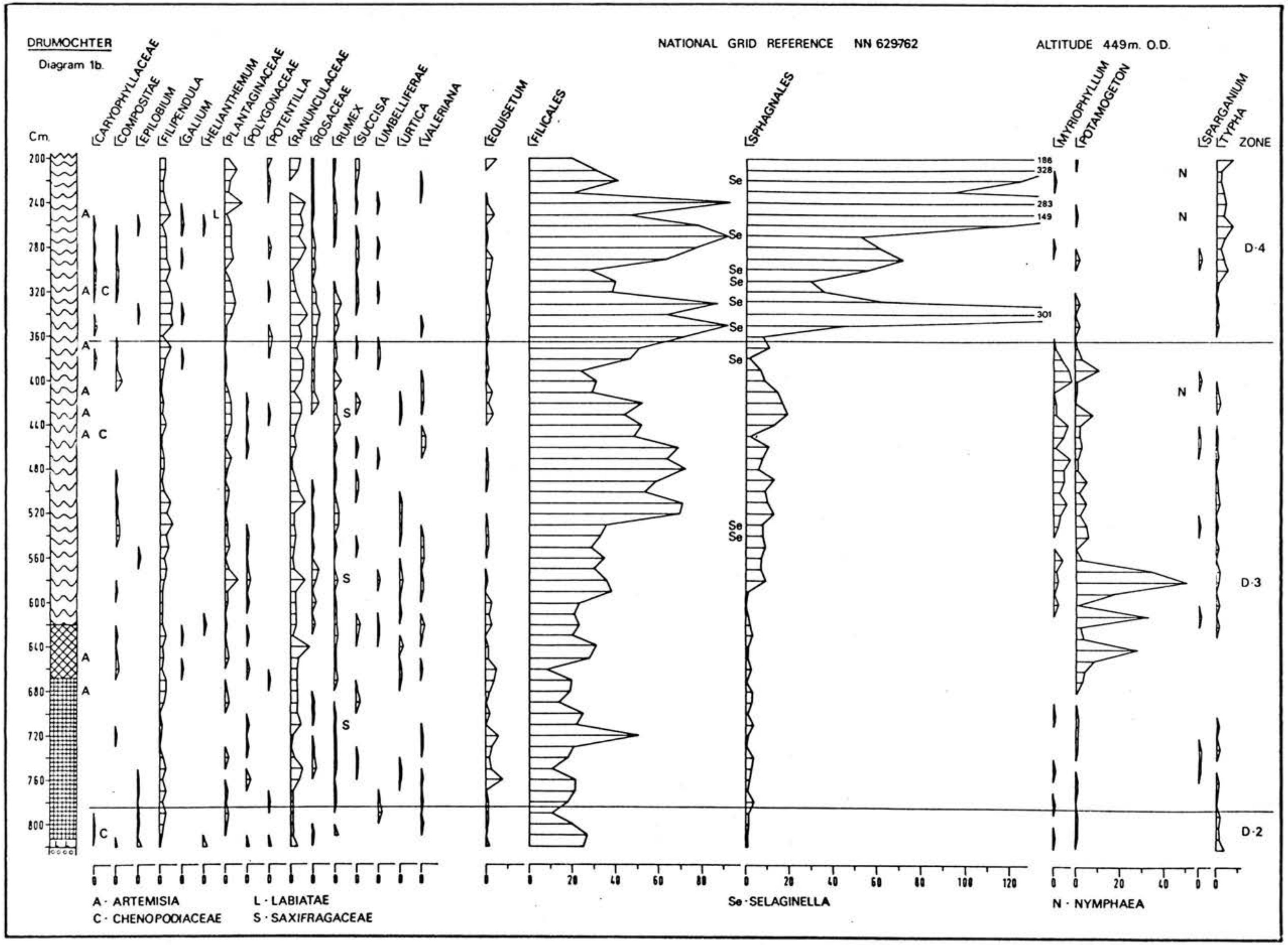

DRUMOCHTER

Diagram 1b.

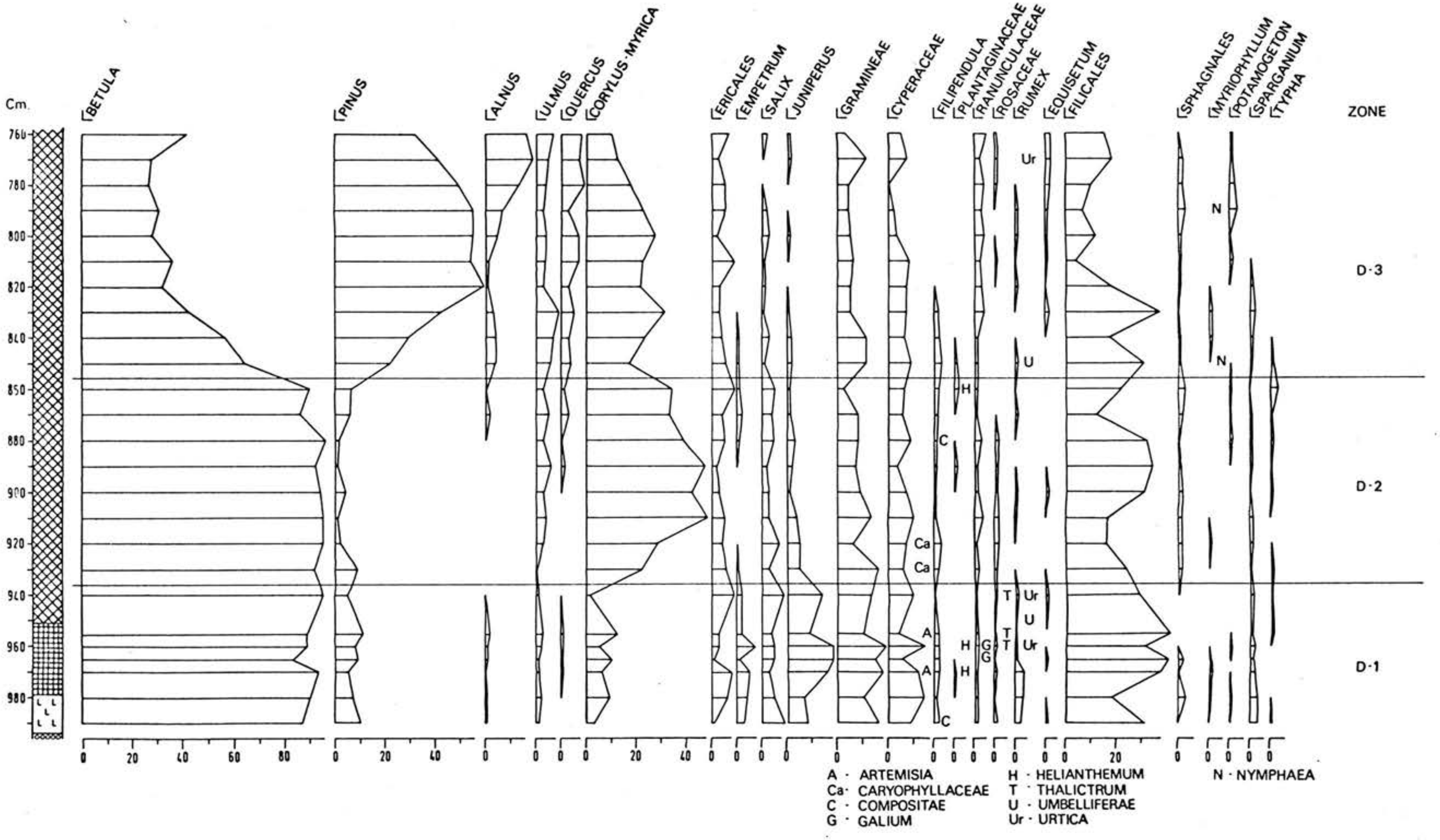
FIGURE 32

Drumochter: pollen diagram 2.

DRUMOCHTER

Diagram 2.

NATIONAL GRID REFERENCE NN 629762 ALTITUDE 449m. O.D.



uppermost being absent from the Drumochter II profile, while the basal assemblage zone is not present in the record from Drumochter I.

Betula-Juniperus assemblage zone

Zone D-1 992-935 cm - Drumochter II

Betula dominates the pollen spectrum in this basal pollen assemblage zone, the majority of the pollen being of tree birch. Juniperus, Gramineae and Filicales all occur in significant percentages, while Salix, Ericales and Empetrum are present throughout the zone. Ulmus and Quercus appear in small quantities. The high values for Pinus and Corylus-Myrica, and the presence of Alnus in the zone are attributed largely to the effect of contamination of the basal sediment by material carried down from above by the Hiller borer (see below), although some grains may be the product of long-distance transport. The zone spans the transition from minerogenic sediment to organic clay gyttja, and reflects the stabilisation of the landscape in the early Postglacial period during the spread of heathland and birchwoods into the area. The upper contact is placed at the rise in the curve for Corylus-Myrica and the decline in the percentages of Juniperus.

Betula-Corylus-Myrica assemblage zone

Zone D-2 Below 785 cm - Drumochter I
935-855 cm - Drumochter II

Betula continues to dominate the pollen spectrum, but

Corylus-Myrica rises to almost 50% of the total arboreal pollen. Juniperus declines steadily throughout the lower part of the zone, and Empetrum disappears completely near the middle. Ulmus rises progressively throughout the zone, while Quercus and Alnus reappear near the upper contact. Pinus rises towards the top of the zone. This assemblage reflects the establishment of birch woodland in the area and the development of a rich shrub understorey. There is also a trend towards mixed woodland, but in general, values for deciduous taxa remain low. The upper boundary of the zone is placed at the decline in the curve for Corylus-Myrica, and the marked expansion of Pinus.

Pinus assemblage zone

Zone D-3 785-365 cm - Drumochter I
Above 855 cm - Drumochter II

This zone is characterised by very high values for Pinus which exceeds 60% of the total arboreal pollen at certain levels. Alnus increases to a maximum at 520 cm and thereafter declines towards the upper contact. Betula is still an important element in the pollen spectrum, while Ulmus and Quercus are constant throughout the zone. Ericales are present in significant quantities, but values for other shrub taxa are uniformly low. The zone reflects the establishment of the Caledonian Pine Forest in this area of the Grampians, with considerable areas of birchwoodland, and occasional stands of mixed forest. The peak in the curve for Alnus may be indicative of wetter conditions towards the centre of the zone. The marked increase in values for Sphagnales at the same level, followed by the rise in the Cyperaceae curve and complementary decline in aquatic pollen, probably mark the expansion of the littoral fen and a rapid infilling of areas of open water. The upper contact of the zone is placed at the rise in the curves for Ericales and Alnus at 365 cm.

Betula-Pinus-Ericales assemblage zone

Zone D-4 Above 365 cm - Drumochter I

Betula, Pinus and Ericales dominate the land pollen spectrum and there are significant contributions from Alnus, Corylus-Myrica and Cyperaceae. Quercus and shrub pollen are present throughout the zone, while Ulmus declines at the lower contact. There is a marked increase in values for Filicales and Sphagnales, with a less-pronounced rise in the curves for Filipendula and Plantago. Pine and birch forests characterise the landscape, but the rise in the curves for Ericales, Plantago and Corylus-Myrica (many of the latter probably being pollen of Myrica gale) reflect a clearing of the forests under the influence of man, and an increasing trend towards heath and moorland. The rising Alnus curve may also be indicative of slightly wetter conditions. Values for aquatic pollen are uniformly low, indicating that the process of infilling in the basin is now virtually complete.

Implications for the glacial sequence

Although a large number of test bores was put down in the Drumochter site, no trace of Lateglacial sediments could be found. The basin is situated amidst a series of morainic hummocks which can be traced from upper Glen Truim through the Pass of Drumochter into Glen Garry over a distance of approximately 14 km (Figure 28). In both Glen Truim and Glen Garry, there is a sharp downvalley termination in this hummocky terrain beyond which is a sequence of outwash terraces. It has been suggested that these morphological limits represent the maximal ice-frontal positions of the Loch Lomond Readvance in the area (Sissons 1974; Thompson 1972). The occurrence of this Postglacial site within the hummocky moraine, in association with the location of the Lateglacial pollen site at Loch Etteridge beyond the hummocky topography, supports this contention. Moreover, as the hummocky moraine can be traced from the limit on Glen Truim through the Drumochter Pass to the presumed ice limit in Glen Garry then it is logical to assume that the former ice frontal position in that valley is also of Loch Lomond Readvance age.

Chapter 5

THE LATEGLACIAL PERIOD

Introduction

In the previous chapter, the pollen profiles were divided into discrete pollen assemblage zones. This method ensured as objective an assessment as was possible of the vegetational record at each of the sites, for no attempt was made at that stage of the analysis to integrate the individual zones into a regional or national framework. Once the zones had been established however, it became possible to correlate zones or groups of zones, thereby developing a system of broader units to serve as the basis for the study of the regional vegetation pattern throughout the Lateglacial period. Comparisons between the profiles (Figure 33) revealed the presence of the milder Lateglacial Interstadial preceded by the harsher Stadial referred to in Chapter 3. Unfortunately, insufficient radiocarbon dates were obtained to permit close correlation between individual zones or groups of zones, or to establish a series of time/depth scales to allow deductions to be made of sediment accumulation rates. Some dates were obtained from the study area however, and some of these, in association with other radiocarbon dates from adjacent areas of the Scottish Highlands and from sites in northern Britain, enabled an approximation to be made of the duration of the

FIGURE 33

Correlation chart of Lateglacial pollen assemblage zones in the study area.

BLACKNESS	ROINEACH MHOR	CORRYDON	TIRINIE	LOCH ETTERIDGE	PERIOD
B-6 Betula- Juniperus- Empetrum	RM-4 Juniperus- Empetrum- Betula	C-7 Betula- Juniperus	T-7 Betula- Juniperus- Empetrum	LE-6 Betula- Juniperus- Empetrum	POST GLACIAL
B-5 Gramineae- Cyperaceae	RM-3 Salix- Cyperaceae	C-6 Artemisia- Filicales	T-6 Artemisia- Rumex	LE-5 Artemisia	STADIAL
		C-5 Lycopodium- Selaginella	T-5 Rumex- Selaginella		
B-4 Betula- Juniperus	RM-2 Betula- Salix- Rumex	C-4 Betula- Juniperus	T-4 Betula- Juniperus- Empetrum	LE-4 Betula- Empetrum	INTERSTADIAL
B-3 Betula- Salix- Gramineae		C-3 Rumex- Selaginella	T-3 Betula	LE-3 Betula- Juniperus	
B-2 Empetrum- Rumex		C-2 Betula- Juniperus	T-2 Empetrum- Betula	LE-2 Empetrum	
B-1 Gramineae- Rumex	RM-1 Rumex- Artemisia- Gramineae	C-1 Rumex- Compositae- Filicales	T-1 Rumex- Artemisia	LE-1 Rumex- Salix	

two major periods.

The Lateglacial Stadial is considered to be almost synchronous with the classical pollen zone III of the Godwin-Jessen system, which is generally held to have spanned the 500 year period between ca. 10,800 and 10,300 B. P. In the study area, four radiocarbon dates were obtained which relate to the upper and lower boundaries of the Stadial. At Loch Etteridge, a sample of organic mud from immediately below the Stadial/Interstadial boundary as determined by pollen analysis, was dated at 10,764 ± 120 B. P. (SRR-302), while a date of 9405 ± 260 B. P. (SRR-301) was obtained from below the Stadial/Postglacial transition. The date of 10,764 ± 120 B. P. is comparable with a number of age determinations on the Interstadial/Stadial boundary (Table 2), and two other dates from the same site (SSR-303, SRR-304) are consistent with results from elsewhere (see below). However, the uppermost date is considerably younger than the conventionally accepted age of ca. 10,300 B. P. for the end of pollen zone III, and possible reasons for this discrepancy will be discussed in the following chapter. At Blackness, a layer of organic sediment immediately below the Interstadial/ Stadial boundary yielded a radiocarbon date of 10,100 ± 135 B. P. (HV-5650), while the Stadial/Postglacial boundary, as determined by pollen analysis, was dated at 9490 ± 160 B. P. (HV-5649). Both of these dates are much younger than dates obtained from other sites: in fact the lower date on the Interstadial/Stadial boundary at Blackness appears to be more comparable with several of the dates

Table 2

Date of onset of Stadial/zone III	Date of end of Stadial/zone III	Site	Reference
10,850 ± 120 B. P.	9800^{+700}_{-600} B. P.	Red Moss, Lancashire	Shotton, Blundell and Williams (1970)
10,835 ± 185 B. P. 10,705 ± 207 B. P.	10,264 ± 350 B. P.	Scaleby Moss, Cumberland	Godwin and Willis (1959)
10,820 ± 170 B. P.	9590 ± 170 B. P.	Bigholm Burn, Dumfriesshire	Godwin and Willis (1964)
11,450 ± 180 B. P.	10,650 ± 170 B. P.	Blelham Bog, Lancashire	Buckley and Willis (1970)
11,385 ± 120 B. P.		Callander, Perthshire	Lowe (unpublished)
10,808 ± 230 B. P.		Garral Hill, Banffshire	Godwin and Willis (1959)
11,260 ± 240 B. P.	10,230 ± 220 B. P.	Abernethy Forest, Inverness-shire	Vasari (unpublished)
12,060 ± 320 B. P.	10,010 ± 230 B. P.	Drymen, Stirlingshire	Vasari (unpublished)
	10,060 ± 270 B. P.	Loch Cuithir, Isle of Skye	Vasari (unpublished)
	10,280 ± 220 B. P.	Loch of Park, Aberdeenshire	Vasari (unpublished)
10,640 ± 260 B. P.	10,010 ± 220 B. P.	Loch Kinord, Aberdeenshire	Vasari (unpublished)

previously published on the Stadial/Postglacial boundary (Table 2). Thus, both the Blackness dates are considered to be too young, possibly as a result of contamination from younger carbon, and hence little significance is attached to these age determinations in the context of the present study. While it is possible that some of the dates presented in Table 2 are also in error either through the hard-water effect (Donner et al. 1971; Shotton 1972), or other sources of contamination, a number of dates are available on the upper and lower boundaries of the Stadial which seem to be in fairly close agreement, and these suggest that the duration of this time period may have been longer (perhaps much longer) than the generally-accepted 500 year span in parts of northern Britain. However, no firm conclusions can be drawn from such a small sample, and clearly substantially more radiocarbon dates are needed if the duration of the Lateglacial Stadial is to be determined accurately.

The duration of the Interstadial is even more difficult to assess. As was discussed above (Chapter 3), recent studies have demonstrated that climatic amelioration following the decay of the Late-Devensian ice-sheet began some considerable time before 12,000 B. P., the date long regarded as marking the beginning of the milder Allerød or pollen zone II. Basal dates from Glanllynau in North Wales (Coope and Brophy 1972) and Blelham Bog in the Lake District (Pennington and Bonny 1970) showed (if the dates are valid) that at these two sites, sediment accumulation began well before 14,000 B. P. Levels within these sites at which there was a marked climatic improvement have been dated at 12,750 B. P. in Blelham Bog and ca. 12,850 B. P. (by inference from sedimentation rates) at Glanllynau. In the present study area, radiocarbon assay on the basal organic sediments at Loch Etteridge yielded a date of 13,151 ± 390 B. P. (SRR-304), while in the adjacent area of the Grampian Highlands, the basal organic muds from a kettle hole near Callander were dated at 12,750 ± 120 B. P. (Lowe unpublished). These dates demonstrate that milder Interstadial conditions began some 750-1000 years before the onset of classical pollen zone II. In Scotland a duration of the order of 2000 years for the Lateglacial Interstadial therefore seems not unreasonable in light of the evidence discussed above.

THE POLLEN RECORD

The Interstadial Record

The pollen record of the Interstadial can be considered in terms of an early phase characterised by herbaceous taxa with relatively low percentages of locally-derived woody plant pollen, and a main Interstadial period with higher proportions of woody taxa, an increased aquatic flora, and significantly lower values for pollen of herbaceous plants. This more general classification of the Interstadial is preferred to the rigid distinction between pollen zones I and II (Godwin-Jessen) or the Pre-Interstadial and Interstadial (Pennington et al. 1972), for the pollen spectra reflect a progressive evolution of the vegetation pattern in response to a number of environmental variables and any a priori division of this record is considered to be potentially misleading.

At all the sites investigated, the basal pollen assemblages are characterised by Rumex, Artemisia, Saxifragaceae, Cyperaceae, Compositae and Gramineae. Of the locally derived woody plant pollen, only Salix is present in any quantity, while pollen of aquatic plants is universally low.

In Loch Etteridge, Tirinie and to a lesser extent Corrydon, Rumex is the most important element in the pollen spectrum during the early Interstadial. Vasari and Vasari (1968) made a detailed study of the fossil fruits of Rumex acetosella agg. from the Lateglacial sediments at Loch Kinord, Loch of Park and Drymen and concluded (p. 52) that the majority of Rumex fruits belonged to R. tennuifolius which is a more northerly species likely to grow on poor acid soils, whereas R. acetosella shows a clear preference for better soils (Jalas 1965). The results of this study suggested to the authors that the main Rumex species in the Lateglacial in the Grampian Highlands was probably Rumex tennuifolius particularly on the generally base-poor acid schists of the eastern and central areas. However, an alternative explanation of the Rumex pollen record during the early Interstadial is possible, for the writer experienced considerable difficulty in distinguishing not only between the pollen of various Rumex species, but also between Rumex and grains of Oxyria. On the Isle of Skye, H. J. B. Birks (1973) recognized a large number of grains of Oxyria dignya in the basal sediments at Lochan Coir a'Ghobhainn. This plant is characteristic of open, rather moist gravels and silts, and is a common pioneer species on freshly exposed substrates in front of retreating glaciers at the present day (Persson 1964; Matthews J. A. personal communication). Thus, the high "Rumex" values recorded in the early Interstadial sediments at Loch Etteridge, Tirinie and Corrydon in particular may reflect not only the former presence of true Rumex species, but also the rapid colonisation of freshly exposed surfaces by Oxyria dignya. To what extent other Rumex records from Scottish sites include grains of Oxyria is not known, for apart from the studies of H. J. B. Birks in Skye, no positive identifications of this genus have been made in sediments of Lateglacial age from northern Britain.

Of the other herbaceous taxa which have consistent records throughout the early Interstadial, genera of the families Gramineae, Cyperaceae, Saxifragaceae, and Caryophyllaceae have all been reported as early colonisers of glacier forelands at the present day (e.g. Stork 1963; Persson 1964; Decker 1966; Crocker and Dickson 1967; Matthews unpublished). A notable absentee however, is Dryas which is a common pioneer species (Decker 1966), and is also an important element of the early Lateglacial pollen record throughout northwest Europe. The plant is a noted calcicole (Elkington 1971) which may account for its absence from the sites on the base-poor micaschists, but the low representation at Tirinie where the bedrock is of limestone and where other noted calcicoles, notably Selaginella and Saxifraga cf. oppositifolia are present, is difficult to explain.

The principal woody plants likely to have been present in the Grampian Highlands following ice retreat were species of willow. Salix has been widely recorded as an early coloniser of bare substrates in front of retreating glaciers. At the Rotmoor Gletscher in Austria for example, Palmer and Miller (1961) discovered Salix herbacea as a pioneer within the first year after recession of the ice front, while Faegri (1933) found species of Salix phylicifolia three years after glacier retreat. In the Kebnekajse Mountains of northern Sweden, Stork (1963) recorded four different species of Salix on a substrate of less than 30 years old. In the present sites, Salix is prominent in the pollen spectrum of the basal Loch Etteridge count, and is present in significant quantities in the basal assemblage zones at all the other sites. Many of the grains are of shrub willow, but a number clearly resemble Salix herbacea which is not only a pioneer species, but is also markedly chionophilous. The presence of this pollen, in association with other grains from taxa with chionophilous characteristics (e.g. Lycopodium selago, Saxifragaceae and Filicales), may reflect initial areas of snowbed vegetation in shaded localities. Associated conditions of soil instability are indicated by the widespread presence of Artemisia in the basal assemblage zones.

The majority of Betula pollen recorded during the early Interstadial is undoubtably of Betula nana. This dwarf shrub is characteristic of open-habitats, and occurs over large areas of the

Arctic at present. In Britain, its current distribution is restricted mainly to the northern and central parts of Scotland (Hutchinson 1966). It has a wide range of tolerance and will thrive in the absence of competition on soils of varying base status, and it is probable that shrubs of Betula nana were common in the early Interstadial Grampian landscape very soon after ice-sheet decay. A significant percentage of birch pollen are clearly of tree birch. Betula pubescens has been found on substrates of less than 100 years old in Iceland (Persson 1964) and it is possible that occasional tree birch did appear in the Grampians at a very early stage in vegetational development. The majority of tree pollen however, are most likely the product of long-distance transport, especially the large numbers of Pinus grains in the basal sediments at Roineach Mhor and to a lesser extent at Blackness. The presence of Alnus and Tilia in the basal assemblage zones at these two sites is probably due to the same effect.

It was originally thought that the high values for Juniperus during the early Interstadial at Blackness were attributable to long-distance transfer. However, if this was the case, then high percentages of Juniperus would be expected in the basal pollen assemblage at Roineach Mhor in adjacent Glen Clova. As the early pollen record there shows only sporadic occurrences of this genus, it is concluded that at least some Juniperus must have grown locally around the Blackness site during the Interstadial. This accords with the observation of Vasari and Vasari (1968) that juniper was a fairly common element in the Scottish flora during pollen zone I. In addition to juniper, isolated grains of *Hippophäe* were found in the basal assemblage at Blackness, and single grains of the genus were discovered in zone T-2 at Tirinie, and in zones LE-1 and LE-3 at Loch Etteridge. Like *Juniperus*, this shrub is shade-intolerant (Pearson and Rogers 1961), but is a poor pollen producer today (Firbas 1934). However, as has been pointed out elsewhere, (Hafsten 1966), isolated grains of *Hippophäe* cannot be accepted as indisputable evidence that the shrub ever grew in the area at the time. Indeed, in view of the presumed quantities of long-distance arboreal pollen in these basal pollen assemblage zones, it seems more likely that *Hippophäe* too was of long-distance extraction.

During the main phase of the Interstadial however, almost all the woody plant pollen recorded in the sites is thought to be of local origin. In all the Lateglacial diagrams, the initial herbaceous period is succeeded by zones characterised by a marked increase in shrub pollen, notably *Empetrum* and *Betula nana*, and to a lesser extent *Salix* and *Juniperus*. At most of the sites, the levels at which the rise in woody taxa take place are preceded by or are coincident with the upward trend in the curves for aquatic pollen.

Empetrum is the dominant Interstadial shrub at Loch Etteridge and Tirinie, but it is less common in the three sites from the eastern Grampian slopes. In all the profiles there are two maxima in the *Empetrum* curve: one at the initial rise in values for the genus, and a secondary peak at the close of the Interstadial immediately before the transition with the Stadial. The present-day distribution of both *Empetrum nigrum* and *Empetrum hermaphroditum* indicates a preference for cool, oceanic environments with a heavy cloud cover and high precipitation (Brown 1971). The genus is characteristic of open conditions, being intolerant of shade, and although it is generally stated to be calcifuge, it is found on soils with a high range of pH (Bell and Tallis 1973). This is supported by the former occurrence of *Empetrum* in significant quantities both on the base-poor schists around Loch Etteridge, and on the limestone substrate near Tirinie. The higher percentages of *Empetrum* in the more westerly areas probably reflects higher precipitation levels in those regions than on the eastern slopes of the Highlands. However, the generally low values for the genus throughout the Interstadial at Roineach Mhor are thought to be a result of continued soil instability around that basin, for *Empetrum* is considered to be intolerant of solifluxion processes (Dahl 1956).

In almost all the profiles, the *Empetrum* maximum which characterises the initial expansion of woody plants is succeeded by peaks in the *Betula* curve. Maximum Interstadial values for birch are reached at Tirinie where many of the grains are undoubtedly of tree birch. As the pollen rain appears to have been relatively rich at this time, it is considered unlikely that these high tree birch counts are due to the effect of long-distance transfer, and thus tree birch seem to have been an important element in the vegetation pattern around this site during the Interstadial. If this was so, then it appears that the regional birch tree line reached at least the southern margins of the Grampians during the Lateglacial. Most of the *Betula* grains recorded at the other sites are of *B. nana* and it is unlikely therefore that the treeline advanced very much further into the Grampians during the Interstadial. At Corrydon, the Interstadial is characterised by a double maximum in the curve for *Betula* with peaks in the birch curve coinciding with high points in the curve for *Juniperus*. This double birch maximum is unique in the study area, but a similar phenomenon has been recorded during pollen zone II at Corstrophine near Edinburgh (Newey 1970), in the Lake District (Smith 1958), and in Denmark (Iversen 1954; Krog 1954). It is possible that this vegetational oscillation is climatically controlled, and further discussion will be found in Chapter 7.

