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# GLACIAL LIMITS, SEA-LEVEL CHANGES AND VEGETATIONAL DEVELOPMENT IN PART OF WESTER ROSS.

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1977

## ABSTRACT.

The area studied is part of Wester Ross, north-west Scotland, and includes the Applecross Peninsula and the land to the east between Strathcarron and Glen Torridon.

Mapping of glacial landforms involved study of aerial photographs and subsequent field work. Evidence was found for the existence of two ice caps and five separate coire glaciers during the Loch Lomond Readvance, their various termini being represented today by clear lateral and end moraines at fourteen out of twenty-five locations. In nine cases, multiple lateral and/ or end moraines suggest fluctuation of these ice margins during the Stadial maximum. An earlier stage of glaciation not related to the Late-Devensian ice-sheet maximum is represented by a single moraine and glacial striae. It is believed that this substage probably occurred between 18,000 and 14,000 years ago.

Former sea-level changes were investigated by accurate mapping and instrumental levelling of raised coastal features. Three major periods of formation were identified :-

1. A pre-glacial or interglacial stage, evidenced by a high-level rock platform at 32 to 37 m O.D.;
2. Raised beaches and deltas lying between 21 and 28 m O.D. relating to a period of very early Lateglacial deglaciation;
3. Postglacial features lying below about 10 m O.D.

Pollen analysis of core sequences from two sites helped confirm the Loch Lomond Readvance age of the end moraines in Strath a' Bhathaich and to elucidate the history of vegetational development in the area between _ca._ 13,000 and 9,000 B.P. The Lateglacial pollen diagram indicates early development of a treeless _Empetrum_- dominated landscape that reverted during the Stadial to tundra-like conditions with a floristically- poor, open vegetation. Both Postglacial diagrams indicate a rapid recovery

in early Postglacial times, with the return of pioneer species shortly superceded by a closed vegetation, and then by immigration of birch trees, and the establishment of a mixed birch-hazel woodland.

ACKNOWLEDGEMENTS.

I should like to thank Dr. W. W. Newey and Dr. J. B. Sissons, Department of Geography, University of Edinburgh, who supervised this research project, for their unstinted help and advice offered over the past four years.

Without a research scholarship from the Faculty of Social Sciences, University of Edinburgh, the project would not have been undertaken, and I am particularly grateful for the grant made available from this source towards the cost of radiocarbon dating. For the same purpose, a generous donation from the Meiklejohn Fund (Department of Geography, University of Edinburgh) was also provided.

The Carnegie Trust for the Universities of Scotland kindly donated money to allow the purchase of aerial photographs of the field area.

The cores for pollen analysis and dating were obtained in the field by the following indispensable team : Dr. J. B. Sissons, Mr. Roger Cornish, Dr. Rick Shakesby, Mr. Donald Sutherland, and Dr. Mike Walker, to all of whom I am very grateful.

I should also like to thank Dr. Mike Walker for his assistance and encouragment when I was attempting to learn pollen analysis, and Mr. David Agnew for help in the laboratory with sediment analyses.

For assistance with computing, I am indebted to Dr. A. D. Gordon (Department of Statistics, University of St. Andrews) who supplied the 'Zonation' program, and to Dr. John Matthews and Mr. Colin Ballantyne, (Department of Geography, University of Edinburgh), for much practical advice.

Mr. John Musto (Babtie, Shaw and Morton) kindly made available to me plans and levelling data for part of the new Applecross road, and Mr. J. Keiller (Highland Regional Council) gave similar assistance for another part of the road.

I would like to thank Dr. Shelagh Smith (Royal Scottish Museum, Edinburgh) for identifying the Lateglacial shells from Loch Kishorn.

Many people living in my field area made work there possible : in particular I am grateful to Mr. A. Edwards, factor of the Applecross Estates, and the many other factors and land-owners for allowing access to their land.

Mr. and Mrs. John Murchison, Achintraid, and Mr. and Mrs. Neill Rieley, Torridon, deserve special acknowledgements for helping make my residence in the area so enjoyable.

Finally, I should like to thank my husband, Peter, for his endurance, moral support and much practical assistance in levelling and field-work during three midge-infested seasons in the north-west Highlands.

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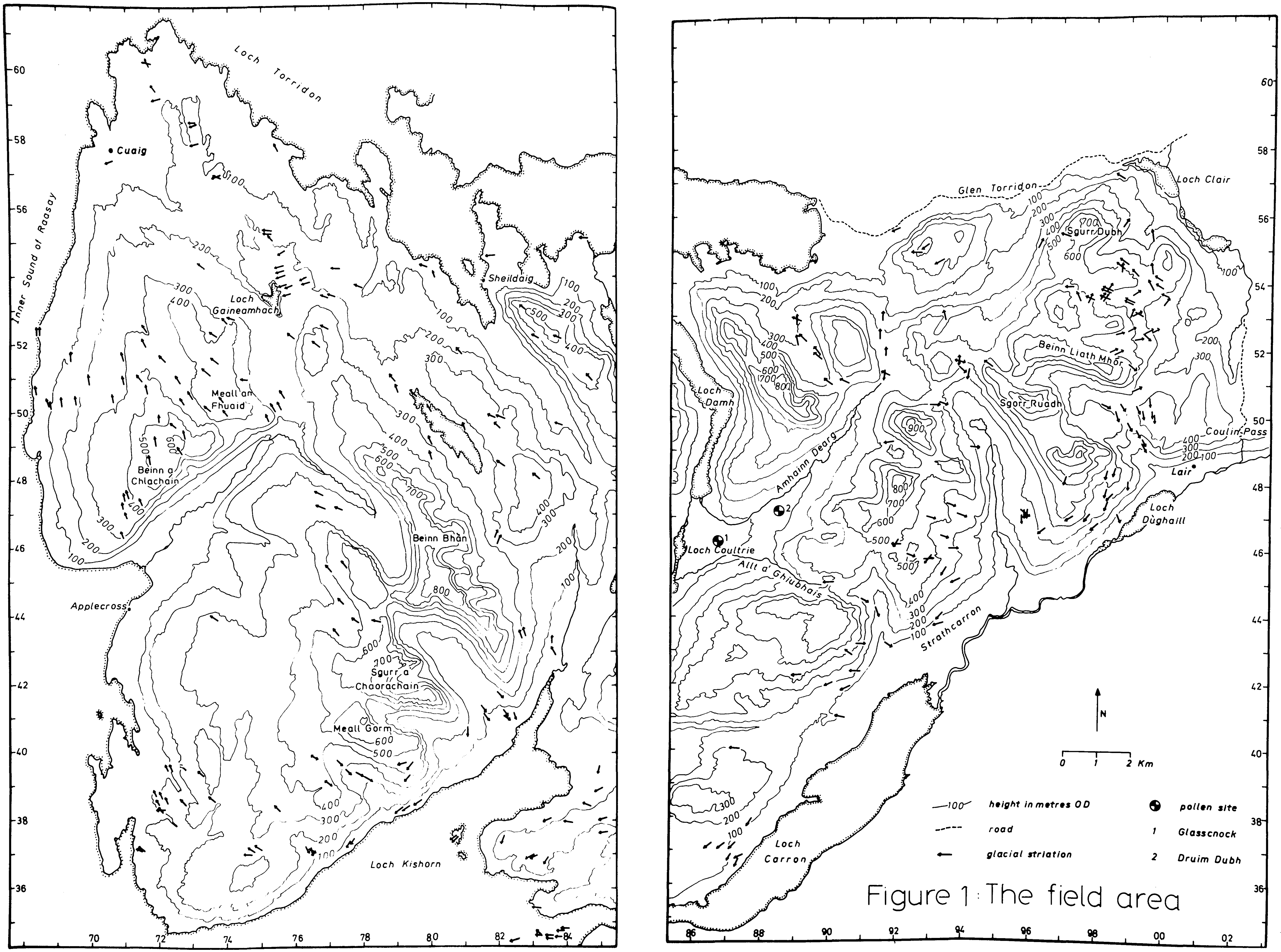


Figure 1 The field area

# CHAPTER ONE.

'The geography becomes more and more uncertain
the farther back we try to follow it.'

(Geikie, A., 1887, P. 159)

Introduction to the field area.

The area studied comprises the Applecross Peninsula and that region lying immediately east of it, bounded by Loch and Glen Torridon, Loch Carron and Strathcarron, and in the east by the valley stretching from the Coulin Pass to Loch Clair (Fig. 1 ).

These 570 square km of Wester Ross cover a range of relief that includes only limited flat land in valley bottoms and narrow coastal strips. Mountains, and high narrow ridges dominate the landscape throughout. The highest peak in the area is Sgorr Ruadh, 958 m O.D., but seven mountains reach over 880 m O.D. and the general character of the region is 'lofty and rugged' to quote A. Geikie (1893, p. 268).

The eastern part of the study area (comprising the region east of Shieldaig - Loch Coultrie - Loch Kishorn) can be contrasted with the Applecross Peninsula. The latter constitutes in part a dissected plateau, with the high flat-topped massif formed by Beinn Bhan, Sgurr a' Chaorachain and Meall Gorm reaching westward to the Beinn a Chlachain - Meall an Fhuaid ridge west of the Applecross valley. Sloping seaward in all directions from this high core is a fringe of lower-lying, undulating land dotted with numerous small lochans, the relief being of low amplitude and comparative monotony. The eastern half of the field area is characterised by much more highly dissected relief with individual mountains and narrow sharp-crested ridges. Steep-sided valleys, interconnected by numerous glacial summits in this eastern part are typically of little areal extent; hence many of the mountains have a conical appearance and the ridges are well-described as 'knife-edge'.

The abundance of bare rock surfaces throughout the area testifies in part to the former importance of glacial erosion in moulding the landscape. Coires are numerous on all of the high ground, near-vertical drops of hundreds of metres being common at their headwalls.

Roches moutonnées, fluted, striated and finely polished rock surfaces on the small scale, and major breaches and troughs such as Strathcarron on a greater scale, all reflect the former action of ice in modifying and trimming the pre-glacial landscape.

Glaciation in places appears to have changed the Tertiary drainage pattern, both erosion and deposition having caused river diversion (e.g. the deflection of both the Allt a Ghiubhais and the Abhainn Dearg by the ice-sheet moraine deposited at Glasscnock). Drainage is radial on each of the two major mountain masses referred to above. Where glacial troughs were overdeepened by ice, ribbon lakes now exist (e.g. lochs Damh, Lundie and Dughaill). Smaller lochs and lochans are numerous, especially in such extensive gently-sloping areas of glacial scouring as the western and northern parts of the Applecross Peninsula.

The high mean annual precipitation, 2,500 mm on the land above 750 m, and over 1000 mm in the lower-lying parts, together with the low mean annual temperature and the western situation of the area, combine to create a surplus of water on the land, such that even in exceptionally dry summers only the smaller burns, fed from the sponge-like peat mosses, dry up completely.

