ASPECTS OF THE GLACIAL AND POSTGLACIAL HISTORY OF NORTH-WEST ARGYLL.

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1981

ABSTRACT

The Loch Lomond Advance limits and raised marine shorelines in N. W. Argyll have been mapped and surveyed. Radiocarbon dated Lateglacial and Postglacial pollen sites at Salen and Loch Shiel provide the vegetational history and chronology for the area. 14 Loch Lomond Advance glacier termini and associated limits were mapped using the distribution of hummocky and fluted moraine, together with a survey of erratic boulders. 83% of the reconstructed former glaciers had a southerly aspect relating to southerly snow-bearing winds. The average firnline gradient was 7.5m/km increasing in altitude towards the north-east; the average firnline height for the area was 369m.

The Main Lateglacial Shoreline, formed during the Loch Lomond Stadial, slopes towards 270 with a gradient of 0.15m/km from 9m in the east to 0m in the west of the area. It was formed by freeze-thaw action operating under exceptional conditions, and its formation was influenced by rock type. Two Postglacial shorelines are recognized : the Main Postglacial shoreline that slopes towards 270, from 14m to 8m with a gradient of 0.06m/km, and a lower shoreline at approximately 5m which has no definite gradient.

An absolute Lateglacial pollen site at Salen, Ardnamurchan, shows an early pioneer community of *Rumex*, *Salix*, Gramineae and and Cyperaceae species being replaced by an Empetrum heath during the Lateglacial Interstadial. Subsequent stadial conditions are reflected by open herb communities and the onset of coarse minerogenic sedimentation. This minerogenic influx ceased around 10,000 to 9,700 B.P. with a rapid recolonization of the surrounding area by pioneer herbs, then dwarf shrub and finally deciduous woodland.

Middle and Late Postglacial vegetational development is recorded by lacustrine sediments from Loch Shiel where the fossil pollen record shows that a mixed deciduous woodland of Quercus, Alnus, Betula and Corylus was progressively cleared by man. Palaeomagnetic and chemical records were obtained from the site. The Main Postglacial Transgression flooded Loch Shiel resulting in the deposition of shells of the marine bivlave *Thyasira flexonosa*.

CONTENTS.

ACKNOWLEDGEMENTS

I received financial support for this research work from the Natural Environmental Research Council. The N.E.R.C. also financed the radiocarbon dates and the coring in Loch Shiel. Aerial photographs for the field area were purchased with a grant from the Earl of Moray Fund, University of Edinburgh.

I wish to thank Dr. J. B. Sissons for his continual interest, encouragement and support throughout this work, for many stimulating discussions and ideas, and for his critical reading of the manuscript. Dr. W. W. Newey has been my guide in all botanical matters and I am very grateful to him for his detailed comments on many parts of the manuscript.

I thank my levelling assistants Mr. J. Faithfull, Mr. C. Fielding, Mr. S. Shepard, Mr. M. Haddon and Mrs. G. E. Wain-Hobson. Other assistance in the field was provided by Mr. C. K. Ballantyne, Dr. R. Cornish, Mr. M. Haddon, Dr. H. Matthews, Dr. M. Robinson, Dr. J. B. Sissons, Dr. R. Shakesby, Dr. V. Squire and Mr. K. Woods. Mackereth cores were obtained from Loch Shiel by the author and Dr. R. Thompson and his coring team from the Department of Geophysics, University of Edinburgh. I am grateful to all landowners for access to their property. I am indebted to Mr. A. Wright and Mr. and Mrs. M. McLeod for their hospitality during my visits to N. W. Argyll.

Many people provided assistance with laboratory analysis; Dr. M. Robinson, Dr. H. J. B. Birks and Mrs. S. Peglar for help with pollen morphology and taxonomy; Dr. R. Thompson for conducting the palaeomagnetic analysis; Dr. H. H. Harkness for supplying the radiocarbon dates and to Dr. S. Smith for the identification of mollusca.

I am grateful to Mr. A. Alexander, Mr. C. K. Ballantyne, Mrs. M. Dale and Mrs. S. Peglar for assistance with data processing. Dr. H. J. B. Birks and Dr. B. Huntley allowed me to use their 'POLLDATA' program.

The Peat Survey of the MaCaulay Institute for Soil Research, Aberdeen allowed me to use unpublished information which I appreciate.

For general help, discussion and comments I would also like to thank Dr. D. Q. Bowen; Miss A. P. Bonny; Prof. C. Kidson; Dr. J. Matthews; Dr. P. D. Moore; Dr. W. Pennington; Dr. E. Shalkovitz, and Dr. W. Williams. I thank Mrs. B. Wynne for typing the manuscript.

Finally, I would like to express my appreciation and gratitude to my parents, Mr. and Mrs. D. Wain-Hobson, for their continuous support and encouragement, and to my wife, Mrs G. E. Wain-Hobson, for all her help in numerous aspects of the work.

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CHAPTER 1. INTRODUCTION.

Thesis aim and outline.

The aim of this thesis is to contribute to recent investigations into the Late- and Postglacial environments of Scotland. The principal lines of research are:-

a) Mapping the limits of the last glacial ice in Scotland (Loch Lomond Advance).

b) Mapping and levelling of raised marine features to determine former relative movements of the sea-level.

c) The reconstruction of the vegetational history from the fossil pollen record, for the Lateglacial and part of the Postglacial period.

Using established techniques and methodology, an investigation has been conducted into the Late- and Postglacial environment of a small part of Scotland, along these three main lines of enquiry. Since Quaternary investigations are essentially multi-disciplinary in nature, it was hoped that this wider approach would provide a better understanding of some of the problems and techniques involved than if attention had been confined to a single field.

Some of the results of this study may be of use as part of a large-scale analysis of Scottish Late- and Postglacial environments (e.g. climatic inferences drawn from Loch Lomond Advance glaciers (Sissons and Sutherland, 1976) and the numerical analysis of past pollen flora (e.g. Birks and Deacon, 1973)).

Part of N. W. Argyll was chosen as a field area because:-

a) There had been little previous work done in glacial geomorphology there.

b) Provisional air photograph reconnaissance suggested reasonably good evidence for Loch Lomond Advance limits and raised marine features.

c) There were no published pollen sites in the area. The nearest Lateglacial pollen site was 20 km south at Oban (Donner, 1957), or 100 km north in Skye (Birks, H. J. B., 1973).

d) Detailed work by Gray (e.g. 1972a)had been done on the raised marine features and Loch Lomond Advance limits of the adjacent area to the south.

e) The area was fairly accessible.

After a brief outline of the environmental background to the field area, detailed evidence will be presented for ice-sheet movement and the extent of Loch Lomond Advance glaciers. A description and interpretation of the raised marine features will follow. A discussion of pollen diagrams for two sites will constitute a third section. Finally, a synthesis of results and conclusions for this area will be related to present knowledge for the rest of Scotland.

A discussion of pertinent literature and methods employed will be made in the relevant sections of the thesis.

Location.

The field area is that part of Argyll north-west of Loch Linnhe, in the Northern Highlands of Scotland. It lies between the latitudes 56°44′N and 56°29′N, and longitudes 6°02′W and 5°15′W. It includes the districts of Morvern, Sunart and Kingairloch; part of Ardgour and part of Ardnamurchan. These districts lie within the political boundary of the Highland Region.

The field area is bounded to the south-west by the Sound of Mull, and is truncated along its south-east margin by Loch Linnhe. The southern half of the Loch Shiel basin forms the northern boundary, together with Glen Hurich and Glen Gour. The field area includes Corran, but excludes the Ardnamurchan peninsular west of Salen (see Fig. 1. 1).

Bedrock Geology.

The area is composed of four rock types, of widely differing age and character (Fig. 1.2). They are the Moinian Schists, the Strontian Granite, Mesozoic sediments and the Tertiary Basalt lavas. The region was mapped between 1902 and 1930 by the Geological Survey, whose officers included E. B. Bailey and W. B. Wright. The area is covered by three Geological Survey memoirs (Bailey 1960, 1924; Lee and Bailey, 1925).

a) The Moine Series.

The Moine Schists crop out over 355 km and form the major rock type. These sediments are highly metamorphosed, but were originally laid down as an alternating sequence of gravels, sands, and clays up to 600m thick (Phemister, 1960). This simple structure has been extensively altered by four periods of orogenisis in the early Palaeozoic. Contemporary with these was systematic regional metamorphism (Read, 1961). The structural complexity of the formation is such that there is no complete stratigraphy available. Outcrops vary between bands of psammitic granulite, banded psammitic schists and gneisses and banded pelitic schist and gneiss. Highly contorted bedding planes and sheared quartz veins are enhanced by weathering to form distinctive outcrops.

b) The Strontian Granite.

This pluton was intruded during a period of igneous activity throughout Scotland associated with the Caledonian orogeny. There were four main phases (Mercy, 1965):-

1. The regional migmatization of the Scottish Highlands. Most of the Moine Schists of the field area crop out within the western limit of migmatization.
2. The Assynt alkaline intrusions and the basic interlude of north-east Scotland.
3. Emplacement of the Newer Granites, including the Strontian Granite.
4. Formation of the ring complexes; e.g. Ben Nevis and Glen Coe.

The Strontian Granite outcrop covers 205 km and is the largest of the Newer Granite batholiths in the Northern Highlands (Phemister, 1960). Emplaced in Moine schists at depth, there is no metamorphic aureole. The initial formation of an outer band of basic, well foliated tonalite was intruded by granodiorite. In turn, this was later intruded by a more acidic biotite granite (Sabine, 1963). This layering from a basic margin to a more acidic, central rock type is typical of the Newer Granites. Potassium-argon dates for this emplacement are 420 ± 19 m.y. for the tonalite, 405 ± 10 m.y. for the granodiorite and 381 ± 17 m.y. for the biotite granite (Miller and Brown, 1972).

The Strontian Granite outcrop is truncated along its south-east margin by the Great Glen Fault. Kennedy (1946) correlated the Strontian granite with the Foyers granite (located on the south-east side of Loch Ness). He suggested that a lateral movement of 105 km along the Great Glen Fault had taken place. It was from Strontionite, mined along the northern granite-Moinian Schist contact that Sir

Humphrey Davey isolated the element strontium at Strontian in 1808.

c) Mesozoic Sediments.

Restricted outcrops of Mesozoic sediments are found along the margins of the Tertiary plateau basalt lavas (Richey, 1961). In Morvern these sediments have been preserved beneath the lavas. They crop out along the coast east of Loch Aline, and on the south side of the Loch Arienas and Loch Teacuis valley. Typically, theyconsist of Triassic conglomerates and Jurassic and Liassic clays, unconformably overlain by Cretaceous greensand and silicified chalk. The thickest sequence (22m) is found beneath the lavas at Ben Iadain (NM 692561).

d) Tertiary Basalt Lavas.

The contintal shelf of Western Britain has several deep asymmetrical basins infilled with up to 460 metres of Mesozoic and Tertiary sediments. These basins are tensional features, resulting from an abortive attempted extension of the Mid-Atlantic Ridge (Naylor and Mounteney, 1974). The Tertiary vulcanism of Scotland was restricted to the intersection of Caledonian shear and Tertiary cross faults (Roberts, 1974). This confined igneous activity in Scotland to six centres. Two of these centres are periphal to the field area; they are Mull and Ardnamurchan.

Before the earliest Tertiary igneous activity there was uplift and erosion of Mesozoic sediments. Harker (1904) suggested three distinct periods of activity:-

1. An extrusive volcanic phase, with outpouring of basaltic lavas. Lava from the Mull vent covered Morvern forming a basaltic plateau area, 125 km^2 with a maximum thickness of 450m.
2. A long and complex plutonic phase, confined to the local volcanic centres.
3. A period of N.E.-S.W. distension, with a massive intrusion of dykes along a N.E.-S.W. trend into virtually every rock type in the area. Minor faulting was widespread.

Roberts (1974) suggested that the Tertiary volcanic activity throughout Scotland took place between 60 and 40 m.y. ago. It can be related to three phases of seafloor spreading that structurally isolated the Rockall Plateau microcontinent from the European mainland.

Physiography.

The field area forms the most southerly part of the Northern

Highlands, and is 700km^2 in extent. It is approximately rectangular in shape, with a main axis running N.E. to S.W., 32 km long, and is 25 km wide. From Strontian, Beinn Resipol (845m) lies to the N.W., Garbh Bheinn (885m), the highest mountain in the area, lies to the east, and Creach Bheinn (853m) to the S.E. These mountains of the Moine Schists form the highest and most rugged ground. The psammitic schists form more rounded hills than the more irregular pelitic types (Bailey, 1926).

The topography of the Strontian granite varies widely within the outcrop. The tonalitic and porphyritic granodionite forms a comparatively low-lying area at 300m. This contrasts with the higher surrounding Moinian hills, and with the central more acidic part of the intrusion, where hills of biotite granite reach 739m (NM 799515) S.W. of Loch a' Choire. This relief inversion occurs on some other Newer Granites , Rannoch Moor and Loch Doon intrusions being the most prominent examples. Others, however, such as the Cairngorms and Lochnager outcrops form some of the largest areas of high ground in Scotland.

Tonalite and granodionite have a typically high plagioclase content (over 66%), which decreases in the biotite granite to between 33% and 50% (Hatch, Wells and Wells, 1961). Goldich (1938) suggested that plagioclase, a basic mineral, is very susceptible to chemical weathering. This difference in plagioclase content of the granite types may be sufficient to have caused the anomalous relief pattern. Besides differences in mineralogy, this topographic inconsistency may be a function of the local emplacemant mechanics of the granite outcrop, resulting in different degrees of foliation. The location of the granite outcrops with respect to differences in precipitation may be important. This could have influenced the rate of chemical weathering and the nature of glaciation.

The plateau lavas of Morvern display the characteristic 'trap featuring' of basaltic lavas (Hatch, Wells and Wells, 1961). This forms a stepped topography best displayed west of Loch Aline and east of Auliston Point. Where the lavas have a soft foundation of Mesozoic strata they form impressive scarps: examples occur south of Loch Arienas and Loch Teacuis, and at Ardtornish Bay (NM 700430) where they form cliffs 200m high. West of Loch Aline sedimentary strata do not crop out below the lavas and the coastline is consequently low-lying and monotonous (Scott, 1928).

The main influences of tectonic activity reflected in the landscape of the field area are:-

a) The Caledonian System. This is dominant throughout the Highlands, with a trend from N.E. to S.W. The Great Glen Fault is responsible for the straight western edge of Loch Linnhe. The zone of shattered rock along the fault has been glacially exploited, forming a precipitous coastline that is continued below sea-level. At one point (NM 760412) the Admiralty Charts record a depth of 120-150m some 180m offshore.

The orientation along the Caledonian trend of the lochs Linnhe, Awe, and part of Shiel and Etive in the S.W. Highlands is striking. Within the area this trend may be responsible for the direction of the mid-section of Loch Sunart (NM 700630 to 650585), Glen Dubh, Glen Geal and part of Strontian Glen (NM 820630 to 863658).

b) The northwest-southeast Tertiary distension. This may have influenced the formation and orientation of the Sound of Mull, the Loch Arienas-Loch Teacuis valley, part of Loch Sunart (NM 710635 to 760600), Loch a' Choire and the Loch Uisge valley.

c) Other Tertiary faults. The plateau lavas in Morven have been truncated by north to south trending faults, for example on the east side of Ben Iadain and the lava plateau at NM 665525.

Scott (1928) suggested the influence of an east-west fault running west from NM 604886 in Glen Tarbert. It has probably been exploited by the Carnoch river, and may have resulted in the steep slopes south of Loch Sunart from Lochead (NM 836603) to Laudale (NM 740600). This coast is precipitous, and strongly contrasts with the gentle northern shore of the loch.

Reconstructions of the pre-glacial drainage pattern suggest an easterly flowing stream system originating west of Loch Linnhe. Rivers from Glen Tarbert and Glen Gour would drain to Loch Tummel via Loch Leven and Glen Coe. These rivers were later intercepted by a Loch Linnhe subsequent stream (Bailey, 1926; George, 1965). Alternatively, Sissons (1967b) has observed that the present watershed usually coincides with the highest ground. If the present watershed coincided with the line of the original watershed, this would place the watershed east of Loch Linnhe, and rivers would flow westwards to be later dismembered by subsequent streams exploiting the Caledonian zones of weakness. Within the field area, these zones influence the drainage, as, for example, the rivers draining the glens noted above under (a).

On a smaller scale, the N.W. to S.E. Tertiary tectonic influence is more important. Many streams have exploited the associated dykes and faults. Resulting gorges may be impressive: N.W. of Achagavel (NM 764560) a stream has incised a straight gorge along a fault, 30m deep for over a kilometre.

Climate.

The field area has a cool, but mild, oceanic climate for most of the year, with excessive precipitation. Deep coastal indentations mean that all parts of the area lie within 8 km of the sea. The result is extreme mildness at low altitudes for this latitude.

The following meteorological data are for lowland regions of the period 1901 - 1930 (Climatological Atlas of the British Isles, 1952). The average mean of daily mean temperatures for January was 4.2°C, and for July 14.1°C, giving a comparatively small annual range of 9.9°C. The average annual maximum was 25.2°C and the minimum -7.9°C, a maximum annual range of 33.1°C. There are no meteorological records for high altitude in the field area but Ben Nevis has a mean annual temperature of only -0.2°C (Manley, 1959). Assuming a lapse rate of 0.68°C for each 100m increase in altitude (Manley, 1952), Garbh Bheinn (885m) would have a mean annual temperature of 3.1°C.

Rainfall varies from 1300mm to 1560mm at the western tip of Morvern, to over 3250mm on ground over 750m altitude. Rain guages at Kingairloch (NM 835534) and Ardgour house (NM 995638), both virtually at sea level, record a mean annual total of 2730mm and 2652mm respectively. Both show a marked winter precipitation maximum (Cruickshank and Jowett, 1972).

The average number of rainy days (more than 1mm of rain per day) is 225 - 250. The average number of mornings with snow lying varies from 5 - 10 at sea level to 50 -100 at high altitudes. Relative humidity is high, being greater than 75% throughout the year. Annual average windspeed is 6.6m/sec, with 15 - 25 gales per year (winds in excess of 16.4m/sec).

Soils and Vegetation.

Soils are poor, as the bedrock does not weather easily to form suitable material for soil development. In an area where rainfall exceeds evaporation for every month of the year, leaching and podsolization are widespread. This accentuates the bad drainage, preventing decay. Nutrients and fine clay particles are quickly removed and bog formation is rapid. Extensive peat bogs have developed on some low, badly drained ground; e.g. Claish Moss, Kentra Moss and Corran. Good soil is largely restricted to the sands and gravels of raised beach deposits.

The vegetation of the area is mainly wet grass moor, of Molinia and sedges with Myrica gale. Interspersed between this are large areas of acid grassland (fescue-agrostis, with nardus, Ericaceae and increasing quantities of Pteridium aquilinum) (Vegetational survey of Scotland, 1953). Woodlands are confined to remnant semi-natural patches of oak (e.g. Ariundle, NM840645), while extensive areas have been planted by the Forestry Commission, especially in Morvern and Glen Hurich.

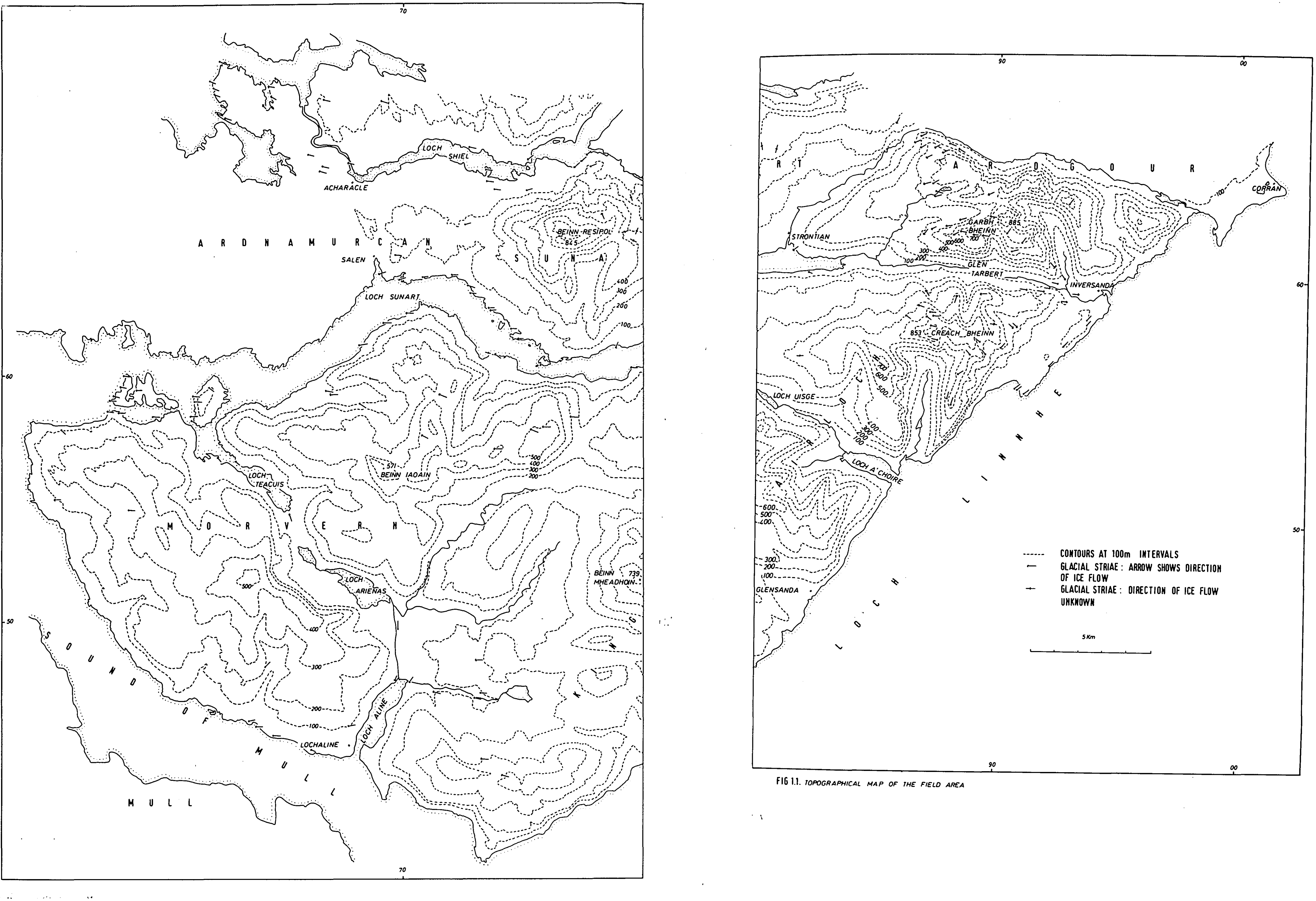

FIG 1.1. *TOPOGRAPHICAL MAP OF THE FIELD AREA*

CHAPTER 2.

PRE-LOCH LOMOND ADVANCE ICE-MOVEMENT.

Introduction.

There is little evidence in Scotland for any specific Quaternary event before the Late Devension: only two interglacial sites are known and both of these are in the Shetland Islands (Birks, H. J. B. and Ransom, 1969). During most of the Late Devension, an ice-sheet existed in Scotland and this will subsequently be referred to as the ice-sheet period.

Radiocarbon dates suggest that much or all of Scotland was ice-free before about 25,000 B.P. At Tolsta Head on the Isle of Lewis peat beneath apparent till has been radiocarbon dated at 27,333±240 B.P. (von Weyman and Edwards, 1973). A date on an organic soil horizon at Tein .dland in Morayshire is 28,100 + 480, - 450 B.P. (Edwards et al., 1977). At Bishopbriggs near Glasgow (not far from the centre of Highland ice accumulation) a bone from a woolly rhinoceros removed from fluvioglacial gravels beneath till has a date of 27,550 + 1370, - 1680 B.P. (Rolfe, 1966).

A major ice sheet then developed, which at its maximum extent reached the North-West Midlands of England and Pembrokeshire in Wales. (Geological Survey Drift Map of Great Britain, 1977) Deglaciation began after 18,000 B.P. according to Penny (1964). Widespread fluvioglacial landforms, especially in the south and east of Scotland, reflect a general downwasting of the ice-sheet in situ., with the hills and mountains emerging above the ice-sheet, and ice becoming stagnant on valley floors and lowlands (Sissons, 1976a).

In the last half century several readvances during deglaciation have been proposed, but most have been rejected or are considered highly improbable. These include the Lammermuir-Stranraer Readvance (Charlesworth, 1926), the Aberdeen and Dinnet Readvances (Synge, 1956, 1963) and the Aberdeen- Lammermuir Readvance (Sissons, 1967b). A Perth Readvance was first suggested by Simpson (1933) and was delimited over a considerable area by Sissons (1963b, 1964). However, Paterson (1974) has shown that evidence used by Simpson in the Perth area can be interpreted differently. Although Sissons (1976a) concludes that there is no firm evidence for a readvance, fluvioglacial deposits in both the Tay and Forth valleys correlate with the main Perth shoreline and 'the marked development of this shoreline and the subsequent drop in the marine limit suggest that the fluvioglacial landforms mark at least a significant halt stage'(Gray and Lowe, 1977, p. 165).

D. Sutherland (pers. comm. in Gray and Lowe, 1977, p. 165) has postulated a halt stage in the Cowal Peninsula (S.W. Grampians) to explain a drop in the marine limit of over 20m. Farther north, the Oban - Ford moraine of supposed Perth Readvance age (Synge, 1966, Synge and Stephens, 1966) has been re-interpreted by Gray and Sutherland (1977). They conclude that the ice limits 'represent only fairly brief diachronous halts in the general recession of the ice.' (Gray and Lowe, 1977, p. 165) and that these may relate to the still-stand at Cowal. In the N.W.Highlands, Robinson (1977) suggests that the ice-sheet readvanced to form a moraine near Applecross (the Applecross sub-stage), and Ballantyne (pers. comm.) believes an ice-sheet moraine to represent a halt stage during deglaciation on An Teallach.

The presence of at least 62 Lateglacial sites in Scotland, many radiocarbon dated, proves that large areas of the country were completely deglaciated by about 13,000 B.P. There is beetle evidence (Coope and Brophy, 1972) of summer temperatures comparable to the present day, and of the retreat of polar waters from the west coast of the British Isles around 13,500 B.P. (Ruddiman and McIntyre, 1973). 'It therefore seems unlikely that such remnants of the ice-sheet as survived at this time could have lasted much longer and total deglaciation by 12,500 radiocarbon years ago seems a conservative suggestion' (Sissons, 1976, p.90).

Previous Work in the Field Area.

The Geological Survey (Bailey, 1924; Lee and Bailey, 1925; Bailey, 1960) mapped a great number of striae in the study area; the writer has found few additional ones. Some glacial erratics were mentioned, principally boulders of Strontian Granite found scattered in parts of Morvern, Mull and Ardnamurchan. Although the Survey officers did not delimit a readvance, they did realize that different directions of ice flow at different times were involved.
'All the great valleys of the district afford striated surfaces indicating a downstream flow of ice. But as one ascends higher and

higher, on to cols and ridges, one meets striae with a direction more and more independent of the local inequalities of the topography' (Bailey, 1924, p.217). The Geological Survey officers concluded that at the maximum of glaciation ice flowed S.W. down Loch Linnhe, fed by converging ice currents from both sides, and was deflected west across Morvern by the local ice accumulation on Mull.

Scott (1928) located several large erratic boulders that are not mentioned by the Geological Survey. His map shows the general direction of ice-sheet movement at maximum glaciation to be S.W. across the region, 'little affected by the two chief valleys - Loch Sunart and Ariena-Teacuis valley - crossing both almost at right angles' (p.172). This does not accord with evidence from striations.

Peacock (1970) summarized the early work of the Geological Survey and described the ice-sheet glaciation. He suggested, though without clear evidence, that an ice-shed during the ice-sheet maximum lay N.E. of Loch Eil, with ice flowing S.W. over the present study area. On the east side of this proposed ice sheet, the Geological Survey has mapped till (outside the study area) while to the west, moraine drift is predominant. The latter is usually found inside former Loch Lomond Advance limits and is frequently associated with hummocky moraine (e.g. in Glen Tarbert and Glen Laudale).

A considerable part of the field area is bare rock, and superficial deposits other than peat and morainic drift are rare. Charlesworth (1955) included this area in his 'Moraine-less West'.

Glacial Breaches.

A glacial breach is formed where ice erodes a preglacial watershed to form a new valley (Linton, 1963). Glacial breaches represent some of the most dramatic evidence for glacial erosion in the Scottish Highlands, although it has not always been accepted that they are mainly of glacial origin. A. Geikie (1865) and Peach and Horne (1910) attributed the breaches of the Northern Highlands to erosion by Tertiary rivers, flowing south-east from a source west of the present coastline. The later capture of these rivers by south-westerly flowing subsequents left many breaches as wind-gaps. As late as 1934 Bremner was still promulgating this idea when Louis (1934) suggested that glacial erosion may have been the dominant process in their formation. Dury (1953) described the capture of the River Callop at Glenfinnan as one of the major breaches through the N.W. Highlands. He concluded that it supports 'the inference of wholesale breaching by transfluent ice, at the expense of hypothetical schemes of major consequents heading west of the present divide or even of the coast' (p. 115).

Linton (1951a, 1951b, 1957) examined many glacial breaches in the Scottish Highlands and demonstrated the ability of confined ice to cut a deep trough through the heart of a mountain mass. At Loch Treig the main east-west Grampian watershed has been breached, and the deepest point of the loch now lies 1330m below the adjacent hills. Although there was probably a pre-glacial col at this point, it is unlikely to have been a major Tertiary river valley, and Linton considers that 550m of erosion by ice occurred.

In areas of intense glacial erosion breaches and glacial valleys may merge to form a complex system of inter-connecting valleys, as in the area between Fort William and Mallaig (Sissons, 1967b). It becomes difficult to separate breaches that utilized a pre-glacial col from those whose origin is solely due to glacial erosion.

Glacial Breaches in the Field Area.

With the exception of Glen Forsa on Mull the field area includes the southernmost part of a belt of major glacial breaches that extends northwards to Western Sutherland (Dury, 1953). One of these breaches, Glen Gour, forms the northern boundary of the field area. The floor of the glen rises to 205m at a point (NM 892650) where adjacent slopes rise to 700m and 760m. Farther south, Glen Faith n' Amean and Coire an Iabhair meet at an altitude of 540m (NM 903630) within a kilometre of the summit of Garbh Bheinn (885m). The most impressive glacial breach is Glen Tarbert, the floor of which rises to only 112m, while the surrounding mountains attain heights of 885 and 870m. These three breaches have small lochans on their watersheds. Glen Gour and Glen Tarbert form such deep incisions through the watershed that it may well be that they have been excavated along major pre-glacial cols.

Breaches are smaller and less well developed south of Glen Tarbert. The Loch Uisge valley runs north-west to reach a col height of 175m, before swinging round to the S.W. to merge with the Arienas-Teacuis valley. This latter valley runs N.W. - S.E. and although it probably is a breach, its formation has been strongly influenced by geological structure. At its deepest point, the floor of Loch Arienas lies 25m and that of Loch Teacuis 27m below sea level.

Between the Loch Uisge valley and the Sound of Mull a number of small breaches have been cut into the Strontian Granite, Glen Sanda being the best example. Finally, the Sound of Mull may be considered to be a glacial breach, having several basins with a maximum depth of 60m.

The majority of the glacial breaches described are major glacial troughs and represent an over-riding of the area by foreign ice. In places glacial erosion probably removed up to 400m of rock, despite the utilization of former pre-glacial cols and river valleys. An unloading effect causing fracturing of rock may have been an important process in glacial excavation.

With repeated breaching the pattern of constricted ice flow would have been reinforced during every major glaciation. Evidence for an ice flow at high level is suggested by the altitude of cross-cut valeys (see Sissons, 1967b) and possible diffluence channels. Cross-cut valleys have dissected a mountain mass above 600m to form the triple peaks of Sgurr Dhomhnuill (NM 890680) on the north side of Glen Gour. Ice has probably over-ridden the southern side of this glen to flow into Gleann Feith n' Amean, as hinted by the striae at NM 896634. Similarly, ice from the Loch Linnhe ice stream may have crossed a col at NM 885565 to flow down Glen Galmadale.

<u>Glacial Troughs</u>.

The study area is bounded by, and dissected by, glacial troughs. These are mainly drowned features and are sometimes associated with glacial breaches. Along the S.E. boundary of the area, Loch Linnhe forms one of the longest fjords in Great Britain. An upper basin, N.E. of Corran, has a maximum water depth of 152m. A larger lower basin extends south of Corran where the sea reaches a depth of 221m between Lismore and the Morvern coast. The axis of this basin corresponds closely with the Great Glen Fault and with the structurally controlled lineation of Lismore. Loch Sunart consists of several basins with a maximum water depth of 90m N.W. of Auliston Point. Many of these basins may be structurally controlled, but the eastern part of the Loch Sunart trough is essentially a continuation of the breach of Glen Tarbert, and has probably been considerably deepened by ice. The basin at the head of the loch is located on granodionite, the loch becoming shallower on the Moinian Schists towards Laudale. This is comparable to the relationship between adjacent relief and rock type, though Scott (1928) suggested that this basin is the waterfall pool of an easterly flowing pre-glacial river!

Major rock basins off the west coast of Scotland are common, evidence that massive erosion has taken place. Immense troughs lie offshore and separate Skye, Jura and Mull from the mainland. Rockhead maps (e.g. Binns <u>et al</u>., 1973) illustrate how deep and extensive some of these troughs are. For example, a remarkable trough some 10km wide and 100km long, reaching rockhead depths of 380m extends S.W. from the Isle of Rhum.

Striae.

In the following description it is assumed that all striae outside the Loch Lomond Advance limit relate to the last ice-sheet glaciation, while those inside the Loch Lomond Advance limit have been formed by that Advance. It is known that ice-sheet movement would have been affected by local topographic irregularities (cf. Virkala, 1960) and care must be taken in inferring the direction of former ice movement from the evidence of striae alone. When measured in the field, the mean angle of a group of striae was taken.

The rock types of the field area do not retain striae easily. The Strontian Granite has a massive texture and only five groups of striae are known on the entire outcrop. They are large shallow grooves, 10 - 15mm wide and 5mm deep. The basalt lavas of Morvern weather fairly rapidly and most of the comparatively few sets of striae found in this area are on Tertiary dykes or other intrusions (e.g. a cluster of striae on a dolerite sill exposed on the coast at NM 621462). On the pelitic type of Moinian schists striae are large and common. However the finer scratches on the psammitic rock types are quickly destroyed and are only found where overlying protective material has been recently removed.

Ice-Sheet Striae.

In Morvern striae range from 240 to 305 with only a few exceptions where ice has been confined to valleys. They indicate a general movement of ice across the area from east to west. Along the shores of Loch Sunart striae are also orientated east-west, between 245 and 307 . Ice-moulded rock along the sides of the loch, especially between Lochead (NM 833603) and Achleek (NM 795603), and from Liddersdale (NM 774599) to Laudale (NM 758598), together with a fine roche moutonnée at NM 835608, support this east-west movement.

On the Ardtoe Peninsula (NM 635710) numerous striae indicate a N.W. ice direction, between 286° and 348°. Ice moulding is abundant along the coast and is well developed with striae at Ardtoe Bay. Ice-moulded rock at NM 627703 may relate to constricted ice flow at the narrow entrance to Kentra Bay.

Farther east, on the very summit of Ben Resipol, striae point west (268°), and on Garbh Bheinn several groups of striae provide more evidence of a westerly flowing ice-sheet. To the south, striae above 680m on Creach Bheinn range from 275° to 310° on the western side of the mountain, while on the eastern side striae above 150m point approximately south-east. Below this altitude, striae orientation is between 232° and 250° roughly parallel with Loch Linnhe. This latter orientation is significantly different from the previous striae directions.

Ice-Sheet Movement as Indicated by Erratics.

The distribution of large erratic boulders was some of the earliest evidence used for the glaciation of Scotland. As early as 1880 a Boulder Committee was formed by the Royal Society of Edinburgh to investigate the distribution of erratic boulders. Using erratics (and striae) Horne (1894) demonstrated the interaction of small valley glaciers with large-scale movement of a regional ice-sheet in the Applecross hills of the N.W. Highlands.

The Geological Survey has recorded on its 1:10560 maps the location of many erratics in the field area. This evidence is summarized on Fig.2.1.A&B together with erratics found during the geomorphological mapping for this thesis. The most numerous erratics are boulders of Strontian Granite found west of the outcrop.

Other erratics are quite rare though occasional blocks of Moinian Schist lie on the granite (e.g. at NM 827497). In Morvern basalt lava blocks from the Ben Iadain outlier have been transported 0.5km N.W. from the outcrop at NM 692567, and 1.5km west at NM 664563. Scott (1928) recorded a Triassic Sandstone block resting on the Morvern lavas 2km south-west of its source near Barr (NM 617560).

The distribution of erratics supports the general inference from striae that there was a general ice-sheet movement from east to west across the area.

Erratics Survey : Method.

It was decided to undertake a survey of erratics to attempt to demonstrate the limits of Loch Lomond Advance ice where morphological evidence for this limit is poor. In the course of this survey, information relating to ice-sheet movement was obtained. The survey method will be described here, but only the data and inferences for the movement of the ice-sheet will be discussed.

Traverses were made by walking along east-west lines corresponding with the National Grid lines. These lines had been transferred from the 1 : 50,000 Ordnance Survey 1st Edition maps to 1 : 25,000 aerial photographs. With the aid of a compass, location on the ground could be obtained to the nearest 25m. Starting at a kilometre grid intersection, 126 paces were counted, this being the average number of paces that approximated to 100m over rough ground. For each 100m section the numbers of Strontian Granite and Moinian schist boulders lying roughly one metre on either side of the hypothetical line were continuously recorded on separate hand counters. After 126 paces, the values were written down, the counters zeroed and the procedure repeated.

The survey covered 172km, recording 13,707 boulders as 1,215 separate totals. In areas that were critical for defining a Loch Lomond Advance limit traverses were made at 500m intervals though the usual spacing was a kilometre. Some gaps exist in the traverses, usually where a crag or water made the survey impracticable and very occasionally by snow patches. Stream widths were included in the paced distance but erratics in the stream beds were noted separately. Conspicuous erratics lying outside the traverse line were recorded separately but are not shown. No attempt was made to measure the size or shape of boulders, though stones less than approximately 15cm were not recorded, except in critical areas where they were noted separately. Local boulders (e.g. granite boulders on the granite outcrop) were counted so that erratics could be expressed as a percentage of total surface boulders along a line. They were not included when sufficiently covered by peat that they might have been confused with bedrock.

The distinction between Strontian Granite and Moinian Schist boulders was obvious. The Moinian Schist forms angular blocks, dark in colour and often weathered to display an intricate pattern of contorted bedding planes or sheared quartz veins. The material ranges in size from small fragments to $4m^3$. Strontian Granite forms either a light grey or pink well-rounded boulder ranging from $0.5m^3$ to $5m^3$ but typically $1m^3$ in size. Surface markings include quartz veins and weathered xenoliths.

Strontian Granite erratics.

Along the western edge of the outcrop boulders have been transported on to the Moinian Schists (Fig.2.1A). The number of erratics rapidly decreases with increasing distance from the granite outcrop. For instance, along northing 58, erratics form 8% of total surface boulders within the first kilometre west of the outcrop. This falls to 1 - 2% five kilometres from the outcrop. At the northern edge of the outcrop no granite erratics have been found along northing 66 between eastings 81 and 82, or elsewhere north of the outcrop. No Strontian Granite erratics have been found in the extensive fluvioglacial gravels of the Shiel basin. Many granite erratics have been moved uphill: for example, along northing 64 boulders have been transported upwards 170m in one kilometre; along northing 58 granite erratics rise to 240m above the granite outcrop in three kilometres.

Only one portion of the eastern granite - schist contact lies outside the limits of the Loch Lomond Advance in the area covered by the erratics survey. This section occurs along the ridge between Beinn na Cille (NM 854542) and Fuar Bheinn. Nowhere have granite boulders been found east of this contact.

Strontian Granite boulders.

On the undulating granodionite plateau south of the head of Loch Sunart small variations in topography are reflected in the distribution of local boulders. On the plateau surface granite boulders are absent on westward-facing slopes but are often abundant on eastward-facing ones (e.g. NM 815600, NM 816590).

High densities of boulders are sometimes found in shallow gullies on the northern edge of this plateau, e.g. 56 boulders /100m in an area where the average for the plateau surface is 3 boulders / 100m. Although these figures partly reflect the extensive peat development on the plateau, this concentration may also be the result of a local movement of ice off the plateau and into the Sunart trough.

Moinian Schist erratics.

Nowhere are Moinian metamorphic erratics found on the granite along the western margin of the outcrop. Outside the Loch Lomond Advance limits, only 6 boulders of Moinian Schist have been found on the entire granite area, with the exception of the northern part of the outcrop, where the Loch Lomond Advance limit is uncertain. Four of these boulders are at NM 855570, one at NM 841600 and another at NM 822600. They form only 0.27% of the total boulders counted on the outcrop.

Conclusion.

The significant amount of erosion recorded by the glacial troughs and breaches indicates that they represent the result of repeated flow of ice along the same routes. That the broad patterns of ice flow during the Pleistocene might be similar is also indicated by the radial arrangement of glacial troughs around major centres of ice accumulation, such as Rannoch Moor (Linton, 1957). The large dimensions of many of the offshore basins also imply multiple periods of glacial erosion. The very nature of a glacial breach requires its formation to belong to a period of extensive glacial development. Thus much of the physiography of the Western Highlands is a composition of multiple glaciation throughout the Pleistocene.

The formation of the glacial breaches of the field area represents a time when the ice-shed was located east of Loch Linnhe, and ice from the high ground of the Ben Nevis-Glen Coe-Ben Etive area overrode the region. Linton (1951a), discussing the formation of the line of breaches in the N.W. Highlands, concluded (page 83) 'that the main area of accumulation lay east of the Atlantic-North Sea watershed, and that the latter was therefore extensively over-run and breached by the westward streaming ice'. The striae and erratics from the field area all suggest that the last major ice movement in the area was in a westward direction.

The extent to which local and foreign ice interacted and the relative importance of each in the formation of the landscape are difficult to assess. Since local ice built up during the Loch Lomond Advance it is reasonable to infer that it also built up as the ice-sheet began to form. It is possible that it accumulated to form a local ice-cap, which subsequently coalesced with ice from outside the area.

The relative importance of glacial breaching in an area must depend on its position relative to the major ice-shed and centres of accumulation. Western Inverness-shire has been intensely glaciated and breached. Corries, as defined morphometrically from the 1:25,000 maps, are virtually absent in this area (M. Dale, pers. comm.). The initial ice-shed was probably displaced eastwards with increasing ice accumulation. This during repeated glaciations would allow westward-flowing ice to breach the area, destroying pre-existing corries. In the study area, only five corries have been identified on the same morphometric basis; others have possibly been destroyed. To the north of the field area along the southern side of Glen Cona, shallow features exist which may represent the remnants of corries, virtually destroyed by extensive ice movement.

The topography of the field area would dictate that the ice-shed of any possible ice-cap during the ice-sheet period would lie east of the Strontian Granite batholith. The erratics survey therefore does not provide any evidence of the existence of a former local ice-cap over the field area during deglaciation. However the very low number of foreign erratics found on the Kingairloch hills does suggest that the local ice flow has removed erratics from the hillslopes. This is particularly likely on the steep slopes above Loch Linnhe where striae north of Loch a' Choire imply downslope movement of ice towards the loch. Below 200m striae are parallel with the loch, and suggest that final active ice movement was S.W. down Loch Linnhe. (This in turn suggests that ice movement in this direction was also important before a large ice cap had developed sufficiently to over-ride the Ardgour and Kingairloch Hills.)

It is thus envisaged that deglaciation in the field area from the ice-sheet maximum involved a brief period when ice flow was related to local centres over areas of high ground before rapid downwasting took place in situ. There is no morainic evidence for a halt stage or readvance associated with ice-sheet deglaciation in the field area. In accord with this is the clear distinction between the density of Moinian Schist erratics carried on to the Strontian Granite by the Loch Lomond Advance glaciers and the density of erratics outside the Loch Lomond Advance limits. If ice-sheet deglaciation had involved a local valley glacier readvance stage prior to the Loch Lomond Advance, then the sharp contrast between the Loch Lomond Advance and ice-sheet erratics illustrated by the erratics survey would not be present. The pattern of deglaciation has thus been different from the initial sequence of glacierization,i.e. during deglaciation the mountains and corries at high altitude became ice free first, with the last active ice being confined to the valley bottoms.

A brief summary of the proposed ice-sheet history in the field area is as follows:

a. Initial glacierization and the development of a local ice cap over the area, probably centered over the hills of Ardgour and Kingairloch.

b. The eastward displacement of the ice shed as this initial ice dome merged with an ice-sheet developed over higher ground to the east. Ice would then have flowed westwards across the field area, utilizing the glacial breaches.

c. A possible return to local ice movement from ice caps located over areas of high ground.

d. Rapid downwasting of ice in situ., with the last active ice being confined to the valleys.

CHAPTER 3.

THE LOCH LOMOND ADVANCE GLACIERS IN NORTH-WEST ARGYLL.

The Loch Lomond Advance in Scotland : Previous Work.

Previous Work : pre 1968.

Early Workers recognized that at the end of the Ice Age there had been a distinctive period of valley glaciation that succeeded the great ice sheet, or mer de glace. A. Geikie (1901, p. 285-286) recognized the distinctive characteristics of this final period of glaciation - 'as the vast covering of ice retreated, it came at last to be restricted to the corries and valleys among the higher groups of hills where it took the shape of local glaciers. Each mass of high ground had its system of glaciers, creeping down the glens, and bearing on their surfaces the heaps of earth and stones they received from the slopes on either side. It is this detritus which remains as so enduring and striking a memorial of the last phase of ice in Scotland.' This simple pattern of deglaciation 'subsequently became obscured by more elaborate, often conflicting interpretations, and has emerged again only quite recently.' (Sissons, 1976, p. 91).

In an important paper in 1933, Simpson described two separate readvances. The Perth Readvance was followed by a later one that formed moraines enclosing the southern part of Loch Lomond and the Upper Forth Valley. From the evidence of marine shells incorporated in these moraines, Simpson (1933) concluded that before the readvance, both Loch Lomond and the Upper Forth Valley must have been indentations of the sea. Other descriptions of the valley glaciation were by Bremner (1939), Wright (1937), McCallien (1937) and Bailey (1960).

By 1894, James Geikie had established a relationship between raised marine shorelines and glacial limits. From the absence of the '100 ft (30m) raised beach' in the upper reaches of Loch Carron and Loch Kishorn, he concluded that the valley glaciation was contemporaneous with this raised beach. On the Isle of Mull, Wright (1937) found that the '100ft (30m) raised beach' could not be traced into the mountain glens, while Bailey (1924), concluded that the '75ft (23m) raised beach' on Mull was contemporaneous with the Loch Don Moraine because the beach was absent from inside this glacial limit.

In 1955 Charlesworth published the first comprehensive study of the readvances of the Scottish Highlands and Islands. He recognized two major retreat stages of the ice-sheet. The first was the Highland Glaciation (Stage A). At this time ice covered the whole of Scotland north of the Lammermuir-Stranraer moraine except for the Shetland Islands, northern Orkney and 'Moraineless Buchan'. There were eleven sub-stages before the Moraine Glaciation (stage M) which was equivalent to the valley glaciation of earlier writers and where ice was restricted to the Highlands and Islands. Stage M was correlated with the Ra and central Swedish moraines of Younger Dryas age, and was thought to be contemporaneous with the '100ft (30) raised beach'. Charlesworth recognized a further nine sub-stages during the final melting of the ice. Maps showing retreat stages of valley glaciers and local ice caps were published in imaginative detail. These limits have not been substantiated in some areas, and have been extensively modified in others by the more detailed, accurate mapping of later workers (e.g. Sissons, 1977a, 1977b).

Donner (1957) determined the relative age of Loch Lomond Advance moraines by using the technique of pollen analysis on sediments sampled from either side of the Menteith moraine (see Chapter 5). The analysis involved the recognition of distinctive climatic periods derived from the reconstruction of the vegetational history from the pollen record. At a site outside the moraine, the basal sediments were Lateglacial in age and three pollen zones could be defined, each associated with a definite litho-stratigraphy. A basal minerogenic layer represented the older Dryas of the continental stratigraphy (equivalent to pollen zone I (Godwin, 1956)). Above this was an organic gyttja, contemporaneous in age to the Allerød interstadial of Denmark (znII) and the Loch Lomond Interstadial (Gray and Lowe, 1977, p. xiii). An overlying minerogenic layer marks a return to the cold conditions of the Loch Lomond Stadial (Gray and Lowe, 1977, p.xiii) of Younger Dryas age (zn III). Above the Lateglacial deposits, Postglacial sediment relates to the vegetational history of the Flandrian. The absence of a Lateglacial stratigraphy from the site inside the Menteith moraine led Donner (1957) to conclude that the cold flora zn III deposits equated with the glacial readvance.

In a similar investigation at Oban, Donner (1957) found Lateglacial stratigraphy outside and only Flandrian sediments inside a limit to the Moraine Glaciation mapped by Charlesworth (1955). However Synge (1966) and Synge and Stephens (1966) proposed that in this area Charlesworth's stage M limit consisted of two separate stages. A younger limit was mapped to the north of Oban and on Mull. This has been confirmed at Loch Etive and Loch Creran as being of Loch Lomond Advance age (Peacock, 1971b; Gray, 1975a). To the south, an

Oban-Ford moraine was believed to be of equivalent age to the Perth Readvance. This area has been re-mapped by Gray and Sutherland (1977) and they suggest that the moraine 'represents only fairly brief diachronous halts in the general recession of ice'(p.44).

McCann modified Charlesworth's Stage M limit in the Western Highlands to include the Loch Etive and Corran outwash fans (McCann, 1961). He described other gravel outwash deposits previously designated as raised beaches at Loch Morar, Loch Shiel, Loch Creran, Loch Nell and Glen Feochen. McCann envisaged a former gravel outwash fan to explain the large areas of raised beach at Ballachulish and placed the terminus of the Loch Leven glacier at this point. In 1966 McCann suggested that all these gravel deposits were contemporary in age and represented the terminal outwash fans of Lateglacial glaciers. He assigned their formation to the Loch Lomond Advance, though associated them with a lower sea level (40ft, (12m)) than the '100 (30m) raised beach' stage proposed by Charlesworth (1955).

Sissons (1967a) provided an absolute age for the Menteith moraine, confirming Donner's 1957 conclusions. Radiocarbon dates from shells in the Menteith moraine and the Loch Lomond end moraine complex gave ages of 11,800 ± 170 B.P. and 11,700 ± 170 B.P. respectively. This implies that the sea occupied the Forth Lowland and Loch Lomond before these areas were re-occupied by glaciers, which redeposited the shells.

Similar dates for the Loch Lomond Advance of 11,430 ± 220 B.P.; 11,530 ± 210 B.P. and 11,805 ± 100 B.P. have been obtained by Peacock (1971a). These radio-carbon dates were derived from shells found in disturbed marine clays, partly buried by terminal outwash at Loch Creran. Another date of 11,330 ± 170 B.P. from shells incorporated into the Kinlochspelve Moraine, Mull (Gray and Brooks, 1972) provided another absolute age for these ice limits.

Sissons (1967b) presented a generalized map of the Loch Lomond Advance limits of Scotland and stressed the need for more detailed work. Some of the more important aspects of these studies completed since 1967 follow.

Previous Work : 1968-1980.

In this section, and throughout subsequent chapters, Loch Lomond Advance rather than Readvance is used. This is because the writer supports the conclusions of Sissons (1974b, 1976a) that there was complete deglaciation of the ice-sheet in Scotland. The subsequent glaciation during the Loch Lomond Stadial was therefore a separate advance.

In producing his 1967 map of the Loch Lomond Advance limits of Scotland, Sissons, among other features, relied on the extensive areas of hummocky moraine (chaotic mounds of poorly sorted debris, often strewn with boulders) to delimit the extent of the advance. In the absence of terminal and lateral moraines, the often abrupt downvalley limit to hummocky moraine was used to mark the maximum extent of a former glacier. The assumption that hummocky moraine is primarily of Loch Lomond Advance age made mapping of the limits of this advance feasible. For instance, in the Lochnagar area Sissons and Grant (1972) determined the terminal margin of some of the advance glaciers on the basis of the downvalley termination of hummocky moraine. In the S.E. Grampians Sissons (1972a) has used these mounds to delimit small glaciers in the heads of Glen Doll and Glen Esk. On the Isle of Mull, Gray mapped a small ice cap and separate valley glaciers on the basis of terminal, lateral, fluted and extensive hummocky moraine, together with drift limits (Gray and Brooks, 1972).

Thompson (1972) mapped an extensive system of Loch Lomond Advance glaciers that existed in western Perthshire primarily from the distribution of hummocky moraine. He argued that the 'logical' pattern of valley glaciers in Perthshire suggested an age relationship - 'the reasonableness of this pattern, the similarity and continuity of these deposits throughout the area, and the presence of a single clear limit to each valley system seem to justify the proposition that the fresh hummocky drift in each valley system is the product of one stage of glaciation' (Thompson, 1972, p.307). Associated with this mapping was a detailed palynological investigation by Lowe (1977) and another study by Walker (1974, 1975a, 1975b) related to the mapping of the Loch Lomond Advance limits by Sissons in the South-East and Central Grampians (Sissons, 1972a, 1974b, 1975a). Pollen analysis of sediments from sites inside and outside these limits, in the manner of Donner (1957), confirmed the Loch Lomond Advance age of these former glacial margins.

This assignment of the formation of hummocky moraine to the Loch Lomond Stadial, and the growing assumption (originating from Sissons, 1967, p.137) that Scotland was completely deglaciated before the Loch Lomond Advance was strongly contested by Sugden (1970, 1973a, 1973b, 1974) and his arguments were discounted by Sissons (1972a, 1973a, 1973b, 1974a).

On the basis of morphological mapping in the Cairngorms, Sugden (1970) proposed that the Loch Lomond Advance was no more than a minor oscillation during the deglaciation of the main ice-sheet, and that ice existed throughout the Lateglacial period over the Cairngorm mountains and in the adjacent Spey Valley. He also mentioned another possibility; that ice lingered in the corries of the Cairngorms as small glaciers throughout the Lateglacial. Sugden (1970) disagreed with the interpretations of the age of the hummocky moraine. He argued that in the Cairngorms, this morainic material was restricted to the heads of glens and was formed by patches of stagnant ice as the last ice-sheet decayed and became isolated from the surrounding plateau accumulation areas.

Sugden (1970, p.215-216) concluded that 'the Loch Lomond Advance was probably less significant over Scotland as a whole than commonly supposed', and that 'the Cairngorm equivalent of the Loch Lomond zn III readvance is problematical'. Sissons and Grant (1972) however, pointed out that Sugden (1970) had omitted an obvious limit to hummocky moraine immediately off his detailed map of part of the Cairngorms, and that this probably represented the Loch Lomond Advance limit in this area, evidence for which Sugden maintains is doubtful. Sissons (1974a) also mentions the contrast in size between fluvioglacial landforms; thus massive accumulations of outwash in the Spey valley and meltwater channels cut to a depth of 30-50m in rock are associated with ice-sheet decay, while associated with the Loch Lomond Advance are delicate meltwater channel systems typically less than 4m deep. These systems are absent from areas covered only by the ice-sheet (Sissons, 1974a).

Sugden (Sugden and Clapperton, 1975) was forced to reject his first hypothesis on the extent of the ice in the Cairngorm region because of a date of 13,151 ± 390 B.P. for basal organic sediments from a Lateglacial site in the Spey valley at Loch Etteridge - (Sissons and Walker, 1974). Sugden concluded that his alternative possibility (Sugden, 1970), that ice remained in the high corries of the Cairngorms, was now correct. Sugden and Clapperton (1975) again strongly critisised the use of hummocky moraine on the basis of:-

a) The discovery of a Lateglacial stratigraphy at a site near Loch Builg, in the Eastern Cairngorms (Clapperton <u>et al</u>., 1975). This is inside an area referred to by Sissons (1967b) as hummocky moraine and shown by him on a general map of Scotland as being inside the Loch Lomond Advance limit. However, the area had never been mapped in detail by Sissons.

b) That the alternative suggestion for the formation of hummocky moraine - the melting of stagnant ice restricted to the heads of glens - can satisfactorily explain its distribution. This is misleading as hummocky moraine occurs in other localities, and does not account for the typical sharp downvalley limit of such moraine.

Sugden has placed far too much emphasis on the use of hummocky moraine in the delimiting of Loch Lomond Advance glaciers. The maps published by Sissons and other workers are essentially based on an association of geomorphic features. These include 'the distribution of fresh hummocky, fluted, end and lateral moraines, drift and boulder limits, together with contrasts with periglacial features and supposed ice-sheet landforms and sediments outside the readvance limits' (Gray and Lowe, 1977b, p.167). Also fluvio-glacial outwash, striae and erratics have been used.

Many Loch Lomond Advance glaciers do in fact have well defined terminal and lateral moraines (e.g. in the N.W. Highlands (Sissons, 1977b; Robinson, 1977)). Fluted moraine is characteristic of Loch Lomond Advance glaciers (Sissons, 1976a, 1976b; Peacock, 1967; Gray and Brooks, 1972). In the North West Highlands, with one possible exception, all fluted moraine occurs within the inferred glacial limits of the Loch Lomond Advance (Sissons, 1977b). Robinson, (1977) mentions that only two former glaciers out of 23 in the Applecross Peninsula have not left fluted moraine. A measure of the validity of the view that these features relate to the Loch Lomond Advance must be the inability (so far) of other workers to locate the three-fold Lateglacial stratigraphy inside an inferred Loch Lomond Advance limit mapped in detail using these techniques.

The detailed palynological evidence from the Lateglacial and the more numerous Postglacial sites shows that there has only been one period of climate cold enough to have maintained glaciers in Scotland since deglaciation. With two possible exceptions, no former glacier has left more than one set of end moraines in Scotland. Although it is impossible to prove that all the moraines of the 'valley glaciation' are of the same age, it is logical to accept the simplest explanation and attribute their formation to the cold stadial conditions represented by the pollen stratigraphy (Sissons, unpublished).

Sissons (1974a) used standard glaciological theory to infer past climates from former glacial limits. While the climatic conditions of the Lateglacial are discussed in detail in Chapter 8, two important papers, Sissons (1974a) and Sissons and Sutherland (1976) are discussed here as they are essentially a development from geomorphic mapping.

In the Central Grampians Sissons (1974a) reconstructed a Lateglacial ice cap using mainly hummocky moraine, meltwater channels and periglacial features. The former ice surface was then contoured. If the assumption is made that ablation and accumulation are linearly related to altitude (Schytt, 1967; Chorlton and Lister, 1971) the firn line may be calculated from the areas between successive contours. The firn line for this Gaick ice cap was 790m, which meant that at the time of maximum advance, the firn line had only to rise another 115-190m to be clear of the ice surface. Further calculations suggested that this ice cap (32km) could easily have accumulated during the 500 years conventionally allocated to the Loch Lomond Stadial. From the average firn line former summer temperatures may be inferred using data provided by Ahlmann (1948) and later Liestol, (unpublished) for modern Norwegian glaciers, a suitable present-day analogy to the former Loch Lomond Stadial glaciers. 'Assuming that precipitation in the Gaick area was 80% of its present value (less precipitation at lower temperatures and a partially frozen North Sea), a July mean temperature of about 3°C at the 790m firn line is indicated, corresponding to a sea level temperature of about 7.5°C.'

Continuing with a more complex analysis, Sissons and Sutherland (1976) were able to make further detailed climatic inferences from 27 former Loch Lomond Advance glaciers in the S.E. Grampians. The glacial limits mapped in detail by Sissons (1972) were supplemented by other quantitative data relating to direct solar radiation, potential avalanching areas and potential snow-blowing areas. These factors were considered to influence the distribution and altitude of these former glaciers.

Equilibrium firn lines for the glaciers while at their maximum extent were calculated (as in Sissons, 1974a) and from these results a regional firn line using trend surface analysis was obtained. The regional firn line when corrected for the influence of direct radiation, had a gradient of 14.5m/km rising from 500m in the south-east to 850m in the north-west. An equation was devised to indicate the appropriate average winter snow-fall on each glacier during its period of growth. Making an allowance for summer rainfall, an average annual precipitation map for the S.E. Grampians during the maximum of the Loch Lomond Stadial was produced. When compared with a map of present precipitation, the values are similar but the distribution is different with more precipitation in the south-east and less in the north and north-west. This different distribution was explained by an increase in snowfall associated with south-easterly winds. It was suggested that these were related to a more vigorous circulation. Inferred annual average monthly sea-level temperatures were 6°C for July and -8°C for January.

Sissons (1977a) presented the geomorphic evidence for 13 Loch Lomond Advance glaciers in the Cuillins and Eastern Red Hills of Skye.

From calculations of the mass balances of these former glaciers, he concluded that 'glaciers that flowed south and south-southwest from the radiating corries of the Cuillins were larger and had much lower equilibrium firn lines than those that flowed north and north-east... It is inferred that the principal snow bearing winds were from the south, snowfall being much higher in the South Cuillins than in the north-east' (Sissons, 1977a, p.23).

A generalized regional firn line derived using linear trend surface analysis from the firn lines of 70 glaciers in the N.W. Highlands showed an inland rise from 350m to 700m. However this regional firn line incorporated considerable local discrepencies and it is not improbable that detailed analysis using the methods applied in the smaller, more topographically homogeneous area of the S.E. Grampians may reveal a more complicated pattern.

Previous Work in the Field Area.

Geological Survey officers mapped the drift deposits of the field area, though their primary concern was with the solid geology (Bailey, 1924, 1960; Lee and Bailey, 1925). With the exception of sheet 52, which has a separate drift map, the glacial mapping has been superimposed on the solid rock maps (Nos. 44 and 53). The The Geological Survey distinguished Morainic drift, boulder clay, and glacial and fluvioglacial deposits. 'Boulder clay' being absent, the most widespread glacial deposit is morainic drift. The distribution of this drift in many places coincides with the Loch Lomond Advance limits mapped by the writer (e.g. the former glacier in a corrie, Camas a' Choirce, south of Ben Resipol, NM776640), while in other places it relates to ice-sheet drift with no association with former glacial limits (e.g. Glen Liddersdale, NM775585). No attempt was made to distinguish morphological features such as areas of hummocky moraine (these being mapped as morainic drift). The Geological Survey envisaged that these drift deposits were the result of a valley glaciation stage during ice-sheet deglaciation.

In a paper on the geology and physiography of Morvern Scott (1928, p.174) stated 'Glen Tarbert, Glen Laudale, Glen Galmadale etc. also show signs of valley glaciation, and small corrie glaciers were present in the glens south-west of the head of Loch a' Choire', although he did not mention any specific evidence for these former glaciers.

Charlesworth (1955, Fig. 9, p.821) mapped a complex system of readvance glaciers in the field area. In the very general location of many of these Stage M glaciers he was correct, though in virtually every case their delimitation in detail was inaccurate (e.g. the eastern end of Glen Tarbert), while in other areas no evidence has been found to justify the proposed limits (e.g. Corrie Reidh). In the absence of clear terminal and lateral moraines by Loch Linnhe, Charlesworth placed his Stage M limit south of Loch Leven, the Loch Linnhe and Loch Leven glaciers being mapped as confluent. This has since been modified by McCann (1966b) but Charlesworth did correctly identify the limit of glacial readvance in Loch Shiel and at the head of Loch Sunart.

The large gravel deposit constricting Loch Linnhe at Corran has received more attention in the literature than any other geomorphological feature in the field area. Early workers (e.g. A. Geikie, 1901, p.502) thought that it was a raised beach deposit. Bailey, (1924) accepted the view of Wilson, an officer of the Geological Survey, that the gravels were formed in a lake that was impounded between a Linnhe glacier north of Corran and a Leven glacier to the south. Peach and Horne (1910, p.495-496) suggested that the two largest lochans in the gravels were kettleholes in the '100ft raised beach'.

McCann (1961) described the Corran gravels and suggested, on the basis of fabric analyses, that they were deposited by streams. He concluded that the fan had been deposited sub-aerially during a period of low sea-level.

McCann (1966b) examined other outwash deposits on the West Highland coast and concluded that they 'are large outwash fans, deposited sub-aerially, which mark the limits of a contemporaneous readvance of the Loch Linnhe and Loch Etive glaciers and indicate a considerable period of still-stand of the glacier fronts at a time when contemporary sea-level was below or at about 30ft (9.1m) above O.D.' (McCann, 1966b, p.87). McCann included a detailed description of the Loch Lomond Advance limit at the western end of Loch Shiel.

Synge (1966) and Synge and Stephens (1966) disagreed with previous interpretations of former glacial limits and proposed two separate readvances in the study area. Synge (1966) interpreted the absence of the '100ft (30m) raised beach' in Loch Linnhe as indicating a continuation of the Oban-Ford moraine northwards along the Morvern shore to Loch Linnhe. This readvance was thought to be of equivalent age to the Perth Readvance, and Synge (1966, p.325) said that 'large lateral moraines between Inversanda and Cilmalieu may indicate part of the ice margin at this stage'. A younger Connel stage of zn III age was placed at the outwash fans of Etive and Corran. Synge (1977) has again maintained that there were two glacial stages, with a 12,000 B.P. readvance ice margin extending from Otterferry on Loch Fyne northwards across the field area to join Loch Lomond Advance ice in the Shiel basin at Pollock (NM 792688). No evidence has been found for Synge's moraines between Inversanda and Cilmalieu and his earlier readvance limit cannot therefore be accepted.

Sissons (1967b) accepted McCann's general view that the major outwash spreads on the west coast of Scotland are all of the same age. Peacock (1970) summarized previous work in the field area, especially that of the Geological Survey, as part of a review of the glacial geology of Western Inverness-shire. He described in detail the terminal ice limit of the Shiel glacier though this is essentially restating McCann's (1966b) interpretation. The figure (p.49) accompanying Peacock's paper of the Loch Shiel outwash complex is basically a reproduction of the drift map (Sheet 52) of the Geological Survey.

The Loch Lomond Advance Limits in North-West Argyll.

Introduction.

The landforms in the field area were mapped on Ordnance Survey aerial photographs at a scale of about 1:25000 using a Delft Stereoscope with X 4 magnification. The details marked on these photographs were then checked in the field and where necessary alterations were made using a hand stereoscope. The relevant geomorphological information was then transferred from the aerial photographs on to Ordnance Survey G.S.G.S. 1:25000 scale maps using a Zeiss Sketchmaster.

The numbers in the following text have corresponding numbers on Figs. 3-1 and 3-2. Fig. 3-1 shows the geomorphological evidence for, and the reconstructed maximum limits of the Loch Lomond Advance glaciers in Kingairloch, Glen Tarbert and Glen Gour. Those for Loch Shiel, by Ben Resipol and Glen Laudale are shown on Fig. 3.2.

Kingairloch.

a) Glen Sanda.

On the S.E. slopes of the Beinn Mheadhoin range small hummocky morainic mounds (2-3m high) with many granite boulders are found at 460m (NM 820494), and further downslope at 300m (NM 820484). Westward there is a definite limit to hummocky moraine along the lower slopes of Meall na h-Easaiche (2) at 320m. The hummocky moraine below this limit is very distinctive, 4-5m high and with a suggestion of N.W.-S.E. linearity on the aerial photographs. Although the latter is difficult to identify on the ground, it suggests that final ice movement was towards Glensanda (a former settlement in Glen Sanda). The hummocky moraine forms discrete mounds on the lower gentle slopes.

The main area of ice accumulation was in the shallow corrie of Leac na Fidhle (3), due south of the summit of Bein Mheadhoin.