The coincidence of *Betula* and *Juniperus* in many of the profiles lends indirect support to the identification of the majority of birch pollen as being of *Betula nana*, for although it can thrive within a forest environment, juniper is markedly heliophilous and shows a clear preference for open, light vegetation (Iversen 1954; Kujala 1958). *Juniperus* peaks are coincident with the double birch maxima at Corrydon and with the single birch maximum at Loch Etteridge. At Tirinie, the peaks in the *Juniperus* curve coincide with the twin *Empetrum* maxima which precede and succeed the high point in the *Betula* (tree birch) curve. At Blackness, *Juniperus* is present throughout the Interstadial, but there is a prominent peak in the curve immediately before the Stadial/Interstadial transition in assemblage zone B-4. The reason for this late-Interstadial maximum is not immediately apparent, but a similar peak in Juniperus was recorded at the end of pollen zone II at Bamburgh in Northumberland and it is possible that this maximum too may be climatically controlled (Bartley 1966). It would appear however, that the late-Interstadial Juniperus maximum recorded in the Blackness sediments was a relatively local phenomenon for in neighbouring Glen Clova, Juniperus is poorly represented throughout the Interstadial. To what extent these low values are a true reflection of the former quantities of juniper in the area is not clear, for it has been shown that in certain present day situations, Juniperus can be a very low pollen-producer, and can therefore be under-represented in the pollen spectrum (Vasari and Vasari 1968). Thus a true representation of this genus during the Lateglacial period may be considerably greater than is shown in the pollen diagrams.

Salix is a common element in the Main Interstadial flora, being particularly dominant in zone RM-2 at Roineach Mhor where it precedes the maximum in the Betula curve. A similar situation occurs in the Blackness profile where zone B-2 is characterised by high values for Salix pollen. In the other sites, Salix is present in small quantities but values are generally low. These Salix counts reflect the diffusion of shrub willows throughout the area, for after the early Interstadial herbaceous phase, very few grains of Salix cf. herbacea were encountered.

Occasional pollen of Corylus-Myrica, Alnus, Tilia, Quercus, and Ulmus were found throughout the Interstadial, but it is most unlikely that any of these taxa grew in the Grampian Highlands at the time. Thus, like Pinus which also has a constant Interstadial record at all the sites investigated, the presence of these grains is once again most probably due to the long-distance effect. In the case of Corylus-Myrica however, there appears to be an alternative explanation. It was found that pollen of this taxon only occurred in Lateglacial sediments which had been sampled using the Hiller borer. No Corylus-Myrica were found in the Lateglacial at Tirinie and Roineach Mhor, both of which had been sampled with the Dachnowski piston corer. Moreover, while a number of Coryloid grains were found in the Loch Etteridge samples obtained with the Hiller borer, no grains of this taxon were discovered in the samples subsequently taken using the Dachnowski piston corer. The majority of the Corylus-Myrica pollen found in samples of Interstadial age can therefore be attributed to the contamination of the Lateglacial sediments by material carried down from the overlying Postglacial deposits by the Hiller borer. This problem of contamination from overlying deposits particularly in respect of Coryloid grains has been noted by Lowe (personal communication) in the adjacent area of the Grampian Highlands. To what extent other apparently anomalous grains in the Lateglacial record can be ascribed to this source is not known.

Characteristic herbaceous taxa of the Interstadial period are Filipendula, Ranunculaceae, Rumex and Gramineae. Filipendula ulmaria is a noted Lateglacial thermophile (Iversen 1954) and most of the Filipendula grains recorded are thought to belong to this species. It is often found in marshy habitats (Clapham, Tutin and Warburg 1962) and, in association with Caltha cf. palustris which seems to be the dominant member of the Ranunculaceae during the Interstadial, reflects the development of floristically-rich marshy areas around the sites. This type of habitat appears to have been particularly well-developed around the smaller basins of Roineach Mhor and Blackness. In general, taxa indicative of bare or open ground are of lesser significance during the main Interstadial, but Rumex remains an important element in the pollen spectra at all sites. At Loch Etteridge, Blackness and Roineach Mhor, Rumex values are high during the initial expansion of woody plants, but percentages decline progressively towards the upper boundary of the Interstadial, while at Corrydon and Tirinie, the Rumex curve fluctuates throughout the period. The presence of the genus in significant quantities during the Interstadial reflects the incomplete nature of the shrub-heath or grassland cover, and the continued presence of areas of bare ground which provided suitable habitats for Rumex and occasionally other open-habitat taxa.

The high values for Gramineae pollen throughout the Interstadial indicate that large areas of grassland must have characterised the Grampian landscape at this period. Studies on modern pollen spectra have shown that Gramineae are constantly under-represented in pollen diagrams (Potter and Rowley 1960), and thus as with juniper it is difficult to obtain a true impression of the importance of these species in the pollen profile. There is also the problem of discerning to what extent the Gramineae record reflects true grassland vegetation, and to what degree the pollen counts comprise species of grass from reedswamp vegetation. The generally higher values for Gramineae during the Interstadial are interpreted largely as a reflection of the spread of true grassland species as the evidence from Cyperaceae counts suggests that the Interstadial was not characterised to any degree by the expansion of reedswamps around the sites (with the possible exception of Blackness).

The main part of the Interstadial period is also marked by the appearance of aquatic flora in significant numbers. *Myriophyllum* is the dominant taxon in all the profiles, the main species present being *Myriophyllum alterniflorum* although occasional grains of *Myriophyllum spicatum* were also encountered. *Myriophyllum* is particularly well-represented at Blackness and Roineach Mhor and in each case the curves for the genus are characterised by a double maximum. These twin peaks are thought to be due either to the gradual shallowing of the lakes through the build-up of sediment, or to the expansion of the littoral reedswamp; either process would result in the contraction of areas of open water and the commensurate reduction in suitable habitats. *Myriophyllum alterniflorum* is characteristic of a wide range of trophic conditions, but it is found to-day in peaty waters and in relatively base-poor pools (Clapham, Tutin and Warburg 1962). This would explain the relatively high percentage of the species at Blackness and Roineach Mhor where the substrate is comprised largely of acid schists. *Myriophyllum* occurs in lesser quantities at the other sites, although significant percentages are recorded during zone C-2 at Corrydon. Other aquatics present in the profiles during the Interstadial are *Potamogeton*, *Nymphaea* and *Typha*, but the occurrence of these genera is sporadic. In general, the low water temperatures and base-poor status of these upland basins throughout the Lateglacial prevented the development of a rich aquatic flora in all but the most favoured localities.

Sparganium has a continuous record throughout the Interstadial at all sites, but is particularly common at Roineach Mhor where the peaks in the curve precede and are interspersed with the maxima for *Myriophyllum*. The lower counts for the genus in the larger basins may reflect the susceptibility of *Sparganium* to wave action, but its overall low representation in the profiles is possibly attributable to the fact that it is a poor competitor with Phragmites and species of Cyperaceae around lake margins (Cooke 1962).

The Stadial Record

Sediments of Stadial age are characterised by a relatively lower pollen content, uniformly low counts for woody taxa, and the virtual absence of aquatics and pollen of thermophilous plants. In every site, open-habitat herbaceous taxa dominate the pollen spectra, notably *Artemisia*, *Rumex*, genera of Caryophyllaceae, Compositae and Saxifragaceae, and the clubmosses *Selaginella* and *Lycopodium*.

Values for Cyperaceae are also generally high.

Artemisia is the characteristic pollen of the Stadial In every profile, the lower boundary of the period can be located by the sudden upward trend in the curve for this taxon. As has been noted elsewhere (Pennington 1970), such a universal dominance cannot be the result of differential pollen preservation (cf. Maher 1963), but must reflect a real change in vegetation composition. *Artemisia* has been recorded throughout western Europe during pollen zone III, and is widely regarded as a genus indicative of disturbed soils. Maximum values for *Artemisia* are attained at Loch Etteridge and Tirinie (over 30% and 25% of total land pollen respectively), but significantly lower percentages are found at the other sites. This is surprising for *Artemisia* has a high production and dispersal rate (Bent and Wright 1963), but it is possible that all herbaceous values are to some extent depressed at Corrydon, Roineach Mhor and Blackness by the abnormally high frequencies of Cyperaceae which is itself a prolific pollen producer. Also, *Artemisia* is a characteristic plant of dry, well-drained habitats in Europe to-day (Iversen 1954) and it may well be that snowpatches and higher soil-moisture content (Andersen 1961) in the eastern sites which are situated closer to the Loch Lomond Readvance limits restricted the spread of *Artemisia* in those areas during the Stadial.

Characteristic associates of *Artemisia* at this time were genera of Chenopodiaceae, Caryophyllaceae and Compositae. Chenopodiaceae are common open-habitat taxa and, along with *Artemisia*, are regarded as some of the most important anemophilous pioneer herbs (Iversen 1964). The curve for Chenopodiaceae closely follows the trend in *Artemisia*, as does the record for Caryophyllaceae. Unfortunately it was not possible to identify specific genera from the latter family with any degree of certainty, but a number of the grains clearly resembled *Silene* spp. Positive identifications of *Silene* cf. *aucalis* have been made in sediments of Lateglacial age on the Isle of Skye (H. J. B. Birks 1973). This species is widespread in Arctic and sub-Arctic areas today as a coloniser of bare ground, being particularly common where soil movement is taking place (Siedenfaden 1931). Many of the Compositae are also recognized as early colonisers and tolerant of solifluxion processes, and this family is particularly well represented during the Stadial at Corrydon.

Selaginella and Saxifragaceae occur at most sites, but both reach their highest values during the early Stadial at Tirinie. Both are characteristic of base-rich soils (Andersen 1961) and the presence of these taxa at this site is clearly a reflection of the limestone country rock in this part of the Grampians. Many of the Saxifragaceae resemble *Saxifraga oppositifolia*, again a species found on disturbed soils in present-day tundra environments (Siedenfaden 1931; Stork 1963; Persson 1964).

Rumex too is present in considerable quantities during the early Stadial at Tirinie. High values for this genus are also recorded at Loch Etteridge, but percentages are lower at Corrydon, Roineach

Mhor and Blackness. Moreover, at the latter three sites, values for Rumex tend to be higher during the preceding Interstadial which is the reverse of the situation at Tirinie and Loch Etteridge. The reason for this is not clear, but as many Rumex species are markedly chionophobous, it is possible that as with Artemisia, snow patches and higher soil moisture in the glens of the northeast Grampians restricted the development of Rumex in these areas during the Stadial. Also, the true Rumex values at these sites may have been supressed to some extent by the very high values for Cyperaceae.

In all the Stadial pollen spectra, Cyperaceae is a dominant element. It exceeds 60% of the total land pollen count at Roineach Mhor, and in none of the profiles do the values for this taxon fall below 15%. These high sedge counts may reflect periods of expansion of the littoral reedswamps, but recent studies of modern pollen spectra have shown that this is not the only possible interpretation of the Cyperaceae pollen record. H. J. B. Birks (1973) found that in modern pollen spectra from montane summit vegetation on the Isle of Skye, Cyperaceae was the dominant element. Similar studies in the tundra regions of Arctic Canada and Alaska also showed high percentages of sedge pollen in areas where local reedswamp development was minimal (Lichtie-Federovich and Ritchie 1968; Rampton 1971). Moreover, several species of Carex have been found as pioneers on unstable soils in Arctic and Alpine areas (Siedenfaden 1931). Many of the Cyperaceae are markedly chionophilous and are characteristic elements of snowbed communities in areas of northern Sweden to-day (Gjaerevoll 1965). The occurrence of Cyperaceae in the Stadial pollen record is therefore difficult to assess reliably, but in view of the studies discussed above, it does seem that many of the grains of this family may well have been derived from Arctic/Alpine communities rather than from local reedswamps.

Other important Stadial taxa are Lycopodium (including L. Selago), Filicales, and Salix (especially Salix cf. herbacea). Lycopodium and particularly L. selago are characteristic of montane communities in Britain to-day, and although both taxa tend to be calcifuge in their edaphic tolerance, the highest counts for Lycopodium spp. were obtained at the limestone-rich site at Tirinie. Filicales values are higher at Corrydon and Blackness and may reflect the former existence of snowpatch communities in those areas, as several of the ferns are associated in the Cryptogameto-Athyrietum chionophilum association described by Ratcliffe and McVean (1962 p. 82) which to-day is well represented in the Cairngorms (H. J. B. Birks 1973). Salix cf. herbacea is also a noted chionophilous species (e.g. Gjaerevoll 1965), and the highest Stadial value for this taxon is recorded at Roineach Mhor, although significant numbers of Salix grains which clearly resemble S. herbacea were found at Corrydon and Tirinie. The very high Salix counts at Roineach Mhor in association with the presence of other chionophilous taxa in the Stadial deposits at that site are thought to reflect extensive areas of snowpatch vegetation in close proximity to ice of the Loch

Lomond Readvance.

Values for aquatic pollen are uniformly low in all Stadial deposits. This may be partly a function of the shallowing of the smaller basins with the inwash of minerogenic sediment and increasing water turbidity or, in some cases to the extension of areas of reedswamp. However, the major reason for the virtual absence of aquatics was extremely low temperatures encountered throughout the Stadial period. As Iversen (1964) has observed, aquatic plants react much more repidly to climatic change than do terrestrial flora, and thus at the close of the Interstadial, a critical temperature threshold may have been reached after which there was a general extinction of aquatic flora in all the sites investigated.

Percentages of woody taxa are also generally low throughout the Stadial with the exception of Salix and, to a cetrain extent, Betula (see below). Pinus is present in small quantities at all the sites, but the low values for the genus suggest that pine never grew in the area in Stadial times. Pinus is therefore ascribed to long-distance transport. Empetrum and Juniperus are present in small quantities and may have grown locally throughout the Stadial. Empetrum is unable to survive severe winter temperatures without a snow cover, but as it is an early-flowering species, it tends to be restricted to areas where snow disappears relatively rapidly (Bell and Tallis 1973). Moreover, as it is also solifluxion intolerant (Dahl 1956) its distribution during the Stadial was probably extremely limited. Many of the Empetrum grains recorded in the Stadial sediments were heavily corroded and it is therefore likely that a number are redeposited pollen washed in from the catchment around the sites. This phenomenon has been reported during pollen zone III in the Lake District (Tutin 1969). Like *Empetrum*, *Juniperus* is dependent on snow cover for protection in many tundra areas where it is found as a dwarf shrub only (Iversen 1954). The low frequencies of this taxon may reflect the occurrence of the poorly-flowering *Juniperus communis* spp. *nana* which occurs in either chionophilous or chionophobous situations at the present day (H. J. B. Birks 1973). Alternatively, the low values could be indicative of the absence of *Juniperus* from the area during the Stadial, or be a function of the fragility of *Juniperus* pollen grains, many of which may have been fragmented in the coarse matrix of the Stadial sediment. The most commonly-occurring dwarf shrub however, appears to have been *Betula nana*. Almost all the birch grains encountered in the Stadial sediments belong to this species, and the former presence of the shrub in the Glen Esk area at least was demonstrated by the discovery of a leaf of *B. nana* in the Stadial deposits at Blackness. Studies in Scandinavia have shown that *B. nana* has a wider ecological tolerance than does *Juniperus* (Nordhagen 1927) which may largely explain why dwarf birch is found throughout the Stadial in consistently higher numbers than *Juniperus*. Some *Betula* grains are *undoubtedly* of tree birch, but in general, these probably represent the products of long-distance transport.

In terms of birch percentages however, the pollen record at Corrydon remains problematical. The vegetational sequence is unlike that at any other site, and the writer experienced considerable difficulty in zoning and interpreting the pollen diagram, for there appear to be marked conflicts between the arboreal and non-arboreal records. If however, the curve for Betula is initially excluded, the milder Interstadial and succeeding Stadial can be differentiated on the basis of fluctuations in the curves for Artemisia, Caryophyllaceae, Filicales, Selaginella, Lycopodium and aquatic pollen, for the trends are comparable with those at nearby sites. However, throughout the Lycopodium-Selaginella assemblage zone (C-5) which represents the early part of the Stadial, and the following Artemisia-Filicales assemblage zone (C-6) which comprises the main part of the Stadial, there is an upward trend in the curve for Betula. A similar situation was recorded at Blea Tarn in the Lake District (Tutin 1969; Pennington 1973) where the rising Betula curve during the early part of the Stadial period was interpreted as representing the delayed arrival of tree birch by contrast with the lowland sites at Blelham Bog and Low Wray Bay. It is unlikely, however that this explanation is applicable to the site at Corrydon, for higher birch values during the Stadial are not recorded at Tirinie and Roineach Mhor which are only 20 km or so away from Glenshee. Similarly, it is difficult to invoke the agency of long-distance transport, as the effects should be visible at neighbouring sites. A number of the birch grains are corroded implying that there has been some redeposition of secondary pollen, but it is improbable that all the Betula grains are derived from that source. Thus, there seem to be only two logical explanations. Either, as a result of local conditions there was a marked increase in the numbers of birch in the Glenshee area during the Stadial, or the higher birch values are a "statistical artefact" resulting from the percentage method of pollen representation (Davis and Deevey 1964). In order to test whether the upward trend in the birch curve reflects a real change in the annual deposition of birch pollen, or simply a percentage fluctuation induced by an increasingly more impoverished local pollen rain, absolute pollen analysis is necessary - a project which will hopefully be undertaken at a future date.

THE SEDIMENT RECORD

Physical properties

With the exception of Roineach Mhor, all the basins contain a comparable sequence of Lateglacial sediments. In each case, the basal deposits consist of coarse sand and gravel which is either outwash or ice-contact material from the decaying ice-sheet. Overlying these glacial deposits are finer silt and clay layers which are generally low in pollen content. At Loch Etteridge, for example, there is a steady upward gradation from sandy to silty sediment over a vertical distance of 20 cm, while a similar stratigraphic trend occurs at Tirinie and Corrydon. At Blackness, however, the basal minerogenic deposits are over 85 cm in thickness and consist for the most part of poorly-comminuted micaschists overlain by a narrow silt/clay horizon. These minerogenic sediments accumulated in the basins immediately following glacier decay and are the result of inwash of unweathered regolith prior to the establishment of a closed vegetation cover.

Overlying these lower minerogenic sediments at Loch Etteridge, Corrydon and Blackness are varying thicknesses of green-brown organic mud or gyttja. The maximum accumulation of these deposits was encountered at the latter site where over 60 cm was recorded. At Tirinie, however, the Interstadial sediment is composed of pure marl with occasional bands of silty-clay marl. These deposits are of a very fine texture with over 70% falling in the category of silt/clay (< 0.002 mm), but as the sediment is over 85% calcium carbonate, flocculation during particle size analysis means that the results should be treated with caution. The accumulation of carbonate-rich marls during the Lateglacial is a fairly common phenomenon having been recorded for example at Corstorphine near Edinburgh (Newey 1970), near Bamburgh, Northumberland (Bartley 1966) and in a site near Tadcaster, Yorkshire (Bartley 1962). These marl deposits either come from the shells of certain mollusca which inhabited the basin, or from aquatic plants such as algae, mosses or species of Chara. These organisms have the power of precipitating calcium as insoluble calcium carbonate (Buckman and Brady 1969). As the marls at Tirinie were rich in shells of pereger

Lymnaea ~~peregra~~ and Pisidium spp. it is probable that the carbonate-rich deposits result from the presence of these molluscs.

The curve for organic carbon follows the same upward trend at both Tirinie and Loch Etteridge. At the former site, organic carbon values rise from less than 2.5% at the base of the profile to over 11% near the Stadial/Interstadial transition, while at Loch Etteridge there is a steady increase from less than 1% organic carbon in the basal minerogenic sediments to over 9% in the upper Interstadial deposits. Organic carbon determination was not carried out at either Corrydon or Blackness, but clearly the trend follows that at Loch Etteridge and Tirinie. At all these four sites, therefore, there is a consistent upward stratigraphic sequence from an initial phase of minerogenic sediment accumulation through to the deposition of much finer and more highly organic material. This pattern reflects the gradual stabilisation and maturation of soils in the study area as a result of the progressive thickening of the vegetation cover, and also the build-up of plant and animal communities in the basins as the ecosystems developed.

This general sedimentary pattern is not present in the Roineach Mhor basin however. There the entire stratigraphic column consists of minerogenic sediment with no organic horizons at all. The curve for organic carbon barely fluctuates, being generally less than 1%, but rising to a peak of 1.2% during the later part of the Interstadial. Above the basal ice-contact gravels, alternating layers of sand and silt grade upwards into three separate series of rhythmically-bedded units of sand and silt/clay. A total of 79 individual rhythmite segments was counted over a vertical distance of 82 cm. Rhythmites have long been suspected to be seasonal deposits (e.g. Johnston 1922; Kuenan 1951), particularly in the vicinity of glacier margins. The whole of the basal stratigraphic sequence at Roineach Mhor is suggestive of very rapid sediment accumulation in a relatively short time span, for if the rhythmite bands are indicative of annual deposition, then almost one metre of material must have been deposited in less than 100 years. Such a rapid sedimentation rate accounts for the sparseness of pollen in the lower 1.25 m and also explains why low pollen values were encountered over the succeeding 90 cm of sediment. Above the rhythmite units, the sediments consist largely of silts and clays (over 80% falling in the $<$ 0.02 mm category), with occasional bands of medium-coarse sand and grit. Although the pollen spectra are indicative of milder conditions, the continued presence of minerogenic sediments in the basin at this time in contrast with the predominantly organic material in the other sites, is a reflection of repeated inwash from the slopes around the site suggesting that complete landscape stability was never achieved in this area during the Interstadial.

At all the sites investigated, sediments of Stadial age are entirely minerogenic with little or no incorporated organic material. These deposits are indicative of a former period of widespread instability in the Grampian landscape with a sparse vegetation cover, and considerable soil movement through the processes of normal run-off, cryoturbation and solifluxion. The type of sediment resulting from these various processes varies from basin to basin and appears to be a function of source material, basin size, steepness of catchment slopes and severity of solifluxion action.

The coarsest minerogenic sediment of all was found in the Stadial horizons at Roineach Mhor and, to a lesser extent, at Blackness. The former site is the only one of the five to contain stratified sediments of Stadial age, for the deposits there consist of alternating layers of coarse grit and medium-coarse sand. Particle size analysis showed that over 70% of the sediment could be classed as sand ($>$ 0.02 mm) and the extreme coarseness of these layers is attributed to repeated inwash of micaceous ice-contact material from the steep esker sides around the basin. At Blackness, the kettle hole slopes are less steep, but there the Stadial sediment is composed almost entirely of coarsely-comminuted Dalradian micaschist derived from erosion of the country rock around the site.

Although the basin at Tirinie is relatively small, the more gently-sloping catchment slopes in association with the more argillaceous underlying limestones resulted in the accumulation of a much more finely-textured sediment during the Stadial. Over 25% of the material is of clay consistency ($<$ 0.002 mm) while a further 40% falls into the category of medium-fine silt. As this site is the most sheltered of all the Lateglacial sites in the study area, and has a marked southerly aspect, it is possible that the intense solifluxion processes which appear to have been operative in the east-facing glens of the southeast Grampians may have been less prominent in this area. Indeed, solifluxion in the sense of mass downslope movement of surficial deposits was possibly of minor importance, for the finely-textured minerogenic sediments may have resulted almost entirely from normal erosion of the catchment through increased run-off induced by a sparser vegetation cover. The marked decrease in carbonate content of these sediments when compared with the underlying and overlying marls is due to the absence of mollusca reflecting relatively lower water temperatures during the Stadial period.

In the two largest basins (Loch Etteridge and Corrydon) the Stadial sediment is also of a relatively-fine texture. In the Loch Etteridge site, over 50% of the deposits can be classed as medium silts or finer, in spite of the fact that much of the country rock in the area is Moinian schist. As at Tirinie, it is possible that normal run-off may have been the dominant process leading to the accumulation of these sediments rather than massive solifluxion as seems to have been the case farther east. At Corrydon, over 140 cm of medium and coarse sand and silt accumulated during the Stadial, almost three times the amount of sediment deposited during the same time span at any of the other sites studied. The principal reason for this considerable thickness of material appears to have been the former presence of a stream which at one time flowed down the slopes above the site and into the western margins of the basin. A large fan now comprises the northeast rim of the kettle hole and is testimony to the size and erosive and depositional power of this stream.

Chemical properties

The proportions of the alkali cations sodium, potassium, calcium and magnesium were determined in the sediment cores from Loch Etteridge, Tirinie and Roineach Mhor. In each case, Ca is the dominant cation present, followed by Mg, Na and K. With the exception of the basal two samples at Roineach Mhor Ca values rise to a maximum during the Interstadial before declining towards the Stadial boundary. Maximum values for Mg are also found during the Interstadial. Percentages of Na are fairly constant at Roineach Mhor and Loch Etteridge, but there is a clear peak in the curve for this cation at Tirinie. The curve for K barely fluctuates and values remain uniformly low at all three sites. As was discussed above, organic carbon percentages reach a maximum in the Interstadial deposits, before declining towards the Stadial boundary. The trend in all the sites therefore is towards higher values for alkali cations and organic carbon during the Interstadial period and commensurately lower values in sediments of Stadial age.

According to Mackereth (1965, 1966), the sediments in any lake basin are a reflection of soil development around the catchment area. He suggested (1966 p. 180) that soils in the vicinity of

a drainage basin undergo two types of change. These are
a) maturation by leaching, in which some components of the soil mineral matter are removed in solution thus leaving the residue *in situ* impoverished in the leached components, and
b) erosive removal of the soil from the site of leaching and subsequent deposition of the eroded material in the lake sediments where it is effectively protected from further leaching. If the landsurface is stable and the rate of erosion slow, then the first process will be dominant and the redeposited sediments may be expected to be altered in composition notably by the loss of those elements most susceptible to removal in solution. If however, the landsurface is relatively unstable and the rate of erosion is high, then the composition of the eroded material will most closely resemble that of the lithosphere, firstly because the eroded material will have been exposed to leaching for a shorter period of time, and secondly because deeper material is removed which has had less exposure to the influence of leaching. Mackereth used the distribution of the alkali cations as being indicative of the relative importance of leaching in the soil around the catchment by demonstrating that a high proportion of these elements in the mineral fraction of the sediments corresponded with other evidence for periods of intense soil erosion, while during periods of low erosion rate and relative soil stability, all mineral material transported into the lakes had been heavily leached of bases. Subsequent work has largely supported Mackereth's findings (Pennington 1970; Pennington *et al.*

1972; Tutin 1969).

The "Mackereth hypothesis" rests on the assumption that a record of former soil conditions around a lake catchment is preserved in the contained sediments of the lake itself. This is generally accepted and is supported by the order of occurrence of the cations Ca Mg Na K in samples from the study area which is comparable with the order found in moderately acid, humid soils of the present day (Buckman and Brady 1969). However, the trends in the curves for the alkali cations at Loch Etteridge, Roineach Mhor and Tirinie suggest that the applicability of the Mackereth concept is more limited than was originally thought for in the above sites, maximum cation values were obtained from samples of Interstadial age and minimum values from Stadial sediments, whereas the reverse obtained in the results of studies by Mackereth and Pennington. The reasons for such a marked discrepancy are not immediately apparent, but the consistency of the results from the present sites requires explanation.

All the studies previously carried out have been undertaken on sediments from large, oligotrophic lake basins. If the proposed hypothesis holds, during a period of soil stability e.g. the late Interstadial, leaching will be the dominant process affecting soils around the catchment, and bases will be carried away in solution, eventually leaving the system completely, largely through outflow from the lake basin. Hence in a lake of this type, unless material is deposited in the basin in quantity and sedimentation is relatively rapid, it is difficult to see how the basal deposits could ever attain a high base status, for elements in suspension will tend to be removed before sedimentation takes place. If on the other hand, bases are being removed from the soils around the catchment of an enclosed basin through the processes of leaching, percolating groundwaters seeping into the basin will tend to concentrate the basic elements in the bottom sediments as there is no outlet for soluble matter from the site. The process of base concentration will be aided by the spread of macrophytic vegetation within the lake waters, the expansion of reedswamp around the margins of the site and by the evolution of aquatic fauna. The pollen record shows that all the basins in the present study supported a rich littoral and/or macrophytic aquatic flora during the Interstadial, while the basin at Tirinie was also characterised by the presence of large numbers of mollusca. The latter, in association with some water plants were responsible for the precipitation of the calcium-rich marl deposits which accounts for the abnormally high Ca and to a lesser extent Mg values in that basin during the Interstadial. However, at Loch Etteridge and Roineach Mhor, there is a progressive upward trend in the curves for Ca and Mg in association with increasing values for organic carbon. Similar correlations between these three curves have been recorded from lake sediment analyses in Sweden (Ericsson 1973). At Loch Etteridge, there is a slight decrease in Ca and Mg values towards the Interstadial/Stadial boundary, while at Roineach Mhor there is a sharp decline in both curves at the transition. This may be partly a function of particle size, for analyses showed a much lower clay-size fraction in the Stadial than in the underlying Interstadial sediment, and there is an intimate relationship between clay minerals in a sediment and cation content. It is also possible that the decreasing amount of Ca and Mg in the sediments at these two sites reflects a successively decreasing amount of leachable material in the soil around the catchments and progressive soil maturation (Berglund and Malmer 1971).