The coastline of this glaciated tract of country is, predictably, rocky and indented. Three major fjords surround the Applecross Peninsula: Loch Torridon, Loch Kishorn and the Inner Sound of Raasay. Loch Torridon strikes 20 km inland from the open sea, while being less than 3 km wide over most of its length, and Loch Carron in the south stretches for over 15 km in a similar manner. The north coast of Applecross is crenellated with numerous small headlands and bays, presumably because the coastline cuts across the inherent grain of the rock and that imparted by glacial erosion. The west and south coasts of the Peninsula are, by contrast, relatively smooth. All coasts are

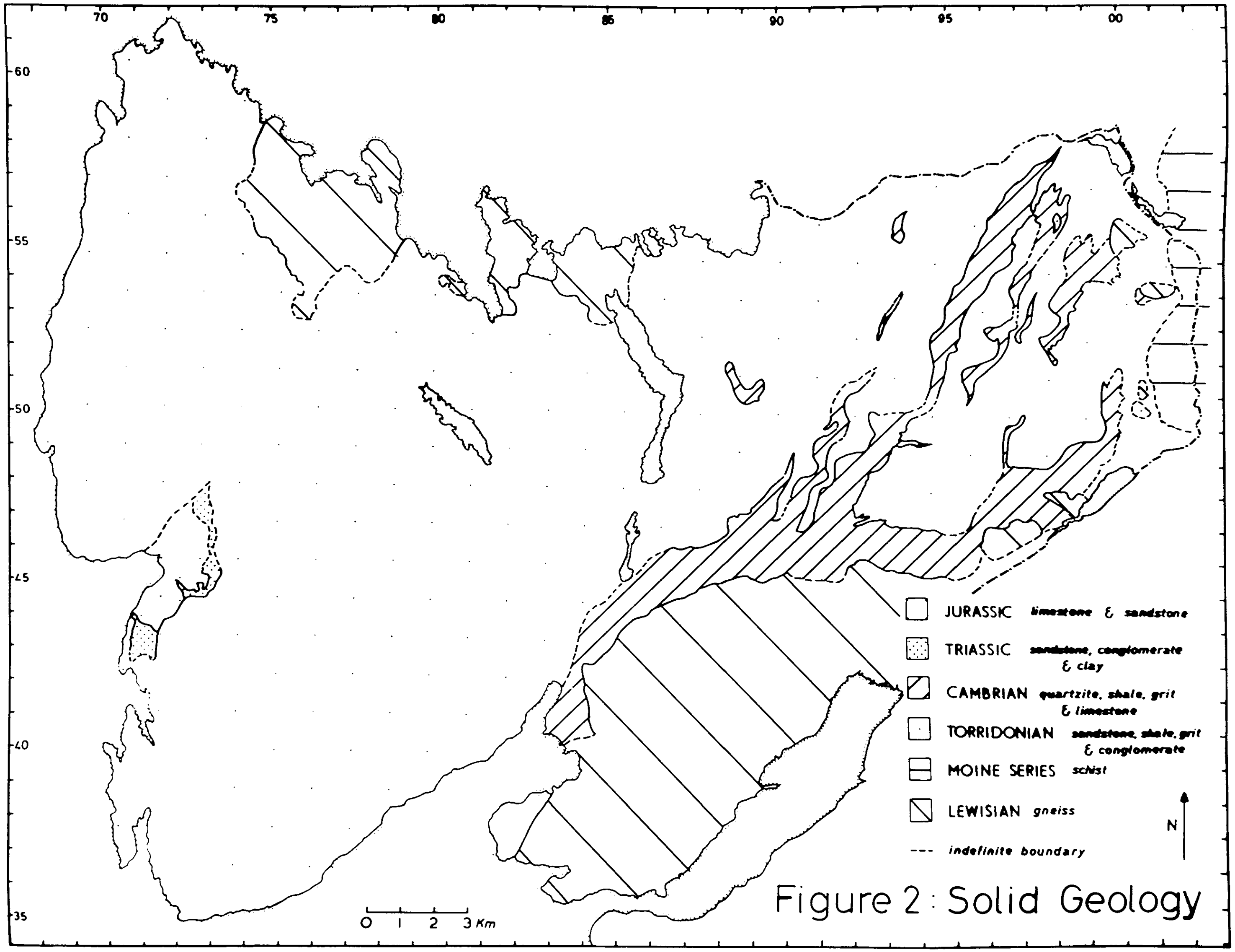


Figure 2: Solid Geology

rocky, fringed in stretches by rock platforms : where the high-level platform is present along west Applecross there are no small islands such as occur to the south and along the north coast. Raised beach deposits are nowhere extensively developed, but short fragments occur commonly in bays and at the heads of sea lochs. Similarly, present-day beaches are frequently poorly developed, stony features, with sandy beaches being concentrated in estuaries and the larger bays.

THE SOLID GEOLOGY : Pre-Cambrian to Tertiary.

The most detailed account of the geology of this part of Ross-shire is contained in the volume 'The Geological Structure of the north-west Highlands of Scotland' (Peach et al., 1907), one of the memoirs of the Geological Survey. Another memoir 'The Geology of Central Ross-shire' (Peach et al., 1913) covers the eastern part of the study area. More recent summaries of the geology include the relevant chapters in Craig (1965) and Phemister (1960).

Torridon Sandstone is the commonest bedrock in the area. Small outcrops of Lewisian Gneiss are present, mainly in north Applecross and between lochs Kishorn and Carron, and outcrops of Cambrian rocks are fairly common in central and eastern parts. Triassic and Jurassic rocks occur in a very restricted area around Applecross village, and on the extreme eastern margin of the area the Moine Schists appear. Intrusive rocks such as basalt and dolerite in the form of dykes and sills are common throughout, and two very small necks of agglomerate occur in south-west Applecross. The east-central part of the field area is traversed by the Moine Thrust plane, so the geology here is more complex than elsewhere.

The oldest rocks of the area are the Lewisian ortho-gneisses, dating from the Laxfordian orogeny between 1600 and 1200 million years ago. They comprise highly metamorphosed plutonic igneous rocks, the principal constituents of which are quartz, feldspar, and ferro-magnesian minerals. The gneisses are intruded by numerous basic and ultra-basic dykes, trending between west-east and north-west to north-east. These ancient and resistant rocks produce very characteristic scenery, exemplified in the area south of Loch Torridon. Though the surface expression of the gneiss must perhaps largely be attributed to glacial scouring, 'knock and lochan' type scenery (Linton, 1959) is particularly well developed on the Gneiss. Geikie in 1887 (pp. 12-13) described it thus 'the whole landscape is one wide expanse of smoothed and rounded bosses and ridges of bare rock, which, uniting and then separating, enclose innumerable little tarns.... The domes and ridges present everywhere a rounded flowing outline, which has only here and there been partially defaced by the action of the weather'.

In its natural successional position, the Lewisian Gneiss forms a basement. Where affected by Caledonian movements within the Moine Thrust Zone, nappes of Gneiss occur imposed upon Torridon Sandstone, which in turn overlies Cambrian rocks as for instance in the area between lochs Kishorn and Carron, where the Gneiss attains an altitude exceeding 600 m. After the Gneiss had undergone extensive erosion, the Torridonian sediments were deposited on its very irregular surface. A current hypothesis (Craig, 1965) suggests that these deposits were laid down from the north-west in a classic geosynclinal sequence, with the major sedimentary basin being sited along the Caledonian orogen. Three distinct Torridonian facies exist, the younger two of which are represented in the field area.

The sandstone-shale facies, or Diabeg group, occurs east of Loch Kishorn. These sediments are believed to have been deposited mainly in shallow water in marine or fluvial environments. Far commoner is the younger arkose facies (Applecross and Aultbea groups), originally over 2,700 m thick, which comprise most of the Applecross Peninsula and much of the eastern part of the field area. These shales, grits and conglomerates were deposited fluvially in conditions that allowed oxidation, hence the red colour, possibly in small drainage basins in the Lewisian hills. Except in the immediate vicinity of the Moine Thrust, these rocks remain practically unaltered since formation 1,000 to 800 million years ago, though faults with throws of several hundred metres, and dykes of Tertiary age, interrupt the sandstone.

The principal constituents of the Torridon sandstone are feldspar, quartz and mica, with some heavy minerals. Near-horizontal bedding planes and vertical joints inherent in the sedimentary structure tend to produce, on erosion and weathering, an alternation of horizontal planes and vertical faces which, in regions of high relief, create spectacular scenery, well exemplified by the Applecross massif. Hinxman (1907, p. 271) noted that 'the characteristic features of these sandstone mountains appear in regular cones, rounded bastions and buttresses, and flat-topped mural precipices, while the parallel lines of bedding which may be traced from base to summit of the cliffs look like piles of Cyclopean masonry......the mountains assume on every side more or less precipitous shapes and rise abruptly in terraced escarpments or round castellated piles of flat cake-like masses, separated from each other and trenched by deep couloirs or rock-chimneys'.

The rocks of the Moine Series are relatively unimportant in the field area, occupying only a few square km in the extreme east of the field area. These schists are of uncertain age, but are thought either to be older than the Torridonian series or contemporaneous with it. The Moine Schists are mainly quartzo-feldspathic granulites and mica-schists. The main phase of metamorphosis of the sediments was during the Caledonian orogeny, when a series of fold movements, beginning in early Ordovician times and possibly lasting into the Devonian, caused a relative shift of the schists at least 6 km to the west and west-north-west. The normal stratigraphic succession is disrupted for nearly 200 km in north-west Scotland along the zone of thrusts stretching from Skye to Sutherland. In the field area the disturbed belt reaches 10 km in width, lying between the major Moine Thrust plane and a western branch of it, the Kishorn Thrust.

Cambrian sediments were laid down upon the warped and eroded Torridonian surface, the general uniformity of which implies marine denudation prior to deposition. These rocks occur in elongated outcrops in the eastern part of the field area, the three Series generally appearing in a disordered sequence.

The three divisions of the Cambrian are as follows. The Arenaceous Series constitutes the oldest sediments: this includes the Basal Quartzite and the Pipe-rock. The Passage Series of dolomitic shales, mudstones and grits is topped by the Calcareous Series or Durness Limestone. Despite the relatively small area of Cambrian outcrops, the rock is very distinctive within the region due to its predominantly pale grey or white colour, and its frequent position as a resistant capping on mountain tops (e.g. Beinn Liath Mhór and Sgurr Dubh). Its susceptibility in this situation to intense frost shattering has given rise to the white mantles of scree enveloping the lower slopes of these and other hills.

Triassic and Jurassic rocks occur only around Applecross village. The former type include red clays, sandstones, and conglomerates, while the overlying Liassic sediments comprise limestone, sandstones and shales.

The igneous activity of the Tertiary period is recorded in the presence of dykes which generally cut south-north across the western half of the field area. These intrusions have in places been exploited by rivers (and in some cases also by ice) as easily-eroded lines of weakness (e.g. by the River Applecross).

## The Quaternary : GLACIATION.

Before discussing the evidence for several stages of Quaternary glaciation previous literature on the glacial geomorphology of the field area will be briefly reviewed. Apart from Charlesworth's contribution (1955), the Geological Survey has provided the sole workers in this area over the last 85 years.

The earliest account of glaciation in the field area appears to be those comments found in the Progress Report for 1892 to 1900 of the Geological Survey. The field area was then being mapped geologically by Horne, Peach and Hinxman, and their observations on glacial phenomena were being recorded in increasing detail throughout the last decade of the 19th. century. In the Report for 1893, erratics and striae indicating high-altitude south-south-east to north-north-west ice movement, moraines in Applecross from both large and small valley glaciers, and raised shorelines are all noted.

By 1913 the Geological Survey memoir for central Ross was published, and under the chapter heading 'Pleistocene and Recent', contains one of the most detailed accounts produced up to the present day of the general sequence of glaciation in the area, exemplified by numerous references to specific features. How little geomorphological research has followed this work is illustrated by the fact that the chapter in Phemister's more recent book (1960), under the same chapter heading, summarises the information given in the 1913 memoir, and adds little of value to it.

Three phases of glaciation are recognised by the Geological Survey in 1913 and 1960. These are:-

1. The period of maximum glaciation, when the whole area was covered with ice. Early-discovered striae on mountain tops indicated the movement of this ice to have been between north-west to just south of west; later on, the complication of an independent westerly direction was added.

2. The confluent glacier phase: throughout this period nunataks were believed to be present. As the ice retreated, more of the high land was exposed. Major ice-dispersal centres existed in the Monar basin south-east of the field area, and the Fannich mountains to the north-east: 'somewhere along the line of Glen Torridon, the Coulin River' etc.,(Peach et al., 1913, p. 85), the two ice caps were confluent. More centres of dispersal appeared with continued down-wasting. Large valley glaciers with small hanging tributary tongues existed towards the end of this phase.

3. The valley glacier stage. Further melting of the glaciers produced individual lobes of ice in each valley, which continued to downwaste. No milder intervals are envisaged in this sequence: Peach and Horne stated in 1913 (p. 86) that 'there is no direct physical evidence in this region of any marked recrudensce of glacial conditions and consequent re-advance of the ice cover over the country'. This view is not altered in the 1960 summary, although Hinxman in 1892, following Geikie, believed it probable that small valley glaciers readvanced, depositing moraines which retain a 'wonderfully fresh appearance' (p. 251). It was then believed that the last glacial advance responsible for these moraines took place in post-Neolithic times: this view, however, was soon dismissed, and the valley

glaciation was correctly assigned to the Lateglacial period (c.f. Peach et al., 1913).