Small fragmented sections of fluted moraine extend down-slope from over 500m to 320m trending in a south-east direction. These flutes merge into hummocky moraine south-west of Meall na Fidhle (4). Fluted moraine west of this point trends S.S.W., and downslope at NM 794497 becomes fragmented, lineated hummocky moraine, that indicates a deflection of ice movement to the south-west.

Hummocky moraine occurs around NM 793497 in the head of a small shallow valley. A well defined limit to this moraine area runs downslope from 450m to 250m along the northern side of the valley; this is interpreted as marking the former margin of the glacier. Large granite boulders (3m) are associated with the hummocky moraine, together with perched blocks (e.g. at NM 792500). Although there is no end moraine, the abrupt limit of hummocky moraine strewn with boulders is in complete contrast to the bare peat-covered ground outside this inferred limit (5). A dfift limit, with hummocky moraine below, marks the lateral position of the southern edge of this ice lobe. Its margin rises to 380m at NM 787490 where the ice merged with the second western ice lobe in upper Glen Sanda.

Upper Glen Sanda, a glacial breach, merges with the top of Glen Doire Dhairaich at NM 780485. A glacier descended to terminate in the upper part of the latter glen (6) where there is a limit to hummocky moraine, which is up to 5m high and consists of a yellow sandy till with incorporated boulders of rotten granite. The southern edge of this former glacier is marked by a drift limit running eastwards from NM 777481 to NM 796480 for over two kilometres. This drift limit initially rises from 200m to 300m in the upper part of Glen Sanda before descending eastwards down the glen to about 150m. North of this drift limit is a large area of hummocky moraine (7) with mounds reaching 6-7m in height, but becoming more sporadic in distribution further east.

The southern drift limit (described above) dies out at NM 796480 and several small mounds of till in the valley bottom N.E. of this point suggest that the former glacier extended to within half a kilometre of the sea (1). The final section of the Glen Sanda river east of these hummocks has a braided channel over coarse gravels. This may represent the eroded and reworked remnant of outwash derived from the glacier.

b) The four corries south-west of Loch a' Choire.

There are no moraines in any of these four north and north-easterly facing corries. In Coire Reidh (NM 831511) and Coire Ban (NM 810525) the valley sides are covered by hill slope debris. Thus a stream at NM 834508 in Coire Reidh has exposed numerous sections of debris consisting of granite stones up to 30cm in size embedded in a light brown sandy matrix. The steep hill slopes and crags of these two corries are associated with numerous debris chutes and abundant scree. In Coire Ban, sections showing angular poorly stratified granite stones and sand reach a depth of 4m (at NM 804518).

The intermediate corries, Coire Beag (NM 820513) and Coire nan Each (NM 810513), contain areas of ice-moulded rock, but there are no striae or roches moutonnées to indicate the former direction of ice movement. At the confluence of the corries is an area of dissected till (NM 823523). A large section has been cut by the river at NM 822524, exposing 5m of light grey clay with unsorted rounded boulders up to 60cm in size. This contrasts with the sections of hummocky moraine (e.g. in Glen Uisge) where the incorporated boulders are more angular and the matrix contains a higher sand content.

East of the Old Mill (NM 824525) an area of alluvial sand and gravel extends for over a kilometre to the head of Loch a' Choire. Although now cultivated, the area is scarred by a former braided channel system. Most of this alluvium may have accumulated during the Loch Lomond Stadial when conditions for weathering in the drainage basin would have been more suitable than during the Postglacial. The The stream draining Coire Reidh has a comparable alluvial deposit, this being a large subaerial fan, now also cultivated, at NM 837523. The stream has incised a channel into its surface.

c) Coire Ghardail and Glen Uisge.

Coire Ghardail (1) is a southerly facing glen rather than a corrie. That ice accumulated in it and flowed south-west to Glen Uisge is demonstrated by excellent fluted moraine that starts high up on the back clope of the glen above 500m (2). The flutes are often initiated as a line of boulders and rubble about 1m high. Some converge and all increase in size down the valley. They form lines of mounds rather than a continuous ridge, individual mounds being up to 5-7m high and from 25m to 200m long. Sections cut by streams in these moraines (e.g. at NM 844567 and NM 845571) show a light grey till with granite boulders up to 1.5m in size. Large ice-transported boulders of granite up to 4m are found in the glen, especially in the southern part.

The majority of fluted moraine is confined to the central and eastern side of Coire Ghardail above the stream Allt a'Cheallaich (NM 845551). A poor drift limit at 500m (4) appears to mark the upper margin of the former glacier on the western flank of Faur Bheinn. The upper edge of small fluted moraine further south delimits an ice accumulation area occupying ground west of the col that leads to Glen Galmadale (3). This fluted moraine records a S.W. movement of ice that merged with the glacier in Corrie Ghardail.

When the Ghardail glacier reached Glen Uisge, a glacial breach orientated N.W.-S.E., ice diverged to flow north-west to Loch Uisge and south-east to Loch a'Choire. The former ice movement up Glen Uisge is recorded by an extensive area of hummocky moraine and associated glacially transported boulders, extending from the south-western side of Corrie Ghardail over 2km to Loch Uisge (NM 805550). There is a clear upper limit to this hummocky moraine along the lower flanks of Ceann na Coille (5), sloping west-wards from 240m to 160m. An abrupt western limit to these hummocks marks the furthest extent of this former ice lobe (6). Sections through morainic mounds in road cuttings (e.g. at NM 827543) display an unsorted deposit of large rotten granite boulders in a light brown sandy matrix.

A small corrie glacier from Coire Shalochain (7) joined the ice in Glen Uisge. Fluted moraine in the corrie indicates a N.W. direction of ice movement, a drift limit at 300m under the slopes of Sgurr Shalochain (8) marking the former lateral position of ice along the southern side of Glen Uisge. A boulder limit (9) marks the terminal limit of the former glacier. Although it is obscured by forestry plantations, it is composed of large (up to 3m) rounded granite boulders and is similar to the limit at Achnalea (see below).

d) <u>Glen Galmadale</u>.

Glen Galmadale is a large glacial trough extending south from the summit of Creach Bheinn, with four corries (4,5,6 and 7) cut into the Fuar Bheinn - Beinn na Cille ridge on the western side, and two corries (2 and 3) in the N.E. corner of the glen. That an ice lobe from a corrie (3) descended into the head of the main valley is indicated by the fluted moraine on the back wall of the glen descending from 425m to 180m adjacent to the corrie. The fluted moraine becomes fragmented and merges with hummocky moraine on the floor of the glen at NM 874563. Fluted moraine 3 - 4m high in the adjacent corrie (2) extends from 480m to 300m. Between the two corries, a large medial moraine, some 15m high, extends down into Glen Galmadale. Initially located on the interfluve between the two corries it became displaced to the western side suggesting the dominance of ice from the more easterly corrie (2). A section by the stream (at NM 874560) displays 4m of light grey sandy till with granite boulders (40 - 150cm).

Most of the glen has a thick drift mantle, though often it is extensively gullied. A poor drift limit is discernible on the eastern side of the glen, sloping from 380 to 250m in altitude. On the western side of the glen, a drift limit of 400m marks the former ice margin on the southern side of Coire a'Chuil Mhaich (4). Further south two corries (5 and 6) both have areas of ice-smoothed rock but they lack striae. There is a poor drift limit on the northern side of the former corrie between 500m and 450m and another at 400m on the southern side of the latter. The burns draining these corries show sections of till (e.g. at NM 866546, 2.8m of till is overlain by 1.3m of slope debris). Many of the streams have cut gulleys, and together with debris chutes, may have destroyed the upper limit of drift in many parts of the glen.

The position of the terminus of the former glacier is uncertain. There is a low mound of till running across part of the valley at Glen Galmadale Lodge (1), probably an eroded fragment of the drift mantle in the glen rather than a constructional feature. South of this point is an area of fluvioglacial outwash (NM 864528) that has been reworked by the Galmadale River (and in places the sea, to form poor raised beach fragments).

Kingairloch : The Evidence of Glacial Erratics.

The prime objective of the erratics survey in this area was to provide evidence relating to possible glacial occupation of the four corries south-west of Loch a'Choire during the Loch Lomond Advance. At the time of the survey, it was thought likely that corrie glaciers had existed in these steep-walled north to north-east facing corries, and that they might have merged with ice from Coire Ghardail and Glen Uisge, although there is no morphological evidence for a terminal limit in the Loch a'Choire area. The whole area is situated on the Strontian Granite outcrop, and it was thought probable that the survey might reveal a situation similar to that found in Glen Laudale or at Camas a'Choire, where ice-sheet erratics from east of Loch Linnhe may be found outside but not inside the Loch Lomond Advance limits.

No relationship was found between the distribution of metamorphic erratics or granite boulders, and the probable location of the former glacial limits within the corries. Only two erratics were located by the survey in 23km of traverses (at NM 837510 and NM 814510). Several Moinian Schist boulders were found in the stream bed at NM823523, while two other erratics have been recorded by the Geological Survey. The failure of the erratic survey in its objective was because of the extremely low number of ice-sheet erratics in the area (see Chapter 2). The distribution of granite boulders showed no consistent pattern. The high numbers recorded below some corrie back walls (e.g. NM 805520) suggest that many were rockfall debris, although this was not obvious in the field.

An attempt was made to map the distribution of porphyritic biotite-granite boulders on part of the porphyritic granodionite granite outcrop, to determine the direction of ice movement in the corries. However no consistent difference could be determined between the two rock types.

North of Loch a'Choire, there are again insufficient erratics to display any relationship with the Loch Lomond Advance limits. Thus, while the evidence is limited, the study of erratics gives no support to the view that glaciers existed S.W. of Loch a'Choire during the Loch Lomond Stadial. This accords with the evidence given previously.

The numbers of granite boulders do however reflect the Loch Lomond Advance limit at the western end of Glen Uisge. For instance, along northing 55, 43 granite boulders were recorded in 1.8km outside the former glacial limit while 532 occurred, associated with hummocky moraine, in an equivalent distance inside the limit.

Glen Tarbert.

a) Coire an Iubhair.

The terminus of a former glacier in this glen is inferred from the limit of sporadic morainic mounds (1). A drift limit traces the eastern margin of this former glacier northwards along the eastern side of the glen. The glen swings round to the west where it joins the upper part of Gleann Feith 'n Amean to form a glacial breach (3). On this now northernside of the glen, the drift limit rises from 450 to 550m along the southern slopes of Beinn Bheag (2). Hummocky moraine (3-5m high) is restricted to the valley floor while streams and debris chutes bring material down-slope to rest against the upper limit of drift. This drift limit extends along the head of the glen e.g. at NM 902630.

A small tributary glacier in a small steep corrie high on the N.E. slopes of Garbh Bheinn (NM 912624) is suggested by the large areas of glacially smoothed rock below the inferred lateral ice limit, contrasting with weathered, shattered rock outcrops above it. The western side of the glen has steep ice-smoothed rock walls (4) and, consequently, the glacier margin may have been slightly higher than the inferred lateral limit at this point. Further S.E. a poor discontinuous drift limit extends along the western side of the glen, sloping from 200m down to the terminal limit at approximately 50m (1).

b) Inversanda.

The limit at the eastern end of Glen Tarbert is marked by an abrupt limit to hummocky moraine and glacially transported boulders 2km west of Inversanda (NM 926595). From this point (1) an outwash plain extends eastwards for nearly 2km from a height (obtained by levelling) of 18.3m to Postglacial beach deposits at approximately 7m O.D. (a gradient of 5.6m/km, see Fig.4.7). The river Tarbert is incised well below the upper part of the outwash fan. Below a bridge at NM 933593 the river has meandered and destroyed much of the original outwash surface. Sections at NM 927596 exposed in the river bank show coarsely sorted and stratified gravels, while further down stream another river bank section 2.5m high displays sands and gravels with crude cross-bedding, incorporating small boulders up to 60cm in size.

Along the northern side of Glen Tarbert, a poor drift limit extends back from the former glacial terminus (1) towards Coire a'Chothruim (2). Hummocky moraine (strewn with boulders and reaching 6m in height) is found immediately inside the limit, becoming more sporadic higher up the glen towards the former ice-shed. On the southern side of the glen, the glacier was confined by the ridge Meall a'Bhaghaid (3). An inferred ice limit is placed at 250m on the northern side of the ridge. Below this limit are large glacially transported boulders, till and glacially smoothed rock, while above are steep slopes of scree and angular rocky crags. Striae on the ice-smoothed rock indicate a west-east ice movement. As on the opposite side of the valley, hummocky moraine becomes more infrequent away from the terminal limit.

c) Coire a' Chothruim.

This very steep sided corrie (4) is situated immediately south of the summit of Garbh Bheinn. The lower slopes of the corrie are mantled in drift, but there is no obvious continuation of the drift limit from Glen Tarbert. The drift mantle has been extensively gullied, exposing sections of unsorted stones and boulders (up to 80cm) in a dark brown sandy-clay matrix (e.g. at NM 897608). It is believed that ice from the corrie joined the adjacent large glacier.

d) Coire nam Frilhallt. (5)

This is the most easterly of three corries situated on the northern slopes of Creach Bheinn, along the south side of Glen Tarbert. The floor and lower slopes of the corrie are thickly mantled in drift, with an indistinct limit on the western side at approximately 400m. The drift is extensively gulleyed, especially on the eastern side of the corrie where a possible upper limit of drift has been destroyed by scree and debris chute material. Large boulders up to 3m are found on the lower slopes and floor of the corrie well away from Postglacial rock-fall debris.

e) Coire Dubh (6)

This corrie is west of, and adjacent to, Coire nam Frithallt (5). Hummocky moraine begins in the lower part of the corrie (NM 872598) with the hummocks increasing in size from about 3m to 8m over a kilometre away in the bottom of Glen Tarbert. Drift is restricted to the valley floor (sections of till are exposed at NM 871599) while the lower parts of the corrie rock-walls are glacially smoothed. Large areas of ice-moulded rock occur at NM 866597 where ice flowed north-west out of the corrie and over-rode the 'corner' between the corrie side wall and the side of Glen Tarbert. The marked contrast between this polished rock and the frost-shattered rock higher up the valley side points to an ice limit along the western shoulder of the corrie at about 380m.

f) Coire Leacach.(7)

Although the least well developed of the three corries on the south side of Glen Tarbert, this corrie formed the largest accumulation area of ice. Fluted moraine descends from 550m and, converging on the present course of the stream Allt Duibhleac Riabbach (NM 855595), illustrates the final north-westerly direction of ice movement. This fluted moraine is associated with a large number of boulders which become more numerous down slope from the former convergence of ice from the corrie and the adjacent flanks of Creach Bheinn. The fluted moraine is approximately 3m high, but below 350m these ridges become very fragmented and finally disintegrate to form an area of chaotic hummocky moraine (2-3m high) with boulders.

An excellent boulder limit descends from the western margin of this area of hummocky moraine (8), from 300m altitude down to the terminal limit of Achnalea (9). This boulder limit cannot be traced uphill above 300m, but there is a marginal area where hummocky moraine dies out, and here an inferred limit has been placed.

g) Achnalea.

The boulder limit marking the western edge of ice from Coire Leacach can be traced down the side of Glen Tarbert from 300m to a point in the glen half a kilometre west of the head of Loch Sunart (9). Large boulders, predominately granite and up to 5m in size, and scattered along the southern side of the glen. There is an obvious distinction between the boulders comprising the boulder moraine and those derived from rockfalls from the valley side (e.g. at NM 842603), where the latter are more angular, are gravity sorted out and relate to a rock scar on the crags above.

The boulder moraine is best developed on the northern side of the glen. Here, a massive spread of boulders - up to 4m in size, but never more than one boulder high - sweeps north-eastwards up the valley side above Achnalea, NM 851609 (Achnalea, Gaelic for 'field of grey', refers to the abundant grey granite boulders), to reach the plateau surface at 250m (10) some 2km away from the terminus. This boulder limit was traced across the granodionite plateau to the north for some 3km before it descends to form a similar but inferior terminal boulder limit in Glen Gour.

An increasing number of morainic hummocks occur west of the present watershed in Glen Tarbert (NM 898602). Extensive hummocky moraine, the best developed in the field area, occurs west of NM 886602 down the valley for 3km to Achnalea. Individual mounds reach over 10m in height and sections (e.g. at NM 844603 and NM 861604) reveal a brown sandy-clay till with angular boulders and lesser debris. These mounds become smaller and more asymmetrical 100m above the valley floor. The hummocky moraine is best developed on the Moinian Schist, becoming more sporadic in distribution and decreasing in size with increasing distance west of the schist-granite contact. The hummocky moraine is completely replaced by boulders that mark the lateral and terminal position of the glacier on the granite outcrop.

h) Gleann Feith 'n Amean. (11)

The former ice margin along the northern side of Glen Tarbert from Coire a' Cholhraim (4) is marked by a poor drift limit under the crags of Meall a' Chuilinn (NM 892607) at about 400m. This limit fades out and cannot be traced round the edge of the ridge, but may be followed along the southern side of Gleann Feith 'n Amean (11). This limit rises to 550m at the eastern end of the glen, below which is a large area of hummocky moraine. As in Glen Tarbert, this moraine is restricted to the Moinian Schist outcrop, and the hummocks decrease in size on the granite outcrop. These morainic mounds reach 5-6m in height, and decrease in size up the valley side, becoming more asymmetrical. On the northern side of the glen, a former ice margin is placed above the limit of hummocky moraine at between 500 and 550m.

i) Coire na Creiche (12)

It is inferred that a glacier descended from Coire na Creiche (12) from an upper limit of 550m on to the granodionite plateau. This upper limit is distinguished on the basis of a contrast between ice-smoothed rock below the limit (especially on the corrie side walls at NM 877638) and frost-shattered angular rocks and rubble above it. The glacier diverged as it left the restrictions of the corrie; some ice probably flowed S.W. to join the Gleann Feith Amean glacier and descend into Glen Tarbert, while the remainder may have flowed north to Glen Gour. An area of hummocky moraine (NM 865628) occurs where the glaciers are believed to have merged, while further north hummocky moraine is continuous across the plateau to Glen Gour. An ice-shed is placed at NM 865637.

Glen Tarbert : Evidence of Glacial Erratics.

The distribution of Moinian Schist boulders on the Strontian

Granite outcrop at the western end of Glen Tarbert supports the morphological evidence (a boulder limit) for a former glacial terminus at this point (Fig. 2.1.B). This limit is reflected in the erratics survey data by a large number of boulders inside the limit, reaching a maximum of 688 per kilometre along northing 60, between eastings 85 and 86. Moinian Schist boulders decrease in number from the Moinian Schist-Strontian Granite contact towards the former glacial limit, beyond which they are very rare. For example, along northing 615 the number of Moinian Schist boulders decreases from the schist-granite contact towards the Loch Lomond Advance limit. Expressed as a percentage of surface boulders for every 500m over 3km from the contact, the values for Moinian Schist erratics are 77%, 50%, 30% inside the limit, and 0.96%, 0%, 0% outside it. The corresponding increase in the number of granite boulders within 3km of the contact is remarkable (see Fig.2.1.A). A similar pattern of erratics distribution occurs along the south side of Glen Tarbert e.g. northings 605 and 600.

Further north, the erratics survey illustrated the transport of Moinian Schist erratics on to the granodionite plateau to stop at the boulder limit e.g. along northing 630 between eastings 875 and 865.

Glen Gour and Ben Resipol.

a) Corrie nan Capull (13)

In this corrie an inferred upper limit is suggested by a contrast between ice-smoothed and frost-shattered rock at approximately 500m. Below the corrie is a large area of hummocky moraine, which is only 2-3m high and is composed of light grey till with small (up to 80cm) rounded boulders of granite and more angular stones of Moinian Schist. The margin of the former ice limit on the plateau is marked by a limit of boulders. These extend in profusion across the area of hummocky moraine and from a point east of Lochain Dubh nan Dubhen (14) to form a lateral limit to the former Glen Gour glacier.

b) Glen Gour.

A lateral boulder limit runs along the south side of the glen from 350m at 14 to below 100m some 2km further west (15). Large boulders up to 5m are scattered along the hillside and on the valley floor. Small groups of morainic mounds occur sporadically in the glen for nearly 5km from NM 865660 to the terminal limit (15). These mounds are up to 8-10m high and are often covered with boulders. At NM 833636 a morainic mound has been partially destroyed by the river, to display 4m of light grey sandy till.

There is no definite lateral limit on the north side of the glen.

However, abundant large boulders are scattered in the woodlands of Ariundle (16) and if fully visible would probably reveal a feature comparable to that on the opposite side of the glen. These boulders and occaisional morainic mounds continue as far south as NM 822631, where the terminal limit of the former glacier is placed.

South of this point (15) is a deposit of eroded and reworked fluvioglacial outwash. The river has cut through the gravels to rest on bedrock, leaving remnants of the outwash surface on the eastern side of the glen. The outwash surface slopes from 13.4 to 9.5m though buildings and cultivation have destroyed much of the feature. Numerous sections along the river bank between NM 816624 and NM 815617, a gravel pit at NM 816625 and trenches dug during the construction of a new housing estate at Strontian, show cross-bedded and poorly sorted stratified sand and gravel. They contain a variety of granite and metamorphic stones, well-rounded and up to 35cm in diameter.

The erratics survey shows that Moinian metamorphic blocks were transported down Glen Gour by the glacier and deposited along the sides of the glen forming part of the lateral boulder deposit (e.g. along northings 630, 635 and 640, between eastings 83 and 84, 83 and 85 and 84 to 85 respectively). The total absence of such boulders along northings 625 and 620 supports the morphological evidence for a glacial limit north of northing 625.

c) Ben Resipol.

Although the Loch Shiel Basin and Glen Hurich were occupied by ice during the Loch Lomond Advance (see below), there is little morphological evidence for an ice limit from the northern side of Glen Gour joining a probable southern lateral limit of the Shiel glacier on the north side of Ben Resipol. Boulders of Moinian Schist are found along northings 635 and 640 in higher numbers (mean 6.7/km) than have been found on the granite outcrop outside other Loch Lomond Advance limits (mean 0.27/km). This suggests a possible former flow of southerly moving ice across the ridge of Meall a' Ghriuth (NM 823664) to overflow into the Loch Sunart drainage basin.

This possibility is supported by striae at NM 827664, NM 836665 and NM 828660, together with several further west at NM 800654 and NM 806654, all recording a southerly movement of ice. These striae are unlikely to be ice-sheet in age as a general east-west movement was then predominant; their location along the ridge precludes their formation by any possible local movement of ice during deglaciation. The lack of morainic evidence may reflect the condition of the ice. Ice from Glen Hurich would be relatively clean because of the lack of nunataks supplying debris to the glacier. A tentative Loch Lomond Advance limit is placed running west from Glen Gour to Coire an t-Suidhe (NM 798662) via Coire Dubh (NM 810655), on the east side of Ben Resipol.

d) Camas a' Choire.

A small glacier occupied this glen on the southern side of Ben Resipol during the Loch Lomond Stadial. In the N.E. corner of the glen (1) an upper limit of hummocky moraine at 400m is believed to mark the former margin of the glacier. This limit descends under the slopes of Beinn a' Choarainn to form a fragmentary end moraine at 230m (2). This end moraine consists of a low line of hummocks up to 4m high, breached by the river and in other places probably by meltwater.

A lateral drift limit runs steeply up the west side of the glen and is continued by the upper limit of fluted moraine in Coire Dubh at 400m (3). No extension of this limit can be traced along the northern back wall of the corrie, but an interpolated limit may be extended to meet the upper limit of hummocky moraine at NM 785652. This hummocky moraine is up to 5m high and becomes smaller and more asymmetrical up the valley side.

The absence of Strontian Granite erratics within the former glacial limits suggests their removal by the glacier (Fig.2.1.A.). The westward carry of granite erratics along northing 64 stops at NM 780640, the upper limit of the former glacier, but erratics are found west of the glacier along northing 64. Where the distribution of these ice-sheet erratics has not been subsequently disrupted it shows a gradual decrease of granite boulders away from the contact (e.g. along northing 63).

Glen Laudale.

A discrete glacier over 3km long existed in Glen Laudale during the Loch Lomond Stadial. The upper limit of this former glacier is recorded at 400m by fluted moraine starting just below the back wall of Coire Dubh (1). These till ridges, 2-3m high, converge on the middle of the glen, increasing in size to a maximum height of 6m. Some of the flutes then become more fragmentary and form elongated hummocks, although still retaining alignment with the original flute (e.g. at NM 726583). Some of the smaller fluted moraine ridges extend continuously for nearly a kilometre. At two places in the glen the glacier over-rode a rock knoll, depositing fluted moraine on the uphill side (at NM 723582 and NM 727581). Large numbers of boulders are scattered among these flutes, often on top of, or orientated along, the axis of the moraine. Streams have cut across the fluted moraine in places e.g. at NM 726578 and NM 727580, to expose sections of light grey clay with unsorted angular debris.

The glacier was constricted in the middle of the glen by adjacent high ground, and the fluted moraine ceases at this point (2). A good drift limit, in places forming a bench 3 to 4m wide, marks the former lateral limit of the glacier on the western side of the glen (3). This feature extends northward at about 200m before descending steeply to the former glacial terminus (4), which is marked by the northern limit of hummocky moraine. Short fluted moraine ridges occur on the north side of the hillslope at NM 735590, with longer ridges further down the glen at NM 738596. The northern end of this fluting along the eastern side of Glen Laudale coincides with the limit to hummocky moraine at the former glacier terminus (4).

An outwash fan slopes steeply away from the terminal limit, from 20m to 7m O.D. (see Fig. 4-6). The present river has formed a flood plain at a shallower gradient below the level of the outwash surface (which is overlain by 4m of peat). The fan covers over 0.5km^2 and extends to a rock knoll at Dunain (NM 744605), which previously was probably an island in Loch Sunart.

Glen Laudale : Erratics Survey Evidence.

The data collected on erratic boulders (Fig.21) strongly support the morphological evidence for a Loch Lomond Advance glacier in Glen Laudale. The ice-sheet, moving westward across the area, left a decreasing number of granite erratic boulders on the Moinian Schist from the western margin of the Strontian Granite intrusion located 4km east of the glen. The northward-flowing Laudale glacier removed most of these erratics from the glen, depositing some at its snout, where a high concentration of granite boulders are now found (northing 600, between easting 735 and 740).

The Loch Shiel Basin.

Introduction.

The largest glacier in the field area during the Loch Lomond Stadial occupied the Shiel valley. This Shiel glacier was a major outlet of ice from the large ice mass that existed over the Lochaber hills at this time (Peacock, 1970; Sissons, 1976a). In the northern basin the glacier was probably restricted to a deep glacial trough. Numerous striae along the shore of the loch between 210° and 248° record this last direction of ice movement. North of Ben Resipol the glacier reached the broad western basin and attained a width of 4km. At its maximum extent the glacier exceeded 25km in length. Ice accumulated in the western basin to a depth of at least 100m. The glacier terminated at a comparatively small rock bar at Acharacle. On deglaciation the glacier left extensive outwash gravels.

a) Acharacle.

Several meltwater channels cut across the watershed of the western basin of Loch Shiel and relate to the maximum extent of the Shiel Glacier. There are no terminal or lateral moraines associated with this limit.

A meltwater channel to the east of the main road (1) crosses the northern watershed between Loch Shiel and Glen Moidart at approximately 95m. Further west, a meltwater channel north of Dalnabreck (2) at an altitude of 90m carried meltwater across the watershed to Loch Moidart. This channel is 10m deep, 20m wide and over 200m long, sloping northwestward. A large flat-topped kame on the southern side of the channel at 88m (Peacock, 1970) has a steep (20m high) ice-contact slope facing Loch Shiel, indicating deposition at the glacier margin.

Three other meltwater channels are located west of Acharacle. They are cut through the 'rock promontory' of Tom a' Chliabhain (4), a ridge with a maximum altitude of 107m that extends north from the high ground of Ardnamurchan. This ridge partially encloses the western end of the Shiel basin and formed a barrier against which the advancing glacier terminated. A massive channel, over 40m deep, cuts through this ridge at NM 673680, its floor rising some 16m before descending to Kentra Moss on the other side of the ridge. On the west side of this meltwater channel, cross-bedded fluvio-glacial gravels indicate that they were deposited by westerly-flowing water. The size of this channel suggests that it has originally been cut sub-glacially by ice-sheet meltwaters.

A small meltwater channel due west of Acharacle school starts abruptly at a height of 30m on the eastern side of Tom a' Chliabhain (4). Meltwater deposited a small fluvio-glacial fan at the western end of this channel, but its contact with the Kentra outwash has been destroyed by the construction of a garage. A third channel 250m long, 30m deep and 40m wide is located in the S.W. part of the ridge at NM 674674. The surface of the Kentra outwash fan grades away from the floor of the channel, suggesting that the formation or re-utilisation of this channel was contemporaneous with the formation of the outwash fan.

Between the Moidart hills north of Shiel Bridge and the rock bar of Tom a' Chliabhain to the south, the limit is amidst fluvio-glacial gravels. An ice-contact slope marks the approximate limit of the glacier, with the outwash surface sloping westwards from this limit. From Shiel Bridge (3) this ice-contact slope (7-8m high) runs south enclosing dead-ice hollows infilled with nearly 5m of peat, and a kettle hole (containing Lochan a' Chunaidh) at NM 674684. A core from the margin of this kettlehole recorded 0.85m of coarse grey sand on top of basal gravels, overlain by 0.4m of peat beneath 6.5m of water.

The dead-ice hollows are separated from the kettle hole and partially from each other by two small eskers, according to Peacock (1970). These features, 5-6m high and no more than 150m long, are more probably the remnants of a kame separating the areas of decaying ice. A gravel pit at the eastern end of one of these kamiform deposits (NM 674685) revealed sections 3-4m high of coarse sand and gravel, with slumped and distorted bedding, indicating the ice-contact nature of the deposits. The well-rounded stones and sparse sandy matrix have been stained bright yellow by the percolating waters from the overlying peat. In this pit the officers of the Geological Survey found marine shells, including Trophon clathratus and Cyprina islandica (Peacock, 1970). No shells were found by the writer, despite digging below the upper layers of sand and gravel that might have been affected by percolating acidic water.

The ice-contact slope extends south from the kettle hole west of Acharacle church (NM 675683) and to the east of the school (NM 674681). Here it forms a low slope 2-3m high and dies out completely towards the large meltwater channel at NM 670680. A terrace extends south-east for 0.5km from Acharacle school, where it is at an altitude of 11.0m, sloping up towards the south-east to 12m O.D. at NM 679675. Sections at NM 681676 and NM 678678 reveal sands and gravels with cross-bedding, sometimes disturbed. The terrace surface has been partially destroyed by streams, cultivation and building. The feature does not possess an ice-contact slope but the disturbance of the bedding points to ice-marginal deposition.

North of Shiel Bridge (3) the ice-contact slope is not visible, but sections in a large gravel pit (NM 677692) indicate that the ice margin probably ran north-east from Shiel Bridge to the valley side at approximately NM 682693. The gravel pit displays 4m of horizontally-bedded sand and gravel with small sets of crossbedding, indicating rapid deposition by fast flowing water. The sandy flow-till mentioned by Peacock (1970) was not observed. The gravels are well rounded, up to 30cm in size and with few fines. This large material suggests the close proximity of the ice margin when the gravels were deposited.

Fluvio-glacial sands and gravels are found further east at Mingarry Park (NM 686695) and at Dalnabreck (NM 703696) along the hillside above the level of the extensive outwash south of the main road. A small gravel pit at Dalnabreck (NM 702695) shows 2 metres of cross-bedded, poorly sorted sands and gravels.

b) Kentra Moss.

This is a large outwash fan, some 3.5 x 1.5km in size, completely covered by peat. The fan slopes westwards from the ice-contact slope at Acharacle; the apex has a sub-peat altitude of 16.2m at NM 673685, descending to 4m at NM 648706 3km away, an average gradient of 5.4m/km (unpublished Scottish Peat Survey height data). This compares favourably with gradients obtained for present day outwash fans, e.g. Skeioararjokull, the largest sandur in Iceland, has a gradient of approximately 5m/km (Embleton and King, 1968, p.413).

Sections in the fan all display dark yellow sands and gravels. At NM 667692 a small stream has incised itself into the edge of the fan revealing poorly sorted sands and gravels. On the S.E. side of the fan at Arevegaig (NM 654682) a 4m high section consists almost entirely of sand. Fine cross-bedding structures indicate deposition by south-westerly-flowing water, while several clay and silt layers indicate periods of quiet water deposition. Numerous small sections around NM 661677 show exposures of fine gravel and sand with small (up to 10cm) sets of cross-bedding.

These sections show a definite decrease in particle size away from the former ice margin. This relationship between decreasing particle size and increasing distance from the apex of an outwash deposit has been shown for seven modern sanders on Baffin Island (Embleton and King, 1968, p. 417). Together with the evidence of morphology and the sedimentary structures, the view of the Geological Survey (1907) and McCann (1966b, p. 93) that this feature was deposited subaerially when the Lateglacial sea-level was at or below present sea-level is endorsed.

c) Claish Moss.

From Acharacle, outwash extends eastwards for 9km as far as Lochan na Ceardoich (NM 756684). These fluvioglacial gravels occupy almost the entire basin with the loch forming a narrow stretch of water in the middle of the valley. Claish Moss is a huge ombrogenous bog overlying the outwash, the majority of which is on the southern side of the loch. To the east of this main expanse of outwash, at Eilean Fhianain, the basin is constricted by Ben Resipol to the south and the increasing altitude of the Moidart hills on the north side of the loch. The outwash surface becomes more fragmentary in this area. Kettle holes occur east of a rock bar at Tom Liaith (NM 736677). Along the southern shore of Loch Shiel from NM 727683 to NM 745677, a highly irregular shoreline consists of a series of partially drowned kettle holes.

A thin gravel promontory into the loch at NM 743680 is the remains of a ridge separating two adjacent flooded kettle holes. On the opposite shore, similar drowned features occur (e.g. at NM 744685).

The highest fluvioglacial deposits are kame terraces, with similar altitudes on the two sides of the loch (e.g. 19.3m at NM 755685 and 19.8m at NM 752685). Along the present loch shoreline ice-contact deposits have been exposed at the base of the steep ice-contact slopes of these kame terraces. For instance, a section 1.5m high at NM 754685 shows chaotic, disturbed bedding in sand and gravel.

There are distinct differences between the gradients and morphology of different parts of Claish Moss. Between Acharacle and Tom Liaith the outwash underlying the moss is very flat, with no visible kettle holes. Its gradient is only 0.8m/km (Peat Survey data). Between Tom Liaith and the easternmost fragment of outwash however, the gradient is 3.6m/km, approaching a more typical value for a sandur. The reason for this difference is unknown.

Corran.

This large area of outwash markedly constricts Loch Linnhe and forms the maximum limit of a large Loch Lomond Advance glacier (McCann, 1966b). The outwash fan slopes south-west from a maximum altitude of 20.5m at NN 014636 to 12.8m where it merges into raised beach deposits at NM 983629, a gradient of 5.7m/km (see fig.4.1.A). The average of seven accurately levelled heights for the highest outwash fragment (around NN 013636) is 20.1m, with an average peat thickness of 2.4m. This contrasts with a height of 23.4m obtained by McCann (1961) using an Abney level.

Gravel pits have exposed two large sections in this highest outwash fragment, at NN 015635 and NN 013634. Both show 3-4m of horizontally bedded sands and gravels with poorly rounded stones up to 30cm long embedded in a coarse grey sand, together with some small sand lenses and cross-bedding. The original ice-contact slope has been destroyed by marine action, but its former location would have been along the N.E. margin of the outwash.

The outwash surface is pitted and partially destroyed by kettle holes. The two largest are occupied by Lochan Cladn a Mhuilinn (NN 006636) and Lochan Croit an Fhraoich (NN 008640), 22.5m and 13m deep respectively (Murray and Pullar, 1910), and were indentified as kettle holes in the '100ft (30m) raised beach' by Peach and Horne (1910). McCann (1961) located another four, and the present author a further four kettle holes. Of the latter, one is water filled (NW 003641) and two are infilled by peat (NN 011636 and NN 003639). The fourth kettle hole forms a large circular depression at NN 002636, some 200m in diameter. It has been breached by a stream draining Corrie Dubh (NM 990650) to the north-west and is partially infilled by sediment.

500m south-west of this kettled area, at the foot of the hillside along the north western margin of the outwash fan, is an old gravel pit (NM 993637). Here, a 5m section has exposed slumped and contorted ice-contact deposits. The beddings of the sand and gravel is mainly distorted and includes involution- type structures: there is a high proportion of angular debris in the gravel which, together with the high clay content of the matrix, indicates the incorporation of ablation or flow till. The deposit has the morphology of a scree slope, formed by the slumping of material from a position between the glacier and the steep valley side during deglaciation. Further south-west, a mound of sand and gravel has a steep ice-contact slope (15-20m high) on its eastern side. These kamiform deposits are above, and not related to, the outwash surface. Their formation is attributed to ice-sheet decay.

McCann (1961) placed the terminal limit of the Linnhe glacier along the N.E. margin of the outwash deposits, 'but the kettle holes in the major deposit show that the ice was at least as extensive as the kettled area' (Sissons 1967b p. 20). The preservation of the ice-sheet mounds (described above) confines the maximum limit of the Linnhe glacier to within 500m of the perimeter of the kettled area.

A corresponding fragment of the outwash occurs on the eastern side of Loch Linnhe. Although outside the field area, a brief examination was made of this deposit. Outwash extends from NN 022635 south for 500m to NN 022628, descending from an altitude of 21.0m to 12.8m, a gradient of 5.2m/km. These altitudes and gradients compare favourably with the adjacent outwash fragment west of Corran Ferry.

At NN 025626, 2m of grey till overlie stratified gravels. Peacock (1971a) suggested that the several mounds in this area may mark the terminal glacial limit. No definite moraines have been located by the writer but the section does suggest a minimal position for the ice margin. No marine shells have been found in this deposit, or in any other comparable deposits of the Corran area.

South from this section, the main road occupies a valley that may have been utilised as a meltwater route (NN 024623). A very impressive meltwater channel is found to the east of this valley, extending from NN 032624 southwards to Onich (NN 024616). It was described by Walker (1924) as a dry valley, whose floor is always less than 30m O.D., and has been incised into the Appin Quartzite to a maximum depth of 60m. At the head of the channel, the floor rises abruptly as a near vertical rock wall, representing an old waterfall/site. It is suggested that the stream Amhainn Righ, which occupies a glen that runs east-west just north of the inferred ice limit, was prevented by the Linnhe glacier from draining into Loch Linnhe, and was diverted southwards to cut this channel. The present course of the Amhainn Righ is north of the meltwater channel and the till section at NN 025626, draining into Loch Linnhe via several waterfalls from Gleann Righ.

It is probable that the Corran outwash fan originally extended right across Loch Linnhe and that meltwaters from the decaying ice north of Corran breached the deposit, probably destroying kettle holes, to allow the sea into the upper Loch Linnhe basin as the ice retreated. With the establishment of a sea-loch north of Corran, tidal scour may have been important in forming the present Corran narrows. Much of the outwash fan was subsequently altered by marine action; mainly erosional in the north, and depositional in the south.

Loch Lomond Advance Limits : Discussion.

Fluted and Hummocky Moraine.

Dyson (1952) first noted the association of fluted moraine and large boulders, and suggested that till might be squeezed into openings in the lee of these boulders, hence producing flutes parallel with the direction of ice flow. Other workers (e.g. Hoppe and Schytt, 1953) sought to explain the regularity of fluted moraine by proposing a rhythmic formation process, Shaw and Freschauf (1973) proposed a kinematic theory of flute formation by the erosion of a till sheet and the incorporation of the eroded material to form parallel ridges.

Boulton (1976) returned to Dyson's explanation of flute formation and maintained that flutes are constructional features. He suggested

> a definition for a flute as being 'long parallel-sided ridges which reflect accurately the direction of ice movement and which form when deformable subglacial materials are intruded into tunnels which tend to open up on the lee sides of single rigid obstructions on the glacier bed' (Boulton, 1976, p. 287).

In Scotland fluted moraine is a characteristic deposit formed during the Loch Lomond Stadial, and is only found inside the advance limits (Sissons, 1976a). Sissons (1977b) noted that the association of fluted moraine with steep slopes suggests its formation by rapidly flowing ice, while Sollid (1973) concluded from a study of the deglaciation of Finmark that flutes are formed on steep slopes and rapid deglaciation is characteristic for their preservation. Robinson (1977, p.83) found that in the Applecross Peninsula 'the areas of most abundant and well-defined fluted moraines are slopes facing north to east', and that 'those glaciers that did not form end moraines were among those that produced most fluted moraine .... this might imply a connection between rapid deglaciation and the non-formation of terminal features'.

This situation is observed in Glen Laudale, a north-facing glen where the abrupt limit of fluted moraine marks the terminal position of the glacier. In the study area fluted moraine is found on the steep back slopes of corries (e.g. Glen Laudale, Corrie Ghardail and Leach na Fiedhe). The maximum height of the fluted moraine is 5m, though in most cases it is between 2 and 3m high. Many flutes start as a line of boulders, between 0.8m and 2m in size. This supports the ideas of Dyson (1952) and Boulton (1976), while the distal ends of some of the flutes also terminate with several large boulders (3-5m). Some areas of fluted moraine have a skeletal arrangement of boulders, possibly owing to the removal of fines during deglaciation or by Postglacial erosion.

Fluted moraine is usually found at a higher altitude than hummocky moraine, which is normally restricted in its location to areas where the ice would be expected to have melted last, namely the valley bottoms. This would presumably also be the location of highest debris content in the glacier. Hummocky moraine is generally accepted as being formed during deglaciation (Sissons, 1967b; Sugden and John, 1976) though it has been found outside the limits of the Loch Lomond Advance in Scotland; it is not so specific in its occurrence as fluted moraine. Hummocky moraine often has a random distribution. In some areas (e.g. Corrie Leachna Fiedhe) the fluted moraine reaches the bottom of the corrie back wall, and becomes fragmented, forming hummocky moraine that retains the original alignment of the flutes, suggesting that the ice became stagnant immediately after forming the flutes.

The Distribution and Preservation of Morainic Evidence.

During the Loch Lomond Stadial, glaciers occupied 130km^2 of the field area, some 19% of the land surface. This ice cover consisted of the southern margin of a large ice mass that occupied the Western Highlands, two small ice caps and four individual valley glaciers. The Shiel glacier, only the southern half of which was in the field area, was an outlet glacier for the large West Highland ice mass, extending considerably beyond the extensive areas of high ground in which it was nourished. Initial ice accumulation in Glen Gour developed into two valley glaciers in a way analogous to ice accumulation in Glen Tarbert. However, the close proximity of Glen Gour to higher ground and to the major ice accumulation areas to the north lead to its coalescence with the major ice mass. The Tarbert glaciers, the most southern extremity of this large ice mass, were essentially a local valley glacier system, nourished by local ice sources that only just merged with the major ice mass at one point (NM 865635).

Of the two independent ice masses, the one at Glen Sanda was the larger, covering 10.4km^2 . The other occupied Corrie Ghardail and Glen Uisge, reaching 8km^2 in size. There were four individual valley glaciers; in order of decreasing size these were Glen Galmadale, Glen Laudale, Corrie an Iubhair and Camas a' Choire (**Fig.3.1&2**). It is possible that not all the glaciers that existed during the Loch Lomond Stadial have been recorded. Likely locations were checked on the air photographs and in the field. Some glaciers may not have left any evidence, while in other cases peat may have obscured the limit; this would apply particularly to small glaciers, almost snow patches, that may have left only boulder limits.

No glacier in the field area has left a typical terminal and lateral moraine as an arcuate ridge of till crossing the valley. Out of 14 glacier termini, 7 of the 8 that have well preserved limits are westerly or south-westerly in aspect, while the 3 that are poorly preserved all have an eastern orientation.

It is difficult to explain this variation in terms of topography or geology. At Glen Uisge, the western limit of the former glacier is clear while in the east it is not so easily located. Similarly in Glen Sanda, the two western limits were easily mapped while the eastern limit is vague. All these limits are on the Strontian Granite and in no case is the topography prohibitive, or the areas of potential debris supply restrictive.

The relationship between the aspect of a former glacier and its morainic legacy has been noted in other parts of Scotland. On the Isle of Skye, Sissons (1977a) found that the best end moraines were formed by south- and south-west-flowing glaciers while some north-east facing corries were unoccupied during the Loch Lomond Stadial. In the Applecross Peninsula, Robinson (1977, p.83) found that 'only one of the ten glaciers that terminated facing between north and north-east left a well defined end moraine .... the other glaciers terminating to the west and south all possess terminal features except for two lobes'.

Sissons (1977a, p.35) concluded 'approximately a hundred Loch Lomond Advance glaciers have been mapped in N.W. Scotland, the great majority of which formed end moraines. Collectively these moraines face in every direction but most of the large moraines are associated with glacial termini that faced between south-east and west. Glacial termini whose maximal extent has had to be inferred from hummocky moraines almost all face between north-west and east. In some instances, these contrasts apply to the differently orientated termini of a single ice mass'.

A major reason for the formation of end moraines by westerly and southerly facing glaciers may be that they are often larger and have lower firn lines than those with an easterly or northerly orientation. Sissons (see below) has inferred from this distribution in N.W. Scotland that these glaciers were supplied by southerly snow-bearing winds. Therefore as a result of the higher precipation that these southerly and westerly glaciers received, there may have been higher rates of ice accumulation and ablation on the glaciers associated with larger quantities of meltwater, providing a greater quantity of debris for moraine construction than would have been available to glaciers on the opposite side of mountains.

Other factors may have influenced the amount and type of debris supplied to the glacier. Where a small valley glacier had large ice-free slopes above, the morainic evidence for glacial occupation of the glen is generally good (e.g. at Camas a' Choire). A well-developed drift limit occurring below high crags is also indicative of a good debris supply. The replacement of hummocky moraine by boulders in Glen Tarbert with the change in rock type from Moinian Schist to Strontian Granite suggests that the ability of the granite to provide only large boulders may have been a factor relating to the absence of an end moraine. However hummocky moraine is abundant on the same granite outcrop further south in Glen Uisge.

The absence of terminal or lateral moraines in association with the large outwash fans of Kentra and Corran is interesting. At Loch Shiel, it is inferred that the Kentra outwash ceased to be formed after the maximum period of glacial advance : this is indicated by the lack of kettle holes in the surface of the fan. The gravels east of this limit, at Claish Moss, represent the deposits associated with deglaciation. Rapid retreat occurred back to a point above sea-level where ice from the adjacent areas of high ground maintained the glacier until total deglaciation occurred. It is suggested that an end moraine is not present at Kentra because outwash spread right across the terminal zone. Even if an end moraine had been formed (e.g. by glacial advance to this maximum limit) it would have been swept away by the large quantities of meltwater that must have accompanied the deposition of such an outwash fan.

At Corran the situation was different from Loch Shiel. It is probable that due to calving, the Linnhe glacier had been prematurely terminated, and that the Corran outwash was formed only during deglaciation.

Thus this environment of the glacier calving into deep water would have prevented the formation of an end moraine.

Glacier Reconstruction.

The Loch Lomond Advance glaciers of N.W. Argyll were reconstructed and their surface area and equilibrium firn lines calculated following the guide laid down by Sissons (1974a, 1977a). The Glen Gour and Loch Shiel glaciers were omitted from these calculations as it was not possible to delimit the accumulation areas of these glaciers. The reconstructed glacier surface was contoured at 50m intervals (Fig.3.1&2). This was a useful exercise as the contours provided a constraint for the interpolated ice margins. As a result, it was necessary to make some adjustments to the inferred ice limit in places e.g. at Coire an Iubhair.

The surface area of each glacier (excluding the former Glen Gour and Loch Shiel glaciers) was measured by superimposing a grid of squares with sides equivalent to 100m on the 1:10,000 map. Firn lines for the glaciers at their maximum extent have been calculated by assuming that ablation and accumulation gradients for each glacier were linearly related to altitude (Sissons, 1974a) (See Table 3-1)

Table 3-1.

Data relating to the Loch Lomond Advance Glaciers of N.W. Argyll.

Glacier.	Area km	Lowest Altitude	Equilibrium Firn Line
G. Uisge	8.03	15	338m
G. Galmadale	8.23	8	390
Laudale	4.56	25	286
Coire an Iubhair	4.25	30	439
Glen Sanda	10.39	10	359
Glen Tarbert E.	5.64	25	384
Glen Tarbert W.	17.26	10	405
Ben Resipol	2.17	30	349

Palaeoclimatic Inferences.

From the altitude of the equilibrium firn lines and the distribution of the former glaciers, two points arise for discussion.

a. Glaciers with a southerly to westerly aspect are larger than those facing north to east. In the study area glaciers with a southerly or westerly aspect form 83% of the total surface area of the former glaciers, a percentage that would be even higher if the Glen Gour and Loch Shiel glaciers had been included in the estimation.

b. The equilibrium firn line increases in altitude from S.W. to N.E. The Laudale glacier in the S.W. had a firn line altitude of 286m, while 20km N.E. the firn line altitude of the former Coire an Iubhain glacier was 439m, a difference of 153m. This gives an approximate regional equilibrium firn line gradient of 7.5m/km. The average firn line for the 8 glaciers is 369m O.D.

This glacier distribution and firn line altitude variation is similar to those of other Loch Lomond Advance glaciers in Western Scotland. On the island of Skye Sissons (1977a) found that Loch Lomond Advance glaciers with a southerly aspect were larger and had a lower equilibrium firn line than those that faced north and north-east. From this he inferred that during the period of glacier accumulation the snow-bearing winds were predominately from the south. The average firn line altitude for the Cullins of 499m is considerably higher than the field area (369m) and reflects a more pronounced 'precipitation shadow' effect. Considerably less snow must have reached the northern side of the Cullins resulting in smaller glaciers with high firn lines (e.g. 739m) while higher values of direct insolation in more southerly locations were unable to overcome the influence of higher snowfall amounts.

On the Isle of Rhum (Ballantyne and Wain-Hobson, 1980) a similar pattern of Loch Lomond Advance glaciation was found to that on the Isle of Skye. The distributioh of the glaciers supports the inferrence of Sissons (1977a) of southerly snow-bearing winds during the Loch Lomond Stadial. The balance between the dominant direction of snow-bearing winds and increased insolation 'appears to have been most favourable for glacier accumulation in locations facing between west and north-west and between east and north-east. At more northerly aspects, decreases in insolation were more than offset by decline in snowfall, so that north-facing glaciers were small' (p.33). The average firn line altitude for the island is similar to that for the field area, 356m and 369m respectively. This probably reflects the comparative closeness and similar relief amplitude of the two areas.

Hence the distribution of Loch Lomond Advance glaciers in the field area supports the proposal (Sissons 1977a) of southerly snow-bearing winds. This is clearly seen at Kingairloch where the Glen Sanda ice-cap existed on the southerly slopes of Bein Mheadhoin despite high insolation while there were no glaciers in the corries on the north-eastern side of the mountain. The firn line altitudes reflect a more general trend of decreasing precipitation in a north-easterly direction.

Conclusion.

The pattern of glaciation in the field area during the Loch Lomond

Stadial was one of ice accumulating mainly in corries and descending to re-occupy the large glacial valleys at lower altitude. The distribution of these glaciers and the altitudes of their equilibrium firn lines supports the hypothesis of Sissons (1977a) that the source of precipitation was from the south. The distribution of the glaciers in the study area may be explained by comparison with the former glaciers of the Isles of Skye and Rhum, where the extent of the Loch Loch Lomond Advance glaciers was determined by a balance between insolation and the direction of snow-bearing winds.

CHAPTER 4.

THE RAISED MARINE SHORELINES OF PART OF NORTH-WEST ARGYLL.

Previous Work on Raised Marine Shorelines in Scotland.

Early Work : 1865-1960.

In the first significant contribution to the study of raised marine shorelines in Scotland, Jamieson (1865) described and attempted to explain the sequence of raised shorelines formed during and since the decay of the last ice-sheet. From sites in the Forth and Tay valleys he inferred the following sequence of events:

a) During the last glaciation the land was depressed by hundreds of feet and the sea flooded low ground.

b) The land emerged while ice still covered part of its surface, the melting ice leaving outwash deposits.

c) Peat covered the formerly submerged land.

d) There was a further depression of the land, by 7-9m in the Forth and Tay valleys, and carse clay was deposited on top of the peat.

e) A final, unequal emergence then occurred, leaving the Forth valley beaches higher than others in Scotland.

Like the initial ideas of the glacial sequence in Scotland, the clarity of this early elucidation became obscured by later work, and it was a century before further substantial contributions were published. The subsequent confusion in raised shoreline studies after Jamieson (1865) may be largely attributed to a lack of appreciation of the theory of unequal emergence and its implications, reflected in the practice of naming a raised beach by its height above present sea-level. The Geological Survey was primarily responsible for this practice, involving the '100ft (30m) raised beach', '50ft (15m) raised beach' and '25ft (7.5m) raised beach'. Jamieson (1906) criticised this method of naming raised beaches, as did Wright (1914), the latter suggesting the term 'Neolithic raised beach' instead of '25ft (7.5m) raised beach'. As late as 1963 Donner claimed to have identified 100ft (30m) , 50ft (15m), 25ft (7.5m), and 15ft (4.5m) raised beaches at various places along the Scottish coastline, while King and Wheeler (1963) identified similar features in Sutherland.

In 1911 Wright described a 'pre-glacial' rock platform between 28 and 41m O.D. in the part of the Inner Hebrides extending from Mull to Islay. The more extensive lower rock platform found in the Firth of Lorn (the '25ft (7.5m) raised beach') was thought by early workers

(Wright, 1914, 1928; Bailey , 1924) to be of Postglacial age as it was covered by Postglacial raised beach deposits. Wright (1928, p. 100) described the Postglacial sea as 'the cliff-maker par excellence', and suggested that the formation of the rock platform represented a longer period than had elapsed with the sea at its present position (Wright, 1914).

Three archeologists, Movius (1942), McCallien (1937) and Lacaille (1948) questioned the use of heights to name a raised beach. They maintained that the '25ft (7.5m) raised beach' of the west coast of Scotland (i.e. the low rock platform) could not have been cut in the time available during the Postglacial. Hence McCallien (1937) relegated its formation to an interglacial period.

Later work: 1960 - 1968.

Donner (1959, 1963) attempted the first study of Scottish raised beaches on the basins of their altitude, measuring them at nearly 100 locations around the Scottish coastline. He drew isobases for the '100 (30m) raised beach', showing the shoreline sloping away from a centre at Callander, at an approximate gradient of 0.1m/km. Donner believed that, except in S.E. Scotland, the 50ft (15m), 25ft (7.5m) and 15ft (4.5m) raised beaches were horizontal.

In an important paper in 1962 Sissons inferred that "the older beaches should be more steeply inclined than the younger ones" (1962, p.94). He hypothesised that unequal emergence had occurred, and as a result proposed the abandonment of the terms '100ft' and '50ft' raised beach then normally used in the literature. Sissons (1962, 1967) also criticized the methods employed in obtaining height measurements on raised shorelines. Previous measurements of the heights of Scottish raised shorelines had been made either by Abney (hand) level (e.g. Bailey, 1924) or aneroid barometer (e.g. Donner, 1963) using high-water mark or the upper limit of seaweed or barnacles as a datum. 'Such methods introduce inaccuracies that cannot be tolerated' (Sissons, 1967b p. 167).

In 1966 Sissons, Cullingford and Smith described the sequence of sea-level changes they had identified in S.E. Scotland. This sequence forms the cornerstone of modern Scottish raised shoreline studies. In outline it is as follows.

a). Six early Lateglacial shorelines associated with a retreating ice-margin occur in east Fife, the oldest having a gradient of 1.25m/km, the youngest between 0.58 and 0.6m/km (Cullingford and Smith, 1966).

b). The main Perth shoreline, backing the most conspicuous Lateglacial raised beach in the area, was then formed after ice had wasted back towards the Highlands. The shoreline has a gradient of 0.43 m/km. Its formation was followed by a 15m drop in sea-level altitude west of Stirling, implying that the ice stood at this point for some time (Sissons and Smith, 1965).

c). The formation of an erosional shoreline, backing an extensive buried gravel layer, occurred at the end of the Lateglacial. The shoreline slopes eastwards from 0m O.D. at Grangemouth with a gradient of 0.17m/km.

d). A sequence of buried beaches underlies Postglacial carse and peat in the upper Forth valley (Sissons, 1966). The High Buried Beach was apparently formed while ice stood at the Menteith Moraine. The Main Buried Beach was believed to have been formed about 9,500 yrs B.P. and the Low Buried Beach about 8,800 B.P.

e). Sea-level reached a minimum level relative to the land at around 8,500 yrs B.P. Peat that had accumulated on top of the then exposed buried beaches was subsequently flooded by the Main Postglacial transgression, which deposited extensive carse clay. Newey (1966) showed by pollen analysis that a salt-marsh vegetation colonized the two lower buried beaches, the succession then changing to a freshwater environment and then back to a marine environment.

f). Following the culmination of the Postglacial sea, its level fell and three later shorelines have been identified in the Forth valley (Smith, 1968).

McCann (1961, 1964, 1966a, 1966b, 1968) has made the most significant contributions to the study of raised shorelines on the west coast of Scotland during this period (1960 - 1968). He demonstrated that the supposed '100ft (30m) raised beach' deposits at Corran (Loch Linnhe) and at Loch Etive are outwash fans deposited by glaciers when sea-level was below 10m O.D.. McCann (1963) criticized correlations of retreat stages and raised shorelines made by Wright (1914) and Charlesworth (1955) at Loch Carron in the N.W. Highlands.

In 1964 McCann described in detail the high 'pre-glacial' rock-platform on Islay and Jura. From the extensive shingle deposits on Jura he concluded that the Lateglacial sea reached a maximum altitude of 30m (100ft) with two short halt stages during its regression from this maximum. McCann (1966a) obtained some 70 heights on the Main Postglacial shoreline between the Firth of Lorn and Loch Broom by levelling from Ordnance Survey benchmarks. He concluded that the shoreline slopes in a W.N.W. direction at a gradient of 0.075m/km. Isobases were computed for this shoreline using trend surface analysis (McCann and Chorley, 1967). McCann (1966a) did not identify any shorelines below the Main Postglacial beach, subsequently identified by Gray (1972, 1974b), and McCann (1966a) was criticised by Gray (1974b) for including heights on the low rock platform in his analysis.

McCann (1968) reported the 'pre-glacial' high rock platform of Wright (1911) in parts of Rhum, Skye and Applecross. He described a decline in this platform from 42m (140 ft) in Ardnamurchan northwards to 23m (70 - 85ft) in N.W. Skye, and southwards to 30m (100ft) in Islay. McCann (p.26) sought to explain these variations in altitude by tentatively concluding that 'the platform appears to be a composite feature and not the product of a single phase of marine erosion'. In 1969, McCann and Richards suggested that there may be two high rock platforms on Rhum, the lower being the younger.

McCann(1968) supported McCallien's (1937) view that the low-level rock platform of the Firth of Lorn was of interglacial age, despite the inconclusive evidence for its having been glaciated. McCann regarded it as a feature inherited by the Postglacial sea and he assumed that the amount of erosion required for its formation was beyond the competence of the Postglacial sea.

In 1966 Synge and Stephens summarized their previous work on raised shorelines in S.W. Scotland and N.E. Ulster (Synge and Stephens, 1960, 1965; Synge, 1966), identifying 7 Lateglacial and 5 Postglacial shorelines. They agreed with McCann (1966b) in associating the Loch Lomond Advance glaciers at lochs Creran and Etive with a low sea-level and obtained the same gradient for the Main Postglacial Shoreline (0.075m/km).

However in a strong criticism of this paper, Sissons (1967c) doubted the relevance of many of the features measured, pointed out many errors and inconsistencies, and questioned the subsequent correlations. This criticism has been later substantiated (e.g. Gray, 1974b; Sissons, 1976a).

Recent Work : 1968 - 1980.

Surface analysis of 500 heights on the Main Perth Shoreline in the forth valley shows it to slope towards 109 with a gradient of 0.43m/km (Smith, Sissons and Cullingford, 1969). Cullingford (1972, 1977) identified four Lateglacial shorelines below the Main Perth Shoreline in the Tay valley, sloping down towards 103 'at gradients that diminish with decreasing age and altitude from 0.51 to 0.24m/km' (1977, p.15).

Detailed measurements of the Main Buried Beach by Sissons (1972b). showed that it has been dislocated in two places in the Forth valley, and that two stretches of it have been uplifted without being tilted. This evidence 'shows that the widely used working hypotheses that raised shorelines in areas of glacial rebound have uniform or gradually changing gradients is not of universal application'...'the concept of the shoreline relation diagram is called into question' (p.115). However, these dislocations appear to be of only local significance and do not invalidate the general conclusions concerning the shoreline history of the area (Sissons, et al., 1966; Sissons, 1976a).

Brooks (1972) provided palynological data supporting the geomorphological evidence that the Main Buried Shoreline is a single synchronous feature, while new radiocarbon dates on peat show that the sea abandoned the Main Postglacial Shoreline before 6,490 ± 125 B.P. in the Western Forth valley (Sissons and Brooks, 1971).

Jardine (1975) described a diachronous Postglacial marine transgression along the northern shore of the Solway Firth between 9,400 and 7,200 B.P. The subsequent regression did not start till about 5,600 B.P. in the eastern, and 5,000 B.P. in the western part of the Solway Firth. However, despite 28 radiocarbon dates, the investigation is marred by the lack of a shoreline sequence and the failure to use pollen analysis in relating dated material to the stratigraphy.

Lateglacial and Postglacial beaches along the coastline of West Invernesshire and N.W. Argyll were briefly described by Peacock (1970). High Lateglacial raised beaches occur up to 46m O.D. but are absent from the sea lochs, while all Lateglacial beaches are absent from the upper parts of Loch Sunart and Loch Nevis. Postglacial beaches are said to range from 5 to 30m in altitude. These raised beaches 'take the form of a sandy or shingly platform backed by a low cliff with caves' (p. 53). This description does not accord with those found by the present writer in N.W. Argyll.

Gray (1972a, 1974a, 1974b) made a detailed study of the raised marine shorelines of the Firth of Lorn. The low rock platform of earlier workers he renamed the Main Rock Platform. It is associated with cliffs, undercuts, caves, arches and stacks. The platform is usually 25m in width but reaches a maximum of 150m, with backing cliffs up to 15m high. Gray established that the rock platform slopes westwards with a gradient of 0.16m/km. He assumed that the platform was of interglacial age, thus supporting the McCallien - McCann arguments. He attributed the slope of the platform to a downwarping off the west coast of Scotland, concluding that 'had eustatic and glacio-isostatic movements been solely responsible for the contemporary elevated position of the shoreline it would now be virtually horizontal'. (p.95). The detailed levelling involved in this study revealed a 2m dislocation of the rock platform in Mull, possibly due to faulting (Gray, 1974a).

Sissons (1974c) proposed that the Main Rock Platform described by Gray (1974a) correlates with the Buried Gravel layer of the Forth Estuary and that it was therefore of Lateglacial age. He named the associated shoreline the Main Lateglacial Shoreline. A critical examination of McCann's (1966a, 1968) descriptions of the rock platform led Sissons to conclude that the evidence of 'possible ice-moulding, striae and glacial drift associated with the platform' (Sissons 1974c, p42) was circumstantial and not conclusive evidence that the platform was of an interglacial age.

The formation of the Buried Gravel Layer in the Forth valley is restricted stratigraphically to a date before about 10,300 B.P. (i.e. before the formation of the High Buried Beach). Assuming the correlation with the Main Rock Platform on the west coast to be correct, this requires the formation of this extensive feature during the Loch Lomond Stadial, a period of only some 1,000 years. Sissons (1974c) acknowledged the problem of providing a suitable mechanism for platform formation and suggested a vigorous periglacial climate, assisted by semi-diurnal wetting of the foreshore.

Peacock (1975) objected to this interpretation on the grounds that the rock platform forms a prominent feature inside the Loch Lomond Advance limit at Corran Ferry (McCann, 1966b) and that 'the writer has observed north of Oban a glaciated surface preserved on the outer sub-horizontal part of the platform' (p.175). The first point does not invalidate Sissons' interpretation and the second is irrelevant (Sissons, 1975b).

Sissons (1974c) predicted that the Main Lateglacial Shoreline should fall below sea-level along the coast of Kintyre and that 'outside the area in which the Main Lateglacial Shoreline is above sea-level ... some low raised rock platforms and cliffs may well correlate with the interglacial feature on the east coast of Ireland described by Stephens (1957).' From 197 levelled heights, Gray (1978) showed that in Kintyre the Main Lateglacial Shoreline has a linear trend-surface slope, NE - SW, of 0.12m/km and a quadratic trend-surface gradient of between 0.11 and 0.16m/km. The resulting pattern of isobases 'is exactly that expected if deformation from the horizontal was due to differential isostatic uplift ... with a major axis aligned approximately N - S over the Western Highlands' (p.160). This work effectively supports the inference of Sissons (1974c) as the platform passes below sea-level along Kintyre and forms a separate feature from the older Irish platform.

Gray (1974b) tentatively identified two high depositional Lateglacial Shorelines (LS 1 and LS 2) at approximate heights of 25 and 22m O.D. along the coasts of the Firth of Lorn. He attributed the absence of widespread Lateglacial shorelines 'to factors such as the steepness of the coastline and the rapid rate of isostatic uplift consequent on deglaciation' (p.132). Linear trend surface analysis of 54 fragment averages for Main Postglacial Shoreline (PS 7) indicated an isobase alignment of N 4 E - S 4 W, and a gradient of about 0.05m/km. This gradient differs from the values of 0.08m/km obtained from the Forth (Sissons et al., 1966) and 0.09m/km for the Tay estuaries (Cullingford, 1972). It has been suggested that this discrepancy may be the result of the funnelling effect of the Forth and Tay estuaries, together with possible complications of isostatic uplift on the west coast related to a separate Mull ice-cap, (Gray and Brooks, 1972). This gradient of 0.05m/km also differs from that of 0.075m/km obtained independently by

McCann (1966a) and Synge and Stephens (1966), a difference attributed to the field techniques and other limitations of this early work (Gray, 1974b).

Gray (1974b) identified two definite Postglacial Shorelines (PS 3, PS 5) below the Main Postglacial Shoreline (PS 1) and suggested the possible existence of a further two intermediate shorelines, PS 2 and PS 4. Calculated gradients for PS 3 and PS 5 are very low, about 0.01m/km, values that approch the height amplitude for the individual shoreline fragments. These lower shorelines were not identified by McCann (1966a) and do not correlate with those described by Synge and Stephens (1966). Gray suggested a possible correlation between PS 3 and PG 3 in the Forth valley (Sissons et al., 1966) which has in turn been tentatively correlated with LC 1 in the Tay (Cullingford, 1972). In 1975, Gray provided detailed evidence that the outwash fans at Creran, Etive and Loch Feochan were related to a low sea-level of about 10 - 12m, as McCann (1966b) had suggested.

On the basis of micro-faunal and molluscan analyses, Peacock et al., (1977) constructed a sea-level curve from a site at Lochgilphead. It shows that sea-level remained between 4 and 10m O.D. from before 11,500 to 11,000 B.P. This height range is in accord with a predicted altitude of the Main Lateglacial Shoreline at Lochgilphead of 7m O.D. (Gray, 1978).

Further north, Robinson (1977) in the Applecross peninsula described a pre-glacial rock platform and fragments of Postglacial shoreline. She suggested that the highest fragments of Postglacial beach at approximately 10m O.D. corresponded to the Main Postglacial Shoreline of the Firth of Lorn, but did not identify any lower shorelines.

Conclusion.

From the published descriptions of raised shorelines on the West coast of Scotland, the following possibilities were envisaged for the field area.