At all the sites however, the uniformly low values for Na (with the exception of Tirinie) and K are striking. Both are loosely-bonded cations, and both should be susceptible to rapid removal in solution. Moreover, both are associated with mineral particles rather than with organic matter (Mackereth 1965). The fact that neither base fluctuates throughout the profiles is surprinsing and is suggestive of a certain constancy of process acting around the catchment. This in turn raises doubts about the validity of the Mackereth concept, for there is ample evidence from the pollen and sediment record of a period of relatively high erosional intensity during the Stadial at all the sites investigated, and especially at Roineach Mhor. Even at the latter however, there is no marked upward trend in the percentages of either Na or K. Whether this is a function of particle size with the inwash of relatively low amounts of weathered clay mineral material, a stratigraphic artefact induced by varying rates of sedimentation resulting in different cation concentrations, or a result of the base elements having already been removed from the sediment in solution is difficult to establish. Investigations of lake sediments in Sweden however, have produced results similar to those obtained from the present study and have been interpreted as simply reflecting soil maturation through time (Berglund and Malmer 1971). In the absence of other evidence therefore, the trends in the cation curves obtained from the present study would appear to reflect the progressive maturation of soils around the sites during the 2000 year period of the Interstadial. Whether these sites are the exception to the general pattern, or whether there is a genuine difference in chemical composition of sediments from lake basins of different size and trophic status is a subject for future research.

THE LATEGLACIAL ENVIRONMENT - EVIDENCE FROM THE FIVE SITES

The palynological, sedimentological and geomorphological record preserved in and around these five Lateglacial sites makes possible the reconstruction of the landscape in these areas of the Grampians from the time of the decay of the Late-Devensian ice-sheet to the disappearance of the Loch Lomond Readvance glaciers.

The radiocarbon date of 13,151 ± 390 B. P. obtained from the basal organic sediments in the Loch Etteridge site constitutes a natural starting point for this palaeoenvironmental synthesis.

The most likely source of any error in this date is the hard-water effect which can give apparent ages that are almost 3000 years too great, although the error is seldom as large as this (Donner et al. 1971; Shotton 1972). There are no limestone outcrops in the area around the site however, and glacial erratics of limestone have not been found. No shells were found in the lake deposits. The possibility cannot be excluded however, that inert carbon from the complex metamorphic rocks of the surrounding area was incorporated into the dated bulk sample. On the other hand, the date of 10,764 ± 120 B. P. from similar (though organically richer) material higher in the profile agrees with expectations, and there can be no hard-water error here. As athickness of 3-4 cm of the sediment was used for dating purposes, the radiocarbon date, if valid, is younger than the age of the very bottom of the organic layer in the basin. It is particularly significant that the site is a deep kettle hole, for it has been shown elsewhere that dead ice may have remained in such kettle holes for hundreds (or even thousands) of years after deglaciation of the surrounding area (Porter and Carson 1971). Thus the basal date, if valid, is a minimum for the deglaciation of this part of the Grampians, and it is therefore difficult to avoid the conclusion that large areas of the Scottish Highlands must have been free of glacier ice by 13,000 B. P. (Sissons and Walker 1974).

Underlying the dated horizons in the Loch Etteridge site are at least 15 cm of minerogenic lacustrine sediment. This initial phase of minerogenic sediment accumulation is characteristic of all the Lateglacial sites investigated, and reflects an initial period of landscape instability following ice-sheet decay, and prior to the colonisation of the areas by vegetation. The pollen rain during this early phase is universally sparse and the spectra reflect either a period of low temperatures under a steppe/tundra climatic regime, or differing rates of plant immigration on freshly-exposed substrates.

It was considered by the early workers that the former was the case and this let to the development of, and rigid adherence to the concept of a cold pollen zone I preceding a milder pollen zone II, with the highest temperatures occurring midway through the latter period. Recent studies of Coleoptera (Coope 1970; Coope *et al.* 1971; Coope and Brophy 1972; Osborne 1972) suggest that the Lateglacial thermal maximum was reached during classical pollen zone I, possibly around 12,500 - 13,000 B.P. after which temperatures declined progressively throughout the Allerød or pollen zone II. This early climatic amelioration is not reflected in the pollen record, and this appears to be largely a function of differing rates of response to environmental change between flora and fauna (Coope *et al.* 1971, p. 97). As the reaction of Coleoptera to climatic amelioration is virtually instantaneous (according to Coope), a rapid rise in temperature around 13,000 B.P. would have been accompanied by an immediate increase in numbers of thermophilous species. With vegetation however, the reaction may have been somewhat delayed, for slower rates of migration and colonisation, problems of thresholds and competition all act as impediments to a rapid response to climatic change. Thus for a time at least during the early Lateglacial, the pollen record appears to have been out of phase with climate.

The zones characterised by open-habitat taxa at the base of the pollen profiles are most probably an indication therefore, of a phase of differential colonisation of open ground rather than a period of severe climatic conditions. As has been discussed elsewhere (Faegri 1963), the fresh soil following deglaciation had a selective influence on diaspores landing on it, and thus in order to establish, species had to be plants that to-day occur on open and generally humus-free soil i.e. a soil type found in semi-deserts or tundra regions. Thus although many of the early Lateglacial plants e.g. Rumex may have semi-desert or tundra affinities, the conclusion does not necessarily follow that the climate at the time was semi-desert or tundra-like. Similarly, the presence of minerogenic sediment in the basins during these zones is not necessarily indicative of widespread solifluxion and cryoturbation, for although these processes may have been operative during ice-sheet decay, the greater proportion of material in the basins at this time is probably the result of normal run-off over humus-free skeletal soils. Approximately 13,000 years ago therefore, the Grampian landscape was one of open-habitats with a predominantly herbaceous vegetation cover, interspersed with large areas of relatively unstable bare ground, and small remnants of decaying glacier ice in shaded localities.

Following the initial phase of vegetation development, the trend towards heathland and grassland establishment can be traced in all the pollen records. Heathland communities appear to have been more widespread in the southwest and western parts of the study area, with *Empetrum* and to a lesser extent *Juniperus* and *Betula nana* being dominant floristic elements in the landscape. An early phase of *Empetrum* and *Juniperus* heath development is recorded in the Blackness, Roineach Mhor and Corrydon profiles, but heathland plants never appear to have been widespread on the east-facing slopes of the Grampian Highlands. In general, these areas were characterised by a floristically-rich closed or semi-closed grassland during the Interstadial. The more extensive development of *Empetrum* heaths in the south and west is probably a reflection of higher precipitation levels and a greater degree of oceanicity in those regions, for the distribution of *Empetrum* during the Lateglacial in Britain has been closely connected with former moisture levels (Brown 1971). If the radiocarbon dates are reliable, it would appear that *Empetrum* heaths dominated the Interstadial landscape in the area around Loch Etteridge for up to 2000 years, for high values of this taxon are recorded throughout the lower levels of the profile at that site, yet the maximum development of *Empetrum* (where it exceeded 40% of total land pollen) was not reached until 11,290 ± 165 B. P. This in turn indicates that the *Betula* phase which succeeded the period of *Empetrum* dominance was restricted to the time period between this date and the onset of the Stadial.

Although a record of birch is preserved at all the sites during the Interstadial, it is apparent that the majority of these grains are of dwarf birch, and that the distribution of tree birch was restricted either to scattered copses and thickets in sheltered localities, or to a small part of the study area in the extreme south. There is good evidence for a phase of tree birch dominance following the Empetrum maximum at Tirinie, and thus the regional treeline must have migrated sufficiently far north to impinge onto the southern margins of the Grampians during the Interstadial. It is clear however, that the expansion of tree birch was highly localised, for no trace of former birch woodland development could be found in the Corrydon profile only 20 km to the east of the Tirinie site. This suggests that the regional birch tree line probably had a north-westerly component of movement, and this point will be discussed further in Chapter 7.

The stabilisation of the Grampian landscape during the Lateglacial Interstadial is reflected not only in the pollen record but also in the stratigraphy and composition of the basin sediments. The cessation of minerogenic inwash at all the sites with the exception of Roineach Mhor is indicative of the gradual establishment of the vegetation cover, while the rise in the curves for the alkali cations calcium and magnesium reflects the steady maturation of the soils around the basin catchments. The higher values for organic carbon content at all the sites during the Interstadial is a result of the inwash of increasing amounts of humus from the maturing soils, in association with the addition of organic material to the basin sediments from decaying macrophytic vegetation, phytoplankton and associated fauna within and around the margins of the former lakes.

The burgeoning of the aquatic flora at the same time as, or slightly before the expansion of heathland communities is confirmation of higher temperatures during the Interstadial, for aquatic plants are widely regarded as more responsive to climatic change than their terrestrial counterparts, and are therefore good thermophilous indicators (Iversen 1954). Unfortunately, little direct evidence can be obtained from the pollen record with regard to the former temperatures in the Grampian Highlands during the Interstadial, but if the curves derived by Coope and others are correct, then it would appear that the thermal maximum was reached at, or a little before the establishment of the heathland communities, after which temperatures then declined steadily towards the Stadial boundary. According to Coope and Brophy (1972 p. 133), there seems to have been a very rapid rise in mean July temperature from 10°C to 17°C (possibly at a rate of 1°C <u>per decade</u>) at around 13,000 B. P. at Glanllynau in North Wales, after which values declined to approximately 12-13°C at the Interstadial/Stadial boundary. Similar palaeotemperature figures have been quoted for the English Midlands (Coope <u>et al.</u> 1971; Osborne 1972), while

Manley (1959) suggested a maximum Allerød July temperature of 13-14°C for the Lake District. The present sea level temperature difference between the study area and the English Midlands is ca. 1.4°C, and thus in the more sheltered valleys of the Grampians, Interstadial July temperatures of 1-2°C cooler than the estimates quoted above would not be unreasonable. On the upper slopes and plateau surfaces however, conditions were likely to have been relatively more severe, and temperatures may not have been much in excess of 10°C in the more exposed localities.

At around, or possibly even before 11,000 B.P. however, a marked change took place in the landscape and environment of the Grampian Highlands. In response to falling temperatures, an ice-cap developed on the Gaick Plateau (Sissons 1974) from which outlet glaciers descended to within 7 km and 13 km respectively of the sites at Tirinie and Loch Etteridge. A second ice-cap formed on the plateau above Glen Esk and Glen Clova, while local glaciers extended to within 3 km and 10 km of Blackness and Corrydon (Sissons 1972 and unpublished). Small glaciers also developed in Corrie Brandy and Corrie Clova only 1.5 km from the site at Roineach Mhor (Sissons 1972). The occurrence of frost wedges in parts of Scotland which are thought to have formed at the time of the Loch Lomond Readvance (Sissons unpublished) give a general impression of the severity of the climate during the Stadial, for Péwé (1966) has argued that these features only develop where the mean annual air temperature is -6°C or colder over a number of years. Using data from estimated firn lines and former precipitation levels, Sissons (1974) has calculated that the June-September temperatures in the Gaick area of the Grampians at the time of the Loch Lomond Readvance were around 1.5°C at the firn line, while the equivalent sea level temperatures were inferred to be about 6.3°C for the four summer months or 7.6°C for July. During the build-up of the ice-cap on the Gaick Plateau, the July temperatures were inferred to be ca. 7°C. Taking altitudinal and latitudinal differences into account, there is good agreement between these figures and those suggested for localities in England, for Manley (1964) has estimated that July temperatures in the Windermere area of the Lake District and the North Midlands were 7.5°C to 8.0°C and 10°C respectively, while Coope et al. (1971), on the basis of Coleoptera evidence, suggested a July temperature of "at or just below 10°C" for the Stadial in the English Midlands. In the present study area therefore, summer temperatures of the order of 5°C to 6°C would seem to be reasonable estimates for the more sheltered valleys, while in the more exposed localities on the upper slopes and plateau surfaces, mean July temperature may have been as low as 1.5°C to 2°C.

The most severe environmental conditions in the study area appear to have been experienced at Roineach Mhor which was the closest of all the sites to the limits of the Loch Lomond Readvance. The extremely coarse minerogenic sediment which accumulated in the basin, the pollen evidence for the widespread distribution of snowbed communities and taxa indicative of disturbed habitats, and the total extinction of aquatic flora testify to the harshness of the climate in Glen Clova during the Stadial. Severe conditions also seem to have prevailed at Blackness in Glen Esk to the northeast which was 7 km from the Loch Lomond Readvance glaciers in Glen Lee and Glen Mark, and only 3 km from the ice front in Glen Effock. There too the sediments are indicative of intense solifluxion conditions, and although the pollen spectrum is floristically-richer than at Roineach Mhor, the record still reflects a tundra landscape with some snowbed communities and taxa indicative of moving soils. At both these sites, values for pollen of woody plants are uniformly low, and most of the *Salix* grains resemble the markedly chionophilous *Salix herbacea*. The pollen and sediment records at Corrydon are also indicative of tundra conditions, although this site is over 10 km from the nearest ice-frontal position. However, the pollen spectrum there is complicated by the high values for birch, the origins of which remain unclear. Although the Stadial pollen record at Tirinie and Loch Etteridge is characterised by significant values for *Artemisia* and other taxa indicative of moving soils, the nature of the contained sediments in the basins, and the higher values for pollen of woody plants (e.g. *Empetrum*) are suggestive of relatively milder conditions than appear to have prevailed during the Stadial at sites farther east. This may be largely a function of continentality, for with the development of the European anticyclone, the sites with an easterly aspect would have been exposed to the bitterly cold winds sweeping across the plain of the North Sea and onto the Grampian slopes, and in these areas, temperatures may have been considerably lower than at localities of a similar altitude to the west.

Chapter 6

THE POSTGLACIAL PERIOD

Introduction

During the first two millennia of the Postglacial, the landscape of the Grampian Highlands developed, in response to progressive climatic amelioration, from one characterised by open tundra communities at the end of the Stadial, to an area of closed coniferous or mixed woodland. Records of these environmental changes are preserved in all the six pollen and sediment profiles investigated. However, a complete Postglacial diagram was only obtained from Drumochter, for accumulation seems to have ceased shortly after the end of the Lateglacial at Roineach Mhor, Tirinie and Blackness, while at Loch Etteridge and Corrydon, problems of time, and the constraints imposed by the original terms of reference of the study precluded a detailed analysis of the entire Postglacial profiles. The primary concern of this chapter therefore, is with the evolution of the Grampian landscape during the early Postglacial, although some discussion is included on the rest of the Postglacial period on the basis of evidence from the Drumochter site.

THE POLLEN RECORD

The transition from Lateglacial to Postglacial conditions is characterised at all the sites by a sudden decline in values for herbaceous taxa, and a marked upward trend in the curves for aquatic and woody plants. The pollen record can best be discussed in terms of the four generally-defined pollen assemblage zones outlined in Chapter 3 and depicted in the correlation chart (Figure 34).

a) Betula-Juniperus zone

Betula is the dominant tree in the history of the forests during this early period, for in all the profiles, values for Betula begin to rise immediately following the close of the Stadial. In contrast to the Lateglacial birch record, these Betula grains are almost entirely of tree birch, and Betula nana seems to have become virtually extinct at a very early stage in the Postglacial. Subfossils of tree birch were found in the sediments at Blackness, Drumochter and Loch Etteridge which indicated local presence of tree birch around a number of the sites, and although these were not identified as to species, it would seem from the results of other research (Vasari and Vasari 1968; H. J. B. Birks 1973) that almost all the Betula fossils found in the Scottish Postglacial are of Betula pubescens. The early birch maximum recorded in the pollen profiles is regarded as a pioneer stage in a protracted succession (Iversen 1960), for trees of the climax forest appear to have been considerably slower than birch in spreading into the Grampians. Firbas (1949) has estimated that Betula migrated at an average of 1 km/year, as its light, winged fruits are readily transported by wind and water. It is also a very high pollen producer (Andersen

FIGURE 34

Correlation chart of Postglacial
pollen assemblage zones in the study area.

BLACKNESS	ROINEACH MHOR	CORRYDON	TIRINIE	DRUMOCHTER	LOCH ETTERIDGE
				D-4 *Betula*- *Pinus*- *Ericales*	
		C-9 *Betula*- *Pinus*- *Ulmus*		D-3 *Pinus* zone	LE-8 *Pinus* zone
		C-8 *Betula*- *Corylus*	T-8 *Betula*- *Corylus*	D-2 *Betula*- *Corylus*	LE-7 *Betula*- *Corylus*
B-6 *Betula*- *Juniperus*	RM-5 *Betula*- *Juniperus*- *Empetrum*	C-7 *Betula*- *Juniperus*	T-7 *Betula*- *Juniperus*- *Empetrum*	D-1 *Betula*- *Juniperus*	LE-6 *Betula*- *Juniperus*- *Empetrum*

1966), although this often makes the former significance of birch woodland in the landscape difficult to assess as *Betula* is constantly over-represented in pollen diagrams. Apart from birch, values for other arboreal pollen are uniformly low in this initial Postglacial period. *Pinus* percentages never exceed 10% A. P., although at most sites there is a constant record of this tree throughout the zone. It is difficult to assess the extent to which pine grew locally at this time, for the values are not sufficiently high to exclude the possibility of all the *Pinus* pollen being the product of long-distance transfer. Values for *Quercus* and *Ulmus* are low and sporadic, but as *Ulmus* in particular is reputed to be a poor pollen producer (H. H. Birks 1970), the pollen record of these taxa may imply a local presence in sheltered localities.

Preceding the birch maximum in all the diagrams are pronounced peaks in the curves for *Empetrum* and *Juniperus*, which in some sites occur at virtually the same level, while in others the *Empetrum* maximum is reached a little before that for *Juniperus*. Studies have shown that *Empetrum* heaths constituted an important element in the landscape of oceanic northwest Europe for a short time during the early Postglacial (Jessen 1949; Iversen 1954). Moreover, this *Empetrum* maximum has been considered to be a feature characteristic of the classical pollen zone III/IV transition as an indicator of progressive climatic amelioration (Watts 1963; Vasari and Vasari 1968). There are very clear *Empetrum* maxima in the present Postglacial profiles at Roineach Mhor and Loch

Etteridge, but peaks in the *Empetrum* curves from the other sites although present are more subdued. It would seem from the present evidence therefore, that while *Empetrum* heaths formed a clear stage in the transition to closed forest, the duration and significance of the *Empetrum* phase varied from site to site throughout the study area. The *Juniperus* maximum on the other hand, is well-developed in all the profiles. This peak in the juniper curve has been recognized in all pollen diagrams from northwest Europe, and is widely regarded as an important reference level in the early Postglacial, marking a transition stage in the development from open-habitat vegetation of the Lateglacial to the closed forests of the Postglacial Climatic Optimum (Iversen 1960). *Juniperus* is well-suited to occupy new ground before the immigration of trees as it reaches maturity quickly, and is tolerant of a wide range of soil conditions (Kujala 1958). According to Iversen (1954), the rising *Juniperus* curve in Postglacial profiles is a clear indication of an improvement in climate allowing formerly dwarfed junipers to grow above the snow cover and to produce and disperse more pollen. The subsequent fall in values for *Juniperus* is, in turn, seen as the suppression of juniper by dense forest, for although this shrub will thrive beneath a forest canopy under certain conditions, it shows a clear preference for open, light vegetation.

Other shrub pollen present during the initial Postglacial period are *Salix*, *Sorbus*, Ericales and *Corylus-Myrica*. *Salix* is present in significant quantities at all the sites, being particularly well represented at Blackness where the rising curve in the upper part of the zone probably reflects the immigration of shrub willows into the rapidly-encroaching fen around the lake margins. All the *Salix* grains in the Postglacial pollen record are of shrub willow, and the least willow (*Salix herbacea*) which was so common at almost all the sites during the Lateglacial appears to have become virtually extinct. A constant record of *Sorbus* is preserved throughout this initial Postglacial zone at Blackness and Roineach Mhor, while occasional grains of the genus were found at Loch Etteridge and Tirinie. The pollen grains resemble *Sorbus aucuparia* which is a common shrub on lighter soils in the north and west of the British Isles at the present day (Clapham, Tutin and Warburg 1962). Ecologically, *Sorbus* has affinities with *Juniperus* in that it is generally shade-intolerant, which accounts for its occurrence during the early Postglacial, and its subsequent extinction with the establishment of closed birch woodland. High values for Ericales are only recorded at Loch Etteridge during this period, and are probably a reflection of extensive tracts of *Calluna* and *Vaccinium* moors interspersed with patches of *Empetrum* heaths, which developed in the more oceanic western areas of the Grampians. Low percentages of *Corylus*-*Myrica* are recorded throughout this zone at all the sites, and values for these taxa rise towards the upper contact. The upward trend in the curves reflects the expansion of hazel to the study area, but it is not certain to what extent the sporadic occurrence of *Corylus* throughout the rest of the zone implies a former presence of hazel at a very early stage in the Postglacial, or whether these grains are a result of contamination from the overlying sediments during the sampling process.

Although the Lateglacial/Postglacial transition is marked at all sites by a decline in values for herbaceous pollen, and particularly those characteristic of disturbed soil conditions, there are in most of the profiles, peaks in the curves for Gramineae and Rumex at, or at little before the boundary and preceding the rise in pollen of woody plants. These early Gramineae and Rumex maxima reflect an initial period of open grassland conditions and represent the first stage in the succession to closed forest. In the majority of the diagrams, this grassland phase spans only a few centimetres of sediment indicating that this stage in vegetational development was relatively short-lived before heathland communities became the dominant floristic elements in the landscape. The only herbaceous taxa which maintain a constant record throughout the zone are the notably thermophilous Filipendula cf. ulmaria and certain Ranunculaceae. The presence of these taxa probably reflects a considerably-enriched marsh flora on suitable habitats around the basin margins.

Rising values for aquatic pollen are also characteristic of the early Postglacial at all the sites investigated, and Myriophyllum is again the dominant aquatic macrophyte present. The Myriophyllum curve reaches particularly high values immediately after the Stadial/ Postglacial boundary at Blackness and Roineach Mhor, but there is a significant upward trend in the curve for this taxon at Tirinie. The majority of the grains at the latter site resemble Myriophyllum spicatum, a species characteristic of base-rich waters (Spence 1964), while at Roineach Mhor and Blackness, almost all the Myriophyllum pollen appears to be of M. alterniflorum, which is more often associated with oligotrophic lakes and ponds (Clapham, Tutin and Warburg 1962). Other aquatic pollen from this period include Potamogeton (particularly common at Blackness), and occasional grains of Nymphaea and Typha. The burgeoning of aquatic flora at, or a little below the Stadial/Postglacial boundary is clearly a reaction to rapidly-rising temperatures (Iversen 1954).

At Blackness and Roineach Mhor, sediment accumulation ceased at the close of the Betula-Juniperus phase, and in both diagrams the hydroseral succession can be clearly traced. An initial period of fairly deep, open water conditions is indicated by high values for Myriophyllum for this macrophyte will not thrive in waters of less than 50 cm depth (Spence 1964). The rapid decline in the Myriophyllum curve is succeeded by rising values for Equisetum and Cyperaceae which reflect the encroachment of the marginal fen and the progressive elimination of areas of open water. The final stage in the sequence is marked by rising percentages for Sphagnales indicating the beginning of Sphagnum peat accumulation and the development of an ombrogenous mire.

b) *Betula-Corylus-Myrica* zone

At Corrydon, Tirinie, Drumochter and Loch Etteridge, the *Betula-Juniperus* phase is succeeded by a zone characterised by high values for *Betula* and *Corylus-Myrica*, with rising curves for *Pinus*, *Quercus* and *Ulmus*, and declining percentages of *Juniperus*, *Empetrum* and *Salix*.

The zone corresponds approximately with classical pollen zones V and VI of the Godwin-Jessen system in that the dominant element in the pollen spectrum is *Corylus-Myrica*. Although a distinction was not made between these two genera, it is apparent from studies carried out in the British Isles and northwest Europe that the majority of pollen in this category during the early Post-glacial is of *Corylus* cf. *avellana* (Godwin 1956). *Corylus* is a moderately shade-tolerant shrub (Iversen 1960), which will flower under a birch canopy, but will not thrive under a heavy deciduous tree cover. In general, its pollen production is low where it is an understorey shrub (Jonassen 1950), but where it is a canopy species, either alone or mixed with birch, high pollen percentages have been found in surface samples (H. J. B. Birks 1973). Thus, where very high values for *Corylus* are found, it is likely that hazel was a canopy species in the woodland (H. H. Birks 1970; Pennington 1956). In general, *Corylus* is relatively more warmth-demanding than *Betula pubescens* and the flowers are thought to be sensitive to spring frost (Godwin 1956). In this respect, it is noticeable that the highest values for hazel are recorded at Corrydon (over 75% A. P.), while much lower hazel percentages are found in the sites to the north and west at Drumochter and Loch Etteridge (less than 40% A. P.). In all the sites, *Corylus* curves behave in an erratic manner, changing quickly from site to site and from sample to sample. This may be either a function of the variable rate of production of hazel pollen, or a result of the shrub being naturally seral and quickly shifting its area of natural abundance (Godwin 1966).

Although *Betula* remains the dominant tree pollen throughout this zone, the period of birch dominance in the Grampian landscape is virtually ended by the immigration of *Corylus*, for the regeneration of birch is impossible with a hazel understorey (Iversen 1960). Both *Ulmus* and *Quercus* increase progressively towards the upper levels of the zone, with *Ulmus* becoming established before *Quercus* at Corrydon and Drumochter. This is probably due largely to former soil conditions, for *Ulmus* shows a clear preference for base-rich soils (Iversen 1960) while *Quercus* will grow on thinner, more acid soils, and also on peaty substrates. *Ulmus* in particular is a poor pollen producer, and hence even though values remain relatively low, it is probable that both oak and elm were present in the Scottish Highlands at this time (H. H. Birks 1970). It has been pointed out (Iversen 1960 p. 9) that by being longer-lived, these two trees compete successfully with pioneer species like *Betula* and *Corylus*, and eventually replace them in a climax forest. Both *Ulmus* and *Quercus* are just as shade-tolerant

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as *Corylus*, and further, they gradually overtake hazel in height. As hazel will not flower under a dense canopy, it therefore succumbs. !

Pinus becomes abundant during the *Betula*-*Corylus* period at Corrydon, but values for this tree remain relatively low further north at Drumochter and Loch Etteridge. Although it has been suggested that *Corylus* competes successfully with pine because the seedlings are more shade-tolerant, and because *Pinus* does not regenerate under a *Corylus* canopy (Iversen 1960), the steady rise in values for *Pinus* at Corrydon and the progressive downward trend in the *Corylus* curve suggest that this is not always the case. *Corylus* is a moderately base-demanding shrub, and it is possible that by the time *Pinus* arrived in this area of the Highlands in significant quantity, the soils had become sufficiently leached to allow the establishment of *Pinus* in preference to *Corylus* which by now was living under sub-optimal conditions (H. H. Birks 1970).

Very few areas of heath and moorland remained during this zone, for *Empetrum*, *Juniperus* and *Salix* values are uniformly low and become increasingly more sporadic towards the upper contact. Only *Filipendula* and Ranunculaceae have a fairly constant record among the herbaceous taxa, while Gramineae and Cyperaceae, although present, maintain generally low values. At all sites however, there is a general upward trend in the curves for Filicales. Although a large number of these grains are of *Polypodium vulgare*, a significant proportion are of *Dryopteris filix-mas*. Both of these species are noted woodland ferns and their increased values reflect the development of a rich understorey beneath a thickening forest canopy.

Accumulation of sediment in the basin at Tirinie appears to have ceased at a fairly early stage in this zone, but the hydroseral succession is not as well developed as in the profiles from Roineach Mhor and Blackness. Following an initial phase of open-water conditions indicated by the high *Myriophyllum* counts, there was a protracted *Equisetum* stage which was finally succeeded by marked increases in the percentages for Cyperaceae reflecting the establishment of reedswamp throughout the basin. There is no record of *Sphagnum* peat accumulation, and the hydrosere is therefore incomplete as the site remains an area of marsh to the present day.

c) Closed forest zone

During the previous two periods, the pollen records at Corrydon, Drumochter and Loch Etteridge were broadly similar. In this zone, however, the evolution of the vegetation pattern differs in detail between the sites on the northwest and southeast of the Grampian watershed. At Corrydon, the pollen record reflects the development of a mixed woodland with *Betula*, *Pinus*, *Ulmus*, *Quercus*, *Alnus* and *Corylus* all present in significant quantities, while at Drumochter and Loch Etteridge, the pollen profiles are dominated by *Pinus*, with some *Betula* and *Alnus*, and lesser quantities of *Ulmus*, *Quercus* and *Corylus*.