The pattern of deglaciation is discussed in the 1913 Memoir for each region covered by Sheet 82, including the Strathcarron - Glen Torridon area. Reference to these observations will be made in later chapters, when the detailed field evidence is discussed.

Three short papers on different aspects of the glacial history date from this period (Hinxman, 1898; Horne, 1899a and b). These are concerned with the Thraill end moraines and their relation to contemporaneous sea-levels, the direction of ice movement at different times in east Applecross, and the composition of till and moraines in the Coulin Forest. Further reference to these will be made later where appropriate.

Charlesworth (1955) produced a detailed map at the scale of 1 inch equal to 6 miles, covering most of the field area, which is published in the monograph 'The Late-glacial history of the Highlands and Islands of Scotland'. Within the field area, fifteen glaciers are demarcated and named on the map (Fig. 8, p. 819), while the positions of other minor tongues are also marked. The 'successive margins' of each are mapped, and in the text the pattern of retreat is described for each named glacier. Since no evidence is discussed to substantiate any of this, no further reference will be made to the work.

Sissons (1967) refers to parts of the field area where end and fluted moraines are particularly well developed: parts of the Applecross massif are mapped in Figures 41 and 42, while a larger area is covered at a smaller scale in Fig. 60. No major disagreement can be made with these limits. In his later book Sissons (1976) briefly alludes to the same areas, again in connection with the Loch Lomond Readvance.

The remainder of this chapter is concerned with glacial chronology. In order to put in context the various stages of ice activity which are dealt with in subsequent chapters, the evidence for three distinct phases of glaciation is summarised. The sequence suggested is broadly similar to that proposed in the late 19th century, and little can be added to that known then of the ice-sheet maximum and its decline. However, as the Lateglacial environment is the prime concern of this study, there is much new information to be presented about the last stage, the Loch Lomond Readvance. Three phases of glaciation can be inferred from several lines of geomorphological evidence.

The general manner in which the landscape has been glacially modified suggests at least a combination of small, coire or valley glaciers which carved out the coires perched facing most directions, and a much more extensive and powerful ice cover that straightened and deepened the major valleys, e.g. Strathcarron and Glen Torridon, continuing their erosion westwards below present sea-level. However, both coire glaciers and ice-sheet cover could have been part of one general cycle of glaciation, with no intervening ice-free stages. The logical sequence for growth of glacial ice is initial coire glaciers extending to form valley glaciers, which with increasingly favourable conditions would eventually coalesce to create a deepening mantle of ice covering most or all of the country.

Striations are the second line of evidence for more than one phase of ice activity, but these too do not prove separate events. Striae are so common on the numerous rock exposures in the field area that they were not mapped or measured unless they were in a critical position: a detailed (and reliable) record of striae can be obtained from the six- and one-inch Geological Survey maps of the area (Fig. 2 ). From the summary on the one-inch sheets, it appears that over the whole area there is a predominant direction of striae from south-east to north-west. This occurs at high altitudes and low down, with some minor deviations due to topographic control. A major swing toward north-north-west occurs west of the Applecross River, especially just north of Applecross Bay; in the extreme north-west corner of the peninsula a westerly direction also appears, both directions being present. It is probable that the ice-sheet that made the ubiquitous north-west aligned striations was deflected north in west Applecross by ice moving out from Skye, which was a local centre of ice dispersal.

Over much of the map striae indicating localised ice movement out of coires and down valleys reflect a later stage of glaciation, when topographic control on ice movement was much greater. These markings correlate well with the proposed limits of the Loch Lomond Readvance glaciers, and in themselves indicate a late, but not necessarily distinct, stage in the glacial sequence. In the eastern part of the field area where several rock types crop out, evidence of valley glacier advance in the opposite direction to the ice-sheet can be seen in the spread of Cambrian Quartzite eastwards over Torridon Sandstone or rocks of the Moine Series. This happens for instance in the Coulin - Achnashellach Forest area, where Loch Lomond Readvance ice moved eastward, and the ice-sheet, westward.

Glacial deposits provide much stronger evidence of the fluctuations of the last ice that existed in the area, and these suggest at least three distinct phases. A detailed account of the features mentioned below follows in subsequent chapters.

A thick till sheet thought to be related to the maximum extent of the Late-Devensian ice-sheet mantles the ground in part of western

Applecross

from north of Kalnakill to around Salacher, and stretching approximately 2 - 3 km inland. Sections in the till show a hard-packed clayey matrix with abundant cobbles and small boulders of mixed lithologies, indicating a non-local source of the ice. A thin ubiquitous scatter of ablation moraine is found over all receptive (i.e. flat or gently sloping) surfaces in the area. Large masses of (presumably) ice-sheet moraine, reaching over 10 m thick and several hundreds of metres in length, occur in several places, for instance a large deposit of moraine in Glen Shieldaig (8350).

The only moraine of the type that indicates a former ice margin, believed not to be related to the Loch Lomond Readvance stage, exists in the centre of the Applecross Peninsula, south of Loch Gaineamhach. For convenience in further discussion, this major morainic ridge will be referred to as the'Applecross Moraine', and the phase of glaciation it represents will be termed the 'Applecross substage'. The dimensions and situation of the moraine prove it to be post-Devensian maximum, but of a pre-Lateglacial age.

The best and most abundant glacial deposits can be referred without reasonable doubt to the Lateglacial Stadial or Loch Lomond Readvance. In the field area, end moraines of valley glaciers are common, fourteen having been mapped, and within the proposed Loch Lomond Readvance limits, fluted and hummocky moraines are abundant. All three types of moraine are known in Scotland only in association with the Loch Lomond Readvance. This evidence shows that the final stage of glaciation involved small valley glaciers radiating in the field area from two main centres of dispersal in the Applecross massif and from the centre of the Eastern Area. Throughout Scotland the Loch Lomond Readvance has been shown by pollen analyses of Lateglacial sites to have followed a period of climatic amelioration, implying that in all probability the ice completely disappeared before the recrudensce of the valley glaciers.

It seems, therefore, that field evidence for three major stages of glacial activity exists in this part of Wester Ross. The clearest evidence is for the youngest, Lateglacial stage, the advance in the 11th millenium B.P. of the Loch Lomond glaciers to positions a few kilometres down valley from the coires. Before this, the maximal Late Devensian ice had engulfed the whole area, probably culminating between 20,00 and 18,000 years ago. At some intermediate stage, a very large glacier presumably lying in the Torridon fjord deposited the Applecross Moraine on its southern margin. Other large scale morainic and fluvio-glacial deposits, lying outside the proposed Loch Lomond Readvance limit, can only be termed 'pre-Lateglacial' as no evidence is known to indicate whether they were deposited by the ice-sheet or during a subsequent stage, such as the Applecross substage.

# CHAPTER TWO

'So that, when the power of ice is insisted on,
much may possibly be referred to mountain rivers;
and when we are asked if glaciers 3000 feet thick
would not be vast agents of denudation, it is admissable
to demand absolute proof that such actually existed
in the Highlands'

(Cole, 1883, p. 46)

The methods employed in mapping the field evidence of glaciation are described below. Techniques employed in mapping and levelling raised shorelines and other features will be discussed in Chapter 5.

Vertical aerial photographs of the whole field area were obtained. These Ordnance Survey photographs, at an approximate scale of 1 : 25,000, were studied initially using a Wild stereoscope, which gives magnification of x8. All glacial depositional features were marked on the photographs using Chinagraph pencil : flutings, end and lateral moraines, and fluvioglacial features were marked individually where possible, while areas of moundy drift were outlined. Periglacial features were similarly noted. Erosional forms such as meltwater channels and coire headwalls were traced. Any other potentially significant features such as unusually dense concentrations of boulders and lineations in bedrock were also marked. Following this preliminary mapping, the photographs were taken into the field, and amended as necessary. A small hand stereoscope was used outdoors. Preconceived ideas are obviously unavoidable in this type of fieldwork: one has had a preview of the field evidence in scrutinising the aerial photographs, and inevitably an interpretation of them starts emerging before foot is set in the field. However, careful investigation of mapped features is essential : some landforms are not immediately apparent on the photographs, such as where deep shadow is cast or relief is low, and other features mapped as being significant are found on field investigation to be something different. Rock knolls can be (usually) differentiated quite easily on photographs from moraine hummocks, but instances occur where field work proves that a mixture of the two occurs, bedrock being present in areas of hummocky moraines and rock knolls having a veneer of drift or shattered bedrock.

In general, the features in this area are very well defined, and aerial photographs made the task of landform mapping immeasurably easier and more precise than if mapping had been attempted without them. Once this mapping was considered complete and satisfactory, the features were marked in ink. The final stage was the transference of the details onto Ordnance Survey 1 : 25,000 maps of the Second Series, using a Zeiss Sketchmaster. The final map showing the geomorphological field evidence (Figs 4a and 4b ) was produced from these sheets. (Place names used in the text are, where possible, shown on the relevant map).

## The Field Evidence.

### 1. The Ice-sheet : Late Devensian maximum.

The main interest of this study is in Lateglacial events, so attention was not directed specifically to evidence of ice-sheet activity. Reference has already been made to the numerous striae, erratics, and ubiquitous ablation moraine that relate to the ice-sheet, and to the evidence of powerful selective erosion that carved out the major glacial troughs and fjords. Since nothing original can be added to the story of ice-sheet glaciation, this stage will not be dwelt upon.

### 2. The Applecross substage.

Good evidence for an intermediate substage between the Late Devensian maximum and Lateglacial times (defined here as the period 13,000 to 10,000 years B.P., see p.25 ) rests in this area mainly upon the presence of one morainic ridge, and the supporting evidence of striations. In the late 19th century the moraine was mapped by the Geological Survey, and a note written on the original six-inch sheet reads