1. High Lateglacial shorelines might occur, especially outside the sea-lochs.
2. The Main Lateglacial Shoreline in the form of a distinctive rock platform should be present along the coast of Loch Linnhe and the Sound of Mull. From the predicted isobases of this shoreline (Gray 1974a) a slope westwards from 9m to 4m O.D. could be anticipated.
3. A Main Postglacial Shoreline between 11 and 13m, with possibly two or more lower shorelines might be expected.

After a brief outline of the methods employed in the present study of raised shorelines, the field evidence and subsequent analysis of raised shorelines in the field area will be presented. The shorelines will be described in chronological order.

Methods and Analysis of Raised Shorelines in the Field Area.

Field Methods.

The raised shorelines were initially located on 1:25,000 aerial photographs, supplemented by the 1:63,360 Geological Survey drift maps. The raised shorelines were then mapped in detail at a scale of 1:10,560 in the field.

Shoreline and outwash altitudes were measured by levelling, using a Hilger & Watts automatic level and a graduated metric staff. Hiller boring rods were used to measure the thickness of any peat overlying the shoreline or outwash, the average depth of peat being obtained from a number of probes. Points were levelled at 30 to 50m intervals along the back of the beach or platform, the distance being measured by pacing. Closing errors in the levelling were no more than 0.15m and were typically less than 0.08m.

Nearly all the levelling was from Ordnance Survey benchmarks. Most were related to sea-level at Newlyn, though in some areas, old benchmarks related to Liverpool sea-level were used. In this case a conversion factor was applied, being the average height difference between the nearest Liverpool/Newlyn benchmarks.

On two occasions sea-level was used to transfer heights (Gray, 1975b). Sea-level was recorded simultaneously at a point close to an Ordnance Survey benchmark and at another location, close to the remote shoreline fragment to be levelled. Sea-level at the first location was obtained by levelling from the benchmark while sea-level at the second location was assumed to be at the same height. The raised shoreline fragment was then levelled from a mark made at this second location.

Raised beaches that did not possess a well-defined shoreline, or had a slope related to a local source of sediment supply such as a stream, were not usually levelled. Fragments of rock platform were also ignored where boulders and talus obscured the back of the platform or where the platform surface was very irregular. Shoreline fragments were subjectively graded during levelling into 3 classes, indicative of their state of formation and preservation:-

GRADE A : Flat-topped raised beaches or a rock platform with a flat surface and well developed shoreline.

GRADE B : Beaches sloping gently seawards or a slightly irregular rock platform, with a small amount of talus debris along the shoreline.

GRADE C : A sloping beach or an irregular rock platform (interrupted by geos, dykes etc.). Large amounts of talus or sub-aerial fan debris along the shoreline, with streams and rivers influencing beach deposition.

The field maps and the location of each shoreline and outwash altitude measurement were then transferred, using a Grant projector, on to a tracing of the new 1:10,000 O.S. maps with the National Grid lines marked on them. Eight figure grid references were obtained for each levelled height from the tracing (see Appendix A), a copy of which constitutes Figs. 4.1. A to O.

Analysis.

Individual shoreline and average fragment heights were plotted on height- distance diagrams. This method has been extensively used by workers in Scotland (Sissons, 1963a, 1966 et al.; Cullingford and Smith, 1966; Gray, 1974a, 1974b) instead of the shoreline relation diagram where it is difficult to comply with all the assumptions involved (Andrews, 1970; Gray, 1972a).

Each shoreline height was plotted against the y- axis and the distance along the x- axis. A shoreline was then identified as an alignment of points. Linear regression analysis was used to calculate best fit lines by which the shorelines are depicted and the gradient, or amount of tilting of each shoreline is obtained. Linear regression analysis has only been used on the average height of each fragment. This avoids the clustered distribution of shoreline heights and the autocorrelation and dependence of residual platform heights unsuitable for regression analysis (Gray, 1972a, 1972b).

Gray (1974a and b) stated that for the Main Rock Platform (Main Lateglacial Shoreline) and the Main Postglacial Shoreline, isobases were approximately N-S. Therefore to provide a check on the orientation of the equidistant diagram, three diagrams were constructed in three different directions; 255 -75 , 270 -90 and 285 -105 . Since the shoreline gradient for the east-west projection was less than that for either of the two adjacent projections, this orientation was used for the shoreline diagrams.

High Lateglacial Sealevels.

No direct morphological evidence for an early Lateglacial sealevel has been found along the coastline of the field area. The absence of high raised beaches from the inner sea-lochs of this area was recognized by Wright (1936). He concluded that these lochs were occupied by glaciers during the formation of the 100ft (30m) raised beach. Peacock (1970, p.53) has delimited an 'eastern limit of high level Lateglacial beaches' in the sea lochs of Western Invernesshire and has related this to a possible still-stand or readvance.

Sissons (1974c) suggested that there might be a correlation between the dislocation of the Main Perth Shoreline at Stirling, the drop of the marine limit in the Loch Fyne-Loch Long area, the limits described by Peacock (1970) and a drop in sea-level recorded in the Beauly and Cromarty

Firth associated with ice-sheet decay (Ogilvie, 1923). The evidence mentioned by Peacock (1970) in the field area is a raised beach at over 35m (116 ft) on the south side of Loch Sunart at Glen Crispdale. These deposits were not found by the author, though it is possible that Peacock may have been referring to earlier, unpublished Geological Survey records as the area is now densely forested. Thus for N.W. Argyll this correlation must remain speculative.

Evidence for a still-stand or readvance during ice-sheet decay is accumulating (e.g. Robinson, 1977; Ballantyne and Robinson, pers.comm.) In Chapter 2 it was suggested that the final movement of ice in the field area occurred in the sea-lochs. Despite the absence of associated ice-sheet moraines this remains the most plausible explanation for the lack of high raised beaches in the field area, especially along Loch Sunart.

There are several local factors that may also have prevented beach formation. Much of the coastline of Loch Linnhe and the Sound of Mull is steep with a cliffline that has left few areas suitable for beach deposition. Elsewhere, early beaches may have been destroyed by subsequent Loch Lomond Advance glaciers and their related outwash deposits, e.g. at Inversanda on Loch Linnhe or at Laudale on Loch Sunart. Thus it seems reasonable to attribute the absence of high Lateglacial raised beaches in N.W. Argyll to the occupation of the inner sea-lochs by ice together with a combination of local factors.

Loch Arienas.

This is the only part of the field area where a high Lateglacial sea-level may be inferred. East of Loch Arienas a suite of fluvioglacial terraces have been preserved in the lower part of Gleann Geal. These terraces descend from approximately 40m at NM 710504 to 25m east of Claggan school house (NM 699497). A gravel pit in a large terrace at NM 704505 reveals 3m of coarsely bedded fluvio-glacial gravels, including Strontian Granite erratics. The location of the terraces suggests that meltwater derived from Gleann Dubh and Gleann Geal drained along the present course of the River Aline to Loch Aline.

During deglaciation, meltwater and stagnant ice must have occupied the Loch Arienas basin and may have formed the area of flat low-lying ground between Loch Arienas and Loch Doire nam Mort (NM665520). The water-shed between this latter loch and the sea at Loch Teacius is at a height of 29m. It is possible that meltwater from the Loch Arienas basin drained across this watershed to Loch Sunart at an early stage in deglaciation, possibly before the Sound of Mull became ice free.

The terraces in Gleann Geal are presumably related to a Lateglacial sea-level. They terminate 2km away from the present coast at Loch Aline, and there are no shorelines in the valley of the River Aline, though it is likely that it was invaded by the sea while the terraces were

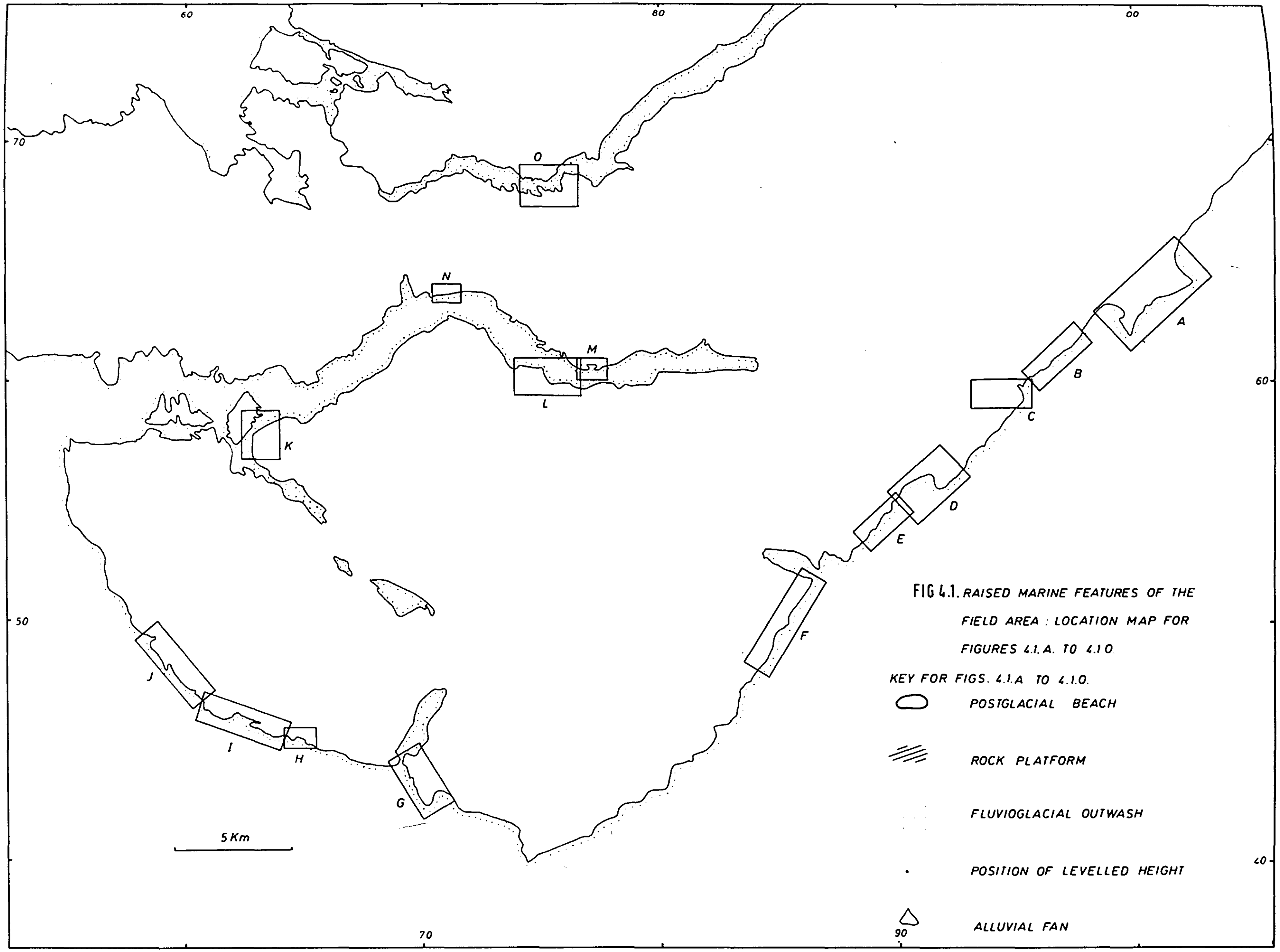

FIG 4.1. RAISED MARINE FEATURES OF THE FIELD AREA : LOCATION MAP FOR FIGURES 4.1.A. TO 4.1.O.

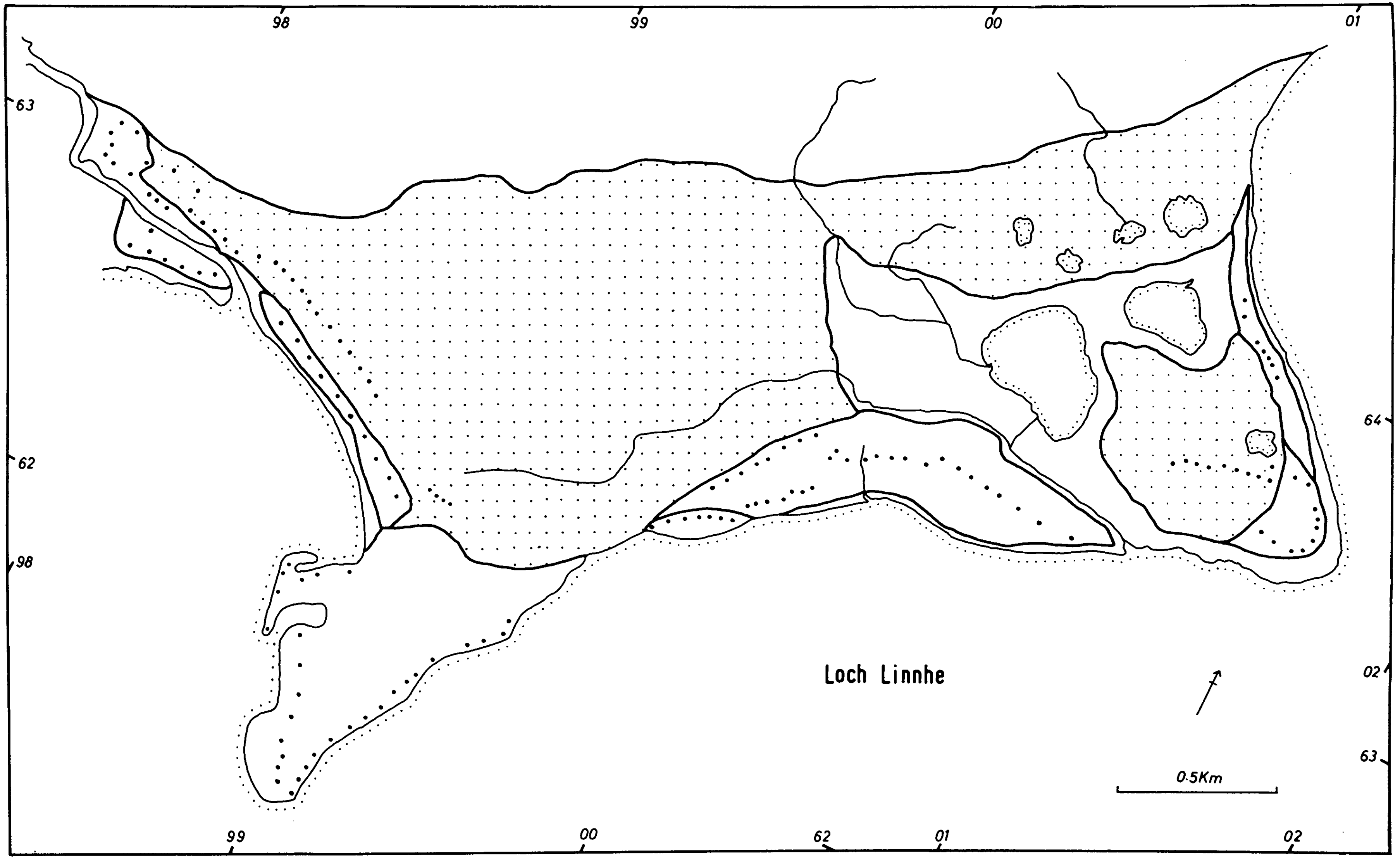

FIG 4.1.A. CORRAN

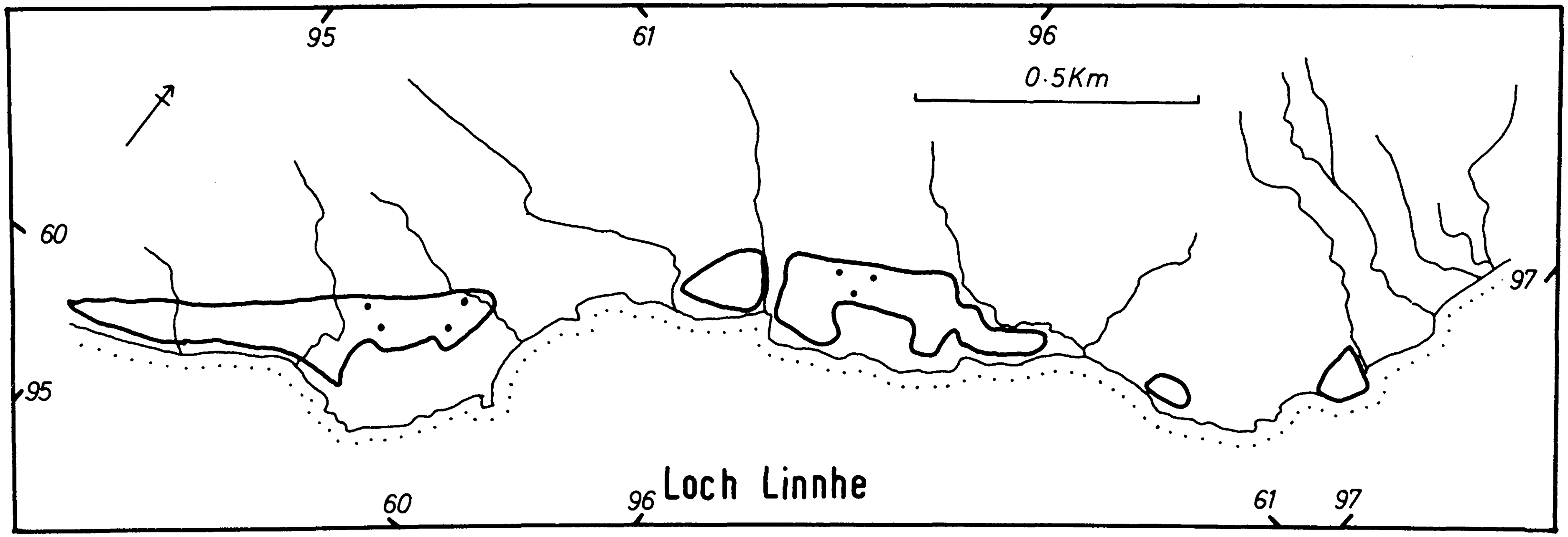

FIG 4.1.B. *GEARRADH*

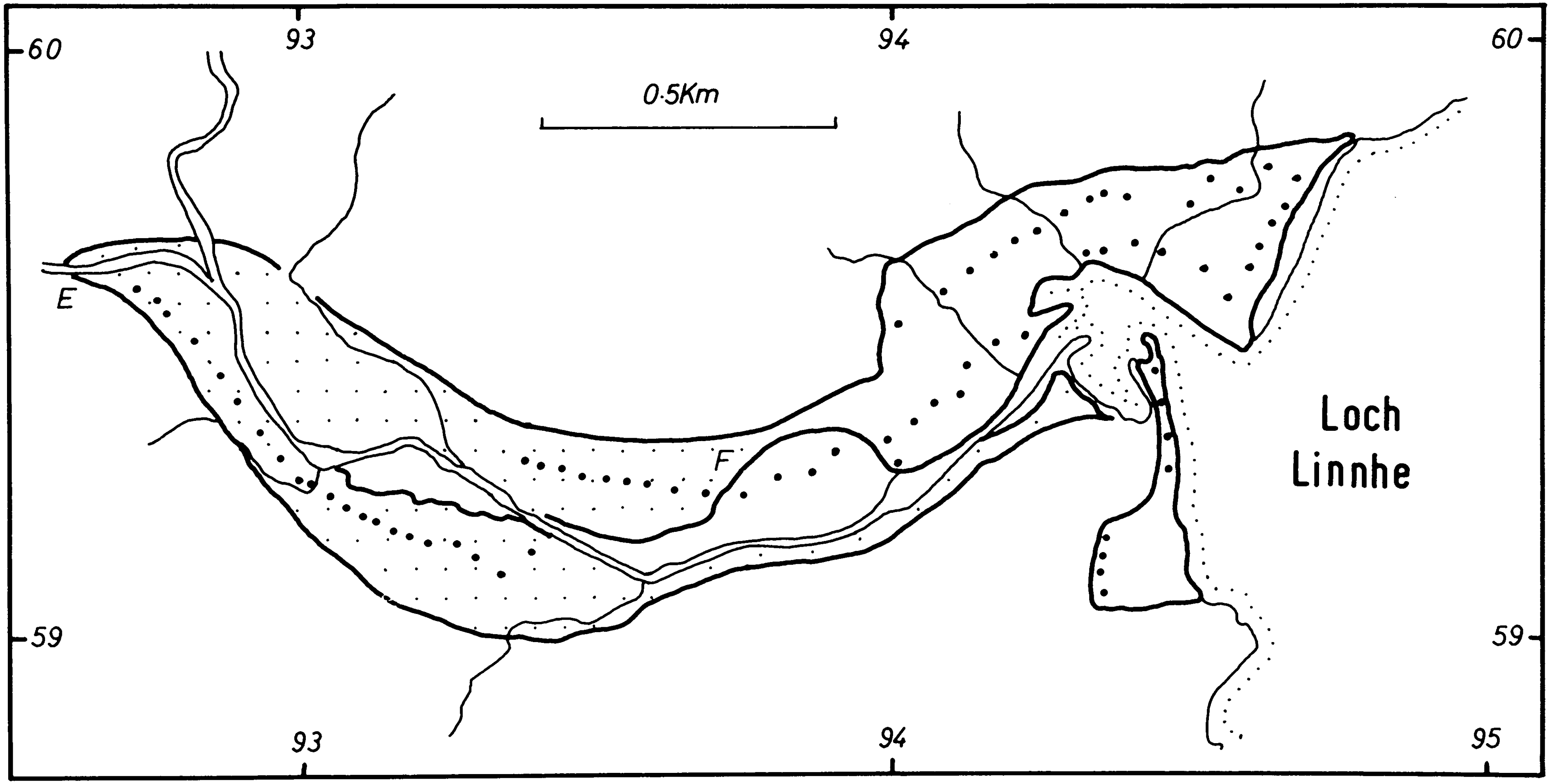

FIG 4.1.C. *INVERSANDA*

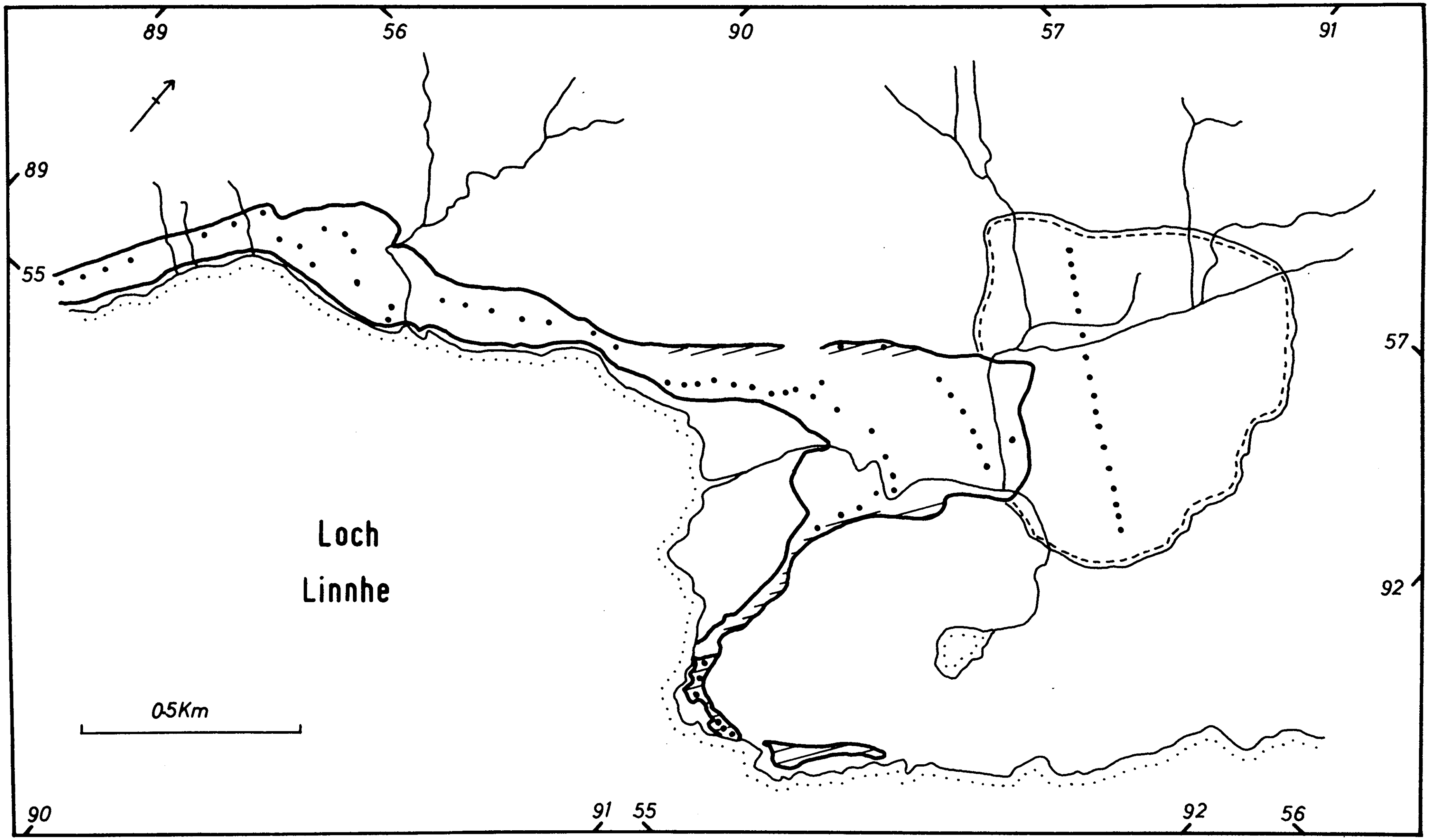

FIG 4.1.D. CILMALIEU

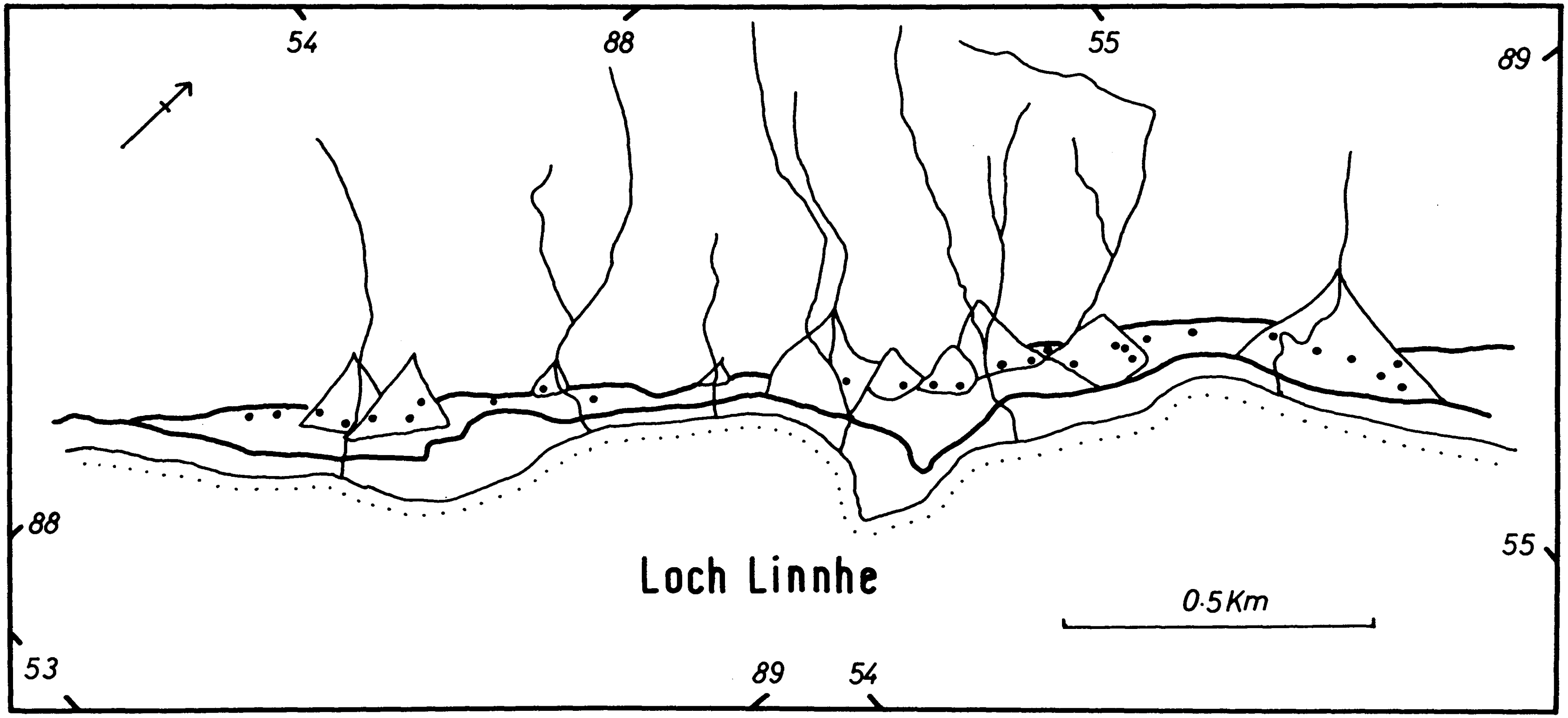

FIG 4.1.E. *AM BROILEIN*

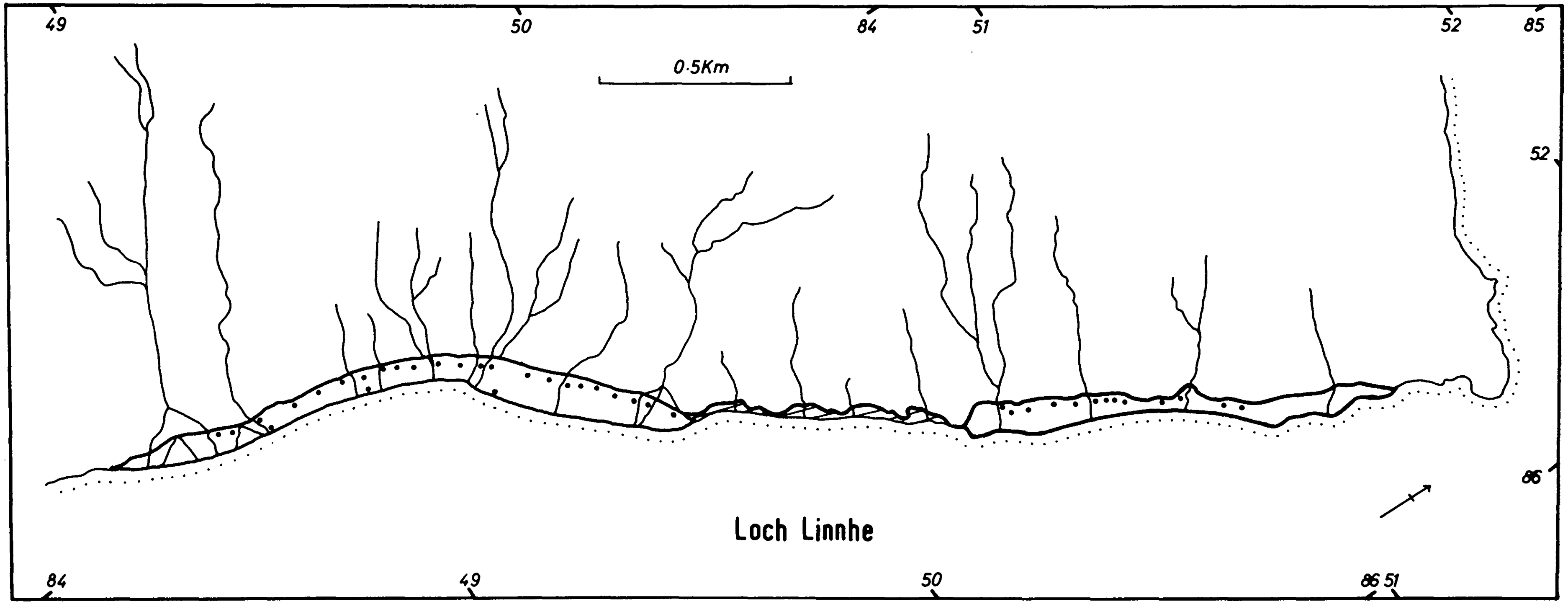

FIG 4.1.F. *AIRIGH SHAMHRAIDH*

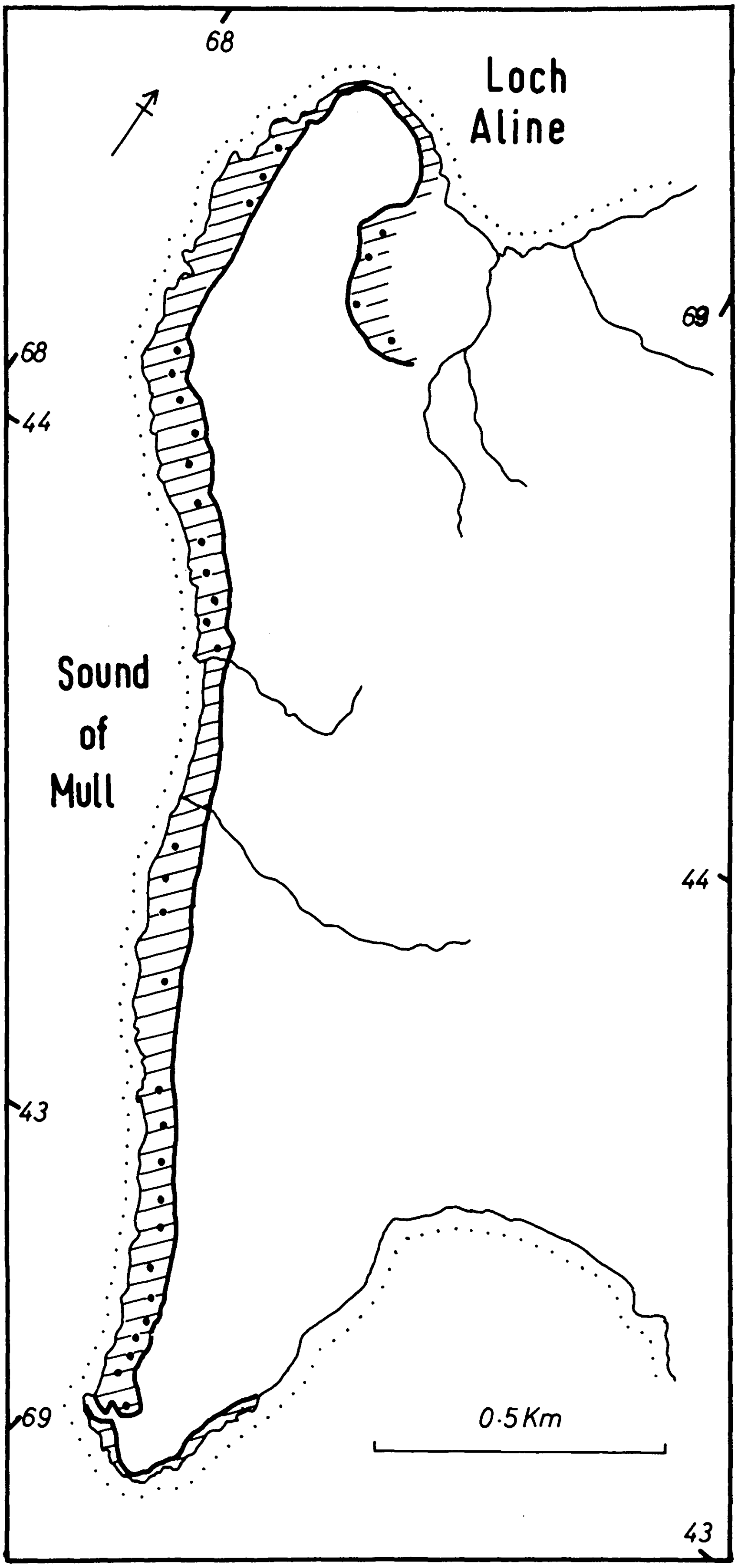

FIG 4.1.G. *ARDTORNISH*

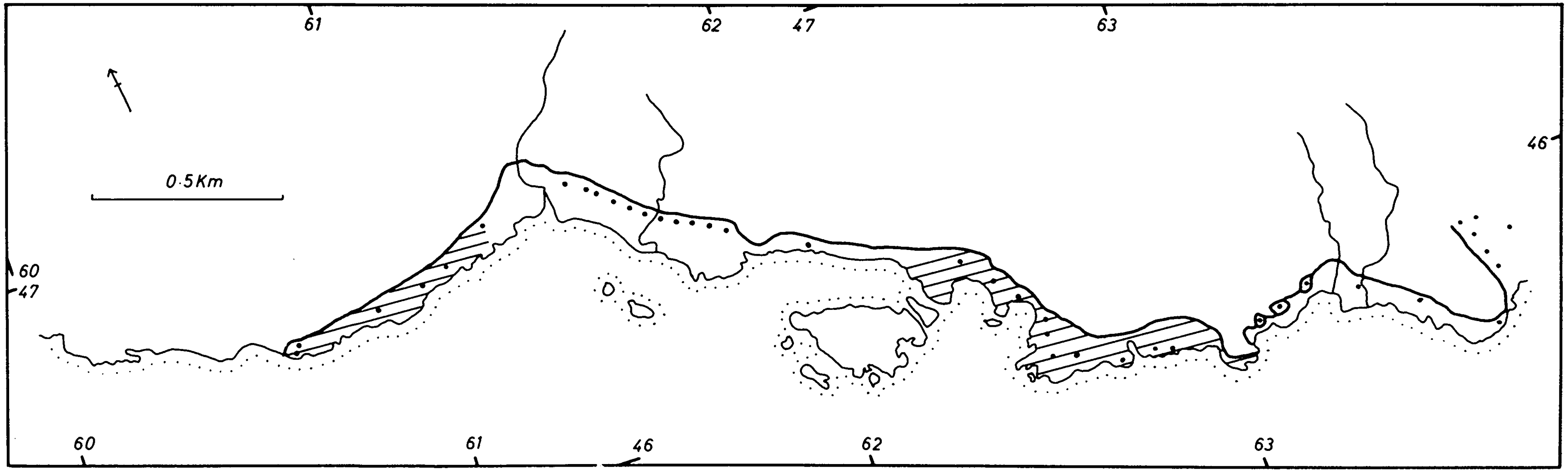

FIG 4.1.1. FIUNARY

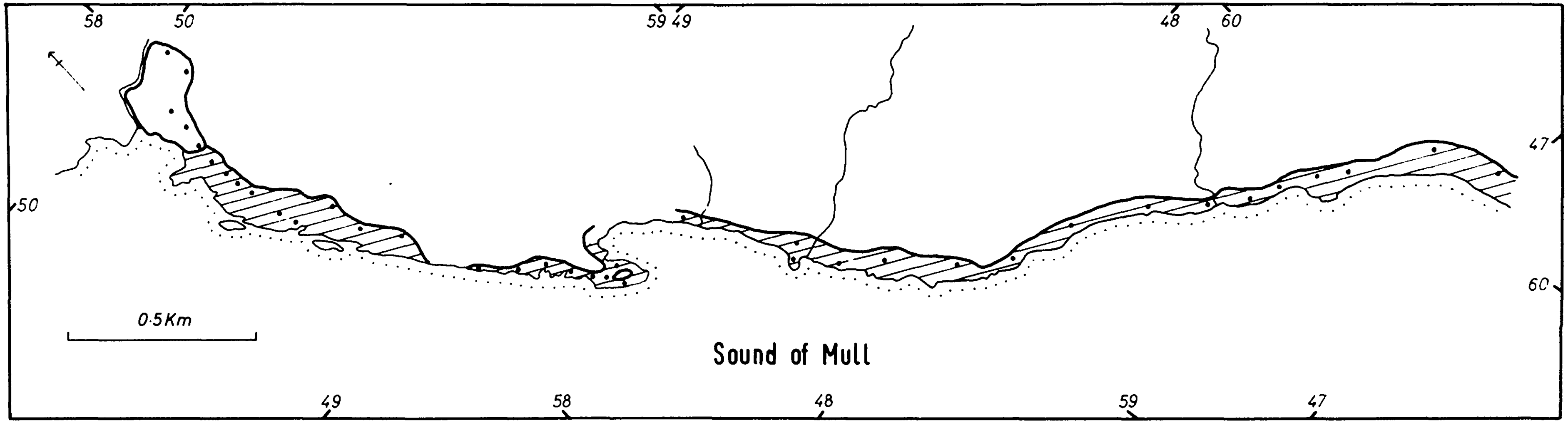

FIG 4.1.J. KILLUNDINE

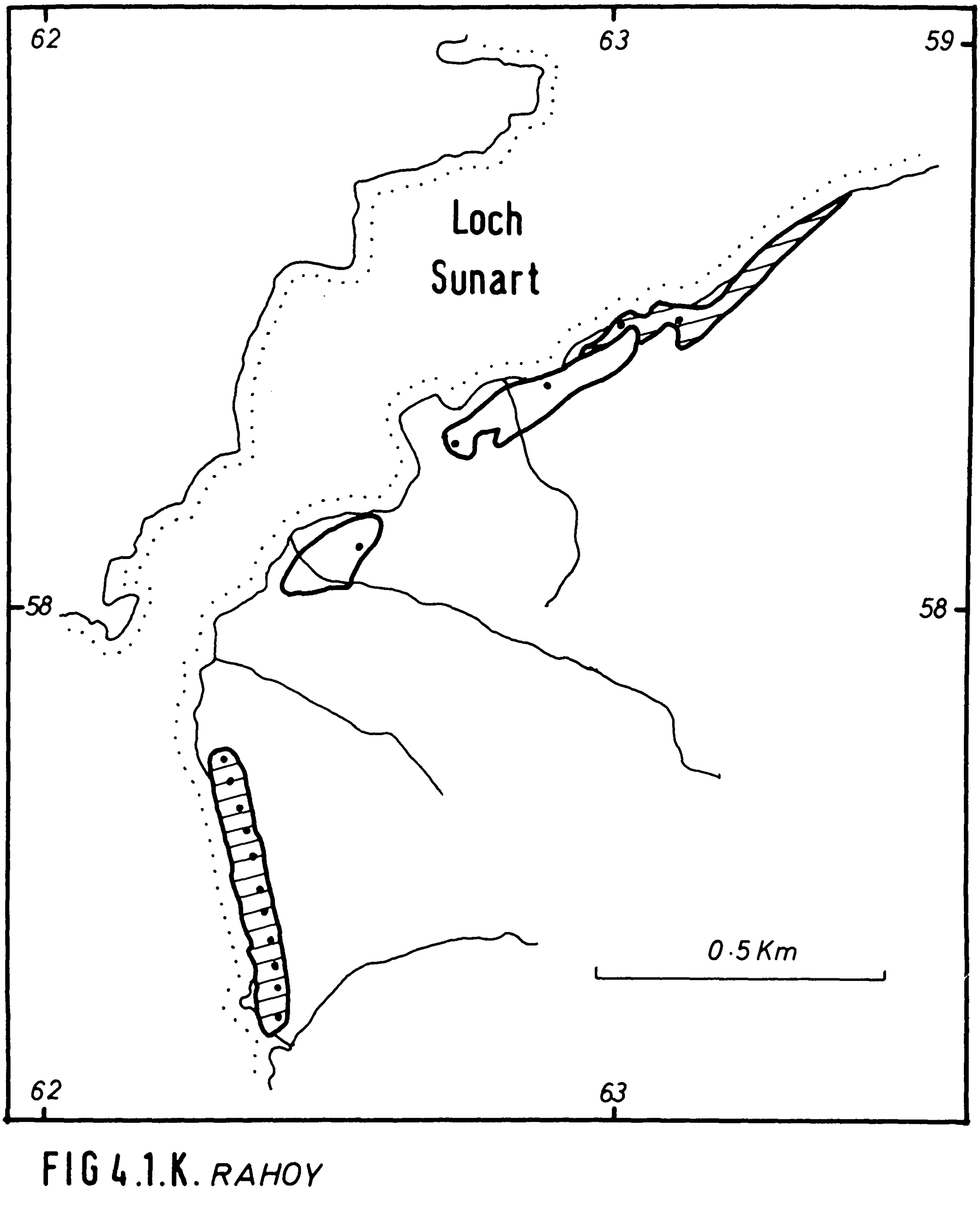

FIG 4.1.K. *RAHOY*

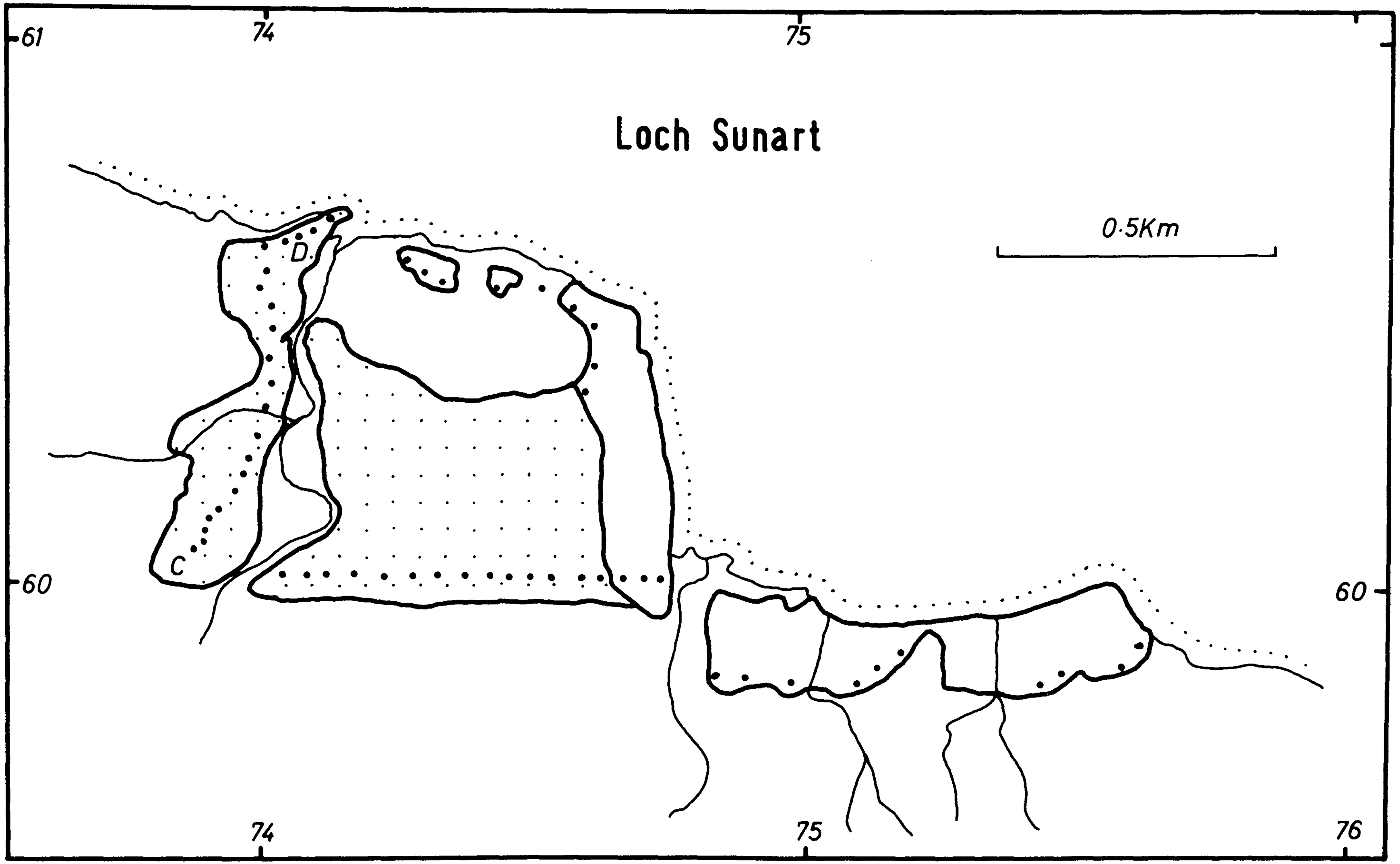

FIG 4.1.L. *LAUDALE*

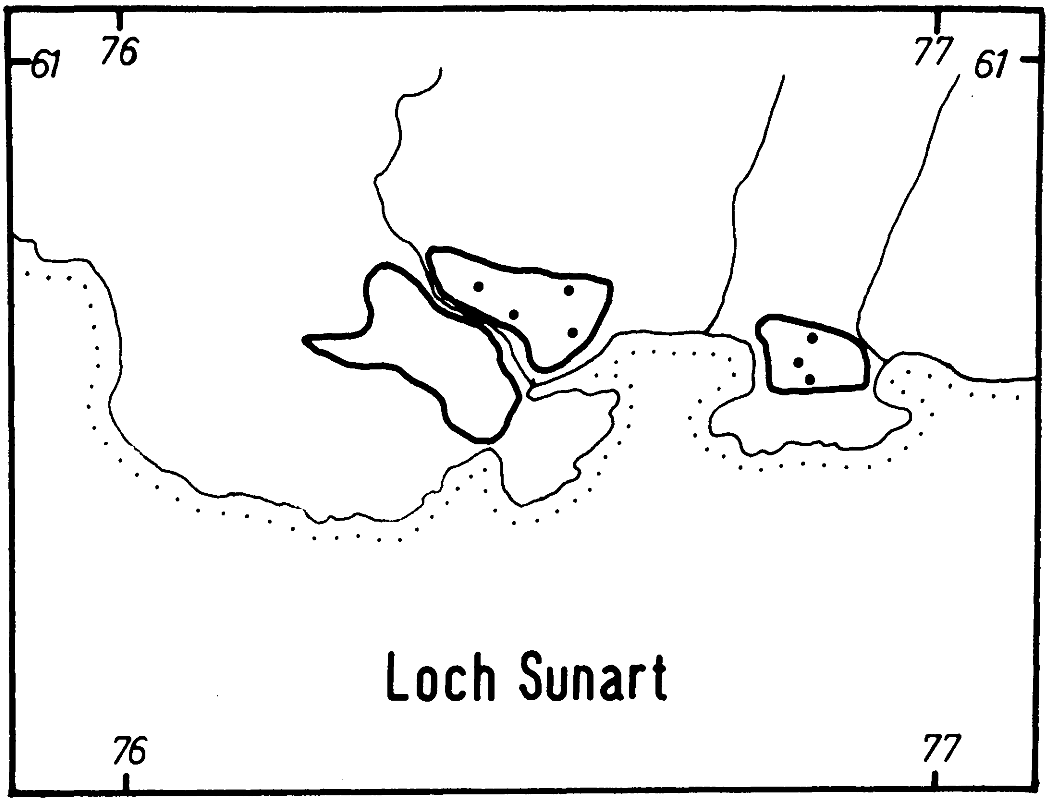

FIG 4.1.M. *CAMASACHOIRE*

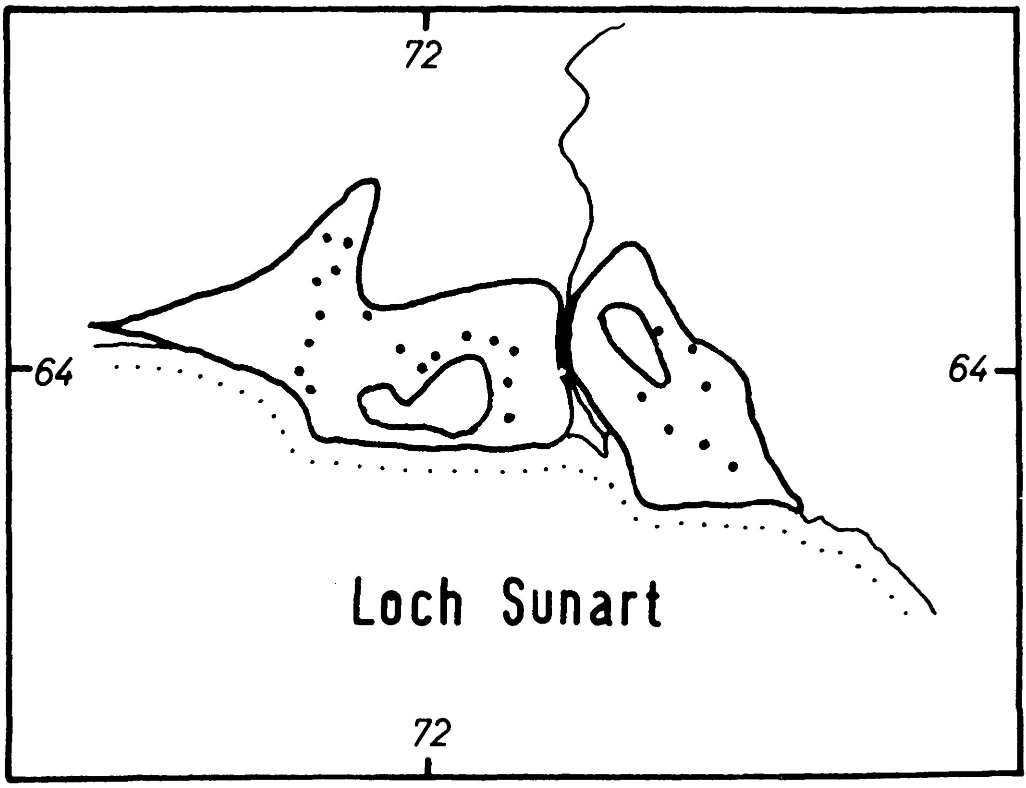

FIG 4.1.N. *RESIPOL*

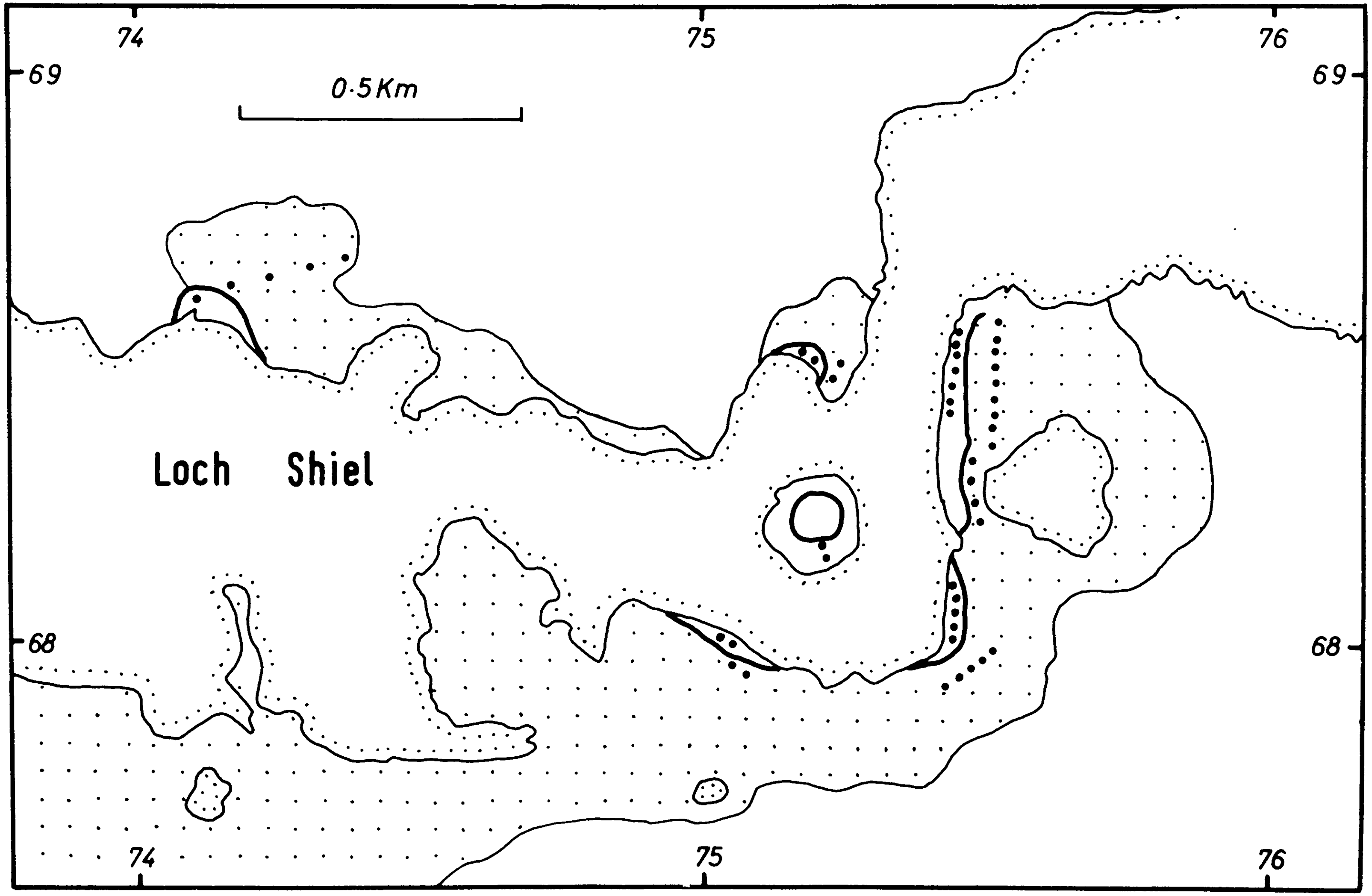

FIG 4.1.0. *ACHNANELLAN*

being deposited. Gray (1974b) described early Lateglacial beaches at an altitude of 22m on the opposite side of the sound of Mull at Craignure, and it is therefore possible that the Gleann Geal terraces relate to a sea-level at approximately that altitude.

The Main Lateglacial Shoreline.

1. The Main Lateglacial Shoreline : Landforms.

The Main Lateglacial Shoreline is represented by a rock platform that is developed with varying degrees of clarity along parts of the coastline of the field area. A rock platform was only mapped as such where there is a backing cliff. The rock platform has an average width of 8m but varies from a few to 25 metres. Cliff height is between 2 and 15m with 5m being a typical figure. These dimensions are considerably less than those for the platform fragments in the Firth of Lorn, described by Gray (1974a, p. 81), which are 'generally 20-30m wide but vary from less than 16m to over 150m'.

The rock platform attains its best development in the field area on a headland of Old Red Sandstone conglomerate at NM 910553. Here the platform is 25m wide with a backing cliff 8-10m high, associated with several caves and undercuts.

This contrasts with the poor development of the platform on the Strontian Granite of the adjacent Loch Linnhe coastline. For example from NM 924566 to NM 914554 the platform varies from 1 to 4m wide with a corresponding cliff height of 2-5m. The platform is very uneven, its surface dissected by eroded Tertiary dykes, while large boulders rest along the back of, and occasionally cover the platform. Further south, at NM 888544 and NM 837487 the development of large alluvial fans prevented platform formation. Between Glensanda (NM 823467) and the Sound of Mull there are only occasional fragments of rock platfrom along an otherwise steep and rugged coastline. This 12km stretch of coast is entirely composed of Strontian Granite.

The rock platform is extensively developed on the Tertiary lavas along the Sound of Mull. For instance, a platform 15-22m wide with a backing cliff 5-12m high extends for nearly 2km N.W. of Ardtonish Point (NM 693425). West of Loch Aline, the rock platform is found for over 10km, from NM 650451 to NM 580493. Accumulations of rubble and boulders at the base of the cliff and degredation of the seaward edge of the platform are not uncommon. As a result, the platform usually lacks the clarity it has where cut into the Old Red Sandstone conglomerates. The average width of the rock platform on the Tertiary lavas is 13m while cliff height is usually between 4 and 15m. The latter figure reflects the influence of the terraced structure of the lavas, which favours cliff formation. There are several shallow caves and undercuts associated with the platform, and in one place (NM 606466) an arch eroded through a dyke stands 5m high above the platform.

The rock platform is absent from most of the coast line composed of Moinian metamorphic rock (e.g. a 4km stretch of coast from Corran Ferry to Inversanda). An exception to this is a platform that extends for 500m along the N.E. shore of Loch Teacius (NM 623575). This platform fragment (average width 15m and cliff height between 8 and 10m) is unusual because not only is it cut into a rock type that is elsewhere resistant to erosion, but it also occurs in an extremely sheltered and almost freshwater environment. No local geological factor explains the former point, but the erosive effect of freshwater as described by Nansen (1921) (see below) may explain the latter.

A rock platform has not been mapped along the sheltered coastline of Loch Sunart. This absence is attributed to the fact that the coastline is composed of Moinian Schists and Strontian Granite, combined with a sheltered environment. However, extremely faint fragments of a possible platform exist in the more exposed western parts of the loch (e.g. on a small island and a promontory at NM 647601).

2. The Main Lateglacial Shoreline : Height Analysis.

A gradient for the rock platform of 0.15m/km was obtained from 10 fragment averages of A and B grade using linear regression analysis (Fig. 4-2). Individual shoreline heights with their corresponding 8 figure grid reference and the average heights for each shoreline fragments are listed in Appendix A. This shoreline gradient of 0.15m/km compares favourably with the overall gradient of 0.16m/km obtained by Gray (1974a) for the rock platform in the Firth of Lorn. The direction of the gradient obtained by Gray was east-west, this direction being used in the present analysis.

In an analysis of 7 fragment averages of A and B grades and 5 fragment averages measured by Gray (1972a) along the northern coast of Mull, the gradient for the rock platform in the Sound of Mull is 0.13m/km (see Fig. 4-3). The rock platform slopes from approximately 7m at Ardtornish Point (NM 692425) to 5m and Drimnin (NM 562528). If an extra 9 C grade fragment averages are included in this analysis, a larger gradient of 0.12m/km results. This shoreline gradient is rejected because of the effect of the shoreline heights on degraded sections of the platform in the Drimnin area. There are insufficient fragment averages to justify the use of trend surface analysis.

The rock platform is morphologically similar to that described by Gray (1974a) and has a comparable gradient and therefore a similar age. It is assumed to correlate with the Main Rock Platform described by

Gray (1972a, 1974a) in the Firth of Lorn and eastern Mull, renamed the Main Lateglacial Shoreline (Sissons 1974c).

3. The Main Lateglacial Shoreline : Age.

The present writer accepts Sissons 1974 interpretation that the rock platform of the Firth of Lorn described by Gray (1974a) and the rock platform of N.W. Argyll described above were formed during the Lateglacial.

Some of the arguments put forward by Sissons (1974c) for a Lateglacial rather than an Interglacial age for the rock plarform in the Firth of Lorn are supported by the present study. No evidence has been found that the rock platform has been glaciated: thus there are no striae, till or erratic boulders on the platform. It might be argued that such evidence may be concealed by the peat that covers parts of the rock platform. This is considered doubtful, however, because in several places (e.g. NM 909554 and NM 623462) the platform has been cut into ice-moulded rock. Striae are present here above and below, but not actually on, the platform.

4. The Main Lateglacial Shoreline : Formation.

The proposed correlation of the Main Rock Platform in the Firth of Lorn with the Buried Gravel Layer in S.E. Scotland and the assignment of its formation to the Lateglacial by Sissons (1974c) presents two problems:

i) that of providing a suitable mechanism for the formation of the platform in a limited time;

ii) that of providing a period of relative land/sea-level stability.

i) A Mechanism for Platform Formation.

The "established" Lateglacial chronology (Sissons, 1976a) requires that the shoreline has been formed during a period of roughly 1,000 years. This is a comparatively short period of time for the erosion of a rock platform by conventional marine action. For example, sea-level has been roughly constant for the last 2,000 years and no comparable erosion has taken place in this time. Hence it seems necessary to invoke special conditions for the production of the platform.

When proposing the Lateglacial age for the rock platform Sissons (1974c) suggested that it was formed by frost action in a peri-glacial climate, aided by the semi-diurnal wetting of the foreshore zone. This subaerial mechanism seems quite feasible with an estimated mean July temperature of 5°C during the Loch Lomond Stadial (Sissons, 1976a). Gray (1978) has reviewed possible mechanisms for rock platform formation and concludes that frost action must have been of prime importance, though it is difficult to find a present example in the world of conditions comparable to these that probably existed during the Loch Lomond

Stadial in Scotland.

There is a disagreement about the effectiveness of marine erosion on present-day high latitude coastlines (Sugden and John, 1976). McCann (1972, et al. 1972) investigated the ice-foot on high arctic beaches in Canada. He found that the ice-foot persisted for a large part of the open-water season, and together with pack-ice, considerably reduced the effectiveness of wave action on the coastline during the brief open-water season. The occasional large storm under favourable open-water conditions may be very important in debris removal and beach erosion. Davis (1972) suggested that the presence of frost-susceptible rocks, freshwater and periodic wave action were vital to the effectiveness of freeze-thaw action along polar coastlines. Sollid (1973) described rock platforms in northern Norway, and suggested that they were primarily the result of frost action, not marine denudation, and that the platforms have been eroded irrespective of exposure.

Nansen (1921), in a long paper on the formation of the Norwegian strandflat, provided excellent descriptions of the action of frost in the formation of rock platforms and his comments and observations are extremely pertinent to the present discussion. Nansen concluded that wave erosion had been of but little direct importance for the planing of the strandflat of northern regions, compared with the erosion effected by frost in, and just above, the shoreline (p.29). He proposed the term 'shore erosion by frost' (p.29) and suggested that the confinement of rock platforms to high latitudes confirms the suggestion that frost action is the crucial mechanism for their formation.

The erosive effect of freshwater is far greater than that of salt-water, and Nansen suggested that this may account for the formation of rock platforms in sheltered areas; an upper layer of freshwater is preserved, and is not mixed with the denser seawater in a low-energy environment. The erosive effect along the foreshore caused by this upper layer of freshwater will be considerably greater than that achieved by the mixed salinity water of a more exposed coastline.

The 'ice-foot' may be important in providing meltwater for freeze-thaw action: 'the accumulations of ice and snow along the shore will year by year eat themselves landwards, making the shore-bench broader, and forming a higher and higher cliff ... thus the typical shore of Arctic lands is developed' (Nansen, 1921, p.33). Nansen also suggested semi-diurnal freezing of the shore as a possible mechanism for platform formation, but strongly discounted the possibility that pack ice or icebergs could have a significant role in the formation of rock platforms. The most important function of marine action is the removal of frost-shattered debris from the platform, to prevent insulation and therefore further freeze-thaw cycles.

This account conflicts with the view of Zenkovitch (1967) concerning the importance of frost action in the erosion of a coastline.

> 'It is now thought that the ice usually protects the shore from wave action during the cold months. Abrasion forms specifically related to the action of ice have nowhere been found, and there is no proof that coasts consisting of approximately identical rocks are more rapidly destroyed in Polar seas, or in the seas that freeze over, than in those that are always free from ice ... it is impossible to agree that the shores of polar seas recede more rapidly than shores in the temperate zone as a result of frost weathering, and the formation of the strandflat cannot be ascribed solely to this process' (Zenkovitch 1967, p. 170).

However, analogies with high latitude, micro-tidal polar coastlines may be misleading, where much lower winter temperatures for longer periods of the year considerably reduce the effect of frost action. Thus the opinions of Zenkovitch may be strongly influenced by work from the high Arctic coast of the U.S.S.R. The more temperate maritime conditions of Norway are probably a more realistic analogue to Loch Lomond Stadial conditions.

PLATFORM.

In an attempt to determine the factors that have influenced platform development, especially to assess the relative importance of marine and sub-aerial processes, the following analysis of the rock platform in the field area was undertaken.

Method. The development of a rock platform was considered to be a function of lithology, direction of dominant winds and the exposure of a coastline segment. These factors are inter-related, especially the last two, and the problem was to examine the independent influence of each factor in the formation of the rock platform.

For every 1km point along the coastline of the field area where the Main Lateglacial Shoreline has been mapped, a point was marked on the 1:50 000 map. For each point the following data were obtained:-

a) Lithology (rock type)

b) Platform width.

c) Height of the backing cliff.

d) Aspect of the site, this being the orientation of a line drawn normal to the coastline at this point.

e) The length of fetch along lines at 20° intervals from true north, measured to the nearest 1mm on the 1:50 000 Ordnance Survey Map.