The most significant difference between these two areas in terms of woodland composition is the relative importance of Pinus. Pinus sylvestris is a light-demanding species which is intolerant of shade. It will grow on a variety of substrates ranging from peats to skeletal sandy soils as long as conditions are not reducing (Carlisle and Brown 1968), and it is therefore an excellent competitive species when compared with Ulmus, and to some extent Corylus. The existence of pine as the climax vegetation on many nutrient-deficient sites in Scotland for a considerable period during the Postglacial is testimony to this competitive ability. In association with birch, it will grow to relatively high altitudes, and pine stumps have been found to elevations of 800 m in parts of the Cairngorms (Pears 1968). Pine became established in many parts of central and southern Britain at a very early stage in the Postglacial (Godwin 1956; Pennington 1969), but took a considerable time to migrate northwards into Scotland (Smith 1965). This it appears, is largely a function of poor seed dispersal, decreasing seed viability with altitude and latitude, and the lack of adequate soil nutrients (H. H. Birks 1970). This relatively slow rate of migration accounts for the later establishment of pine forests in the northern Grampian Highlands than at the more southerly site of Corrydon. The better competitive ability of Pinus, cooler climate and poorer soils to the north of the Highland watershed, may explain why mixed deciduous woodland never became established to any degree in this area of Scotland. Ulmus and Quercus are both present in the Loch Etteridge and Drumochter profiles, but the generally low values for these trees suggests that their former distribution was extremely localised. *Corylus* is still a significant element in the pollen spectrum, but the relatively low values of hazel when compared with the previous zone suggest that this species remained as an understorey shrub for the rest of the Postglacial.

Alnus values rise to a peak during this zone at all the three sites. This is a relatively warmth-damanding species which is commonly found today by streams and in waterlogged localities, but it is not topographically limited by stream and river courses if the rainfall is high (McVean 1953). It is relatively resistant to wind and exposure, and thus in the Scottish Highlands it often occurs on hillslopes with a southerly aspect, merging into birch and oakwoods in more acid habitats (McVean 1953). In general however, its distribution is controlled by the height of the water table as the seeds are not dispersed far from the parent tree ? when water transport is available. Thus the very slow northward migration of the species may be largely a result of the predominantly east-west alignment of rivers in northern Britain (McVean 1956). The steady upward trend in the curve for alder is probably a reflection of a gradual increase in moisture induced by greater precipitation, as it is unlikely that temperature increase affected the expansion for temperatures were generally regarded as being sufficiently high long before *Alnus* migrated into the Grampian

Highlands. In view of the relatively high values for *Alnus* in all the pollen diagrams, it is likely that the pollen record reflects not only considerable areas of alder fen and carr around the margins of the sites and in suitable habitats along watercourses, but also large expanses of alder scrub in moister localities on the hillsides.

At Drumochter, the *Alnus* maximum is preceded by peaks in the curve for *Potamogeton*, and succeeded by increased values for *Myriophyllum*. If the rising alder curve is in part a reflection of increased precipitation, then the rise in aquatic flora could be indicative of a period of higher water levels in the basins, and the subsequent expansion of suitable habitats for the development of aquatic vegetation.

d) Betula-Pinus-Ericales zone

A record of the late Postglacial period is only preserved in the Drumochter site, where the uppermost zone is characterised by high values for *Betula*, *Pinus* and Ericales, and a marked increase in the amount of non-arboreal pollen in the spectrum.

Although percentages of *Betula* and *Pinus* remain high, and the curve for *Betula* actually rises towards the top of the profile, there is an overall decline in absolute numbers of tree pollen. *Alnus* is still present in significant quantities which may be indicative of slightly wetter conditions, while *Quercus* and more particularly *Ulmus* decline to very low values, with occurrences of the latter becoming increasingly more sporadic. The rising curve for

Ericales in association with the re-appearance of a number of shade-intolerant herbs that were present in earlier zones, is indicative of the spread of Calluna and Vaccinium moorland, and a progressive reduction in the amount of forest cover. Rising values for Sphagnales reflect not only the infilling of the Drumochter basin and the growth of ombrogenous Sphagnum peat, but also the spread of treeless blanket bog across the surrounding hillsides. This vegetational change is partly due to changing climatic conditions, with a marked increase in precipitation, but is also a reflection of man's activity in clearing the woodland, resulting in the replacement by moorland (H. H. Birks 1970). The rising values for Plantago cf. lanceolata have been recorded in the upper levels of many British pollen profiles in association with declining levels for arboreal pollen, particularly Ulmus (Godwin 1956; Pennington 1969), and can be regarded as indicative of the expansion of agricultural activities, especially in more sheltered lowland sites.

THE SEDIMENT RECORD

In all the sites which contain a sediment record extending back to the Lateglacial, the transition from Stadial to Postglacial conditions is accompanied by a stratigraphic change from minerogenic to organic sediments. This horizon is sharply-defined and reflects the sudden cessation of mineral inwash, and the beginning of eutrophication of the basins.

At Loch Etteridge, Corrydon, Roineach Mhor and Blackness, the basal Postglacial deposits consist of a fine, brown, organic mud or gyttja, which occasionally has a high silt or clay fraction giving the material the consistency of a fine paste. It is always highly decomposed and contains few recognisable macrofossils. The early Postglacial sediments at Tirinie are again the fine calcareous marls and clay marls which characterised the Lateglacial Interstadial at that site. Once again, these marls are rich in shells with *Lymnaea peregra* ger being the dominant species present. Overlying these marl and gyttja deposits which are clearly limnic in origin, are considerable thicknesses of telmatic and terrestrial *Sphagnum*, *Sphagnum*-*Eriophorum* and sedge peats which become increasingly less humified towards the upper reaches of the profiles. These latter deposits are the products of varying rates of basin infill, and reflect the growth of ombrogenous peat mires in all the basins with the exception of Tirinie, for the recent history of the latter site has been one of progressive reedswamp development.

At Drumochter, the basal gravels which resulted from the decay of the Loch Lomond Readvance glaciers in the area are overlain by several centimetres of silty clay. These lower minerogenic deposits grade upwards into clay gyttja, pure organic gyttja, and *Sphagnum*-*Eriophorum* peat. The basal silts and clays reflect an initial period of open-habitat conditions immediately following glacier decay, and prior to the establishment of a closed vegetation cover, during which the inwash of loose morainic debris was taking place from around the basin catchment.

The curve for organic carbon rises markedly at the Stadial/Postglacial transition at Roineach Mhor, and rather less rapidly at the same horizon at Tirinie. There is also an upward trend in the curves for alkali cations, especially Ca and Mg, and again this is the reverse of the pattern observed by Mackereth (1965, 1966) in the Lake District, and Pennington et al. (1972) in northern Scotland. The high values for Ca and Mg at Tirinie are clearly a product of the precipitation of pure $CaCO_3$ by aquatic and semi-aquatic flora and fauna, but at Roineach Mhor, the rising curves for the cations must be indicative of base concentration in the organic sediments through an early leaching phase of the surrounding soils.

THE EARLY POSTGLACIAL ENVIRONMENT

The rapid climatic amelioration at the Lateglacial/Postglacial transition can be traced in the stratigraphy and pollen record at all the sites beyond the limits of the Loch Lomond Readvance. As was shown in Table 2 (Chapter 5), the precise date of this event seems to have varied from area to area, but the balance of evidence favours a significant rise in temperatures some time between 10,300 and 10,000 B. P.

The date of 9405 ± 260 B. P. obtained from below the Stadial/Postglacial transition at Loch Etteridge is therefore considerably younger than the majority of dates for that boundary.

On the Isle of Skye, a date of 9420 ± 150 B.P. was obtained from the Lateglacial/Postglacial boundary at Lochan Coir a'Ghobhainn but as the whole series of dates from this site was apparently too young, little significance is attached to the importance of this radiocarbon assay. The Lateglacial/Postglacial boundary at Bigholm Burn, Dumfriesshire, was dated at 9590 ± 170 B.P. (Godwin and Willis 1964), but subsequent datings on other samples from the same site suggested contamination by younger carbon from overlying sediments, and that the original date was at least 400 years too young (Godwin, Willis and Switsur 1965). It was originally considered that the relatively late date of 9590 B.P. at Bigholm Burn reflected a delay in organic mud deposition, and the late cessation of minerogenic inwash through solifluxion. This is a possible explanation for the apparently anomalous Loch Etteridge date, for the site is in the very centre of the Grampian Highlands, and protracted minerogenic deposition could well have continued long after vegetation had become established at other sites in Highland Britain. A recent date of 10,230 ± 220 B.P. on the Lateglacial/Postglacial boundary at Abernethy Forest, Inverness-shire (Vasari unpublished) casts doubts on this hypothesis however, for the latter site is only 40 km to the northeast of Loch Etteridge, and is relatively close to the upland massif of the Cairngorms. Prolonged minerogenic inwash at Loch Etteridge would surely have been accompanied by solifluxion in the vicinity of Abernethy Forest, but if the radiocarbon dates are correct, then clearly this did not occur. The upper Loch Etteridge date is therefore thought to be suspect, and is either the result of a very slow rate of sedimentation, or the contamination of the sampled horizons by younger organic material from higher up the sediment column.

The distribution of hummocky moraine, in association with other geomorphic evidence of glacier stagnation indicates that much of the Loch Lomond Readvance ice wasted in situ (Sissons et al. 1973). The extent to which late melt-out of residual ice impeded sediment accumulation in the kettle hole at Drumochter is not known: studies in North America have demonstrated that buried ice can remain for up to 2000 years after deglaciation (Wright et al. 1963; Heusser 1973). However, the pollen spectra in the basal sediments at Drumochter are comparable with early Postglacial pollen records at sites beyond the Loch Lomond Readvance limits, and thus it is possible that the Grampian Highlands became virtually ice-free very soon after the end of the Lateglacial Stadial.

In view of the rapid rise in temperatures at the opening of the Postglacial, the sudden stagnation and disappearance of glacier ice from the study area would not be unexpected. It has been suggested (Coope 1970; Coope et al. 1971; Coope and Brophy 1972; Osborne 1972) that mean July temperatures in the English Midlands rose from less than 10°C to over 17°C in a few hundred years. These estimates are based on the distribution of thermophilous Coleoptera, which again appear to have immigrated more rapidly than vegetation, implying a time-lag between rising temperatures and plant response. In the present profiles, the first indications of climatic amelioration are in the rising values for aquatic pollen, which in every case precede the stratigraphic transition from minerogenic to organic sediment, and also the rise in the curves for thermophilous landplants and woody taxa. This early increase in the pollen of aquatic plants endorses the opinion expressed by Iversen (1954) on the superiority of aquatic plants as thermal indicators due to their virtually immediate response to climatic change. The amelioration of climate is also reflected in the nature of the basin sediments, for the Lateglacial/Postglacial boundary is characterised at all the sites by a sudden stratigraphic change from minerogenic to organic deposits, reflecting the closing of the vegetation cover and the stabilisation of the landscape. There is a marked decline in values for open-habitat herbaceous taxa indicative of moving soils, and an increase firstly in open grassland plants, and later in heath and moorland species. Thus, around 10,000 B. P., the landscape of the study area was probably one of open parkland, with occasional areas of bare ground and disturbed soils, patches of dead ice in sheltered hollows, and scattered copses of tree birch interspersed with heathland plant communities.

It would seem from the pollen and sediment records that the period of open grassland was relatively short-lived, and was soon succeeded by a landscape of Empetrum and Juniperus heaths. The juniper peak is an important reference level and can serve as the basis for comparisons of early Postglacial vegetational development between individual pollen sites. A date of 9140 ± 105 B. P. (HV-5648) was obtained from this horizon at Blackness, but as it has been shown that the juniper peak may be a diachronous phenomenon (Smith and Pilcher 1973), it is difficult to make an assessment of the timing and duration of the Juniperus and Empetrum phases over the area as a whole. Moreover, there are grounds for suspecting that the Blackness date may be in error, but this point will be discussed more fully in the next chapter when the occurrence of the Juniperus maximum is examined in a regional context.

Other shade-intolerant shrubs which were common elements in the Grampian landscape during the Empetrum and Juniperus phases were species of Ericales, Sorbus and Salix. The greatest moorland development took place in the upper reaches of the Spey Valley where the hillsides appear to have been covered with large tracts of Vaccinium and Calluna-dominated moors, interspersed with areas of Empetrum heath. The southeast slopes of the Grampians saw the early immigration of tree birch, probably Betula pubescens, and for some time, the vegetation must have been a mosaic of birch copses and heath and moorland communities, separated by areas of grassland which became increasingly more dominant on the upper slopes. Eventually, however, the open heathland plants succumbed to the spread of birch woods, with the latter probably becoming firmly established a little after 9500 B. P.

Although the sediments of the early Postglacial are almost entirely organic, two bands of fine silt/clay of between 1 and 2 cm in thickness were found in the basin at Corrydon. The lower minerogenic layer occurs just below the peak in the curve for *Juniperus*, while the upper band is located above the maximum for *Corylus*-*Myrica*. Similar minerogenic horizons have been found in the predominantly organic Postglacial deposits at Tynaspirit near Callander (Lowe unpublished), and several such layers have been discovered in sites on the Continent, where their presence has been attributed to climatic fluctuations during the early Postglacial. In southwest Norway, a silt/clay horizon 4 cm thick was dated at 9830-9900 B. P., and was thought to have resulted from renewed soil instability, presumably associated with climatic deterioration (Anundsen 1971). In Italy, a slight recession in climate in the early Pre-Boreal was dated at 10,000-9650 B. P., and was termed the Piottino Oscillation (Zoller 1960), while in northwest Germany, Behre (1966) found a similar climatic fluctuation marked by a variation in the arboreal pollen record. Closely-spaced pollen counts (up to 1 cm interval at Tynaspirit) failed to reveal a clear vegetational oscillation in the Tynaspirit and Corrydon profiles, which may indicate that the minerogenic horizons are not related to climatic deterioration, but may simply be the result of short periods of increased run-off from around the catchments. However, the possibility of a climatic fluctuation, or a series of climatic fluctuations of relatively short duration, and which were not sufficiently prolonged to affect the regional vegetation pattern cannot be ruled out, for it has been suggested (Coope, G. R. personal communication) that the rise in the early Postglacial temperature curve was probably not uniform, and that short periods of lower temperatures may well have occurred within an overall trend towards climatic amelioration.

Following the establishment of birch woodland at around 9000 B. P., hazel spread rapidly into the study area. The arrival of this shrub in large quantities suggests that the climate had improved sufficiently for the successful reproduction of *Corylus*, with relatively high summer temperatures and fewer spring frosts (H. H. Birks 1972a). It is probable that pure hazel woods developed on the better soils, while in poorer sites, birch and hazel grew together. The higher values for *Corylus* to the south of the Grampian watershed suggest that hazel competed with birch as a canopy species in the woodland, while in the vicinity of Loch Etteridge and Drumochter, the landscape was probably one of more open birch forest interspersed with patches of hazel scrub. *Juniperus*, *Empetrum* and other light-demanding species were unable to compete with hazel and birch, and must therefore have become extremely localised in their distribution, being restricted largely to the upland slopes above the regional treeline.

The landscape of birch and hazel woodland in turn gave way to one of closed forest, with mixed woodland characterising the area to the south and east of the Grampian massif, while pine forest dominated the northern and western slopes. In the vicinity of Corrydon, elm arrived at a relatively early stage in the birch hazel period in response to higher temperatures and the continued presence of areas of base-rich soil. Oak and pine soon followed, and the forest cover was diversified still further by the later arrival of alder. Oak and elm probably became established on the lower slopes, while the light-demanding pine which could not compete with the shade-tolerant seedlings of *Corylus*, *Ulmus* and *Quercus* was most likely restricted to the upper slopes on the shallow, more acid soils. Birch was still an important element in the landscape, but like pine, the seedlings will not tolerate shade, and thus birch copses too were probably restricted to hillside sites. The immigration of alder in significant quantities may be indicative of a trend towards increasing climatic wetness which allowed *Alnus* to spread onto moist soils independent of the regional water table (McVean 1953), and may even have allowed it to invade parts of the mixed oak forest on the more mineral soils (H. H. Birks 1972a).

To the north of the Grampian watershed, cooler temperatures and more acid soils seem to have been the dominant factors limiting the spread of deciduous or mixed woodland to that area. At both Loch Etteridge and Drumochter, the Postglacial pollen record is dominated by *Pinus*, and pine woods seem to have been the climax forest type of much of the Scottish Highlands. No dates were obtained from the study area on the beginning of *Pinus* expansion, but in the nearby Cairngorms, the opening of the *Pinus* pollen assemblage zone was thought to have taken place at about 7000 B. P. (H. H. Birks 1970). Birch was still present in significant quantities, and probably formed the natural treeline along with pine depending on local conditions. Juniper scrub and dwarf-heath communities probably characterised the areas above the treeline, which may have been as high as 800 m in sheltered localities. Oak and elm were present in much smaller amounts than in the area to the south, and elm in particular was likely to have been restricted to favourable sites on the valley floors. Despite the fact that Alnus is a singularly hardy tree (McVean 1953), it did not arrive in this area of the Grampians until after the establishment of pine forest. It is unlikely, however, that it ever grew with pine, as the Pinus seedlings cannot thrive in the shade of Alnus, and conversely, Alnus cannot become established on acid blanket and bog peat, or on the drier habitats favoured by Pinus (H. H. Birks 1970). Thus the two species probably formed a mosaic, with pine always the dominant tree in this area of the Highlands.

In interpreting the landscape history of the Grampian Highlands during the early and mid-Postglacial, it is necessary to bear in mind the degree to which the percentage method of expressing pollen figures conveys an impression of the virtual disappearance of herbaceous vegetation. Absolute pollen analysis has shown (Davis and Deevey 1964; Pennington 1973) that numbers of grains per year of grasses and sedges for example, were maintained long after the arrival and establishment of trees in an area. In the present pollen profiles, the continued presence of Gramineae, Cyperaceae and other herbaceous taxa throughout the forest period in apparently lower amounts demonstrate that large areas of grassland still existed between tracts of woodland, probably on the upper hillslopes and plateau surfaces.

The record of man's activities in the study area is only preserved in the Drumochter profile. The decline in absolute numbers of arboreal pollen, and the rising curves for Ericales and Sphagnales reflect forest clearance on a large scale, and the colonisation of formerly wooded hillsides by heather moor and blanket peat. Although *Ulmus* was never present in quantity near Drumochter during the Postglacial, there is a marked fall in percentages of tree pollen, and a complementary rise in values for pollen of herbaceous plants, particularly *Plantago* cf. *lanceolata*. This transition is one of the most widely discussed in the entire history of European vegetation, and while a detailed consideration of the boundary lies outside the scope of the current study, some mention is necessary in light of the pollen spectra in the upper levels of the Drumochter site. The fall in values for *Ulmus* pollen, or the Elm Decline, appears in all Postglacial pollen diagrams from northwest Europe, and radiocarbon dates on the horizon have shown it to be approximately synchronous on either side of *ca.* 5000 B. P. (Pennington 1969). It was originally considered that the decline in *Ulmus* was due entirely to deteriorating climatic conditions (Godwin

1956), but more recent research suggests that anthropogenic factors may have been of greater importance (Iversen 1960). Detailed pollen analyses have established a close relationship between the Elm Decline and pollen associated with early Neolithic farming such as Plantago lanceolata and Urtica dioica (Pennington 1969). Thus the transition at around 365 cm in the Drumochter profile may mark the first stage of human interference in the natural vegetation pattern by the clearing of the woodland for agricultural purposes. However, due to its remoteness, this upland area of Scotland has probably never supported a particularly dense population, and thus the impact of Neolithic man was initially less severe than in the lowlands to the south and east.

Chapter 7

LATEGLACIAL AND EARLY POSTGLACIAL ENVIRONMENTS IN THE GRAMPIAN HIGHLANDS: A REGIONAL SYNTHESIS

Introduction

Thus far, the discussion of former environments has been restricted to that portion of the Grampian Highlands within the confines of the present study area, and inferences on landscape change have been made almost exclusively on the basis of results obtained from the six sites investigated. The purpose of this chapter therefore, is to broaden the scope of the study by integrating the new data with that already published, thereby producing a regional impression of the Grampian landscape during the Lateglacial and Early Postglacial periods. Although an account of this nature has been facilitated by the veritable "explosion" of interest in Quaternary studies in Scotland over the last decade, the geomorphic and vegetational history of large areas of the Highlands remain a relative mystery, and the discussion is therefore, of necessity, biased towards those areas from which records are available. The chapter is divided into three sections, beginning with the Interstadial, and followed by the Stadial and Postglacial periods respectively.

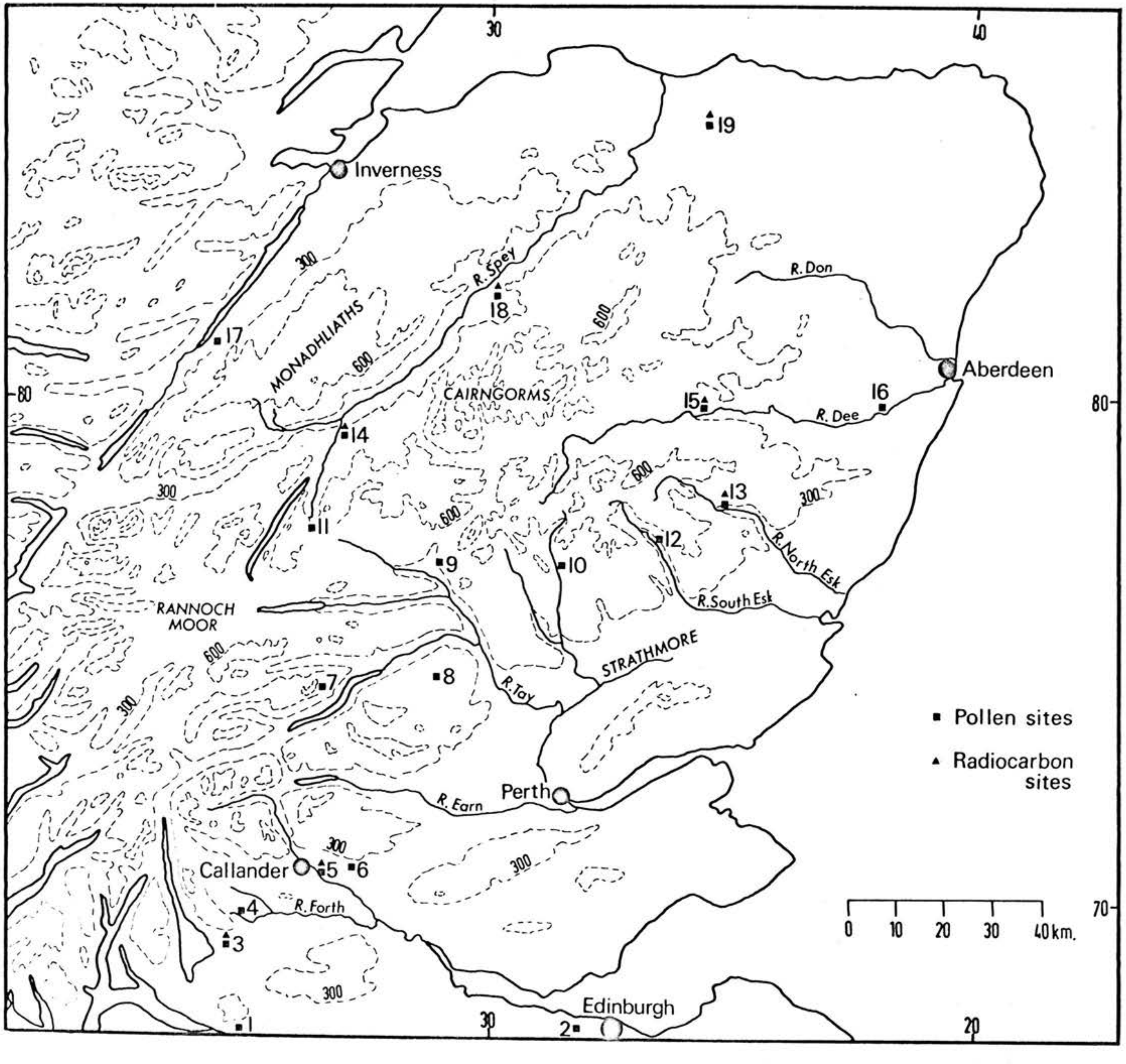
The Interstadial

At the height of the Late Devensian glaciation between

FIGURE 35

Index map of pollen sites in the Grampian Highlands.

1) Garscadden Mains (Mitchell 1952; Donner 1957).
2) Corstorphine (Newey 1970).
3) Drymen (Donner 1957; Vasari and Vasari 1968;
Vasari unpublished).
4) Gartmore (Donner 1957).
5) Tynaspirit (Lowe unpublished).
6) Loch Mahaik (Donner 1957, 1958, 1962).
7) Lochan nan Cat (Donner 1962).
8) Loch Creagh (Donner 1962).
9) Tirinie (Walker unpublished).
10) Corrydon (Walker unpublished).
11) Drumochter (Walker unpublished).
12) Roineach Mhor (Walker unpublished).
13) Blackness (Walker unpublished).
14) Loch Etteridge (Sissons and Walker 1974; Walker unpublished).
15) Loch Kinord (Vasari and Vasari 1968; Vasari unpublished).
16) Loch of Park (Vasari and Vasari 1968; Vasari unpublished).
17) Loch Tarff (Pennington *et al.* 1972).
18) Abernethy Forest (H. H. Birks 1970; Vasari unpublished).
19) Garral Hill (Donner 1957; Godwin and Willis 1959).


30
40
Inverness
19
R. Spey
18
R. Don
17
MONADHLIATHS
600
300
CAIRNGORMS
Aberdeen
80
15
16
R. Dee
14
600
13
300
11
12
9
10
R. North Esk
R. South Esk
RANNOCH MOOR
STRATHMORE
8
7
R. Tay
Pollen sites
Radiocarbon sites
Perth
R. Earn
300
Callander
5
6
300
4
R. Forth
3
0
10
20
30
40 km.
70
1
Edinburgh
2
20

17,000 and 20,000 years ago, the Grampian Highlands were submerged beneath an ice-mass of at least 1000 m in thickness, which is known to have extended as far south as Holderness in Yorkshire. If the radiocarbon dates are correct, ice had retreated from the Lockerbie area of the Southern Uplands and from the Loch Droma area of the northwest Highlands by a little after 13,000 B. P. (Bishop 1963; Kirk and Godwin 1963), while the Firth of Clyde became ice-free by 12,600 B. P. (Bishop and Dickson 1970; Peacock 1971). Sites at Drymen to the east of Loch Lomond, and Callander in the southeast Grampians were deglaciated by 12,510 ± 310 B. P. (Vasari unpublished) and 12,750 ± 120 B. P. (Lowe unpublished) respectively. It is important to point out that these two dates are minimal for deglaciation, as the dated horizons are in kettle hole basins and overlie up to 10 cm of minerogenic lacustrine sediment. In the Spey Valley, two further radiocarbon dates have been obtained which place even more severe constraints on the timing of ice-sheet decay as these sites are located in the heart of the Grampian Highlands. At Abernethy Forest in the lee of the Cairngorms, the basal organic horizons from a sediment profile in a former meltwater channel yielded a radiocarbon date of 12,700 ± 270 B. P. (Vasari unpublished), while the lowest organic material in the Loch Etteridge site was dated at 13,151 ± 390 B. P. Again it must be emphasised that these dates if valid, are minimal for ice-sheet decay, for not only do minerogenic sediments of lacustrine origin underlie the dated horizons, but in the case of the

Loch Etteridge sample, 3-4 cm of material were necessary for dating purposes owing to the low organic carbon content of the sediment (Sissons and Walker 1974). Taken together, these two dates are considered to be particularly significant, for as there is a clear overlap in standard errors they are mutually corroberative, and moreover, both have been obtained from sites in the vicinity of extensive areas of high ground where glacier ice would be expected to have remained until a relatively late date. The implication is difficult to avoid therefore, that by 13,000 B. P., large areas of the Grampian Highlands must have been virtually ice-free.

At about this time, two significant and probably interrelated events seem to have occurred. Coleoptera and radiocarbon dates from sites in North Wales and the English Midlands (Coope and Brophy 1972; Osborne 1972) indicate that around 13,000 B. P. temperatures rose very rapidly, with the summer temperatures becoming at least as warm as those of the present day, while sea floor sediments indicate that deglacial warming of the North Atlantic Ocean adjacent to the British Isles occurred at about 13,500 B. P., polar waters having retreated far to the west by 13,000 B. P. (Ruddiman and McIntyre 1973). According to Peacock (1970) and Sugden (1970), large masses of glacier ice remained in the Loch Arkaig and Cairngorm areas throughout the Lateglacial period, but in view of the profound environmental changes referred to above, it is difficult to believe that any remnants of the British ice-sheet which may have remained at about 13,000 B. P. could have survived for much longer. Total deglaciation of the entire Grampian Highlands by about 12,500 B. P. would therefore seem to be a conservative suggestion (Sissons and Walker 1974).