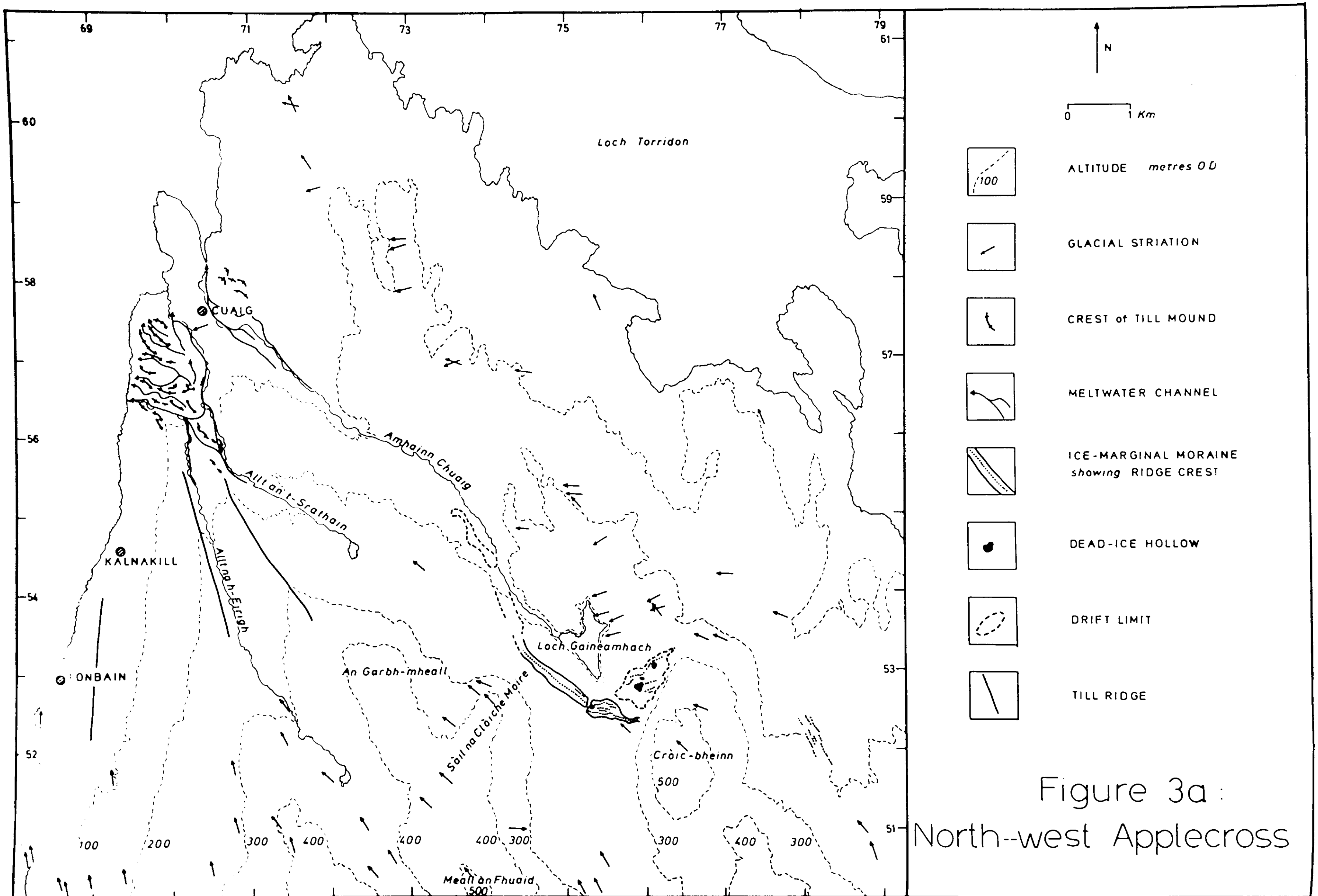


Figure 3a:
North-west Applecross

'limit of later glaciation or margin of Loch Torridon glacier'. One other reference from this period of relevance here is quoted below (p.24).

The ridge in question stretches for almost 2 km from the north-western flank of Croic-bheinn to the north-east flank of Sail na Cloiche Moire (7552). The feature is continued in a north-westerly direction by a low broad ridge of boulders which tails off after a few hundred metres into undulating boulder-strewn country, where it soon becomes impossible to trace the line farther. On the eastern side of Croic-bheinn a group of large moraine ridges, copiously strewn with erratic blocks, trends south-east away from the hill for several hundred metres before merging into shelving bedrock. Beyond here there appears to be no further evidence of the feature. On the north-western flank of Croic-bheinn is a small area of moundy drift containing several small kettle-holes. The main ridge of the Applecross moraine bounds this area on its southern margin.

The major part of the moraine is a well-defined complex feature about 200 m wide, and of varying height, the main ridge reaching over 15 m. It is divided in two by a deeply incised stream channel (probably cut by Lateglacial meltwater, see p. 40 ). The eastern part is broad, comprising up to four parallel ridges, the inner ones being relatively short and discontinuous linear mounds that decrease in height towards the north, and are terminated by a steep slope to lower ground. The southern margin is also steeply sloping. Near the stream channel is a large dead-ice hollow behind the principal ridge : the moraine surface is also pocked in places by minor hollows, presumably created by the melting of enclosed ice blocks. The western part of the moraine is narrower and simpler in construction : there is one major ridge dropping 6 m on its northern side to a

Fig. 3:1. The Applecross moraine from the north.

Fig. 3:2. The distal slope of the Applecross moraine.

broad-crested subsidiary feature. Some low moundy debris is also present on the south side, at the foot of the main ridge.

Boulders are abundant all over the surface of the moraine, some reaching over 4 m in length. Torridon Sandstone predominates, but gneiss is also present, both rock types occurring locally. Excavation of three pits in different areas of the moraine revealed sub-angular and rounded to sub-rounded boulders of varying size, densely packed in a sparse reddish sandy-gritty matrix. In places on and below the surface no interstitial material is present between the blocks. It appears, therefore, that the ridges are composed of till, and the feature is best interpreted as an ice-marginal moraine.

The ice that deposited the Applecross moraine lay on its north-east side. This is inferred from the manner in which the ridge hugs the foot of the Sail na Cloiche Moire cliffs, and is convex up-valley. In the western part there is a very distinct difference between the till or moraine-plastered, boulder-strewn ground north-east of the ridge and the hillside to the west with its shelving bedrock and paucity of boulders. Further support for a north-eastern source of ice is present in the form of striations: on ground unaffected by the Loch Lomond Readvance glaciers the predominant direction of ice movement is to the north-west, and this region is no exception. The striae recorded on the relevant Six-inch Geological Survey map show a very consistent direction of North 20° to 35° West in the valley between Meall an Fhuaid and Croic-bheinn and on the latter hill itself, that parallels the alignment of the moraine. However, on the other side of the Applecross moraine, east of Loch Gaineamhach, the striae by contrast are directed West 30° South, in other words, inland towards the moraine. This south-westerly direction is most likely to be associated with the general trend of striae along the Torridon trough.

The age of the Applecross moraine and the phase of glaciation that produced it are not accurately known. However, it is most likely that the Applecross substage occurred between 17,000 and 13,000 years ago : in other words this represents a glacial fluctuation that took place during the 4000 years between the end of the Late Devensian maximum and the beginning of the Lateglacial Interstadial.

It is currently believed that at its maximum the Devensian ice reached beyond the Outer Hebrides, to North Rona and possibly beyond. Therefore, the Applecross moraine is unlikely to relate to this period.

The other, initially more plausible, explanation is that the moraine ridge is part of the widespread Loch Lomond Readvance deposits. There are several strong arguments against this. If it is accepted that the ice that deposited the moraine lay on its north-east side (as argued above), the source of the glacier also lay on that side. From the moraine, which lies at about 210 m, the land falls to the north, north-west and north-east, nowhere rising above 280 m between there and Loch Torridon. This low-lying, undulating tract of country could not conceivably have nourished a glacier of any size, far less of the dimensions indicated by the Applecross moraine , during the Lateglacial Stadial. The only other possibility is that the Applecross moraine is the south-eastern lateral limit of a long tongue of ice emerging from Croic-bheinn. However, the accumulation area of the hill is far too small to have produced such a glacier: Croic-bheinn is only 494 m high, is fairly conical, and has no coire; the moraine joins the hillside more or less at 90° half-way along the straight slope. The evidence of striae presented above also argues against a movement of ice out from Croic-bheinn. The only logical conclusion is that a very large valley or outlet glacier moving westward along the Torridon fjord deposited the ridge along part of its southern margin.

The question now arises of correlation with glacial events in Britain and north-west Europe. Since the hypotheses of the Aberdeen-Lammermuir and Perth Readvances are no longer admissable (Sissons, 1974), correlatives must be sought outside Scotland.No glacial stages of the inferred age (17,000 to 13,000 B.P.) are known in England. Morner believes that there was a global event, the second maximum of the Weichselian glaciation, at 13,000 to 12,800 B.C., i.e. 15,000 to 14,800 B.P. (Morner, 1973 ). Detailed geomorphological evidence from western Norway suggests that there was a glacial stage at 15,000 to 13,000 B.P. which left moraines on the Lofoten Islands during the 'Inner Andoya Stage' (Moller and Sollid, 1972). Dating of this and earlier events was achieved by relating raised shorelines of known age to the moraines. It is at least possible, therefore, that the Applecross substage reflects a contemporaneous oscillation of the ice front over western Scotland, during the 'confluent glacier' stage, in response to similar climatic changes which affected Norway between 15,000 and 13,000 B.P. With no means at present of dating, the position in the glacial chronology must remain imprecisely defined as post- Late Devensian maximum, and pre-Lateglacial.

Outside the hypothesised Loch Lomond Readvance limits, most of the Applecross Peninsula is unremarkable in terms of glacial features. Large tracts comprise typical knock and lochan topography, while much of the remainder is denuded shelving bedrock with little or no surficial deposits save boulder ablation moraine. The north-west corner of the peninsula is an exception, and the area around Cuaig is the final one to be discussed in this section.

A group of large meltwater channels dissects the coastal area south and west of the village. These channels are some tens of metres deep, and drain in a south-east to north-west or west-north-west direction, emerging high up on the coastal cliffs. Those at present carrying rivers have been lowered to reach present sea-level, for instance the Amhainn Chuaig, Allt an t-Srathain, and the Allt na h-Eirigh. The channels are associated with thick till deposits: interspersed with the channels are large stone-strewn till mounds, elongated in a west to north-westerly direction. The mounds are fairly irregular, sharp-crested features, individually several hundred metres long and about 10 m high, and lack the symmetry of form and mutual alignment usually associated with drumlins. These features occur only in the Cuaig area, a smooth till sheet stretching to the south and south-east.

Roadside sections cut through one of the mounds near their southern margin showed the till to comprise sub-angular to sub-rounded large cobbles and small boulders, mainly of Torridon Sandstone, in a fairly coarse matrix. This till appeared to differ visually from that exposed in sections by the road to the south, where the matrix apparently contained a higher clay content and the individual clasts were smaller and less rounded. Detailed analyses would be necessary to acertain if these tills are in fact significantly different.

The smooth till sheet is bounded very clearly on its north-eastern side by a 2 km long till ridge that stretches directly north-north-west from An Garbh-meall towards the till hillocks described above, in the vicinity of which the ridge breaks up. The ridge has a remarkably flat and even crest, is 20 to 30 m wide, and on its north-east side falls as much as 30 m to the adjacent land. The height difference is much less on the south-west side, where the ridge adjoins the till sheet. These smoothly mantled slopes contrast markedly with the rugged rock knolls and heaped and scattered ablation moraine on the north-east side. Officers of the Geological Survey describe the feature on Sheet 81 as a 'boulder clay drum', and differentiate this till from that composing the till hillocks near Cuaig, and the moraine lying to the north-east. No bedrock was observed on the surface of the ridge, and it is believed to be a genuine constructional feature composed entirely of till. The regularity of form and its straightness liken it to a giant fluted moraine, and similar features are recorded in the literature (Embleton and King, 1968, pp 325-6), though they do not usually occur in isolation. (Two other till ridges do occur west of the major feature, beside the Allt na hEirigh and parallel to the coast between Lonbain and Kalnakill: in these cases, however, rock structure and/or stream erosion could at least partly account for the morphology.) As a streamlined depositional form the ridge reflects the direction of movement of the ice that formed it : the ice therefore moved north-north-west, a direction already recorded by numerous striations a few kilometres to the south (Fig. 1 ).

In the northern corner of the peninsula, therefore, two different directions of ice movement are indicated by the alignment of the crested till hillocks at Cuaig and some striae farther east (see above) that contradict the general pattern of ice-sheet movement, established by striations and the till 'drum' ridge(s). The simplest explanation of the glacial sequence here involves two stages of glaciation, the former depositing the thick and featureless till sheet and the long till ridge(s), under ice moving north-north-west, and the latter involving ice derived from a more easterly source, eroding the previous till sheet and creating the large moraines near Cuaig. On deglaciation, this ice also deposited much ablation moraine (e.g. in and around the Amhainn Chuaig valley), and its meltwater probably eroded the channels among the till hills. Since it is known that a separate stage of glaciation occurred just to the east, producing the Applecross moraine, it is reasonable to infer that the Applecross substage also was responsible for the unique depositional and erosional features around Cuaig. It seems, therefore, that the former ice margin can be imprecisely traced beyond the Applecross moraine, using the till sheet border and the southern margin of the group of till mounds.

It should be noted that B.N. Peach in 1893 arrived at the same conclusions regarding the glacial history of this area, having observed the landforms during geological mapping in the field .......

'as the Torridon sandstone sinks northwards, it passes under boulder-clay, which is arranged in drumlins, with their larger axes parallel to the general trend of the striae. Still further north the drumlins, which belong to the time of greatest glaciation, are truncated obliquely by rampart-like mounds ranged in a W.N.W. and E.S.E. direction. These are the moraines of a large valley-glacier which, to judge from the arrangement of the moraine-mounds and the direction of ice-striae on the rocks, flowed out of the hollow of Loch Torridon during a later time of glaciation'.....(Geikie,A., 1894, p. 268).