Various independent and dependent derived variables were generated from these input variables by a FORTRAN program, PLATFORM. The derived variables were :-

a)The minimum volume of rock removed (i.e.½cliff height x platform width).

b) The maximum volume of rock removed (i.e. cliff height x platform width).

c) Platform width /total length of fetch.
d) Approximate length of fetch normal to the shore.
e) A measure of the exposure of each site based on the number and size of fetch measurements.
f) Total fetch.
g) A vector for exposure.

These independent and dependent derived variables were then regressed on each other, using an SPSS Scattergram package on Edinburgh University's 360/370 IBM Computer.

Results. The quality of the input data was too poor to warrant the complexity of the analysis. However some correlations may be tentatively suggested:-

a) Total fetch was apparently more strongly correlated with the volume of rock removed (an indicator of platform development) than was fetch normal to the coast. This may be expected if marine action was important in the formation of the platform, as the narrowness of Loch Linnhe and the sound of Mull would result in the longer, oblique fetches being more important.

b) The maximum and minimum volumes of rock removed were regressed against total fetch. This distribution showed that well developed platforms do not occur in sheltered localities, but that small platform widths could occur on exposed sections of the coastline.

c) Exposure, irrespective of fetch, does not appear to correlate with platform width.

These results are considered inconclusive in supporting either marine or frost action as the dominant agency in platform formation.

ROCK TYPE AND PHYSIOGRAPHY.

The Main Lateglacial Shoreline is poorly developed around the coast of N.W. Argyll. The average platform width measured at 1km intervals along the coast where the platform is present is only 8.2m. This compares to rock platforms generally 20-30m wide, but varying from less than 10m to over 150m in the Firth of Lorn (Gray, 1974a p.81). From field mapping a relationship was suspected between platform development and rock type. The mean platform width for the sedimentary conglomerates, Tertiary lavas, Strontian Granite and Moinian Schists are 20.8m, 12.7m, 10.1m and 6.3m respectively. Using a chi square test, there is a statistically significant difference between platform widths on these different rock types at the 0.05 level. With a t - test, the null hypothesis that there were no significant differences between mean platform widths cut in different combinations of rock types, was rejected at the 0.05 level.

These statistical differences between mean platform widths on different rock types demonstrate that the lithology of the coast line is an important factor in determining platform development. The large majority of the platforms mapped and surveyed by Gray (1974a) were cut into rocks that are less resistant to marine erosion and frost attack than those of the study area. Well developed rock platforms are found around the islands of Shuna, Lismore and Kerrara, and along parts of the adjacent mainland coast. These platforms are cut into Dalradian limestone and slates and Old Red Sandstone conglomerates.

Very little information is available on the susceptibility of different rock types to frost action and marine erosion. Zenkovitch (1967 p. 175) stated that observations on the granite coastline at Murmansk in winter showed that 'not even the slightest ledge is formed in such rocks at contemporary sea-level, let alone an abrasion niche'. In describing submerged sections of the strandflat, Nansen (1921) stated that there is a typical difference between platforms on granite, or similarly resistant rocks and those cut in limestone or other less resistant rocks : the former are narrow, less clearly defined and have a very uneven surface while the latter are flat, broad and well defined.

A further factor that probably influenced platform development was topography. The very steep nature of the Loch Linnhe coastline in the field area (described in Chapter 1) may have reduced the efficiency of wave action by the 'rebound' or 'breakwater effect'. The sea at its present level has had little effect in destroying ice-moulded rock along the coastline of the field area (e.g. at NM 623461) and it is probable that the rock platform along this steep coastline is almost entirely due to frost action, the role of waves being merely that of debris removal. Nansen (1921) mentioned work by Vogt, who described ledges 8-12m wide cut in gabbro on extremely steep fjord walls. These ledges are rough and the surface angular, showing 'no appreciable traces of having been rounded by the waves' (Nansen, p.36).

On the opposite shore of Loch Linnhe and the Firth of Lorne (outside the field area), marine erosion may have been more effective owing to the low relief of the coastline, while the more sheltered environment may have enhanced the effectiveness of frost action by preserving an undisturbed fresh-water layer over salt-water. Combined with rocks that were probably more susceptible to marine erosion and frost action than the harder rocks of the field area, this may help to explain the contrast in the development of the rock platform between the different areas.

ii) Providing a period of land/sea-level stability for Platform Formation.

The second problem relating to the formation of the rock platform during the Lateglacial is that eustatic sea-level change and isostatic uplift must have been approximately balanced. Gray (1978,p.162) suggests that 'the rates of rise of land and sea were closely matched in the Firth of Lorn thus explaining the clarity of the features there, while away from this area isostatic recovery was too slow for optimal development', thus explaining 'the progressive decrease in clarity (of the platform) in all directions away from the Firth of Lorn'. However the rock platform is excellently developed down the west coast of Jura (McCann, 1964; A. G. Dawson, unpublished) and exists far from the centre of isostatic uplift in the Forth valley and beyond to St. Abb's Head (Sissons, 1976b). This distribution of the shoreline requires comparable rates of land and sea-level change over much of Scotland. There is a greater probability of an isostatic-eustatic balance over a large area if the rates of change are minimal. There are several possible reasons for this.

Isostatic rise may have been minimal because:-

a. Most isostatic uplift had taken place prior to the Loch Lomond Advance. This is illustrated by the difference in shoreline gradients between the earliest East Fife shorelines (1.25m/km), the Main Perth Shoreline (0.43m/km) and the Main Lateglacial shoreline (0.17m/km) in the Forth Valley (Sissons, 1976b). The two former shorelines were associated with ice-sheet decay, that was probably completed in the central Grampian Highlands by 13,000 B.P. (Sissons and Walker, 1974).

b. Ice-sheet isostatic uplift that was still occurring during the Lateglacial may have been diminished by the development of Loch Lomond Advance ice-caps over the Western Highlands. This may be reflected in the difference between the two early shoreline gradients and the Lateglacial shoreline gradients sited above, though it is not possible to determine the proportion of the gradient difference attributable to either ice-sheet isostatic rebound or the accumulation of Loch Lomond Advance ice. The effect of the latter may be illustrated by the isobases of the Main Lateglacial Shoreline. The centre of isostatic uplift for this shoreline is approximately coincident with the main area of ice accumulation during the Loch Lomond Advance (Gray and Lowe, 1977).

Eustatic sea-level rise may have been minimal as:-

a. Considerable eustatic sea-level rise from the ice-sheet deglaciation had already taken place. For instance Hughes, Denton and Crosswald, (1977) postulate rapid deglaciation of the Arctic Ice Sheet, with 'an initial major recession of peripheral terrestrial portions as opposed to later major retreat of interior marine portions' (p. 601). Deglaciation of the former ice sheets may have had a greater effect on eustatic sea-level than the latter due to the displacement of the marine portions by sea water.

b. Glacial advance of the Scandinavian ice-sheet may have slightly decreased eustatic rise during the Lateglacial.

Postglacial Raised Shorelines.

Postglacial Raised Shorelines : Landforms

The Postglacial raised shorelines of the field area consist of raised beaches composed of sand and gravel. These beaches are conspicuous as their well-drained soil forms the best agricultural and often the only flat land in the field area. The raised beaches may be divided into two catagories.

1. Small depositional raised beaches. These beaches have a scattered distribution, their location and size being related to a local source of sediment, invariably a river. A typical size for these beaches is about 500 x 500m (e.g. at Kinlochteacius, NM 655545) though some are no more than 20m broad and 80m long (e.g. at Camas Salach, NM 684613). Most of these smaller beaches slope steeply at right angles to the shore. Some of the larger raised beaches have a second lower shoreline, but many slope seaward to merge with the present storm beach. Nowhere in the field area are there more than two shorelines in succession. Fossil beach ridges and spits are not uncommon and there are several examples of a raised tombolo, the best being at Camasachoirce (NM 768606).

Sediment supply, and hence beach size, varies with the different rock types of a drainage basin. At Barr (NM 620564) a large area of raised beach deposits (up to 1km wide) is related to a comparatively small river, but here soft Mesozoic rocks crop out within the drainage basin. Alternatively, along the coast of Loch Sunart, many raised beaches have suffered from 'sediment starvation', resulting in a thin layer of beach material with Moinian schist outcrops protruding through the beach (e.g. at NM 757610). Along the Loch Linnhe coastline south of Cilmalieu to NM 837487 there is an unusual beach sequence. The Postglacial sea has partially eroded several large alluvial fans and has re-deposited this material, together with that from probable smaller fans that were completely destroyed, to form several long fragments of raised beach. These beaches slope seaward and also slope away from the apex of each fan, making objective altitude measurement of the shoreline difficult.

In several areas the height of the raised beach has been influenced by the Main Lateglacial Shoreline. The rock platform has provided a shelf on which the beach material has subsequently been deposited. This is best seen at several locations along the Sound of Mull, e.g. Savory Bay (NM 641456), Fiunary (NM 615466) and near Killundine (NM 579496).

2. Raised beaches associated with the Loch Lomond Advance outwash.

A more complex and larger series of Postglacial beaches has been formed by the erosion and subsequent re-deposition of part of these outwash fans.

The best example of this is at Corran, where the Postglacial sea has eroded the higher northern part, and redeposited material on the southern margin of the outwash fan. A steeply sloping beach has been eroded along the northern margin of the outwash, destroying the probable former ice-contact slope. The sea has breached the large kettleholes and destroyed much of the fan surface; a high remnant of the fan has been preserved at NN 012637. Further south, the sea at the maximum Postglacial level has redeposited fluvioglacial material forming a series of beach ridges at Clovulin (NN 003633), into which a lower shoreline has been cut (NM 998627). At Sallachan (NM 987626) a storm beach marks the upper limit of the disturbance of the fan surface by the Postglacial sea, while a lower beach has been eroded below this feature (NM985626).

The erosion of Lateglacial outwash deposits by a river, and the subsequent deposition of this material by the Postglacial sea has occurred at Inversanda, Laudale and Strontian. In each case a spit has been formed, the best example being at Inversanda (NM 946595).

At Kentra Bay (NM 648697) the fluvioglacial outwash fan of the former Shiel glacier merges with the present storm beach. While fragments of raised beach exist around the margin of the bay, a transgression of the fan was probably prevented by the large peat bog, Kentra Moss, that covers the outwash. Two shorelines have been eroded into the Claish outwash depsoits above the present shore of Loch Shiel. These shorelines extend for several kilometres around the area of Eilean Fhianain (NM 750683), though again the sea has been prevented from transgressing the outwash by Claish Moss. This situation is analogous to that described by Sissons and Smith, (1965) in the Forth Valley. That the Postglacial sea flooded the basin is also demonstrated by marine sediments from the bottom of the Loch. (see Chapter 6.)

The Postglacial Shorelines : Height Analysis.

The Main Postglacial Shoreline.

Fragment height averages for the Main Postglacial Shoreline were plotted on an equidistant diagram with an east - west projection. This orientation was used because the linear surface produced by the trend surface analysis of 54 fragment averages by Gray (1974b, p.133) 'indicates an isobase alignment of N4 E - S4 W'. This trend surface analysis was used because it was considered that there were insufficient fragment averages from the field area to provide a meaningful analysis.

The linear regression analysis of 18 A and B grade heights for the Main Postglacial Shoreline produced a gradient of 0.062m/km (see Fig. 4.4).

In a further analysis, 3 C grade heights were included and a similar gradient, of 0.061m/km, was obtained. The similarity of these gradients with those produced by Gray (1974b) for his PS1 shoreline (the Main Postglacial Shoreline) suggest that this is the same feature.

It is probable that this shoreline correlates with the Main Postglacial Shoreline in the Forth Valley, formed around 6,500 B.P. (Sissons and Brooks, 1971). This shoreline has a gradient of 0.08m/km in the Forth (Sissons et al. 1966) and 0.09m/km in the Tay estuaries (Cullingford, 1972). Gray (1974b) suggested that the discrepancy in the gradient of the shoreline between the east and west coasts of Scotland may reflect the funnelling effect of the Forth and Tay estuaries, differential isostatic uplift and tectonic movement. A discrepancy exists between the gradient of 0.06m/km obtained by the writer and that of 0.075m/km given by McCann (1966a) and Synge and Stephens (1966). This difference may be attributed mainly to the unsatisfactory field techniques used by these workers.

The Low Postglacial Shorelines.

Gray (1974b) identified four Lower Postglacial shorelines below the Main Postglacial shoreline (PS1). Two of these, a PS3 shoreline at approximately 8m and a PS5 at 3-4m O.D. he considered to be definite features while the remaining PS2 and PS4 shorelines at 10 and 7m respectively are tentative. In the present analysis, the evidence is inadequate for such details to be elucidated. The shoreline diagram (fig. 4.4) shows a wide scatter of shoreline altitudes. However, as described in the previous section, the seaward slope of many of the beaches and the influence of the Main Lateglacial Shoreline and alluvial fans have rendered many fragment averages unsuitable for height analysis.

However, having discarded these biased heights, a linear regression analysis of 19 Low Postglacial Shoreline fragment averages produced a gradient of 0.0004m/km along an E.W. plot. This shoreline must be regarded as a horizontal, but the height variation of each fragment makes the analysis of limited value.

The height of the shoreline (approximately 5m) indicates that it may correlate with the PS5 shoreline of Gray (1974b). The intermediate shoreline PS3, and the tentatively proposed PS2 and PS4 shorelines described by Gray (1974b) have not been identified. This may reflect the smaller number of fragment averages for the low Postglacial shorelines; 19 as opposed to 90 fragment averages obtained by Gray for all the shorelines below PS1, though nowhere in the field area are there more than two Postglacial Shorelines in one location.

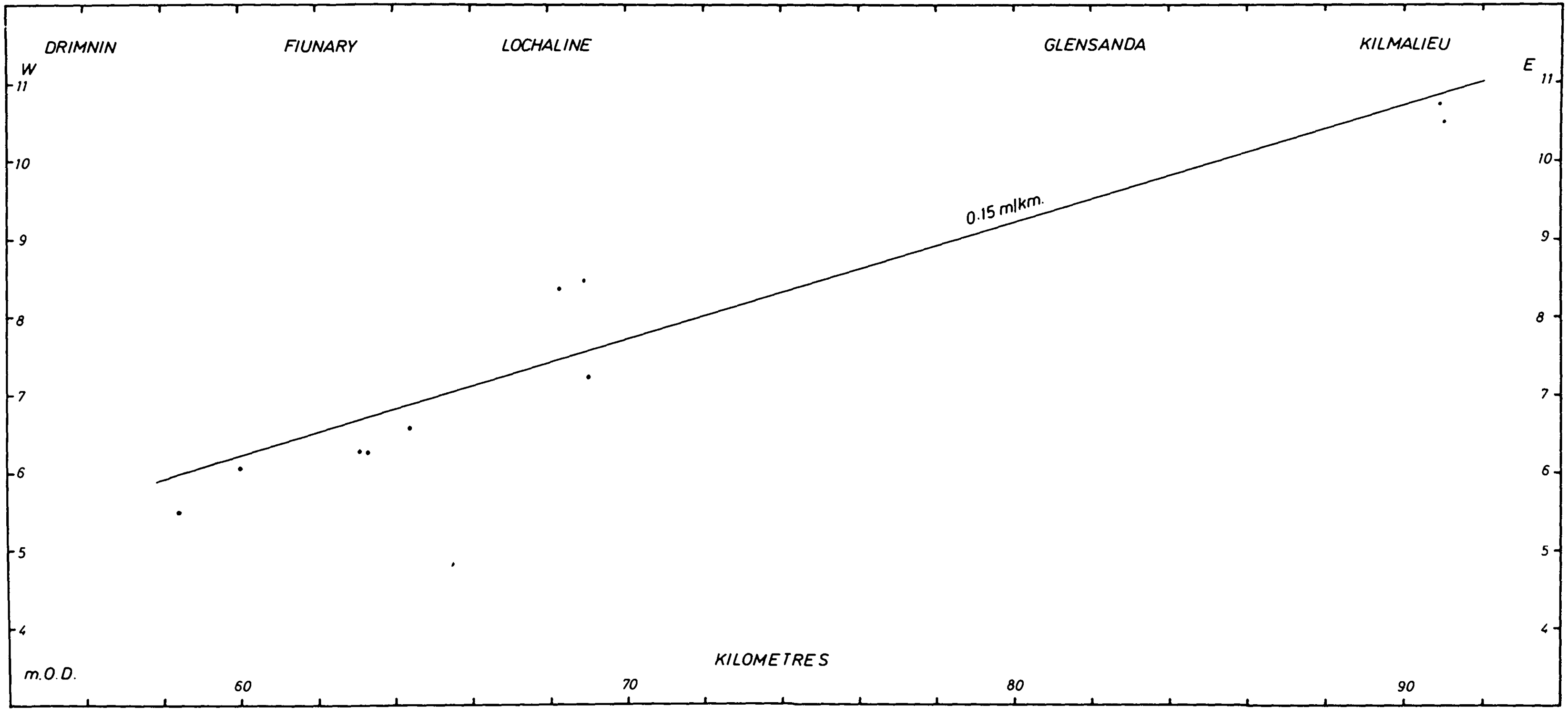

FIG 4.2. LINEAR REGRESSION ANALYSIS FOR THE MAIN LATEGLACIAL SHORELINE FRAGMENT AVERAGES ALONG LOCH LINNHE AND THE SOUND OF MULL.

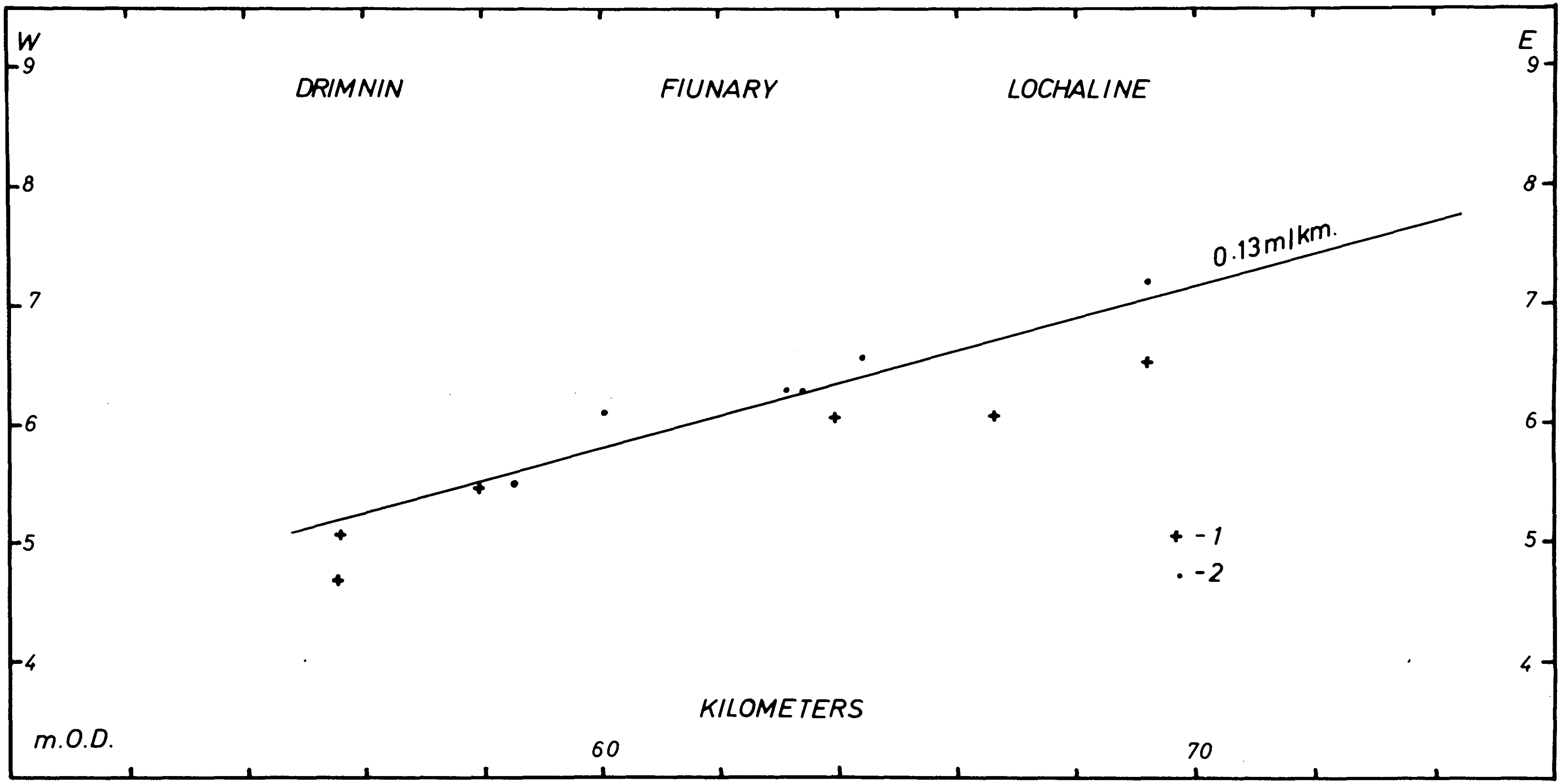

FIG 4.3. LINEAR REGRESSION ANALYSIS FOR THE MAIN LATEGLACIAL SHORELINE FRAGMENT AVERAGES ALONG THE SOUND OF MULL. 1-M.J. GRAY'S HEIGHTS, 2-WRITER'S HEIGHTS.

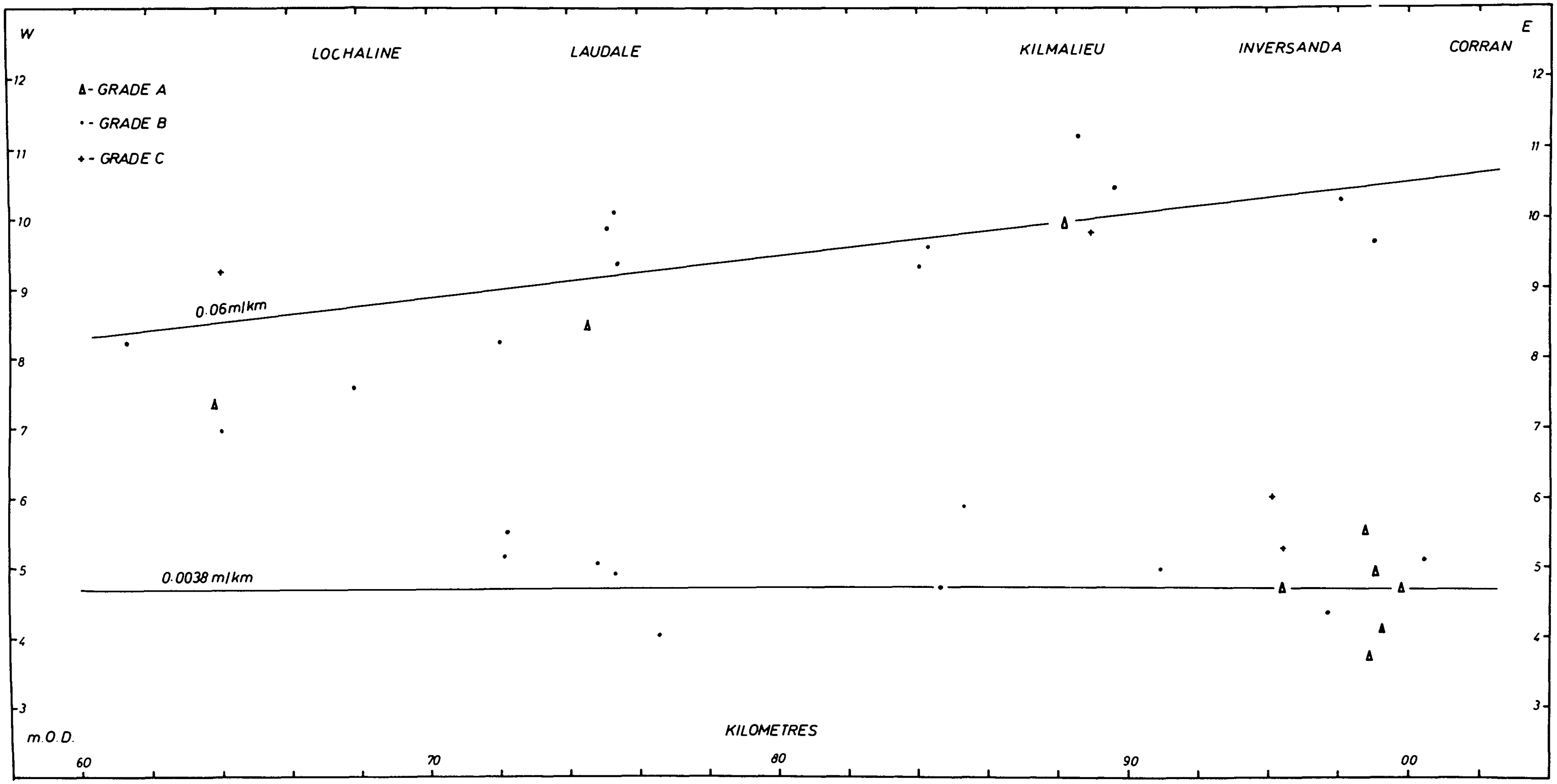

FIG 4.4. LINEAR REGRESSION ANALYSIS FOR THE MAIN AND LOW POSTGLACIAL SHORELINE FRAGMENT AVERAGES IN PART OF N.W. ARGYLL.
(SEE TEXT FOR GRADE DEFINITION)

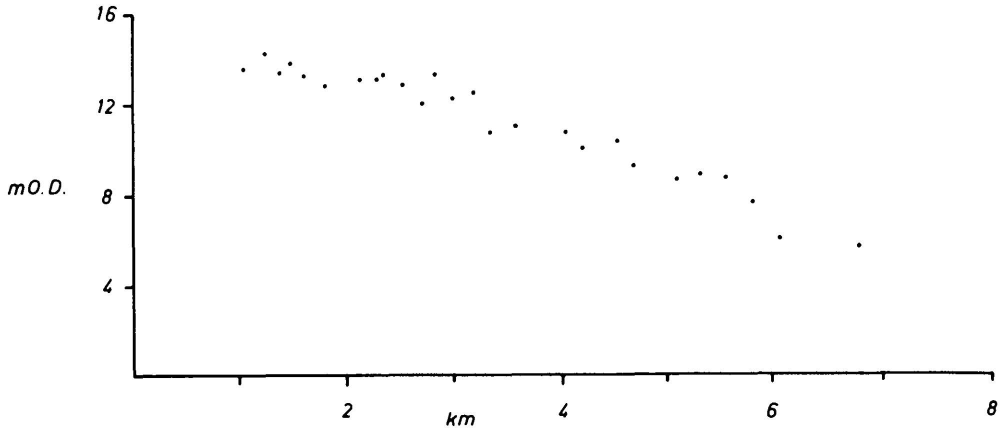

FIG 4.5. KENTRA OUTWASH TRANSECT A-B.

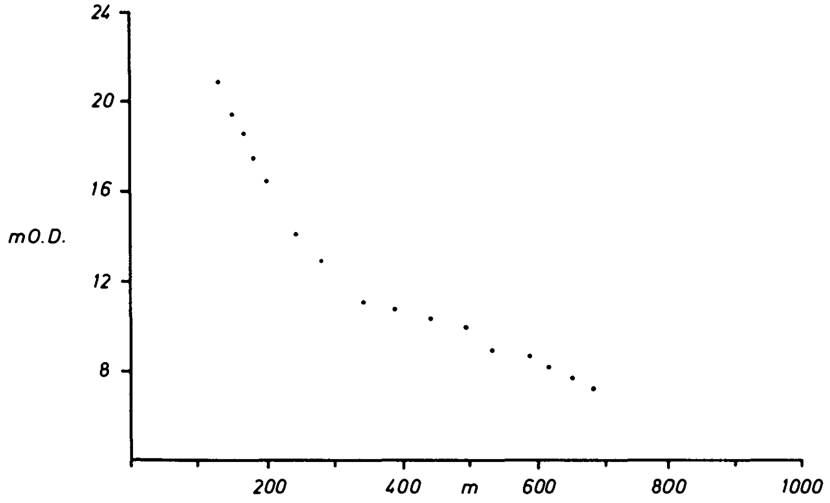

FIG 4.6. LAUDALE OUTWASH TRANSECT C-D.

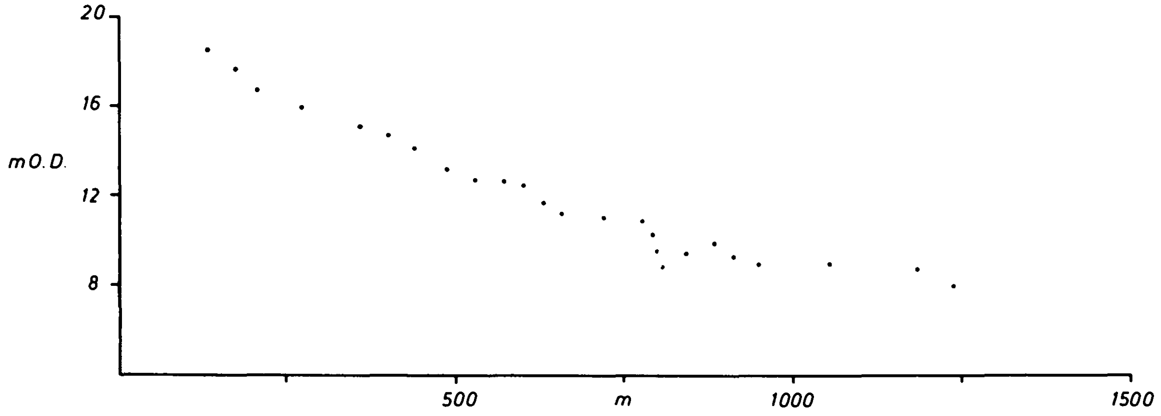

FIG 4.7. INVERSANDA OUTWASH TRANSECT E-F.

CHAPTER 5.

POLLEN ANALYSIS : THEORETICAL CONSIDERATIONS AND ANALYTICAL METHODS.

Introduction.

The reconstruction of the past vegetational history of an area by pollen analysis involves determining the type and abundance of taxa that were present in the former ecosystem; what plant communities these taxa represented; the importance of these plant communities in the ecosystem; the time at which the ecosystem existed and the environment in which the ecosystem developed. The first part of this chapter discusses the assumptions and complications involved in these various elements of vegetational reconstruction while the latter part describes the pollen analytical methods used in this study.

Chapter 6 is concerned with the Lateglacial vegetational history of the field area as recorded by the fossil pollen record from a site at Salen. In Chapters 7 and 8 the pollen record from a sequence of lacustrine sediments from Loch Shiel is described. Supplemented by paleomagnetic and chemical analysis, an environmental reconstruction is then made for the area during the latter part of the Postglacial.

Pollen Analysis : Theoretical Considerations.

Pollen analysis has developed from a fairly safe assessment of past vegetation patterns inferred from the different pollen grains and spores of plants preserved in peat, first described by Von Post (1916) to a highly refined and versatile technique that provides important information for environmental reconstruction.

The technique assumes the production and uniform dispersal of a great quantity of pollen grains. Pollen analysis is possible because of two properties of the pollen grains and spores. The first is the great morphological diversity of the grain. Due to number and type of apertures and the immense structural variation of the exine, it is possible to identify pollen grains to genus level (e.g. Salix) or to identify all the species of a genus (e.g. Plantago). The second property is the very resistant nature of the pollen exine and spore wall. This wall is composed of a complex carbohydrate which is resistant to oxidation. This enhances pollen grain preservation and allows the grains to be separated from a sediment for examination.

1. Pollen Diagram Interpretation.

In a pollen diagram the frequency of each pollen taxon for a constant sample number may be expressed as a percentage of the total pollen counted or of any specific pollen total or pollen sum. The pollen sum defines 'the plant communities presumed to occur within the area under investigation' (Faegri and Iversen, 1975 p.124), and it is important to include within this total all meaningful taxa. This prevents the dangers of drawing conclusions based on the absence of important species. It is however necessary to exclude the presence of disturbing species, for instance, the pollen from local species if a regional analysis is being made.

The use of pollen percentage values in the majority of pollen diagrams has the fundamental disadvantage that the pollen percentage values are interdependant. Consequently percentage frequency variation may mask numerical changes in the frequency of each taxon and may 'represent statistical artefacts rather than significant vegetational changes' (Davis and Deevey, 1964 p. 1293).

Absolute pollen analysis 'requires the relation of numbers of fossil pollen grains to unit volume of fresh sediment (pollen concentration) in order to compare throughout the profile numbers of grains deposited per unit area in unit time (pollen influx). This permits consideration of pollen curves as independent variables rather than as interdependent percentages or proportions' (Bonny, 1972 p.393).

Absolute pollen frequencies have been calculated in this study in an attempt to provide a more accurate interpretation of the fossil pollen spectra in terms of past vegetation. Pollen influx data are more sensitive than pollen percentage data and include a consideration of the sedimentation rate, though the data have a greater variance (M. B. Davis, 1967a, 1967b, 1968, 1969; Pennington, 1973).

Absolute pollen frequencies are particularly useful in distinguishing between treeless and some forested vegetation covers (Ritchie and Lichti-Federovich, 1967) and for detecting lower pollen productivity. 'Present experience indicates that absolute diagrams will be most valuable for the interpretation of Lateglacial pollen sequences, many of which record vegetation that changes drastically in pollen productivity as tundra was replaced by park tundra and woodland, and woodland replaced by forest' (Faegri and Iversen, 1875 p.162). As total pollen influx values are different for each major vegetation formation, they may be used to identify these formations (Davis, Braubaker and Webb, 1973).

Although absolute pollen analysis involves a more complex laboratory preparation and requires the chronological calibration of the diagram by radiocarbon dating, the additional information has been shown to provide a greater understanding of vegetational history (M. B. Davis, 1967, 1969; Pennington and Bonny, 1970; Pennington, 1973, 1976).

Besides the errors and assumptions that are involved in the construction of a pollen diagram, there are further complications when a diagram is interpreted. The differences in the pollen productivity of plants reflected by an over- or under- representation of species in the pollen diagram has long been known. Estimates have been made for the production and dispersal of pollen grains for various taxa. For example, based on production of figures provided by Pohl (1937) 'a pollen spectrum registering 33% each of pine, oak and beech should represent a vegetation of 5% pine, 35% oak and 60% beech' (Faegri and Iversen, 1975 p. 153).

Correction factors (e.g. R - values) have been devised by Davis, (1963), Livingstone (1968) and Andersen (1970) in an attempt to obtain a quantitative picture of past vegetation. Restrictions on the use of R- values have been well documented (Davis, 1969; Birks, 1973) and the use of alternative correction factors (e.g. Andersen, 1970) may not be valid because pollen productivity may differ with varying ecological circumstances. For instance where Corylus avellana is present as an understorey shrub, its pollen productivity is poor (Jonassen, 1950) compared with the greater pollen output when it occurs at the edge of the forest (Janssen, 1966), or in Skye where it forms part of the woodland canopy (Birks, 1973).

The best method of checking the validity of the representation of taxa in a pollen diagram is to compare the modern pollen rain with the species composition and abundance in the adjacent community. The use of surface samples of modern pollen rain 'as a comparative means for finding modern vegetational analogues for former vegetation is the soundest basis currently available for the interpretation of pollen diagrams in terms of past vegetation. If there is a close match between the modern and fossil spectra then a vegetational reconstruction can be made with some confidence' (Birks, 1973 p.299). An important assumption is that the rate of pollen production for each species has remained constant over time.

There are several limitations in the use of modern pollen rain studies -

a) A correspondence between modern pollen rain and present day vegetation has been shown for large-scale and medium-scale vegetation patterns (Davis and Webb 1975; Webb, 1974a, 1974b; Birks et al., 1975). This 'supports the use of fossil pollen spectra in the reconstruction of the relative composition of past vegetation' (Williams, 1977 p.63). However on a smaller scale the poor representation of some species and the poor taxonomic resolution possible with others may present difficulties in reconstructing small vegetational variations (Birks, 1973; Webb, 1974b).

b) A modern pollen rain spectrum should be available for the principal vegetational types in the area where the past vegetational history is being elucidated. The disturbance of present plant communities by man may however make an accurate comparison impossible.

c) The use of modern pollen rain data where terrestrial surface samples have been used may not be applicable to fossil pollen spectra from a lacustrine environment. This is because of pollen mixing within the lake water (M. B. Davis, 1968) and within the lake sediments (R. B. Davis, 1967, 1974; Nichols, 1967a, 1967b; Pennington, 1973). Ideally lacustrine surface samples should be used in the interpretation of the fossil pollen spectra but this is not always possible because lakes surrounded by natural or semi-natural vegetation are often unavoidable (Williams, 1977).

d) The fossil pollen assemblage may have been derived from two or more vegetation types.

e) There may be no modern vegetational analogue for the fossil vegetation as represented by the fossil pollen spectra.

A different approach to modern pollen rain studies may be to estimate the probability of pollen transport from a stand of known vegetation over a series of set distances. From this information a 'synthetic' fossil vegetation may be reconstructed from the fossil pollen rain (Birks, 1973; Walker, 1972).

The method used to interpret most pollen diagrams is to group together the pollen and spore types of ecologically related taxa that occur at the same stratigraphic level. Each group is then interpreted as reflecting a plant community while the basic assumption is made that the ecological tolerances of all plant species have not changed over time (Birks, 1973).

The level of pollen identification often makes it impossible to allocate a plant to a specific ecological group while other species have a wide ecological tolerance. In these circumstances the use of certain indicator species may be of value. These species can be identified to their lowest taxonomic level and a few have specific ecological tolerances. An indicator species may represent a specific plant community. For instance, <u>Oxyria digyna</u> is characteristic of a pioneer community at the base of Lateglacial pollen sequences (Birks, 1973; Williams, 1977); its pollen may be taxonomically distinguished from other Polygonaceae (Birks, 1973) while Matthews (1974a, 1975a) has shown it to be an important pioneer species colonizing the recently exposed parts of glacier forelands in the Jotunheimen.

In the use of this ecological approach to pollen diagram interpretation, some attempt is made to infer the probable extent of the different ecological groups within the 'pollen catchment area'. But the 'exact delimitation of the pollen catchment area is impossible and the "area" will essentially be different for different pollen taxa' (Williams, 1977 p.67). In this situation modern pollen rain studies provide valuable information on the dispersal of pollen from the surrounding vegetation on to a specific site (Tauber, 1965, 1967; Tinsley and Smith, 1974; Janssen, 1973).

Pollen analysis is often undertaken to infer past periods of climatic change. It is essential that the climatic inferences are made from the reconstructed past vegetation and are not implied directly from the fossil pollen spectra. The recognition of non-climatic factors such as a vegetational succession in a pollen diagram is crucial.

Faegri and Iversen (1975 p. 144) state that a 'pollen diagram represents nothing but the parts of the pollen rain that have been recorded after fossilization'. This suggests two further sources of error in pollen diagram interpretation; that of the differential destruction of pollen grains and the contamination of the deposits sampled.

In the former case it is possible to distinguish various types of exine deterioration (Cushing, 1967) which has been used to provide additional information in evaluating a pollen diagram (Lowe, 1977). The latter case of the redeposition and contamination of deposits has been well documented. These include the irregular deposition and reworking of lake sediments (Nichols, 1967a, b; Pennington et al. 1972); unconformities in a seemingly undisturbed sequence of sediment (Lundquist, 1924) and the displacement and redeposition of allochthonous material (Jones, 1958; Birks, 1970).

2. Pollen Diagram Zonation.

The original Jessen-Godwinian zonation scheme was devised to correlate different pollen diagrams using biostratigraphy. However this was based on the assumption that 'climatic changes were widespread, had widespread synchronous effects upon the dominant vegetation formations and that a series of pollen zones was an expression of these changes' (West 1970, p.1180). As a result, pollen zones assumed a chrono-stratigraphical meaning.

As the vegetational history of Great Britain was elucidated, attempts to impose the Jessen-Godwinian system proved unsuccessful (see chapters 6 and 7) and the disagreement between litho-, bio-, and climato-stratigraphical units became more apparent (Coope, 1970; Pennington, 1970; Pennington and Bonny, 1970; Coope and Brophy, 1972; Walker, 1974; Lowe, 1977). This discrepancy was first realized for Lateglacial sequences, but the diachroneity of major vegetational changes within the Flandrian in N.W. Europe is now recognized (Birks, 1973; Hibbert et al., 1971; Smith and Pilcher, 1973).

In 1970, West advocated the separation of pollen assemblage zones from the stratigraphical chronology. He argued that a pollen assemblage zone 'reflects a vegetational unit' and that 'zones of similar aspect may occur at different times and in different situations' (p.1180). West recommended the establishment of type sites where a pollen zone - a biostratigraphical division - can be independently chronologically calibrated e.g. by radiocarbon dating. This biostratigraphical division would then become a chronozone. The correlation of another pollen diagram with that type site would involve a chronological correlation using radiocarbon dating as well as the zone description amd comparison of the biostratigraphy of that pollen diagram.

Birks (1973) has established guidelines for the vertical subdivision of a pollen diagram into pollen zones based on the Code of Stratigraphic Nomenclature (Geological Society of London 1967, 1969). He defines a pollen zone as 'a body of sediments with a consistent and homogeneous fossil pollen and spore content that is distinguishable from adjacent sediment bodies by differences in the kind and frequencies of its contained fossil pollen grains and spores' (p. 273). If there are similar changes in the frequencies of a range of pollen and spore types within a locality, then a local pollen zone may be established. If there are broad similarities in the pollen and spore composition of several local pollen zones, then a regional pollen zone may be defined. Both of these pollen zones are biostratigraphical units and under the stratigraphic code correspond to assemblage zones. The advantage of using these pollen assemblage zones is that they 'are defined solely on the observable contained fossils without any reference to the sediment lithology, to the inferred environmental and climatic conditions or to the assumed time equivalence' (Birks, 1973 p.280).

Pollen diagrams have traditionally been zoned subjectively by the pollen analyst though it is difficult not to be influenced by lithological, ecological and climatic variations and associations. Therefore 'it is preferable to achieve an objective zonation based purely on the changes in all taxa present, with the same criteria being rigorously and consistently applied to each zone boundary' (Robinson, 1977 p. 140). For this purpose Gordon and Birks (1974) have devised three computer programs involving the use of con~~t~~strained agglomerative and divisive procedures that may be used to identify, delimit and define biostratigraphical zones. As the analyst is required to define the criteria used for subdivision at the outset, these conditions may then be applied to several diagrams.

If the pollen zones produced by the three different zonation programs coincide, then one may have considerable confidence in the reality of these zones. It has been found that these numerically defined pollen zones usually correspond to the subjectively determined zones delimited by an experienced pollen analyst. However the additional advantages of consistency of zonation, rapidity of implementation and repeatability of results make these numerical zonation techniques particularly valuable, especially when reconstructing regional vegetational history from a large number of diagrams (Gordon and Birks, 1974).

Pollen Analytical Methods.

1. Sampling.

Cores from the site at Salen, Ardnamurchan, (see Chapter 6) were obtained using a modified hand-operated Dachnowski piston corer. The modification from the original Dachnowski design was the use of a larger sampling chamber. This allowed cores 60cm long and 5cm in diameter to be obtained, providing more material for radiocarbon dating and reducing the risk of contaminating samples for pollen analysis (Lowe, 1977). An important aspect of sampling has been the use of an instrumental level and a staff to obtain the precise depth of the cores extracted (Walker and Lowe, 1976). A series of cores were alternately taken from two holes on the bog surface and the use of the level and staff meant that a continuous column of sediment could be subsequently reconstructed. The cores were extruded from the sampling chamber on to semi-circular plastic troughs 70cm in length and covered with a plastic sheet. Auger attachments were used to penetrate particularly coarse layers of sediment, especially the coarser Loch Lomond Stadial layer of the tripartite Lateglacial stratigraphy, to allow the underlying softer interstadial deposits to be sampled.

The cores were stored in the laboratory at Edinburgh in a cool dark room. The outer part of the core was carefully cleaned, and at the desired sampling interval a disc of sediment was removed and its centre section sealed in a glass phial. This enabled the sample to remain moist and so maintain its volume, a requirement of the absolute laboratory preparation.

At Loch Shiel three cores were taken in 6m long U.P.V.C. liners using a Mackereth pneumatic piston cover (Mackereth, 1958). Whole core magnetic scanning (Molyneux <u>et al</u>., 1972; Molyneux and Thompson, 1973) was used to establish the basic sediment and palaeomagnetic stratigraphy. Core 3 was chosen for detailed analysis as it had the longest undisturbed limnic sequence of the three cores. The core was cut in half by slotting the U.P.V.C. liner with a circular saw and opening with a sharp knife. One half of the split core was sub-sampled for more detailed palaeomagnetic studies and the remaining half was used for palynological, chemical and radiocarbon analysis.

2. Sediment Description.

A description of the sediment and stratigraphy was made for each core, broadly based on the system proposed by Troels-Smith (1955). Details of sediment changes at a lithological boundary, sediment colour (and changes after exposure to air) and sediment structure were noted. An estimate of the degree of humidification of organic sediments was obtained from supernatant colour after the deflocculation of the samples in 10% sodium hydroxide.

With the Salen site, a more detailed account of the sediment properties was made by recording on a 5 point scale the degree of darkness, stratification, elasticity and dryness of the samples in an attempt to quantify minor stratigraphical changes (Birks, 1973).

3. Laboratory Preparation.

The samples taken from the cores were subjected to chemical and physical processes allowing the pollen grains to be separated from the matrix and to be identifiable under the microscope. The preparation used relies on the resistant nature of the pollen exine to allow other extraneous matter to be removed. The slides were prepared following the method described by Faegri and Iversen (1975) but with several modifications (Bonney, 1972; Robinson, 1977). The main stages in the preparation were:-

a) The deflocculation of the sediment by boiling in a 5% solution of sodium hydroxide. Sieving removed coarse inorganic particles and macrofossils while subsequent repeated washing removed humic acids.

b) The removal of minerogenic particles by treatment with 50-60% hydrofluoric acid. Depending on the clay content of the sample, the length of treatment varied from 5 days in cold hydrofluoric acid to a more typical 1 hour in hot acid (Pennington *et al*, 1972; Walker, 1974).

c) The removal of colloidal silicates and silicofluoides by treatment with 10% hydrochloric acid.

d) Dehydration with glacial acetic acid, followed by Erdtman's (1969) acetolysis which destroys cellulose and then further dehydration.

e) The mounting of the residue on a slide with safranin-stained glycerine jelly.

Minor changes were made to this basic procedure. These were: the retention of the sample in polythene centrifuge tubes after the hydrofluoric acid treatment; the use of a mechanical agitator to disturb the centrifugant after decanting; washing the sample repeatedly after sieving until the centrifugant was clear (pers. comm. Sylvia Peglar). Some of the Loch Shiel samples required further treatment with cold nitric acid to remove pyrite spherules (Vallentyne, 1963).

The use of the absolute counting technique required several additional procedures to the laboratory preparation (Bonney, 1972). The preparation differed from that of Bonney in that the exotic pollen suspension (*Ailanthus altissima* grains in glycerol) was added at the beginning, not at the end, of the preparation (Robinson, 1977). The reason for this is stressed by Faegri and Iversen (1975 p.164) 'from the moment the indicator pollen is added, it is no longer necessary to work quantitively as any loss of material incurred will affect indicator pollen in the same way as the native pollen of the sample. As it is in reality almost impossible to get material quantitatively out of a centrifuge tube, this advantage can hardly be overrated'. The additional stages that the absolute preparation entailed were:-

a) The displacement of 1cm of sediment by dilute NaOH in a modified

5c.c. measuring cylinder. The sediment was then washed into a boiling tube and accurately weighed.

b) The addition of several drops of homogeneous exotic suspension and the re-weighing of the solution to determine the amount of exotic suspension added.

The same exotic pollen suspension was used for both the pollen sites, and it had been prepared and then standardized using a haemocytometer as described by Matthews (1969).

Silicone oil was not used as a mounting medium because the smaller grain size (as opposed to a glycerine mount) increased the difficulties of identification. The type slide collection was also mounted in glycerine, which would have made comparison with silicone oil slides impracticable. The major disadvantage of glycerine jelly as a mounting medium, that grains cannot be moved for easier identification, was partially overcome by counting the slides within a few days of their being prepared, before the glycerine had completely set.

4. Pollen Counting.

The prepared pollen slides for Loch Shiel were counted on a Baker Patholett microscope with x10 complan oculars while slides for the site at Salen were counted on a Vickers Patholett microscope. Routine counting was made using a x40 objective while a x90 oil immersion objective was used for more difficult identifications.

Pollen grains were counted by making equally spaced traverses across the slide until 1,000 grains had been counted. An automatic counter was used to record the more numerous pollen taxa while the remainder were marked on a count sheet.

5. Pollen and Spore Identifications.

The identification of most non-arboreal pollen grains has been made to genus and occasionally to species level. The taxonomic level to which identification is possible is limited by the experience of the analyst; the standard of optical equipment available; the advances in pollen morphological data and the reference collection available. More taxa were identified from the Salen site than from Loch Shiel because the Loch Shiel site was analysed first. Consequently the experience gained in counting the Shiel site allowed further sub-division of taxa to be made with greater confidence.

The comparison of fossil grains with modern pollen from the type slide collection provided an essential aid to identification. Wherever possible, a second microscope was used to facilitate comparison between the fossil and modern pollen grains. The co-ordinates of difficult grains were recorded to allow them to be compared together, and so increase the reliability of their identification.

The key of Faegri and Iversen (1975) together with the two volumes of Erdtman, Berglund and Praglowski (1961), Erdtman et al. (1963) and the taxonomic details of pollen grains described by Birks (1973) were invaluable. However additional comments on the pollen types defined in the pollen diagrams are required to indicate the reliability of the pollen counts.

BETULACEAE.

No attempt was made to distinguish between the pollen grains of the tree birches (probably Betula tortuosa or B. pubescens,) and those of the dwarf birch (B. nana). Birks (1968) measured each grain to obtain this distinction, but recent doubts as to the validity of this identification (pers. comm. Birks) appear to make the time required to separate the species too long to be justified. A further disadvantage is the possible past hybridisation between B. nana and B. pubescens (Godwin, 1975).

CORYLACEAE.

Grains of Corylus avellana were not separated from those of Myrica gale.

ERICACEAE.

In the Salen diagram, Calluna vulgaris was counted separately from other Ericaceae tetrads (Oldfield, 1959). Grains of Vaccinium sp. and Erica tetralix were thought to compose most of the Ericaeae counted from Loch Shiel.

EMPETRACEAE.

No distinction was made between grains of Empetrum hermaphroditum and E. nigrum. It was noted that many of the grains in the Lateglacial stadial samples from Salen were corroded or shrunken (see Robinson, 1977) and that this would have made the distinction of these species by size statistics difficult (Anderson, 1961).

RANUNCULACEAE

In the Loch Shiel diagram, all Ranunculaceae pollen grains were undifferentiated. However, in the Salen pollen diagram, Caltha palustris, Ranunculus repens and Thalictrum were distinguished while the Ranunculus undifferentiated category included R. acris and R. trichophyllus.

POLYGONACEAE

Rumex acetosa and R. acetosella have only been differentiated in the Salen diagram. Rumex undifferentiated type probably includes Oxyria digyna (especially in the early Lateglacial sediments at Salen) and also R. palustris and R. crispus.

HALORAGACEAE

At Loch Shiel, the majority of the Myriophyllum grains recorded were M. alterniflorum with the remainder comprising of M. spicatum and M. verticillatum. In the Salen diagram, M. alterniflorum has been separated from the latter two species.

SALICACEAE

No separation has been made of the various species (Faegri and Iversen, 1975; Birks, 1973). However Salix herbacea was almost certainly present in the Lateglacial sediments of the Salen site.

LYCOPODIACEAE

Lycopodium clavatum, L. inundatum, L. selago were distinguished in the Salen diagram, while the undifferentiated type included L. alpinum and L. annotinum.

COMPOSITAE

Several types were recognized in both pollen diagrams; Ambrosia type (Birks, 1973); Liguliflorae type including Crepis and Taraxacum species; Artemisia species type.

POLYPODIACEAE

These spores remained undifferentiated in the Loch Shiel diagram while at Salen, several species were distinguished; Athyrium filix-femina, Athyrium alpestre type; Dryopteris carthusiana type, Dryopteris filix-mas type and a Thelypteris type (Birks, unpublished key). Polypodiaceae without an 'outer jacket' were recorded as undifferentiated species.

PRE-QUATERNARY SPORES.

Several pre-Quaternary spores were recorded from the Loch Shiel sediments. These may have been derived from the Tertiary leaf beds on the Isle of Mull (Scott, 1922).

INDETERMINABLE

Grains that could not be identified were recorded as indeterminable. In the Salen diagram they were categorized as concealed, deteriorated, corroded, crumpled or unknown.

6. Pollen Diagram Construction.

The necessary computations required to produce the percentages of each taxon per sample, the pollen concentration and the influx rates for each taxon at both the sites were made by the Fortran computer program POLLDATA. This program was also responsible for drawing the pollen diagrams on a graph plotter, and was written by H. J. B. Birks and B. Huntley (unpublished). The program was run on both the Edinburgh and Cambridge Universities IBM 360/370 computers.

The raw count data may be read into the program either by taxa or by level. Besides sample depths, the program requires the concentration of exotic pollen grains added as grains per cm^3 (Matthews, 1969); the volume of sediment used in the analysis ($1cm^3$); the exotic pollen count for each sample (standardized for a constant volume, in this case $1cm^3$) and (to calculate pollen influx values) the sediment accumulation rate expressed as radiocarbon years per cm.

CHAPTER 6.

SALEN : A LATEGLACIAL SITE.

The Lateglacial Vegetational History of Scotland : Previous Work.

The last decade has seen a rapid increase in the number of Lateglacial pollen sites in Scotland, reflecting interest in a unique period of Scotland's vegetational history. Present knowledge of the Lateglacial climate relies heavily on palynological data, though important contributions have been made by palaeoentomology (Coope, 1975; Bishop and Coope, 1977) and from the reconstruction of former glaciers from geomorphological evidence (Sissons, 1974a; Sissons and Sutherland, 1976). Despite the various limitations in making palaeoclimatic inferences from palynological data (Faegri and Iversen, 1964; Birks, 1973; Chapter 5) there is general agreement on the broad pattern of vegetational change and climatic variation throughout the Lateglacial period.

The first sub-division of Lateglacial sediments on a biostratigraphical basis in the British Isles was made from a site in the Wicklow mountains of Ireland by Jessen and Farrington (1938). The sediment found at this site was divided into a pre-Allerød (Older Dryas) cold phase or Zone I; an Allerød cool temperate interstadial (or Zone II) and then a post-Allerød or Younger Dryas cold period (Zone III).

This tripartite division became established in a numerical scheme of zonation of Late- and Postglacial periods proposed by Godwin (1940; 1956). It was assumed that these pollen zones were directly comparable with the lithological changes of the Lateglacial sediment, and that they represented discrete climatic periods. The Zone I deposits are typified by minerogenic sediment, of which coarser basal deposits underlie finer material above them.

Gyttja (an organic-rich sediment) corresponds to pollen Zone II while Zone III is characterized by a return to minerogenic sediment. Godwin (1975) has used these three pollen zones to describe the vegetational history of the Lateglacial. Mitchell, Penny, Shotton and West (1973) have also subdivided the Late Devensian deposits of Great Britain on the basis of these pollen zones. The assumption was made that the lithostratigraphic, biostratigraphic and climatostratigraphic boundaries of these zones equated with each other and that the zones were synchronous.

With the increasing amount of palynological data available for regional comparison, coupled with radiocarbon dating and additional climatic data derived from Coleopteran studies (notably Coope, 1975) the diachronous nature of these zone boundaries is now recognized (Lowe and Walker, 1977). In particular, there have been discrepancies in the recognition of the

Bölling equivalent climatic oscillation in Zone I (Gray and Lowe, 1977; Pennington, 1975b).

On the basis of beetle fauna Coope (1975) described a warm climatic oscillation in Britain from 13,000 to 11,000 B.P. which has been called the Lateglacial Interstadial (Sissons and Walker, 1974; Coope, 1975). This interstadial includes the previously defined pollen zones I and II while the following Loch Lomond Stadial is equated with a period of colder climatic conditions represented in many pollen diagrams by Zn III. This broader interpretation of a relatively warm interstadial succeeded by colder stadial conditions forms a convenient division in which to describe the Lateglacial vegetational history of Scotland.

The Lateglacial Interstadial.

Many workers have concluded that the Lateglacial Interstadial represented an uninterrupted vegetational succession from ice-sheet deglaciation to the vegetational revertence of the Loch Lomond Stadial. In the Teith valley of the S.W. Grampians, Lowe (1977) has recorded 'a continuous succession from open-habitat communities ...... through dwarf shrub communities to a Late Interstadial phase of juniper heath and birch copses' (p. 299). This is supported by the work of Walker (1974) in the central and S.E. Grampians who concluded that the vegetational succession had been uninterrupted from about 13,000 B.P. to the beginning of the Loch Lomond Stadial (Walker, 1974; Lowe and Walker, 1977). From a detailed analysis of Lateglacial pollen profiles on the Isle of Skye, Birks (1973 p. 383) concluded that 'the present interpretation of the pollen stratigraphy suggests that there was a progressive unidirectional vegetation succession from low-alpine or mid-alpine communities to subalpine juniper scrub, presumably in response to a climatic amelioration starting about 12,000 radiocarbon years B.P.'

Pennington et al. (1972) examined lake sediments from many sites in northern Scotland. On the basis of lithostratigraphical, palynological, palaeochemical and diatom studies they concluded that there had been only one period of cold climatic conditions that was comparable with the Loch Lomond Stadial. Coope (1975) also found no oscillations within the Lateglacial Interstadial that could be equated to a Bölling period. Bishop and Coope (1977) concluded from the presence of the Coleoptera species Haliplus obliquus, Heamonia appendiculata and Eubrychius velutus at a site at Roberthill, that average July temperature at around 13,000 B.P. was at least as warm as that of the present day. At other sites in S.W. Scotland, southern species were displaced by northern types of beetles, indicating a continuous climatic deterioration throughout the Lateglacial Interstadial.

There is evidence from several sites, however, of a minor climatic oscillation within the Lateglacial Interstadial. These include pollen profiles from the basal sediments at Loch of Park in the Dee valley

(Vasari and Vasari, 1968; Vasari, 1977); a site in the eastern Grampians at Loch Builg (Clapperton *et al.*, 1975) and at Cam Loch in Sutherland (Pennington, 1975b). Vasari (1977) suggested that pollen profiles from N.E. Scotland may be correlated with the continental chronozone scheme where a small climatic recession within the Lateglacial Interstadial is recognized (Mangerud *et al.*, 1974). In central and western parts of Scotland, however, contrasting climatic conditions prevailed and an interstadial oscillation is not found in these regions.

Pennington (1977) has also reinterpreted the basal sediments at Belham Tarn, where she suggests there is evidence for an oscillation on the basis of the increased erosion of mineral soils. However minor lithological changes may only reflect changes in sedimentation and may not necessarily reflect climatic change (see Chapter 5).

The evidence for a climatic recession during the Lateglacial Interstadial is debatable. Much of it (e.g. at Loch of Park) is based on small variations in the percentages of a few plant species e.g. *Betula*, *Empetrum* and *Juniperus*. These variations may represent statistical artefacts (Davis and Deevey, 1964) rather than climatic variations. Further examination of these deposits is required using absolute pollen analysis which should preclude the possibility of confusing statistical anomalies in the reconstruction of the pollen record.

A generalized account of the vegetational succession during the Lateglacial Interstadial will now be given to provide a framework for discussion and comparison later in this chapter.

Initial colonization of deglaciated ground consisted of an open-vegetation cover of taxa including Gramineae, Cyperaceae, Chenopodiaceae, Caryophyllaceae, *Salix* (c.f. *herbacea*) and *Lycopodium* (c.f. *selago*). Taxa of assemblages that are today found in a base-rich environment suggest the initial development of a species-rich grassland upon newly-deglaciated ground or on bare mineral soils after the cessation of solifluction (Gray and Lowe, 1977). In the basal deposits of sites on Skye, Birks (1973) found taxa which indicated chionophilous communities. At Cam Loch, Pennington (1975b) found basal sediment of an age before 13,000 B.P. containing *Oxyria-Rumex* pollen with *Salix herbacea*. These species are characteristic pioneer species that are often the first plants to colonize recently deglaciated ground in Norway (Matthews, 1974a, 1975, 1977).

Further vegetational development consisted of species typical of present arctic and alpine communities. These included the herbaceous genera *Armeria*, *Artemisia*, *Epilobium*, *Galium*, *Koenigia*, *Plantago*, *Polygonum*, *Succisa*, *Thalictrum*, *Rumex* and *Valeriana*; the club mosses *Selaginella* and *Lycopodium selago* together with the shrub species *Salix*, *Juniperus* *Betula nana*, *Empetrum nigrum*, *Sorbus* and *Hippophae rhamnoides*. Initial pollen concentration was approximately 100 grains/cm^3/year which then increased to 1000 grains/cm^3/year (Pennington, 1977).

With the stabilization of soils and amelioration of temperature, there is evidence from the fossil pollen record of the gradual development of closed vegetation cover. The interstadial pollen record is characterized by maximum percentages of arboreal pollen (mainly Betula), though there are Scottish pollen diagrams that do not display this characteristic increase of Betula pollen during the interstadial (e.g. Moar, 1969b).

The diachronous development of birch woodland suggests a regional differentiation within the Late Devensian vegetation of Britain. Consequently it is difficult to apply a pollen chronology such as that proposed by Godwin (1956). The distribution of tree birch (Betula pubescens) is assumed to be related to a north- south thermal gradient (Pennington 1970, 1977) coupled with an east- west oceanicity gradient (Birks, 1965). The problems associated with the interpretation of birch pollen during the Lateglacial are well discussed by Lowe (1977).

In the central and eastern Scottish Highlands the dwarf birch cover was associated with juniper and willow while copses of tree birch would have been confined to low-lying ground. Moss heaths and poor grassland would have occupied higher ground (Lowe, 1977; Walker, 1974). Moar (1969a) concluded that climatic amelioration during the Lateglacial was expressed by an increased density of the dominantly herbaceous vegetation and that no influx of birch forest occurred in northern districts. Empetrum and Juniperus heathlands spread rapidly in contrast to the increased stability of grasslands in southern Scotland. This conclusion is supported in N.W. Scotland by the work of Pennington and Lishman (1971); Pennington et al., (1972)and in eastern Scotland by the investigations of Vasari and Vasari (1968). The northern margin of birch forest was assumed to be in northern England (Pennington, 1970; Bartley 1962, 1966).

Birks (1973) used the relationships between modern pollen rain and vegetational types on the Isle of Skye to infer vegetational patterns from Lateglacial pollen assemblages. Communities represented during the interstadial were snow-bed communities, species-rich grassland, Rhacomitrium heaths, Empetrum heaths, juniper scrub and occasional birch copses. Some juniper and Betula nana dominated communities have no modern analogues. Birks (1973) found that the Lateglacial flora on Skye was as diverse as its modern counterparts, and that this 'is readily interpretable in terms of the same broad ecological factors that influenced the present flora and vegetation of the island' (p. 388).

In northern Scotland, interstadial vegetation was characterized by Empetrum heath and grassland cover, together with variable amounts of juniper (Moar, 1969b; Pennington, 1972, 1977). From a site at Loch Droma, Kirk and Godwin (1963) stated that the vegetation cover consisted of a complex of communities including Empetrum heath together with snow-patch vegetation, marsh communities and varied herbaceous plant cover of base-rich species.

Evidence from S.E. Scotland suggests an open, virtually treeless landscape with birch copses being established in sheltered localities. Newey (1970) concluded from a site at Corstorphine near Edinburgh, that 'even during the relative warmth of Zn II, tree-pollen frequencies were very low' (p.1175). Thus again, a species-rich grassland with taxa indicative of base-rich conditions predominated throughout the Lateglacial Interstadial.

There is evidence that soil disturbance continued throughout the Lateglacial, especially on higher ground. This is suggested by the presence of taxa indicating base-rich conditions at many sites throughout the interstadial, and the continued inwash of a proportion of minerogenic sediments (Kirk and Godwin, 1963; Moar, 1969a; Newey, 1970; Pennington et al., 1972; 1977; Walker, 1974; Lowe, 1977).

In the eastern Grampians, Lowe and Walker (1977) found that large areas of bare ground with disturbed soils persisted throughout the interstadial. These areas were reflected by the continued presence of Rumex and other open-habitat taxa e.g. species of Caryophyllaceae, Chenopodiaceae, Compositae and Clubmosses.

The Loch Lomond Stadial.

A return to cold climatic conditions in the Loch Lomond Stadial is represented in the pollen record by a reduction of the pollen assemblages representing trees and shrubs; the return of a greater quantity of minerogenic sedimentation; the absence of aquatic pollen and an increase in pollen of taxa that are characteristic of open ground and disturbed soils i.e. certain taxa of Compositae, Caryophyllaceae, Cruciferae and Chenopodiaceae. The presence of these taxa in considerable quantities suggests that over most of Scotland there was extensive disruption of the vegetation cover and the destruction of soils that had developed during the Lateglacial Interstadial.

There is a considerable similarity between the pollen profiles of different Scottish Lateglacial sites during the stadial. Numerous pollen records from many parts of Scotland suggest the widespread occurrence of disturbed soils - a function of increased solifluction - and base-rich conditions. Regional differences appear to have been smaller than comparable regional variations in vegetation during the interstadial.

Lowe and Walker (1977) suggested that while the major reason for the change in vegetation is accepted as being due to the increase in frost disturbance of ground not protected by snow-cover (Pennington *et al.*, 1972), regional and local differences in the pollen record may relate to a variation in the extent and thickness of snow cover. For instance Walker (1974, 1975a) proposed that differences in the representation of *Artemisia* pollen at sites in the central and eastern Grampians reflected variable snow-cover as this plant is known to be chionophobous (Andersen, 1961; Iversen, 1954).

On the Isle of Skye, Birks (1973) suggested that the characteristic vegetation during the stadial was a mosaic of low- and mid- alpine chionophilous vegetation that was differentiated by ecological factors of slope, aspect, exposure and other factors. This was at a time when climatic conditions were uniformly severe at all sites on the island. At some sites (e.g. L. Meallt) *Betula nana* heath vegetation was typical during the stadial. In other, more exposed areas (e.g. Lochan Coir'a' Ghobhann) the fossil pollen record indicates disturbed soils and snow-bed communities (Birks, 1973).

Similar variation existed throughout Scotland. In lowland areas in the Grampians, Lowe and Walker (1977) found *Rumex* - dominated vegetation with juniper and dwarf birch in sheltered localities. However Moar (1969a) found pollen of *Koenigia*, indicative of disturbed soils in lowland sites in S.W. Scotland. Newey (1970) also suggested an open vegetation as a consequence of increased solifluction at Corstorphine in S.E. Scotland.

The Loch Lomond Stadial/Postglacial transition.

The termination of stadial conditions at around 10,000 B.P. is reflected in most sites by a change from minerogenic to organic sediment accumulation. Higher temperatures brought a cessation of solifluction processes in lowland areas, allowing soil stabilization and the development of widespread vegetational cover. The rate of vegetational succession was rapid (Pennington et al., 1972, 1977; Vasari, 1977; Lowe, 1977) with an initial rapid expansion of aquatic flora (*Myriophyllum alterniflorum* and *Potamogeton*.). Initial colonization by grassland species was followed by *Salix* - *Empetrum* heath, *Juniperus* heath and then birch woodland. This pattern of vegetational development during the Lateglacial-Postglacial transition is found in N.E. Scotland (Moar, 1969b) northern Scotland (Pennington *et al.*, 1972), Skye (Birks, 1973) and in the Grampian Highlands (Walker, 1974; Lowe, 1977).

Salen : The Site.