The palaeoclimatic and radiocarbon evidence also has a bearing on the nature and form of ice-sheet decay in and around the Grampian Highlands. Previous investigations seemed to show that during the overall period of ice-sheet wastage, a significant forward movement of the ice-front took place, an event which became termed the Perth Readvance. A mammoth tusk overlain by till at Kilmaurs near Glasgow was dated at 13,700 +1300/-1700 B. P. and this, in association with other geomorphic evidence led Sissons (1967b) to conclude that the Perth Readvance probably culminated around 13,500-13,000 B. P. However, more recent studies near Perth (Paterson 1974) and in the vicinity of Aberdeen (Clapperton and Sugden 1972), have shown that evidence previously thought to have been indicative of a readvance can now be interpreted as resulting simply from ice-sheet decay. The recent radiocarbon and palaeotemperature evidence lend credence to this hypothesis, as a marked glacier readvance is difficult to reconcile with the apparent rapid rise in temperatures at, or a little before 13,000 B. P., and also with the relatively small amounts of glacier ice which seem to have remained in the Grampian Highlands at that time. The concept of the Perth Readvance is therefore tenuous, and the balance of evidence appears to favour progressive and fairly rapid decay of the Late Devensian ice-sheet within the Grampian area, a process which was more or less complete by 13,000-12,500 B.P.

The thinning and retreating ice exposed large areas of fresh substrate to the rapid colonisation by pioneer vegetation. Many of these herbaceous plants e.g. Rumex, Artemisia, have steppe-tundra affinities, but as was discussed above, the presence of these taxa in the early Interstadial pollen records is not necessarily indicative of a steppe or tundra climatic regime, for the occurrence of such plants in the Lateglacial landscape was more often governed by factors of competition, migration rates, soils and edaphic conditions. Indeed in view of the high summer temperatures postulated by Coope et al., it is possible that the vegetation of the Highlands bore little relation to climate at this early stage. High values for arboreal pollen are recorded at Blackness, Roineach Mhor and Loch Kinord (Vasari and Vasari 1968) during the early Interstadial, but these occurrences are considered to be the result of long-distance transport of tree pollen from the Continent to sites on the slopes of the eastern Grampians, producing vastly inflated tree pollen counts due to the impoverished nature of the local pollen rain.

In most of the Lateglacial pollen records, there is an uninterrupted succession from open-habitat herbaceous vegetation through to the arrival and establishment of shrub and heathland taxa. Exceptions to this general trend are found in the basal assemblages at Loch of Park (Vasari and Vasari 1968) and Loch Tarff (Pennington et al. 1972). At the former site, an initial Rumex phase is succeeded by maxima in the curves for *Salix* and *Betula*, which in turn give way to increased values for *Rumex*, Cyperaceae and *Artemisia*. Finally, there is a general and sustained rise in woody plant pollen which is interpreted as the beginning of the Alleröd or pollen zone II. The two *Rumex*-dominated zones tend to be poor in pollen with large quantities of secondary or long-distance grains, while the intervening *Betula* zone and the succeeding Alleröd have a higher pollen content, with the majority of woody plant pollen apparently of local origin. The pollen record is interpreted by the authors as being indicative of a steadily ameliorating climate, which is interrupted by a colder phase of relatively short duration. It is possible that this sequence can be correlated with the "Bölling Oscillation" recognized in parts of northern England (Walker and Godwin 1954; Oldfield 1960; Bartley 1962), in Ireland (Watts 1963) and on the Continent, and which has been dated at 12,700 B. P. in southwest Norway (Chanda 1965), and 12,000-12,400 B. P. in the Netherlands (van der Hammen *et al.* 1967). However, at other sites in the Grampian Highlands which have been shown by radiocarbon assay to contain sediments of Bölling age, notably Loch Etteridge, Callander and Drymen, no trace of a climatic fluctuation can be found in the pollen records from the basal sediments. Moreover, no vegetational oscillation can be detected in the early Interstadial deposits at Loch Kinord and Blackness, both of these sites being located within 30 km of Loch of Park. Thus, if the pollen fluctuation at the latter site is climatically-determined, the temperature oscillation must have been of sufficiently small amplitude and short duration to leave the vegetation at the surrounding sites virtually unaffected.

At Loch Tarff which is situated in the lee of the Monadhliath Mountains to the west of the Grampians, there is a marked fluctuation in values for woody plant pollen in the basal Rumex assemblage zone. An initial phase with high Rumex values is succeeded by a subzone dominated by Empetrum and Juniperus, after which percentages of heathland plants decline sharply before rising again at the beginning of the main Interstadial. Although this pattern could be interpreted as indicative of a climatic fluctuation, it is suggested (Pennington et al. 1972 p. 275) that the pollen trends provide no certain evidence for changes in temperature because of the possibility that the small percentage decline in woody plants (Empetrum and Juniperus) could be due to the percentage method of pollen representation, as indeed proved to be the case at Blelham Bog in the Lake District (Pennington and Bonny 1970). An alternative explanation is therefore possible for the apparent fluctuation in pollen of woody plants in the basal sediments at Loch of Park, but clearly the problem can only be resolved by the application of absolute pollen analysis to test whether these oscillations represent a real change in annual pollen deposition, or only a small percentage fluctuation i.e. a "statistical artefact" (Davis and Deevey 1964).

In general therefore, the balance of evidence would seem to favour a continuous and uninterrupted process of vegetational development in the Grampian Highlands throughout the early Interstadial, and this hypothesis is borne out by the sediment record at all the pollen sites. In each case, the basal minerogenic deposits which accumulated in the basins through the processes of normal run-off and solifluxion during the period immediately following ice-sheet decay, are succeeded by sediments which become increasingly more organic. This trend reflects the progressive stabilisation of the landscape with the closing of the vegetation cover and the formation of humus in the gradually developing soils. There is no record of a second phase of minerogenic inwash in any of the sediment profiles which could be interpreted as indicative of a climatic deterioration. It is therefore possible to envisage the early Interstadial vegetation of the Grampians as a succession in response to temperature changes on steadily maturing soil profiles, the rate of plant colonisation varying from locality to locality.

In many areas, the period of pioneer vegetation appears to have been relatively short-lived with woody plants becoming established very soon after ice-sheet decay. Empetrum heaths for example, were present in the vicinity of Loch Etteridge at a little after 13,000 B. P., juniper and birch were common in the Callander area around 12,700 B. P., while numerous tree birch were to be found near Drymen some time before 12,500 B. P.

In general, the pollen records show that the Interglacial landscape of the Grampians varied from one of heath and moorland with virtually no trees in the north and west, to a region of closed grassland with tree birch in sheltered localities in the south and southeast.

The area to the northwest of the Highland watershed was dominated by *Empetrum* heaths throughout the entire Interstadial period. The main *Empetrum* phase followed the break-down of the pioneer communities, and a secondary maximum occurred shortly before the onset of the Stadial following a limited period during which juniper and birch (*Betula nana*) flourished. At Loch Etteridge, the initial expansion of the *Empetrum* heaths lasted until 11,290 ± 165 B. P. before birch and juniper became important. At all sites in the northern Grampians, juniper was a common element in the pollen spectrum, and in some areas it seems to have flowered more profusely towards the end of the Interstadial (see below). Large expanses of grassland appear to have been interspersed with the heathland communities, and were probably characteristic of the steeper hillslopes. At Garral Hill in Banffshire (Donner 1957), periods of *Empetrum* dominance in the pollen records are accompanied by maxima in the curve for Ericales, suggesting a former landscape of *Empetrum* heaths interspersed with tracts of *Calluna* and *Vaccinium* moorland. Values for birch and pine are universally low, and the majority of the birch pollen is undoubtedly of *Betula nana*. At Loch Tarff, the Interstadial pollen spectra are interpreted as representing a locally treeless landscape, and arboreal grains present in the pollen record are considered to be the product of long-distance transfer (Pennington *et al.* 1972). However, subfossil remains of tree birch have been found throughout the Lateglacial profiles at Loch Kinord and Loch of Park, and have even been discovered in sediments of zone I age at the latter site (Vasari and Vasari 1968 p. 17). Thus, tree birch must have been present in the Dee Valley at least during the Interstadial. It is most unlikely that pine ever grew locally at this time however, and in view of the complete absence of *Pinus* subfossils from all the sites in the northern Grampians, all pine pollen in samples of Interstadial age are thought to be of long-distance origin.

The Interstadial landscape of the south and eastern Grampians differed considerably from that which was to be found to the north of the Highland watershed, in that it appears to have been one of open parkland with tree birch and juniper scrub in the valleys and on the lower slopes, and a mosaic of heath, moor and grassland communities at higher elevations. In southwest Scotland and the eastern lowlands, the landscape appears to have been one of closed grassland, with occasional copses and thickets of tree birch and shrubs on the more sheltered hillsides (Moar 1969; Newey 1970). A similar type of vegetation cover has been described for the lowland areas of northeast England at that time (Bartley 1966; Turner and Kershaw 1973), where the largely unforested landscape was thought to be due mainly to the exposed easterly situation. Higher arboreal pollen values have been obtained from sites within the lower valleys of the southern Grampians (Donner 1957; Vasari and Vasari 1968; Lowe unpublished), where it would seem that tree birches became established in sheltered localities at an early stage in the Interstadial. It is clear from the pollen record at Tirinie that copses of tree birch were present on the southern slopes of the Gaick Plateau, while the former occurrence of tree birch in the Dee Valley has already been discussed. It would appear however, that few birch trees ever grew beyond the Highland watershed where the landscape seems to have been essentially treeless throughout the Lateglacial. The pollen evidence suggests that birch migrated into Scotland along the Atlantic seaboard where the relatively warmth-damanding Betula pubescens was able to take advantage of the moderating influence of the Atlantic airstream. Within the Grampian Highlands, the main area of birch concentration appears to have been in the southern valleys, with absolute numbers of tree birch declining northwards. At no site however, are Betula values sufficiently high to suggest the establishment of birch woodland in the Grampian area during the Interstadial.

The slopes of the eastern Highlands which lie within the confines of the present study area formed a transitional zone between the parkland landscape of the south and east and the heathlands to the north of the Grampian watershed. The lower valleys were characterised by juniper and willow scrub, with Betula nana and occasional tree birch in sheltered localities, while grass and heath communities were to be found on the upper slopes and plateaux, with areas of heathland increasing gradually northwestwards.

The fundamental reason for the differentiation in the vegetation pattern during the Interstadial was undoubtedly climatic. The northward extent of tree birch was restricted by gradually decreasing temperatures, while low temperatures, increasing dryness and exposure acted as an effective barrier to the eastward migration of trees. Increased precipitation levels in the north and west resulting in the progressive reduction in soil base status as shown by chemical analysis, were clearly responsible for the establishment of large areas of acidophilous Empetrum heath. In the absence of competition from shade-tolerant taxa, these open-habitat communities were then able to persist virtually uninterrupted throughout the Interstadial. In the south and east, lower rainfall values prompted the development of a grassland landscape, for in most areas, lower moisture levels inhibited heathland development, and in many valley sites the diffusion of trees and shrubs acted as a further check. Only on the higher slopes where precipitation was greater and competition less severe, did heathland plants become established in any quantities.

According to Coope (1970), temperatures reached maximum values during the early Interstadial at ca. 13,000 B.P., and then declined progressively towards the Interstadial/Stadial boundary. There is no direct evidence from the Grampians on former temperature levels in the area during the Interstadial, but there would seem to be some indication of a possible temperature fluctuation within that time period, with a phase of higher temperatures shortly before the onset of the Stadial. At Corstorphine (Newey 1970) and Corrydon, double maxima occur in the Interstadial pollen record for Betula, while at Drymen, Loch Kinord "B", Blackness and Loch Tarff, a pronounced Juniperus maximum occurs towards the close of the Interstadial. At Corstorphine, Corrydon and Loch Tarff in particular, there is a slight decrease in values for woody plant pollen near the middle of the period. Such widespread similarities in the pollen records suggest that the fluctuations are unlikely to be statistical artefacts resulting from the percentage method of pollen representation (see above), nor that the oscillations are purely the result of local edaphic or other factors. The succession can therefore possibly be interpreted as a result of temperature fluctuations during the later part of the Interstadial, comparable with the threefold division of the Allerød sediments in Denmark (Iversen 1954; Krog 1954). If this was so, then the secondary peaks in the birch curve, and the pronounced maxima for Juniperus could represent a period of slightly warmer conditions during which juniper in particular flowered more freely at sites where it was present (cf. Iversen 1960; Pennington et al. 1972).

The Stadial

At approximately 11,000 B. P. a marked change took place in the environment of the Grampian Highlands. In response to falling temperatures, ice began to accumulate on the plateaux and summits, and in the high corries. This recrudescence of glacier ice which has been termed the Loch Lomond Readvance, was long considered to have begun at around 10,800 B. P., but it is now apparent that in many areas of the Grampians, falling temperatures at the close of the Interstadial may have prompted the development of glaciers before that date (Sissons in press). Manley (1962) has estimated that only 50-100 years of cold summers and heavy winter snowfall would have been sufficient to re-establish glaciers in the high corries of the Lake District, and thus in the Scottish Highlands, with a more northerly location and larger expanses of high ground, the time taken for glacier formation would probably have been considerably shorter.

However, Manley (1959) has also suggested that Scotland was never completely ice-free during the Lateglacial period, and this view has been supported by Peacock (1970) and Sugden (1970). The latter author invoked the concept of a steadily-downwasting ice-sheet to explain the landforms of deglaciation in the Cairngorm Mountains, and suggested that not only the Cairngorms, but also adjacent areas of the Spey Valley were occupied by glacier ice throughout the Lateglacial period. In this scheme, the Loch Lomond Readvance is envisaged as a minor oscillation of the ice-front around the Cairngorm margins. In other areas of the Grampian Highlands, the nature and distribution of glacial landforms in association with pollen analysis and radiocarbon dates from sites near former ice limits has proved that the Loch Lomond Readvance was a significant glacial event, and of considerably greater magnitude than the ice-cap oscillation postulated by Sugden (Sissons 1972; Sissons and Grant 1972; Sissons et al. 1973; Thompson 1972). In the Gaick Forest area for example, it has been shown that a plateau ice-cap with an average thickness of about 110 m developed during the Lateglacial Stadial in places (Sissons 1974). Moreover, the discovery of deposits which have been proved by pollen analysis and radiocarbon assay to be of Lateglacial age at Loch Etteridge and Abernethy Forest refutes the hypothesis that ice remained in the Spey Valley throughout the Lateglacial period. Indeed, in view of the evidence discussed above, it seems unlikely that glacier ice remained anywhere in Scotland during the Interstadial, thus the concept of a steadily downwasting ice-cap on the Cairngorms becomes increasingly more difficult to accept.

At sites beyond the limits of the Loch Lomond Readvance, the transition from Interstadial to Stadial conditions is marked by the renewed inwash of minerogenic material reflecting the break-up of the plant communities in response to rapid climatic deterioration, and the onset of solifluxion processes at the higher sites and increased run-off over bare and disturbed soils in lower areas. In the northern half of the Grampians, this transition has been dated at 10,808 ± 230 B. P. at Garral Hill (Godwin and Willis 1959), 10,764 ± 120 B. P. at Loch Etteridge, and 10,640 ± 260 B. P. at Loch Kinord (Vasari unpublished). The close grouping of these dates reflects the generally synchronous nature of climatic deterioration in the northern half of the Grampians, although a slightly earlier date was obtained from the horizon beneath the transition at Abernethy Forest (Vasari unpublished). Two dates have been obtained on the Interstadial/Stadial boundary from sites in the southern Grampians; these are 12,060 ± 320 B. P. at Drymen (Vasari unpublished), and 11,385 ± 120 B. P. at Callander (Lowe unpublished). However, these two dates are rather older than those obtained from sites further north, and are also older than dates obtained from the zone II/III boundary in northwest England (Godwin and Willis 1959). As it is unlikely that climatic deterioration in the southeast Grampians preceded falling temperatures in the rest of the Highlands, and in other parts of northwest Britain, it is suggested that these two dates are erroneous, possibly as a result of the incorporation of inert carbon into the samples submitted for radiocarbon assay.

At all the Grampian sites, the onset of harsher Stadial conditions led to a rapid decline in numbers of heath and parkland plants, and a sharp increase in open-habitat tundra species, particularly those taxa characteristic of disturbed soils. In the northern Highlands, the pollen spectra are dominated by Artemisia, a plant widely recognized as indicative of frost-disrupted or solifluncted soils. It is well known from the present day that solifluxion will destroy a humus layer and turn up unleached subsoil, thus preventing podzolisation (Andersen 1961). Acidophilous heath plants are therefore absent from such localities, and thus the beginning of the Stadial saw a marked decline in areas of Empetrum heath. At Loch Etteridge and Loch Tarff, Empetrum is replaced in the pollen spectra by Artemisia and common associates such as Caryophyllaceae, Compositae and smaller quantities of Rumex. Present day montane and arctic species of moss and sedge are also more common. A similar type of pollen spectrum characterises the Stadial at Loch Kinord, but no record is available at present of the Stadial landscape around the northern margins of the Highlands, for at Garral Hill which is the only pollen site in the area, the minerogenic Stadial sediments were not analysed for pollen content. Particularly severe environmental conditions appear to have prevailed in the east-facing glens within the present area of investigation, where the extent of solifluxion activity is reflected in the extremely coarse sediment in the basins. The presence of Salix herbacea and other markedly chionophilous taxa in the pollen records are indicative of the former distribution of snow patches, a phenomenon which may have restricted the spread of Artemisia in the area, as the present day records for the genus indicate that it has marked xerophilous affinities and is intolerant of snow cover (Andersen 1961).

In the lowland areas of the south and west, values for *Artemisia* are considerably lower. At Drymen and Callander, the Stadial pollen spectra are dominated by *Rumex*, with significant quantities of Gramineae and Cyperaceae, a situation which is comparable with pollen records from other lowland sites in eastern Scotland and northeast England (Newey 1970; Bartley 1966; Turner and Kershaw 1973). The abruptness of the transition from upland to lowland vegetation is demonstrated by comparisons of the two Lateglacial pollen diagrams from the Dee Valley. At Loch Kinord which is situated at 175 m O. D., the Stadial spectra are characterised by high values for *Artemisia* which exceed 20% of total land pollen, while at Loch of Park approximately 25 km further east at 75 m O. D., the Stadial pollen record shows significant percentages of Gramineae, Cyperaceae and *Rumex* with the curve for *Artemisia* never rising above 10% of total land pollen. Moreover, values for *Betula* (*nana*), *Salix* (shrub willow) and *Juniperus* remain higher than at the Highland sites. The only exception to this general rule is the site at Corrydon, where for apparently local reasons which are not fully understood *Betula* pollen is present in quantity during the Stadial.

Soil instability appears to have been one of the most significant factors governing vegetational development during the Stadial. In the northern Highlands, low temperatures, repeated temperature oscillations across the freezing point, and the widespread development of snowbeds particularly on the eastern slopes, prompted solifluxion and cryoturbation, which in turn led to soil movement and the disruption of the existing plant cover. As a result, large areas of bare and unstable ground were created providing ideal habitats for Artemisia and its associates in the absence of competition from other open-habitat taxa. In the lowland areas however, despite the prevailing periglacial climate areas of moving soil were more restricted and the bare surfaces were colonised by Rumex and Gramineae. In the event of competition from these taxa, the Artemisia associations which had become so dominant in the Highlands, were severely limited in their distribution.

Although there is no direct evidence on Stadial temperatures in the Grampians, there is some evidence to suggest that relatively milder conditions prevailed in the south and west than on the more exposed eastern slopes. In the east-facing glens, the former extent of solifluxion indicated by the basin sediments and the widespread development of snowbeds are suggestive of a harsher environment than was to be found in the regions around Loch Tarff and Drymen. In spite of the high values for Artemisia at the former site, the higher values for woody plant pollen and lower percentages of markedly chionophilous taxa may be indicative of a slightly milder climatic regime. Indeed it is possible that in many of these western areas, solifluxion in the form of mass downslope movement of surface material may have been less effective than the process of normal erosion from rapid run-off over largely unvegetated ground. Certainly, in these western areas, some ameliorating effect should have been felt from the Atlantic airstream, while farther east, the Grampian slopes would have been exposed to the colder winds from the Continent. Environmental conditions towards the upper reaches of the eastern glens would have been made even more severe by the effects of local glacier winds blowing downvalley from the ice-caps above Glen Clova and Glen Esk, and on the plateau of the Gaick Forest.

The Early Postglacial

At around 10,000 B. P., rising temperatures prompted a further dramatic change in the landscape of the Grampian Highlands, and initiated a succession which culminated in the establishment of large areas of forest over the entire region some 2500 years later. The rapidity of this climatic amelioration is reflected in the abrupt change from minerogenic to organic sediment accumulation in the basins beyond the limits of the Loch Lomond Readvance, indicating the sudden cessation of solifluxion and minerogenic inwash, and the beginnings of vegetational and landscape stability. The radiocarbon evidence suggests that this marked change in the Grampian environment took place between 10,300 and 10,000 B. P. (Table 2), although in some of the higher and more exposed areas, it is possible that minerogenic deposition implying solifluxion and sparse vegetation may have continued locally until well into the Postglacial. At present the rate of decay of the Loch

Lomond Readvance ice is not known, as no radiocarbon dates have yet been obtained from the basal sediments in basins within the former readvance limits. However, in spite of the fact that there is well-documented evidence from Europe and North America to show that residual ice can remain in kettle holes long aftdr deglaciation, pollen analyses from Drumochter and Lochan nan Cat (Donner 1962) which are the two highest sites within the Loch Lomond Readvance limits, indicate that both these areas were ice-free early in the ninth millennium B. C. It is therefore assumed that deglaciation at the end of the Stadial was a relatively rapid process, but one which would not be unexpected if the rate of climatic amelioration at the Lateglacial/Postglacial boundary as suggested by Coope and others is correct.

At the onset of the Postglacial vegetational changes occurred which were not unlike those which characterised the early Interstadial, for all the diagrams show successive maxima for Rumex, Gramineae, Empetrum, Juniperus and Betula. It is apparent from the pollen analyses that the Grampians remained largely unforested for some considerable time after deglaciation, and that the dominant features of the vegetation cover were formed initially by open grassland, then by Empetrum heaths and later by juniper scrub. During this early phase prior to the arrival of birch forest, the landscape must have resembled that of an area like southern Greenland at the present day (Vasari and Vasari 1968).

However, within this overall framework, the records from sites so far analysed indicate a considerable degree of regional differentiation within the Postglacial vegetation pattern. In the northern and western areas represented by the diagrams from Loch Tarff and Loch Etteridge, the initial phase of open grassland soon gave way to a heath and moorland landscape dominated by *Empetrum*, with areas of *Vaccinium* and *Calluna*, and eventually with large expanses of juniper scrub. Although tree birch was present in the area, it seems likely that the establishment of birch woodland took place at a much later date than in the regions to the south and east. On the eastern foreland of the Grampians typified by Loch Kinord and by sites within the present study area, the early grassland phase was succeeded by a short period of *Empetrum* heaths, before juniper scrub and tree birch arrived in quantity. There is evidence in the form of macrofossil remains for the local presence of pine in the vicinity of Loch Kinord (Vasari and Vasari 1968 p. 77), but in view of the low percentages of *Pinus* in the pollen spectra at other sites, it is unlikely that pine enjoyed a wide distribution at this time. Finally, in the southern and eastern areas of the Grampians e.g. near Drymen and Loch of Park, the grassland and heathland phases were much more restricted, and the landscape was soon characterised by extensive areas of birch woodland. However, a more protracted phase of heathland development is recorded at the higher sites such as Lochan nan Cat and Loch Creagh (Donner 1962).

The most significant reference level in the succession to closed forest is the Juniperus maximum which can be found in all the early Postglacial pollen diagrams from Scotland. However, radiocarbon dates on this horizon suggest a variable rate of plant succession and landscape development in different parts of the Highlands, for there appears to be over 500 years difference between vegetational changes in southern Scotland and the northern Highlands. The following table presents the dates so far obtained on the juniper peak in northern Britain.

Table 3

Date of juniper peak	Site	Reference
10,275 ± 350 B.P. to 9750 ± 180 B.P.	Scaleby Moss, Cumberland.	Godwin, Walker and Willis (1957)
10,337 ± 200 B.P.	Din Moss, Roxburghshire.	Switsur and West (1973)
10,420 ± 120 B.P.	Callander, Perthshire.	Lowe (unpublished)
10,010 ± 220 B.P. to 9820 ± 250 B.P.	Loch Kinord, Aberdeenshire.	Vasari (unpublished)
pre 9085 ± 120 B.P.	Loch Maree, Wester Ross.	H. H. Birks (1972b)
9474 ± 160 B.P.	Loch Sionascaig, Wester Ross.	Harkness and Wilson (1973)

If the radiocarbon dates are correct, there appears to have been a progressive northward migration of juniper with peaks before 10,000 B. P. in northwest England and southeast Scotland, between 10,000 B. P. and 9800 B. P. in the Dee Valley, and at ca. 9500 B. P. in the northwest Highlands. However, the date at Callander seems to be out of sequence with the other five, for it is unlikely that juniper would reach a maximum in that area of the Grampians before the juniper rise at the more southerly lowland sites of Scaleby Moss and Din Moss. In a regional context therefore, the date of 10,420 ± 120 B. P. at Callander would appear to be erroneous. Similarly, there seems to be a discrepancy between the dates quoted above, and the age of 9140 ± 105 B. P. obtained from the juniper maximum at Blackness in the present study area. This date was one of a series from that site, and it has already been suggested that the other dates in the sequence appear to be too young. The regional vegetational trend outlined above endorses the view that the date is in error, and thus it appears likely that the maximum juniper development probably occurred some time before 9140 B. P. at Blackness.

Approximately 9500 years ago therefore, the Grampian landscape was one of birch woodland with willow and juniper scrub in the lowland areas to the south and east, while within the glens, occasional copses of tree birch were interspersed with large areas of juniper, with shade-intolerant heath and grassland communities on the upper slopes. To the north of the Highland watershed, the dominant vegetation cover was *Empetrum* heath, *Calluna* and *Vaccinium* moorland interspersed with patches of juniper scrub, and occasional stands of dwarf and tree birch. Apparently, these more northerly areas did not support a birch woodland until shortly before 9000 B. P.

Whether closed birchwoods ever existed in the Grampian area is difficult to establish, for if the assumption of Faegri and Iversen (1964) is correct that a non-arboreal pollen component of less than 10% of the total tree pollen indicates continuous forest, then few areas of the Highlands can be considered to have been completely covered by birch woodland during the early Postglacial. Closed birch forest probably existed around the south eastern margins of the Highlands, and in the south-facing glens, but it appears that the birch cover was sporadic with tree totals falling rapidly away into the uplands of the north and west.

Following the phase of open birch forest, the landscape underwent further change with the arrival of hazel in the area. It would appear from the records that hazel not only came to occupy the previously treeless slopes, but also moved into the birch and juniper woods where it proved fatal to the juniper which had earlier thrived under the open birch canopy and on the hillslopes. The warmth-loving hazel is indicative of much higher temperatures around 9000 B. P., and it became particularly well established on south-facing slopes of the Grampians where it appears to have developed as a canopy species within the birch woodland. The pollen diagrams from Gartmore (Donner 1957), Drymen, the Callander area and the uplands of western Perthshire all show very high percentages of <u>Corylus</u> which often exceeds 150% of the total arboreal pollen. Hazel values decline northwards, and are markedly lower in the regions to the north of the Highland watershed where levels of less than 40% of the total arboreal pollen are recorded for <u>Corylus</u> at Loch Tarff and Loch Etteridge. Similar low values are also found in the upper Dee Valley at Loch Kinord. The northward expansion of hazel must have been severely limited by cooler climatic conditions, and the vegetation cover in these areas continued to be characterised by birch, juniper and heathland plants, while the south and east presented a much more diverse landscape with birch and hazel woods as the dominant floristic elements.

The development of mixed forest was again a feature of the south and eastern Grampians, while the area to the north was characterised largely by pinewoods. The arrival of oak and elm heralded the decline of the hazel-dominated woodlands, a process which was further precipitated by the decrease in soil base status through progressive leaching. Mixed oakwoods became especially dominant in the Callander and Drymen areas, although birch remained an important landscape element, presumably occupying sites on the hillslopes which were unfavourable to the other deciduous trees. Further north, around Corrydon and Loch Kinord, the mixed woodland was further diversified by the arrival of pine which would have occupied areas of poorer, more acid soils, while the other tree species and elm in particular, were probably restricted to more favourable habitats on the valley floors. In the Spey Valley area of the northwest Grampians, the birch-hazel phase was succeeded by the spread of birch and pine woodland, with pine as the dominant tree species. The beginnings of the pine forest expansion in the northern Grampians has been dated at ca. 7000 B. P. (H. H. Birks 1970).

The rising values for Alnus which follow the establishment of woodland in the Highlands reflects a climatic shift from a rather continental type which had hitherto prevailed (especially in the east) to a more maritime one. This in turn led to a rise in water tables (Pennington et al. 1972) and an extension in areas of moist open ground which afforded suitable habitats for alder seedlings. Alnus had been present in small quantities in many areas before this time, but had been largely restricted to waterside localities by competition from other tree species. With the onset of wetter conditions, alder was able to expand at the expense of birch and hazel in the more southerly areas, and although its immigration into northern regions was restricted by competition from pine, sufficient moist habitats were to be found in the vicinity of Drumochter and Loch Etteridge for alder to form a mosaic in the landscape with pine and birch. This climax woodland then persisted almost uninterrupted until the arrival of Neolithic man in the Grampian region at around 5000 B. P.