Further evidence supporting the hypothesised Applecross substage limit is presented in Chapter 6, where it is shown that the marine limit (the highest Lateglacial sea-level) is lower in this region of north-west Applecross than to the south.

## 3. The Lateglacial Period.

The evidence of the third phase of glaciation, the Loch Lomond Readvance, will now be considered in detail. This final advance of the Late Devensian ice took place during part of the Lateglacial period, which throughout this work is considered to have lasted from ca. 13,000 to 10,000 radiocarbon years B.P.,being thus in accordance with the Quaternary stratigraphy proposed by Mangerud et al. (1974) for Norden. Their term 'Late Weichselian Substage' is therefore identical to the term 'Lateglacial period' as used here. The chronology recommended by Mitchell et al. (1973) is rejected since no subdivision of the Late Devensian is proposed, and since this period lasts from 26,000 B.P. till 10,000 B.P., the time span is too broad for convenience.

The Lateglacial period is subdivided on climatological grounds into two major phases, an Interstadial and a Stadial. Though uncertainty exists as to whether the Interstadial can be further subdivided by a colder oscillation, it is assumed for the time being that in Wester Ross there was only one non-glacial phase followed by the Loch Lomond Readvance or Lateglacial Stadial. Precise dating of the Interstadial/Stadial boundary depends upon the criteria chosen to define the onset of cold conditions : the conventionally accepted date is 10,800 B.P. The conclusion is drawn that a more severe climate began to be reflected in environmental change at that time. The reappearance of glacier ice, however, could have occurred centuries earlier: this is a problem that will be discussed later, in the chapter dealing with environmental inferences drawn from the evidence of pollen analysis.

Prior to the Lateglacial period, which began about 13,000 B.P.

and coincides with the first biotic evidence of climatic amelioration (Coope, 1975; Pennington, 1975a), the Late Devensian is not further divided. No 'pre-Interstadial'period is envisaged to fall within the Lateglacial period since this would logically be part of the previous Stadial, i.e. glacial conditions being prevalent. The Lateglacial period ends at 10,000 B.P., by which time deglaciation is assumed to have been complete, and very rapid environmental change was occurring and was continued throughout the subsequent Postglacial period.

The term 'Postglacial' is preferred to 'Flandrian', since the latter has been defined in different ways (West, 1967; Mangerud et al., 1974). 'Postglacial' as used here refers to the period succeeding the Lateglacial Stadial, theoretically commencing at ca. 10,000 B.P. (Mangerud et al., 1974). In the field area the Lateglacial/ Postglacial boundary is clearly defined in litho- and bio-stratigraphical evidence from the Glasscnock pollen site (Chapter 7), but no absolute date is attached to it.

The remainder of the chapter is concerned with all glacial and fluvioglacial features associated with the Loch Lomond Readvance in the study area. Periglacial features are considered separately in the following chapter, since these form a distinct suite of landforms and have different origins.

The Evidence for Loch Lomond Readvance Glaciers in the Western Area.

Where Loch Lomond Readvance glaciers are concerned, the Western Area (Fig. 4a) falls naturally into two unequal parts, separated by the valley of the Applecross River. The main centre of ice dispersal was the high plateau comprising Meall Gorm, Sgurr a' Chaorachain and Beinn Bhan; from this dissected tableland glaciers flowed outwards in all directions except to the south-west. To the north-west lay a minor accumulation area centered upon Meall nan Doireachan, which nourished two very much smaller glaciers, and includes the small glacier on Meall an Fhuaid. The former part is considered first.

On the eastern side of the plateau are three deeply incised glacial valleys that increase in dimensions to the north. The Coire nan Arr valley is the largest and separates Beinn Bhan from Sgurr a' Chaorachain: it is a typical U-shaped valley terminating abruptly in a deep trough head. The valley sides are steep throughout and near-vertical on the north-facing scarp of Sgurr a' Chaorachain, the cliffs reaching over 450 m in height. By contrast, the valley floor has a very gentle gradient in its upper reaches : 1 km from Loch Kishorn it starts to descend more rapidly towards the fjord, being thus a hanging valley. All three valleys which open onto Loch Kishorn from the plateau have similar profiles, though the more peripheral Coire Sgamhadail is a much shallower and less well-developed feature.

These three valleys contained glaciers in the Lateglacial Stadial. Lateral moraines delimiting the snouts occur at the ends of the valleys where the glaciers were able to spread out, unrestricted by the steep trough sides, and started to plunge down towards the Kishorn fjord. One end moraine only is (periodically) visible marking the terminus of the Coire nan Arr glacier, which spread over what is now the estuary of the Kishorn river, and the head of the loch. This moraine comprises an arc of boulders protruding above the intertidal sand and mud flats, extending across the shore to be continued upslope as the innermost lateral moraine on the south-west side, and as the inner margin of the lateral moraine belt on the opposite side of the valley. The maximal extent of this glacier must have reached the north-east shore of the loch, and evidence to confirm this exists in the presence of numerous large perched erratic blocks of Torridon Sandstone on the shore and rock platform at Seafield Farm. Between these two limits lay another two, recorded only in the long strings of boulders that descend the hillside west of Russel Farm. These moraines are excellent features several metres high and wide, stretching for approximately 1 km between the road and shore, consisting of sandstone boulders (which attain maximum dimensions of ca. 5 m) heaped together to form parallel ridges, the intermediate ground also being liberally strewn with moraine blocks. The moraine ridges were presumably buried or destroyed on the former (Postglacial)beaches of the loch, since today on the raised beach fragments near Russel only one small rounded ridge continues the line of the innermost moraine. Where no beach was formed the moraine rubble continues right down to the present shore : the glacier limit is clearly demarcated thus on the beach.[1]

Up-valley, the lateral moraines disappear as the ground steepens beyond the valley entrances, Several low linear moraine ridges trace the movement of the ice out from the great south-western buttress of

1: Between Russel and the Allt a' Chumhaing valley much of this evidence has been destroyed since 1974 during the creation of an oil-platform construction yard.

Sgurr a' Chaorachainn: these trend obliquely downslope, and from their position and dimensions are most probably fluted moraines rather than ice-marginal deposits. Flutings also occur abundantly on the opposite side of the valley where the gradient steepens down to the loch : these are best seen on aerial photographs or from a distance in the field, where the corrugated effect shows up in sharp contrast to the near-horizontal shelving bedrock of Beinn Bhàn. In the field fluted moraines are frequently, as in this case, difficult to pick out from the general cover of peat, rock and moraine on the valley floor.

Much of the upper valley is filled with moundy drift, individual hummocks being a few metres high. The limit of ice here can only be approximated : a clear drift limit encircles the whole of Coire nan Arr, marking the junction between the scree-mantled steep upper slopes and the drift-plastered lower slopes, and as this junction grades into the lateral moraines in the east, it is possible that at least in the middle part of the valley this marks the former ice-margin. A small tongue of ice descended from Coire a' Chaorachain into the main valley : again, drift mantles the coire floor, and one distinct moraine fluting descends eastward from the backwall. The question whether or not the Coire nan Arr glacier was confluent over its breached backwall with the Coire Attadale glacier and the Coire nan Cuileag glacier will be considered later, once the general pattern of the glaciation of the massif has been described.

To the south-west of the Coire nan Arr glacier lies a deep, stepped valley : the lower and major portion of it is Coire na Bà, while perched 100 m or more above is Coire Beag na Bà. This much narrower but equally precipitous valley held a glacier that at its terminus almost joined that described above. Lateral moraines trace the former limits : again four lines can be discerned on the steep loch-side slopes. They are well-developed on the eastern side, forming ridges of boulders and finer moraine debris that curve discontinuously down from the south-western flank of Sgurr a' Chaorachain. Up-valley the moraines are less clearly distinguished, but generally three low ridges can be traced in the belt of moraine before it disappears on the steep valley slopes below the Sgurr. On the south-west side of the glacier, the steep shoulder of Meall Gorm rising from the loch seems to have restricted the outward spread of the glacier, and here again there is only one broad band of moraine, containing a single clearly defined ridge, to delimit the glacier. Unlike the situation in Coire nan Arr, traces of all four successive limits at the former snout are seen on land (the outermost being along the shore). A small meltwater channel, occupied by a misfit stream, crosses the hillside between the margins of the two glaciers, proving their contemporaneity.

The third valley, Coire Sgamhadail, is a smaller and much less impressive valley, and contains correspondingly inferior moraines. The glacier snout produced only two limits, or only two are clearly preserved, again low ridges of boulders and drift that curve downslope more or less continuously over hundreds of metres from where the valley opens onto Loch Kishorn. The innermost margin is linked to the lateral moraine on the western side, a belt of moraine rubble emerging from below the cliffs on Carn Chalein. As in the previous two cases the margins are not defined in the upper reaches of the valley, but a drift limit can be traced around the valley, with occasional patches of fluting and hummocky moraine lower down.

Coire Sgambadail, like Coire na Bà, has a major rock step across it, levelling out at 300 m : above it the valley head is a wide basin-shaped depression, presumably effective in accumulating snow despite its rather low altitude. The valley step is built of successive shelves of sandstone, which at the top of the steep rise show evidence of intense ice-plucking, with great clefts aligned across the valley reaching over 5 m deep where blocks were prised and pulled apart along joint planes; elsewhere are blocks delicately balanced in heaps.

Striations in these three valleys confirm the evidence of the moraines : ice moved down-valley in a south-easterly direction in contradiction to the previous movement of the ice-sheet towards the north-west, a fact noted by Horne (1899a).

This pattern of small valley glaciers moving outwards from the core of the Applecross plateau is repeated on the north-east side, where a series of small tongues nourished by the Beinn Bhàn ridge emerged from the coires and coalesced to form a long apron of ice, or piedmont glacier, on the lower slopes of Beinn Bhàn. Four coire glaciers were thus united, and a further two glaciers occupied smaller coires farther north on the ridge.

The southern limit of the piedmont lobe was formed by the small glacier that occupied Coir Each : no moraine ridge is present, but there is a very clear drift limit, with bare sandstone ribs to the south that are masked by the moraine cover to the north. A medial moraine marks the former junction of the Coir Each ice and that descending from Coire na Feòla : this long, low broad-crested ridge is <u>ca</u>. 50 m wide over its kilometre length, though less than 4 m high. It tails down from the spur that divides the two coires, and is surrounded by numerous well-developed flutings that plunge downslope as low parallel ridges, strewn with boulders and separated by shallow wet troughs. These moraines tend to disappear on the lower, flatter ground. On the northern side of Coire na Feòla is a second medial moraine, a great belt of boulders commencing at the ridge A' Chioch, and continuing downslope almost as far as the terminal complex. Both these coires are floored by sandstone bedrock eroded into flat, smooth plates, with a thin scatter of fine morainic material, and much peat in the hollows. As in all of the coires in the Applecross plateau, the sidewalls are draped with scree, and talus cones have accumulated on the coire floors. This activity has destroyed or obscured any evidence of a former ice margin that may previously have existed (e.g. trim lines), so the postulated limits on back and sidewalls are tenuous.

The third coire on the Beinn Bhàn ridge is fairly complex in shape, unlike the others. The headwall has a distinct step in it, at ca. 520 m, 10 m above which is another small shelf. Both these steps contain tiny rock basin lakes which are deep in relation to their areas. Above the shelves the coire headwalls continue to rise vertically for another 370 m, and below them another steep wall descends 120 m to the relatively gently dipping area around Lochan Coire na Poite. Glacier ice evidently was present in the rock basins, for flutings in drift corrugate the cliff below them : from here the glacier swung to the north-east, and then turned towards the south-east. The rocky hill Druim Glas (821455) is crossed by many fluted moraines, best seen from a distance, which show quite clearly how the ice emerging from Coire na Poite and Coir' an Fhamhair diverged once free from the restriction of the spurs A' Chioch and A' Phoit.