Two possible coring sites were located from aerial photographs at positions that were as close to the inferred limit of the former Shiel glacier as was possible. Preliminary investigations using a Hiller corer revealed the three-fold Lateglacial stratigraphy at both sites (NM 692646 and NM 693654). The latter site was chosen for detailed pollen analysis because it had a greater thickness of Lateglacial Interstadial gyttja.

This site, subsequently named Salen, lies 0.5 km N.E. of Salen, Ardnamurchan at 56° 44'N, 5° 47'W and at NM 693654. The site consists of a small lochan, some 200m long by 50m wide, that is surrounded by 'poor fen' (Ratcliffe, 1964 p. 427). The lochan occupies a basin in the Moinian Schists which is geologically structurally controlled; a steep cliff some 20-25m high is situated on the eastern side of the lochan.

A series of cores was taken from the western margin of the fen at a point that was as close as possible to the central axis of the basin. Along this axis 11m of Postglacial peat was recorded. Cores were obtained for pollen analysis from the early Postglacial and Lateglacial sediment using a large Dachnowski (Abbey) borer (see Chapter 5). However, while obtaining further cores for radiocarbon dating using the 'multiple-shot' technique (Walker, 1974; Robinson, 1977), the large chamber of the corer was damaged during the penetration of the coarse stadial sands and clays. Three subsequent attempts were made to obtain Lateglacial Interstadial gyttja for dating. This included the excavation of a large hole some 2m deep into the stadial deposits. However, sufficient material for a basal Lateglacial radiocarbon age determination could not be obtained.

The present vegetation surrounding the lochan is a mixed deciduous oak woodland. This woodland is composed of *Quercus*, *Alnus*, *Betula* and *Corylus*. The bog surface is mainly made up of grasses and sedges (*Eriophorum vaginatum* and *Scirpus cespitosus*), some *Calluna vulgaris* and *Sphagnum*. To the south of the lochan, a forestry plantation has been established.

Salen : The Stratigraphy.

The stratigraphy of the core used for pollen analysis and radiocarbon dating is described in table 6 - 1. As stated above, a hole was dug through the Postglacial peat and into the stadial sands and clays. A large sample of the stadial deposit was recovered and it was found that the description of the stadial sediments in the cores alone does not give a representative description of the coarseness of this deposit. Great force was required to penetrate this layer with the large (5cm wide) Dachnowski sampling chamber. It is assumed that the point at the end of the sampling chamber pushed the larger stones to

TABLE 6 - 1. The Stratigraphy of the Cores used for Pollen analysis and Radiocarbon Dating.

DEPTH (cm)	DESCRIPTION.
0 - 240	Postglacial peat, not sampled.
240 - 276	Dark brown peat. Fibrous and saturated. Peat becoming lighter in colour with depth.
276 - 280	Brown peat with mottled yellow gyttja. Occasional fine fragments of mica.
280 - 286	Yellow gyttja. Very fine organic fragments, too decomposed for identification, with a few mica fragments.
286 - 355	Light gray clay with some fine sandy layers 2 - 3cm thick. The clay forms a sharp horizontal boundary with the overlying gyttja. Occasional fine rootlets present in the clay.
355 - 395	Coarse sand with angular stones up to 6cm long. Rhythmites of sand with finer sand, and clay layers at 379cm. Organic fragments found at 371 and 383cm.
395 - 405	Light grey silt and clay, increasing in clay content with depth.
405 - 408	Mottled olive yellow gyttja with fine mica fragments. Sharp transition at 405cm between clay and gyttja.
408 - 412	Dark brown gyttja with occasional mica flakes and organic fragments.
412 - 420	Light yellow gyttja. Fine texture with few organic fragments visible.
420 - 422	Increasing silt content, changing in colour from light yellow to grey.
422 - 427	Light grey clay.

one side during sampling.

An analysis of stone roundness (Wadell, 1932) was made on the stones retrieved during the excavation of the site. The average dimensions of the 56 stones (Folk,1955) were:-

Average length of main axis	10.1cm
Maximum length of main axis	24.4cm
Minimum length of main axis	4.0cm

Using the class mean to describe stone roundness, the classes were:-

TABLE 6 - 2	%	Wadell class	Rho scale
Very angular	56	.12 - .17	0.00 - 1.00
Angular	33	.17 - .25	1.00 - 2.00
Sub-angular	7	.25 - .35	2.00 - 3.00
Sub-rounded	4	.35 - .49	3.00 - 4.00

55 of the stones were local Moinian schist while the remaining stone was composed of quartz, probably derived from a quartz vein intruded into the Moinian Schists.

Another interesting fact emerged from the excavation. Postglacial tree roots up to 3cm thick were found penetrating the stadial clays to a depth of 30cm. Thus contamination of lower layers in this manner could lead to erroneous radiocarbon ages being obtained.

Salen : Radiocarbon Age Determinations.

Two radiocarbon dates were obtained for the Salen site (table 6 - 3). These age determinations were made by Dr. H. H. Harkness at the Scottish Universities Research and Reactor Centre, East Kilbride, Glasgow. The dates are expressed as radiocarbon years before present with 1950 A.D. being the zero datum. A half-life of 5568 ± 30 was used.

SRR - 1211 was taken from the basal Postglacial peat deposits while material for date SRR - 1212 was removed from the inferred Interstadial/Stadial boundary. However, this sample contained insufficient organic material for radiocarbon dating. Rather than obtain no age determination at all, it was decided to combine this material with a sample obtained by Dr. H. J. B. Birks of the sub-department of Quaternary Research at Cambridge. He had independently sampled the same site at a point less than 10m away from the coring location only some 3 weeks after the writer obtained the cores analysed here. As Dr. H. J. B. Birks was primarily interested in the Postglacial section of the core, he allowed the author to use the Lateglacial section of his core.

TABLE 6 - 3. The Radiocarbon Age Determinations for Salen.

LABORATORY NO.	SAMPLE DEPTH	AGE	$\delta^{13}C$
SRR - 1211	220-230 cm	9,796 ± 75	-20.6%
SRR - 1212	370-380 cm	10,643 ± 75	-23.7%

This core was obtained by Dr. H. J. B. Birks and Dr. W. Williams using a Livingstone corer. These cores were stored in silver foil on a plastic tray, and kept in a cold store. A sample from this core was keyed into the Salen diagram using pollen analysis. The correspondence of the pollen record and the closeness of the two core locations suggested that a combination of the samples might provide a viable date. However because of the unusual source of the material the possibility for contamination exists, hence extreme caution must be employed when interpreting the radiocarbon date.

Salen : The Fossil Pollen Stratigraphy.

POLLEN ZONE SA1

Percentage Pollen Diagram (Fig. 6 - 1).

This basal pollen zone is characterized by an increase in shrub pollen from less than 8% to 40% with a comparable decrease in fossil spores. Empetrum rises rapidly from 2% at the base of the profile to

36% at the upper zone boundary. Cyperaceae rises to 15% while Gramineae values remain lower at around 7%.

There are pronounced basal peaks of Rumex species (reaching 28%) followed by a peak of Saxifraga undiff., and Lycopodium selago spores. Polypodium spores initially form as much as 50% of the total pollen and spore spectra before declining to 10 - 15%. Aquatic pollen values remain below 5%.

Concentration ($\times 10^{-3}$grains/cm^3) Pollen Diagram (Fig. 6 - 2).

Total pollen concentrations range from 46 near the base of the zone to over 86 near the top. Tree pollen values remain low (less than 11) while Empetrum concentrations expand rapidly from 2 at the base of the profile to 26 at the upper zone boundary. Cyperaceae pollen values expand more rapidly than Gramineae values, while high basal concentrations of Rumex pollen are succeeded by Saxifraga undiff. Lycopodium concentrations fall from 10 to zero before reaching a peak of 13. Polypodium values however remain between 10 and 15 throughout the zone. These values are low when compared to the representation of Polypodium in the percentage diagram.

Armeria, Artemisia, Caryophyllaceae, Chenopodiaceae, Filipendula, Liguliflorea, Matricaria type, Pinus sylvestris, Rosaceae, Ranunculaceae, Thalictrum Umbelliferae and Urtica are all first recorded in this zone.

POLLEN ZONE SA2

Percentage Pollen Diagram (Fig. 6 - 1).

This zone is typified by an expansion of tree and shrub pollen towards the middle of the zone, with a subsequent decline in the pollen values of these species towards the upper zone boundary. Betula pollen increases sharply in the middle of the zone to 17% while Pinus and Salix percentages remain low. The small increase of Betula/Corylus/Myrica grains is probably associated with the increase in Betula pollen grains.

Empetrum values range from 36% at the basal zone boundary to 17% at the top of the zone. Artemisia reaches a peak of 9% near the upper zone boundary as do Cyperaceae and Gramineae pollen. Filipendula is present throughout the zone.

Of the various spores recorded, Dryopteris filix-mas. increases to a maximum in the middle of the zone in contrast to Lycopodium selago spores. The distribution of Polypodium spores is similar to that of Dryopteris filix-mas. The boundary between zones SA 2 and SA 3 is delimited by the fall of Betula pollen to 1%, the rise of Cyperaceae pollen above 30% and the demise above this level of aquatic pollen. Many other herb pollen records cease at this level. These species include Artemisia, Caryophyllaceae, ChenopodiaceaeLiguliforeae, Ranunculus repens and R. undiff., Rumex acetosa, R. acetosella and aquatic pollen, Myriophyllum alterniflorum and M. undiff.

Concentration (x10^{-3}grains/cm^{3}) Pollen Diagram (Fig. 6 - 2).

The pollen concentration values for many species show a much greater variation in their pollen spectra than is suggested by the percentage pollen diagram. Species representation is similar, but with a pronounced peak in Empetrum, Cyperaceae, Gramineae and Polypodiaceae near the top of the zone which is not represented on the percentage diagram. Concentrations at this level reach 143 as opposed to the second highest value of 86. This former peak may be anomalous (see below).

POLLEN ZONE SA3

Percentage and Concentration Pollen Diagrams (Fig. 6 - 1 & 2).

The pollen record of the zone is composed of only 7 levels, inclusive of the zone boundary levels. Only 21 of the 60 taxa recorded in this diagram are represented at these levels. Pollen concentrations of Betula, Empetrum, Cyperaceae, Gramineae with spores of Lycopodium selago and Polypodiaceae reach a maximum in the lower part of the zone before decreasing to the upper zone boundary. There are several variations between the pollen concentrations and the percentage diagram, probably reflecting the low number of species recorded at each level.

POLLEN ZONE SA4.

Percentage Pollen Diagram (Fig. 6 - 1).

The base of this zone is marked by the presence of numerous species found in pollen zone SA2 but not in zone SA3. Betula pollen increases rapidly to a diagram maximum of nearly 30% while Salix pollen also forms a diagram maximum of 12% at the same level. Empetrum, Artemisia and Cyperaceae pollen decrease from initial high levels at the basal zone boundary, while Gramineae pollen increases from 0% at the bottom to 27% at the top of the profile. The middle of the diagram is dominated by a large peak in Polypodium spores.

Concentration (x10^{-3}grains/cm^{3}) Pollen Diagram (Fig. 6 - 2).

Pollen concentrations closely reflect the percentage values in this zone. There is the initial rise of Betula pollen, followed by a peak of Polypodiaceae and then the subsequent expansion of Empetrum, Gramineae and herb pollens. New taxa first recorded in this zone are Caltha, Helianthemum, Labiatae, Papilionaceae, Plantago undiff., Juglandaceae and Dryopteris carthusiana

Salen : An Interpretation of the Fossil Pollen Record.

Zone SA1.

Betula pollen is recorded throughout the zone forming approximately 5% of the total pollen spectra. As Betula is a high pollen producer (Andersen, 1966) it must have formed a small component of the vegetation.

The Betula pollen is assumed to have been derived from the dwarf birch species Betula nana (Seddon, 1962). B. nana has a wide ecological tolerance and is characteristic of open habitats, but not in areas with a late snow-cover (Dahl, 1956).

The Salix pollen spectra has a distinctive peak (of 8%) in the middle of this zone. Salix is usually under-represented in modern Scottish sub alpine pollen spectra and this under-representation is also known from studies in Lapland (Birks, 1973). Much of this Salix pollen is probably derived from the species S. herbacea. This plant is a geniune snow-bed and pioneer species (Hafsten, 1963). Palmer and Miller (1961) found that in Austria, S. herbacea colonized ground within a year of glacier recession. It has an ecological preference for fresh soils poor in lime and may be regarded as an important member of the pioneer community of this zone.

The shrub pollen spectra are dominated by the rapid increase of Empetrum pollen throughuot the zone. Pollen from both E. nigrum and E. hermaphroditum may be included in the spectra. Both these species have a wide ecological tolerance, though they are intolerant of solifluction (Brown, 1971) and are rarely found in a chionophilous plant community (Hafsten, 1963). These dwarf shrubs thrive on acid soils and are indicative of soil poverty (Vasari and Vasari, 1968). H. H. Birks (1972b p. 736) describes Empetrum habitats as being 'wind-blasted plateaus' and 'acid cliff ledges'. Empetrum has a preference for oceanic climates, probably because it is restricted to areas where snow cover disappears relatively rapidly (Bell and Tallis, 1973).

Initial high values of Rumex species are indicative of open ground vegetation (Clapham, Tutin and Warburg, 1962). Dahl (1956) found that Rumex acetosa is common in low-alpine belts in the Rondane, Sweden, while many Rumex species are markedly chionophobous, being restricted by snow patches and higher soil moisture (Walker, 1975a). Birks (1973) found that Rumex acetosa pollen is always abundant in the modern pollen rain of Scottish sub-alpine vegetation. Matthews (1975) has investigated the succession of plants that colonized a glacier foreland at Storbreen, Norway. Rumex species, especially Oxyria digyna is one of the first plants to colonize the exposed ground. The Rumex pollen spectra may include pollen grains of Oxyria digyna as the pollen grains of the latter are morphologically similar to Rumex and cannot easily be distinguished (Birks, 1973, p. 236).

Matthews (1976) notes that Rumex is closely followed as a pioneer plant by Saxifraga species. This is suggestive, as an 8% peak of Saxifraga pollen is recorded at only the second level from the base of the profile, while Rumex pollen declines at this point. Saxifragaceae are characteristic arctic and alpine plants and the pollen spectra are thought to include *S. stellaris*, *S. hypnoides*, *S. aizoides* and *S. oppositifolia* (Birks, 1973). On the Isle of Skye Birks (1973) found that *S. stellaris* pollen 'is virtually exclusive to spectra from summit vegetation((p. 286). He also found that *S. hypnoides* is a high pollen producer so this species may form a high proportion of the Saxifragaceae pollen that has been recorded at Salen. Palmer and Miller (1961), like Matthews (1975) found that *Saxifraga aizoides* can establish itself on fluvioglacial gravels within one year of exposure, and probably owes its success as a pioneer species to a perennial root system. *Saxifraga* species are characteristic of base-rich soils (Anderson, 1961; Dahl, 1956). They are found on disturbed soils in present tundra environments (Stork, 1963; Perssen, 1964) and on bare gravels and screes in the Alps (Palmer and Miller, 1961).

Other herb species represented in the fossil pollen rain at the base of the profile are *Artemisia*, Caryophyllaceae, Chenopodiaceae, Cyperaceae, Gramineae, Rosaceae, Umbelliferae and *Thalictrum*. *Artemisia* is widely regarded as a genus that is indicative of disturbed soils (Walker, 1974; Simpkins, 1974) and has a high pollen production and dispersal rate (Bent and Wright, 1963). An important anemophilous pioneer herb, *Artemisia* is generally thought to represent Lateglacial steppe or tundra conditions (Hafsten, 1963) though it is intolerant of snow-cover.

Thalictrum alpinum is recorded throughout the zone. It is presently restricted above 650m and is common today only in the Scottish Highlands. This altitudinal restriction is in contrast to the wide altitudinal variation and lowland occupation during the Lateglacial (Godwin, 1956). A slight calcicole, *Thalictrum alpinum* prefers open soil conditions and freedom from closed cover vegetation (Dahl, 1956).

Cyperaceae are mainly chionophilous and are characteristic elements of snowbed communities in areas of northern Sweden today (Gjaerevall, 1965). Birks (1973) found that Cyperaceae pollen was dominant in modern pollen rain spectra from mountain summit vegetation on the Isle of Skye. This is supported by modern pollen rain studies from the tundra regions of Canada and Alaska where sedge pollen values were high in areas where local reedswamp development was minimal (Lichti-Federovich and Ritchie, 1968). Gramineae pollen values are less than Cyperaceae in this zone. However, although grass pollen is very characteristic of sub-alpine pollen spectra, low pollen values are more common from high alpine communities (Birks, 1973). As a result, grass species may have been well represented in the surrounding vegetation.

High values of *Lycopodium selago* and Polypodiaceae characterize this zone. Lycopodium selago is presently found on the rock ledges and mountain tops up to 1300m in Britain and is typical of open montane habitats (Clapham, Tutin and Warburg, 1962). Dahl (1956) found L. selago at higher levels on soliflucted soils in the Rhondane. Birks (1973) recorded an abundance of L. selago spores in modern Scottish alpine communities, despite low cover on the ground. Lycopodium alpinum is also present at the base of the zone, and is a chionophilous species sensitive to solifluction (Dahl, 1956).

Polypodiaceae species include Polypodium vulgare and Blechnum spicant. The former is presently found up to 900m and the latter, a calcifuge, is common in mountain grasslands, dwarf shrub heath and on rocky ground up to 1300m. Dryopteris felix-mass would have been associated with these two species and is found throughout the British Isles today on rocks and screes ascending to 1050m (Clapham, Tutin and Warburg, 1962).

These Pteridophytes support the inferences made from the tree, shrub and herb pollen that a cold alpine type of open vegetation existed. The pollen zone represents a pioneer plant community inhabiting fresh ground with the cessation of solifluction at low altitude.

Zone SA2.

The expansion of Betula pollen from 6% to over 18% in this zone is probably a reflection of the arrival into the area of tree birch, Betula pubescens, establishing itself in sheltered lowland areas. No distinction was made between pollen grains of Betula nana and tree birch species (see Chapter 5) so the assumption is made that the influx of Betula nana pollen has remained constant. The subsequent fall in Betula pollen towards the top of the zone reflects the decline of first Betula pubescens and subsequently B. nana in the surrounding vegetation.

Salix pollen remains comparatively constant throughout the zone, as do the small values of Pinus pollen. The latter is interpreted as being derived from long distance transport and these low values are typical of many Scottish Lateglacial pollen diagrams (e.g. Walker, 1975a; Robinson, 1977).

Shrub pollen and indeed the total pollen spectra are dominated by Empetrum (both E. hermaphroditum and E. nigrum). Percentage values fluctuate considerably while pollen concentration values show three major peaks, the lowest of which forms the lower zone boundary. Both E. hermaphroditum and E. nigrum have a preference for cool, oceanic conditions with heavy cloud cover and high precipitation (Brown, 1971). Intolerant of shade and solifluction (Iversen, 1954), Empetrum heaths must have constituted an important element in the landscape of the adjacent area. This heath community was probably supplemented by other Ericaceae, notably small quantities of *Calluna vulgaris*.

Artemisia is a species that is intolerant of snow cover and is generally thought to represent Lateglacial steppe or tundra conditions (Hafsted, 1963). As *Artemisia* is widely regarded as being indicative of disturbed soils and solifluction (Walker, 1974; Simpkins, 1974) the increase in *Artemisia* pollen towards the top of the zone may reflect the resurgence of solifluction.

Cyperaceae pollen is characteristic of snowbed communities and mountain summit vegetation (Dahl, 1956; Birks, 1973). The pollen recorded in this zone was probably derived in part from alpine communities on the higher ground above the site (e.g. the south-west slopes of Ben Resipol). The rapid increase of Cyperaceae pollen to 44% of the total pollen spectra at the top of the diagram is indicative of the establishment of more widespread plant communities. A similar situation is reflected by the Gramineae pollen record during this zone. Pollen values remain at approximately 20% throughout the zone, with a slight increase at the upper zone boundary. The contribution of grass pollen is not known (Birks, 1973) but the later increase of Gramineae pollen may reflect the increasing distribution of sub-alpine communities in the area. Birks (1973) found from modern pollen rain studies that the predominence of grass pollen in sub-alpine zones is a reflection of two prolific pollen producers, *Anthoxanthum odoratum* and *Deschampsia cespitosa*. Also, open grassland communities may have been more extensive than is suggested by the pollen record because of the under-representation of many grass species in the pollen rain.

Rumex pollen is indicative of open and disturbed habitats (Simpkins, 1974; Dahl, 1956). The continued presence of *Rumex* throughout this zone is regarded as evidence for the persistence of solifluction and the associated sub-alpine and alpine plant communities on the more mountainous ground to the N.E. of the site.

Dryopteris filix-mas, recorded in the central and upper portions of this zone is indicative of rocky and scree vegetation. Many of the spores may have been derived from the crags on the eastern side of the lochan. *Lycopodium selago* is recorded in high concentrations at the upper and lower boundaries of the zone. This species is typical of open habitat communities on high ground today (Clapham, Tutin and Warburg, 1962) and is characteristic of solifluctéd soils (Dahl, 1956). The spore record is interpreted as reflecting the stabilization of soils towards the middle of the pollen zone and the subsequent increase in spore concentrations indicating the onset of periglacial conditions and soil break-up. Polypodiaceae spores, however, increase towards the centre of the zone reflecting the stabilization of soils and the development of more closed plant communities.

Pollen grains of aquatic species are represented by Myriophyllum alterniflorum and M. undiff.; the latter include M. spicatum and M. verticillatum. M. alterniflorum is common today in base-poor and peaty water while M. spicatum and M. verticillatum prefer more base-rich conditions (Clapham, Tutin and Warburg, 1962). The latter two species may have existed locally where streams carrying base-rich sediment entered the lochan. The cessation in the pollen record of all Myriophillum species at the upper zone boundary is interpreted as reflecting the decreasing temperatures with the onset of the Loch Lomond stadial. Walker (1974) however has suggested that Myriophyllum species prefer a clear water habitat and that their demise during the stadial may represent the increased sediment input into the lochan related to the increased solifluction activity. A combination of both these factors appears likely.

Zone SA3

This pollen zone has a very low pollen concentration and may be equated with the minerogenic clays, sands and angular solifluction debris found between the depths of 286 and 405 cm in the profile. The base of the pollen zone is marked by the abrupt termination of the pollen spectra of many species, notably the herb pollens. This zone has a poor variety of plant species, with an average of only 8 being recorded at each level (in the zone). This contrasts with an average of 22 in zone SA1, 23 in zone SA2 and 28 in zone SA4.

Zone SA3 consists of 7 levels, inclusive of the zone boundaries. With the exception of one level, pollen concentrations are low. The principal taxa are Empetrum, Cyperaceae, Gramineae, Lycopodiaceae and Polypodiaceae. The lowest level in the zone contains several species that are not recorded in the rest of zone SA3. These are Betula, Pinus sylvestris, Salix, Rumex undiff., Saxifragaceae, Lycopodium clavatum, Selaginella selaginoides and Myriophyllum alterniflorum. These species are considered to relate to the interstadial flora and will not be discussed in this section.

The principal taxa are the first five mentioned above and they may collectively represent a tundra vegetation. Although Empetrum is intolerant of solifluction (Brown, 1971) it is a low alpine species with a wide ecological tolerance (Hafsten, 1963). It is characteristic of the oceanic west coast (Bell and Tallis, 1973) and was probably restricted to more favourable coastal areas. Cyperaceae are markedly chionophilous and Gramineae pollen values remain low, possibly because grass pollen is typically under-represented in high-altitude chionophilous vegetation. Lycopodium selago is characteristic of solifluctecd soils (Dahl, 1956) and there is typically an abundance of L. selago in modern Scottish alpine communities (Birks, 1973).

It is suggested that certain levels in this zone are anomalous and are related to the inwash of interstadial vegetation. For instance, the presence of Myriophillum undiff. and Betula undiff. at level 3.10m.

Zone SA4.

The lower boundary of this zone is delimited by the presence of pollen grains of many species not found in zone SA3, but which were recorded earlier in zones SA1 and SA2, together with pollen grains of some species not previously recorded at this site. The top of the profile forms the upper zone boundary.

Betula pollen increases within 4cm of the zone boundary from 0% to nearly 30% of the total pollen spectra. This rapid increase is attributable to the colonization of open ground by Betula nana, establishing itself as a pioneer species as the shrub thrives in the absence of competition and is characteristic of open habitats (Andersen 1961). An initial increase in Salix pollen probably represents the colonization of base ground with Salix forming part of a pioneer community. Salix herbacea was probably the most dominant species as it is a noted chionophile and pioneer of glacier forelands (Palmer and Miller 1961; Matthews, 1975). As many Salix species (including S.herbacea) are snowbed species this peak in Salix pollen may represent the ephemeral development of snowpatch vegetation during a period of climatic amelioration. The presence of Alnus pollen, a relatively warmth-demanding species (McVean, 1953) at the top of the profile reflects the progressive amelioration of climate throughout this zone.

Ericaceae dominate the shrub pollen. Empetrum concentrations fall from zone SA3 to SA4 and then rise to the top of the profile. Empetrum thrives on acid soils but is restricted by solifluction (Vasari and Vasari, 1968). If the Empetrum record of zone SA3 is regarded as being somewhat anomalous, then the Empetrum spectra in zone SA4 represent the expansion of Empetrum heath with ameliorating climatic conditions. This heath development is reflected by a similar increase of Ericales pollen.

The herb pollen record shows a similar pattern of pioneer communities at the base of this zone to that which was recorded in zone SA1. Cyperaceae and Gramineae pollen increase generally throughout the zone; firstly on low ground (as is reflected by the high Cyperaceae values) and then as closed vegetation cover develops, they are restricted to the open vegetation to higher altitudes. *Rumex* species are present throughout the zone. *Rumex acetosa* is not present in any quantity, in contrast to the base of zone SA1. It is a species restricted by snow patches and higher soil moisture and it may have been affected by the rapid melting of snow and ice in the vicinity of the site.

The improving climatic conditions are reflected by the rapid increase of the aquatic pollen spectra. The sudden increase of *Myriophyllum alterniflorum* is regarded as being an early indicator of ameliorating temperatures as it does not require the establishment of a substrata like terrestrial plants. Walker (1974) has also suggested that the rapid colonization is less dependant on temperature than on the cessation of inwash and the subsequent increased clarity of the water. Both support the general inference of the stabilization of soils associated with the termination of stadial conditions.

Salen : The Site compared with other Lateglacial Sites in Scotland.

P.a.z.SA1 Rumex-Salix-Polypodiaceae.

This pollen assemblage zone represents the establishment of an open, treeless vegetation after deglaciation of the ice-sheet. The pollen record is similar to many other British Lateglacial pollen diagrams. Pollen concentrations range from 45 to 86 in this zone, which is slightly more than the 20-40 (X 10^{-3} grains per cm ^{3}) found from shrub tundra in Greenland (Fredskild, 1969). However, they are comparable with figures of less than 100 for the basal Lateglacial sediments at Low Wray Bay, Windermere (Pennington, 1977). This zone is comparable to the *Rumex* - Gramineae zone of Western Britain described by Pennington (1977).

In the N.W. Highlands, Pennington (1975b, 1977) has established a basal pollen assemblage zone (p.a.z.) consisting of *Rumex* - *Lycopodium selago* - *Salix herbacea* from the palaeolimnological studies of 18 lochs. Basal *Rumex* levels are high at these sites, forming between 20 and 40% of the total pollen spectra; this is comparable with 27% at Salen. *Salix* levels are generally 5% higher than at Salen. There is however no evidence for a Bölling oscillation at Salen that Pennington has demonstrated occurred at some sites in the N.W. Highlands (Pennington, 1975b, 1977).

Birks (1973) also found no evidence for a Bölling Interstadial on the Isle of Skye and concluded that 'there was a progressive unidirectional vegetation succession ... presumably in response to a climatic amelioration starting at about 12,800 years B.P.' (p. 383). Basal pollen assemblage zones on Skye are of *Lycopodium* - *Salix herbacea* - *Rumex* types with *Salix* values being similar to Salen (e.g. 7% of *Salix* pollen at Lochan Coir 'a' Ghobhainn).

Rumex values are lower on Skye (usually by about 5%) than those recorded at sites in the N.W. Highlands and at Salen. Similarly, to the south of the Salen site at Drimnagall, Argyllshire, Rymer (1977) records Rumex values reaching 20%. Pennington (1977) compared these high Rumex levels with surface samples from pioneer communities in the Jostedalsbre (Faegri, 1933) where Rumex pollen was abundant. She concluded that this Rumex - Gramineae basal zone in western Britain

> 'represents primarily those communities which were able to colonise and develop on immature soils, at a time when the length of snow-lie in the lowlands had been reduced, and solifluction had become less intense. The presence of taxa indicative of tall herb communities and of dwarf-shrub heath (Betula nana, Empetrum) shows that a vegetation mosaic, representative of unstable and of stabilized habitats must have been present' (p. 258).

This conclusion aptly describes the probable conditions during the onset of pollen deposition at Salen. Empetrum and Betula nana represent the stabilized vegetation with Cyperaceae, Gramineae and Lycopodium selago on more unstable ground.

The presence of 23 taxa in the basal layer of the zone suggests the spread and vigour of the initial colonization. This may reflect rapid climatic amelioration; the lack of existing competition; the absence of control by intolerance to shade that would enable many species to establish themselves simultaneously and the initial base-rich conditions that allowed the establishment of a species-rich grassland before subsequent leaching of the immature soils depleted their nutrient status.

P.a.z. SA2. Empetrum - Gramineae.

The p.a.z. SA1 represented the establishment of pioneer vegetation in response to ameliorating climatic conditions after deglaciation. This vegetational succession continued progressively till the end of the Empetrum - Gramineae p.a.z. SA2. The open vegetation dominated by Rumex and Lycopodium species gave way to an Empetrum heath with dwarf birch and perhaps tree birch remaining on the lower hill slopes. Open grassland vegetation, however, persisted on higher ground.

This vegetational sequence is typical of Lateglacial Interstadial pollen diagrams published for Western Scotland. On the Isle of Skye, Birks (1973) found high percentages of Betula pollen at Loch Meodal, associated with macro-fossils of Betula pubescens. At other sites, shrub-dominated communities were recorded e.g. the dominance of juniper and dwarf birch communities and the Empetrum heaths associated with low values for Calluna at Loch an Coir 'a' Ghobhainn and Loch Cill Chriosd. Birks found that at the latter site, the pollen spectra could not be compared with any surface pollen spectra from Highland Britain today. The high

(30%) Empetrum values and low Calluna percentages (less than 2%) form a comparable situation to the Salen pollen record. Gray and Lowe (1977) have suggested, in relation to the sites on Skye, that such a modern analogue should not be expected because of the unstable relationship between biota and climate, as inferred from Coleopteran evidence, that existed at this time. This suggestion is supported by the fact that Birks (1973) found the vegetational responses to edaphic factors to be more important criteria, rather than the climate, for vegetational differentation.

The p.a.z. SA2 is unusual in that juniper is not represented in the pollen record. The expansion of the juniper pollen frequently recorded during the Lateglacial Interstadial and again at the beginning of the Postglacial is often characteristic of the transition from herb-dominated to tree-dominated pollen assemblages, generally interpreted as a response to climatic amelioration (H. H. Birks, 1972b). A possible explanation for the absence of juniper pollen may be that if juniper was present, it occurred as small prostrate plants that were restricted in their pollen production by snow cover. The absence of a juniper rise is also found at some other Lateglacial sites in Scotland, (e.g. Glassnock in Wester Ross (Robinson, 1977)) and northern England (e.g. at Greeland, Dolton-in-Furness (Johnson et al., 1972).

The plant communities represented by the pollen record in this p.a.z. appear to show a greater affinity with the sites of Skye and the N. W. Highlands than those farther south e.g. Drimnagell, Argyll (Rymer, 1977). Comparison may also be made with sites in the southern Grampians (Walker and Lowe, 1977; Lowe, 1977; Walker 1974). 'Following the initial period of vegetational development, the trend towards soil stability is marked in all profiles by an increase in percentages of locally derived woody-plant pollen and ... a significant decrease in the numbers of open habitat taxa' (Walker and Lowe, 1977, p. 115). Total tree pollen increases towards the middle of p.a.z. SA 2 to 20% of the total pollen spectra with a comparable decrease of herb pollen. As at the sites of Cambusbeg and Tynespirit, near Callander, tree birch would have formed limited woodland cover. The high values of the shade-intolerant Empetrum, however, suggest that this vegetation cover must have been restricted.

The persistence of Rumex pollen throughout the interstadial, together with high values of Cyperaceae, and Gramineae pollen, and Lycopodium selago spores reflect the continued presence of open grassland. This implies that bare ground and unstable soils persisted at higher altitudes in the area. An analogous situation occurred at the Amulree site in the S.E. Grampians (Lowe and Walker, 1977).

P.a.z. SA3. Empetrum - Gramineae - Cyperaceae.

The pollen spectra at Salen during this zone are not sufficiently detailed to make a detailed comparison with other pollen sites in Scotland. However, they can be broadly equated to the Loch Lomond Stadial pollen assemblage zones of other Lateglacial sites. This zone (SA3) corresponds to the Gramineae - Cyperaceae p.a.z. of Pennington (1977) for Western Britain, who states that 'in each instance, the sediment lies between deposits containing raised percentages of Betula which are correlated with the Late Devensian interstadial and the base of the Flandrian sequence' (p. 265).

The absence of Artemisia pollen in this zone is typical of comparable stadial pollen assemblage zones determined by Birks (1973) in Skye, by Walker (1974) in the Grampian Highlands and by Brown (1977) on Bodmin Moor. However, there are other sites in Western Britain that do record high values for Artemisia e.g. Drimnagall in Argyll (Rymer, 1977) or Glanllynnan in North Wales (Simpkins, 1974). Artemisia is intolerant of snow cover and is found in dry habitats (Iversen, 1954). It is a plant typical of a continental periglacial environment. Consequently, if precipitation during the stadial remained high (or approaching present levels) as suggested by Sissons and Sutherland(1976) then the predominance of Artemisia in the latter sites is surprising.

It is difficult to estimate if many of the interstadial soils survived through the stadial period. The increase in indeterminate crumpled and degraded pollen grains during this zone suggest that considerable areas of the lowland soils were destroyed. This destruction would account for the anomalously high values of Betula undiff. and Empetrum pollen found in this zone; their derivation from interstadial soils is far more probable than from the stadial pollen rain.

The increasing evidence from other disciplines supports the palynological conclusions for climatic deterioration and the associated destruction of the interstadial vegetation. This includes the analysis of diatom assemblages (Haworth, 1976; Pennington, 1977); the chemical analysis of lake sediments (Pennington et al., 1972; Pennington, 1977); and studies on fossil Coleoptera indicating rigorous climatic conditions (Bishop and Coope, 1977). On the basis of this evidence the widespread destruction of the interstadial soil horizons in most parts of Scotland must be accepted. There is no reason to suggest that the area surrounding the Salen site was not similarly affected.

The pollen record from many Lateglacial sites in Scotland reflects vegetation characteristic of base-rich conditions. This vegetation is sometimes similar to the pioneer vegetation of the early interstadial period (Birks, 1973). However, the only taxa that have been recorded at Salen that would be in this category are Lycopodium selago and Rumex undiff. Other species that are typical of open vegetation which were present during zones SA1 and SA2, but were not recorded during zone SA3, are Compositae, Cruciferae, Caryophyllaceae and Chenopodiaceae.

P.a.z. SA4. Betula - Salix - Empetrum.

The abrupt resumption of numerous species in the pollen record at the lower zone boundary marks the beginning of the Postglacial period. This transition is typical of many Scottish Lateglacial pollen diagrams. The rapid soil stabilization and the development of first open and then closed vegetational cover is interpreted as a direct response to ameliorating temperatures and the rapid colonisation of maturing soils by immigrating plant communities.

The re-colonization of the area surrounding the site at Salen occurred in a comparable manner to the pioneer communities of p.a.z. SA1. The re-establishment of dwarf, then possibly tree birch, Empetrum heaths and the rapid increase in the aquatic pollen spectra are characteristic of early Flandrian vegetation (Pennington et al., 1972; 1977). Relatively swift changes, with the establishment of a closed vegetation occurred after the initial open pioneer plant communities. The absence of the juniper rise is unusual, although it has not been found at other sites in Western Britain (e.g. Glassnock in Applecross (Robinson, 1977)). The recording of Alnus and Corylus/Myrica pollen grains at the top of the profile marks the beginning of mixed deciduous forest development.

Salen : Chronology

The basal Postglacial radiocarbon date of 9,796 ± 75 (SRR - 1211) obtained for the Salen site is comparable with two radiocarbon dates obtained by Birks and Williams (unpublished) from Salen. These two basal Postglacial dates of 10,093 ± 95 B.P. (SRR - 1186) and 9,483 ± 70 B.P. (SRR - 1185) were taken from the bottom 6 and 5 cm of the core respectively. Comparison of the writer's pollen diagram with an unpublished Postglacial pollen diagram for Salen by Williams shows that the basal Postglacial organic material had similar pollen spectra. Thus an age of between 10,093 and 9,796 B.P. can be accepted at Salen for the Loch Lomond Stadial Postglacial transition.

This approximate age of 10,000 B.P. for the Lateglacial/Postglacial transition has been widely accepted elsewhere in Britain (e.g. Mitchell et al., 1973; Godwin and Wills, 1958). However, this almost universal acceptance for the termination of the Lateglacial Stadial by about 10,000 B.P. differs from radiocarbon dates obtained from Rannoch Moor. Here, basal Postglacial dates of 10,600 ± 240 (SRR - 1074) and 10,520 ± 330 (BIRM - 723) have been obtained, (Lowe and Walker, 1976; Walker and Lowe, 1977, 1979). These dates were unexpected because the Rannoch Moor basin is believed to be one of the last centres of deglaciation of Loch Lomond ice in Scotland (Sissons, 1978b, 1977c). Even allowing for considerations such as the large standand deviation of these dates and for the possibility of hard water error, deglaciation of the Rannoch Moor basin appears to have been completed by 10,200 B.P.

Lowe and Walker (1980) review the problems associated with their series of radiocarbon dates from Rannoch Moor. They discuss the different possibilities for error associated with radiocarbon dating and attribute the discrepancies between radiocarbon dates at different sites to various combinations of these errors. Sutherland (1980) discusses the problems of dating deposits from a newly deglaciated terrain. Sutherland points out that freshly deglaciated ground is distinctive in its chemical and biological character with the possibility of contamination from a variety of sources (e.g. old carbon available from rocks and interglacial soils; carbon from a predominance of aquatic sources). He concludes that on balance, these potential sources of error will make observed dates slightly older. Such a conclusion does not reconcile the Rannoch Moor dates with the established chronology or with the basal Postglacial dates described above from Salen, some 50 km further west.

The second date from Salen (10,643 ± 75, SRR - 1212) for the interstadial/stadial boundary is rather young by comparison with the 'established' Lateglacial chronology. This boundary is frequently put at 11,000 B.P. (e.g. Mangerud <u>et. al.</u>, 1974; Mitchell <u>et al</u>., 1973). However, some sites do have younger radiocarbon ages for this transition e.g. 10,698 B.P. at Cam Loch (Pennington, 1975b) and 10,764 ± 120 B.P. at Loch Etteridge (Sissons and Walker, 1974).

This date (SRR - 1212) must be treated with caution. Due to the combination of samples for dating purposes (see above), contamination is not unlikely. Secondly, the penetration of roots into the stadial minerogenic sediment may have introduced younger carbon into the sample. The material for dating was carefully scrutinized for obvious contamination, but it is still possible that microscopic particles may have been incorporated in the sample.

Unfortunately, no basal radiocarbon date has been obtained for the Salen site. By comparison with the basal pollen assemblage zones of other dated sites in the N. W. Highlands (Pennington <u>et al</u>., 1972, 1975b, 1977) it is reasonable to infer that the basal sediments are approximately 13,000 radiocarbon years old.

Conclusion.

After deglaciation of the area around 13,000 B.P. a pioneer vegetation of Rumex, Salix, Gramineae and Cyperaceae species became established. There was then a continuous vegetation succession, from this pioneer community, throughout the Lateglacial Interstadial. Shrub vegetation, especially Empetrum heaths were widespread with dwarf birch being established in lowland areas. Open grasslands persisted on higher ground throughout the interstadial.

The end of the interstadial at approximately 10,700 B.P. was marked by an abrupt change to cold climatic conditions. Minerogenic inwash was accompanied by the deposition of pollen grains and spores from a small number of alpine species, notably Lycopodium selago. The pollen and spores of only 8 taxa were recorded during the stadial as opposed to 23 in the preceding interstadial. Warmer climatic conditions at around 10,000 B.P. led to the beginning of the Postglacial period. The initial pioneer herb assemblages were replaced by Empetrum heath scrub and finally the development of closed deciduous woodland.

The palaeoclimatic implications of the palynological evidence from the Salen site will be discussed in the following chapter. This evidence will be considered in relation to Lateglacial climatic inferences made in previous chapters and compared with Scotland as a whole.

CHAPTER 7.

THE PALYNOLOGICAL HISTORY OF THE LOCH SHIEL DRAINAGE BASIN FOR PART OF THE POSTGLACIAL PERIOD.

Introduction.

The original intention of obtaining cores from the Loch Shiel basin was to test the interpretation that the Loch Lomond Advance ice limit was located at the western end of the basin (McCann, 1966; chapters 3 and 4 this volume). The sequence of Lateglacial sediments obtained from a site near Salen, some 2-3 km outside this limit, provides positive evidence that the Shiel glacier did not reach this point (see Fig. 3.2). The absence of Lateglacial sediments inside the limit would provide negative evidence for the Lateglacial limit (Donnor, 1957; Robinson 1977; Lowe, 1977). However as early Postglacial sediments were not recovered from Loch Shiel the proposed Loch Lomond Advance limit cannot be tested by this method (but see Chapter 3.).

Aerial photographs revealed raised shorelines above the surface of the present Loch, suggesting that Loch Shiel had once been part of the sea. Preliminary samples of lacustrine sediment proved to contain palaeomagnetic remnants (Thompson, unpublished) so a combined investigation of the lake sediments with Dr. Thompson of the Department of Geophysics, Edinburgh University, was possible. Dachnowski cores had previously been taked from a low-lying basin by the River Polloch (NM 787687) with the aim of obtaining basal Postglacial, and possibly marine, sediments. However the stratigraphy of these cores suggested that neither of these sediments had been obtained and that the nearby river had continually interfered with the sediment deposition of this basin. Detailed analysis of these cores was therefore not attempted.

The author hoped to obtain early Postglacial and marine sediments from the bottom of Loch Shiel using a Mackereth corer. Dr. R. Thompson was concerned with investigating Holocene geomagnetic secular variations from the Postglacial gyttja of British Lakes (Thompson, 1973, 1975, 1977; Creer, Thompson, Molyneux and Mackereth, 1972). Although the geomagnetic chronology relies on radiocarbon dates for absolute ages, once a sufficiently large number of dated palaeomagnetic records have been obtained, it may be possible to use rapid palaeomagnetic analysis as a method of transferring reliable age estimates between sites, by the construction of a palaeomagnetic 'master curve' (Thompson and Wain-Hobson, 1979). As a result of the dependence of this method on radiocarbon dating, with its inherent errors, it is desirable to supplement these dates with additional stratigraphical information. This is invariably pollen analysis (Thompson, 1977) so a combined project appeared to be mutually beneficial.

Mackereth cores from Loch Shiel were obtained by Dr. R. Thompson and the writer. The former analysed the cores for their palaeomagnetic remnants while the latter undertook detailed pollen and chemical analysis of the sediments and obtained the 14C age determinations. In this chapter, aspects of the environmental history of the Loch Shiel basin for the latter part of the Postglacial will be discussed. After a brief review of the Postglacial vegetational history of Scotland, the site is described. Then follows a detailed account of the pollen stratigraphy and inferred former vegetational history. The lithological, palaeomagnetic and chemical stratigraphy of the lacustrine sediments are discussed later.

The chapter concludes with a discussion of the Postglacial environment of the Loch Shiel basin, and a comparison is made between this and the Postglacial record from other sites in Scotland.

The Postglacial Vegetational History of Scotland: A Review.

Introduction.

The pollen record from the Loch Shiel cores described in this chapter cover only the latter part of the Postglacial period. However, as a background to the vegetational changes during this period a brief outline of the vegetational history of the whole of the Postglacial period will be given, though the emphasis will be on the post-climatic optimum period.

The first half of the Postglacial period is characterized by the successive immigration of tree species into Scotland. Many Scottish Postglacial pollen diagrams indicate a series of pollen maxima of Juniperus, Corylus and Pinus. These species were succeeded in parts of southern Scotland by the establishment of such thermophilous tree species as Alnus, Quercus, Ulmus and occasionally Tilia. The widespread establishment of this deciduous forest was associated with the climatic optimum. After this period these woodlands became influenced by anthropogenic activity and climatic change. Dwarf-shrub heaths dominated by Calluna vulgaris replaced mature forest on sloping sites with the widespread development of blanket bog and raised moss mires on many flat summits. Extensive clearance of lowland forests by man culminated in the present landscape.

In 1906 two Scandinavian botanists, Blytt and Sernander related vegetational changes to differences in the biostratigraphy of the peat bogs. Sernander (1908) then related these phases to changes in the Baltic Sea and hence provided the first chronological division of the Postglacial. With the development of pollen analysis (Von Post, 1916) subsequent palynological investigations allowed Jessen (1949) to divide the Late- and Postglacial vegetational history of Ireland into chronological pollen zones. Godwin (1956) accepted Jessen's zonal divisions for Ireland and applied them to British pollen diagrams .

This six-fold numerical division of the British Postglacial by Godwin (1956) became widely adopted. The zonation scheme was based on the assumption that the relative variations in tree pollen at many different sites were synchronous throughout Northern Europe. These variations were essentially considered to be a response to climatic fluctuations. Godwin et al., (1957) made a very detailed analysis of a site at Scaleby Moss in Cumberland which was considered to show all the characteristic features of a Postglacial pollen diagram. However, subsequent radiocarbon dating of 16 horizons at a site at Red Moss, Lancashire (Hibbert et al. 1971), when compared with the Scaleby Moss site, revealed that some features of the Postglacial vegetational development (e.g. the Alnus and Corylus rises) were in fact diachronous. This conclusion was substantiated by Smith and Pilcher (1973) who stated that ' where sufficient dates are available, most of the vegetational developments of the earlier part of the Postglacial are diachronous' (p.903).

As a result of the non-synchronous nature of the Godwinian zones and therefore the invalidity of inter-regional comparison, this system has been replaced by a chronostratigraphic approach. Pollen diagrams from a certain area are assigned to a local zonation division based on the recognition of local pollen assemblage zones. These are later incorporated into a regional picture by the formation of regional assemblage zones. Radiocarbon dates then allow the absolute ages of these regional zones to be determined (see Chapter 5).

As the use of the Godwinian zonation system to describe the Postglacial vegetational history has now been discarded (e.g. Birks 1977), the following outline of the Postglacial vegetational development of Scotland will be based on radiocarbon years B.P.

10,000 - 7,000 B.P.

The rapid rise in temperatures which terminated the cold phase associated with the Loch Lomond Advance was reflected in the swift development of pioneer vegetation reminiscent of the early Lateglacial Interstadial. The pollen spectra indicating this initial period of vegetation expansion are dominated by successive maxima of Empetrum, Juniperus and Betula pollen. The diachronous nature of this vegetational expansion and development is suggested by the fact that the juniper rise occurs later in pollen sites on high ground (Birks, 1973; Vasari and Vasari, 1968).

Tree birch (Betula species) was present before the juniper rise in many parts of Scotland, but its widespread colonization after juniper probably reflects its higher temperature requirement (Iverson, 1960). Vasari and Vasari (1968) considered that in eastern districts of Scotland Betula woodland was more abundant than on the west coast where a more open treeless landscape prevailed. Here Salix and Juniperus remained as important vegetational components until much later into the Postglacial. However by 8,800 B.P. birch woodland had established itself over most of lowland Scotland.

The expansion of birch was followed by the expansion of hazel pollen at many sites. This expansion occurred as early as 9,500 B.P. in the Morar Peninsula (Williams, 1977) and is indicative of the rapidly ameliorating temperatures of that time. Walker (1966) maintained that hazel flowers successfully within the 15°C July maximum isotherm while Betula pubescens can dominate stable communities within the 10°C July isotherm. Hazel was able to colonize previously forestless ground, replacing light Betula-Juniperus scrub and being particularly fatal to the light demanding juniper. The importance of Corylus in the woodland communities decreased northwards and westwards from the Grampian Mountains (Lowe, 1977).

There are marked regional contrasts in the development of forest cover over Scotland as a whole, In northern Scotland and the Grampian Highlands, Pinus sylvestris became and remained dominant over much of these areas. Vasari and Vasari (1968) showed that pine became established in the Abernethy forest region by 7,000 B.P. and that it has remained dominant in this region until the present day (Birks, H. H. 1975; O'Sullivan, 1974). The date of establishment of pine forests varies, but even in N.W. Scotland, Pennington et al. (1972) have shown that pine became dominant between 7,000 and 8,000 B.P. Pennington (1970) suggested that in the Lake District the spatial distribution of Pinus was controlled by edaphic factors. This differed from Betula, Corylus, Ulmus and Quercus whose immigration had been climatically controlled.

However in the mild, oceanic coastal lowlands of the N.W. Highlands oak dominated deciduous forest developed (Birks, 1973; Williams, 1977). There is also little evidence of Pinus dominance in the southern fringes of the Highlands or over the Midland Valley (Lowe, 1977; Newey, 1966) where the hazel-birch association was penetrated by more thermophilous tree species e.g. Ulmus, Quercus and occasionally Tilia (Birks, 1977).

7,000 - 5,500 B.P.

The immigration of Alnus was used in the Godwinian zonation scheme to divide the Boreal from the Atlantic period. However the 'Alnus rise' in Scotland is far more spatially varied than in England and may have taken place over 1,000 years later (Pennington, et al. 1972). The extent to which Ulmus and Quercus invaded the pine forests varied in different locations. Little impact was made on the forests of the Abernethy region and in many other locations north of the Highland Edge. Oaks were dominant however in N.W.Scotland on low-lying littoral areas along western coasts and extending inland along the sea-lochs (McVean, 1964). South of the Highland Edge deciduous forests became dominant (Donner, 1962; Brooks, 1972) especially in S.E. Scotland. Here Ulmus and Quercus are well represented, a reflection of the more favourable environmental conditions in the Pentland and Moorfoot hills (Newey, 1968).

The successive immigration of trees into Scotland reached a climax around 5,500 B.P. with the widespread establishment of mixed deciduous forests on low ground. On higher ground, pine forests reached altitudes of 800m in the Cairngorms (Pears, 1974). This period is traditionally referred to as the Climatic Optimum (Pennington, 1970).

5,500 B.P. to present.

The vegetational history of Scotland throughout this period reflects a complex interaction between climatic variations and anthropogenic activity. As the effect of man's influence on the landscape is difficult to assess, it is often not possible to make specific inferences about climatic variations. For example, after the initial colonization of exposed ground after deglaciation, there is a natural tendency for leaching to occur throughout an interglacial period with the removal of base rich minerals from the soil. Typically, this results in a decrease of deciduous trees complemented by a return of Calluna and Betula heath, a situation known as revertance (Godwin, 1975). However, during the Postglacial, woodland clearance by man would also favour these light-demanding species, so complicating the sequence of revertance.

Probably the most characteristic feature of many British Postglacial pollen diagrams is the decline of Ulnus pollen approximately 5,000 years ago. The reasons for this decline have been vigorously debated (Troels - Smith, 1955b, 1956, 1960; Seddon, 1967). It is now generally accepted that anthropogenic activity, rather than climatic change, has been the prime cause of the elm decline. Evidence for the early activities of man in the Postglacial is becoming more widespread. For instance in northern Scotland, the earliest evidence of anthropogenic influence upon the landscape is from a horizon in the lacustrine sediments of Loch Clair, dated at 5,300 B.P. (Pennington *et al*. 1972). In the Morar Peninsula , Williams (1977) found that an abrupt decline in elm pollen between 4,500 and 5,100 B.P. was associated with woodland clearance. The formation of open grassland was inferred from an increase in the pollen influx values for *Plantago lanceolata* and *Pteridium aquilinum*.

Around 5,000 B.P. a climatic threshold appears to have been crossed in Highland Britain where soil degradation, as a result of rapid leaching, had reached a point that allowed extensive blanket peat to develop. In the central and N.W. Highlands the spread of blanket peat lead to the demise of extensive pinewoods as they succumbed to poor nutrition, problems of regeneration and possible wind damage. This combination of naturally adverse factors was probably concluded by anthropogenic burning (Pennington *et al*., 1972; H. H. Birks, 1975). H. J. B. Birks (1977 p. 128) states that 'the widespread/spectacular decline in pine pollen' in the N.W. Highlands around 4,000 B.P. may have been caused by a 'combination of climatic changes and human activity including burning', with the replacement of pine forests by treeless bog. This 'pine decline' also occurred in N.E. Ireland between 4,000 and 3,800 B.P. (Smith and Pilcher, 1973).

Between 4,000 B.P. and the present day the pollen of dwarf shrub-heath and mire communities found in many sites throughout Scotland reflects the widespread development of open moorland vegetation on acid leached soils. Numerous Scottish Postglacial pollen diagrams reflect this reduction of forest cover commensurate with an increase of plants indicative of open vegetation (Birks, 1977). Gramineae, Cyperaceae and Ericaceae form the most important constituents of the non-arboreal pollen. They are closely associated with the herb pollen of *Armeria*, *Artemisia*, Compositae, *Galium*, *Plantago sp*., Ranunculaceae, *Rumex*, *Succisa*, *Urtica*, and *Pteridium aquilinum*.

The reduction of forest cover during the last 2,000 years has been severe, especially with the introduction of iron as a tool, and the domestication of animals preventing forest regeneration (Vasari and Vasari, 1968). Durno (1965) described examples of 'Landnam' clearance associated with 'cultural' pollens and minerogenic inwash of sediments in the upper part of site profiles. He attributed the sediment inwash to the effect of shifting cultivation with the indiscriminate clearing of forest for cultivation. This was typically indicated by the pollen of *Plantago lanceolata*, *Rumex* and *Artemisia*. Regeneration of the forest then occurred with colonization by *Betula*, *Quercus* and some *Ulmus*, though the latter never regained its former status except perhaps on richer coastal sites.

The delimitation of 'Landnam' clearances sensu Iversen (1949), as a history of small temporary clearances, requires detailed pollen and radiocarbon dating (Turner, 1965). Many Scottish pollen diagrams are not sufficiently detailed for a comprehensive picture of 'Landnam' clearances to be obtained. However local sequences of temporary clearance have been described for some areas e.g. Ayrshire (Turner, 1965).

The introduction of cattle and especially sheep during the agrarian changes of the 18th and 19th centuries was an important factor in preventing the regeneration of woodland. The popularity of 19th century grouse and deer shooting perpetuated the rotational burning of the heath, and this also contributed to the demise of the forest cover (Pearsall, 1968).

Loch Shiel : The site.

Loch Shiel is a long narrow loch consisting of two basins. The larger is the north-easterly basin, which has been glacially excavated along a Caledonian fault and here the loch is confined to this narrow glacial trough. In this basin the deepest point of the floor of the loch lies 125m below sea level while the surrounding hills rise to 870m above the water surface. At Polloch (NM 788688) the loch turns westwards into the large broad western basin. This basin is surrounded by low hills up to 100m altitude; where not occupied by the loch the floor is extensively covered by fluvio-glacial sands and gravels, upon which an extensive bog (Claish Moss) has developed.

Two coring sites were chosen in regions of low gradient at the eastern end of the westerly basin. Cores LS1 and LS2 were taken in a central, open area at a water depth of 25m, 0.5km S.S.W. of Dalelia Pier (NM 733686). Core LS3 was taken from a more marginal site, sheltered by partially submerged dead-ice hollows (see Chapter 3). The water depth at this second site, 1.5km S.S.E. of Dalelia Pier, was 15m (NM736682). All cores were taken in 6m long UPVC liners using a Mackereth pneumatic piston corer (Mackereth, 1958).

The Loch Shiel basin is situated in an area of potential oak forest with birch (McVean and Ratcliffe, 1962). Remaining woodland fragments consist of Quercus petraea and Betula pubescens with Corylus avellana occurring in more open areas. Alnus glutinosa is found on the damper sites within the deciduous oak woods and along the margins of the extensive lowland peat bogs. Rocky and boulder strewn hill-slopes that lie within woodland areas are covered with bryophytes, lichens and ferns (Birks, 1977; Tittensor and Steele, 1971). Isolated patches of Pinus sylvestris occur on fragments of fluvio-glacial outwash which are not covered by peat. Otherwise coniferous woodland is restricted to the extensive forestry plantations that have been established in Glen Hurich. The surrounding hillslopes are covered by acid grassland with *Festuca ovina*, *Agrostis spp.*, *Nardus stricta*, and dwarf shrubs of Ericaceae. Areas of grass moor consist of *Molinia*, *Cyperaceae* and *Myrica gale*. Large areas of blanket peat cover the more gentle hill slopes.

South of Loch Shiel lies Claish Moss, a large bog some 1.0x 1.5km in extent. This bog is a fine example of the ridge and pool system of mire development. This 'eccentric raised mire' has been studied by Moore (1977) and he has described the bog structure. Moore found that the ridges consisted of *Sphagnum umbricatum*, *S. fuscum* and *Rhacomitrium* species, associated with *Calluna vulgaris*, *Erica tetralix*, *Myrica gale* and *Drosera rotundifolia*. Around the margins of the pools, *Sphagnum pulchrum* and *Eriophorum angustifolium* are found while the pools contain *Carex limosa*, *Menyanthes trifoliata* and *Rhynchospora fusca*. Each section of Claish Moss has been divided by streams that drain into Loch Shiel from the northern slopes of Ben Resipol. The bog is in close proximity to the coring sites.

The Lithostratigraphy of the Loch Shiel Cores.

Core LS3 was used for pollen, palaeomagnetic and chemical analyses. This was because initial palaeomagnetic reconnaissance of the three cores indicated that core LS3 contained the longest undisturbed sedimentary sequence. This core contained 520 cm of sediment which is composed of two major sediment types, namely brown organic lacustrine mud overlying marine sediment. The top 40 cm of sediment was very disturbed and the mud/water interface was difficult to recognize, but was estimated to lie some 40 cm below the top of the core tube (see Table 7 - 1 and Fig. 7 - 3).

Table 7 - 1. The Stratigraphy of core LS - 3.

Depth	Description.
0 - 40 cm	Empty core tube.
40 - 80 cm	Very disturbed dark brown mud. The mud-water interface was estimated to lie at 40 cm.
80 - 160 cm	Fine homogeneous dark brown mud, with occasional fine fragments of mica.
160 - 180 cm	Very fine silt particles discernable in the mud.
180 - 350 cm	Fine homogeneous dark brown mud.
350 - 360 cm	Very fine silt particles discernable in the mud.
360 - 400 cm	Fine homogeneous dark brown mud with occasional fine fragments of mica.
400 - 600 cm	A transition at 400 cm to a dark brown mud containing numerous small white marine bivalve shells of the species *Thyasira flexonosa in situ*. A small (2cm long) fragment of birch wood was found at the sediment transition at 400 cm.

From 80-400 cm the sediment consists of a fine dark brown flocculated organic mud with occasional fine fragments of mica. A fine silt content is perceptible at depths of 160-180 cm, 200 cm and between 350 and 360 cm. There is the occasional suggestion of rhythmites in these more silty sections, with mica fragments forming faint 'bedding planes'. No mechanical analysis for particle size of the lake sediments was attempted because of the limitations of this method discussed by Pennington _et al_. 1972. The sediment becomes more compacted with increasing depth down the core, but is otherwise remarkably consistent in texture and colour. On exposure to air, small specks of orange ferric oxide, 'a scarlet limonitic scum' (Caspari, 1910, p. 264) were observed. This is derived from the ferruginous alkali-humus which forms up to 30% of brown organic mud. Caspari (1910, p. 264) stated that 'brown organic mud is the Scottish loch deposit _par excellence_. Its characteristic constituent is an impalpable brown humus - like product of the decay of vegetable matter. This substance usually shows no coarse remnants of tissue and is quite amorphous, though often coagulated into tiny balls'. This description is directly applicable to the brown organic mud of Loch Shiel.

At 400 cm there is a hiatus in the core with a transition to marine sediment. This sediment is virtually identical in physical characteristics to the overlying brown organic mud except that it contains an abundance of small marine shells of the species _Thyasira flexonosa_ (S. Smith _pers. comm._). The majority of these small white bivalve shells have remained joined together and are regarded as being _in situ_. At the present day, this species is found inhabiting sandy muds at depths between 11 and 180m, well below the intertidal zone. It has a wide geographical distribution and is found in localities from Iceland to the Mediterranean sea (Tebble, 1966 p. 79). _Thyasira flexonosa_ is presently found in Loch Etive, which may be regarded as equivalent to a marine Loch Shiel. These marine sediments confirm the conclusion, based on the evidence of raised shorelines above the present loch, that Loch Shiel was a sea-loch during part of the Postglacial.

The marine regressive boundary may also be an unconformity. A small (2cm long) fragment of birch wood was found at this boundary and is not _in situ_. There is no evidence that the birch fragment has been disturbed during coring and it may represent erosion of the marine sediments. There is no major break in the pollen record across this regression, and it is likely that the amount of sediment removed was small.

Core LS1 contains approximately 200cm of organic mud with the regressive boundary occurring at 250cm from the top of the core tube. There is no evidence that this boundary is erosional. The lithostratigraphy of the sediments, although not examined in great detail, appeared to be identical to those of core LS3, including the presence of the marine shell Thyasira flexonosa in the marine sediment. An incomplete sample was recovered from the LS2 core tube and so this core was not examined.

Radiocarbon Age Determinations.

Five radiocarbon age determinations were made on samples of lacustrine sediment from Loch Shiel by Dr. H. H. Harkness at the Scottish Universities Research and Reactor Centre, East Kilbride, Glasgow. The five samples were all taken from the brown organic lake muds to avoid erroneously old ages which may have resulted from the marine input of old carbon (Dickson et.al. 1978). The age determinations for the five samples, four of which were from core LS3 and one from core LS1, are shown in table 7 - 2.

Table 7 - 2.

Radiocarbon Age Determinations.

Sample	Depth cm.	Age Determination Yr.	δ^{13}C, %
CORE LS3			
SRR - 1143	165 - 175	2741 ± 45	-27.1
SRR - 1144	205 - 215	2484 ± 40	-28.0
SRR - 1145	265 - 275	2366 ± 55	-28.3
SRR - 1146	342 - 352	3471 ± 100	-27.3
CORE LS1			
SRR - 1210	346 - 356	3883 ± 65	-24.0

The radiocarbon dates are expressed as radiocarbon years before present with 1950. A.D. being the zero datum. A half-life of 5568± 30 years has been used. Each sample consisted of 10cm of sediment. The position of the samples used for dating was determined by the position of the major swings in paleomagnetic declination and by the fossil pollen record. The dates SRR - 1143, -1144, -1145 correspond with the palaeomagnetic declination swings D, E and F (see fig. 8. 3.) while SRR - 1145 also corresponds with the pollen zone boundary between zones LS1 and LS2. Material from directly above the marine regression boundary was not dated from core LS3 because of the possible erosional nature of this contact.

At the time these samples were submitted for dating it was thought that the dates SRR - 1143 and - 1144 would have been below any zone of sediment inwash associated with forest clearance. This was because pollen concentration and influx diagrams were not available. When the dates SRR - 1143 to SRR - 1146 were known, it was assumed that the upper two dates (SRR - 1143 and SRR - 1144) were in error. This was because they did not form a positive depth/age relationship, (Fig. 8.3.) which is generally recognized by Quaternary workers to represent a normal sequence of sedimentation, and because of their anomalous position on the palaeomagnetic declination - 14 C age master curve (Fig. 8.3.).

A further sample was obtained from 1 to 11cm above the marine regression in core LS1 to test this assumption. If the dates SRR - 1145 and SRR - 1146 are correct, then a sedimentation rate of 0.6mm/year for the core may be obtained. On the basis of this sedimentation rate an approximate age of 4,200 B.P. may be derived for the marine regression in core LS3. The new date, obtained from 10cm of sediment 1cm above the regression in core LS1 gave an age of 3,888 ± 65 B.P. The difference of approximately 300 years between this new date and SRR - 1146 from core LS3 may be due to several reasons:

a. If the date of 3,888 B.P. is assumed to be taken from a point in the centre of the 10cm sample, then applying the sedimentation rate obtained from core LS3 to the lower 6cm produces an age of 3,988 years B.P. for the marine regression.

b. The possibility that some marine sediment was eroded before the deposition of the freshwater muds, as suggested above, would produce an older age prediction for the regression in core LS3.

c. The sedimentation rate of 0.6mm/year must be regarded as a crude approximation. There is no evidence to suggest that sedimentation rate was constant over this period, or that the rates were the same at both sites.

d. The errors involved in the technique of radiocarbon dating.

While these errors have been mentioned, it is considered that the correlation between the ages of the marine regression in the two cores is sufficiently good to be able to reject dates SRR -1143 and SRR - 1144 as erroneous.

The Fossil Pollen Record.

The pollen diagram is divided into two pollen zones. This division has been made subjectively, the criterion for the zone boundary being the fall of tree pollen below 46% of the total pollen spectra. Zonation of the pollen diagram using statistical methods (see Chapter 5) has not been attempted because of the probable inwash of old pollen, contaminating certain sections of the diagram (see below). It was decided that numerical zonation techniques would therefore produce erroneous zone boundaries.

The fossil pollen record as shown by the percentage pollen diagram (Fig. 7 - 1) and the pollen concentration diagram (Fig. 7 - 2) are briefly deacribed. Pollen concentrations are expressed as the number of pollen grains x $10^{-3}/cm^3$.

Zone LS1 600cm - 260cm.

Pollen percentages.

This zone is dominated by deciduous tree pollen which reaches a maximum of 73% at the base of the profile, and decreases to form 46% of the total pollen spectra at the zone boundary.

Betula values reach a diagram maximum of 34% at 380cm while the average for the zone is 25%. Betula values fluctuate, reaching maxima every 30 - 40cm. This is most pronounced between depths of 270 and 380cm. Alnus values decline from a basal maximum of 37%. and remain at approximately 27% throughout the zone. Below 410cm Pinus pollen forms 7-8% of total pollen values with a maximum of 12%. Above 410cm it forms only 2 - 3% of the total pollen spectra for the rest of the zone. Quercus values vary throughout the zone, from 2 to 12%. Corylus pollen declines from a basal maximum of 24% to an average of 15% for the remainder of the zone. Gramineae values average 9% for the greater part of this zone, but rise sharply to 27% at the upper zone boundary. Values fluctuate between 4% and this maxima of 27% throughout the zone. Cyperaceae pollen however remains low at 3%.

Rumex values fluctuate between 2 and 5%, though generally decreasing up the zone. Pollen grains of Plantago undiff, Ranunculaceae, Umbelliferae, Succisa and Nymphaea are present in this zone but form less than 2% of the total fossil pollen spectra. Filicales values fluctuate considerably, between 13 and 30% of the total fossil pollen and spore spectra, with a diagram maximum of 30% at 430cm.

Pollen concentrations. (x10^{-3} grains/cm^3)

Betula values vary from 2 - 41 with a diagram maximum at 570cm. These pollen values vary considerably and the fluctuations are similar to those of Alnus, whose values range from 2 - 63 at 590cm. Pinus values vary from 1 - 12, with low values above 410cm. Quercus values show considerable variation between a diagram maximum of 20 at 590cm and 2 at 450cm.