Chapter 8

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH IN THE GRAMPIAN HIGHLANDS

The basic aim of the present study was to present an overall impression of the evolution of the physical landscape of a part of the Grampian Highlands during the Lateglacial and early Postglacial periods. However, from within this general framework a number of specific conclusions emerge, and these are set out below.

Firstly, the results of the investigation contribute significantly to the current state of knowledge on the timing of ice-sheet decay in Scotland. Of particular importance is the site by Loch Etteridge in which the basal sediments have been shown by radiocarbon assay to be at least 13,000 years in age. The location of this site in the heart of the Grampian Highlands strongly suggests that large areas of Scotland must have been free from glacier ice by 13,000 B. P., and in view of the marked environmental changes postulated on the basis of faunal evidence from other areas in and around the British Isles, total deglaciation by 12,500 B. P. would seem to be a conservative estimate. The presence of Lateglacial sediments in the Loch Etteridge site, and also in the basin at

Abernethy Forest, refutes the hypothesis that a body of ice remained in the Spey Valley area throughout the Lateglacial period (Sugden 1970), and raises serious doubts about the continued existence of a downwasting ice-cap in the Cairngorm Mountains during the milder Interstadial.

Secondly, the discovery of five sites which have been shown by pollen analysis to be Lateglacial in age, places severe areal constraints on the extent of the Loch Lomond Readvance in the central and eastern Grampians. The occurrence of Lateglacial sites in Glen Esk, Glen Clova, Glenshee and Glen Fender proves that all the ice-contact deposits in the lower glens relate to the decay of the Late Devensian ice-sheet, and hence the marked readvance limits which have been identified upvalley from the pollen sites (Sissons 1972, 1974; Sissons and Grant 1972) must presumably be of Loch Lomond Readvance age. The relationship between pollen sites and former ice limits is clearly demonstrated by the "paired" sites of Loch Etteridge and Drumochter. The former basin contains sediments which are Lateglacial in age, and lies beyond a marked downvalley termination in hummocky moraine which has been recognized as a readvance limit (Sissons 1974). The Drumochter site is situated in a large dead-ice hollow within the hummocky moraine, and as repeated borings in the basin revealed no trace of Lateglacial deposits, the morphologically-defined glacier limit must be related to the Loch Lomond Readvance.

Thirdly, the study demonstrates the value of assessing each site independently by dividing the profiles into individual pollen assemblage zones, before integrating the vegetational sequences into a regional framework. Important differences have been shown to exist in the pollen assemblages at all the sites, and the recognition of local palaeoecological characteristics is significant in the study of the spatial variation in the vegetation pattern through time. However, once the local pollen record had been established, it was possible to discern a vegetational succession for the region as a whole, and this was considered in terms of an Interstadial, a Stadial and a Postglacial period. This system was thought to be preferable to the classical pollen zones I/II/III etc. which have been applied in the past to totally different pollen assemblages in widely differing ecological and topographical areas, and which still carry what now appear to be totally erroneous climatic connotations.

Fourthly, the investigation illustrates some of the problems as well as the advantages of sediment analysis as a technique in palaeoenvironmental reconstruction. While it is clear that the study of the physical properties of the kettle hole sediments was of considerable value in elucidating former environmental conditions, the results of the chemical analyses were equivocal in that the trends in the cation curves which were obtained from the Lateglacial deposits at Loch Etteridge, Roineach Mhor and Tirinie are the reverse of those previously found in lake sediments from the Lake District and northern Scotland. Studies by Mackereth and Pennington have shown that the highest values for the cations Na, K, Mg and Ca were obtained from sediments of Stadial or early Interstadial age, while in the present investigation, maximum percentages of these bases were discovered in deposits of Interstadial and Postglacial age. Similar results to those obtained from the present study area have been found in lake sediments in Sweden where the accumulation of bases during apparently milder phases is attributed to progressive leaching on the slopes around the catchments, and a general trend towards soil maturity. In the absence of an alternative explanation, the present results are interpreted in the same way, but clearly considerable research is needed in order to establish why there should be such a discrepancy in results of chemical analyses between smaller, enclosed, eutrophic basins, and larger, oligotrophic lakes.

The present study raises a number of further points which are considered to be of some importance in the formulation of future research projects of a similar nature in the Grampian Highlands.

1) Although a considerable body of data now exists on the Lateglacial and early Postglacial environment in the Grampians, large areas remain relatively uninvestigated. Very few pollen diagrams have been produced for the region to the west and southwest of the present study area for example, nor is there much

information from the northern margins of the Cairngorm massif. The information which is available demonstrates the diachronous nature of vegetational development in the Highlands, particularly in the succession towards closed forest where stages such as the juniper peak may have been delayed by up to 1000 years in some areas. Thus, until a more comprehensive body of data is assembled, with important reference levels fixed by radiocarbon control, all future discussions on vegetational history must, of necessity, be highly generalised, and the correlation of pollen assemblages over wide areas will be misleading and often spurious.

2) Recent studies (e.g. Pennington 1973) have demonstrated the value of absolute pollen analysis as a technique in Quaternary palaeoecology. The measurement of pollen influx per unit volume of sediment is clearly more satisfactory than the expression of pollen frequencies on a relative percentage basis, as problems arising from differential pollen deposition and concentration rates, as well as statistical errors resulting from the percentage method are largely avoided. Moreover, with the addition of radiocarbon dates on critical horizons, it becomes possible to determine pollen input to the lake basin per year (e.g. Pennington and Bonny 1970). It is considered that all future pollen analytical studies undertaken in the Grampian Highlands should be based on the absolute method, as this technique may yield more valuable information on former environmental conditions, and also permits a more refined level of correlation between pollen sites.

3) More research is required along the lines advocated by H. J. B. Birks (1973) on the relationship of modern pollen rain to vegetation, particularly in respect of reconstructing former plant communities from data obtained through pollen analysis. In order that this may be achieved, much needs to be learned on the nature and form of pollen dispersal, and the factors which govern the accumulation of pollen grains in lakes and peats. Improved microscopy and identification techniques need to be developed which will allow more accurate identifications to be made, for at present it is still exceptional to be able to make a positive determination at the species level in fossil pollen spectra, and most pollen analysis is still carried out to the family and genus levels only. Until these methods become more refined, inferences on former climates and landscapes made from pollen records will be based more on intelligent speculation than on proven fact.

4) In general, the limits of former glaciers in the Scottish Highlands have now been fairly well established, but there is still a pressing need for increased radiocarbon control on the major glacial events. Of particular importance in the study of landscape evolution are the dates at which the Late Devensian ice-sheet and glaciers of the Loch Lomond Readvance finally decayed. In order to establish the timing of ice-sheet wastage, it will be necessary to obtain a number of radiocarbon dates from basal kettle hole deposits at sites which are of comparable location to Loch

Etteridge i.e. well into the heart of the Grampian Highlands. With regard to the Loch Lomond Readvance, the most profitable area for future research would seem to lie in and around the great basin of Rannoch Moor, which is considered to have acted as the major ice-dispersal centre for the Grampian area during the Lateglacial Stadial (Sissons 1967a). A number of sites in this locality with the basal sediments dated by pollen analysis and radiocarbon, would be highly significant in the establishment of the date at which ice finally disappeared from Scotland at the close of the Lateglacial period.

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APPENDIX A - POLLEN COUNTS - Blackness I

Depth (cm)	Betula	Pinus	Alnus	Ulmus	Quercus	Juniperus	Sorbus	Corylus-Myrica	Salix	Ericales	Empetrum	Hippophäe	Gramineae	Cyperaceae	Artemisia
75	95	4			1	9		12	29		3		78	63	
85	83	7				11		6	51		2		72	58	
100	85	7	2			23	3	2	11		8		94	44	
110	90	8		1		4	2	5	13	2	6		94	57	
120	90	6				13	7	1	8	2	13		55	84	1
130	77	3				21	5		7		12		63	93	
135	55	5				31	1		8	1	18		73	92	2
145	47	1			1	11	3		4	2	19		60	128	
155	50	6				13	5		3	1	19		81	95	
160	39	2				16			8	1	17		71	104	1
165	32	4				22	2		7	1	9		72	102	4
170	29	8				13		1	4	1	13		87	88	7
180	18	8	1			16			8		8		80	107	6
185	21	12	1	1		25		1	9		10		81	106	
190	25	4				11			6		7		85	118	6
200	18	4				13	1		15		7		78	98	3
210	23	1				29	1		15		15		73	103	
215	26	3				61			4		13		74	75	2
220	30	2				72		1	10	2	24		75	59	1
225	33	2				31			19		25		78	63	1
235	39	1	1			25	1		26	3	29		100	42	4
245	33					12			5		16		94	77	3
250	47	1				20		1	11		2		105	67	1
260	51	2				8			33		2		99	42	3
270	17	2				8			23		4	1	92	81	1
275	18	3				14	2		21	1	14	1	60	82	4
280	18	4				11			25		19		65	92	1
285	17	5				13			27		24	1	55	84	1
290	12	17	2			16			12		27		76	91	5
300	22	31	4			19	3	1	15		3	1	80	56	4
310	16	39	5			26			2		6		69	47	13
320	14	35		1		30			4		4	1	78	69	10
330	16	38	3			22			5		4		77	61	13
340	17	46	1			23		1	5		7		78	58	10
350	19	32	2			26			5		2	1	83	52	11
360	10	39	9			30							103	51	6

Blackness I (continued)

Depth (cm)	Caryophyllaceae	Chenopodiaceae	Compositae	Dryas	Epilobium	Filipendula	Galium	Helianthemum	Plantaginaceae	Polygonaceae	Potentilla	Ranunculaceae	Rosaceae	Rumex	Saxifragaceae
75	1					4								2	
85	1					1				4			2		
100						3		1	2			5	1	4	3
110			1				1	1				2	4	3	4
120			1			7							2	6	1
130			1			5			2			2	2	6	
135			2			2				1				6	
145	2	1	3		1	3	1		1			8	2	4	1
155		1				2				1	1	11	1	9	2
160	1	3	2		2	2		2	6	1		10		10	1
165			7			3		1		3	2	8		14	3
170	6	6	3			1	1	3	1	6		2		6	4
180	2	2	7		1	3	1	1	2	6		2	4	7	4
185	7					3		2	2			2		8	
190			4		1	2				2		5		11	3
200	10	3	8				1	3	3	10		7	3	1	4
210	2	4	11					6	3	3		3	1	2	
215	2	1	6					4	1	3		7		10	1
220	5	2				2	1	1				7		5	
225		1	6		2	2		1		1		17	1	12	
235	1		1			1			6	1		3		12	
245	2		2			4	1					34	1	17	
255						1						36		15	
260			2			8		3	4			12	4	26	
270						6	3	3	8	6		17		15	7
275	1		8			2		3		3		15	5	30	5
280			2		2	4	2			3		19	2	32	5
285	1	1	3			3	1	1	2	1		12		30	1
290		2	8		2	1				3		13	5	25	3
300	3	3	7	2				1	6	3		8	7	8	3
310	3	6	5	2		1		3	12	2		5	7	17	2
320	4	6		1		7		1	2	1			4	13	1
330	1	6	4			2		1	1	8		2	7	15	8
340		7	3					2	1	7			4	11	7
350		4	4			1		6	7	4		5	8	12	4
360		3								3			6	14	3

Blackness I (continued)

Depth (cm)	Succisa	Thalictrum	Umbelliferae	Urtica	Valeriana	Equisetum	Filicales	Lycopodium	Selaginella	Sphagnales	Myriophyllum	Potamogeton	Sparganium	Typha	Nymphaea
75						55	16			18	1	2			
85						46	22			7	1	1	2		
100				1		29	16			4	19	2	1		
110						16	5			3	14	4	1		
120		2		1			22		1	1	88	18	2		
130						2	2				141	5			
135				2			7			1	198	13	3	1	
145				1		4	8			1	288	10	2		
155				1			9	2	1	1	356	8	4		
160				2		1	3	5			239	4	1		
165				1		2	14	6	9	2	132	3	3		
170			1	8			17	1	8	2	110	6	4	1	
180	1	3		2		1	11		8	3	21	3	5	1	
185		1	2	4			33	8	6	1	141	4	1	1	1
190		6	1	1	1	2	21	2	5	3	111	6	3		
200		3		8			14	8	10	9	24	4	3	1	
210				4		4	17	2	10	1	67	3	7		
215		2	1	2		1	8			1	253	7	3		
220		4	2	1			19		4	2	387	1	2		
225		1	2	2		3	11			2	410	7	3		
235				2							677	3	2		
245				2	1	2	7				69	4	2	1	
255				1			3		1		23	1	11		
260		1	1	3			7	2			8	6	4		
270		3	1				14	2		1	17	6	6		
275		1	2	3	1	1	9			3	181	6			
280				1		2	14		1		98	4	7		
285		2		6		4	6		1	1	106	10	4		
290				1		17	9		1	3	69	1	1		1
300	1	2		1	4	3	12	7		4	17	1			
310	1	3		2		2	8	8		3	3	1	2	1	
320		5		4			7	5	5	5	11	4	2		
330							10	6	1	6	5	1	1		
340	2	1		3			6	2		11	3		2	1	
350	2			2	1		11	3		3	8		1		
360							10	7		12	20	9			

APPENDIX A - POLLEN COUNTS - Blackness II

Depth (cm)	Betula	Pinus	Alnus	Juniperus	Salix	Empetrum	Sorbus	Gramineae	Cyperaceae	Artemisia	Caryophyllaceae	Chenopodiaceae	Compositae	Epilobium	Filipendula	Galium	Helianthemum	Polygonaceae
157	24	1	1	10	3	2	1	19	33						1			
158	8	2		10	1	8	1	18	43	1				1				
159	12	1		11	3	5		16	42									
160	10	2		7	3	5		12	50									
161	15	1		11	4	5		12	40	1								
162	12	1		8		10		12	42		1				3			
163	14			16		4		14	41				1		1			
164	11	2		20	4	6		7	40									
165	13			18	1	3	2	9	40	3					2			
166	8			14	6	1		7	43	2	3		2		1		1	2
168	10	2		6		1		10	57	1								
170	9	1		8	5	5		20	41				2				1	
172	5	4		5	5			14	39	3	1	1	3					
174	5	1		6	4	2		14	38	5	2							
176	3	5	1	4	3	7		17	38	3	4	1	1					
214	7			4	3	5		9	39	3	6	1	8	3	1	1		
216	7	1		4	2	8		16	40	3	3		7					
218	9			2	2	10		11	44		2		4	1	1		4	
220	9	2		7	2	10		12	36		4		4				1	
222	8			6	3	6		13	37		4		4	1			4	
224	9	1		8	3	9		16	32	1	2		6	1			2	1
226	9	1		12	4	6		13	30		2		3	1	3	1	1	
228	10	2		15	2	7		18	24		2	1	3		1		1	
230	12			12	4	8		18	24				1		2	1	2	
232	16	1		14	4	7		23	14		1				1	2		
234	15	2		11	10	8		20	10				2				3	1
236	18	2		9	3	16		23	12				2			1		
238	20			6	5	18		26	9				1	1	2			

Blackness II (continued)

Depth (cm)	Plantaginaceae	Ranunculaceae	Rosaceae	*Rumex*	Saxifragaceae	*Thalictrum*	Umbelliferae	*Urtica*	*Valeriana*	Filicales	*Lycopodium*	*Selaginella*	Sphagnales	*Myriophyllum*	*Potamogeton*	*Sparganium*	*Typha*
157		1		1		1		2		2			4	75	8		
158		2		2						2				121	16		
159	1	1		5				3		3				90	6		
160	1		2	5				3		3			1	101	10		
161	1	1	2	4				2	1	1	1		2	108	2		
162		2		2			1			2				153	8	2	
163		1	2	4				3		1				118	4	2	
164		3		3				4		2		1		213	7		
165		3		4				1		1				83	7		
166		4		8			1	2	1	4	1	1		26		1	
168		4		3	1			2		2	2			76	2	2	
170		1	1	4				2				1		92	2		
172	3	9		5				1	1		1	1		75	4		
174	1	9	1	10				2		1	1	1		26	2		1
176		5		7				1		2	3	1		21	1	2	
214	1	2		6						5	3	1	2	7		2	
216			1	6	1			1		6	7	8	1	10		2	
218		1		5	1			2	1	6	4	4		9		3	
220		3	1	8			1			10	3	3		26		1	
222	1	3	2	4			1	1	1	8	5	9		28		1	
224		1	1	4				2	1	4	3	10	1	37		1	
226	1	3	1	5				4		3	2	1		65			
228	1	3	2	8						2		1		65			
230			1	11			1	3		2	1			38		2	
232		2		9		1	1	4		2				129		1	
234		6	1	13				3		1	1			123			
236	1	1		9				3		1				110			
238			2	2				3						277	2		

APPENDIX A - POLLEN COUNTS - Roineach Mhor

Depth (cm)	Betula	Pinus	Tilia	Alnus	Juniperus	Salix	Sorbus	Empetrum	Gramineae	Cyperaceae	Artemisia	Armeria	Caryophyllaceae	Chenopodiaceae
145	228	8		1	1	4		6	3	14				
150	112	12			39	32	1	17	23	43			1	
155	111	2			61	5		21	27	55			1	
160	79	5			61	7	1	18	45	65				
165	39	1			77	10	6	39	37	72				
170	26	5			41	10	8	87	60	42				
175	21	1			29	1	1	53	118	35				
180	13	1			8	7		8	65	178				
185	12	2			5	29			56	135	8		4	
190	10				3	14		2	10	124	13		7	5
195	13	6			1	33		1	3	193	10		15	1
200	8	2			1	124			10	142	2	1	1	
205	7	4			1	28		2	11	200	11		8	
210	9	3				130		2	6	116	13		11	
215	7	2			1	150		5	6	89	8	2	4	
220	11	6				59		3	7	180	8		9	
225	26	1			3	10		14	12	171	2		10	
230	21	7			2	18		12	20	144	9		22	6
235	28	6		1	4	24		12	51	108	2		5	1
240	25	3			7	26		9	56	108	3		4	
245	37	3		1	9	42		1	33	99	2		1	
250	15	3		1	11	81		7	30	77	7	1	1	1
255	8	7			3	20		12	39	103	1	1		
260	4	3			8	25		1	47	119	2		1	1
265	8	16		1		6		1	6	26	1			
270	2	16			1	11		2	12	21				1
280	7	13			1			2	21	23	2			1
290	3	15			4	5		1	20	19	3		1	4
300	6	24				5			28	12	2	1	2	
310	6	31				4		2	10	26	3		1	1
320	5	36	1	2	1				8	21	5		1	1
330	4	47						2	5	21	2		1	1
340	4	50		1		2		2	5	21			1	1
350	7	41		1		3		1	11	20	6			1
360	7	33		1	1	2		1	12	21	6		1	1
370	7	30		3		2		1	11	26	7		3	
380	6	39		5		1		1	10	18	1		3	2

Roineach Mhor (continued)

Depth (cm)	Compositae	Dryas	Epilobium	Filipendula	Galium	Helianthemum	Labiatae	Leguminosae	Plantaginaceae	Polygonaceae	Ranunculaceae	Rosaceae	Rumex	Saxifragaceae
145	1			16							1	1		
150				19							1	1		
155				11							2		2	
160	1			8					1		2		4	
165				6	1						2		7	
170				5	1				1		6	2	2	
175	1			1	1				1		11		18	
180			1	1	2						3	1	8	1
185	1	1	2	1		2					6	2	32	
190	1			1							1		10	
195	5		1			1					10	2	1	3
200											2	1	4	
205	3			1		2					9	2	5	4
210	2										1		6	1
215	4				1	1				2	2		9	
220	2	1			1		2				6	1		1
225	8		1	1		3	2	1		1	7	1	14	
230	7		2	2							6	5	11	
235	4		4	1	2	1	1				8	3	27	3
240	10		2	1		2					18	3	20	
245	1			1	1	5					38	2	20	
250	10		1	1		3	1				22	3	20	
255	14		1			4	1				37	2	41	3
260	9			5	1						28	1	41	
265	7		2								14	3	8	1
270	6		1			1			1		22		6	
280	7		2				1				17		3	
290	2										12		9	
300	1					1			1		5	3	9	
310			1			2					3	1	8	
320						2					6	2	9	
330	2										3	1	9	
340											3	2	7	
350	2						1				2		5	
360						2					3	1	6	
370											1	1	6	
380			1			1					5	1	5	

Roineach Mhor (continued)

Depth (cm)	Thalictrum	Umbelliferae	Urtica	Equisetum	Filicales	Lycopodium	L. selago	Selaginella	Sphagnales	Myriophyllum	Nymphaea	Potamogeton	Sparganium
145		1		1	270				42				
150					45				90	1			
155				3	12				6	1		1	
160		1		2	9				3				
165	1	3			8	1			2			1	1
170	1		1	57	9					3			
175	2		3	926	2						3	6	
180			2	3	4					105		1	
185		1	4		11			1		150		1	10
190	1			1	6	1		1		1			
195					2		1						
200	1				2	1							
205	2				9	1	2						3
210					8	1	1						2
215	1				4								1
220	2		1		6	4	3	1		2			1
225	4	1	4		24	1	3	1		5			7
230	2	2	2		30	6	1	4		9			4
235					15					8			5
240			3		23	5				74			15
245		1	3		21	2		1		50	1		23
250	1		2		16	2	1			16			20
255			3		16		2		3	33			17
260			3		10	1				62			8
265					12				4				3
270					6	1					1		9
280					7				1				6
290	2			2	6	1					1		2
300				3	1				1				
310			1		2	2			5	1			
320					2				1	1	1		
330	2				3	3			2				
340	1				2	2			2				
350	1				4	4			3				
360	1	1				1			5				1
370	2				4				4				
380	1				2	2			5				1

APPENDIX A - POLLEN COUNTS - Corrydon

Depth (cm)	Betula	Pinus	Alnus	Tilia	Picea	Quercus	Ulmus	Corylus-Myrica	Juniperus	Salix	Ericales	Empetrum	Gramineae	Cyperaceae	Artemisia	Caryophyllaceae
640	50	30	36			14	20	33	1	3	1		18	27		
650	49	14	43			19	25	49		5			11	5		
660	45	24	37			20	24	51		3	2		19	10		
670	45	41	40			10	14	36		6	3		17	24		
680	51	30	35			15	19	42		2	3		12	20		
690	49	45	31			12	13	38	1	6	2	2	15	25		
700	48	34	31			16	21	33	1	5			28	18		
710	50	31	32			17	20	37		4			21	16		
720	57	23	19			26	25	38		2	2		21	6		
730	48	45	19			16	22	43	1		3		22	15		
740	51	44	17			15	23	44	2	7			21	6	1	
750	59	37	18			16	20	55	1	4	2		23	10		
760	73	23	12			22	20	60	1	6			9	8		
770	71	36	13			17	13	59		9			14	13		
775	77	40	5			12	15	60		10	2		14	37		
780	66	48	4			15	17	57		3			11	17		
785	62	45	10			12	21	58		5	1		10	13		
790	75	43	5			9	23	64		4		2	9	6		
800	89	35	2			4	14	43		4	1	1	31	30		
810	102	26				3	19	101	1	7	2		14	4		
820	115	13	2			2	18	106		8		2	15	6		
830	117	12	1			2	16	119	3	5		3	16	28		
840	133	10					7	108	1	11		2	20	15	2	
850	142	3					5	108	1	12		2	5	18		
855	140	4				3	3	70		8	3	1	13	15		
860	145	3	2					11	8	20	1		14	12		
865	142	7					1	2	83	29		8	28	13	1	
870	66	5						4	90	20		17	51	19		
880	51	11	1					8	17	21		3	33	75	8	4
885	26	17	1	1			2	1	5	9		10	17	88	21	18
890	30	18						3	3	12		9	19	82	31	14
895	32	24	1					4	7	19		6	15	7	32	25
900	54	17	2				1	12	10	15	1	7	17	81	19	9
905	54	16	5					9	5	22			32	73	4	9
910	59	28	1					7	8	9		4	18	62	20	14
915	81	12	1				7	22	19	11		1	26	52	6	5
920	71	14	1				1	6	13	15		8	27	63	10	9
925	75	16						16	14	10		6	25	67	12	8
930	51	17						3	5	13		14	20	79	18	11
935	29	24							5	8		11	18	84	27	17
940	36	15						3	10	17	1	9	19	78	18	22
945	59	9	7				3	16	15	9		6	25	82	9	6
950	44	27						3	12	16		7	14	91	5	20
955	37	19	1					6	10	26	2	4	23	89	9	12
960	34	17	1			1		3	8	13		7	26	85	12	15
965	33	20					3	3	16	11		13	31	90	16	10
970	37	9	1					3	21	10		9	21	103	2	5
975	41	9	2				1	13	15	13		3	25	94	8	10
980	19	11						1	3	12		13	19	137	6	13
985	15	14							1	6	1	13	23	124	6	15
990	14	10						4	7	5		5	24	131	3	19
995	18	4	3					3	2	9		5	30	126	7	15
1000	16	11	2					4	5	6		7	23	124		12
1005	18	3	2					1	4	12		8	15	49	7	12
1010	8	7							2	4		5	10	146	2	17
1015	7	8							2	10		5	23	135	4	18
1020	4	8								4		5	16	143	3	12
1025	11	9	11			1			7	10		2	37	118		6
1030	13	6							18	11		8	36	115	3	3
1035	41	3	5					5	34	5	1	12	28	110		3
1040	22	2						1	11	6		8	30	99	4	9
1045	16	5	2						11	6		5	41	119	1	4
1050	12	10							10	9		5	32	120	2	7
1055	35	4	4						44	10		20	32	87		2
1060	23	2						1	17	24		23	37	105	5	2
1065	10	4							6	13		10	21	104	13	5
1070	9	4			1			1	3	8		6	18	79	16	18
1075	4	6						1	5	10		3	19	101	20	15

Corrydon (continued)

Depth (cm)	Chenopodiaceae	Compositae	Epilobium	Filipendula	Galium	Helianthemum	Labiatae	Leguminosae	Polygonaceae	Plantaginaceae	Ranunculaceae	Rosaceae	Rumex	Saxifragaceae	Succisa
640				21				1			7	2	1		
650				9			1				5	2			
660				19						2	5	6			
670				25							3	2	3		
680				17		1				2	7	4	2		
690				18							7	4			
700				22							2				
710		1		23						3	1	5	4		
720				16			1			1	5		7		
730				19						1	3	2			
740				16	1					1	6	5	4		
750				16						1	7	4			
760			1	20						1	7	3			
770				11						1	7	1	1		
775	1		1	7						2	6		1		1
780				16							10	1	4	1	
785				25						3	4	4	1		
790			1	13						4	6	1			
800			1	13						8	8	1	5		
810			1	15						5	7				
820		3	1	23					1	1	5		2		
830				14				1		9	4		2		
840		3	5	18			2			8	5		2	1	
850		4	4	12						2	1	4	3		
855				7			1			4	2	1			
860	1			11						1	1	2		1	
865				21						1		1	7		
870		2		7	2		1			4	1		7		
880	3	13	1	3			1		1	6	7		24		
885	7	26	3	2			4		2	4	6	1	22	1	
890	8	20		3	1	5	4			1	5	3	19		1
895	2	13		2						1	2		24	4	
900	2	6	1	11		1	1			2	2	5	16		
905		3	1	5			1		1	10	5	3	13	4	
910		20		7		1	1		1	1	1	1	5	1	
915	1	3		10	1					9	3	1	10	2	
920	5	11	1	14	1		1		2		8	2	8	1	
925	1	7	1	5	3	1	1		1	1	8	2	19	2	
930	3	23	2	11	2		2				7	3	10		
935	4	20	2		1	3			1	4	4		16	2	
940	2	24	1	8	2					2	7	2	13	2	
945		12		5	2					4	16	1	7	2	
950	2	29	1	3		1			1	2	6		7		
955	6	21		4		2	2		1	3	1	5	12	1	
960	2	29	1	3	1			1		4	10	1	16	1	
965	6	15	1	3	1				2	5	6	3	10		
970	1	18	1	9	2				3		3	1	3		
975		9		2		2	2			8	5	2	22	2	
980		27	3						4	1	7		10	1	
985	4	25	1	2		5	3		1	2	6	3	21	2	
990	3	31	5	4		1	1			1	13	2	14	1	
995	2	32	1	3	1	2		2	1	1	8	1	15		
1000	2	48	2	2	1					4	12	4	15		
1005		30		4		2			2	1	3	5	21	2	
1010	1	49	7	1	1						5		23		
1015	2	43		1			1				4	1	28	2	
1020	2	56	2	3	1	1					10	1	21		
1025	1	31		2					2	1	12	4	30	1	
1030		37		2	2	1			2	1	11	2	27		
1035	1	16		5	1		1		4		2	2	17		
1040	4	42		4	3	2			4	3	10	2	32		
1045	3	33	1	4			2		1		8	2	34	2	
1050	1	37		7		2			2	2	7	4	23	1	
1055	1	19		1		2	1		2	2	4		20	1	
1060		13	2	3	3				4	3	6	1	18	1	
1065	3	54			1				4	1	4	3	37	4	
1070		69	4	1	1		2		1	1	10	3	44		
1075	1	51	3	1	2						9	1	42		