The fourth coire of this group, Coir' an Fhamhair, also contributed to the ice flow eastwards, and in front of A' Phoit the two glaciers must have been confluent. Topographic control directed most of the ice south-eastwards into the Lochan Coire na Poite basin, but a small tongue also turned to the north-west, where a perfect end moraine is preserved delimiting the former ice lobe. The moraine ridge commences as a large boulder-strewn mound about 15 m high, from which a round-crested ridge 10 m high loops downslope towards Loch Gaineamhach (8246) and back up on the western side, skirting the base of the cliffs. It is probable that the large quantities of littoral sand that give Loch Gaineamhach its name (sandy loch) are derived from the outwash of this glacier.

Fluting on the northern end of Druim Glas indicates that ice from the southern half of Coir' an Fhamhair flowed in very close proximity to the minor lobe, the two being confluent if contemporaneous, thus making part of the well-defined margin a medial moraine. The lateral extent of the adjacent ice can only be approximated by tracing the cover of drift : on the north-east side of the Allt Loch Gaineamhach is a fairly distinct zone with many boulders, which correlates well with the clear drift limit farther to the south. Why the smaller (northern) lobe should have produced such a remarkably well-defined limit while the neighbouring ice did not form any marginal moraines is not known, though the roughness and steepness of the topography traversed by the latter glacier may have had some prohibiting influence. The existence of only a single moraine delimiting the northern Coir' an Fhamhair tongue is interesting in view of the fact that throughout the field area (e.g. the Kishorn termini) there is substantial evidence for several oscillations of the ice front while near its maximum Lateglacial position. It is possible that the Coir' an Fhamhair northern lobe relates to only one of the four stages, logically the first and most extensive advance, possibly when the exit to the south-east was inadequate. However, it is equally possible that only some glaciers were balanced sufficiently delicately to respond to the factors causing the oscillations, and these Beinn Bhàn glaciers may have had but one readvance, stillstand and retreat.

The end moraine complex of these four glaciers, which coalesced to create a piedmont lobe, is a collection of rather poorly defined sub-parallel mounds and ridges. At the south end is one distinct curving ridge, under 10 m high, which borders the moraine complex and probably marks the maximal ice extent. No pattern was seen in the assemblage of boulder-strewn moraines, except that they are aligned at 90° to the flutings descending from the coires above. It is possible that meltwater from the retreating glaciers destroyed much of formerly more continuous ridges.

The southern-most of the independent glaciers on Beinn Bhàn was nourished in Coire Toll a' Mheine, a fairly large coire perched high up on the ridge, facing north-east. Despite excellent lateral limits, especially in the northern side, this glacier left no clear trace of its former terminus. On the southern side of the coire fluted moraines stream out of it from the rock face: the outermost of these also delimits the drift spread, and here the contrast with bedrock makes the former ice margin position obvious. Below the flutings is an area of steep-sided hummocky moraines, which reach 10 m in height and are strewn with sandstone blocks. East of the small river that enters Loch Lundie, these moraine hummocks grade into bedrock knolls which are also liberally scattered with boulders; hummocky moraine again appears to predominate just before the ground starts rising toward Beinn a' Chait. A line can be drawn separating this hummocky and drift-strewn area from the surrounding land where bare rock ribs predominate, but in this area the exact limit of the Loch Lomond Readvance glacier cannot be more precisely defined. It is highly probable that at least in part it is submerged by Loch Lundie.

High up on the northern side of the coire is a series of lateral moraines : within a belt several hundred metres broad there are at least three separate moraine ridges that extend discontinuously downslope for over 0.5 km. These ridges are remarkable both for their excellent state of preservation (some looking more like stone walls than natural features) and for the elevation at which they occur. These are the highest lateral moraines found in the field area, commencing at about 550 m on the shoulder of Beinn Bhàn. The innermost ridge is the best feature, comprising a linear accumulation of boulders, ca. 8 m wide and under 3 m high, reaching several hundred metres in length. The other marginal deposits form lower and more scattered lines. Lower down, where the glacier swung round to the north, a single lateral moraine borders the drift-covered and hummocky area above the loch. Towards the shore this feature disappears, and as to the south-east, only a contrast between drift and bedrock continues the presumed margin.

The northernmost coire on the ridge is Coire Gorm Beag, a feature so broad and shallow that it scarcely deserves the term 'coire'. However, it nourished a small tongue of ice, the limits of which are again obscure. One short lateral ridge high up on the south side tails downslope into a broad boulder scatter and some moraine hummocks. Inside this line the hillside has a relatively dense covering of moraine, flutings occurring on the upper slopes. These and striae indicate ice movement directly downslope towards Loch Lundie, under which lies (presumably) the end moraine, if any ever existed. The northern limit of the ice may be assumed to have been associated once again with the limit of the drift that forms a veneer of varying thickness over the protruding sandstone ribs.

On the opposite side of the Applecross plateau, two coires facing north-west contained relatively large glaciers by comparison with those so far described. Coire Attadale is a deep glacial trough between Beinn Bhàn to the north-east and Carn Dearg to the south-west. Like Coire nan Arr immediately south of it, it ends abruptly in a trough head, rising 230 m to the Bealach nan Arr, a breached watershed at 600 m. The Attadale trough has a simple long profile, with a long gradual rise up the valley into the flat-floored peaty trough head. The latter area is occupied by several small lochans, interspersed with hummocky moraine, some of which is fluted. The Attadale glacier deposited the longest Lateglacial lateral moraine in the field area on its western margin, continuing north-westwards for 1.5 km the line of the Carn Dearg ridge. This superb feature is a low belt of Torridon Sandstone boulder moraine _ca._ 15 m high, about 60 m wide at its maximum, and is bounded by a steep bank along the proximal side. The outer margin is less distinct, having little or no relief. This may in part be due to the thick peat that clothes the surrounding slopes. Towards the Applecross valley the moraine becomes less distinct, and where it turns south-westwards plunging into the steep-sided valley no single ridge is present, but a whole suite of low and rather vague mounds trend obliquely downslope, much eroded and confused by the gullies that dissect the hillside. Similar moraines indicate part of the former ice margin on the north-western side : from the western extremity of the Beinn Bhàn ridge descends a belt of low (under 2 m high) round-crested ridges for a few tens of metres. No other clear indication of the limit is evident in this region. The head of the Applecross valley is choked with thick, gullied till, which on the west-facing slopes has slumped in two places to form spoon-shaped depressions, through which flow small tributaries of the Applecross River. Hummocks in the drift reach a maximum height in the valley bottom, being about 7 m high, their size decreasing upslope. The hummocky relief is enhanced by the numerous small channels and gullies that drain the slopes.

The Attadale glacier terminated in the lower valley of the River Applecross, some 8 km from its source. The outer limit comprises a linear till ridge reaching 6 m in height, curving upslope on both sides of the river. On the north-west side a second longer ridge parallels the outer one, several tens of metres inside it. The limit on the opposite side of the valley is a stony ridge abutting against the uppermost of a series of kames that clothes the lower valley side near Applecross House. Inside the valley glacier limit no such fluvioglacial features exist. Mutually-parallel meltwater channels incised across these deposits were probably eroded by proglacial streams issuing from the Lateglacial ice. The continuity of both channels and kames has been subsequently disrupted by river erosion by the Allt a' Chuirn Deirg and the Allt Beag. Other depositional features in this area related to pre-Lateglacial ice decay include a beaded esker, and several channels draining more directly downhill among the kames.

Further retreat stages of the Lateglacial ice occurred about 1 km upstream, and are marked by a large irregular mass of moraine in the valley bottom and its associated lateral features. The well-defined south-eastern limit of the moraine represents the second still-stand or readvance position of the ice. Two short lateral moraines on the north-west side of the valley trend uphill at a shallow angle above the complex, and are probably related to this former ice margin. The morainic mass is crossed by some minor ridges, the best-developed being on the upvalley side, from where they are continued by clear lateral moraines on the north-western valley side. Two such boulder-strewn, sharp-crested ridges rise for several hundred metres above the valley floor, they then coalesce and eventually merge upvalley into broad linear tracts of boulders on the steep hillside. The innermost lateral moraine is a lower feature running parallel with the earlier ridges, swinging round to cross the terminal complex on its inner side. It appears, therefore, that at least four main ice marginal positions existed here during the Stadial, and further minor fluctuations are implied by the double lateral features described above.

Contemporaneous with the large Attadale glacier were four very small ice lobes, situated immediately above and north of the valley glacier. The ice tongue in Coire Glas was probably the smallest glacier in the field area : it covered ca. 0.25 square km and terminated at a point some 0.75 km from the headwall. A single moraine ridge that reaches 4 to 15 m high on its proximal side (under 10 m on the distal side) curves down from the south-western side of the re-entrant, swinging to meet the moraines opposite in a pointed terminus. The limit on the north-eastern side comprises three or four much shorter and lower ridges. The floor of the tiny 'coire' slopes steeply valley-ward, and a true sidewall is absent on the south-west side : the former ice tongue might therefore be best classified as a niche glacier (Groom, 1959). Below the moraine terminus is the apex of a large debris cone, presumably an outwash fan from the Coire Glas ice. The fact that this fan underlies the Attadale glacier moraine complex (see above) on the north-east side implies that the cone predates the moraine, i.e. that the Coire Glas glacier was active when the Attadale glacier had retreated upvalley beyond the moraine complex, thus allowing the cone to accumulate. The Attadale ice must then have readvanced to just below Coire Glas, leaving the south-west part of the fan intact. It can be inferred, therefore, that at least one of the three subsidiary stages in this case was a readvance, and not merely a period of equilibrium during general retreat.

The second small ice tongue also flowed to the south-west, high above the Applecross river valley in Coire Muchdaroch. Again lateral and end moraines record the former glacier margin : lines of sandstone blocks descend sharply from bedrock ribs on the south-western side, swinging round to connect with the 6 m high end moraine, that is in turn continued to the north by another area of boulder moraine. Inside these features is a smooth drift hillside : outside, bedrock predominates. It is probable that ice also spilled north-west through the headwall breach, to occupy the An Dubh-loch depression : the small channel incised into the floor of the breach certainly implies a continuous ice cover at some stage. Moraine hummocks exist south-west and north of the loch, but the former ice margin can only be suggested with reference to the distribution of these mounds and bouldery drift.

The third minor glacier in this area was nourished on the steep east-facing slopes of Meall an Fhuaid. Excellent fluted moraines stripe the eastern slopes of this hill : these features are short (only a few tens of metres long at most) round-crested till ridges trending

Fig. 6:1. The Applecross plateau, looking over the head of Coire nan Cuileag to Beinn Bhan.

Fig 6:2. Maol Chean-dearg from the west, Coire an Ruadh-staic on the right.

directly downslope , ceasing abruptly on the valley floor. An arcuate sprawl of hummocky moraine and short moraine ridges defines the former ice limit : beyond it the ground lacks moraine. Striations on the lower hillside support the implications of the fluted moraines. Meltwater from this glacier probably flowed both north and south : it is possible that the deep cleft through the Applecross moraine less than 1 km away was cut in part by Lateglacial meltwater.

The other large glacier on the north-western side of the Applecross plateau flowed out from Coire nan Cuileag. This is a shallower and less steep-sided trough than Coire Attadale, and this may account for the smaller dimensions of the glacier that occupied it in the Lateglacial Stadial. Again, as in the Attadale situation, the lateral moraine on the glacier's western margin remains a well-defined feature while the eastern margin is not so clear : this is probably due in both cases to the topography of the valley sides, moraines being formed and preserved only on the gently sloping land on the western sides. Several parallel ridges of sandstone blocks stream north-west from Creag Gorm (the road follows this line for several hundred metres here), each ridge being under 6 m high, round-crested, and incorporating minor mounds along its length. This moraine complex swings north to skirt Carn Breac, and terminates in a belt of moraine hummocks south of Lochan Dubha. In this case the belt of hummocky moraine very clearly indicates the former ice margin. Inside the limit the valley floor is only sparsely covered with moraine : some small flutings near the lochan are evident, but only at the head of the coire are these relatively frequent. No former ice limit exists on the western flanks of Carn Dearg, but a strip of hummocky moraine extends right along the hillfoot and into the upper Allt a' Chuirn Deirg valley. At the southern end of this belt the mounds are quite large (10 m high) rounded features scattered with the inevitable sandstone blocks : in the steep-sided river valley 2 km away the moraines are aligned diagonally to form a chevron pattern, and individually are much smaller and neater features, generally about 5 m high and 3 to 4 m broad. Some rock knolls and ridges are present among moraine hummocks a short distance upstream from here.