Corylus pollen concentrations display a marked similarity in fluctuations to that of Quercus. Pollen concentrations vary from 2-42 with an average of 12. Gramineae concentrations vary from 2 to a zone maximum of 38 at 260cm, while Filicales spores range from 2 - 50 with high values at the top and bottom of the diagram.

Total pollen concentration for the whole zone is characterized by large variations from one level to the next. This difference may be as great as 160 (e.g. between 580 and 590cm) with peaks of high pollen concentration being typically 40cm apart.

Zone LS2 260cm - 90cm.

Pollen Percentage.

Betula values vary from 9 - 26% of the total pollen, while Alnus pollen is present in similar amounts, ranging from 11 - 24%. Fluctuations in pollen percentages of both species are markedly less in this zone than in LS1, especially the variation in Alnus values. Quercus pollen percentages fall from 10% to 0% at 120cm.

Corylus pollen averages 14% throughout this zone though with a marked fall at 110cm. Ericaceae values rise from 2% to 12% at the top of the profile; there is a comparable rise in Cyperaceae pollen from 4 to 18% at 110cm. Gramineae pollen forms 30% of the total pollen the lower half of this zone (i.e. below 120cm) but this figure declines to 10% above 120cm.

Pollen percentages of Plantago, Potentilla, Ranunculaceae, Rosaceae, and Urtica increase slightly throughout this zone while Rumex undiff. pollen percentages decrease. Filicales values decrease from a zone maximum of 28% at 250cm to a diagram minimum of 8% of the total pollen and spore spectra at 110cm.

The variations in ~~/~~total pollen percentages throughout this zone reflect a decrease of tree pollen with a corresponding increase of herb pollen percentages.

Pollen concentrations. ($x10^{-3}$ grains/cm^3)

Betula values vary from 8 to 40 at 140cm while Alnus values have a similar range of 10 - 44, and also reach a maximum at 140cm. Quercus values have a double maximum of 8, and Corylus values are consistently between 10 and 15, except for a peak of 45 at 140cm. Ericaceae values increase from 0 to 15 near the top of the zone and similarly Cyperaceae values range from 20 at 260cm to a diagram maximum of 37 at 110cm. Values then drop sharply to 12 at 90cm. Gramineae pollen values fluctuate throughout the zone, reaching a maximum of 70 at 140cm, but decreasing rapidly to 8 at 90cm.

There is a marked increase in Ranunculaceae pollen together with a combined Rumex total of over 30, at 110cm. Total pollen concentrations vary from 74 at 250cm to 254 at 140cm.

The Inferred Vegetational History of the Loch Shiel Basin.

Zone LS1.

Tree pollen forms 46 - 70% of the total pollen spectra in this zone. This large section of the pollen rain is chiefly composed of Betula, Alnus, Corylus and Quercus pollen which together form 70% of the fossil tree pollen rain. This represents a former oak forest with birch woodland described by McVean and Ratcliff (1962) as forming the potential forest cover in Western and Southern Scotland.

Quercus probably formed a major component of the mixed deciduous forest, along the margins of the sea-lochs. As Quercus petraea is present today on 'shallow siliceous soils of the North Western Hills to the exclusion of Q. robur' (Tansley, 1949, p. 247) then the majority of oak trees were probably of this species. Although Quercus forms only 5 - 10% of the total pollen in this zone, it is usually under- represented in pollen spectra (Godwin, 1975). Andersen (1973) adds a note of caution, mentioning that 'the representation of this species in lake sediments cannot have been reduced by losses during dispersion as the pollen grains of the species are rather small'. However, Quercus was still an important component of the deciduous forest (Moore, 1977; Williams, 1977; McVean, 1964).

Betula pubescens formed another major component of the mixed deciduous forests, and may have formed a birch woodland as a successional stage to oak (McVean, 1964). Betula may also have occupied a wide variety of ecological locations: it probably formed a deciduous woodland above the mixed deciduous forest up to 800m (2,500ft) as, for example, it is found in Glen Gour today; it would have quickly colonized any clearing vacated by man (Vasari and Vasari, 1968). Finally it may have been associated with Alnus as a stage in a fen hydrosphere colonizing the bog surface (Godwin, 1975). The variations in Betula pollen, especially in the upper sections of this zone, may reflect the cyclical clearance of the deciduous woodland by man, with the subsequent colonization of the ground by birch scrub.

Alnus was another important contributor to the tree pollen spectra, forming up to 50% of the total tree pollen. Like Betula, Alnus is a prolific pollen producer (Andersen, 1973) and Alnus pollen is especially susceptible to over-representation in lake sediments (Birks, 1972a), because of its ecological preference for wet sites

(Clapham, Tutin and Warburg, 1962). Alnus formed an important component in the mixed deciduous oak woodland (Tittensor and Steele, 1971). Although commonly found in waterlogged sites it would not have been topographically restricted to this environment in a region of high rainfall such as the field area. Also, as Alnus cannot become established on blanket bog and peat (H. H. Birks, 1970) it would not have invaded the extensive areas of raised peat bog in the Shiel basin (e.g. Claish and Kentra Mosses). Thus much of the Alnus pollen would have been derived from the mixed deciduous forest.

Corylus was probably present as a shrub-layer in the oakwoods up to an altitude of about 650m. Hazel is light-demanding (Iversen, 1960) and may have formed extensive stands with birch where oak was absent. Corylus will flower under a birch canopy but will not thrive under a heavy deciduous tree cover (Iversen, 1960) where its pollen production is reduced (Jonassen, 1950; H. J. B. Birks, 1973). Thus while Corylus is an over-producer of pollen (Andersen, 1973) it may only have formed part of the forest canopy during the early part of this zone when Corylus forms 24% of the total fossil pollen rain. Later, pollen productivity may have been restricted as Corylus occurred more as an understorey scrub (H. H. Birks, 1970; Pennington, 1970).

Ulmus was probably an early constituent of the deciduous forest. Comparison with pollen diagrams by Moore (1977) and Williams (unpublished) indicates that the elm decline occurred in this region before the sediment at the base of the profile was deposited, and has therefore not been recorded. A particularly poor pollen producer (Walker, 1974) Ulmus, though poorly represented (1%) was definitely present in the deciduous woodland community.

Pollen grains of Pinus sylvestris form 1 - 5% of the total pollen spectra. A classic over-producer of pollen (Godwin, 1975), Pinus may have been represented by only a few individuals in the vegetation throughout this zone. Many of the pollen grains recorded may have been derived from long distance transport from more easterly pine forests e.g. to the N.E. of the Shiel basin (Stevens and Carlisle, 1959). If local stands of pine had existed, then higher, more variable pollen values would have been expected due to over-representation and the differential pollen accumulation on the water surface. However in the lower part of the zone, isolated patches of pine may have been present on more acidic, open, damp sites where it was able to compete with the mixed deciduous woodland.

Salix occurred to a limited extent as part of the oak woodlands, being present on wetter sites from which it was displaced by Alnus earlier in the Flandrian (H. J. B. Birks, 1977). Fraxinus and Ilex may also have been present in small quantities, though the pollen of the former is sparsely produced and poorly preserved. Being light demanding, Fraxinus was favoured by the Neolithic clearances (Godwin, 1975).

The decrease in tree pollen throughout the zone is complemented by an increase of herb pollen from 10 - 43% of the total pollen spectra. Gramineae pollen increases dramatically at the top of the zone reflecting the expanding areas of open grassland commensurate with the reduction of the deciduous woodland. Grass pollen is usually under-represented in the modern pollen rain (Potter and Rawley, 1960) with pollen values being low in the pollen spectra despite the abundance of grass on the ground (Birks, 1973). Thus an increase in Gramineae pollen from 10 - 34% represents the establishment of considerable areas of open grassland in the landscape.

The rise of grass pollen is associated with an increase in herb pollens indicative of an open grassland environment. Plantago lanceolata is first recorded at 430cm and is regarded as a classical indicator of early human influence upon natural vegetation (Vasari and Vasari, 1968). Similarly Plantago undiff. values increase throughout the upper part of this zone. These robust species belong to open grassland vegetation (Sager and Harper, 1964) and are closely associated with the activities of man (Godwin, 1975).

Ranunculaceae undiff. is first recorded at a depth of 500cm and forms 1 - 2% of the fossil pollen spectra in this zone. Typical of contemporary pastures and meadows (Clapham, Tutin and Warburg, 1962) it may be associated with grasslands and human activity, though it is often over-represented in the total pollen spectra (Birks, 1973).

Other herb species that may have formed part of the grassland communities and contributed to the fossil pollen rain were : Rosaceae, especially Potentilla though this tends to be over-represented in modern pollen spectra (Birks, 1973) and Filipendula; Compositae; Caryophyllaceae; Umbelliferae and Urtica species. Rumex species are typically associated with open and disturbed habitats (Simpkins, 1974) with a clear preference for better soils (Dahl , 1956). Rumex acetosella 'appears at the beginning of the human era, occupying much of the open ground suited for weeds' (Vasari and Vasari, 1968, p. 52). Rumex forms 3 - 4% of the fossil pollen grains recorded in this zone, and although it is likely to be over-represented (Birks, 1973) it forms a reliable indicator of man's presence within the Shiel basin.

The oak woodlands had an associated understorey of ferns. Dryopteris species and Blechnum spicant formed a considerable proportion of the spores in the undifferentiated Filicales category. The increase in spores of Pteridium aquilinum is suggestive of forest clearance as this species forms a typical understorey fern in areas of heavy grazing. Spores of Polypodium vulgare have been persistently recorded. This is consistent with the fact that it is characteristic of damp woodlands of the oceanic west (Clapham, Tutin and Warburg, 1962) and is therefore not a good indicator of anthropogenic activity (Godwin, 1956). There has been a constant input of Sphagnum spores into the Loch, probably from the adjacent Claish Moss, together with spores of Osmunda regalis a fern typical of lake margin communities (H. H. Birks, 1972b).

Zone LS2.

This zone comprises the remainder of the pollen record from 260cm to 80cm. The mud - water interface and a possible maximum of 60cm of sediment were lost during sampling. The use of a mini-corer in conjunction with the traditional 6m Mackereth corer could have allowed this upper layer to have been investigated, but such equipment was not available and the additional information was not required for the project.

The fossil pollen record of this zone records the continued destruction of the mixed deciduous oak woods that was initiated in LS1, with its replacement by open grassland and heath communities. Betula pollen declines to 10%, its lowest contribution to the pollen spectrum. Alnus pollen values remain fairly constant at 15% while Quercus pollen values fall from 8 to 0%. This steady decrease in tree pollen reflects the continued reduction of the mixed oak woodlands within the basin. Alnus and Betula values show less regular variation than in Zone LS1, indicating the progressive inability of the woodlands to recolonize after clearance, as anthropogenic activity became more widespread and the total area of grassland increased.

Corylus values fall initially in this zone, but then rise from 12 to 20% at 150cm. During Zone LS1 the pollen influx curves for Corylus and Quercus show a remarkable similarity in their variations, implying a close ecological relationship, the hazel forming a shrub layer in the oakwoods. However in this zone, the similarity ends, reflecting the decrease of Quercus woodland. This destruction of the woodland canopy may have allowed Corylus to increase its pollen production and dispersal (Jonassen 1950, Godwin, 1975) without an expansion of the shrub. Alternatively the increase may represent the contribution from hazel coppices that recolonized areas cleared by man. However the situation is further complicated by the fact that the Corylus pollen also includes pollen grains of the morphologically similar Myrica gale pollen (see Chapter 5). Therefore it is possible that the increase in Corylus pollen may also reflect the increased pollen production from Myrica as the now widespread heath communities became established.

The development of open heath communities is indicated by the rise of Ericaceae and Empetrum pollen in the upper part of the zone. Empetrum is a poor pollen producer (H. H. Birks, 1972a)that has a wide ecological tolerance (Brown, 1971) and is characteristic of open conditions, being intolerant of shade (Bell and Tallis, 1973). Much of the Ericaceae pollen was probably contributed from Calluna vulgaris which is dominant over large areas of heathland on the west coast of Scotland (McVean and Ratcliffe, 1962). Erica tetralix was probably another contributer to the fossil pollen rain and is a plant with a preference for an oceanic climate. It may have been confined to the altitudinal zone of potential forest in Scotland (Vasari and Vasari, 1968) indicating that this vegetation replaced woodland and was not an addition to it. This is also indicated by the low previous pollen values for Ericaceae recorded during the earlier period. This fairly constant total was probably derived from Claish Moss while the later rise was derived from the establishment of heathland and was in addition to this source.

The rapid expansion of Gramineae pollen in this zone is one of the most prominent features of the pollen diagram. Values vary from 10 to 12% in LS1 to over 35% in LS2. This is despite the fact that modern pollen spectra show that Gramineae pollen are constantly under-represented in pollen diagrams (Potter and Rawley, 1960). Birks (1973) found that Gramineae is under-represented in modern Scottish pollen spectra despite the abundance of grass on the ground. He suggested that this might reflect the predominance of viviparous grasses in the plant communities. From the present vegetation it may be inferred that this increase of grass pollen saw the establishment of large areas of acid grassland with Festuca-Agrostis, Nardus and Ericaceae, and areas of grass moor with Molinia, sedges and Myrica gale. The rise of Cyperaceae pollen supports the latter inference regarding the grass-moor vegetation.

'Cultural pollens' that were first recorded in zone LS1 increase in this zone, e.g. Plantago undiff.or Ranunculaceae, the latter which reach a peak of 4% at 120cm. Rosaceae, Potentilla and Filipendula values slowly increase towards the top of the profile reflecting the increasing establishment of open grass and heathland communities. Urtica pollen is recorded throughout much of the zone. It is characteristic of cultivated and waste ground and is closely associated with the activites of man (Godwin, 1975).

Filicales values decrease during zone LS2. This probably reflects the destruction of the deciduous woodlands where they formed the understorey vegetation.

A Comparison of the inferred vegetational history of Loch Shiel with other Scottish Postglacial sites.

The inferred vegetational history of the Loch Shiel drainage basin corresponds to Flandrian vegetation changes recorded from other sites in western Scotland. Moore (1977) outlined a similar pattern of vegetational development from a site at Claish Moss. As already suggested, the Ulmus decline occurred below the base of the LS3 profile and has not been recorded in this diagram. Moore found the Ulmus decline to be well marked and associated with a rise in Rumex acetosa and Gramineae pollen, similar to the Ulmus rise at more northerly sites e.g. Loch Tarff (Pennington et al. 1972). He suggested that the elm decline was a direct consequence of anthropogenic activity : 'the intensity of the Ulmus decline is too great to be considered as a reflection of distant changes in forest composition' and 'there is no reason to doubt that it represented a real change in the abundance of Ulmus within the vicinity of Claish Moss' (Moore, 1977, pp. 394 - 395). Moore visualized a series of localized clearances of relatively short duration that continued from the elm decline to historic times. He found that during a destructive phase of forest clearance, cultural pollens increased.

This is supported by the Shiel pollen record. Comparison of Betula, Gramineae and Plantago lanceolata implies that Betula pollen decreases as a result of anthropogenic activity and is associated with an increase of Gramineae and Plantago pollen. During a subsequent regenerative period, Betula pollen increases while Gramineae and Plantago pollen decrease. The best destructive phase is seen between 330 and 310cm and the following regenerative phase from 310 to 290cm. Turner (1965) described a similar relationship between Gramineae and Plantago pollen, interpreted as representing temporary clearances, at Bleak Moss in Ayrshire between 3000 and 3400 B.P.

The variation in Betula pollen with forest clearance is indicative of preference by man for clearing the drier soils occupied by birch wood (Nichols, 1967c). The destruction of birch is sometimes related to a rise in Alnus pollen, presumably because the alder stands on wetter sites which were not cleared during early phases of forest destruction (Smith 1958; Durno, 1965). The expansion of birch during regeneration has been well documented by Iversen, 1949.

Moore (1977) did not obtain radiocarbon dates for his pollen profile. However by comparison with dated profiles from Flanders Moss (5192 ± 120 and 5014 ± 120, Smith and Pilcher, 1973) and a date of 5360 ± 110 B.P. for the elm decline at Loch Clair (Pennington, et al. 1972) he suggested that the elm decline occurred at a similar time in the Shiel basin. Williams

(1977 and unpublished), from a site at Loch Doilead near Mallaig, placed the elm decline at 4,600 B.P. in the Morar peninsula and at 5,000 B.P. at Salen, Ardnamurchan. Williams found evidence for a district woodland clearance phase as early as 6,000 B.P. This 'represents a temporary habitation by man presumably in a semi-nomadic existence and it is the earliest record of woodland clearance by man in the northwest of Scotland' (Williams, 1977 p. 244). By comparison with these sites the elm decline in the Loch Shiel area can be assumed to lie between 5,000 and 4,600 B.P.

The generalized picture of the elm decline leaving 'Quercus, Corylus and Betula with Alnus and Salix on wetter sites as the major forest components' (Birks, 1977 p. 126) summarizes the woodland status at this time. The persistent expansion of open woodland vegetation with blanket peats on more gentle slopes is characteristic of the field area, and a large part of the Western Highlands (Durno , unpublished; Donner, 1957; Rymer, 1974; Nichols, 1967c; Moore, 1977; Williams, 1977 and unpublished; Peglar, 1979).

No attempt has been made to construct chronozones for N. W. Argyll. Apart from inadequate radiocarbon dates for such a purpose, an extensive unpublished study of the Flandrian forest history of Western Scotland has been undertaken by palynologists from Cambridge (H. J. B. Birks, H. H. Birks, Peglar, Williams). This study involves the analysis of many pollen sites with numerous radiocarbon dates. It is into the regional chronozones established on a large scale such as this, that partial records of the Postglacial should be incorporated (West, 1970).

CHAPTER 8.

THE PALAEOMAGNETIC AND CHEMICAL STRATIGRAPHY OF THE LOCH SHIEL SEDIMENTS.

The Palaeomagnetic analysis of the Lake Sediments.

Mackereth (1971) provided the first continuous record of changes in geomagnetic declination for the past 13,000 years by analysing sediments from Lake Windermere. Although he ~~was~~ primarily interested in using oscillations of declination as a means of dating sediments, the sediments also provided invaluable information for palaeo-secular variation studies (Creer et al. 1972). Together with palynological and chemical analyses the palaeomagnetic remnants may provide further information about the history of a lake drainage basin (Thompson et al. 1975).

Variations of magnetic declination are primarily used for chronological comparisons as they are greater than variations in inclination. Both however record the past variations of the geomagnetic field (Thompson, 1977). The dating of the secular variation of declination for Lake Windermere (Thompson, 1973) and the Fourier analysis of the declination curve revealed a periodicity of 2,800 years. This provided a reference curve by which to obtain sediment age by comparison with a previously radiocarbon dated declination record (Thompson, 1977). This 'master curve' compares major declination swings with radiocarbon years. The method is limited by:-

a) the quality of the match between the declination data of the samples and the master curve.

b) the accuracy of the C14 dates of the sediments that were used to construct the 'master curve'.

c) Possible areal limitation depending on regional secular variations.

Another use of palaeomagnetism in studing lacustrine sediments was demonstrated by Molyneux and Thompson in 1973. They used magnetic suscepti bility to correlate cores from the same lake. This method provided a non-destructive, rapid reconnaissance technique that would detect disturbance in sedimentation before more detailed palaeolimnological studies were undertaken. This core correlation technique was illustrated by Thompson et al. (1975) using lake sediments from Lough Neagh. Diatom analysis revealed that variations in magnetic susceptibility were synchronous with depth from core to core within the lake. Magnetic susceptibility measurements made during this study also revealed information on the history of the lake drainage basin. Susceptibility was found to be a function of the detrital titanomagnetite content of the sediment. It was directly related to the amount of allochthonous inorganic material washed into the lake from the soil of the drainage basin. This rate of sediment inwash reflected a period of forest clearance and agriculture that was inferred from pollen analysis. This relationship was illustrated by correlations between magnetic susceptibility and the pollen frequency of Plantago lanceolata, Pteridium aquilinium and Gramineae.

The Palaeomagnetic Record of the Loch Shiel Sediments.

The methods and instrumentation used in the palaeomagnetic analysis of the Loch Shiel sediments are described in Thompson and Wain-Hobson (1979). Besides the initial 'whole-core' palaeomagnetic reconnaissance of two cores there was a more detailed analysis of 219 subsamples from core LS3. The natural remnant magnetism was found to be stable and thus it holds a true record of post geomagnetic changes (Figs. 8 . 2 and 8 . 3).

Magnetic Declination.

Clear oscillations are visible with a peak to peak amplitude of 40 - 50 (Fig. 8 - 2). These peaks are labelled A to G and this repeated sequence confirms that these oscillations are a reflection of past changes of the geomagnetic field. In the marine section of the core declination changes are minimal, indicating a faster rate of sedimentation.

The oscillations of magnetic declination can be matched with other declination variations from Lake Windermere (Creer *et al*. 1972) and Loch Lomond (Dickson *et al*. 1979). The peak A at 60cm is interpreted as being the 130 B.P. westerly maximum, known from historical records. This is found in Lake Windermere at 30cm but at 1 metre in Loch Lomond. Peaks B and C occur as smaller fluctations in Windermere, but are a turning point in the Loch Lomond records. D is a turning point and E 'corresponds to a westerly maximum which is characteristically broad or double in a record of high deposition rate' (Thompson and Wain-Hobson, 1979, p. 386) (see Figs. 8 . 2, 8 . 3). F is a sharp easterly turn at a depth of 260cm. It occurs at 180cm in Windermere and at 270cm in the Loch Lomond palaeomagnetic record. Swing G is not clearly defined (as in Loch Lomond) and occurs at 5 metres in Loch Shiel, 220cm in Lake Windermere and 360cm in the Loch Lomond record. The extended nature of the declination record below F compared to the more detailed record from Lake Windermere and Loch Lomond indicates a faster rate of deposition during this mid-Postglacial period.

Magnetic Inclination.

The inclination record shows a series of low amplitude oscillations and is not a true reflection of the ancient magnetic field. Inclination remnance in recent fine-grained sediments is probably of post-depositional origin (Kent, 1973; Lovlie, 1974; Stober and Thompson , 1977; Thompson and Berglund, 1976). Low inclinations do however correlate with the marine sediment (see Fig. 8 . 2) and suggest a totally different sediment structure for these marine deposits. In the Loch Lomond cores a similar layer of marine sediments also have low intensity and susceptibility values Dickson et al. (1978).

The older part of these inclination and declination records (between 2,000 and 3,000 years B.P.) shows the oscillations to be in phase over this period (Thompson and Wain-Hobson, 1979). This earlier in-phase behaviour has been found in other European records, e.g. Lake Vuokonjorvi, Finnish Karelia (Stober and Thompson, 1977). This substantiates the opinion that the Loch Shiel record reflects true palaeomagnetic behaviour.

Magnetic Susceptibility.

No correlations were found between magnetic susceptibility and possible indicators of erosion. These were grass, Ericaceae and *Pteridium* pollen, and the iron oxide content of the sediments (Thompson et al. 1975).

The Loch Shiel Palaeomagnetic record compared with other sites in Britain.

The palaeomagnetic record from Loch Shiel displays more detail than the original Windermere records, but is surpassed by the finer, longer record from Loch Lomond. The greater resolution of the geomagnetic record from these Scottish lochs probably results from a higher ratio of rate of deposition to time of stabilization of the magnetic remnance. The Loch Shiel and Loch Lomond records are directly comparable; examples of this similarity 'are the shorter period declination fluctuations B and C which consistently appear. Also turning point E is always broad and often appears double. Turning point F is characteristically sharp and of high amplitude and on inflection is commonly found between G and F. The westerly maximum G also contains a higher frequency fluctuation but it is normally not as pronounced as at E' (see Fig. 8 . 2) (Thompson and Wain-Hobson, 1979). Thus the British geomagnetic field declination record consists of a series of fluctuations of several frequencies with a concentration of energy in the periods between 2,500 and 3,000 years B.P.

The fine geomagnetic record allows the independent comparison of 14C age determinations between lakes. It may ultimately result in a rapid non-destructive method of dating lake sediments provided a satisfactory 'master curve' can be produced. This was first attempted by Mackereth (1971). Palaeomagnetic declinations are plotted as abscissa

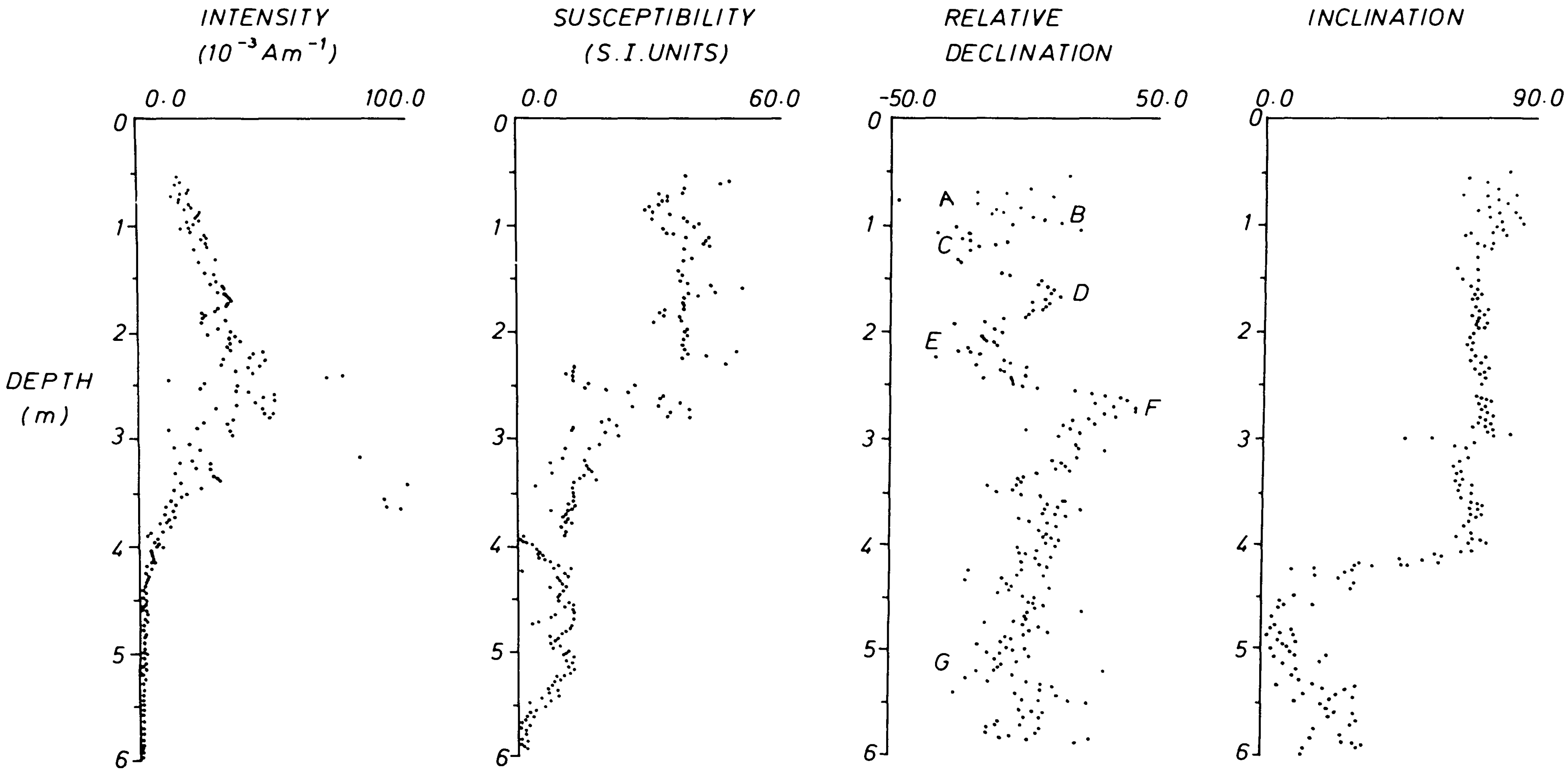

FIG 8.2. SINGLE SAMPLE NATURAL REMANENT MAGNETISM FOR CORE LS-3.

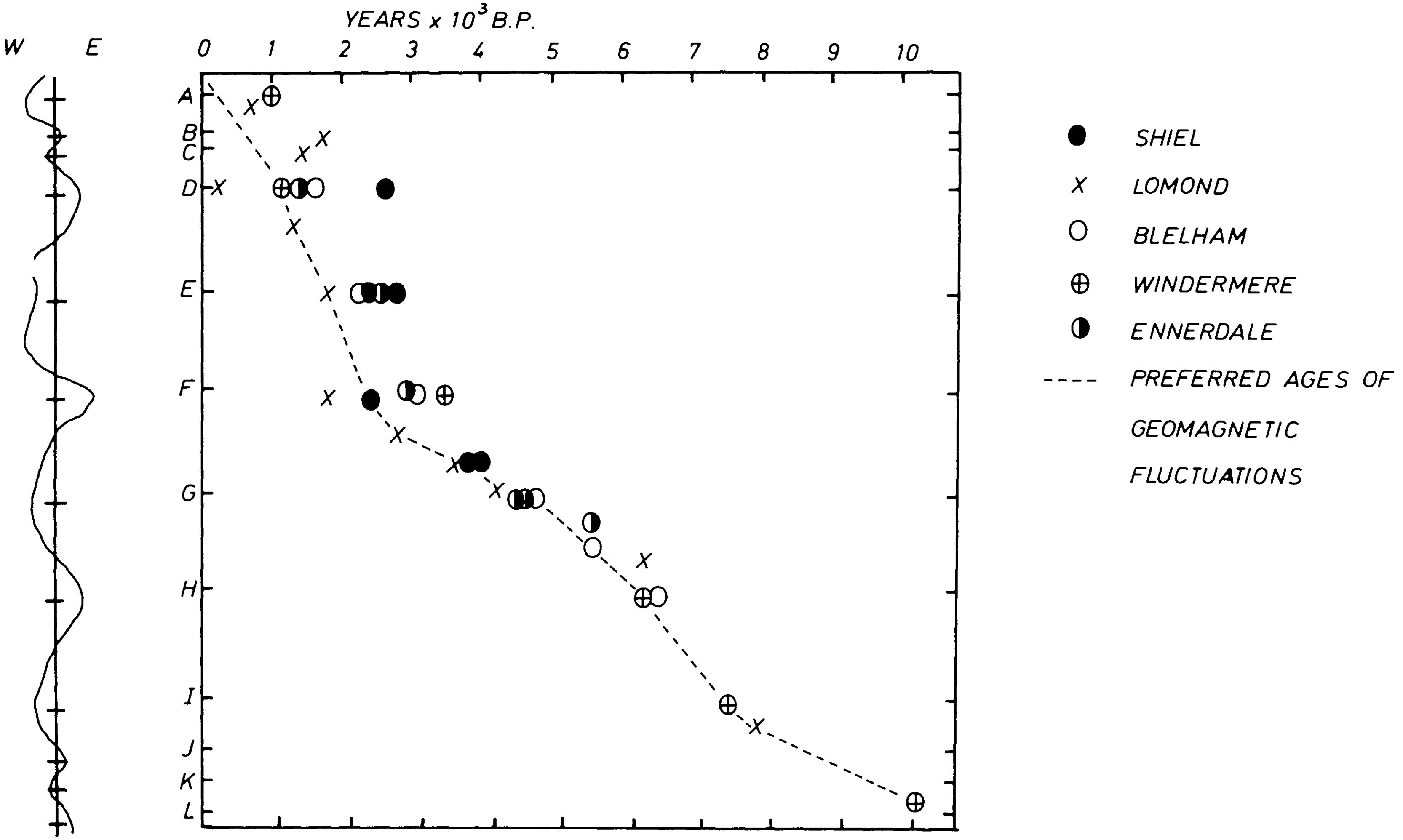

FIG. 8.3. GEOMAGNETIC DECLINATION VARIATIONS (A-L) VERSUS CONVENTIONAL RADIOCARBON AGES FOR FIVE LAKES IN GREAT BRITAIN.

with the major swings lying at equal intervals (Fig. 8 . 3). This is done for ease of comparison and not because there are periodic fluctuations in inclination. 14C ages are plotted as ordinates. Two of the Loch Shiel dates (SRR - 1143 and SRR - 1144) increase with age with decreasing depth and are thought to be due to the erroneous input of old carbon into the lake. They are included on Fig. 8 . 3 to show their anomalous position in relation to the general pattern of 14C dates used to construct the 'master curve'.

Only the lower two 14C dates from core LS3 are assumed to be correct (i.e. SRR - 1145 and SRR - 1146). This assumption was substantiated by the re-dating of a sediment sample from core LS1 (SRR - 1210) which accords closely with SRR - 1146 from core LS3 (see above).

While laboratory radiocarbon errors are small and errors in matching palaeomagnetic curves are thought to be minimal (Thompson and Wain-Hobson, 1979), there must be additional large errors in 14C dating during this time period. This error (e.g. as represented by the spread of radiocarbon dates at point F) is thought to be due to the contamination of lake deposits by old carbon, derived from the erosion of old soils and peats in the lake drainage basin. This is apparent between points F and D, the last 3,000 years B.P. Thus radiocarbon ages from lacustrine sediments in the late Postglacial may be considerably anomalous although they still conform to a positive time/depth curve.

Palaeomagnetic dating allows the assessment of individual dates from one site and by means of a 'master curve', with age determinations from other palaeomagnetic sites in Britain. An independent calibration of the palaeomagnetic record (for example by a sequence of varves) would allow further checks to be made on 14C dating results and other established chronologies.

The Chemical Analysis of the Loch Shiel Sediments.

Introduction.

Pioneering work on lake sediment chemistry was made by Mackereth (1965 and 1966) who found that the majority of lake sediment is derived from the lake drainage basin. The organic material, once oxidized, remains relatively stable and therefore there is a close chemical similarity between lake sediments and the soils of the lake drainage basin. Post-depositional modifications are slight and as a result, the chemical stratigraphy provides a valid record of Postglacial sediment composition at its time of decomposition (Mackereth, 1966).

Variations in the gross composition of lake sediments with time is related mainly to the intensity of erosion in the drainage basin. For instance, Al lies mainly in alumina-silicates and correlates closely with total particulate matter (Spencer and Sachs, 1970). It may thus be used as an indicator of the changing rate of erosion in a lake drainage basin (Thompson and Wain-Hobson, 1979). Titanium has a similar ionic potential to aluminium and is also an indicator of erosion.

Mackereth (1966) found that Na and K were associated with the mineral fraction of lake sediments and that they reflected the rate of erosion in the drainage basin. High K values were indicative of more intense erosion with relatively ineffective leaching of the soils. Low K values suggested that the soils in the drainage basin had been exposed for a long period of time before their removal and deposition in the lake. This conclusion is supported by the close positive relationship between other indicators of erosion (e.g. grass pollen) and magnetic susceptibility found in sediments from Lough Neagh (Thompson *et al.*, 1975) and the strong correlation between K and susceptibility found in the adjacent Lough Fea (Oldfield *et al.*, 1978). The close relationship between the chemical composition and the pollen and palaeomagnetic stratigraphy of lake sediments shows the desirability of obtaining the chemical record where the latter analysis has been undertaken. It wasbecause of this premise that the chemical analysis of the Loch Shiel sediments was made.

Methods.

The chemical analysis of ten elements (Si, Al, Na, K, Ca, P, Ti, Fe, Mg and Mn) was made on 25 samples taken at 20cm intervals from core LS3. The sediment was prepared following instructions by J. G. Fitton (unpublished) to obtain sample discs. These samples were then analysed by a Philips PW 1450 X-ray fluorescence spectrometer at the Dept. of Geology Edinburgh University, from which a count ratio was obtained. Four specially prepared standard samples with a known chemical concentration were also analysed. By constructing graphs of the sample count ratio against chemical concentration of each element, the concentration of each element in the sample could be obtained. The concentration of each element is expressed as a % weight of oxide (see Fig. 8 - 1 and appendix B).

The chemical record of the Loch Shiel sediments.

Fig. 8 - 1 shows the % weight of oxide for each element analysed plotted against sediment depth. The % of total mineral matter varies between 93 and 98% and shows no systematic change in depth. The limnic sediments have elemental compositions closely resembling the marine sediments in the core. The greatest changes occur at the top of the

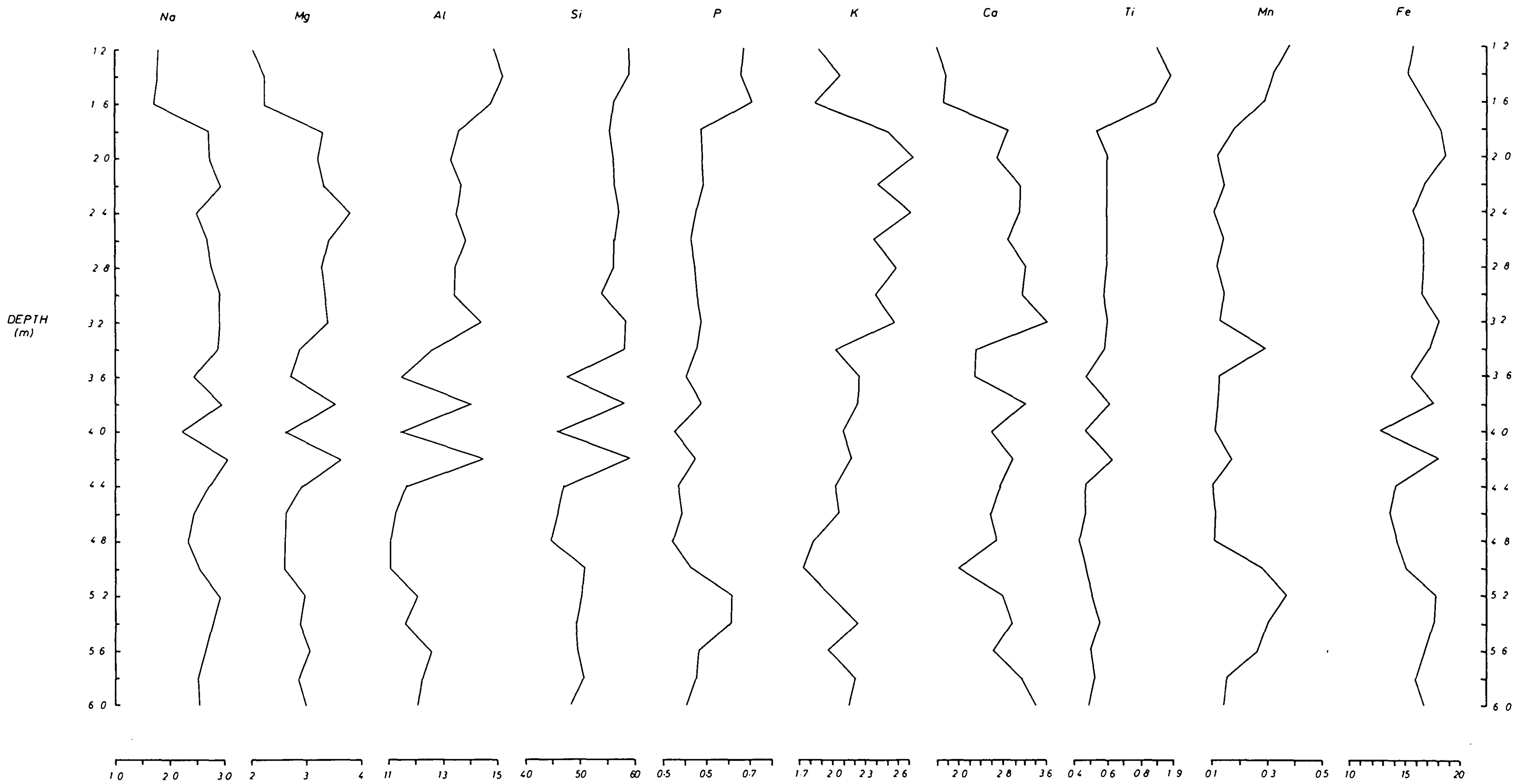

FIG 8.1. CHEMICAL COMPOSITION OF CORE LS-3.

profile above 170cm depth. Typical values (in weight % oxide) of the elements in the marine and uppermost limnic sediments are Si (50 - 59%) Al (12 - 15%), Ti (0.5 - 0.9%), Mg (3.0 - 2.2%), K (2.1 - 1.9%), Na (2.6 - 1.8%), Ca (3.0 - 1.79%), Fe (17 - 16%), Mn (0.2 - 0.3%) and P (0.4 - 0.7%). The changes in chemical composition through the Shiel profile are small. For example, Mackereth (1966) found that the K content varied between 1 and 3% in Esthwaite Water in the English Lake District, a change an order of magnitude greater than in Loch Shiel.

Thompson *et al.* (1975)and Oldfield *et al.* (1978) showed a correlation between 'erosive indicators' (Na, K, Mg, and Fe) and magnetic susceptibility in Lough Neagh. However no clear correlations were found between magnetic susceptibility and any of these elements in the Loch Shiel sediments. This may reflect the differences in geology between the two drainage basins. The Antrim basalts provided the detrital titanomagnetite which was an ideal mineral to record the palaeomagnetic susceptibility. This is in contrast to the complex chemistry of the Moinian Schists of the Loch Shiel basin.

Element/Al ratios are frequently used as a standard method of comparing lacustrine and marine elemental compositions (M. E. Sholkovitz pers. com.). In the Loch Shiel sediments these ratios show little variation with no change across the marine regression. The most consistent change is at 170cm where the Mn, P and Ti/Al ratios increase and the Ca, Fe, K, Mg, Na and Si/Al ratios decrease. These changes can be explained by an increase in the grain size of the sediment above this level.

Loch Shiel : A Discussion.

One of the interesting aspects that has arisen from this study of the Loch Shiel lacustrine sediments is the advantage of a multidisciplinary approach to elucidating the history of a lake-drainage basin. This approach provides invaluable additional information for reconstructing the former environment compared with that which would have been available from one line of investigation alone e.g. pollen analysis. The usefulness of the different methods is illustrated by the evidence presented for the marine transgression in Loch Shiel.

The main stratigraphical evidence for the marine transgression is the presence of shells of the marine bivalve *Thyasira flexonosa* lying *in situ*.below 400cm in core LS3. The inference that marine conditions prevailed in Loch Shiel during part of the Postglacial is supported by a stratigraphic regressional boundary in the core; by a marked decrease in palaeomagnetic inclination and intensity, and by the presence of raised shorelines above parts of the present loch shore (see Chapter 4).

A more marked change in sediment composition, chemistry and pollen record might have been expected as a result of this major change in the environment of deposition. However there is little indication from the pollen diagram that the pollen grains below 400cm were deposited in salt water. This failure of the pollen record to register marine conditions is not as unreasonable as may be supposed: the pollen rain from surrounding areas (including the pollen input from rivers and streams) would only contain pollen of maritime or brackish species if the marine transgression had provided suitable locations (i.e. a salt marsh) where these species could grow. The northern part of Loch Shiel is surrounded by steep hillslopes with a rocky shore while in the western basin peat had already stabilized the fluvio-glacial outwash by the early Postglacial (Moore, 1977). If the Postglacial sea had been able to flood Claish Moss, then a situation analogous to the River Forth carse land may have developed (Sissons, 1966) and the transgression would have been clearly represented in the pollen record (Brook s, 1972). The presence of raised shorelines along the margins of the loch indicate that Claish Moss has not been inundated, while Moore (1977) records a peat succession that is unbroken from the early Flandrian to the present day from a site in the middle of the Moss. This suggests that peat growth equalled or exceeded the rise in sea-level, a situation similar to the development of Flanders Moss (Sissons and Smith, 1965).

The marine sediment in core LS3 is similar to the overlying brown organic mud. The main stratigraphical difference between the two types of sediment is that there is no indication of rhythmites in the marine section of the core. This difference may be due to flocculation of sediment particles in a marine environment of deposition. The similarity between the sediments probably reflects the same source of sediment supply. Sediment input from rivers and streams would not vary but the proportion of sediment that may be related to seaborne detritus is not known. Changes in sediment chemistry do not indicate the marine regression. As already mentioned, detrital inwash would remain constant while Na and K salts may have been leached from the upper part of the marine sediments.

The palaeomagnetic record however reveals the marine sediment clearly. The magnetic inclination, intensity and susceptibility remnants are not recorded below 400cm (Fig. 8 . 2). A similar situation occurs in Loch Lomond (Dickson et al., 1978; Turner and Thompson, 1979). Here, both the marine transgression and regression boundaries are present forming a discrete layer of marine sediment 70cm thick, between freshwater lake sediments. As at Loch Shiel, intensity and susceptibility remnants are not recorded by the marine sediment, forming a marked contrast to the palaeomagnetic record of the adjacent sediment(see Fig. 8 - 2, Dickson et al., 1978).

The marine sediment in the Loch Lomond cores was also indentified by the presence of marine molluscs and cysts of planktonic dinoflagellates. Some species of the latter are characteristic of the reduced salinity and shallow turbid conditions of the eastern Irish Sea today (Dickson et al., 1978). No dinoflagellate cysts have been found in the Loch Shiel marine sediments (J. D. Peacock, pers. comm.). Further information regarding salinity changes across the marine-freshwater sediment transition might be provided by diatom analysis.

The salinity of the 'marine' Loch Shiel is difficult to access. Price and Calvert (1973) found that the salinity distribution in Loch Etive was essentially estuarine in the outer basin with a sluggish mixing in the inner basin of the loch. At depth there was little water exchange with the sea. The morphology of Loch Etive compares closely with that of Loch Shiel, and so by comparison, it is suggested that the salinity distribution in Loch Shiel was also estuarine and that true marine conditions were never achieved.

The progressive clearance by man of the deciduous woodland and its replacement by open grassland and heath communities have been the most important change in the vegetational history of the lake basin. The extent to which soil erosion accompanied this woodland clearance, and the amount of inwash of old soils and peats, together with the recirculation of lake sediment is difficult to determine.

It has already been mentioned that the upper two 14C dates (SRR - 1143 and SR - 1144) from the sequence of four dates taken from core LS3 are regarded as being in error. This error has been attributed to the contamination of the samples by old carbon. It is suggested that this is derived from the inwash of old soils and peats. The evidence for soil inwash associated with anthropogenic activity will now be discussed.

The pollen concentration diagram (Fig. 7 - 2) records the number of pollen grains deposited per cm^3. Therefore anomalously high peaks in pollen concentration values may represent :-

a. An unusually large influx in the pollen rain at that level.
b. The deposition of old pollen grains derived from outside the lake.
c. The redeposition of lake sediment.

Near the top of the profile, levels 110cm and 140cm have very high pollen influx values, the latter being twice the average for the pollen diagram. These high values are regarded as not being an accurate record of the pollen rain since they probably include additional pollen from other sources. The pollen diagram does not record large numbers of aquatic species and other plants that are likely to be concentrated in a lacustrine environment (Faegri and Iversen, 1975). As a result, the additional pollen is considered to be derived from old sediment.

Bonny (1976) conducted a survey using pollen traps to estimate the recruitment of pollen to the lake sediment of five lakes in the English Lake District. She found a discrepancy between the pollen deposition rates between the sites, that were determined by limnological factors as well as vegetational distribution. 'Total annual pollen deposition cm^2 mud surface' ... varied ... 'by four and five times between the lakes investigated' (Bonny, 1976, p. 882). This may be a function of within-lake variations in pollen sedimentation (Davies, Brubaker and Webb, 1973; Pennington, 1973) or lake size (Davis, 1967a; Pennington, 1973; Bonny, 1976). While redeposition within the lake must be acknowledged as a source of contamination, there is no definite evidence that this occurred in Loch Shiel.

The most likely source of the additional pollen influx is eroded soils and peats in the drainage basin washed into the loch by rivers and streams. The chemical record (see above and Fig. 8 - 1) indicates a change in sedimentation above 170cm, when Mn, P and Ti/Al ratios increase and the Ca, Fe, K, Mg, Na and Si/Al ratios decrease. These changes may be explained by an increase in grain size at this level. The average Ti/Al ratio from 120 - 160cm is 0.062, while from 180 - 600cm it is 0.043. The average Ti/Al ratio for fine grained sediment is 0.033 (Goldschmidt, 1954) but this increases with an increase in the grain size of the sediment (Hirst, 1962). Thus the chemical record suggests that there was an apparent inwash of coarser particles into the loch in the upper sections of the core.

Further evidence for the inwash of material into the upper sections of the profile is given by the sedimentation rate. On the basis of two radiocarbon dates (SSR - 1145 and SSR - 1146) an approximate sedimentation rate of 0.6mm/year has been obtained. This is a comparatively fast accumulation rate for Postglacial lacrustrine sediment (G. Boulton, pers comm., G. Boulton et al. 1981) and may reflect the acceleration of inwashed material from the lake drainage basin consequent upon deforestation. It is unlikely that this accumulation rate is a result of redeposition within the lake. Pennington (1973, 1974, et al. 1977) found that the annual Postglacial increment of sediment for five Lake District lakes is 0.45mm year. Pennington (1974) found that the major lakes of the Lake District, whether shallow or deep, have a maximum total depth of Postglacial sediment of between 3 and 6 metres. This indicates that no acceleration of sediment accumulation in the middle of any of the shallow lakes (as a result of redeposition of material recirculated from the littoral parts of the lake) can have occurred. Pennington (1973) also found that differences in lake morphometry have not led to different accumulation rates in the past. The rapid rate of sedimentation may therefore be attributed to the association between progressive deforestation of the lake drainage basin and increased soil erosion with the accelerated transfer of soils into the lake basin. It is unlikely that the high rate of sedimentation is the result of 'cultural eutrophication' (Pennington 1973).

Evidence for the early human occupation of N. W. Argyll is scant. The first record of human activity in the area is probably the Ardnamurchan Mesolithic Industries. Ritchie (1968) describes people fetching Rhum bloodstone from the island and working it into artefacts at domestic sites along the northern shoreline of the Ardnamurchan Peninsula. Feachen (1963) notes three vitrified forts at Loch nan Gobher, near Corran (NM 970633), at Rahoy by Loch Teacius (NM 633564) and at Shielfoot at the mouth of the river Shiel (NM 663702). A brooch and axe head found at Rahoy suggest an early Iron Age date for these forts. The construction of these forts is pertinent : a heavy timber stockade of upright posts would be set in a trench and packed with stones around this skeleton of stout timbers to form a wall. Vitrification of the stones resulted when these timbers were set on fire, presumably by hostile attack. As the circumference of the fort near Corran is approximately 280m, their construction must have required the felling of a substantial number of trees. Feachen (1963) estimates that the earliest of these forts were built by incoming (sea) traders between 2,300 - 2,000 B.P. The importance of timber in their construction provides additional evidence for the effects of anthropogenic activity on the deciduous woodland of the Loch Shiel drainage basin.

Gaskell (1967) describes forest clearance in Morvern in the more recent past. He quotes accounts of the forests burning 'as one great ember' in 1746 as a reprisal, for Morvern was a loyalist centre to the Jacobite cause. Battarbee (1978) noted an increase in sedimentation rate associated with anthropogenic activity from the detailed study of many cores from Lough Neagh. He found that the sedimentation rate varied from 0.3cm/year at 3,000 B.P. to 0.8cm/year at the present day. Battarbee attributed this rapid acceleration in the rate of soil inwash from the catchment area to 17th century forest clearance and agricultural expansion.

CHAPTER 9.

THE LATEGLACIAL CLIMATE OF N. W. ARGYLL.

Introduction.

Palaeoclimatic evidence for the Lateglacial period has been derived from two major sources of data. The first is the fossil biological record, principally pollen analysis and Coleopteran studies. The second source is inferred from glacialogical data derived from reconstructing the Loch Lomond Advance glaciers.

An outline of the palaeoclimatic information presently available for the Scottish Lateglacial is given below. Palaeoclimatic evidence derived from the field area is then discussed in this context.

The Lateglacial climate of Scotland: Previous Work.

a. Palynological evidence.

Pollen diagrams form the most widespread biological data available for the Lateglacial period. The problems of inferring climatic change from the reconstruction of the vegetation are well documented (see Chapter 5). As plants respond to a wide range of ecological parameters of which climate is only one, it is not usually possible to derive actual temperatures and precipitation values from palynological data.

However broader climatic inferences can be made and, coupled with radiocarbon dating, pollen diagrams provide an important stratigraphic and chronological control for the Lateglacial period. For instance, the rate of climatic change can be estimated and the local environmental conditions ascertained. This contrasts with the information derived from reconstructed glacier limits because the maximum advance of each glacier represents a finite point in time.

b. Coleopteran evidence.

G. R. Coope has pioneered the use of fossil beetle remains to indicate climatic change. He found that Coleoptera display a remarkable degree of evolutionary stability such that the composition of fossil assemblages resembles that of modern faunas. Beetles are extremely sensitive to temperature variations and can colonize an area extremely rapidly. They are therefore early indicators of temperature fluctuations.

On the basis of Coleoptera assemblages from 5 sites in Scotland, Bishop and Coope (1977) produced a graph showing variations in the average July temperatures near sea-level for the period 13,500 to 9,000 B.P. During the Lateglacial Interstadial annual July temperatures were between 12° and 15° C while estimated temperatures during the Stadial was below 9° C.

clusions (e.g. Sissons 1976) that the Rannock Moor basin formed the centre of isostatic uplift.

Loch Lomond Stadial - Postglacial Transition.

Stadial conditions ended with the abrupt termination of minerogenic sedimentation at Salen. This occurred somewhere between 10,000 and 9,700 B.P. Re-colonization of the area followed a similar sequence to the early interstadial colonization. An initial period of pioneer herbs was succeeded by dwarf scrub. Tree birch immigrated into this environment to be followed by Corylus and later Alnus. It is probable that podzolization again took place, leaching the base-rich content of the soils that had been derived from the stadial.

The Loch Lomond glaciers melted in situ, with the exception of the Shiel glacier. The Shiel glacier retreated leaving a large outwash fan that marked its maximum extent (Kentra Moss). A second area of extensive outwash deposits (beneath Claish Moss) was formed as the glacier receded up the Shiel valley.

Postglacial Period.

Environmental evidence for the early and middle part of the Postglacial period is not available from the study area. There is no pollen record for this period from approximately 9,500 to 4,500 B.P. During part of this time the Main Postglacial Shoreline was deposited; by comparison with the Forth Valley this occurred at about 6,500 B.P. The shoreline slopes towards 270 from 14m at Corran to 8m by Loch Sunart, the gradient being 0.06m/km. Relative sea-level subsequently fell from this Postglacial maximum with the deposition of another beach at approximately 5m O.D. This lower shoreline has no definite gradient.

The Main Postglacial transgression flooded Loch Shiel to form a sea-loch. The presence of the marine bivalve Thyasira flexonosa and the palaeomagnetic record of lacrustrine cores clearly delimit the marine sediment.

The fossil pollen record from Loch Shiel shows that a mixed deciduous woodland of Quercus, Alnus, Betula and Corylus species covered the surrounding hillsides. This woodland was progressively cleared by man. Soil erosion associated with these clearances is marked by the input of old pollen into the loch. This input of old carbon was responsible for two anomolous radiocarbon dates. The chemical record shows a change in sedimentation towards the top of the profile. This change is due to the influx of coarser sediment particles related to soil erosion.

c. Other microfossil data.

Planktonic foraminifera from deep-sea ocean cores have provided useful data on the temperature of the oceans at various points around the British Isles (Ruddiman and McIntyre 1973; Ruddiman, Sancetta and McIntyre, 1977). This marine microfossil evidence shows that the Loch Lomond Stadial corresponded with a return of polar waters to a latitude as far south as S. W. Ireland (Ruddiman et al. 1980).

d. Molluscan evidence.

Two main faunal assemblages of marine shells are recognized for the Lateglacial: the arctic and subarctic assemblages (Sissons, 1967b). The former contain Arctic bivalves while the latter have a rich boreal fauna comparable with that found off the northern coast of Norway today (Peacock et al., 1977). However the use of such molluscan evidence in climatic interpretation is limited as only crude indications of ocean temperatures may be inferred.

e. Geomorphological evidence.

The detailed reconstruction of Loch Lomond Advance glaciers from geomorphological evidence of their limits has allowed Sissons (1974a, 1977a, b, 1979, 1980a, b,; Sissons and Sutherland, 1976) to make detailed palaeoclimatic inferences for the Lateglacial Stadial (see Chapter 3). Firn line altitudes of the reconstructed glaciers have been calculated from the altitude-area distributions of the former glacier surfaces.

Sissons has examined the firn line altitudes of 226 data points on reconstructed glaciers covering those areas of Scotland where the Loch Lomond Advance has been delimited. This includes the study area, where the firn line for all these data points rises from below 300m in S. W. Argyll to above 1,000m in the Cairngorms. Superimposed upon this general gradient is the contrast between north and south-facing glaciers in many mountain regions. 'Owing particularly to the influence of direct insolation one might expect north-facing glaciers to have been larger and to have extended to lower altitudes than south-facing ones. Yet the converse applied'. (Sissons, 1979b,p.518). Thus, for instance, in the N. W. Highlands, the Isle of Skye and Rhum, N. W. Argyll and S. E. Grampians, the Loch Lomond Advance glaciers were larger and descended to lower altitudes on the south and south-western side of the uplands than on their north-eastern sides. Sissons (1979b) has suggested that there must have been something overriding the influence of insolation. 'The only possible explanation is much higher precipitation on the southern sides of individual upland areas than on their northern sides. This in turn implies that the principle snow-bearing air streams were from southerly directions' (Sissons, 1979b, p.519).

Outside Scotland, Sissons (1980a) has mapped the Loch Lomond Advance limits in the Lake District. Here the firn line does not trend in any particular direction but the large number of small glaciers are instead related to areas of potential snow blowing. Snowfall was associated with south to south-easterly winds and snow blowing was again related to southerly winds.

Using Liestol's graph that relates winter accumulation to summer temperatures at the firn line of some Norwegian glaciers, Sissons and Sutherland (1976) derived a former summer sea-level temperature of 6.0°C for the South-East Grampians. They also produced a precipation map showing that precipitation varied from 750 to 1750mm per annum.

The Lateglacial Climate of N. W. Argyll : A Discussion.

The Salen site provides a vegetational record for the Lateglacial period in the study area. An initial pioneer community of Salix, Rumex and Lycopodium is replaced by an Interstadial heath vegetation with Betula nana, B. Pubescens and Empetrum.

The only thermal parameters that may be directly obtained from the pollen diagrams relate to the species Betula pubescens, whose presence is inferred during the interstadial (pollen zone SA2). Iversen (1954) has maintained that this tree species requires a mean July temperature of at least 12°C. If temperatures remained above 12°C long enough for the tree birch to have immigrated into the area, then the July mean temperature of 14°-15°C as suggested by the more sensitive coleopteran evidence (Bishop and Coope, 1977) would be compatible with this former temperature. Precipitation probably remained high throughout the interstadial as reflected by the values for Empetrum pollen; Empetrum has a preference for a cloudy, oceanic climate.

The vegetation of the Loch Lomond Stadial is not well represented, the poor pollen record reflecting the cold climatic conditions that were inhospitable to vegetational development. However the cessation in the pollen record of many interstadial species marks the break-up of the vegetation cover with the onset of solifluction. The low values of Artemisia pollen in zone SA2 agree with the general distribution of this species during the stadial. Species of Artemisia are intolerant of snow and favour dry ground. Pollen percentages of Artemisia increase from sites in the Western Highlands to Strath Spey in the central Grampians where it reaches 40-65% of total land pollen (Walker 1975; Birks and Matthewes, 1978). This trend of Artemisia pollen, indicating drier conditions towards Strath Spey corresponds with the deductions made from the firn line altitudes of the Loch Lomond Advance glaciers. In the study area the firn line varies from 286m in the S.W. of the area to 439m in the N.E. with a gradient of 7.5 m/km. The average firn line altitude for the 8 glaciers is 369m O.D. Using Leistol's curve, an average July temperature of about 4°C at sea-level is inferred. Discontinuous permafrost indicates a minimum mean annual temperature of no more than -1°C (Sissons, 1979b). The second main piece of climatic evidence derived from the reconstructed Loch Lomond glaciers is that 83% of the total surface area of these former glaciers have a southerly or westerly aspect, despite high insolation factors. This distribution of former glaciers is found on many upland areas throughout Scotland, and implies that the source of precipitation was from a southerly and westerly direction (Sissons, 1979b).

In Chapter 4 the conclusion was reached that the Main Lateglacial Shoreline (rock platform and cliff) was predominantly formed as a result of frost action. The debris that was produced was removed by marine processes. As the rock platform must have been formed at a rate greatly in excess of any process operating today, it is therefore probable that the climatic conditions were unusual.

A situation may have arisen where the cold polar waters that surrounded northern Britain (Ruddiman and McIntyre, 1973) were in sharp contrast with the warmer southerly winds that originated south of the oceanic and atmospheric polar fronts. Thus along the coast there was a pronounced temperature contrast between the cold sea-water and the milder atmospheric temperatures. This situation may have provided an unusually high number of freeze-thaw cycles that enabled the mechanism of frost erosion (Nansen 1921; Dawson, 1980) to be so effective. High precipitation during the stadial (Sissons and Sutherland, 1976) would have reduced the salinity of the sea lochs as also would glacier meltwaters. This increase in fresh-water would have allowed even more effective freeze-thaw action, especially if the fresh-water was confined to the upper layers of the sea in a sheltered environment (see Chapter 4). The coarse angular debris found in the stadial sands and clays at the Salen site indicates that freeze-thaw and solifluction processes were very effective in the vicinity of the site without the added advantage of semi-diurnal wetting and debris removal found in a marine environment.

The Loch Lomond Stadial - Postglacial transition is marked by the sudden termination of minerogenic sedimentation and the rapid succession from a pioneer vegetation assemblage through to an Empetrum heath stage. This rapid vegetational development is interpreted as the response to the dramatic rise in summer temperatures from 6°C to 14°C that occurred between 10,000 B.P. and 9,500 B.P. (Coope, 1977). It seems probable that glacier melting was rapid, with the majority of the small glaciers in the field area melting *in situ*.

CHAPTER 10.

CONCLUSION.

This final chapter forms a summary of the evidence for the environmental changes that have taken place in N. W. Argyll and that have been described in previous chapters.

The orientation of the glacial breaches in the field area, the fact that the majority of striae are between 240° and 307°, and the distribution of erratic boulders all show that the area was overridden during the ice-sheet period. Ice flowed westward over the field area from a large ice-cap centred over the Ben Nevis - Glen Coe - Ben Etive areas of Scotland.

It is thought that during ice-sheet wastage local caps became established. There was a reversal of ice-flow under favourable conditions as, for example, along the steep west coast line of Loch Linnhe. The last active ice was confined to the major glacial troughs such as Loch Linnhe.

The only evidence for high sea-levels associated with the melting ice-sheet in the field area has been preserved at Loch Arienas, Morvern. Here, a suite of fluvio-glacial terraces are believed to relate to a former sea-level between 20 and 25m O.D.

By approximately 13,000 B.P. deglaciation was virtually complete and a pioneer plant community had become established. An open vegetation cover consisting of Rumex, Salix, Gramineae and Cyperaceae species developed. This floral colonization was in response to rapidly ameliorating temperatures as illustrated by Coleopteran evidence, (Bishop and Coope, 1977).

Lateglacial Interstadial.

Evidence for the environmental conditions during the interstadial are confined to the Lateglacial pollen site at Salen. It is assumed that the ice-sheet melted completely and that the subsequent Loch Lomond Advance was a separate glacial event.

At Salen, there was a continuous vegetational succession from the initial pioneer plant communities. A shrub vegetation of Empetrum heath developed with the establishment of dwarf birch in sheltered areas. Although this heath required the termination of solifluction and the formation of an interstadial soil in the vicinity of the site, it is thought that solifluction persisted at higher altitudes throughout the interstadial. On the basis of Coleopteran evidence (Bishop and Coope, 1977) average annual July temperatures were between 14° and 15°C. This accords with the presence at Salen of tree birch that requires a mean July temperature of at least 12°C. Pedogenisis throughout the interstadial would have led to a decline in the base status of the soils as a result of progressive leaching under a humid environment.

Loch Lomond Stadial.

The deterioration of climatic conditions with the approach of the Loch Lomond Stadial is reflected in the fossil pollen record at Salen. *Myriophyllum* species cease to be recorded, indicating a drop in water temperature while an increase in Polypoiaceae and open herb communities reflects the onset of solifluction. The coarse sediments and clasts obtained from the stadial sands and clays suggest that the interstadial soil was completely destroyed. The vegetation record for the stadial zone SA3 supports this inference as the plants recorded are indicative of solifluction.

Limits of Loch Lomond Advance glaciers were mapped in the field using the distribution of hummocky and fluted moraines. The use of glacial erratic boulders in these former glacial margins proved to be particularly helpful.

At the maximum extent of the Loch Lomond Stadial glacer, ice covered 19% of the area. There were 14 glacier termini and 8 of these have well preserved limits; 7 of these glaciers had a westerly or south-westerly aspect. The glacier surfaces were reconstructed with contours at 50m intervals. 83% of the total surface area of the former glaciers had a south to westerly aspect. The firn line sloped from 286m in the S,W. to 439m in the N.E., a gradient of 7.5m/km, the average altitude being 369m. This glacial distribution supports the contention of Sissons (1980b) that precipitation was related to snow-bearing southerly winds. Snowfall was sufficiently great to out-weigh the high insolation of glaciers in such locations.

During the stadial, the Main Lateglacial Shoreline was formed. The associated rock platform has an average width of 8m and an average backing cliff 5m high. The main mechanism for its formation is considered to have been a freeze-thaw action operating under extremely favourable conditions. Warm southerly winds with a cold sea, combined with a surface layer of fresh to brackish water promoted rapid rock disintegration. Debris was removed by conventional marine processes and by ice-rafting. Rock platform formation was influenced by rock type. Better platforms were found on the sandstone conglomerate and Morvern lavas than on the Moinian Schist and Strontian Granite where the platforms were narrow, less clearly defined, and had an uneven surface.

The Main Lateglacial Shoreline slopes towards 270° with a gradient of 0.15m/km from a height of 9m in the east of the area to 0m O.D. in the west. The direction of this platform gradient accords with previous conclusions (e.g. Sissons 1976b) that the Rannoch Moor basin formed the centre of isostatic uplift.

Loch Lomond Stadial - Postglacial Transition.

Stadial conditions ended with the abrupt termination of minerogenic sedimentation at Salen. This occurred somewhere between 10,000 and 9,700 B.P. Re-colonization of the area followed a similar sequence to the early interstadial colonization. An initial period of pioneer herbs was succeeded by dwarf scrub. Tree birch immigrated into this environment to be followed by Corylus and later Alnus. It is probable that podzolization again took place, leaching the base-rich content of the soils that had been derived from the stadial.

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APPENDIX A

LEVELLED HEIGHTS

NOTES.

1. Heights are grouped into fragments and transects (Chapter 4). Heights are given in the following order : Main Lateglacial Shoreline; Postglacial Shorelines and outwash deposits.
2. All the heights in this appendix are located on Fig. 4 - 1, diagrams A to O. The relevant diagram number is shown above the heights for each fragment.
3. The first two columnsgive the 8 figure National Grid reference for each point. All lie in grid square NM except those with eastings 0000 - 0004 which lie in grid square NN.
4. The third column gives the average grade for each fragment as discussed in Chapter 4.
5. The fourth column gives the height in metres O.D. above O.D. Newlyn. All heights were levelled directly from O.S. bench marks, Newlyn datum, except where indicated as follows:-

   \+ Heights levelled from synchronous sea-level marks.

   ++ Heights levelled from O.D. Liverpool bench marks that were subsequently corrected to the Newlyn datum.
6. The fifth column gives the depth of any peat overlying the point.
7. Average heights and grid references for a fragment have been shown between horizontal lines. Heights listed below the lower line were not measured along the back edge of the fragment and have therefore not been used for height analyses.

Main Lateglacial Shoreline.