Corrydon (continued)

Depth (cm)	Thalictrum	Umbelliferae	Urtica	Valeriana	Equisetum	Filicales	Lycopodium	L. selago	Selaginella	Sphagnales	Myriophyllum	Nymphaea	Potamogeton	Sparganium	Typha
640				1	3	122	2			1			3		
650						46					1	5	1		
660			1	1	1	73				1		2	5		1
670		1			1	113				2		2	2		1
680		2		3	2	103				2			4		
690	1	2			5	121				2		1	2	1	
700	1	1	1		2	83									
710			1	1	1	92						1	5		1
720					4	98	1			1			10		
730					5	113							3		
740		2			5	119						3	4		
750		1		3	10	89						1	12		
760					6	131				2		2	14		
770			1		3	152					1	1	8		
775					5	78	3			3		2	1	7	
780					3	115			1			2	10		
785			1		6	109				1		2	9		
790			1			102			1	1			1		
800		1	2		5	135				1	1	2	16	2	
810				1		141				4			1		
820					1	184	2			6			1	3	
830		2			11	169			1	7		1	2	2	
840		1			9	125	1			3			1		
850			1		2	35									
855					4	31							4		
860	1				1	24	3				2	1	2		
865		3		1	1	44	1				1				
870	1	2			1	72	2				2		2	1	
880	2	1	1		4	45	10		6	1			2	2	
885		1	1	1	1	85	26	4	11	1	2			1	1
890	6		3		1	59	16	4	10		3			6	
895	7	2	2			44	17	4	3	1	2			2	
900	3	1	1		1	45	10	1	5	3	2			3	
905	1	2				33	6		2	2	4	1	3	2	
910	3		1	5		42	12		5	1	1	3			
915				2	3	56	4			1			7	3	1
920	2		2	2		32	7		1			2	1	1	
925					2	77	12		1	1			3	1	
930				5		70	20	9	9	2	1			1	
935	6			7		65	31	4	6					7	1
940	6			2		71	21	5						4	
945	1		2		5	71	7		2		3		4	1	
950	5		1	3	1	51	21		4	2				4	
955	2		1	1		45	15	1	6	1	3			1	
960	3		1	3		67	31	1	4		1	1	1	5	1
965			1	1		16	58	1	7	2			1	5	
970				1	2	62	10	1	6		1	1		3	
975	2	1	2	2	3	70	14	2	6	6	6	1	5	2	
980	5			7		77	24	1	12					4	
985	2	2		3		66	37	11	26	1	1		1	8	
990	2		1	5		63	33	4	40		4		1	9	1
995		3	1	4	2	76	34	6	29				2	10	
1000					1	72	31	6	32		4			7	
1005				2	1	53	23	3	37	1	2		2	8	
1010	1	1	2	8	1	54	38	4	35		5	2		14	
1015				3		50	24	2	39	2	1	2		10	
1020	2	1		5	2	43	31	1	46	1	3	1		12	
1025					3	21	13		31		1		3	9	
1030			1	1	2	26	12	4	9					6	
1035	3		1		6	23	9		8	3	9	3	2	8	
1040				2	3	46	14	2	17	2				10	
1045	2	2		5	6	39	12		16		7		1	11	
1050	1	2			3	43	12		29		9	1		13	
1055	3	3			3	28	1		12	2	20	1		9	
1060	5	1	1		2	41	5		1		17	3	2	5	
1065	3					72	13			2		1	2	7	
1070				2		129	7	2	2		5			4	
1075	2		1	2	2	127	9	4	1		3		1	3	

APPENDIX A - POLLEN COUNTS - Tirinie

Depth (cm)	Betula	Pinus	Alnus	Quercus	Ulmus	Juniperus	Salix	Corylus-Myrica	Ericales	Empetrum	Hippophäe	Sorbus	Gramineae	Cyperaceae	Artemisia
230	89	10		1		8	52	25	2	2			29	406	
235	92	8				4	20	24		2		1	22	212	1
240	137	13				2	27	24					12	276	
245	132	18	1				23	45	1	3		1	21	240	1
250	133	16			1		43	32	1	4		1	38	222	2
255	133	16			1	2	10	12	2				16	130	
260	137	10			3	7	7	5				2	11	41	
265	146	4				2	14	4	1	1			14	50	
270	145	5				3	7	4	2	2		1	21	33	1
275	139	11				4	22	7	1			1	14	38	
280	148	2				1	15	2	2	2			10	40	
285	144	6				4	12	4					16	31	
290	145	5				8	13	2		4			15	13	
295	143	6			1	21	18	2		2			22	43	
300	146	4				18	15			3			25	32	
305	143	6			1	18	18			1			15	21	
310	148	2				54	17			1			33	32	1
315	147	3				56	22			1			21	24	
320	60	4				29	9		1	25			75	66	
325	58	7				9	9			20			75	83	2
330	45	10				15	6			21			77	89	2
335	36	5				19	11			21			83	75	
340	39	6				10	13			30			100	50	1
345	24	2				12	11			2			92	66	2
350	20	4				2	15			7			102	43	31
355	14	10				2	9			1			42	53	82
360	13	9				4	12			8			72	35	38
365	21	17				3	13			2			67	53	42
370	16	8				6	14			7			81	36	29
375	16	25				4	7			5			64	47	20
380	16	8				9	20			4			65	37	11
385	15	22				1	4			1			54	40	21
390	17	7				4	7			6			65	51	10
392.5	39	8				7	8			15			70	58	4
395	69	17				8	7			11		1	86	40	4
397.5	74	5				24	10			25			73	44	2
400	64	4				8	11			23			87	49	5
402.5	103	8				11	4			10			66	45	1
405	105	2				8	3			13			57	52	2
407.5	123	6				11	3			13			42	61	3
410	80	3				22	10			60	1		48	28	9
412.5	61	4				13	3			68			51	28	22
415	29	3				2	12			8			103	27	33

Tirinie (continued)

Depth (cm)	Caryophyllaceae	Chenopodiaceae	Compositae	Dryas	Epilobium	Filipendula	Galium	Helianthemum	Plantaginaceae	Polygonaceae	Potentilla	Ranunculaceae	Rosaceae	Rumex	Saxifragaceae
230						33	3					3		3	6
235		1				27	12					7	2	1	
240			1			22						10	4	2	
245						13	1					5	4	3	4
250						26	3		1			10	5	3	1
255	1	1	1			20	1				2	6	5		2
260						11				1		3	3		1
265						16		3				6	6	1	1
270		1				9						3	1	1	4
275	1		1			12					1	6	4	1	
280		1				16	1					4	4	1	3
285						15					1	5	3		
290						29						3	2	1	
295			1			25						1		3	
300						11						2	2		
305						14		1					1		
310						5						1	1	2	
315	1					11						3	1	4	4
320	2				1	1	1	1		3		10	2	6	4
325	1		1			5	2		9			7		12	
330	2				2	1			7			14		7	2
335	1	1	7		5	1		1	4			11	1	13	3
340	1	1	1		3	2	3		5		1	5	6	16	3
345	3	2	5		3	4	2		5		1	15	1	36	6
350	11	4	3	1	1	2	1	2	2			4	7	23	15
355	9	1	2		1	1	1					8	7	43	16
360	14	5	5			3		1				5	6	45	20
365	7	2										3	4	47	17
370	9	3	1	1	1	1	2					11	6	50	15
375	6		1			2	1			2		8	4	55	28
380	12	6	15	1	1	2	2	4	2	1		4	5	59	15
385	14	4	4			1	2	2				5	5	73	29
390	14	5	7	1	2		4	3	1			7	3	29	25
392.5	4		5		1	2	2	9	1			7	2	42	8
395	3	1	1		2	3	2	8	1			5	2	25	2
397.5						1		12	3			7	1	12	5
400	1	1	5			1	2	6				3	6	18	2
402.5			5			1	1	3	1			5	1	28	6
405	2	1	3			3	1	3				1		39	3
407.5						4	1	5	2			3		15	5
410		2	2		1			11				2	1	19	
412.5	1		1			3	2	4				1	2	32	4
415	1		2			1	2	2		2		4	5	53	10

Tirinie (continued)

Depth (cm)	Succisa	Thalictrum	Umbelliferae	Urtica	Valeriana	Equisetum	Filicales	Lycopodium	L. selago	Selaginella	Sphagnales	Myriophyllum	Potamogeton	Typha
230		1			2	2	47	1		4				
235						3	70			1				
240			2			5	40			1			1	
245			1			11	41	1		2			5	
250			1			5	75	2		2			10	2
255	1	1	2			28	65	1					1	
260					1	5	26							
265		1	2		1	11	43			2	1		2	
270			1			12	20						4	
275						6	22			2			8	1
280						3	14					1		
285						6	16			1			5	
290			2			14	14				1		1	1
295				1		7	32						2	
300				1		6	19						1	
305						2	6						7	
310						4	19				1		1	
315						2	20					2		
320			4			6	7	1						
325						13	15	2		2	1	1	2	
330	1			1		9	3			1				
335		1				22	9	1						
340	1	3		1		52	19			1	1	4		
345		3		1			2	1				23		
350							16	2		10	1	9		
355		3					1	6		20				
360		2					2	4		32				
365			1				9	7	1	16				
370		5				1	3	9		13		1		
375	1	1					1	11	1	38				
380		5		1	2		13	12		34		1		
385		3					3	18	2	66				
390	1	3			3	1	7	11		53				
392.5		2	1		2		7	1		19		1		
395		1			1	1	1	2		10	2	3		
397.5							1	2		2				
400		2		1	1	3	6	2		2	1	1		
402.5							5			3				
405			1				5	1		1	1	2		
407.5					3		4	1		1		3		
410							2	1						
412.5		1	1	1			5							
415			1			2	6	1				1		

APPENDIX A - POLLEN COUNTS - Loch Etteridge I

Depth (cm)	Betula	Pinus	Alnus	Quercus	Ulmus	Juniperus	Corylus-Myrica	Salix	Ericaceae	Empetrum	Sorbus	Hippophäe	Gramineae	Cyperaceae
480	42	76	24	5	3		16		4				4	6
490	44	69	28	5	4	2	16	1	4				2	7
500	28	92	19	8	3	1	11	1	8				4	7
510	34	92	15	3	6		13	1	3				3	3
520	49	78	13	5	3	2	13	1	4				5	5
530	38	92	12	5	3	1	29	4	4				10	6
540	44	95	6	4	1	7	17	3	3				3	1
550	46	94	3	4	3	7	38		1				9	8
560	72	67	3	3	5		16		2				8	6
570	103	28	12	2	5		28	5	1				4	4
580	125	12	7	4	2	2	38	5	3				6	8
590	135	3	2	1	9	2	42	2	1				2	11
600	141	2		6	1	1	51	5	2				10	7
610	133	6	4	5	2	1	48	2	3				8	2
620	138	2	2	4	4		48	6	6				13	18
630	145	2		1	2	3	54	4	2				5	7
640	141	4	1		4	9	31	7	8	1			12	11
650	146	3	1	1		4	4	11	3	5			16	6
660	149	1				45	2	12	4				55	22
670	142	5				148		20	65	43			138	42
675	44	4				29		9	12	42			84	45
680	40	9	1			10		9	5	6			75	67
685	13	9				8		14	8	3			34	46
687.5	27	5				12	1	15		14			22	41
690	23	4				12		14	5	24			42	56
692.5	26	5				11		10		43			30	69
695	29	4	1			12	1	7		60	1		47	81
697.5	38	2				23	2	8		41			30	84
700	71	8				26		5		47			28	72
702.5	76	3				30	1	6		71			40	47
705	45	4				13	2	3		72		1	54	47
707.5	61	2				26	2	3		130			22	39
710	49	1				9		3		145			38	31
712.5	54	1				11		6		163			15	27
715	36	4				11	1	1		162			16	30
717.5	33	1				5		9		147			18	38
720	30	2	1			11		9		127			27	37
722.5	29					8		9		102			36	28
725	30	2				10		22		36		1	30	63

Loch Etteridge I (continued)

Depth (cm)	Artemisia	Caryophyllaceae	Chenopodiaceae	Compositae	Epilobium	Filipendula	Galium	Helianthemum	Labiatae	Leguminosae	Plantaginaceae	Polygonaceae	Ranunculaceae	Rosaceae	Rumex
480						1							1		1
490						1							4		2
500						2					1		7		
510					1	1							2	1	1
520						1				1			5		
530													3		
540														1	2
550						2					1				
560						1					3		5	1	1
570				2							2		1	1	1
580						2					1		1	1	2
590						3					1				1
600				1											1
610													1	1	5
620				1		3					1		3	3	4
630						2									4
640				1											3
650						1		1							1
660				1		1								1	2
670						2					1	1	2	1	18
675	1	1		2									1	3	19
680	7	6		3	1	5	1				1	2	2	5	40
685	75	7		5		6	1	1		2	2	1	2	3	53
687.5	97	13		3		3	1						4	2	33
690	57	9	1	4		3				4			13	7	21
692.5	14	8	2	6							2	6	2	2	23
695	14	7	2	5							1	4	2	5	9
697.5	3	9	1	1		4					1	2	2	2	42
700	5		1	1		3	1						1	2	25
702.5	4					1						2	3	1	12
705	4	2		2			2					2	3	2	35
707.5	3						1				2	1			7
710	5			1		1	1	1				1		1	10
712.5	2	1												3	11
715	1	3		5		1		1				4	1		13
717.5	6			1		2	2					4		2	35
720	4	1		2		1							1	1	40
722.5	3	3		4			2						1	4	67
725	13	4		1		2	1		1					6	52

Loch Etteridge I (continued)

Depth (cm)	Saxifragaceae	*Thalictrum*	*Urtica*	*Valeriana*	*Equisetum*	Filicales	*Lycopodium*	*Selaginella*	Sphagnales	*Myriophyllum*	*Nymphaea*	*Potamogeton*	*Sparganium*	*Typha*
480			1		1	2			2			7	2	
490					2	3					2	2		
500						4								
510												2		
520				1		1			1					
530						3			1			2		
540						6			1		1	7		
550					1	4			1			3	1	
560					4	4						1	1	1
570									1			8		
580						6						4	3	
590						6					1	3		
600				1		5			1		1	3	3	
610				1		4			1			1		
620					1	18			2				4	
630						9			1				2	
640	1				2	4			3		1	1	1	1
650						5			1			3		
660			1		2	7				8		4		
670					2	22				5		5	2	
675		1		1		5				7	2	12		
680			2		3	5	2			1	1	4	2	
685	4			1	1	2								
687.5	3	1	2		1	10							2	
690	3					5	1							
692.5	4	5	1			16	5		1			2	6	
695	5		2	2		16	8			1		3	2	
697.5	3		2			11	7	1		2			2	
700	1		1			3	1	1		2			3	
702.5			1				1			3		1		
705	2	1	3			10			4				1	
707.5			2			7		1		2			1	
710	1					1				1			1	
712.5			4			1							2	
715	2	3	3			10							1	1
717.5	2		1		1	10				3				
720	4		1			5								
722.5			1		1	3	1		1				1	
725	12	1	2			5	1			4				

APPENDIX A - POLLEN COUNTS - Loch Etteridge II

Depth (cm)	Betula	Pinus	Juniperus	Salix	Ericaceae	Empetrum	Gramineae	Cyperaceae	Artemisia	Caryophyllaceae	Chenopodiaceae	Compositae	Dryas	Epilobium	Filipendula	Galium
690	7	10	2	9		6	7	10	24	1	1	3	1			
692.5	11	3		3		8	7	7	32	4		2				
695	12	4		2		10	3	9	34	3						
697.5	7	4	1	1		2	6	6	44	6	1		1	1		
700	7	5		3		9	10	3	40	3						
702.5	7	7	1			11	4	9	39	9	1					1
705	10	5	3	4		5	7	4	35	5	4					1
707.5	10	4				10	12	5	36	6					1	
710	14		1	3		28	5	11	14	1	1	1				
712.5	25		1	5		33	2	7	5	3						
715	26	2		1		18	5	19	2	3		1		2		
717.5	22	5	8	1		15	7	18				2				1
720	35			3		16	9	14				1				1
722.5	25	2	4	2		7	12	2		1					1	
725	17		3	5	1	45	3	13		1						
727.5	8		1	5		33	10	9	3		2			2		
730	10		1	14		8	6	18	2	1		2	1			

Loch Etteridge II (continued)

Depth (cm)	*Helianthemum*	Plantaginaceae	Ranunculaceae	Rosaceae	*Rumex*	Saxifragaceae	*Thalictrum*	Umbelliferae	Filicales	*Lycopodium*	*L. selago*	*Myriophyllum*	*Potamogeton*	*Sparganium*	*Typha*
690			2	3	19	2			1	1	1				
692.5	1		2	2	14	3	1		1	1					
695				1	18	2	2			1	1				
697.5			1		12	4	1	1		1	1				
700			3		12	4	1		1	4	1				
702.5			1		8	2			1	2	1				
705			2		12	1			2						
707.5				1	11	3	1		2	6					
710	1		5	2	9	4			2			1			
712.5			1		11	5	1	1		6					
715			3	1	15	2			1	4		1			
717.5			1	1	18	1				1			2	1	
720					5		1								
722.5			1		5	1				1					
725				1	9	2			1						
727.5			2	1	23	1			4		1				1
730			6		24	5	2		2	3		1			

APPENDIX A - POLLEN COUNTS - Drumochter I

Depth (cm)	Betula	Pinus	Alnus	Tilia	Ulmus	Quercus	Corylus-Myrica	Sorbus	Ericales	Empetrum	Salix	Juniperus	Gramineae	Cyperaceae
200	95	30	19			7	4		62	1	2	2	81	162
210	63	70	14			3	12		36	5	1		40	77
220	55	74	12		1	5	12		39		4		42	83
230	58	73	15		1	3	16		48		5		34	87
240	68	41	12	1		8	14		68	4	6		49	73
250	75	52	16			7	10		40		5	2	64	117
260	63	56	22		4	5	19		40		4		32	68
270	60	58	23		2	7	16		72	4	1		35	63
280	54	71	19		1	5	18		67	2	7		30	60
290	63	52	28		3	4	14		57	7	3		27	59
300	67	57	22		2	2	17		53		2		41	42
310	66	63	18		1	2	25		48		3		38	52
320	55	62	27		1	5	16		35		2	1	37	70
330	56	58	27		2	7	22		62	5	1	1	36	55
340	55	72	17		2	5	9		36	3	2		29	198
350	64	55	27			4	17		35		1		39	60
360	50	76	14		4	6	7		15		1		30	89
370	55	75	12		3	5	11	1	5		1	1	22	101
380	38	89	8		7	8	4		3				17	54
390	50	75	13		3	9	11		9		2	2	29	92
400	58	63	23		3	3	16		14		1	3	48	65
410	39	74	18		8	11	14		16	3	1	4	43	78
420	32	85	25		3	7	11	1	9	1		2	28	55
430	33	73	30		4	10	13	2	15	1	1	2	22	47
440	29	80	27		4	10	19		16	1		2	15	41
450	21	96	20		3	10	10		3		1	1	14	19
460	29	81	30		3	7	16		16			1	13	18
470	34	76	22		14	4	18		7	1	2	1	13	14
480	31	74	34		6	5	15		9	2	1	3	21	16
490	32	70	37		4	7	18		10		1	3	30	22
500	28	60	39		8	13	14	1	14		3	2	20	14
510	28	66	39		6	11	15	1	18		1	1	19	21
520	36	52	50		6	6	12		14		3	2	23	18
530	30	49	59		5	7	10		8	2			18	10
540	29	61	49		2	9	16		13		1		30	28
550	26	57	58		6	3	16		7		1		14	14
560	26	55	60		3	6	7		3	1		3	18	18
570	44	51	44		2	10	17		10	1	4	6	20	23
580	47	39	49		5	10	20	1	22		2	2	30	31
590	41	41	51		5	12	19	1	6		4	3	15	14
600	47	38	50		9	6	19		5		1		7	3
610	43	49	33		16	9	18		10		1	3	12	9
620	46	54	33		7	10	13		3		3		11	14
630	46	52	33		11	8	14		10		2	2	7	7
640	47	47	24		18	14	19		9				10	6
650	47	57	21		7	18	13		7			4	8	4
660	52	56	31		5	6	19		6		2	2	11	3
670	50	53	25		7	15	18		8	1	2	2	13	2
680	46	65	17		11	11	12		5		2	1	7	4
690	51	71	15		8	5	28		7		1	1	6	12
700	48	71	17		7	6	36		9		3	3	8	2
710	42	72	13		6	17	27		5		6	1	5	4
720	48	75	14		7	6	23		3			1	6	
730	63	66	4		9	8	33		6		3	1	6	3
740	59	70	7		9	5	25		7		3		8	9
750	82	51	7		2	8	42		7		5	14	9	8
760	85	40	5		10	10	20		12	4	3	2	14	9
770	87	39	12		5	7	34		15	2	7	2	7	2
780	102	22	8		5	13	29		18	2	2	4	5	10
790	114	15	7		10	8	47		11		6	2	7	2
800	118	7	10		8	7	40		11	1	8	2	9	3
810	124	4	5		13	4	59		8		8	4	8	14
820	135	6			5	4	33		4		6	4	10	2

Drumochter I (continued)

Depth (cm)	Artemisia	Caryophyllaceae	Chenopodiaceae	Compositae	Epilobium	Filipendula	Galium	Helianthemum	Labiatae	Plantaginaceae	Polygonaceae	Ranunculaceae	Rosaceae	Rumex	Saxifragaceae
200						5				3		9	1	2	
210						5				9		6	2	2	
220						3						4	2		
230						3				3		3	2	1	
240	1					5				12		10	2	1	
250	2					6	1	1	1	2		7	2	1	
260		1		1		4				4		11	3		
270				1		4				4		4	1	1	
280		1			2	2	2			5		6		1	
290						5	1			6		9	2		
300		1		1		8						2	2	1	
310		1		1		5				4		3			
320	1	1	1	1		8				6		5	3	1	
330					1	9				7		7	3	4	
340						8	2			5		12	5		
350		2				9				2		6	5	3	
360						2				2		7	3		
370	1					5				1		5	1	1	
380		1				3	1			2		9	1	2	
390						1				2		9	2		
400				1		1				1		7	1	4	
410	1			3		3				2		3	1		
420						2				4	1	8	1		
430	1					5				5		8	5	1	1
440						1				4	1	5	1	1	
450	1		1			1				1		3			
460						3					2	5	1		
470						3				4		1	1	2	
480						2				2		3			
490				1		3						5	2	1	
500						8				3		6	1	1	
510				1		4				1		9			
520				2		6				2	2	4	2		
530				3		4				2		3		3	
540				1		9						2	1	3	
550						3				3		3	1	2	
560					1	4					1	2	5		
570						3				2	1	3	3		
580						2				9	3	10		3	1
590				1		2				2		5	2		
600						1				2	2	4		1	
610						2						5	1	1	
620						4		1		2		4		1	
630				1		1	1				2	1		3	
640						3				1		13		1	
650				1		2				3		6		1	
660				2		4					2	4		1	
670						5						4		3	
680						2				2		4			
690										3		4	1		
700						2						2	1		
710						1					1	7	2	1	1
720				1								2		1	
730						3					1			1	
740						4				3		3	1	2	
750						2						6	3	1	
760					1	5					3	5		1	
770					1	1						1			
780					1	5				2		1		1	
790					1	3				1				2	
800		1			1	2				3		2			
810		1				3				2		1	2	2	
820				1	1	3		1			2	5		1	

Drumochter I (continued)

Depth (cm)	Potentilla	Succisa	Umbelliferae	Urtica	Valeriana	Equisetum	Filicales	Selaginella	Sphagnales	Myriophyllum	Nymphaea	Potamogeton	Sparganium	Typha
200	3	3				7	30		279			1		9
210		3					55		492		1		2	3
220	2	1			1		61	1	187	1				3
230	1				1		28		140				1	5
240		1	1			1	141		424				1	7
250						6	72		224		1	1	1	4
260	4	1	1				113		92	1		3	1	3
270		1				1	147	2	79					5
280							118		174					10
290						4	94		109			2	3	4
300		1				2	44	1	86					7
310		1	1			2	60	2	45					2
320	2						57		56					
330		2				2	130	1	96			2	1	
340						3	93		452					
350			1		1		210	1	70			2		
360	4					1	108		12					1
370	1	1	1	1			77	2	16	1		2		
380						1	70		2	6		4	1	
390						2	94		11	11		16		
400					1		125		14	12				
410		1		1	2	4	66		18		1	1	1	
420		2		1	1	1	55		25	2		12		3
430	2					4	36		28	2		3		
440							47		19	7		3	1	
450					2		44		3	10		4	1	
460			1				79		15	10	1	1	2	
470						1	66		12	10		2	1	
480						1	78		9	7		8	1	2
490		2	1			1	72		20	6	2	6	2	
500		2					103		14	4		8	1	
510				2			94		15	9		9	1	
520				1	2	1	80		12			8	1	
530				1		1	88	1	10	3		3		
540				1			108		19	4				1
550		1			2	1	106		14		2	5	2	
560			1		1		105		10	6	1	53	1	
570				1			54		10	2		76	4	
580			1	1	1		50		13	3		22		
590				2	1		29		2			2		1
600						5	37			3		49		
610				1	3	3	30		2			3	1	1
620		3	1		1		39		3			4		
630		1	1			5	44		3			41		2
640				3		2	34		1		1	10		
650						2	32		1			6		
660				1		7	35		2			4		
670	1			1	1	6	30		5					
680		1					46							
690		2				3	42		4			2		
700						3	11		4	1		2		
710							30		2			2		1
720					1	9	29		4					
730						5	21		2				2	1
740		1				3	38					1	2	
750		1	1		1	5	33		6	2		2	2	
760				1		16	77		4			2		2
770				2	1		31		2			1		1
780	1					1	27		1	1		2		
790			2		1	2	34		6			1		3
800						2	28		1		1			1
810							39		2	2		1		1
820	2					4	37		1					4

APPENDIX A - POLLEN COUNTS - Drumochter II

Depth (cm)	Betula	Pinus	Alnus	Ulmus	Quercus	Corylus-Myrica	Ericales	Empetrum	Salix	Juniperus	Gramineae	Cyperaceae	Artemisia	Caryophyllaceae	Compositae	Filipendula
760	56	47	24	11	12	15	11		2	1	5	7				
770	42	62	28	7	11	18	3			1	16	11				
780	41	74	19	6	10	27	7				6					
790	46	84	11	4	5	33	8		3		6	3				2
800	42	84	8	6	10	40	3		5	3	8	4				1
810	53	79	2	6	10	33	14		1		9	12				
820	51	89	1	4	4	32	5		2		8	7				
830	62	61	5	13	8	46	5		1	1	7	10				1
840	82	44	8	11	5	36	6	1	4	3	17	9				4
850	97	32	6	9	6	26	7	1	2	3	16	14				2
860	136	9		4	1	52	13	1	8	1	3	9				3
870	127	9	3	7	4	52	6	3	6	2	10	7				2
880	144	2		4		59	8	1	8	4	10	10			1	2
890	139	1		9	1	70	3		3	5	6	3				1
900	141	4		5		62	3		10	1	14	7				1
910	143	1		6		75	8		5	6	13	10				2
920	143	3		4		42	6		9	7	9	11		1		4
930	137	13				50	9	1	4	8	24	9		1	1	1
940	142	7		1		1	13	3	18	21	20	15	1		1	
955	124	16	3	5	2	18	5	3	6	13	13	5	1			5
960	134	12	1	3		8	4	10	8	29	36	27		1		3
965	134	13		2	1	21	2	2	7	28	23	8				3
970	139	7	1	2	1	9	12	7	5	24	29	28	1			3
980	133	10	3		4	13	9	6	7	10	15	19				2
990	139	15	3	2		4	2	4	14	12	24	25			1	3

Drumochter II (continued)

Depth (cm)	Galium	Helianthemum	Plantaginaceae	Ranunculaceae	Rosaceae	Rumex	Thalictrum	Umbelliferae	Urtica	Equisetum	Filicales	Sphagnales	Myriophyllum	Nymphaea	Sparganium	Typha	Potamogeton
760				8						1	22		1			1	1
770				2	1				1		26	3			3		1
780				6	4					3	15	3					3
790					4	1				2	11	5					4
800				6		1				1	17	1		1			
810				3	1					1	6	2					1
820				4		1					28	1			1		
830				4						1	56		2		2		
840				2							50	1	2		1		
850			2	2	1			1			47	1		1	1		1
860		1	1	2							31	4				4	1
870			1		1						18	3			1		
880				5	4						49				1	2	1
890			2	1	1						51	1			2		
900				2	2	1				1	47	3				1	
910				3	1	3					25	2			2		
920				2	3						23	2	1		2		
930				4	2						35	3				1	
940					1	2	1	1	1	2	43				3		
955							1				63				1	1	
960	1	1		2		1	1		1		47				3		1
965	1			1	2	2				1	65	2			1		
970		1	1		1	6					56		2		3		
980				1		4					25	4	1		5		1
990					2	3	3	1		1	47	2			4	1	