The last glacier on the central Applecross plateau to be considered here is the one that occupied Coire nan Clach, a very small valley perched at 530 m immediately north of Meall Gorm. Evidence for occupation by local ice is present in the form of striations and moraines. Horne (1899a) postulated a small ice tongue moving westwards down the valley, having spilled over from the trough head of Coire Beag na Bà. This deduction was based upon clear striations indicating such ice movement (south 28° west) superimposed upon an earlier set (west 30° north). Horne also noted local moraines and the innumerable boulders in the little valley. The moraine mounds are concentrated in the valley bottom : they are smoothly rounded hummocks 2 to 3 m high. A large curving moraine descends several hundred metres from the cliffs of Meall Gorm. This is an 8 m high, broad ridge composed of loosely packed sandstone boulders, and within a few metres west of it the thick, blocky drift thins out and stops. This presumably marks the margin of the former ice lobe. Unfortunately, the margin of the ice is not so clear on the northern side, where the moraine blocks are everywhere thinner upon the ground, and thus a drift limit is difficult to establish. However, the degree of topographic control on ice movement in this site allows a fairly accurate estimate of the northern limit to be made.

One region of the plateau that presents a problem is the area stretching from the upper Allt Beag valley towards Coire nan Clach.

No evidence exists for occupation by local ice other than an area of well-developed hummocky moraines between the Allt Beag and its tributary from the east, on the western slopes of Carn Breac. These mounds are under 5 m high and boulder-strewn, and have a clear upslope limit : outside the area is the ubiquitous peat and sandstone. No evidence was found of ice having spilled over from the adjacent Coire nan Cuileag glacier, since the area between the hummocks and the lateral moraine lacks glacial deposits. Downstream the mounds grade into a more general drift cover. There is no end moraine, but the hummocks cease just above the confluence of the two rivers, giving way to a narrow valley bottom thickly infilled with drift, and farther downstream, with the fluvioglacial deposits connected with ice-sheet deglaciation (p. 37 ). Another separate and smaller patch of moraines exists north-east of Loch Odhar, but these larger hummocks are less typically Lateglacial in nature. If the existence of 'typical' hummocky moraine alone were sufficient justification, ice was last present in this basin in Lateglacial times, but in the absence of substantiating evidence, this cannot be confidently inferred.

A problem concerning ice limits around the central plateau is related to the coire backwalls, in particular Coire Beag na Bà, Coire nan Cuileag, Coire nan Arr and Coire Attadale. The evidence for ice having overridden the col between Coire nan Clach and Coire Beag na Bà is quite conclusive : in the other cases evidence is not so strong, partly because both ice sheet and Loch Lomond Readvance ice moved in approximately the same direction, and striae are therefore of little help. There are four possibilities : that the four glaciers were at no time confluent over their breached headwalls and functioned as separate ice lobes, or that glacier ice formed links between one, two, or all three possible pairs of coires, i.e. over the Bealach na Bà, Bealach nan Arr, and across the ridge joining Carn Dearg and Sgurr a' Chaorachain.

Evidence of moraines is not conclusive : flutings descend the relatively gentle headwall of Coire nan Cuileag, but are not continued over the watersheds : a few moraine-like mounds are present beside the road in the Bealach na Ba, but without excavation it is impossible to tell if these are true moraines or rounded, drift-strewn rock knobs masquerading as moraines. Even if these could be shown to be morainic, the age is debatable. Only one of the cols, Bealach nan Arr, has a 'swept' appearance with smoothly eroded sandstone slabs and an extremely sparse boulder cover, in sharp contrast to the deep felsenmeer immediately east of the col (p. 92 ), higher up on the Beinn Bhàn spur. This may be indicative of a very narrow ice connection between the two trough heads. The col between Coire nan Arr and Coire nan Cuileag is only 15 m higher than the Bealach nan Arr, but apart from the edge of the precipitous cliffs on the south-east side, the bedrock slabs here are thickly strewn and even piled with sandstone blocks : most appear to be moraine (of ice-sheet or later derivation) but others have the appearance of frost-rived bedrock blocks that have collapsed and piled up more or less in situ. No distinction can be made between areas of frost shattering and areas covered with moraine debris : the whole of the headwall area of Coire nan Cuileag is a chaotically boulder-strewn wilderness with no apparent clues to help solve the problem. A survey of the distribution of erratics might be of value in inferring where Loch Lomond Readvance ice had existed and removed earlier-deposited moraine blocks. A purely subjective opinion formed when studying the area was that erratics are notably scarce in the central headwall area of Coire nan Cuileag (775435) but are definitely present and more common on the problematic ridge above Coire nan Arr. A reasonable deduction, if this observation were reliable, would be that in fact Loch Lomond Readvance ice did not cross the col.

The Bealach na Ba is the highest pass of the four, at 625 m . The moraine-like mounds have already been mentioned; no reliable indications of late ice occupation were found. Of all the passes, this one is the most likely to have held a snow or névé cover, being a relatively sheltered and flat area as opposed to the other narrow and exposed cols. It is therefore, conceivable that glacier ice built up in the hollow between Meall Gorm and Sgurr a' Chaorachain, either independently at first or associated with the expanding glaciers to north and south.

From the very tenuous evidence outlined above, no confident conclusions may be drawn. The writer's subjective opinion is that ice did traverse the Bealach nan Arr, and despite the absence of firm evidence, it is inferred that the plateau basin lying between Meall Gorm, Sgurr a' Chaorachain and Carn Dearg did harbour glacier ice during the maximum of the Loch Lomond Readvance, thus linking the glaciers to north and south. The tops of the mountains and the flat expanse of the Beinn Bhàn ridge certainly would not possess deep snow fields : presumably these parts would be subject then, as now, to high winds, prohibiting snow lie but causing drifting into the deep and sheltered coires that nourished the Loch Lomond Readvance glaciers.

# CHAPTER THREE

'These ridges have been a fruitful source
of wonder and legend to the people......'

(Geikie, 1865, p. 309)

The evidence for Loch Lomond Readvance glaciers in the Eastern Area.

Whereas the Western Area during the Lateglacial Stadial comprised a core of land with glaciers radiating from it, the region inland was a network of glaciers around nine nunataks. Few of the glaciers were independent and self-contained, as were the majority in the Applecross Peninsula, but high-level cols were created or utilised and confluent glacier ice formed an ice cap that reached from Glen Torridon to Strathcarron, and from the Coulin Forest to Beinn Damh. This interconnection of glacier ice makes the area difficult to subdivide for description, so the evidence for the Loch Lomond Readvance will be presented in sequence, as far as possible, from west to east across the area.

A major centre of ice dispersal in the west was Maol Chean-dearg. From here ice streams moved north towards Glen Torridon; eastwards into Coire Fionnaraich and thence south to Strathcarron and north to Glen Torridon; and south-westwards towards Loch Coultrie. From the latter stream, which is discussed first, a tongue crossed into Coire Roill to the north-west.

The south-western outlet from the centre of ice dispersal will be referred to by the name of the valley, Strath a' Bhàthaich. The glacier that occupied this valley reached <u>ca.</u> 6 km in length, depositing one clearly defined outer end moraine (Druim Dubh) flanked by long lateral moraines, and three inferior terminal ridges within several hundred metres inside it. Ice was contributed to the Strath a' Bhàthaich glacier by two large coires on its south-eastern side : Coire an Ruadh-staic and Coire nan Cadham. A third, smaller glacier situated to the south-west, emerging from the Cadh an Eididh basin, failed to reach Strath a' Bhàthaich and will be described later. The limit of the major outlet glacier is particularly important in the study because two sites, intentionally chosen at either side of the end moraine, were used to provide cores for pollen analysis in order to help prove the age of the glacial readvance responsible for such features.

Druim Dubh (i.e. 'black keel') is a curved moraine ridge 20 m high on the south-western valleyside as far as the Amhainn Dearg, the river having eroded through the moraine and destroyed that part of it. The ridge is asymmetrical with a more gently sloping and lower proximal side, and a steeper, more boulder-strewn slope facing downvalley. On the northern bank of the Amhainn Dearg it is continued as a belt of low curving ridges and mounds, rising obliquely uphill for a few hundred metres. Thereafter the former glacier margin can be traced by a clear drift limit along Meall na Saobhaidhe. The lateral limit on the south side is more spectacular : a continuous boulder ridge stretches upvalley from immediately above the south-east end of Druim Dubh into the entrance of Coire nan Cadham. The moraine forms a single feature 5 m high at its lower end, after some tens of metres branching into several lower and separate ridges. Both of the local rock types, Torridon Sandstone and Cambrian Quartzite, are present in the moraine rubble. A lower set of ice marginal deposits skirts the cliffed valley side and merges into moraine hummocks just inside the end moraine. This series of large elongated mounds and low ridges presumably defines a later stage during ice decay, and probably correlates with one or more of the three retreat stages. These minor end moraines are not impressive features in the field, being low (3 or 4 m) discontinuous stony ridges parallel to Druim Dubh, separated by several tens of metres of very wet bog. In this region all of the flat and gently sloping valley floor is poorly drained : farther upvalley, bedrock ribs emerge and beyond the river confluence, hummocky moraine appears.

The inner lateral moraine belt is comtinued eastward into Coire nan Cadham by a well-defined low ridge bordering a spread of quartzite rubble, and continues to join the coire headwall on the south side. This same point is reached by the upper lateral moraine, continued for the final few hundred metres by a drift limit in the steep, boulder-strewn sidewall. Further proof of glacier movement out of the coire and downvalley is present in the form of fluted moraines, long low moraine ridges swinging round to the south-west once free of the coire walls. Hummocky moraines, also aligned approximately west-east, cover an area of the coire floor, which elsewhere is typically composed of smooth shelving bedrock, peaty hollows, and a scatter of fine and coarse moraine rubble.

Fluted moraines are extremely well developed on the north-west spur of An Ruadh-stac, between Coire nan Cadham and Coire an Ruadh-staic. These superb features reach from 2 to 4 m in height and from a few tens to hundreds of metres in length, streaming out downvalley from the rocky spur (Fig. 6:2). Hummocky moraine is present in the western part of Coire an Ruadh-staic, and north of this is another area of exceptionally fine fluting, in this case adjoining the south-west shoulder of Maol Chean-dearg. It is apparent that in the field area the most extensive development of fluted moraine occurs immediately beyond such spurs or rock bastions : further examples will be noted. At the head of Coire an Ruadh-staic two cols lead south and east : from the occurrence of large moraines immediately below these cols and the distribution of frost-shattered and moraine blocks, it appears that ice overrode both. The mounds east of the lochan in Coire an Ruadh-staic just below the headwall are very large (ca. 15 m high) somewhat flat-topped, and steep-sided features, with several kettlehole lochans among them.

Probably the most remarkable features produced by the Strath a' Bhathaich glacier are the linear hummocky moraines that occur among the more typical moraines littering the valley bottom and lower side slopes, from the south-western shores of Loch an Eoin to within 1 km of the former glacier snout. Between the latter point and the Allt an Ruadh-staic, the mounds are fairly typical Lateglacial moraines : irregularly shaped, haphazardly grouped, and interspersed with wet depressions. However, upvalley from the Allt an Ruadh-staic the nature of the mounds is different and very distinctive, for they are low (5 m high) short, linear, sharp-crested ridges. Below Maol Chean-dearg, on the slopes between the Amhainn Dearg and the Allt an Ruadh-staic, the trend is from south-east to north-west, i.e. not directly downhill but at a slightly oblique angle. The moraines consistently repeat this pattern wherever they occur on the upper hillfoot slopes : they commence immediately below the great quartzite screes of Maol Chean-dearg and are themselves (as far as can be seen) completely composed of quartzite rubble at this point. Below the north side of the Coire an Ruadh-staic re-entrant, the upper margin of these ridge moraines falls and is replaced by an area of fluted moraines which indicate formation by ice moving south-eastwards out of the coire. One very small area of hummocks adjacent to these flutings shows quite clearly that here the flutings are superimposed upon the moraine ridges, yet elsewhere no overlapping has occurred along the common boundary. Another larger area where superimposition seems to have occurred exists nearer the valley floor, around a small kettlehole lochan (907498) : here the two directions are not so clear, but a downvalley alignment is confused with the north-westerly trend of the moraine ridges, which here are much broken up, presumably by subsequent ice movement in the downvalley direction.