1 FIG. 4 - 1 D

9023	5577		12.64
9029	5578		12.40
9026	5577	C	12.52

2 FIG. 4 - 1 D

9093	5538		10.91
9095	5534		10.86
9097	5531		10.51
9095	5534	A	10.76

3 FIG. 4 - 1 D

9104	5530		11.35
9106	5530		10.09
9109	5530		10.13
9107	5530	A	10.52

4 FIG. 4 - 1 D

9068	5613		12.32
9075	5619		12.58
9072	5616	C	12.45

5 FIG. 4 - 1 G

6823	4426		8.02
6825	4422		7.99
6829	4418		8.84
6833	4416		8.80
6831	4411		8,02
6840	4406		7.86
6845	4400		9.00
6848	4397		9.24
6852	4393		7.37
6831	4411	A	8.35
6819	4465	C	7.01
6820	4459	C	6.49
6820	4454	C	6.18

6 FIG. 4 - 1 G

6871	4348		8.58
6874	4343		7.64
6880	4333		8.79
6889	4316		8.35
6897	4306		8,74
6900	4300		8.52
6889	4316	A	8.47
6853	4389	C	5.66
6857	4387	C	6.74

7 FIG. 4 - 1 G

6903	4296		7.57
6905	4289		7.78
6908	4286		7.62
6909	4282		6.80
6909	4277		7.09
6910	4274		6.41
6909	4282	A	7.21
6910	4270	C	5.78
6915	4266	C	5.62

8 FIG. 4 - 1 I

6353	4572		6.39
6339	4580		6.19
6346	4576	B	6.29

9 FIG. 4 - 1 H

6424	4538		6.00
6436	4532		6.40
6441	4527		7.51
6448	4522		8.24
6458	4516		7.37
6441	4527	A	7.10

10 FIG. 4 -1 J

5793	4985		4.57
5792	4978		4.70
5790	4974		4.18

5790	4968		3.99
5790	4963		4.46
5790	4959		4.52
5790	4954		4.33
5790	4968	A	4.39

11 FIG. 4 - 1 J

5791	4946		4.02
5792	4940		4.18
5802	4936		4.37
5803	4926		4.61
5808	4916		4.26
5802	4936	C	4.28

12 FIG. 4 - 1 J

5815	4896		5.04
5821	4887		5.71
5827	4882		5.62
5830	4876		5.47
5833	4871		5.57
5835	4867		5.74
5829	4880	B	5.53
5839	4867	B	6.18

13 FIG. 4 - 1 J

5837	4863		5.63
5860	4862		3.96
5872	4833		4.05
5888	4815		3.41
5866	4845	C	4.26
5876	4835		2.28
5880	4823		3.10

14 FIG. 4 - 1 J

5911	4789		3.76
5928	4783		5.66
5946	4770		3.14
5956	4758		5.15
5987	4736		6.21
5946	4770	B	4.78

15 FIG. 4 - 1 J

6009	4722		5.11
6013	4706		6.43

15 FIG. 4 - 1 I

6065	4660		6.93
6064	4658		6.40
6088	4662		5.36
6101	4667		6.73
6123	4674		5.68
6006	4678	B	6.09
6103	4664	C	3.67

16 FIG. 4 - 1 I

6304	4573		6.18
6311	4581		6.12
6317	4583		6.46
6326	4586		6.43
6315	4582	B	6.29

17 FIG. 4 - 1 K

6302	5851		4.45	+

18 FIG. 4 - 1 K

6233	5764		4.06	+
6234	5761		3.85	+
6235	5756		4.68	+
6237	5752		4.68	+
6238	5748		4.79	+
6239	5742		4.50	+
6240	5737		4.25	+
6241	5733		4.27	+
6242	5728		3.90	+
6243	5724		5.07	+
6243	5720		4.60	+
6239	5752	B	4.42	

Postglacial Raised Shorelines.

19 FIG. 4 - 1 A

9842	6275		5.12
9849	6272		5.31
9855	6269		5.45
9860	6266		4.49
9868	6262		5.82
9875	6258		6.05
9881	6255		5.74
9887	6250		5.79
9893	6246		5.82
9898	6242		5.58
9902	6236		5.82
9875	6258	A	5.54

20 FIG. 4 - 1 A

9895	6214		3.62
9886	6208		3.51
9883	6205		3.64
9877	6208		3.42
9875	6204		3.81
9877	6198		4.04
989	6189		3.97
9877	6208	A	3.72

21 FIG. 4 - 1 A

9894	6180		4.26
9898	6172		4.15
9899	6165		4.15
9899	6156		4.24
9902	6152		4.72
9902	6148		5.51
9904	6144		4.51
9909	6142		4.99
9909	6154	A	4.56

22 FIG. 4 - 1 A

9909	6147		4.57
9910	6151		4.37
9910	6156		3.69
9913	6163		4.85
9917	6169		3.92
9920	6174		4.24
9923	6179		4.07
9925	6185		4.06
9927	6190		3.99
9928	6193		4.25
9931	6200		4.21
9921	6176	B	4.19

23 FIG. 4 - 1 A

9878	6268		12.94
9875	6270		12.70
9870	6273		12.46
9865	6276		12.39
9861	6278		12.21
9856	6281		11.58
9851	6283		11.99
9847	6285		12.28
9843	6287		12.04
9839	6289		12.38
9835	6290		12.61
9832	6291		11.72
9826	6291		11.75
9820	6289		11.16
9815	6291		12.87
9847	6285	A	12.21

24 FIG. 4 - 1 A

9811	6292		10.46
9806	6293		10.25
9801	6295		9.77
9800	6301		9.81
9792	6303		10.79
9801	6296	B	10.22

25 FIG. 4 - 1 A

9782	6301		3.89
9775	6309		2.29
9770	6310		2.31
9769	6305		2.44
9770	6298		2.82
9774	6297		2.48
9780	6296		3.44
9788	6293		4.69
9791	6293		4.55
9794	6292		4.26
9790	6293	B	4.39

26 FIG. 4 - 1 A

9907	6248		9.60
9910	6247		10.11
9912	6247		9.80
9915	6247		9.26
9911	6247	B	9.69

27 FIG. 4 - 1 A

9793	6283		7.57
9788	6277		8.16
9795	6277		7.17
9801	6277		8.52
9895	6280	C	7.85
9807	6278		5.51
9812	6278		4.40
9816	6280		4.31

28 FIG. 4 - 1 A

9975	6268		5.56
9978	6272		5.26
9983	6275		4.60
9987	6277		4.65
9989	6278		4.27
9993	6279		4.28
9996	6280		4.41
9987	6277	A	4.72

29 FIG. 4 - 1 A

9999	6287		7.01
0001	6288		6.68
0004	6290		6.54
0008	6293		6.03
0009	6296		4.93
0012	6299		5.94
0015	6302		5.78
0016	6312		4.77
0021	6314		4.60
0026	6316		4.82
0029	6319		4.64
0033	6320		4.05
0037	6322		4.02
0044	6324		4.16
0048	6327		4.14
0054	6327		4.09
0058	6325		4.95
0064	6324		5.02
0069	6324		4.90
0076	6323		5.03
0083	6323		4.91
0095	6323		5.13
0040	6310	B	5.10

30 FIG. 4 - 1 A

0159	6350		13.82
0161	6352		13.64
0163	6356		13.74
0162	6360		13.88
0161	6362		13.57
0159	6365		13.57
0154	6371		12.83
0149	6371		13.24
0154	6360	A	13.54
0147	6351		11.62
0152	6350		12.01

31 FIG. 4 - 1 A

0130	6397		6.55
0127	6400		6.44
0125	6401		6.62
0122	6402		6.99
0120	6404		6.36
0122	6402	B	6.59
0113	6410		4.92
0111	6414		4.28

32 FIG. 4 - 1 B

9538	6029		12.65
9542	6-27		14.17
9551	6040		13.98
9552	6034		13.76
9545	6032	B	13.64

34 FIG. 4 - 1 C

9399	5933		5.96
9401	5929		6.49
9404	5937		3.36
9407	5940		6.25
9411	5941		6.06
9413	5946		6.29
9418	5950		6.53
9422	5952		6.67
9411	5940	B	5.95

35 FIG. 4 - 1 C

9433	5965		5.97
9456	5958		5.16
9460	5963		4.91
9462	5966		3.92
9464	5970		4.72
9466	5973		5.53
9468	5978		5.64
9471	5981		5.73
9463	5980		5.46
9450	5973	A	5.23
9436	5966		3.92
9441	5967		3.42
9445	5965		3.64
9453	5962		3.96
9458	5976		2.87
9454	5977		4.74
9440	5974		6.37
9375	5947		5.93
9381	5949		4.91
9386	5951		5.28
9391	5954		4.28

36 FIG. 4 - 1 C

9435	5975		8.06
9433	5974		7.08
9429	5972		6.35
9424	5969		7.18
9421	5968		6.61
9412	5965		7.22
9413	5962		7.40
9409	5958		7.64
9401	5953		7.46
9421	5968	C	7.2

37 FIG. 4 - 1 C

9446	5934		4.89
9445	5940		4.63
9444	5945		4.57
9445	5940	A	4.70
9447	5929		6.53

38 FIG. 4 - 1 C

9435	5917		14.42
9436	5913		13.65
9435	5911		13.38
9436	5908		13.71
9435	5911	A	13.79

9063	5594		7.96	
9067	5598		6.77	
9070	5600		6.67	
9057	5590	C	7.29	

49 FIG. 4 - 1 B

9076	5601		8.71	
9086	5603		8.32	
9092	5602		8.00	
9097	5599		7.95	
9099	5597		7.79	
9085	5600	C	8.15	

50 FIG. 4 - 1 D

9096	5593		6.13	
9096	5588		5.46	
9094	5584		3.96	
9091	5578		4.25	
9093	5585	B	4.95	

51 FIG. 4 - 1 F

8537	5092		5.28	++
8541	5096		5.78	++
8530	5084		5.04	++
8527	5079		4.23	++
8522	5071		7.97	++
8520	5069		6.71	++
8519	5067		6.32	++
8517	5065		6.53	++
8515	5060		5.09	++
8526	5075	B	5.88	++

52 FIG. 4 - 1 F

8512	5056		8.34	++
8509	5049		8.37	++
8511	5053	B	8.36	++

53 FIG. 4 - 1 F

8457	4972		9.42	++
8452	4968		8.54	++
8448	4965		8.66	++
8444	4962		9.72	++
8440	4959		11.20	++
8437	4956		8.47	++
8434	4953		10.22	++
8432	4950		9.79	++
8427	4947		10.11	++
8442	4959	B	9.57	++

54 FIG. 4 - 1 F

8399	4882		4.97	++
8406	4909		4.42	++
8425	4936		4.77	++
8450	4905	C	4.72	++

55 FIG. 4 - 1 F

8414	4933		10.23	++
8411	4928		9.69	++
8408	4923		9.28	++
8405	4919		8.96	++
8403	4916		8.84	++
8402	4911		9.86	++
8399	4904		9.20	++
8398	4898		9.00	++
8397	4891		9.33	++
8396	4881		8.89	++
8395	4875		9.16	++
8392	4871		9.18	++
8402	4911	B	9.30	++

56 FIG. 4 - 1 H

6398	4582		7.71	
6386	4583		7.03	
6378	4583		7.04	
6376	4586		7.45	
6371	4587		7.78	
6374	4578		7.08	
6386	4580	B	7.35	

39 FIG. 4 - 1 E

8810	5352		7.45
8813	5355		7.22
8817	5361		6.59
8821	5363		7.91
8815	5358	C	7.29

40 FIG. 4 - 1 E

8823	5367		9.26
8827	5372		9,02
8826	5375		11.45
8825	5371	A	9.91

41 FIG. 4 - 1 E

8833	5384		8.73
8838	5391		8.04
8844	5397		6.88
8838	5391	C	7.88

42 FIG. 4 - 1 E

8868	5430		13.13
8875	5437		12.21
8878	5441		9.78
8881	5445		10.40
8883	5447		10.42
8883	5451		10.90
8885	5456		11.43
8886	5459		11.09
8890	5460		10.63
8876	5445	B	11.11

43 FIG. 4 - 1 E

8894	5469		9.58
8895	5472		9.59
8898	5479		10.14
8896	5474	A	9.77

44 FIG. 4 - 1 E

8907	5488		12.5
8913	5492		13.43
8918	5496		13.52
8923	5498		13.69
8915	5493	B	13.29

45 FIG. 4 - 1 E

8923	5501		7.30
8926	5499		8.86

FIG. 4 - 1 D

8924	5504		9.23
8924	5509		8.97
8930	5514		7.87
8933	5519		7.72
8938	5529		8.57
8942	5534		8.31
8945	5540		8.65
8945	5547		9.24
8934	5523	C	8.47

46 FIG. 4 - 1 D

8955	5545		9.86
8960	5547		10.36
8965	5546		10.69
8961	5554		9.44
8966	5556		9.89
8969	5555		11.39
8975	5550		10.65
8965	5547	B	10.33
8985	5550		9.95
8986	5548		8.28

47 FIG. 4 - 1 D

8992	5559		8.23
8997	5562		7.53
9003	5567		7.37
9009	5569		7.54
9013	5572		7.60
9003	5566	C	7.65

48 FIG. 4 - 1 D

9044	5580		6.42
9047	5583		6.64
9049	5585		7.59
9051	5588		8.04
9055	5590		7.72
9059	5593		7.82

57 FIG. 4 - 1 H

6375	4572		6.85
6369	4559		5.51
6372	4566	C	6.18

58 FIG. 4 - 1 H

6402	4559		6.87
6409	4546		6.09
6414	4540		5.74
6417	4538		5.76
6412	4545	A	6.12

59 FIG. 4 - 1 I

6147	4677		7.86
6152	4674		8.07
6155	4672		7.98
6158	4669		7.36
6161	4665		7.25
6165	4663		7.09
6169	4660		7.80
6173	4658		8.74
6171	4656		9.46
6181	4654		9.47
6184	4651		9.34
6160	4664	A	8.22

60 FIG. 4 - 1 K

6289	5840		3.05
6272	5830		4.82
6256	5811		4.28
6272	5825	C	4.05

61 FIG. 4 - 1 L.

7459	6036		7.91
7461	6041		8.31
7462	6048		8.73
7458	6052		8.95
7460	6043	A	8.48

62 FIG. 4 - 1 L

7452	6055		7.68
7443	6055		8.32
7433	6056		7.59
7430	6058		6.73
7426	6060		6.92
7438	6063	C	7.45

63 FIG. 4 - 1 L

7412	6068		7.03
7410	6065		7.49
7407	6064		7.45
7404	6063		7.36
7400	6062		7.59
7400	6058		7.19
7399	6055		7.67
7405	6062	C	7.39

64 FIG. 4 - 1 L

7483	5984		4.90
7489	5984		5.52
7497	5983		4.64
7490	5984	B	5.02

65 FIG. 4 - 1 L

7510	5982		10.29
7514	5985		10.35
7518	5988		9.34
7544	5983		10.82
7548	5985		10.66
7559	5986		9.45
7562	5990		9.58
7544	5984	B	10.07

66 FIG. 4 - 1 M

7648	6069		4.41
7655	6072		3.72
7655	6067		4.07
7653	6069	B	4.07
7644	6073		6.13

67 FIG. 4 - 1 M

7682	6063		6.29
7684	6066		6.72
7684	6061		5.96
7683	6063	C	6.32

68 FIG. 4 - 1 N

7226	6397		5.63
7230	6393		5.13
7234	6391		5.34
7238	6389		5.74
7231	6393	B	5.46
7235	6398		6.94
7232	6403		8.99
7229	6405		8.04

69 FIG. 4 - 1 N

7210	6394		4.87
7210	6398		5.45
7210	6396	B	5.16
7210	6403		6.99

70 FIG. 4 - 1 N

7208	6404		8.96
7205	6405		8.50
7201	6402		9.03
7199	6401		7.56
7197	6403		7.42
7203	6402	B	8.29

71 FIG. 4 - 1 N

7193	6407		10.68
7189	6413		12.00
7190	6416		10.92
7192	6411	C	11.2
7187	6407		8.73
7185	6403		7.79
7184	6400		5.93
7185	6397		5.21

72 FIG. 4 - 1 O

7546	6855		9.65	+
7545	6853		9.86	+
7545	6851		9.55	+
7545	6848		10.14	+
7544	6846		9.68	+
7544	6842		10.15	+
7543	6840		10.24	+
7545	6846	B	9.89	

73 FIG. 4 - 1 O

7545	6810		9.42	0.1	+
7545	6807		9.60	0.5	+
7545	6805		8.98	0.2	+
7545	6803		8.97	0.1	+
7545	6801		9.94	0.2	+
7545	6805	B	9.38		

FIG. 4 - 1 O

7518	6851		9.598	0.3	+
7520	6850		10.66		+
7504	6801		4.99		+
7505	6799		9.61		+
7411	6861		9.61		+

Outwash.

FIG. 4 - 1 A CORRAN

0141	6371	18.83	2.0
0143	6367	20.39	1.9
0139	6366	20.53	1.9
0136	6366	20.13	2.4
0132	6365	20.15	2.6
0128	6364	20.17	2.1
0124	6362	19.72	2.0
0120	6361	19.45	2.0
0117	6360	19.01	2.5
0113	6359	18.11	2.1

FIG. 4 - 1 C INVERSANDA

9272	5969	18.33	0.35
9276	5957	17.55	0.20
9277	5955	16.89	0.10
9282	5951	15.89	0.80
9286	5945	15.00	1.30
9289	5940	14.61	1.30
9293	5935	14.05	1.35
9296	5931	13.19	1.30
9299	5927	12.74	1.25
9302	5926	12.58	0.40
9305	5924	12.33	0.40
9308	5923	11.71	0.50
9310	5921	11.14	0.30
9312	5920	11.97	0.40
9315	5918	11.03	1.10
9321	5916	10.74	0.70
9326	5916	8.99	0.80
9329	5913	8.09	0.80
9333	5911	8.01	0.30
9339	5914	6.77	0.40
9338	5930	9.39	0.80
9340	5929	9.64	0.40
9344	5928	9.17	0.80
9347	5927	8.88	0.40
9352	5927	10.73	0.65
9355	5926	9.83	0.60
9358	5926	8.89	0.80
9364	5925	8.68	0.55
9369	5924	7.87	0.55

FIG. 4 - 1 L. LAUDALE

7401	6052	8.12	
7401	6047	8.46	
7401	6042	8.79	
7401	6037	9.94	
7400	6032	10.25	
7399	6027	10.69	
7398	6023	11.01	
7397	6020	12.78	
7395	6017	14.09	
7392	6014	16.41	
7390	6012	17.55	
7390	6010	18.52	
7389	6008	19.49	
7388	6007	20.73	
7404	6002	19.04	1.00
7409	6002	17.89	1.05
7412	6002	17.88	1.50
7417	6002	15.88	2.15
7422	6002	15.25	2.00
7427	6002	14.31	2.20
7432	6002	13.76	2.80
7437	6002	12.92	3.00
7442	6002	15.47	0.50
7446	6002	14.56	0.90
7450	6002	14.03	
7453	6002	11.00	0.80
7459	6002	10.35	0.75
7463	6002	10.02	0.30
7467	6002	9.28	0.40
7470	6002	8.39	0.35
7474	6002	7.77	

FIG. 4 - 1 O. SHIEL

7549	6821	18.44	0.6	+
7548	6824	18.49	0.3	
7548	6828	18.93	0.3	
7548	6832	19.76		
7551	6835	19.55	0.3	
7552	6838	20.50	0.2	
7552	6840	19.94	0.5	
7552	6843	19.64	0.4	
7552	6856	11.54	1.0	
7552	6849	18.08	2.0	
7552	6851	19.23	2.0	
7552	6853	20.39	0.8	
7553	6857	20.79	0.3	
7552	6799	17.82	0.3	
7550	6797	15.81	3.0	
7548	6796	15.65	3.0	
7546	6794	17.69	0.3	
7543	6792	16.94	0.9	
7525	6849	20.74	0.3	
7524	6847	18.81	1.0	
7506	6796	13.84	1.0	
7507	6794	14.04	1.0	
7417	6863	15.98		
7424	6865	14.33	2.3	
7431	6866	13.88	2.5	
7438	6868	15.14	1.5	

APPENDIX B

CHEMICAL DATA

NOTES.

This appendix lists the results of the chemical analysis of the core LS3 from Loch Shiel (Chapter 8).

1. Sample depth is given in centimetres below the mud-water interface in the core tube.

2. Chemical results are expressed as a percentage weight of the oxide.

Sample Depth (cm)	Na	Mg	Al	Si	P
40	1.820	2.05	14.86	59.00	.681
60	1.808	2.27	15.27	59.20	.67
80	1.724	2.26	14.82	56.50	.715
100	2.740	3.34	13.62	55.90	.488
120	2.760	3.24	13.38	56.25	.488
140	2.960	3.35	13.72	56.55	.497
160	2.517	3.81	13.56	57.20	.455
180	2.700	3.42	13.83	56.40	.433
200	2.760	3.30	13.50	56.42	.463
220	2.908	3.37	13.42	54.30	.455
240	2.941	3.40	14.42	58.60	.487
260	2.894	2.90	12.62	58.40	.467
280	2.446	2.73	11.50	47.80	.410
300	2.975	3.55	14.12	58.25	.483
320	2.237	2.63	11.42	46.10	.374
340	3.080	3.63	14.48	59.20	.452
360	2.723	2.92	11.66	47.20	.384
380	2.455	2.71	11.36	46.30	.387
400	2.360	2.63	11.10	45.00	.363
420	2.564	2.60	11.15	51.00	.430
440	2.968	2.96	12.13	50.55	.620
460	2.812	2.90	11.62	49.50	.617
480	2.675	3.07	12.60	49.90	.482
500	2.540	2.87	12.25	50.80	.445
520	2.692	3.00	12.15	48.65	.414

Sample Depth (cm)	K	Ca	Ti	Mn	Fe
40	1.87	1.60	.91	.384	15.80
60	2.07	1.78	.99	.325	15.33
80	1.85	1.72	.90	.298	16.78
100	2.50	2.90	.54	.180	18.02
120	2.73	2.70	.61	.123	18.56
140	2.42	3.12	.60	.144	16.94
160	2.72	3.10	.60	.112	15.85
180	2.38	2.90	.60	.143	16.66
200	2.58	3.21	.60	.120	16.86
220	2.40	3.18	.59	.144	16.54
240	2.56	3.64	.61	.132	18.27
260	2.04	2.31	.59	.298	17.28
280	2.25	2.30	.48	.124	15.55
300	2.47	3.25	.62	.121	17.73
320	2.10	2.60	.47	.107	12.94
340	2.43	3.00	.63	.169	18.02
360	2.04	2.76	.47	.102	14.21
380	2.06	2.60	.46	.118	13.67
400	1.88	2.70	.43	.109	13.85
420	1.74	2.00	.48	.283	15.13
440	1.97	2.80	.51	.374	17.74
460	2.23	2.97	.56	.304	17.70
480	1.97	2.63	.51	.266	16.96
500	2.20	3.16	.53	.151	16.00
520	2.15	3.40	.49	.124	16.72

APPENDIX C

POLLEN COUNTS

NOTES

1. The actual number of pollen and spores recorded for each taxa at each level are given.

2. Sample depth is given in centimetres for Loch Shiel, measured from the top of the core tube. For Salen, depths are given in metres below ground level.

POLLEN COUNTS : SALEN.

No.	TAXA	2.136	2.181	2.218	2.155	2.291	2.328	2.364
1	ALNUS	1	-	-	-	-	-	-
2	BETULA	43	22	34	16	154	14	-
3	PINUS SYLVESTRIS	11	5	9	2	10	3	-
4	BETULA/CORYLUS/MYRICA	-	-	-	2	6	1	-
5	CORYLUS/MYRICA	1	-	-	1	10	-	-
6	SALIX	16	15	14	17	63	15	-
7	CALLUNA	-	-	3	-	-	-	-
8	EMPETRUM	66	68	55	9	8	16	31
9	ERICALES	47	28	10	7	19	19	-
10	ARMERIA	-	-	-	-	-	-	-
11	ARTEMISIA	-	-	1	-	2	-	9
12	CALTHA	1	-	-	-	-	-	-
13	CARYOPHYLLACEAE	1	-	-	1	1	-	1
14	CHENOPODIACEAE	1	-	-	1	-	-	-
15	CRUCEFERAE	35	41	16	42	47	60	-
16	CYPERACEAE	1	-	-	-	4	1	-
17	EPILOBIUM	-	-	1	1	-	-	-
18	FILIPENDULA	-	-	5	5	-	-	-
19	GALIUM	-	1	-	-	-	-	-
20	GRAMINEAE	141	97	69	18	58	27	-
21	HELIANTHEMUM	-	-	-	-	-	-	-
22	LABIATAE	-	-	-	-	-	-	-
23	LIGULIFLORAE	-	-	1	1	1	-	1
24	MATRICARIA TYPE	1	1	2	1	-	4	-
25	PAPILIONACEAE	1	-	-	-	-	-	-
26	PLANTAGO UNDIFF.	1	1	-	-	-	-	-
27	POTENTILLA	-	-	-	-	-	-	-
28	RANUNCULUS REPENS	1	-	-	-	-	1	-
29	RANUNCULLUS UNDIFF.	-	-	-	7	2	9	2
30	ROSACEAE	-	7	1	3	13	4	1
31	RUMEX ACETOSA	-	-	-	3	-	-	-
32	RUMEX ACETOSELLA	13	10	8	7	1	4	-

No.	2.421	2.567	3.310	3.486	3.617	3.663	3.679	3.695	3.710	3.726	3.742	3.758
1	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	50	-	-	2	41	35	8	35	64	65
3	-	-	12	-	2	6	14	7	2	4	3	6
4	-	-	-	-	-	-	2	-	-	-	5	2
5	-	-	-	-	-	-	-	-	-	-	-	-
6	-	1	10	-	-	4	14	12	4	12	22	14
7	-	-	-	-	-	-	-	-	-	-	11	-
8	231	71	166	173	108	78	222	142	76	159	175	214
9	-	-	-	-	-	2	2	2	-	1	7	1
10	-	-	-	-	-	-	1	-	-	-	-	1
11	-	-	-	-	-	-	3	2	22	6	3	1
12	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	1	2	-	1	1	1
14	-	-	-	-	-	-	-	3	-	-	1	-
15	4	-	114	6	97	216	227	133	30	118	66	65
16	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	1	1	-	-	-	-	-	1	-	-
18	-	-	-	-	-	-	1	-	-	3	3	2
19	-	-	-	-	-	-	-	-	-	-	-	-
20	7	5	192	9	14	28	140	171	44	132	87	111
21	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	3	2	-	-	-	-
24	-	-	-	-	-	1	7	1	-	3	1	-
25	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	1	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	1	-
29	-	1	-	2	-	-	-	-	1	2	2	1
30	-	-	-	-	-	-	2	3	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	1	1	1	1	2	-

No.	3.774	3.789	3.805	3.821	3.837	3.853	3.860	3.884	3.900	3.916	3.936	3.947
1	-	-	-	-	-	-	-	-	-	-	-	-
2	68	71	35	33	34	33	24	53	25	26	21	34
3	4	7	3	3	4	2	5	8	3	3	3	1
4	-	-	1	1	-	1	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-
6	2	10	12	2	10	3	19	18	25	28	13	22
7	6	8	-	-	1	3	3	6	-	-	-	1
8	178	98	172	102	193	165	174	231	164	65	59	13
9	5	2	1	1	-	2	-	-	-	-	1	1
10	-	-	-	-	-	1	1	-	2	4	-	-
11	1	-	3	2	6	1	6	14	8	8	1	6
12	-	-	-	-	-	-	-	-	-	-	-	-
13	3	-	-	-	1	-	-	-	2	5	-	1
14	-	-	2	1	-	-	-	-	-	2	4	1
15	62	62	62	88	67	72	114	87	94	49	-	49
16	1	-	-	-	-	-	2	-	1	-	-	-
17	-	-	-	-	-	-	1	-	-	1	-	-
18	6	4	6	6	2	-	4	-	-	-	-	1
19	-	-	-	-	1	-	-	-	-	-	-	-
20	101	-	116	117	133	95	96	43	35	45	-	39
21	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-
23	-	1	1	2	1	2	5	1	3	-	1	1
24	2	-	1	-	-	2	1	-	-	-	1	1
25	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	1	-	-	-	-	-	-	-	-	-
28	1	2	2	-	-	-	-	-	-	-	-	-
29	-	2	-	1	2	3	5	2	1	-	-	-
30	1	-	-	1	9	-	-	1	-	2	-	1
31	-	-	-	2	2	-	-	3	-	5	4	44
32	-	-	5	1	2	-	3	17	35	5	32	66

No.	TAXA	2.136	2.181	2.218	2.255	2.291	2.328	2.364
33	RUMEX UNDIFF.	4	4	10	10	6	6	-
34	SAXIFRAGA UNDIFF.	1	-	-	-	-	-	-
35	SOLIDAGO	-	-	-	-	-	-	-
36	THALICTRUM	-	1	3	1	-	-	-
37	UMBELLIFERAE	-	1	1	1	1	-	-
38	URTICA	1	2	1	1	1	3	-
39	VALERIANA OFFICINALIS	-	-	-	1	-	1	-
40	JUGLANDACEAE	1	-	-	-	-	-	-
41	ATHYRIUM ALPESTRE	1	10	5	1	1	3	-
42	DRYOPTERIS CARTHUSIANA	-	2	2	1	-	-	-
43	DRYOPTERIS FELIX-MASS	4	39	11	13	8	-	-
44	EQUISETUM	-	-	-	-	-	-	-
45	FILICALES UNDIFF.	7	2	4	2	5	1	-
46	LYCOPODIUM ALPINUM	1	-	-	-	-	-	-
47	LYCOPODIUM CLAVATUM	1	-	-	-	-	2	-
48	LYCOPODIUM INUNDATUM	1	-	-	1	-	-	-
49	LYCOPODIUM SELAGO	1	3	7	10	2	7	-
50	LYCOPODIUM UNDIFF.	1	-	-	-	-	2	-
51	SPHAGNUM	-	-	-	-	-	-	-
52	POLYPODIUM VULGARE	4	7	7	10	1	1	-
53	POLYPODIACEAE	102	194	239	61	103	50	2
54	PTERIDIUM AQUILIUM	1	-	-	-	-	-	-
55	SELAGINELLA SELAGINOIDES	-	6	1	-	-	1	-
56	MYRIOPHYLLUM ALTERNIFLORUM	45	39	69	157	58	64	-
57	MYRIOPHYLLUM UNDIFF.	3	15	11	11	14	2	-
58	NYMPHEA	-	-	-	-	-	-	-
59	POTAMOGETON	19	8	13	22	7	15	-
60	TYPHA LATIFOLIA	-	-	-	-	2	-	-
61	INDETERMINATE CONCEALED	24	16	13	18	16	4	29
62	INDETERMINATE CORRODED	-	-	-	2	-	-	-
63	INDETERMINATE CRUMPLED	7	1	-	3	4	2	10
64	INDETERMINATE DEGRADED	-	-	-	-	1	1	-

p189 does not exist.

No.	2.421	2.567	3.310	3.486	3.617	3.663	3.679	3.695	3.710	3.726	3.742	3.758
33	-	-	14	1	-	1	2	5	2	7	7	5
34	-	-	4	-	-	-	1	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	-	-	-
36	-	-	-	-	-	-	5	-	-	2	3	-
37	-	-	1	-	-	-	-	-	-	10	4	-
38	-	-	-	1	-	-	-	-	-	1	2	1
39	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	1	-	-	1	1
42	-	-	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	6	-	2	5	15
44	-	-	-	-	-	-	2	-	-	-	-	-
45	-	-	-	-	-	3	2	5	3	1	1	-
46	-	-	-	-	-	4	-	2	-	-	-	-
47	-	-	4	-	-	-	1	2	-	-	-	-
48	-	-	-	-	1	-	-	-	-	-	-	-
49	62	48	52	20	8	105	76	23	44	44	32	33
50	-	-	-	-	-	-	-	-	-	-	-	-
51	-	-	-	-	-	-	-	-	-	-	-	-
52	-	-	-	-	-	4	3	1	9	1	2	2
53	38	-	56	20	-	-	-	-	-	-	-	-
54	-	-	-	-	-	-	-	-	-	-	-	-
55	-	1	6	-	-	6	15	8	-	5	-	4
56	-	-	12	-	-	-	11	25	6	12	16	18
57	-	-	-	-	-	-	2	5	-	6	-	1
58	-	-	-	-	-	-	1	-	-	-	-	-
59	-	-	-	-	-	-	-	-	-	-	1	-
60	-	-	-	-	-	-	-	-	-	-	-	-
61	21	-	3	61	23	12	1	10	20	9	9	3
62	-	1	-	-	-	6	2	1	-	2	4	-
63	16	-	4	72	7	18	15	6	36	-	1	1
64	-	-	-	-	-	2	-	-	-	-	-	-

No.	3.774	3.789	3.805	3.821	3.837	3.853	3.860	3.884	3.900	3.916	3.936	3.947
33	5	5	2	7	7	7	4	8	7	-	28	40
34	-	-	-	-	-	-	-	-	-	-	36	-
35	-	-	-	-	-	-	2	-	-	-	-	-
36	1	2	2	2	1	1	1	1	2	1	2	-
37	-	1	1	5	1	-	3	-	1	-	1	-
38	1	-	1	1	-	2	-	2	2	1	-	-
39	-	-	-	-	-	-	-	-	-	1	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-
41	1	-	2	1	-	-	-	-	-	-	-	-
42	-	-	-	-	-	-	-	-	-	-	-	-
43	4	17	13	11	2	-	-	-	2	2	4	5
44	-	-	-	-	-	-	-	-	-	-	-	-
45	2	-	4	5	-	-	2	-	3	-	4	3
46	-	-	-	-	-	-	-	-	1	-	6	-
47	-	-	-	1	-	1	-	1	-	-	-	-
48	-	-	-	1	-	-	-	-	-	-	-	-
49	18	21	21	29	29	40	56	56	97	-	88	84
50	-	-	-	-	-	-	-	-	-	-	-	-
51	10	-	-	-	-	-	-	-	-	-	-	-
52	2	4	4	1	3	-	3	4	3	6	1	3
53	-	-	78	76	78	65	60	89	90	109	131	116
54	-	-	-	-	-	-	-	-	-	-	-	-
55	2	2	1	1	2	-	1	-	-	-	1	-
56	9	18	18	9	9	14	4	14	15	2	4	6
57	4	-	2	2	-	1	2	3	3	1	-	2
58	-	-	-	-	-	-	-	-	-	-	-	-
59	1	-	-	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	2	1	-	-	-
61	5	8	6	2	2	4	7	3	1	3	6	8
62	-	3	8	-	-	1	-	4	-	5	-	-
63	1	-	4	4	4	2	1	2	1	1	2	2
64	-	-	-	-	-	-	-	-	-	-	-	-

POLLEN COUNTS : LOCH SHIEL.

No.	TAXA	90	100	110	120	130	140	150
1	BETULA	109	119	114	125	141	131	62
2	ALNUS	140	133	89	96	136	139	76
3	FRAXINUS	-	-	-	-	-	-	-
4	PINUS	2	2	3	1	5	5	12
5	QUERCUS	11	11	8	-	31	28	20
6	TILIA	-	-	-	-	-	-	1
7	ULMUS	15	9	8	-	3	1	-
8	CORYLUS	140	91	53	95	111	147	125
9	EMPETRUM	-	10	-	2	-	-	1
10	ERICACEAE	93	87	50	45	8	41	48
11	ILEX	2	-	-	2	1	-	1
12	SALIX	6	6	7	8	7	12	8
13	ARTEMISIA	-	-	-	1	-	1	-
14	CARYOPHILACEAE	1	1	3	3	-	-	-
15	CHENOPODIACEAE	-	-	-	-	-	-	-
16	COMPOSITAE	6	4	22	3	7	3	2
17	CRUCIFERAE	-	-	-	-	-	-	-
18	CYPERACEAE	120	144	154	104	63	38	82
19	EPILOBIUM	-	-	-	-	-	-	-
20	FILIPENDULA	6	9	-	-	-	-	-
21	GALIUM	1	-	-	-	-	-	-
22	GRAMINEAE	80	134	163	199	222	225	202
23	HELIANTHEMUM	3	-	-	-	-	-	-
24	LABIATAE	2	-	-	-	-	-	-
25	LEGUMINOSA	-	-	2	5	4	-	-
26	PLANTAGO LANCEOLATA	-	-	-	-	-	1	-
27	PLANTAGO UNDIF.	-	-	-	20	4	5	4

No.	160	170	180	190	200	210	220	230	240	250	260	270
1	86	74	103	108	148	96	153	167	122	96	133	227
2	129	110	109	102	103	100	109	106	99	150	133	150
3	-	-	-	-	-	1	-	0	3	1	3	7
4	9	15	12	15	16	17	8	13	10	9	10	8
5	16	27	30	37	40	50	46	64	27	19	32	64
6	-	-	-	-	-	-	-	-	-	-	-	-
7	-	2	-	15	9	18	12	6	2	5	1	6
8	139	88	108	109	106	102	103	79	88	78	103	137
9	1	3	-	1	-	1	-	3	-	2	-	-
10	36	32	45	41	45	34	37	33	30	-	15	16
11	2	1	0	3	2	3	5	3	-	1	-	2
12	6	8	3	-	-	-	-	-	-	-	-	-
13	1	-	-	2	-	1	-	-	-	1	-	-
14	-	-	-	-	-	-	-	-	-	-	2	-
15	-	-	-	-	-	-	-	-	-	-	-	-
16	-	2	1	1	-	1	2	-	-	2	-	1
17	1	3	0	4	2	2	-	1	-	3	-	2
18	51	45	47	35	28	26	27	26	27	27	32	20
19	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-
22	210	239	221	181	198	237	240	110	260	189	190	95
23	-	-	-	-	-	-	-	1	1	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	2	1	1	-	-	2
26	-	-	1	-	-	-	-	-	-	-	-	3
27	1	4	3	5	3	-	4	1	4	2	8	5

No.	280	290	300	310	320	330	340	350	360	370	380	390
1	106	114	245	213	90	153	180	157	165	149	255	188
2	178	179	152	209	176	173	138	217	179	198	176	192
3	4	4	5	-	-	-	-	-	20	1	-	-
4	6	8	9	10	11	7	6	13	11	5	13	13
5	60	62	24	33	40	59	30	43	39	34	40	38
6	-	-	-	-	-	-	-	-	-	-	-	-
7	4	1	5	7	4	3	2	2	5	3	4	1
8	124	127	113	123	129	128	73	118	129	104	122	92
9	1	1	-	-	-	-	-	-	-	-	-	-
10	18	23	9	11	21	10	10	10	11	13	10	13
11	-	-	7	2	1	1	-	-	-	-	-	-
12	-	3	7	1	1	1	4	-	4	1	2	-
13	1	-	-	-	1	-	-	-	-	-	-	-
14	-	1	-	-	1	-	-	-	-	-	-	-
15	-	2	-	1	1	6	-	-	2	1	1	1
16	-	-	-	-	-	-	-	-	-	2	3	1
17	2	1	6	-	3	2	-	1	1	-	3	4
18	28	24	28	28	25	22	21	22	28	20	20	19
19	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-
22	146	129	106	78	113	114	34	92	80	91	62	63
23	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-
25	1	2	-	1	1	-	-	1	5	1	1	4
26	-	-	-	-	-	-	-	-	-	1	-	1
27	6	6	1	1	6	7	-	-	2	2	3	2

No.	400	410	420	430	440	450	460	470	480	490	500	510
1	168	188	194	148	169	152	131	139	183	128	152	124
2	180	165	239	146	161	191	186	150	151	154	154	196
3	-	-	-	-	-	-	-	-	-	-	-	-
4	11	6	6	24	29	18	26	76	34	23	28	33
5	67	32	60	24	16	12	55	36	37	22	22	58
6	-	-	-	-	-	-	-	-	-	-	-	-
7	3	3	4	2	7	5	3	3	5	2	3	7
8	94	92	98	79	80	112	86	81	91	73	94	104
9	-	-	-	-	-	-	4	-	-	-	-	-
10	21	13	13	8	2	11	11	13	9	10	14	11
11	-	-	-	-	-	-	-	2	2	3	-	1
12	3	4	3	1	1	4	6	3	4	3	3	3
13	-	-	-	-	-	1	-	-	1	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-
15	1	-	-	2	-	-	1	-	1	-	7	3
16	1	-	-	2	2	-	-	-	2	-	-	-
17	2	1	-	2	1	3	-	3	-	2	-	-
18	19	18	20	15	16	16	33	21	24	18	22	19
19	-	-	-	-	-	-	-	-	-	1	1	-
20	-	-	-	-	-	-	-	4	-	1	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-
22	83	64	68	78	78	68	67	64	25	66	56	70
23	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-
25	2	2	-	-	-	2	-	1	1	-	1	1
26	-	1	1	-	-	-	-	-	-	-	-	-
27	1	-	1	-	2	1	4	-	1	-	-	-

No.	520	530	540	550	560	570	580	590	600
1	106	164	154	139	134	167	150	-	-
2	168	164	180	157	166	175	185	176	159
3	-	-	-	-	-	-	-	-	-
4	30	19	22	21	29	26	22	31	32
5	34	42	42	44	52	44	45	56	45
6	-	-	-	-	-	-	-	-	-
7	2	3	1	4	4	4	2	1	2
8	75	70	81	80	88	85	87	118	92
9	-	-	-	-	-	-	-	-	-
10	9	8	12	13	8	7	10	9	8
11	1	-	-	-	1	-	-	2	1
12	3	6	2	1	3	1	1	5	2
13	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-
15	1	-	-	6	1	2	-	1	-
16	-	-	-	-	-	1	1	2	0
17	1	1	-	-	3	-	1	-	-
18	16	16	15	18	15	16	5	5	16
19	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-
22	54	56	63	55	75	53	25	45	53
23	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-
25	1	1	2	-	1	1	2	3	2
26	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-

No.	TAXA	90	100	110	120	130	140	150
28	POTENTILLA	3	4	1	9	10	9	2
29	RANUNCULACEAE	1	-	14	29	22	8	3
30	ROSACEAE	2	6	3	1	1	12	6
31	RUMEX ACETOSA	-	-	84	-	-	-	-
32	RUMEX ACETOSELLA	-	-	26	-	-	-	-
33	RUMEX UNDIF.	-	-	-	4	4	5	-
34	SAXIFRAGACEAE	-	-	-	-	-	-	-
35	SUCCISA	4	6	-	-	1	2	1
36	UMBELLIFERAE	6	1	-	-	-	-	1
37	URTICA	-	-	-	4	12	9	3
38	VALERINA	-	-	-	-	-	-	-
39	MENYANTHES	-	-	-	-	-	-	-
40	MERIOPHILUM UNDIF.	-	-	-	-	-	-	-
41	NYMPHAEA	1	-	-	-	-	-	-
42	POTAMOGETON	1	-	-	-	-	-	-
43	TYPHA UNDIF.	-	-	-	-	-	-	-
44	DRYOPTERIS	-	-	-	-	-	-	-
45	FILICALES	143	96	75	109	106	106	111
46	LYCOPODIUM	10	-	1	-	-	-	-
47	SELAGINELLA	-	2	-	2	-	1	-
48	SPHAGNUM	49	30	4	-	-	-	7
49	PTERIDIUM	4	-	4	5	-	4	4
50	POLYPODIUM VULGARE	-	-	8	8	8	6	14
51	OSMUNDA	-	-	2	-	-	-	-
52	INDETERMINATE	3	-	4	9	4	1	76
53	PRE-QUATERNARY	9	-	1	2	5	4	1

No.	160	170	180	190	200	210	220	230	240	250	260	270
28	-	3	9	3	1	2	1	4	2	4	3	1
29	15	12	11	7	11	6	13	9	-	11	11	8
30	8	8	7	9	6	3	11	3	7	5	4	7
31	-	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-	-
33	24	4	4	4	4	5	6	6	3	1	6	6
34	-	-	-	-	-	-	-	-	-	-	-	-
35	-	1	2	2	-	1	-	-	2	-	-	-
36	-	1	2	2	-	1	-	-	2	-	-	-
37	9	6	3	1	12	4	2	7	2	3	5	-
38	-	-	-	1	1	2	-	-	-	1	1	-
39	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	-	-	-	-	-
42	-	-	-	-	-	-	-	-	-	1	-	2
43	1	-	1	-	-	-	-	-	-	-	-	3
44	-	-	-	-	-	-	-	-	-	-	-	-
45	148	141	137	117	145	135	133	126	180	254	230	128
46	2	-	2	-	-	1	-	1	1	2	2	0
47	-	-	1	1	-	1	-	0	1	2	1	0
48	9	4	9	20	15	7	7	73	17	14	8	8
49	-	3	-	-	-	-	2	-	1	-	-	-
50	14	3	12	16	10	7	3	5	7	18	10	6
51	-	-	-	1	1	2	1	1	-	3	3	8
52	3	23	6	16	15	17	-	-	-	5	2	4
53	-	1	-	4	-	-	-	-	1	-	1	-

No.	280	290	300	310	320	330	340	350	360	370	380	390
28	-	5	2	-	1	2	1	1	3	1	1	-
29	7	9	7	10	6	6	1	8	4	-	6	5
30	6	6	4	4	6	6	6	4	4	4	1	1
31	-	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-	-
33	16	11	33	8	5	6	23	11	17	10	6	13
34	-	-	-	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	1	-	-
36	-	-	-	-	1	1	3	-	-	1	1	-
37	-	-	2	-	-	1	-	-	-	-	-	-
38	-	1	-	1	2	1	-	-	-	-	-	-
39	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-
41	-	-	-	4	1	-	-	3	4	1	3	-
42	-	-	-	4	1	-	-	3	4	1	3	-
43	-	-	1	-	1	-	1	2	1	1	-	-
44	-	-	-	2	1	-	-	-	-	-	-	-
45	199	196	142	126	208	141	120	120	144	186	115	194
46	1	-	-	-	-	-	-	-	-	-	-	1
47	-	-	-	-	-	-	-	-	-	-	-	-
48	13	9	12	3	10	4	12	8	11	12	7	8
49	-	-	-	-	4	31	2	2	9	13	3	13
50	11	15	2	9	7	7	13	10	2	6	5	12
51	5	-	1	3	2	3	-	12	6	1	-	2
52	-	14	-	-	3	8	37	7	9	6	3	3
53	-	-	-	-	-	-	-	-	1	-	2	-

No.	400	410	420	430	440	450	460	470	480	490	500	510
28	2	7	2	1	1	1	5	2	1	2	-	2
29	7	11	8	7	4	4	7	17	-	2	4	-
30	2	3	4	2	4	4	-	-	16	1	1	2
31	-	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-	-
33	24	16	14	16	19	22	6	26	18	24	14	18
34	-	-	1	1	-	-	-	-	-	-	-	-
35	-	-	-	1	1	-	-	1	-	-	-	-
36	-	-	2	1	-	-	-	-	1	1	-	-
37	-	-	-	3	2	-	-	-	-	1	-	-
38	-	-	-	1	-	-	-	-	2	1	-	-
39	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	17	13	5
41	-	4	2	1	-	-	-	-	-	-	-	-
42	-	4	2	1	-	-	-	-	-	17	13	5
43	-	-	-	-	-	-	-	-	-	-	-	-
44	-	-	-	-	-	-	-	-	1	-	-	-
45	164	174	133	249	234	234	96	118	99	145	111	114
46	1	-	-	-	-	1	-	-	-	-	-	1
47	-	1	-	1	1	-	-	-	-	3	1	3
48	13	13	14	17	11	16	9	10	8	12	20	14
49	4	6	3	2	1	1	4	1	-	-	2	3
50	5	6	-	11	17	15	4	6	9	7	10	13
51	-	2	-	5	7	-	1	3	4	2	3	2
52	4	20	4	7	4	5	2	-	32	8	8	6
53	-	-	-	-	-	-	-	-	-	-	-	-

No.	520	530	540	550	560	570	580	590	600
28	2	2	1	2	3	2	-	1	1
29	-	-	-	-	-	-	-	-	-
30	-	-	2	-	1	-	2	10	-
31	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-
33	14	25	8	17	11	21	18	16	12
34	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-
36	2	-	1	1	-	-	-	-	-
37	-	1	1	-	-	-	-	-	1
38	1	-	1	-	1	1	-	2	-
39	-	-	-	-	-	-	-	-	-
40	4	-	5	-	1	6	1	-	-
41	-	-	-	-	-	-	-	-	-
42	4	-	5	-	1	6	1	-	-
43	-	-	-	-	-	-	-	-	-
44	-	-	-	-	-	-	-	-	-
45	153	160	201	164	131	208	198	104	135
46	-	-	-	-	-	-	-	-	-
47	3	1	1	2	-	4	-	1	3
48	13	12	6	5	13	3	6	29	3
49	1	-	2	-	-	-	-	-	-
50	12	8	11	7	5	7	7	7	12
51	4	-	2	1	4	-	1	-	1
52	2	2	2	5	5	3	5	53	4
53	-	-	-	-	-	-	-	-	-

APPENDIX D

PUBLICATION :

'Palaeomagnetic and stratigraphic study of the Loch Shiel marine regression and overlying gyttja'

by

R. THOMPSON & T. WAIN-HOBSON

Journal of the Geological Society, Volume 136, part 3, p.p. 383 - 388. (published May 1979).

Palaeomagnetic and stratigraphic study of the Loch Shiel marine regression and overlying gyttja

R. THOMPSON & T. WAIN-HOBSON

Reprinted from the
JOURNAL OF THE GEOLOGICAL SOCIETY
vol. 136 part 3, pp. 383–388
(published May 1979)

Jl geol. Soc. Lond. Vol. **136**, 1979, pp. 383–388, 4 figs, 1 table. Printed in Northern Ireland.

Palaeomagnetic and stratigraphic study of the Loch Shiel marine regression and overlying gyttja

R. Thompson & T. Wain-Hobson

SUMMARY: Palaeomagnetic, chemical and pollen analyses have been carried out on cores 6 m long from the SW basin of Loch Shiel, Scotland. A marine regression in one core is dated at 4200 C^{14} years BP. Palaeomagnetic declination and inclination variations in the limnic gyttja are interpreted as reliable records of ancient geomagnetic field changes. Comparison with 4 other British limnic palaeomagnetic sites indicates that systematic errors in C^{14} age determinations have been caused in many of the sites by inwash of old soils and peats. The inwash effect is suggested to have been more pronounced and to have started significantly earlier in England than previously documented. Palaeomagnetic direction correlations and transference of C^{14} age determinations from the palaeomagnetic master curve described, can help overcome these dating difficulties.

The earliest palaeomagnetic investigations of British Holocene geomagnetic secular variations were carried out on Postglacial gyttja from the lakes of the English Lake District. C^{14} age determinations on the gyttjas allowed a chronology of fluctuations in direction of the geomagnetic field to be erected (Mackereth 1971). Piston cores, up to 6 m long, were extracted from the bed of Loch Shiel, NW Scotland, firstly to compare their magnetic remanence with the English records, and secondly as part of a project on the vegetational and raised shoreline history of part of NW Argyll. C^{14} dating of the palaeomagnetic direction variations in the Shiel limnic gyttja confirms their origin as records of ancient geomagnetic secular changes and permits refinement of the original Lake District chronology.

Coring sites

Loch Shiel separates the district of Moidart from Ardnamurchan and Ardgour in the NW Highlands of Scotland. The loch surface is 3.5 m above sea level, 27 km long, and up to 1.5 km wide. Its deepest point is 125 m below sea level, and its surface is 870 m below the highest surrounding hills. At Polloch the loch turns westwards into a large, broad basin. This southwesterly basin is floored and almost completely filled by fluvio-glacial sands and gravels upon which an extensive bog has developed, Claish Moss. The whole of the Shiel basin was occupied by the ice of the Loch Lomond readvance, with a limit at its western end (McCann 1966). Two coring sites were chosen in regions of low bottom surface gradient. Cores 1 and 2 were taken in a central, open area at a water depth of 25 m, 0.5 km SW of Dalelia Pier. Core 3 was taken at a more marginal site. The water depth at this second site, 1.5 km off Dalelia Pier, was 15 m. All cores were taken in 6 m long UPVC liners using a pneumatic piston corer (Mackereth 1958).

0016-7649/79/0500–0383$02.00

Palaeomagnetic methods and instrumentation

Whole-core magnetic scanning was carried out on-line to a 4K micro computer using apparatus developed by Thompson and Molyneux (Molyneux *et al.* 1972; Molyneux & Thompson 1973). This magnetic scanning established the magnetic stratigraphy and palaeomagnetic chronology. The core with the longest limnic sequence (core 3) was then chosen for more detailed studies. It was sliced lengthwise, one half being subsampled for further palaeomagnetic studies and the other half used for palynological, chemical, and C^{14} analyses. The palaeomagnetic subsamples were taken perpendicular to the slice using plastic 'cubic' holders of sides 20×20×17 mm. A 'digico' low-noise, ring, fluxgate magnetometer was used to measure the remanence of the individual subsamples. Reversible, initial susceptibility was measured with an air cored coil susceptibility bridge. Partial alternating field demagnetization was performed using a transistorized optical ramping system (De Sa & Widdowson 1975) modified with an active filter.

Core correlations, magnetic intensity, and susceptibility variations

The whole-core horizontal intensity logs of cores 1 and 3 (Fig. 1) contain a pronounced double peak (numbered 1 and 2) followed by an intensity minimum and a rapid rise to peak 3. Peaks 1 and 2 lie at 220 and 160 cm, and the rise at 120 cm in core 1. In core 3 the depths of the features are 330, 270, and 230 cm (Fig. 1), showing a displacement of 110 cm. Similarly, whole-core susceptibility records show a correlative

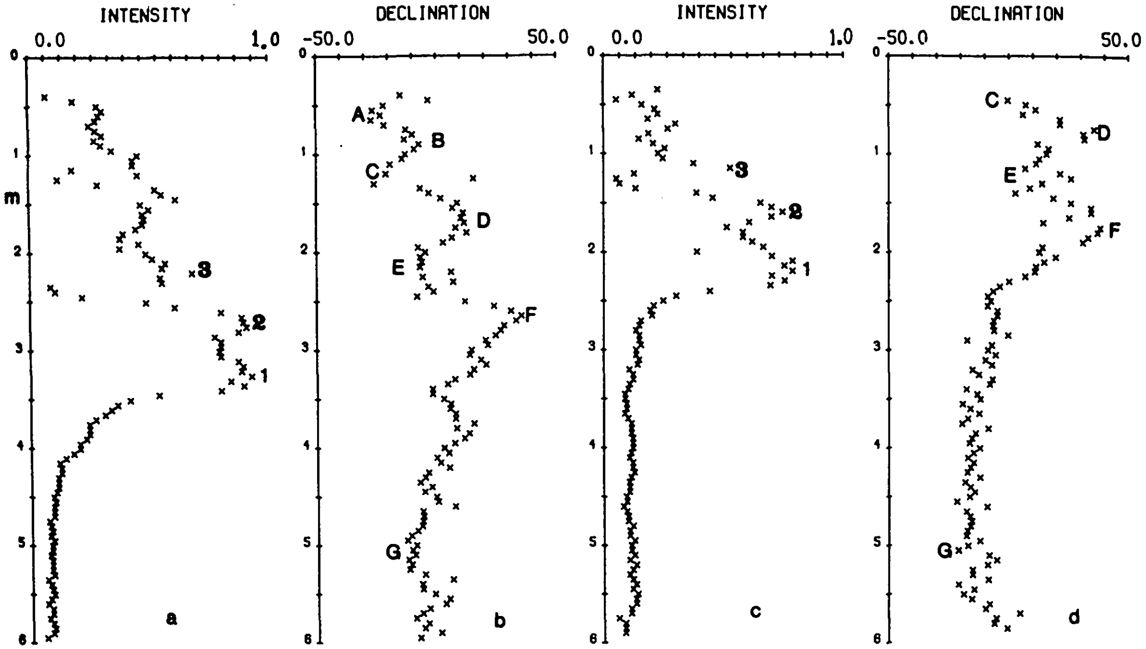

FIG. 1. Whole-core horizontal intensity (a, c) and relative declination (b, d) logs for cores 1 (c, d) and 3 (a, b). Turning points *A–G* discussed in text. Mean declination set to zero. Intensity range in 10^{-1} Am^{-1}.

broad double peak followed by low values, then an abrupt rise (Fig. 3).

The mud/water interface lies at about 40 cm in both core tubes. (Note depths in text and diagrams refer to depth in core tube, rather than depth below mud/water interface). Core 1 contains a compressed upper record but a longer, older sequence. Core 3 with the longer and more detailed upper succession was thus chosen for palynological, chemical and further magnetic analyses.

Stratigraphy and the pollen record

Core 3 contains 540 cm of undisturbed sediment and has two major stratigraphic sections. From 600 to 400 cm the dark brown organic mud has an abundance of *in situ* shells of *T. flexonosa*, a species which presently inhabits sandy muds around the British Isles between depths of 11–180 m (Tebble 1966). This marine sediment is lithologically homogeneous, and with the exception of the shells is very similar to the overlying lacustrine sediment. There is a lithologically clear boundary at 400 cm which marks the marine regression. The overlying sediment is again homogeneous. Fine silt is disseminated in the sediment at depths of 350–360, 200, and 160–180 cm. From 180 to 60 cm the sediment is a dark brown, flocculated organic mud, with occasional fine-grained mica fragments. The top 20 cm of sediment is very disturbed, and the true mud/water interface is difficult to recognize, but is estimated to lie near 40 cm below the top of the core tube.

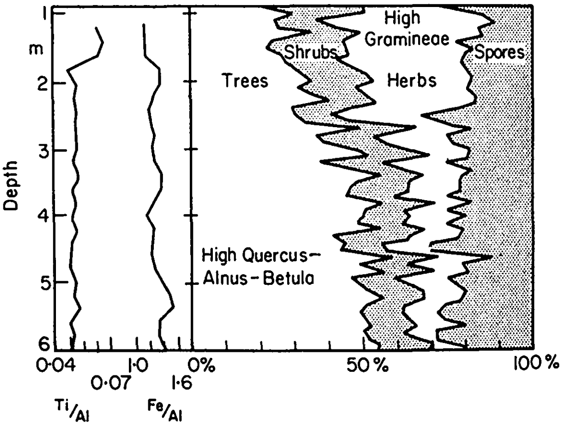

FIG. 2. Summary diagram of pollen and chemistry for core 3, Loch Shiel. Depths measured from top of core tube.

An absolute pollen diagram has been constructed from the analysis of samples taken at 52 levels and it shows two major pollen zones (Fig. 2).

Pollen zone 1 (600–260 cm)

This represents a complex period, but with a fairly constant input of the major pollen components. High

Betula and *Quercus* values reflect the mixed oak woodlands of the surrounding hills. Comparison with a complete Postglacial pollen diagram from the adjacent Claish Moss (Moore 1977) suggests that this zone represents a series of forest clearances, after the elm decline.

There is no indication in the fossil record of the change from a marine to freshwater environment. This may reflect the lack of suitable locations for saltmarsh development. Moore (1977) does not find any evidence of a marine transgression across Claish Moss, though shorelines along the margin of the loch suggest that part of the Moss should have been inundated by the Postglacial sea. Peat accumulation may have been sufficiently rapid for it to have kept pace with the rising sea level. This situation would have been analogous to that of Flanders Moss in the Forth Valley (Sissons & Smith 1965).

Pollen zone 2 (260–80 cm)

This zone is marked by a fall in tree pollen and a rise in non-arboreal pollen values, especially *Gramineae*, *Cyperaceae*, *Plantago* spp, and *Ericaceae*. Extensive forest clearance is indicated in this zone.

Chemical changes (Fig. 2) are minimal down the core, suggesting that true marine conditions were never attained in Loch Shiel.

Radiocarbon age determinations

Five C^{14} age determinations (SRR-1143–1146, Table 1) were made by D. D. Harkness at the Reactor Centre, East Kilbride. The 5 samples were all taken from the limnic sediments to avoid erroneously old ages which could result from marine input of aged carbon. Two of the determinations show increasing apparent C^{14} age up the core (Fig. 3). The likeliest explanation of these anomalously old near-surface age determinations is the recycling of older carbon from soils and peat in the drainage basin (e.g. O'Sullivan *et al.* 1973). The pollen record for the section of anomalously old ages, 260–100 cm, indicates possible increased erosion of soil profiles associated with forest clearance. The lower two age determinations are potentially useful chronologically. They are compared below with palaeomagnetic age estimates and used with these palaeomagnetic declination oscillations to date the marine regression at 4200 years BP.

TABLE 1: C^{14} age determinations

Sample	Depth, cm	Age determination, Yr	$\delta^{13}C$,%
Core 3			
SRR-1143	165–175	2741±45	−27.1
SRR-1144	205–215	2484±40	−28.0
SRR-1145	265–275	2366±55	−28.3
SRR-1146	342–352	3471±100	−27.3
Core 1			
SRR-1210	346–356	3883±65	−24.0

Age determinations expressed as conventional C^{14} years BP at the ±1 σ confidence level.

Sea-level change

At present, Loch Shiel drains into the sea via the River Shiel over a waterfall with a threshold height of approximately 2.5 m. At high spring tides this fall is submerged and seals are able to swim up into the loch. Two raised shorelines, cut into fluvio-glacial gravels around the margins of the loch in the southern basin, imply that Loch Shiel must have been a sea loch for a considerable part of the Postglacial. The highest shoreline is at 10 m, which correlates with the main Postglacial shoreline in the area (Wain-Hobson, unpublished data), while the lowest shoreline is at approximately 3 m. Assuming that the main Postglacial transgression would have flooded the loch by about 6500 years BP (Sissons 1977), then a date for the regression of about 4200 years BP would not be unreasonable.

Palaeomagnetic record

Stability of natural remanence

In order for sediment to hold a true record of past geomagnetic field changes, the natural remanent magnetization (NRM) must have a coercivity considerably higher than typical earth field values (50 μT). Magnetization of low coercivity will not remain in the ancient field direction but will continually follow changes of the ambient field. Low coercivity may result from the movement of domain walls within magnetic grains or more simply from the physical rotation of small magnetic grains in the sediment. Alternating field (AF) demagnetization was performed on 16 pilot samples to test the stability of remanence. The median destructive field (MDF) varied between 12 and 55 mT. The natural remanence changed direction by less than 3° during partial demagnetization up to the MDF. The natural remanence is thus magnetically stable.

Between measurement of the NRM and AF demagnetization, the subsamples were stored in zero field in order to remove any viscous components. Varying amounts of remanence, from less than 10% up to 80%, were lost during storage while the directions of remanence remained constant. These losses were originally attributed to viscous magnetic behaviour, but are now thought to result predominantly from physical rotation of the magnetic grains with drying during storage as discussed in detail by Stober & Thompson (1977).

Magnetic declination

Clear oscillations with peak amplitude of 40–50° are labelled *A–G* in Fig. 1. The same oscillations can be

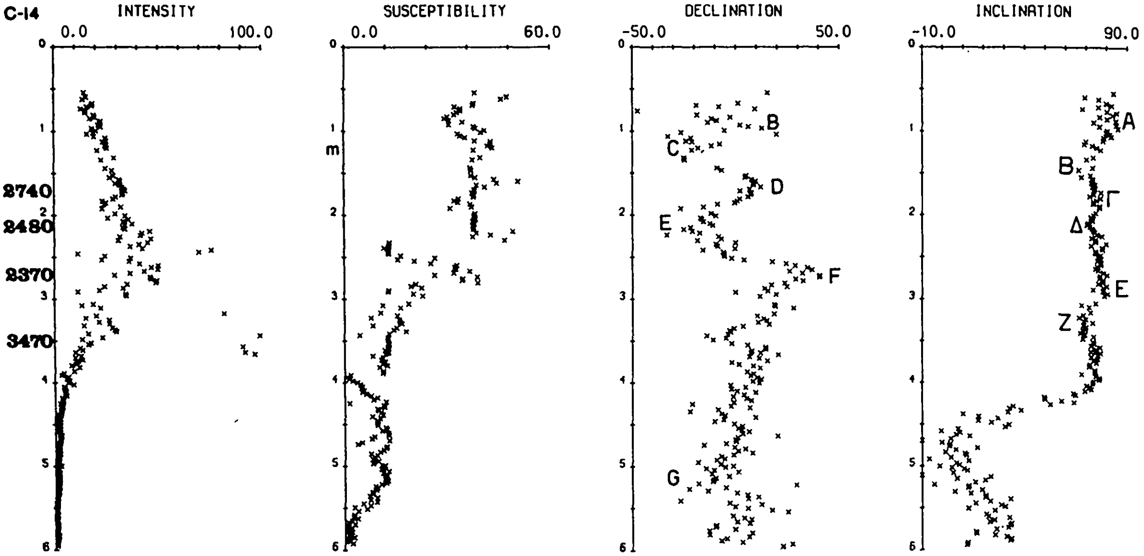

FIG. 3. Core 3. Single sample NRM intensity (10^{-3} Am^{-1}), initial susceptibility (SI units), relative declination, and inclination. Turning points *B–G* and *A–Z* discussed in text. Mean declination set to zero.

seen in each whole-core declination record. This repeatability gives confirmation that these oscillations are a reflection of past changes of the geomagnetic field. In the lower section of both cores, minimal changes in declination are found which suggests the marine sediments were deposited more rapidly than the limnic sequence above.

The declination record can be matched with other secular variation patterns from British lakes. Turning point *A* is interpreted as the AD 1815 westerly maximum known from historic records. *B* and *C* are the smaller fluctuations found at about 60 cm depth in Lake Windermere (*see* Thompson 1977, fig. 2). *D* is the Windermere turning point at 100 cm, *E* corresponds to a westerly maximum which is characteristically broad or double in a record of high deposition rate (as in Lough Neagh, Thompson 1973, fig. 3; Thompson 1975, fig. 4). Turning point *F* in contrast to *E* is sharp, often of large amplitude, and lies at 185 cm depth in Lake Windermere.

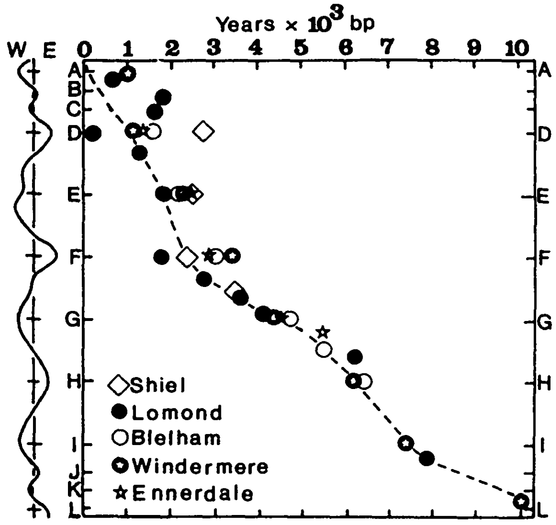

FIG. 4. Geomagnetic declination variations (*A–L*) *v*. conventional C^{14} age for 5 British lakes. Dashed line shows preferred ages of geomagnetic fluctuations as discussed in text.

Magnetic inclination

Inclination measurements were made on 219 subsamples from core 3. In the upper 414 cm of core 3 magnetic inclination varies by only 15° peak to peak and has a mean inclination of 75.4°. Fisher's α_{95} of these upper 138 measurements is 0.9°. The inclination expected on a time-averaged geocentric axial dipole model is 72.0°. The difference is probably due to non-vertical penetration of the corer. The oscillations *A* to *Z* (Fig. 3) although of low amplitude and only here shown from one core, show many similarities to the inclination record from 3 cores from Loch Lomond (Dickson *et al.* 1978; Turner & Thompson, in prep) and are likely to be a reflection of past field changes.