APPENDIX B

RESULTS OF PARTICLE-SIZE ANALYSIS

Sample depth (cm)	Sand (>0.02 mm)	Medium silt (0.02-0.006 mm)	Fine silt (0.006-0.002 mm)	Clay (<0.002 mm)
Loch Etteridge II				
690	33.4	28.2	9.4	30.0
695	21.4	30.0	15.0	23.6
700	43.2	27.6	4.0	25.2
710	19.7	33.0	19.6	27.7
715	22.4	33.4	9.8	34.2
725	34.8	22.8	4.0	38.4
730	45.4	24.2	9.0	21.4
733	55.8	19.6	1.6	23.2
735	51.4	23.0	1.4	25.2
Roineach Mhor				
190	50.0	17.4	1.0	31.6
205	58.4	4.4	3.2	34.0
210	56.4	6.0	2.2	35.4
230	58.4	2.8	1.8	27.0
240	22.6	24.2	15.4	37.8
260	10.6	32.2	17.0	40.2
270	17.2	31.2	13.4	37.8
300	10.6	24.4	14.2	40.8
320	12.8	29.4	16.6	41.2
370	0.6	28.0	16.8	54.6
400	2.6	25.0	21.0	51.4
420	4.6	24.6	18.2	52.8
460	0.4	25.8	20.8	53.0
Tirinie				
320	39.6	24.0	13.0	24.4
330	47.6	22.6	11.8	18.0
340	34.2	28.0	11.6	26.2
350	39.6	28.4	13.6	28.4
360	38.1	26.1	11.6	26.2
370	33.4	29.4	11.0	25.6
380	41.4	26.0	10.4	22.2
390	44.6	27.6	10.2	17.6
400	27.2	21.0	19.0	32.8
407	35.6	18.4	16.8	29.2

APPENDIX C

ORGANIC CARBON CONTENT

Sample depth (cm)	Organic carbon (%)	Sample depth (cm)	Organic carbon (%)
Loch Etteridge II			
690	3.3	715	4.3
695	3.3	720	7.0
700	3.5	725	4.8
705	2.2	730	1.3
710	2.0	735	0.4
Roineach Mhor			
150	25.0	290	0.6
170	26.0	300	0.3
190	1.7	310	0.2
200	1.8	330	0.2
205	0.6	350	0.1
210	1.6	370	0.2
215	0.8	390	0.2
230	0.4	410	0.2
240	1.3	430	0.3
250	0.9	450	0.3
260	1.2	470	0.3
270	1.2	490	0.4
280	0.5		
Tirinie			
320	5.4	375	5.0
325	5.1	380	2.6
330	5.2	385	4.9
335	5.0	390	3.1
340	3.2	395	10.2
345	3.8	397.5	6.7
350	5.8	400	9.3
355	7.9	405	6.3
360	4.2	410	4.3
365	7.0	415	3.6
370	4.3		

APPENDIX D

RESULTS OF ALKALI CATION DETERMINATION
(expressed in milliequivalents per 100 gm sediment)

Sample depth (cm)	Na	K	Ca	Mg
Loch Etteridge II				
690	0.883	0.340	2.275	2.300
695	0.898	0.322	2.530	2.010
700	0.852	0.322	2.275	1.870
705	0.852	0.340	2.530	1.870
710	0.959	0.376	2.800	1.870
715	0.883	0.358	2.800	2.010
720	1.065	0.376	3.150	2.370
725	0.974	0.394	3.150	2.590
730	0.853	0.286	1.750	2.010
735	0.715	0.179	1.310	1.290
Rhoineach Mhor				
150	2.320	0.430	15.750	9.210
170	1.830	0.540	0.175	16.110
190	0.520	0.130	0.175	1.000
210	0.590	0.290	1.400	1.730
230	0.530	0.160	4.380	1.580
250	0.700	0.490	4.560	3.310
270	0.680	0.490	3.500	3.310
290	0.680	0.510	3.150	3.310
310	0.600	0.360	2.100	2.450
330	0.590	0.350	2.100	2.370
350	0.600	0.250	1.400	2.160
370	0.840	0.490	1.400	2.560
390	0.840	0.490	0.700	2.300
410	0.700	0.490	1.050	2.010
430	0.850	0.540	1.050	2.300
450	0.860	0.510	0.700	2.300
470	0.940	0.670	1.140	2.520
490	0.810	0.580	4.560	2.300

APPENDIX D continued

Sample depth (cm)	Na	K	Ca	Mg
Tirinie				
320	3.800	0.179	112.7	12.380
325	4.100	0.179	119.7	13.530
330	3.900	0.179	112.0	14.390
335	3.800	0.143	112.0	14.970
340	3.900	0.143	117.6	18.420
345	3.000	0.322	107.8	18.990
350	3.600	0.179	112.0	5.760
355	1.300	0.537	45.5	5.180
360	1.200	0.445	30.1	4.890
365	1.200	0.445	24.5	5.180
370	1.200	0.358	24.5	5.470
375	0.900	0.322	24.5	4.030
380	0.800	0.250	21.7	3.450
385	0.900	0.322	23.5	3.160
390	1.200	0.268	26.6	4.600
395	2.100	0.358	101.5	6.330
397.5	3.300	0.179	122.5	11.800
400	3.800	0.322	133.0	13.530
405	3.300	0.214	124.0	10.940
410	3.300	0.179	122.5	13.810
415	2.300	0.393	105.0	10.940

APPENDIX E

DETERMINATION OF TOTAL CARBONATE PERCENTAGE

TIRINIE

Sample depth (cm)	%$CaCO_3$
320	83.54
330	71.91
340	84.17
350	84.60
360	00.11
370	00.04
380	00.02
385	00.00
390	01.90
400	78.89
407	63.03

(*Reprinted from Nature Physical Science, Vol.* 244, *No.* 135,
pp. 75–77, *July* 30, 1973)

Loch Lomond Readvance in the Grampian Highlands of Scotland

IT has long been recognized that, following ice-sheet decay, glaciers developed on a much more restricted scale in parts of the Scottish Highlands and Southern Uplands. Yet little detailed investigation of the limit of this readvance has been carried out. Here we summarize evidence for the limit from a large area of the Grampian Highlands based on detailed stereoscopic examination of vertical aerial photographs followed by field mapping. In Fig. 1 we show the readvance limit generalized from maps at much larger scales.

The best morphological evidence for glacier readvance is provided by end moraines, which mark the limit in various localities in the Grampians but are absent from the remainder of the area covered by Fig. 1. On the hill slopes around the southern part of Loch Lomond an end moraine was traced continuously or intermittently for 40 km by Simpson[1]; the Menteith moraine in the Forth valley extends continuously for 20 km. An arcuate end moraine in the Teith valley near Callander has kame terraces pitted with kettles on its upstream side while down valley from the moraine outwash terraces lacking kettles extend for many kilometres. On the slopes of the Rannoch valley several sub-parallel lateral moraines occur, the outermost extending intermittently for 30 km and attaining a maximum height of 30 m. This moraine slopes down eastwards through 350 m in 12 km and where it reaches the valley floor, at the eastern end of Loch Rannoch, a large outwash spread begins.

Farther east in the Grampians end moraines are smaller and shorter but are nevertheless often clear features. They are most common in corries and near the head of small steep-sided valleys and sixteen examples have been mapped in such locations. They vary in height up to 10 m and in length up to 2 km and are sometimes composed entirely of boulders. In glens Clova and Muick end moraines can be followed intermittently for several kilometres.

Within the end moraines in the Highland valleys there often occurs a distinctive moundy terrain which, where well developed, covers areas of several square kilometres and comprises hundreds of closely spaced boulder-strewn hummocks. This characteristically fresh hummocky

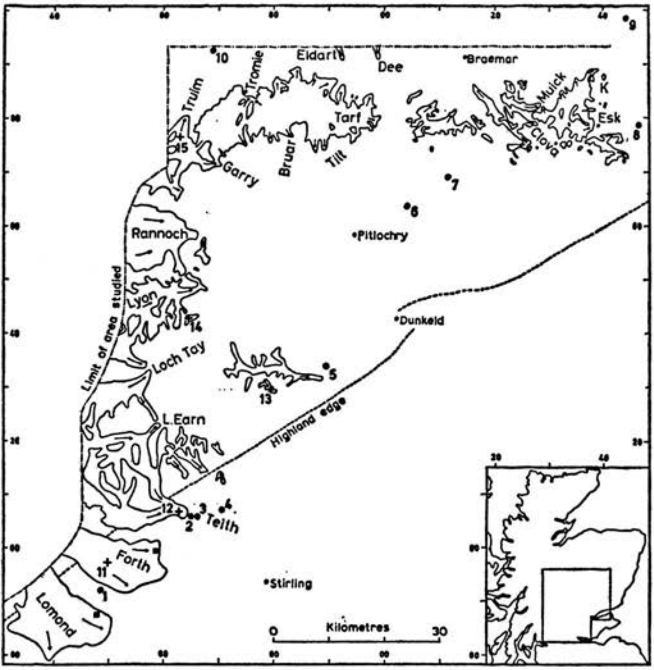

Fig. 1 The limit of the Loch Lomond readvance and related pollen and radiocarbon sites in the Grampian Highlands. ——, Limit of readvance; ●, lateglacial pollen sites; +, postglacial pollen sites; ■, radiocarbon sites; L, Lochnagar; K, Mount Keen.

moraine does not occur outside the end moraines. It does occur, however, in many valleys where end moraines are absent or feebly developed. Further, it often ends suddenly when followed down these valleys and outwash terraces frequently begin at or within its termination. Within the limit of the hummocky moraine the outwash terraces may be kettled but outside the limit they lack kettles. Such relationships, which suggest the former limits of glacier tongues, are well displayed in the Dee and Eidart valleys of the southern Cairngorms, in several valleys south of Braemar, in the Tarf valley, and in glens Esk, Garry, Truim, Tromie and Lyon. In Glen Muick outwash is absent—the hummocky moraine terminates in Loch Muick—but the lateral limit of mounds rises rapidly up valley, whereas in Glen Dochart the mounds terminate at the western end of Loch Tay. In many other valleys not named on Fig. 1 (such as Glen Tanar in Aberdeenshire;

glens Mark, Effock, Doll and Caenlochan in Angus; glens Diridh, Mhairc, Errochty, Lochay, Turret and Artney in Perthshire) there is a similar abrupt ending to the hummocky moraine and this is usually associated with outwash terraces.

Systems of very small meltwater channels (typically less than 4 m deep) are intimately associated with the hummocky moraine, especially in the central and eastern Grampians. As this moraine is followed up valley towards higher ground it dies out but the channel systems continue into the higher ground, implying that the former ice tongues inferred from morainic evidence existed contemporaneously with ice on this higher ground. The very small channels are best developed in the area between glens Truim and Tilt, where hundreds are cut into the undulating summit plateau at altitudes of 700 to 900 m and point to the former existence of a plateau ice cap.

The survival of these small channels at high altitudes means that no significant down-slope movement of debris has taken place since they were formed on the ground in which they occur, for most of them run along hill sides and some are as little as 1 m deep and 2 m wide. Yet on some other areas of high ground (and in places down to altitudes of 600 m) there are large solifluction sheets with fronts up to several metres high and major solifluction lobes composed of boulders up to a metre or more across. Because it is generally accepted that such large periglacial features are fossil[2–4] the most probable explanation of this contrast is that these features were formed contemporaneously with the glacier readvance inferred from moraines and related evidence. In accord with this, on Mount Keen and Lochnagar, where granite bedrock has favoured the development of great numbers of major boulder lobes, such lobes are completely absent within the corrie and valley end moraines but abound immediately outside them[5,6]. Thus major solifluction forms constitute additional evidence that helps in delimiting the readvance.

This evidence points to the former existence of much larger glaciers in the west than in the east (Fig. 1). In the west the ice extended beyond the Highland edge as piedmont tongues in the Loch Lomond, Forth and Teith valleys. The glacier in Glen Dochart was 22 km long whereas that in the Rannoch valley was up to 12 km broad and attained a depth of 400 m. Although the ice cap in the central Grampians between glens Truim and Tilt had an area of nearly 300 km^2, it was relatively thin and its outlet glaciers terminated in the valleys cut into the plateau or extended only a short distance beyond the plateau edge. Farther east a much smaller ice cap was situated on the plateau between glens Clova, Muick and Esk. In the east only two glaciers had a maximum thickness of more than 200 m and the longest was only 9 km, whereas small (0.5 to 2 km) glaciers occupied corries and certain valley heads.

To test the hypothesis that this morphological evidence relates to the Loch Lomond readvance, we carried out detailed pollen analyses for nine sites. The alternative method of radiocarbon dating organic material from moraines or related deposits is not practicable because no such material, other than marine shells, has been found. Marine shell dates are available from the Menteith moraine in the Forth valley and from near Loch Lomond[7] and confirm Donner's conclusion based on pollen studies that glaciers in these two areas advanced during pollen zone III (*sensu* Godwin), that is between about 10,800 and 10,300 radiocarbon yr ago on current evidence.

Donner[8,9] found that at a site inside the Menteith moraine (11 ; Fig. 1) deposition did not begin until pollen zone IV of the early postglacial. But at two sites outside the moraine (1, 4) a suite of sediments that could be correlated with the traditional pollen zones I, II and III of the lateglacial sequence was followed by postglacial deposits. We adopted this approach, involving sites inside and outside the mapped readvance limit.

Six sites outside the limit were studied. All are infilled basins containing up to 13 m of sediment. This usually consists of a considerable thickness of postglacial peat and lake muds underlain by the three-fold lateglacial sequence of clay, organic mud (gyttja) and clay. Site 5, however, has a pure clay profile below the postglacial sediments. Pollen counts of at least 300 grains (excluding aquatics and spores) were made at each level studied in the lateglacial deposits (except at site 5) and the following generally defined assemblage zones are recognized.

(a) An early postglacial *Betula-Juniperus* zone. This assemblage characterizes the early postglacial at every site investigated and is marked by a prominent *Juniperus* peak (15 to 45% of total land pollen) with significant quantities of *Betula, Salix* and *Empetrum*. This assemblage has been widely reported in pollen diagrams from NW Europe and is regarded as an important reference level indicating rising temperatures and a transition stage in the development towards closed forest[10].

(b) A zone dominated by herbaceous pollen and coinciding with the upper clay deposit which accumulated in the basins during the colder climate of the stadial (pollen zone III). The low values of arboreal pollen and the prevalence of species associated with disturbed soils (especially *Artemisia*) testify to the severity of the climate at this time. *Artemisia* is particularly common at the higher sites, reaching 33% of total land pollen at site 10. This *Artemisia* assemblage has been widely recognized in northern Britain[11,12].

(c) A zone characterized by more thermophilous species, notably *Betula, Juniperus* and *Empetrum* at the higher sites and *Betula* (including many tree birch), *Juniperus* and *Filipendula* in lower areas. The accumulation of predominantly organic muds in the basins during this pre-stadial (zone II or Alleröd) phase indicates virtual stability of the landscape and cessation of solifluction. The early part of this zone (conventionally interpreted as pollen zone I) is represented by clay and clay muds which grade upwards into pure organic deposits. The pollen assemblage suggests a pioneer vegetation characterized by *Salix* cf. *herbacea* and *Rumex,* whereas the presence of *Artemisia* in small quantities indicates an initial period of soil instability.

It is possible to interpret these vegetational changes in the traditional terms of a cold pollen zone I, mild zone II and cold zone III. On this scheme the I/II boundary is dated at about 12,000 yr BP. Using sites in western Britain, however, Coope and others[13–15] have concluded from coleoptera studies that the period of maximum warmth was reached during the later part of zone I, while Pennington and others[11,12], from pollen, chemical and diatom evidence, suggest that milder interstadial conditions began perhaps 1,000 yr before the onset of classical zone II. It is therefore preferable to refer to a cold stadial (previously termed zone III) preceded by a milder interstadial.

These vegetational changes are common to all six sites investigated by us (2, 3, 5, 7, 8, 10 ; Fig. 1). The general zonation is also applicable to the diagrams of Vasari and Vasari[16] (1, 9) and is partly represented in the incomplete diagrams of Donner[8,9] (1, 4; Fig. 1). Together with data from an unpublished lateglacial site (J. M. Dickson, personal communication ; 6, Fig. 1), this evidence imposes severe areal constraints on possible Loch Lomond readvance limits, especially as some of the sites are located in the interior of the Highlands.

At five sites within the mapped limit of the readvance, pollen studies have been carried out with the specific object of testing the hypothesis that lateglacial deposits are absent. Donner[8,17] investigated sites 11 and 14, the last being located in a corrie at an altitude of about 700 m. At both these sites the earliest recorded assemblage suggested a zone IV

Table 1 Pollen Sites

Map reference No.	Reference	National grid reference	Altitude (m)
	Lateglacial pollen sites		
1	8, 16	NS/490923	210
2	*	NN/658051	60
3	*	NN/665048	60
4	9	NN/705072	210
5	*	NN/895338	300
6	‡	NO/041639	260
7	†	NO/132674	330
8	†	NO/463786	230
9	16	NO/435997	160
10	†	NN/688929	300
	Postglacial pollen sites		
11	8	NS/500976	90
12	*	NN/627067	80
13	*	NN/799294	350
14	17	NN/649425	700
15	†	NN/629762	450

* J. J. L., unpublished.
† M. J. C. W., unpublished.
‡ J. H. Dickson, unpublished.

age. Sites 12, 13 and 15 have been studied by us. The basal pollen assemblage zones at sites 12 and 15 compare favourably with those found by Donner and comprise a *Betula-Juniperus* zone (with some *Salix* and *Empetrum*), followed by a *Betula-Corylus* zone, succeeded by a mixed forest zone. At site 13 the earliest recognizable zone is the *Betula-Corylus* zone.

The sites inside the readvance limit provide only negative evidence, for it may be argued that the deepest part of a site was not located or that the onset of accumulation was delayed. But we suggest that the five pollen sites inside the limit and the ten outside it together constitute significant evidence when considered in relation to the mapped ice limit (Table 1).

A further consideration is particularly relevant. The radiocarbon dates from the Loch Lomond and Forth valleys confirm that large glaciers existed here during the stadial, at which time large ice tongues existed in Mull[18] and at Loch Creran[19] on the west side of the Grampian Highlands (shown by radiocarbon dates on marine shells). It may therefore be inferred that glaciers existed in many other parts of the Grampians at this time. The lateglacial pollen evidence proves that these glaciers could only have existed farther into the mountains than the sites themselves. In this more mountainous ground the morphological evidence described above indicates a limit of former glaciers over an extensive area. Further, there is no evidence for any other glacier limit over this area. It is thus very difficult to avoid the conclusion that the mapped limit, shown in Fig. 1, represents the limit of the Loch Lomond readvance.

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Received May 7, 1973.

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Printed in Great Britain by Flarepath Printers Ltd., St. Albans, Herts.

(Reprinted from Nature, Vol. 249, No. 5460, pp. 822–824, June 28, 1974)

Late glacial site in the central Grampian Highlands

THE last British ice sheet probably reached its greatest extent 17,000–18,000 radiocarbon yr ago, when it covered much of the British Isles. We suggest here that this ice mass had disappeared 5,000 yr later. Significant new evidence comes from Loch Etteridge in the heart of the Grampian Highlands of Scotland (Fig. 1).

Loch Etteridge (grid ref. NN688929) lies in a deep kettle hole bordered by eskers and kame terraces at an altitude of 300 m, in upper Strathspey. The deepest accessible part of the kettle infill was sampled using a piston corer with a chamber 50 cm long and 5 cm in diameter. Seven metres of peat and gyttja overlie a typical late glacial sequence comprising organic deposits between minerogenic deposits (Fig. 2). Pollen analyses of the late glacial and basal postglacial deposits were carried out at 2.5-cm intervals. Samples for radiocarbon dating were obtained by combining material from four bores put down at the corners of a 30-cm square. This was possible because of the well defined stratigraphy, and was facilitated because the full sequence (Fig. 2) was obtained in a single chamber in each bore.

A date of 9,405 ± 260 yr BP (SRR-301) was obtained for the basal 4 cm of the postglacial organic deposits. The pollen spectrum is dominated by *Artemisia*, which exceeds 30% of the total land pollen, whereas values for woody taxa are less than 10%. Immediately above the dated sample, open habitat taxa decline markedly and pollen of woody plants increases. The radiocarbon date is much later than the date of approximately 10,300 yr BP which is conventionally assigned to the end of the Loch Lomond Stadial. In Skye, however, the cessation of minerogenic deposition varies considerably in different lochs, and the youngest date relating to this event is 9,420 ± 150 yr BP (ref. 1). Protracted minerogenic deposition at Loch Etteridge may be related to its altitude and to its location 8 km from the margin of a plateau ice cap which covered nearly 300 km^2, and which is considered to have developed during the Loch Lomond Readvance[2].

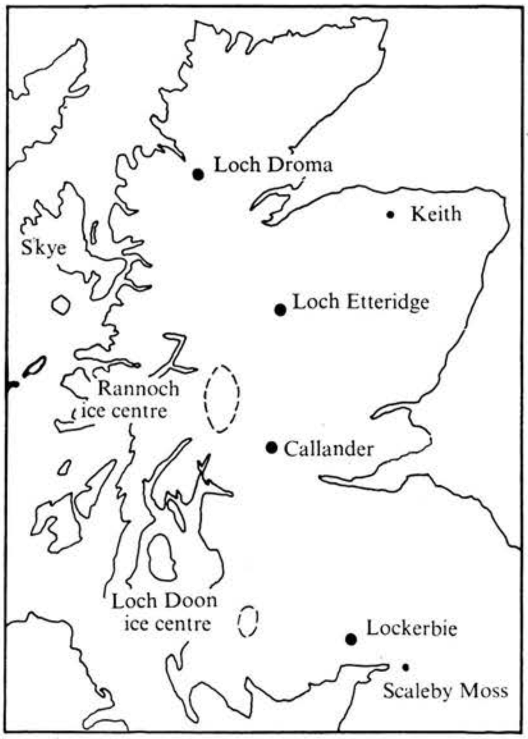

Fig. 1 Locations referred to in the text.

At the top of the Late Glacial interstadial deposits the pollen spectrum is characterised by woody plants, especially *Empetrum* and *Betula* c.f. *nana*, but *Artemisia*, Saxifragaceae and *Rumex* are also significant. In the overlying clay, pollen of woody plants declines and that of open habitat taxa increases. The top 1.5 cm of the interstadial deposits gave a date of 10,764 ± 120 yr BP (SRR-302). This accords with the value of 10,800 yr BP generally accepted for the beginning of the Loch Lomond Stadial, indicated, for example, by dates from Keith in Banffshire and from Scaleby Moss in northern England[3]. It has been inferred that at about 10,800 yr BP minerogenic deposition (implying solifluction on surrounding slopes) began at sites in Skye[1]. It therefore seems that at this time temperatures fell, probably rapidly, over a large area. It does not follow, however, that the glaciers involved in the Loch Lomond Readvance began to build up at this time.

Studies of Coleoptera at sites in England, Wales and the Isle of Man, suggest that a fall of temperature began before 12,000 yr BP and continued until the end of the Late Glacial interstadial[4], by which time mean July temperatures were probably 4°–5° C below present values. The interstadial climate may have been moderately continental, with winter temperatures depressed even more below present values[4]. For glaciers to develop on Ben Nevis a fall of more than 2° C in the present mean summer temperature is required[5]. Combining these figures it seems that the Loch Lomond Readvance began before, perhaps well before 10,800 yr BP. It can also be inferred, in view of the varied relief of Scotland and the marked gradients of former snow lines, that glaciers began to develop at different times in different places.

At the base of the more organic interstadial deposits, the pollen spectrum is dominated by *Empetrum* (over 45%), but *Betula* c.f. *nana* and *Juniperus* are also significant. A sample 1.5 cm thick yielded a radiocarbon date of 11,290 ± 165 yr BP (SRR-303).

The pollen spectrum at the base of the organic deposits is characterised by high values of *Rumex* (over 20% of total land pollen) with *Salix* (many of which resemble *Salix c.f. herbacea*) and Saxifragaceae also important. Values for woody plants increase progressively towards the upper part of the dated horizon.

The basal organic deposits gave a radiocarbon date of 13,151 ± 390 yr BP (SRR-304). The most likely source of any error is the hard water effect, which can give apparent ages that are almost 3,000 yr too great, although the error is rarely as large as this[6,7]. Limestone does not crop out in the area draining to Loch Etteridge, however, and glacial erratics of limestone have not been found. No shells were found in the lake deposits. The possibility cannot be excluded, however, that inert carbon from the complex metamorphic rocks of the surrounding area was incorporated in the dated bulk sample. On the other hand, the date of 10,764 ± 120 yr BP from similar (though organically richer) material higher in the sequence agrees with expectations, and there can be no hard water error here.

Because a thickness of 3–4 cm of the deposits was used for dating, the date obtained, if valid, is younger than the age of the very bottom of the organic layer. It is particularly significant that the site is a deep kettle hole, in which dead ice may have remained for hundreds (or even thousands) of years after deglaciation of the surrounding area[8]. Thus the basal date, if valid, is a minimum date of deglaciation.

The Loch Etteridge date is not unique in Scotland. Wood from lake deposits near Lockerbie in Dumfriesshire has

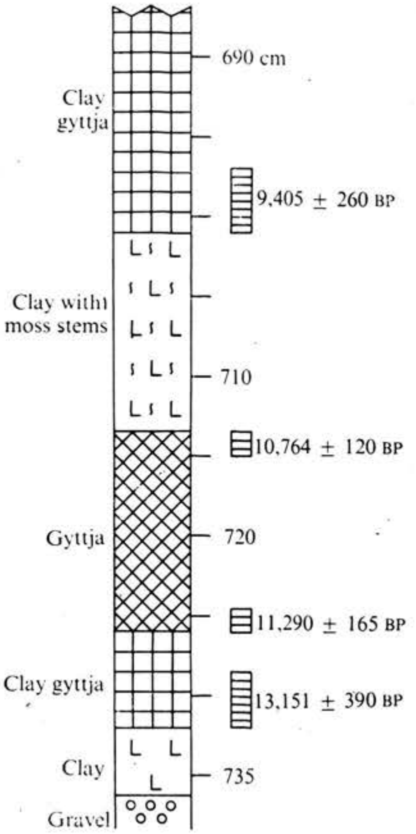

Fig. 2 Stratigraphy and radiocarbon dates at Loch Etteridge.

been dated at 12,940 ± 250 yr BP (ref. 9). Lockerbie is only 60 km from the major centre of icesheet accumulation in the Southern Uplands (Loch Doon Basin). In the heart of the mountains of NW Scotland a date of 12,810 ± 155 yr BP has been obtained for deposits from Loch Droma[10]. Near Callander the basal organic deposits in a kettle hole have provided a date of 12,750 ± 120 yr BP. This site is only 45 km from the centre of the area of greatest ice sheet accumulation in the British Isles (around the Rannoch basin). The Loch Etteridge basal date adds significantly to this evidence, because the site is in the middle of the Grampian Highlands.

Together, the four dates (all of which, if valid, are minimum dates of deglaciation) show that by about 13,000 yr BP the last ice sheet had disappeared from most of Scotland. At about this time two significant, probably interrelated, events are reported to have occurred. Coleoptera and radiocarbon dates from a site in North Wales, indicate that at about 13,000 yr BP temperatures rose very rapidly, with summer temperatures becoming at least as warm as those of the present day[11]. Seafloor sediments indicate that deglacial warming of the North Atlantic Ocean adjacent to the British Isles occurred at about 13,500 yr BP, polar waters having retreated far to the west by 13,000 yr BP (ref. 12). In view of these profound changes we find it difficult to believe that any remnants of the British ice sheets which may have remained at about 13,000 yr BP could have survived for much longer. Total deglaciation by 12,500 yr BP seems a conservative suggestion.

The last British ice sheet, which probably reached its greatest extent at about 17,000–18,000 yr BP, had therefore wasted away by 12,500 yr BP at the latest. Subsequently, glaciers built up again in many mountain areas, and were especially extensive in the Scottish Highlands[13] where they began to accumulate before the climatic deterioration which occurred at about 10,800 yr BP. The glaciers probably reached their maximum extent about 10,300 yr BP, but it is not yet known how long they took to decay. The fact that minerogenic deposition, which implies solifluction and sparse vegetation, continued locally till approximately 9,400 yr BP may be significant in this context.

This research was financed by the Natural Environment Research Council. We thank Dr D. D. Harkness for the radiocarbon dating.

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Received March 6; revised April 8, 1974.

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Printed in Great Britain by Henry Ling Ltd., at the Dorset Press, Dorchester, Dorset