The lowest 1.5 m of the core shows markedly lower inclinations of around 10–20° (Fig. 3). Such palaeomagnetic records (Noel & Tarling 1975; Morner 1977; Abrahamsen & Knudsen 1977) have been interpreted as recording excursions of the geomagnetic field. Thompson & Berglund (1976) have argued that these Late Weichselian and Holocene low-inclination palaeomagnetic directions are more likely to be a result of sedimentary processes than a true reflection of the ancient magnetic field. It has been repeatedly demonstrated that the geomagnetic field was of normal polarity during the period 5000–3000 years BP (Mackereth 1971; Opdyke *et al.* 1972; Kovacheva & Veljovich 1977). The stable low-inclination remanence in Loch Shiel thus cannot be a true reflection of the ancient magnetic field. Remanence in recent fine-grained sediments is most probably a post-depositional remanent magnetization (PDRM) (Kent 1973; Lovlie 1974; Stober & Thompson 1977). The low inclinations correlate with marine deposition, suggesting that the structure of fabric of the sediment, related to the packing of clay minerals, can influence the stable PDRM. Interestingly, the declination is not markedly affected.

Promoters of recent excursions draw attention to the common occurrence of low-inclination, normal declination from European localities (Morner 1977) and interpret this direction as of geomagnetic significance. The Shiel record, however, demonstrates that this palaeomagnetic direction is not alone sufficient for determining a recent excursion and highlights the difficulties which can be encountered in shallow-water estuarine sediments.

Comparison with other British limnic palaeomagnetic sites

Figure 4 summarizes available palaeomagnetic declination data and conventional C^{14} age determinations from 5 British sites. Following Mackereth (1971) we plot the palaeomagnetic declinations as abscissa so that the major swings (*A, D, E, F, G, H, I, L*) lie at equal intervals. Mackereth suggested the oscillations in declination may be periodic. However, later work has revealed additional higher frequency changes in declination and no clear long-term periodic fluctuations in inclination. The interpretation of age determinations advanced here also leads to the declination cycles having markedly different lengths, particularly when a dendrochronology calibration is applied. The British geomagnetic field declination record is thus seen to be composed of a series of fluctuations of different frequencies but with a concentration of energy in the periods between 2500 and 3000 years.

The palaeomagnetic curves from Lochs Lomond and Shiel show more detail than do the original Windermere records. The greater resolution of these geomagnetic records probably results from the higher ratio of rate of deposition to rate of stabilization of remanence in Lomond and Shiel.

Recognition of the above fine geomagnetic detail permits a correlation, between the lake sediments investigated, which is based solely on the palaeomagnetic records. Thus a direct comparison of C^{14} age determinations can be made between lakes in geographically distinct regions. Such an exercise has not been possible previously for the post-Elm decline period, because of the lack of synchronous bio- or litho-stratigraphical horizons.

In most of the lakes studied apparently old C^{14} age determinations have been found near the top of the sediment profiles, i.e. increasingly older ages are found in stratigraphically younging sediments. In general, Quaternary research workers accept age determinations falling on a positive time–depth curve as reliable and only reject those on an inverted, negative time–depth curve.

C^{14} laboratory experimental errors (including errors due to the random disintegration of C^{14} atoms) are small (roughly equivalent to the size of the symbols in Fig. 4) compared to the between-lake discrepancies. Errors in matching the palaeomagnetic curves from lake to lake are also considered to be small, as extensive curves with high-frequency fine details are being correlated. The typical total random error involved can be best judged by the closeness of fit of the age/feature points in Fig. 4 to a smooth curve below turning point *F*. It follows that there must be additional large systematic errors influencing the C^{14} age determinations during the time range of fluctuations *F–D*.

We now consider which, if any, of the age determinations are useful in the range *F–D*. Discrepantly young ages could result from diffusion of young carbon down the core. A more plausible possibility would be contamination by young carbon due to smearing from wall friction during coring. This is unlikely to be a common problem, as Mackereth cores have an internal fixed piston, and laminated material shows only minor signs of smearing. Also, material for C^{14} dating is routinely taken only from the centre of the cores. However, particularly anomalously low ages, for example at turning point *F*, could have resulted in this manner. The major systematic errors are thus thought to result from contamination by old material, in particular from influx of old soils and peats. We suggest this effect has been more pronounced and started significantly earlier than previously believed. C^{14} age determinations may be significantly anomalously old during times of forest clearance and ploughing even though the time–depth curve has not inverted from a positive to a negative relationship.

Palaeomagnetic correlations offer a possibility of assessing this dating difficulty and transferring reliable age estimates between sites. Our preferred ages of geomagnetic fluctuations in Fig. 4 are given by a smooth curve passing through the youngest C^{14} age determinations at each level (excluding Lomond points *D* and *F*). We propose that transference of ages from this master curve to the lake sediments under investigation gives the best estimate of the true C^{14} age of the deposits.

ACKNOWLEDGMENTS. The authors would like to thank Dr E. R. Sholkovitz for assistance with chemical analyses, Dr S. Smith for identification of the shells, NERC for funding the coring and C^{14} dating, and for providing a studentship for TW-H.

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Received 28 March 1978, revised typescript received, 1 September 1978.

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The Journal of the Geological Society

Vol. 136, Part 3, May 1979

Oceanic and continental transform faults

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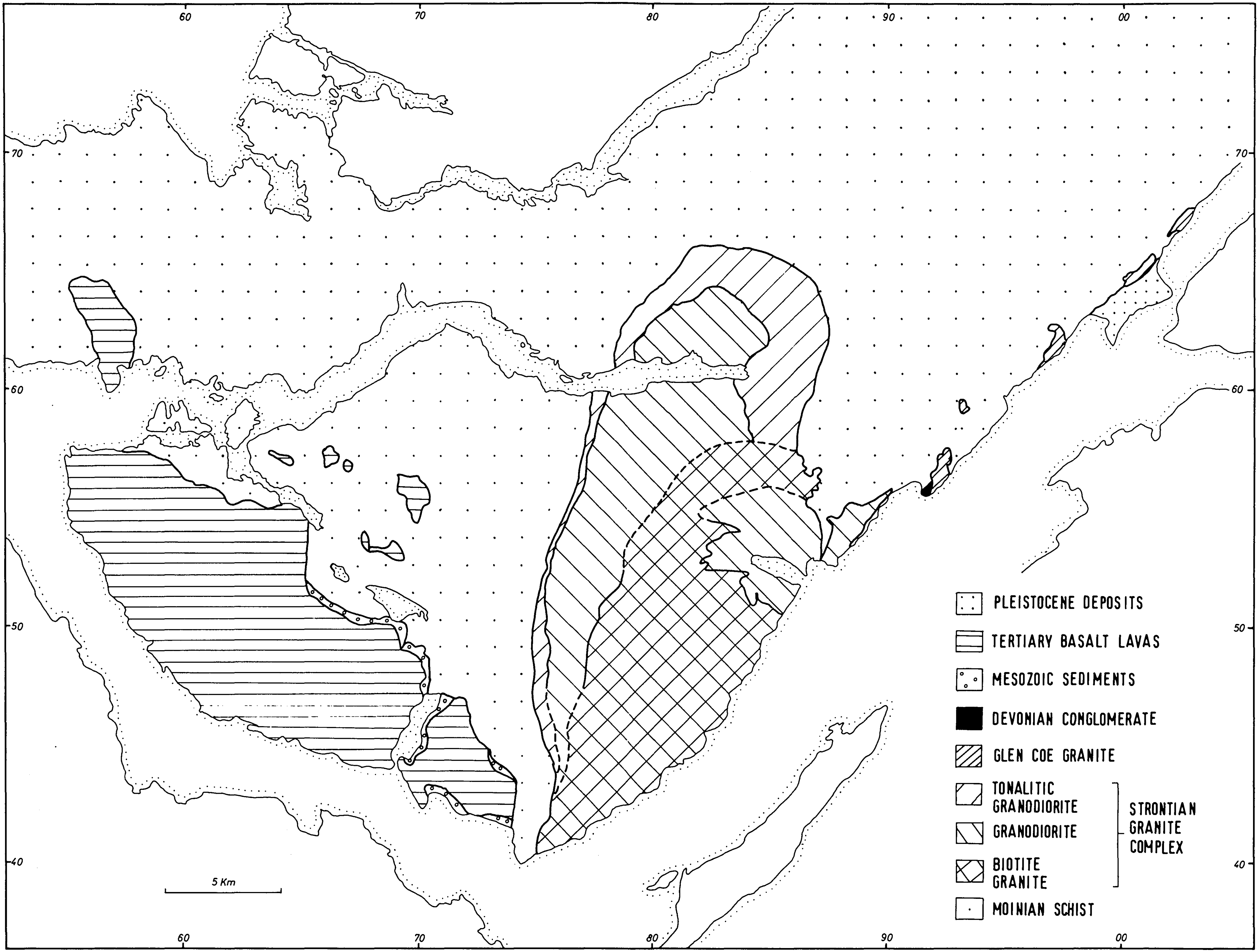


FIG 1.2. *THE BEDROCK GEOLOGY OF THE FIELD AREA.*

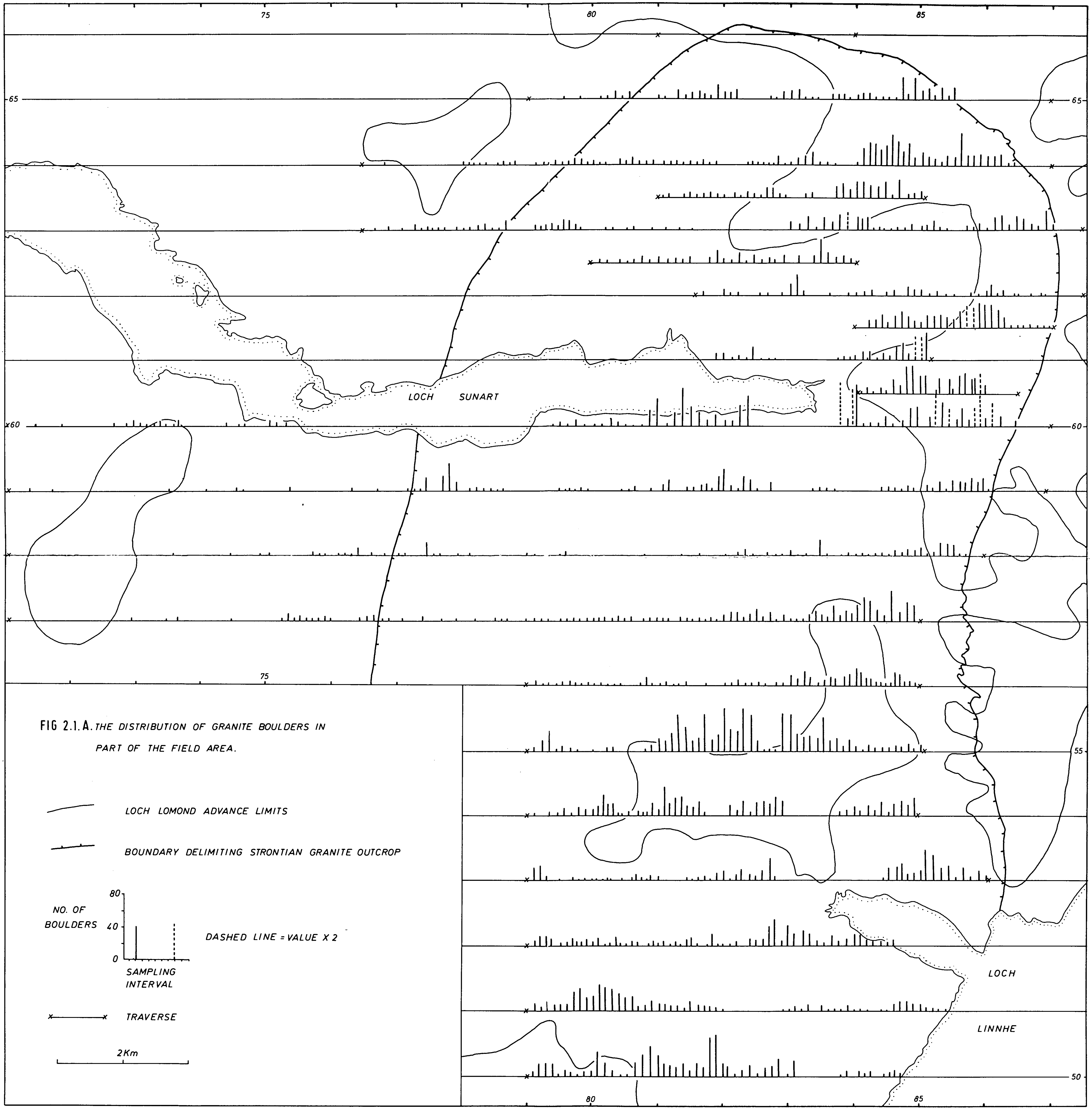


FIG 2.1. A. *THE DISTRIBUTION OF GRANITE BOULDERS IN PART OF THE FIELD AREA.*

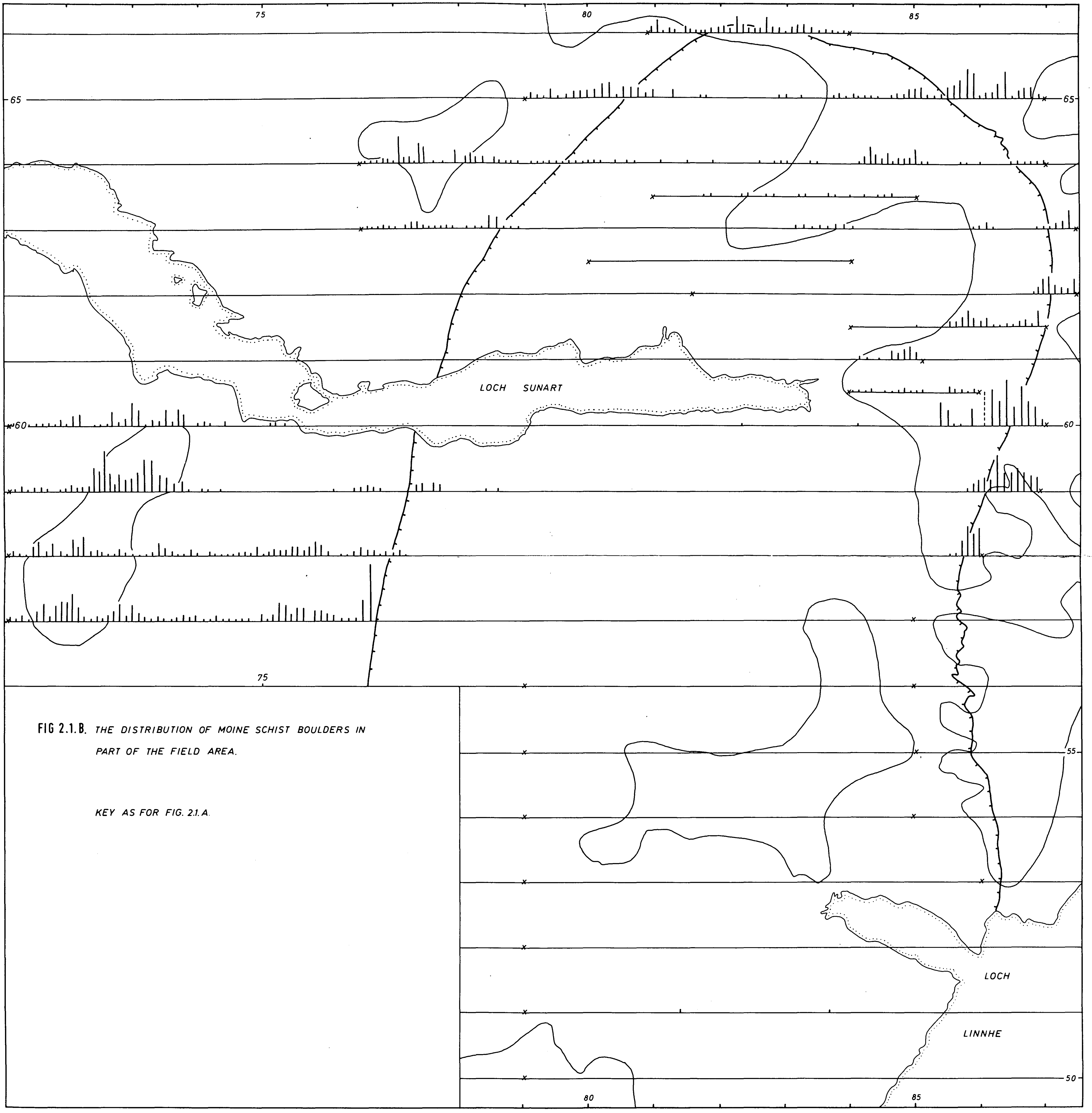


FIG 2.1.B. THE DISTRIBUTION OF MOINE SCHIST BOULDERS IN PART OF THE FIELD AREA.

KEY AS FOR FIG. 2.1.A.

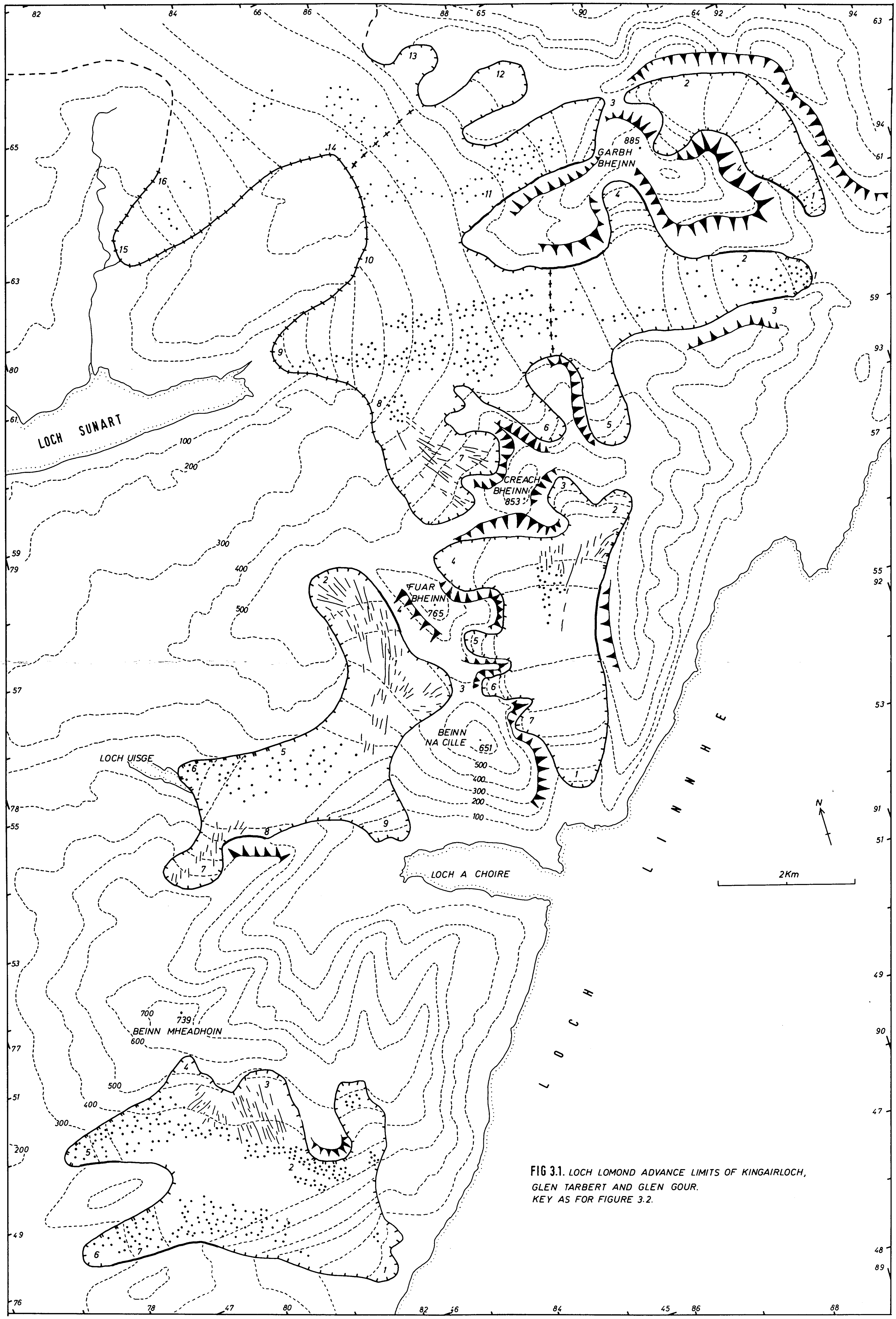


FIG 3.1. *LOCH LOMOND ADVANCE LIMITS OF KINGAIRLOCH, GLEN TARBERT AND GLEN GOUR. KEY AS FOR FIGURE 3.2.*

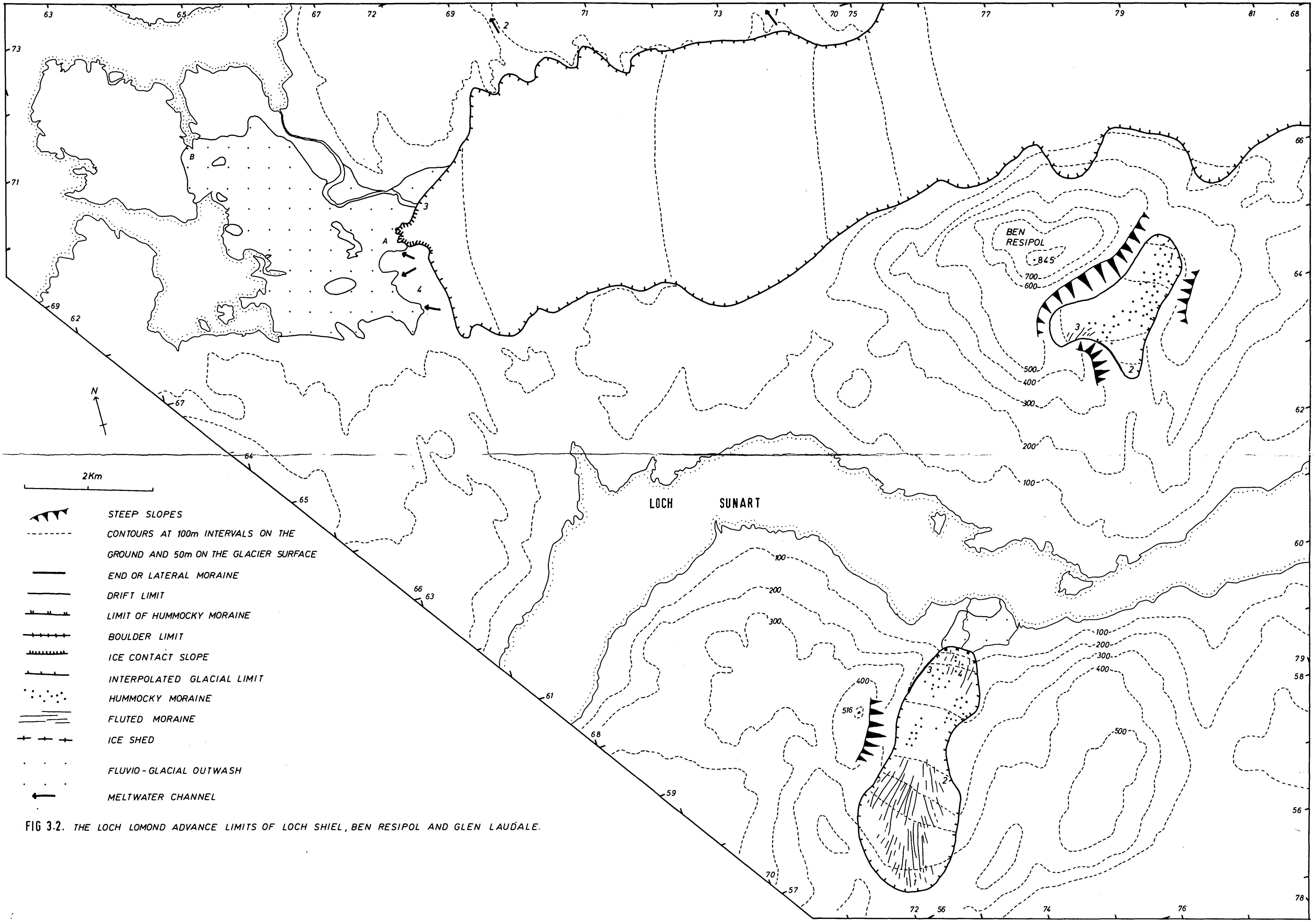
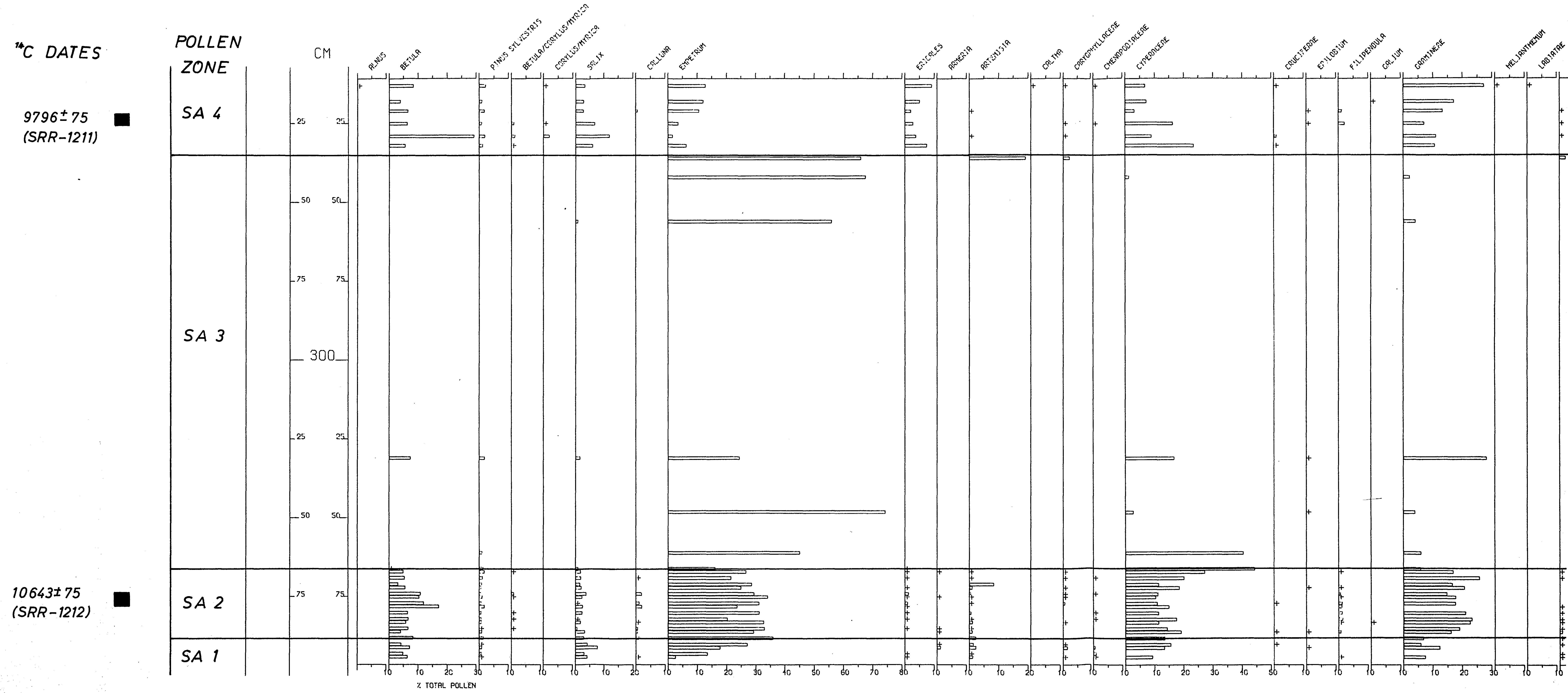
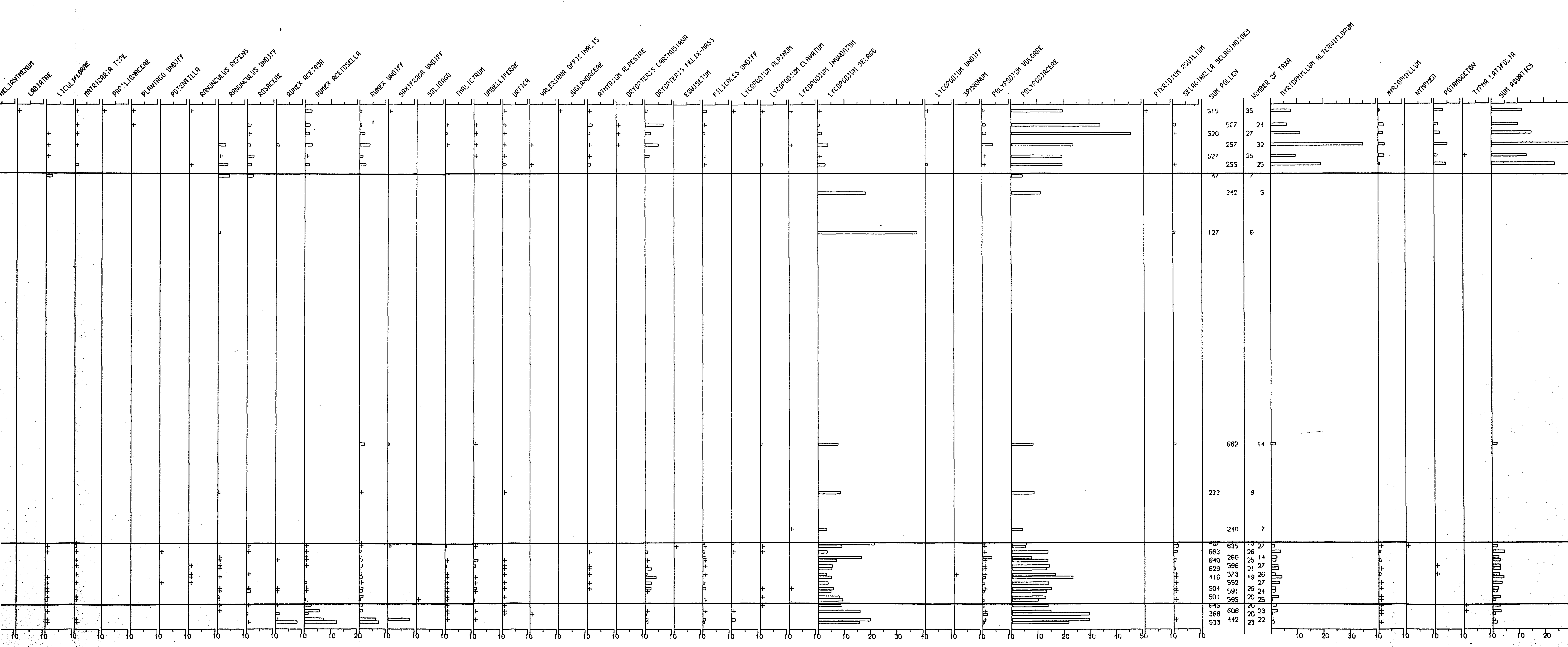


FIG 3.2. THE LOCH LOMOND ADVANCE LIMITS OF LOCH SHIEL, BEN RESIPOL AND GLEN LAUDALE.

FIG. 6.1. SALEN. ANALYST TIMOTHY WAIN-HOBSON

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LABIATAE
LIGULIFLORAE
MATRICARIA TYPE
PAPILIONACEAE
PLANTAGO UNDIFF
POTENTILLA
RANUNCULUS REPENS
RANUNCULUS UNDIFF
ROSACEAE
RUMEX ACETOSA
RUMEX ACETOSELLA
RUMEX UNDIFF
SAXIFRAGA UNDIFF
SOLIDAGO
THALICTRUM
UMBELLIFERAE
URTICA
VALERIANA OFFICINALIS
JUGLANDACEAE
ATHYRIUM ALPESTRE
DRYOPTERIS CARTHUSIANA
DRYOPTERIS FELIX-MASS
EQUISETUM
FILICALES UNDIFF
LYCOPODIUM ALPINUM
LYCOPODIUM CLAVATUM
LYCOPODIUM INUNDATUM
LYCOPODIUM SELAGO
LYCOPODIUM UNDIFF
SPHAGNUM
POLYPODIUM VULGARE
POLYPODIACEAE
PTERIDIUM AQUILINUM
SELAGINELLA SELAGINOIDES
SUM POLLEN
NUMBER OF TAXA
MYRIOPHYLLUM ALTERNIFLORUM
MYRIOPHYLLUM
NYMPHEA
POTAMOGETON
TYPHA LATIFOLIA
SUM AQUATICS
515 35
567 21
520 27
257 32
527 25
255 25
47 7
342 5
127 6
682 14
233 9
240 7
487 635 13 27
663 26
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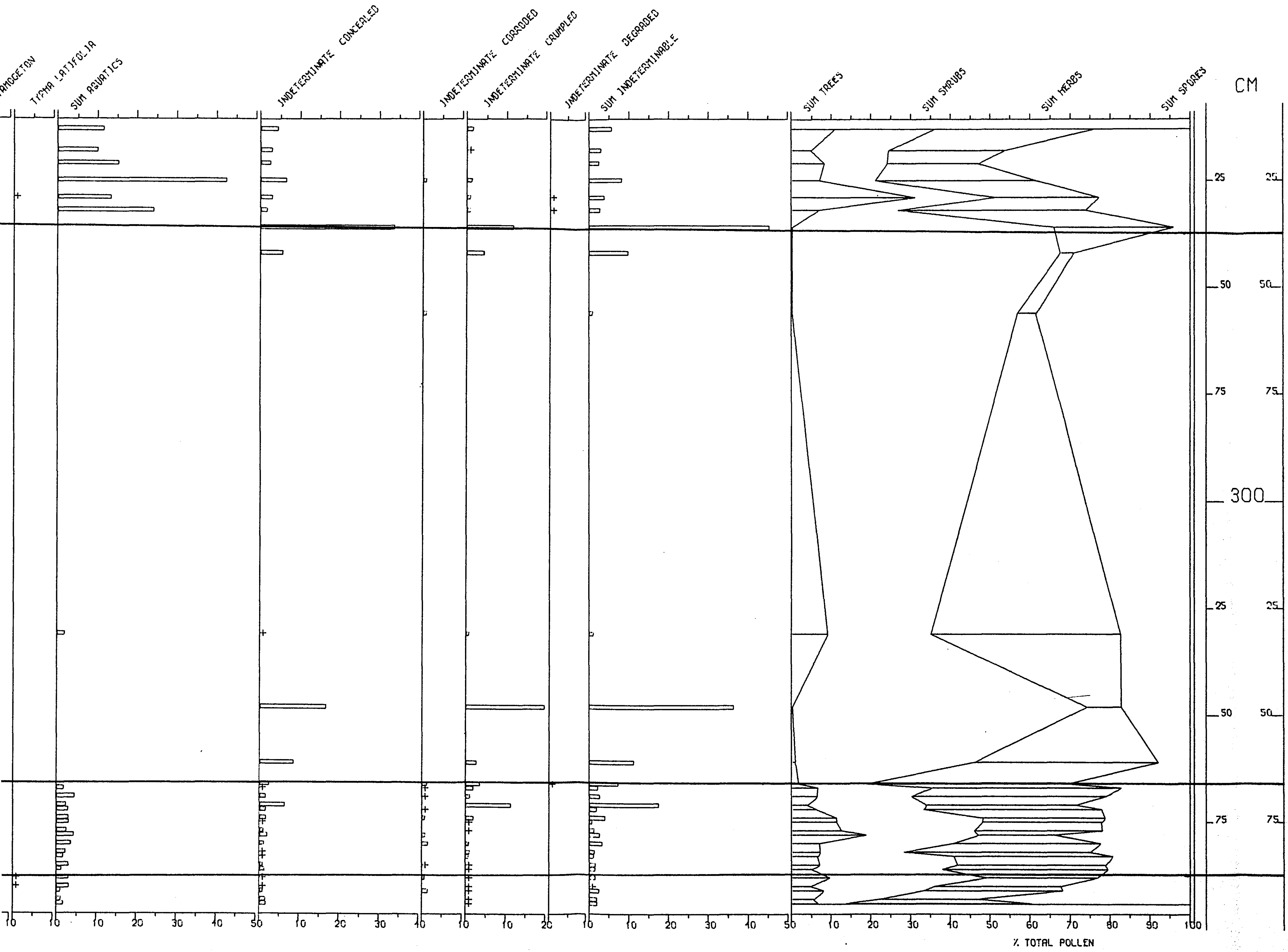
AMOGETON
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INDETERMINATE CORRODED
INDETERMINATE CRUMPLED
INDETERMINATE DEGRADED
SUM INDETERMINABLE
SUM TREES
SUM SHRUBS
SUM HERBS
SUM SPORES
CM
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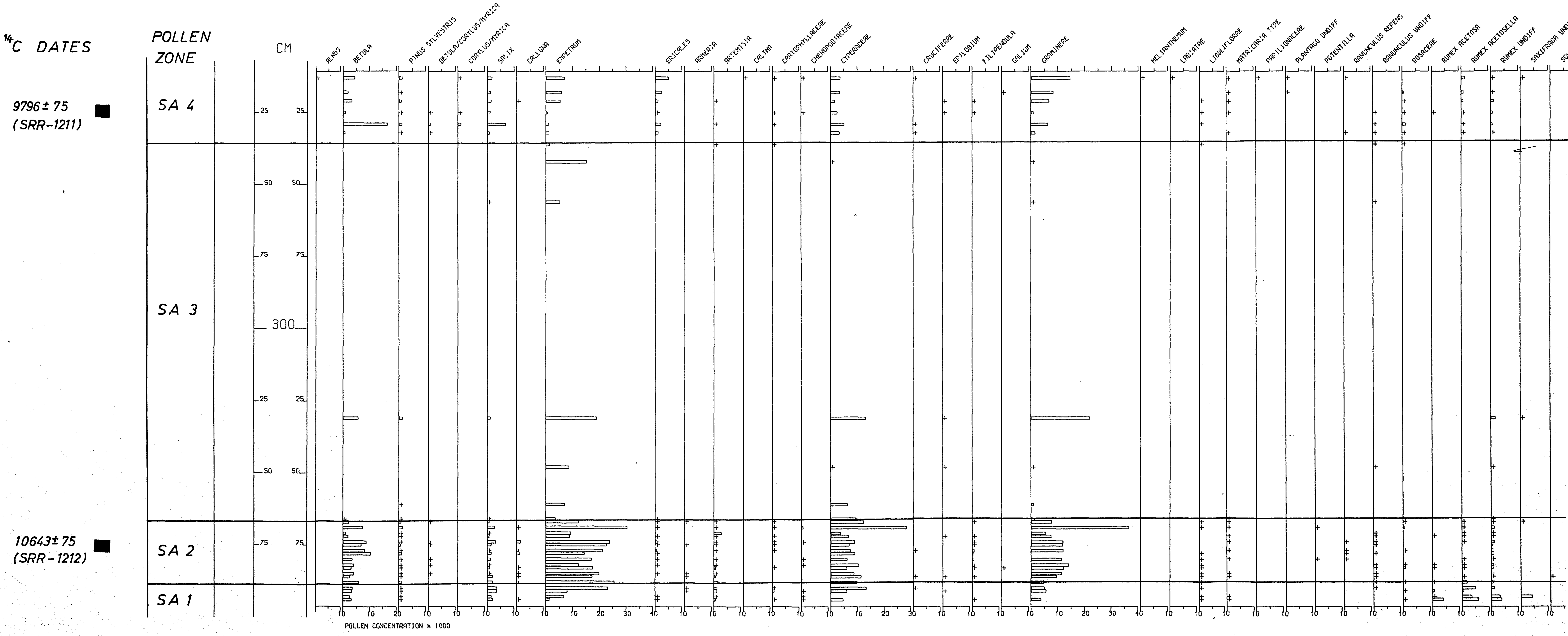
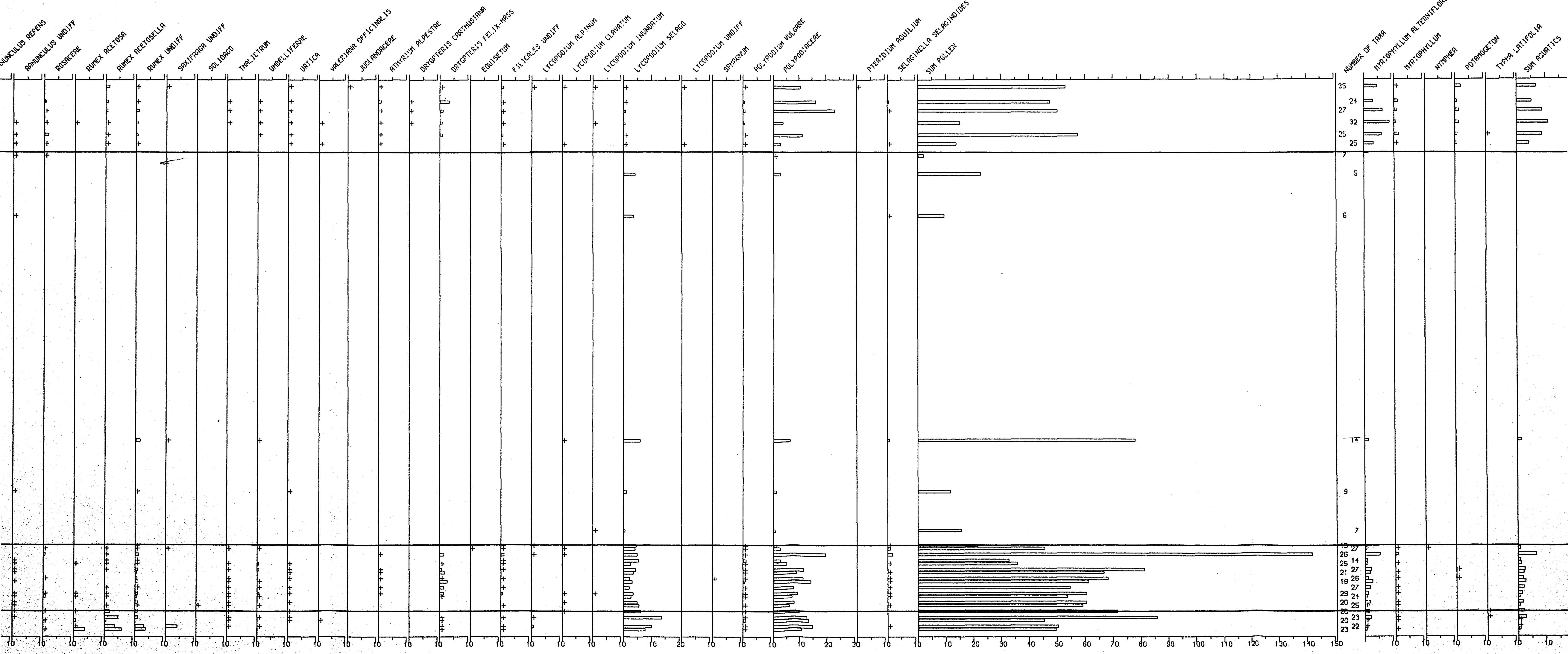
50 50
75 75
300
25 25
50 50
75 75
10 10 10 20 30 40 50 10 20 30 40 10 10 20 10 10 20 30 40 50 10 20 30 40 50 60 70 80 90 100
% TOTAL POLLEN

FIG. 6.2. SALEN. ANALYST TIMOTHY WAIN-HOBSON

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RANUNCULUS UNDIFF
ROSACEAE
RUMEX ACETOSA
RUMEX ACETOSELLA
RUMEX UNDIFF
SAXIFRAGA UNDIFF
SOLIDAGO
THALICTRUM
UMBELLIFERAE
URTICA
VALERIANA OFFICINALIS
JUGLANDACEAE
ATHYRIUM ALPESTRE
DRYOPTERIS CARTHUSIANA
DRYOPTERIS FELIX-MASS
EQUISETUM
FILICALES UNDIFF
LYCOPODIUM ALPINUM
LYCOPODIUM CLAVATUM
LYCOPODIUM INUNDATUM
LYCOPODIUM SELAGO
LYCOPODIUM UNDIFF
SPHAGNUM
POLYPODIUM VULGARE
POLYPODIACEAE
PTERIDIUM AQUILINUM
SELAGINELLA SELAGINOIDES
SUM POLLEN
NUMBER OF TAXA
MYRIOPHYLLUM ALTERNIFLORUM
MYRIOPHYLLUM
NYMPHAEA
POTAMOGETON
TYPHA LATIFOLIA
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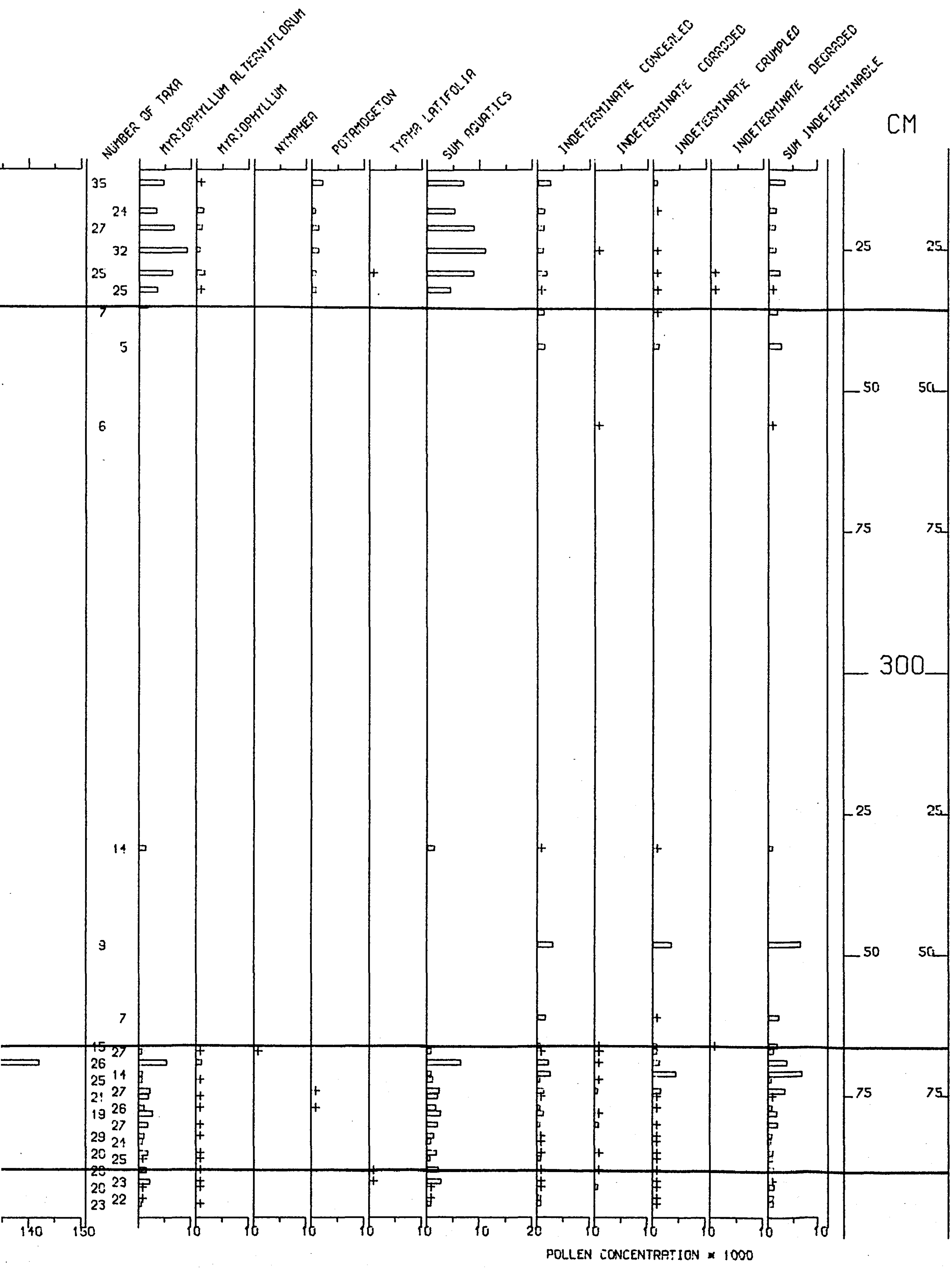
NUMBER OF TAXA
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MYRIOPHYLLUM
NYMPHEA
POTAMOGETON
TYPHA LATIFOLIA
SUM AQUATICS
INDETERMINATE CONCEALED
INDETERMINATE CORRODED
INDETERMINATE CRUMPLED
INDETERMINATE DEGRADED
SUM INDETERMINABLE
CM
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32
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25
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5
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14
9
7
15 27
26
25 14
21 27
19 26
27
29 24
20 25
20
20 23
23 22
25
50
75
300
25
50
75
140
150
10
10
10
10
10
10
10
20
10
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10
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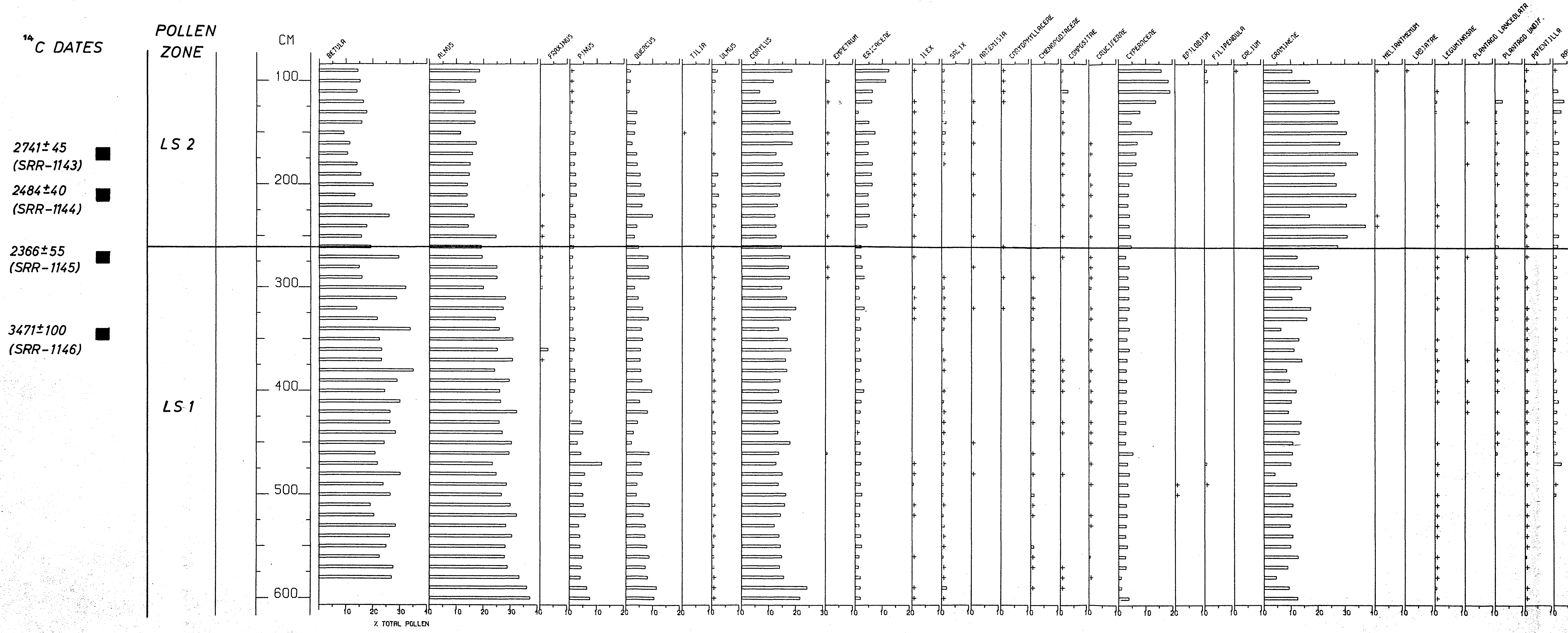
10
POLLEN CONCENTRATION × 1000

FIG.7.1.

LOCH SHIEL. CORE 3 ANALYST: TIMOTHY WAIN-HOBSON



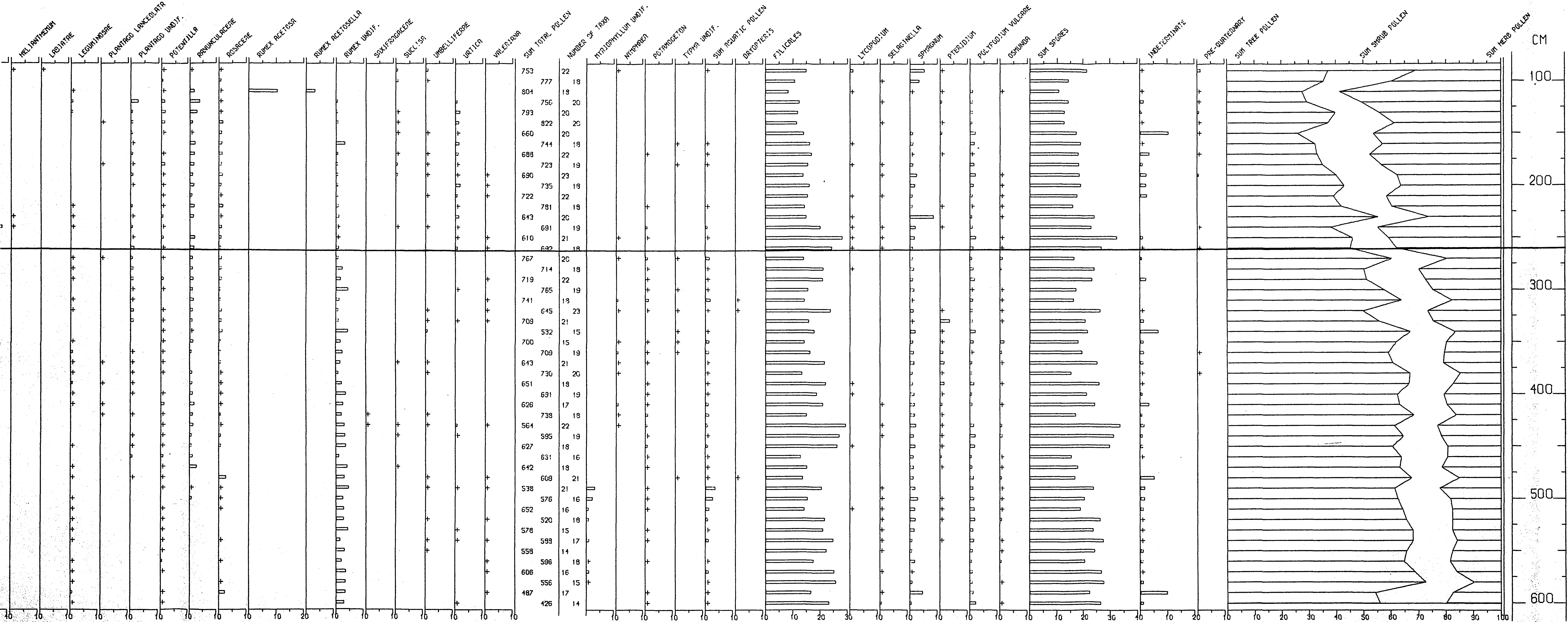
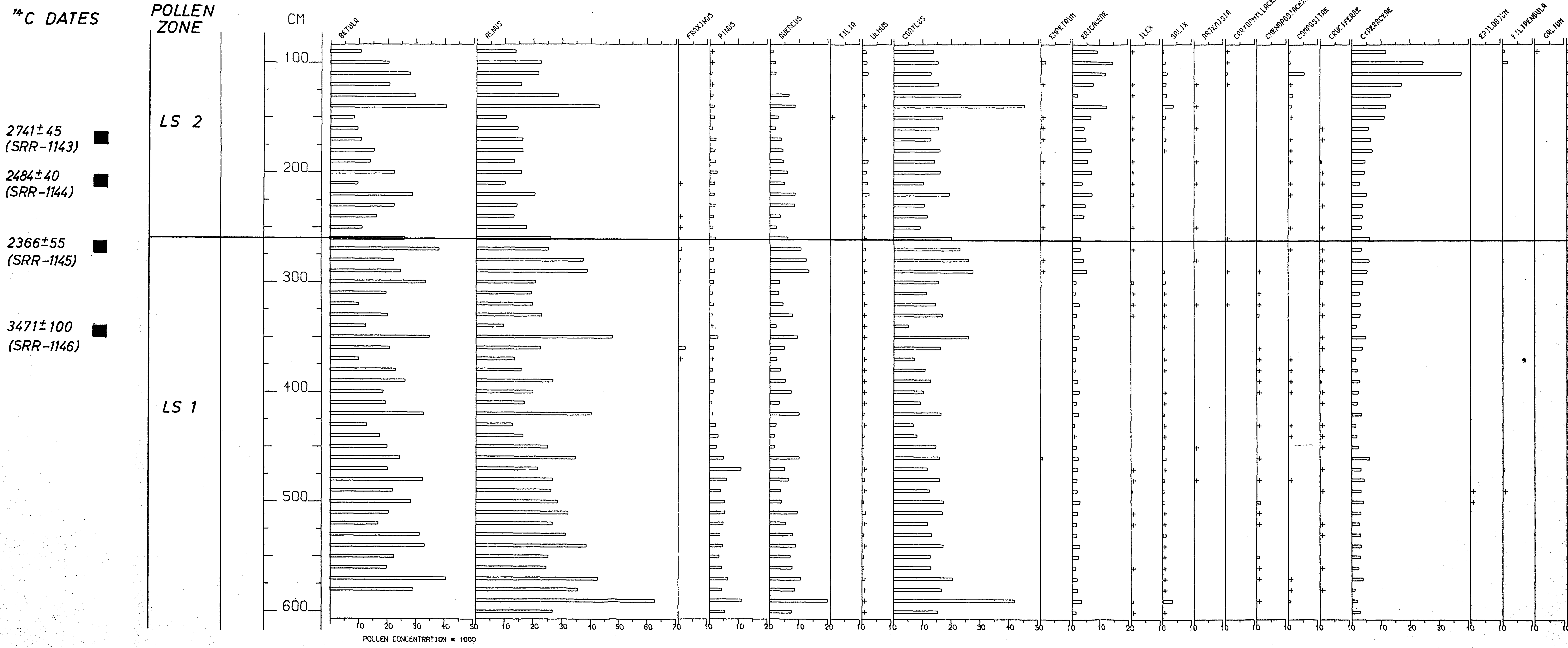
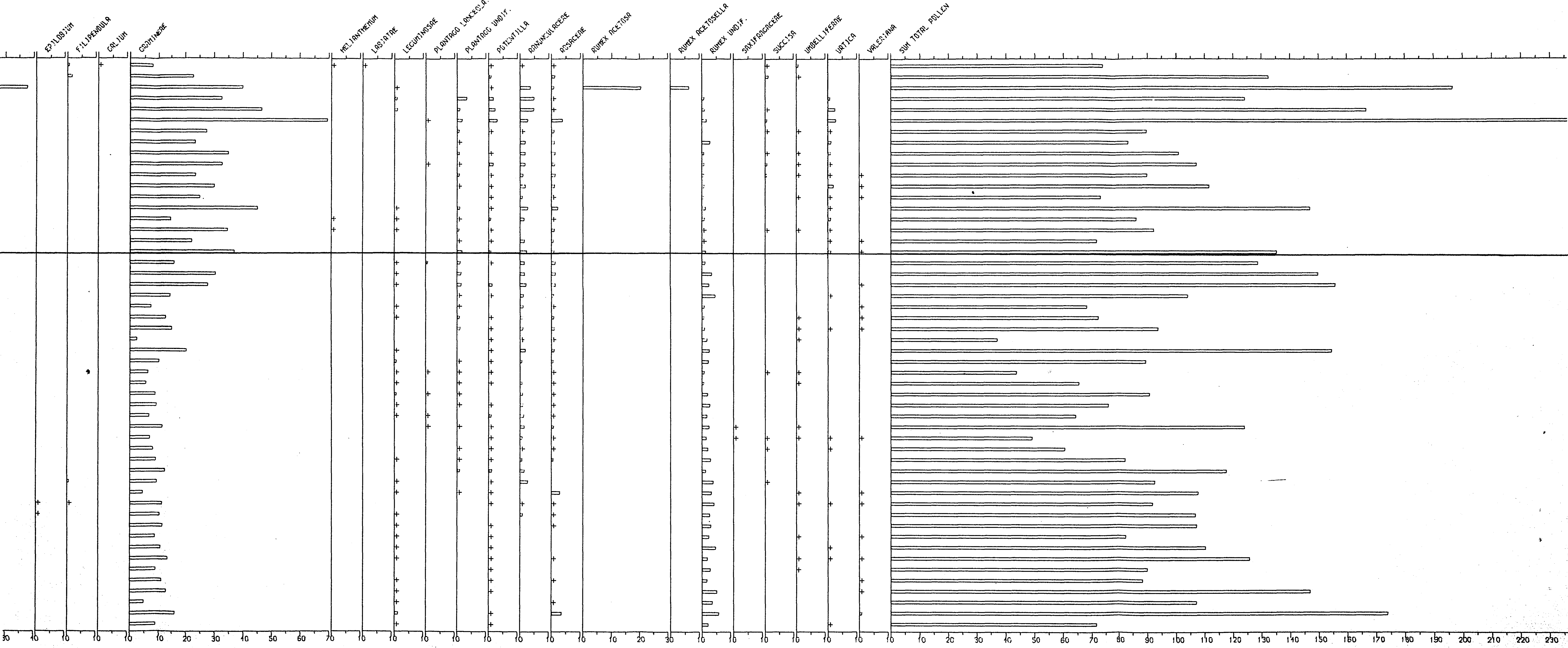

HELIANTHEMUM
LABIATAE
LEGUMINOSAE
PLANTAGO LANCEOLATA
PLANTAGO UNDIF.
POTENTILLA
RANUNCULACEAE
ROSACEAE
RUMEX ACETOSA
RUMEX ACETOSELLA
RUMEX UNDIF.
SAXIFRAGACEAE
SUCCISA
UMBELLIFERAE
URTICA
VALERIANA
SUM TOTAL POLLEN
NUMBER OF TAXA
MYRIOPHYLLUM UNDIF.
NYMPHAEA
POTAMOGETON
TYPHA UNDIF.
SUM AQUATIC POLLEN
DRYOPTERIS
FILICALES
LYCOPODIUM
SELAGINELLA
SPHAGNUM
PTERIDIUM
POLYPODIUM VULGARE
OSMUNDA
SUM SPORES
INDETERMINATE
PRE-QUATERNARY
SUM TREE POLLEN
SUM SHRUB POLLEN
SUM HERB POLLEN
CM
100
200
300
400
500
600
753 22
777 18
804 18
750 20
793 20
822 20
660 20
744 18
688 22
723 19
690 23
735 18
722 22
781 18
643 20
691 19
610 21
692 18
767 20
714 18
719 22
765 19
741 18
645 23
709 21
532 15
700 15
709 19
643 21
730 20
651 18
691 19
626 17
738 18
564 22
595 19
627 18
631 16
642 18
609 21
538 21
576 16
652 16
520 18
578 15
599 17
558 14
596 18
606 16
556 15
487 17
426 14
10 20 30 40 50 60 70 80 90 100
% TOTAL POLLEN

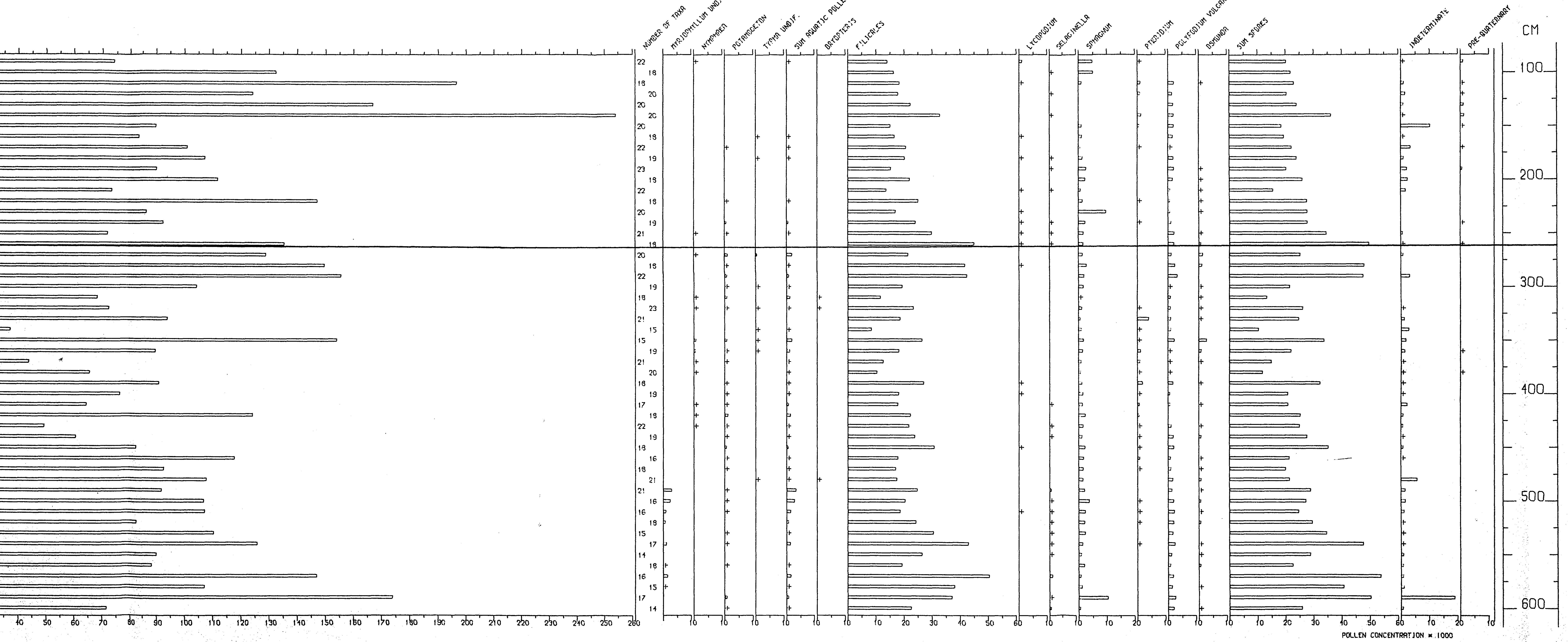
FIG. 7.2.

LOCH SHIEL. CORE 3 ANALYST: TIMOTHY WAIN-HOBSON





EPILOBIUM
FILIPENDULA
GALIUM
GRAMINEAE
HELIANTHEMUM
LABIATAE
LEGUMINOSAE
PLANTAGO LANCEOLATA
PLANTAGO UNDIF.
POTENTILLA
RANUNCULACEAE
ROSACEAE
RUMEX ACETOSA
RUMEX ACETOSELLA
RUMEX UNDIF.
SAXIFRAGACEAE
SUCCISA
UMBELLIFERAE
URTICA
VALERIANA
SUM TOTAL POLLEN
30
10
10
10
10 10 20 30 40 50 60 70
10
10
10
10
10
10
10
10 10 20 30
10
10
10
10
10
10
10
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230


NUMBER OF TAXA
MYRIOPHYLLUM UNDIF.
NYMPHAEA
POTAMOGETON
TYPHA UNDIF.
SUM AQUATIC POLLEN
DRYOPTERIS
FILICALES
LYCOPODIUM
SELAGINELLA
SPHAGNUM
PTERIDIUM
POLYPODIUM VULGARE
OSMUNDA
SUM SPORES
INDETERMINATE
PRE-QUATERNARY
CM
100
200
300
400
500
600
22 18 18 20 20 20 20 18 22 19 23 18 22 18 20 19 21 18 20 18 22 19 18 23 21 15 15 19 21 20 18 19 17 18 22 19 18 16 18 21 21 16 16 18 15 17 14 18 16 15 17 14
40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260
10 10 10 10 10 10 10 20 30 40 50 60 10 10 20 10 10 10 10 20 30 40 50 60 10 20 10
POLLEN CONCENTRATION × 1000