South-westwards from this main area of linear moraine ridges is another small patch on the south bank of the Allt an Ruadh-staic, immediately east of the river confluence : these ridges are similar in form to those described above, but are oriented east-west. On the opposite side of the valley from this the moraines are much more typical, some being conical or ridged while others are totally irregular, no particular alignment being obvious. Farther upvalley on the north side, below the small coire-like feature, (900504), similar moraines to those on the south bank occur, with the appearance of two conflicting and superimposed orientations, though in this case the alignments are not so clear. One set seems to trend more or less directly downslope, while the other is downvalley. The proportion of Torridon Sandstone debris increases markedly from south-east to north-west across the valley, reflecting the distribution of bedrock types below the surface drift.

The final major area of hummocky moraines occurs in the head of Strath a' Bhathaich, and continues over the low watershed to Loch an Eoin : these hummocks are densely strewn with boulders, much sandstone being present here. At the south-eastern edge is a distinct alignment of individual mounds that is predominantly downvalley, while farther north and north-west individual mounds tend to be elongated, where at all, in an irregular fashion across the valley. Once again, some of the latter might be explained as ridges originally directed downslope (i.e. from the foot of Maol Chean-dearg) but subsequently altered by later ice moving at 90° to them. The general impression given by this area on the aerial photographs is of a chaotic assemblage of small boulder-strewn hummocks, incorporating many wet hollows and with no clear overall pattern or orientation.

The unusual small aligned ridges pose the question of genesis. Throughout the above description they have been referred to as 'moraine', due to the appearance of the stony debris of which they consist, and the lack of features indicative of fluvial deposition. Since no sections were observed in these ridges the internal composition is unknown, but the only possible alternative, i.e. that the ridges are eskers, is considered highly unlikely because of close, sub-parallel spacing of the mounds : esker networks tend to reflect the former drainage pattern under the glacier and some form of dendritic system would surely have evolved over such a wide area. Another argument against genesis purely by meltwater deposition is the slight angling upvalley (i.e. up glacier) of the ridges : this surely did not reflect either the slope of the ice-surface or that of the ground underneath, the two most influential factors on the flow of en- and subglacial water. However, meltwater was almost certainly present during deposition of the moraines if (as seems most likely) they were formed during ice stagnation, possibly along crevasse lines, or successive upturned debris-rich planes within the ice, that retained on melting the spacing and orientation of the original structures. An explanation of deposition prior to ice stagnation, i.e. by active ice, involves even more complicated hypotheses of formation and will not be attempted. If the stagnation hypothesis is correct, and the inference (from superimposed fluting) of later ice movement downvalley is accepted, the unavoidable conclusion is that the Strath a' Bhàthaich glacier was in a well-advanced state of decay when the ice was re-activated, or a readvance of 'new' ice occurred, to form the flutings which in places

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clearly override the hummocks. This conclusion is perhaps not out of keeping with the evidence of the multiple end moraine, though this in fact could simply mark three retreat stages, with no implication of further readvance.

Good evidence exists to show that the Strath a' Bhathaich glacier was confluent with that occupying Coire Roill at least during part of the Loch Lomond Readvance stage. A high-level col (Drochaid Coire Roill) leads through the breached watershed between Beinn Damh and Beinn na h-Eaglaise : in this col are hummocky moraines, and a little downslope to the north and west commences a series of fluted moraines, the dimensions of which surpass most in the field area. Lines of less spectacular fluted moraine trace the movement of ice on the other side of the col, down out of the small re-entrant on the Damh ridge (900504) and tailing downvalley from the spur that flanks the Drochaid Coire Roill on its south side.

The Coire Roill fluted moraines override, and are interspersed by, small hummocky moraines, the whole area being littered with large sandstone blocks that reach up to 8 m in length. The alignment of the flutings shows that these blocks were quarried from the headwall cliffs, and particularly from rock knobs and bastions of which remnants still exist : the longest fluting stretches for 1 km downvalley from one such projection, and reaches some tens of metres in breadth. In this valley the fluting is best developed where the slope of the valley floor is greatest : i.e. near the headwall, and again on a valley step at the base of Creag na h-Iolaire. Hummocky moraine predominates elsewhere on the valley floor, along with much smooth bare sandstone on the north-east valley side, the lower flanks of Beinn na h-Eaglaise. Where this hillside becomes less steep at its northern end, a broad belt of moraine comprising several lines of boulders marks the limit of the valley glacier where it left Coire Roill to plunge the short distance down to Loch Torridon (Coire Roill being another hanging valley as are most in the field area that are branches of a major trough). Where the slope steepens towards the loch the moraine disappears : no further trace of the limit is evident until the slope again slackens, below the cliffs by the road (888539); here a spread of ground moraine and many boulders choking the river probably indicate the former proximity of the ice. Since no end moraine exists, and the extensive fan built out into the loch is not boulder-strewn as is the area immediately inland, it seems logical to suggest that the Coire Roill glacier terminated in the vicinity of the cliffs. No lateral limit on the north-west side is present to help pinpoint the former terminus : farther uphill a distinct drift limit can be discerned, but lower down this disappears. It is possible that the terminal position of the glacier is now below sea-level, the intervening coastal stretch being masked by raised beach or fan deposits, but the simpler and therefore preferred hypothesis is the first.

The source of the Strath a' Bhàthaich glacier was probably initially the Loch an Eoin basin. Hummocky moraines extend over the watershed from the south-east, and encircle Loch an Eoin : moraines are especially well-developed on the northern and eastern shores and lower hillslopes. These are rounded, boulder-strewn, and in general about 7 m high: a dam of moraine separates two lochans and the spread of hummocks continues eastward into the Bealach na Lice. A wider outlet existed to the north-west, between Beinn na h-Eaglaise and Meall Dearg. The floor of this pass is polished smooth, paved with great slabs of sandstone, and strewn with moraine which from a distance can be seen in places to be aligned north-south. Hummocky moraine is absent from the valley floor, but present high up, perched at 430 m on a ledge of Meall Dearg. These fluted mounds are similarly oriented to the north.

Ice descending from the Meall Dearg area was channelled north-westwards along the valley of the Abhainn Thraill,down to the west end of Glen Torridon, where the glacier reached its equilibrium position and deposited a series of end moraines. A lateral limit can be traced almost continuously from the steep eastern face of Beinn na h-Eaglaise down the Thraill valley to the end moraines. Two moraine ridges, ca. 4 m high and 20 m wide are the highest record of the ice margin on Beinn na h-Eaglaise : above and beyond here the hillsides are too steep and scree-mantled to retain moraines. Downvalley, the former ice limit is indicated by a low, broad-crested ridge that swings westward, following the hillside, and falling in altitude while increasing in dimensions towards Annat. Near the end moraine the ridge is a stony, moundy feature 18 m high (on the proximal side), clearly delimiting the drift-strewn region lying within the terminal arc. The corresponding lateral moraine in the west end of Seana Mheallan is a rather poor feature by comparison : it constitutes a broad tract of moraine incorporating several lines of heaped blocks and elongated mounds, which fan out as the land drops toward Glen Torridon and disappear on the steepest stretches. The lateral moraine ceases upvalley after about 1 km, and the former ice margin to the east on Seana Mheallan can only be estimated using the drift limit where possible and inference elsewhere.

The Thraill glacier deposited at least four end moraine ridges near the head of Loch Torridon. The earliest worker in the field noted a section (no longer visible) in one of the moraines by the river, which showed the 'moraine-stuff' to rest 'immediately upon the raised beach deposits, which consist of alternating layers of horizontally-bedded sand and rolled shingle' (Hinxman, 1898, p. 250). He assumed the 'flat' area surrounding the terminal moraines to be the 50-foot raised beach ; this will be further discussed in Chapter 5. Suffice it to say here that an outwash fan slopes seaward from the outer moraine, and the base of the section Hinxman described was in all probability fluvioglacial in origin. A large section in the outer ridge visible today (904549) shows a completely unsorted till with a sandy matrix containing sub-rounded boulders up to 2 m long, most being Torridonian.

South of the River Torridon the composite moraine forms a complex of mounds and ridges. The innermost ridge is a very low feature (1.5 m high) bordering the flat boggy land enclosed by the terminus, and paralleling a longer, higher ridge that curves round to terminate in the south near the steep hillside. To the west the moraine forms large, stone-strewn mounds, and the main outer ridge borders these, separated from them by a small valley. The distal side of this outer ridge reaches ca. 10 m in height.

East of the confluence of the two rivers (Torridon and Abhainn Thraill) is a major ridge, curving upvalley between the rivers for just under 1 km. Small morainic mounds rising above the bog surface link the line of the moraine complex to the lateral moraine on the shoulder of Seana Mheallan. This large ridge must equate with either the moundy drift on the south side of the River Torridon or the inner moraine there : fluvial action has probably destroyed the initial continuity of these features. However, the outer limits in the north side of the glen are better preserved : three ridges can be distinguished. Flanked by the river, the main ridge is a broad-crested undulating feature 7 to 10 m high, that curves eastward to terminate by the road in a stony mound. Beyond it lies a middle moraine, 3 m high at the north-eastern end but rising westward; and north of this lies the outermost ridge, present only in the west, 2 m high on the proximal side but falling ca. 4 m to the peat-covered outwash beyond. One of these outer three ridges must correlate with the steep-fronted outer ridge south of the river. River dissection has thus prevented reliable correlations of these fragmented moraines, but there are at least four separate moraine ridges, and possibly five.

The next area of Loch Lomond Readvance glaciers to be discussed is that to the south and south-east of Strath a' Bhàthaich : no one centre of ice-dispersal was present here, but a large valley glacier flowed out of Coire Fionnaraich to terminate in Strathcarron; and an apron of ice stretched from Meall nan Ceapairean south-westwards to Glas Bheinn, occupying the valley of the Amhainn Bhuachaig and tonguing over the Bealach a' Ghlas-chnoic to terminate above Strath a' Bhàthaich. This wide expanse of glacier ice (about 25 square km) had four separate termini, two of which are represented by clear end moraines, and the other two can be located to within several hundreds of metres.

One of the latter ice fronts was in the Bealach a' Ghlas-chnoic. Moraine hummocks and short flutings at the base of north-facing cliffs on Glas Bheinn indicate movement of ice north-westwards downvalley : this ice flowed westwards through the col, as is evidenced by its much-eroded nature. No indication of the former ice limit remains on the north side of the valley, but a short ridge dipping steeply north-westward marks part of the former southern limit. This round-crested ridge is dissected by a burn from the south, and the resulting section shows a loose sandy till incorporating cobbles and pebbles. On the proximal side at the west end the ridge is about 12 m high, but less than half that on the distal side; downcutting by the river on the north side has exaggerated the height even more at the eastern end where the ridge is perched on the steep hillshoulder high above the river. Many loose boulders are present inside the ridge and just beyond it ; these , however, are not continued far, and it is inferred that the ice lobe reached little farther than the end of the moraine ridge.

A larger volume of ice flowed due south to Strathcarron, being supplied from the same source area as the small Bealach a' Ghlas-chnoic tongue. At Tullich House a large complex mound of till marks the former glacier snout, diverting the Amhainn Bhuachaig eastward before it swings south again to flow into Loch Carron. This end moraine complex is a massive deposit, quite unlike all other such features in the field area in its dimensions and form. In plan, the deposit is fan-shaped with the western part missing and replaced by a true outwash fan that slopes seaward from near Tullich House. The edges of the moraine have been trimmed by river action on the north and north-east sides, and the steep front facing south-east possibly underwent erosion by the sea during the Postglacial transgression. The margin of the moraine is indented by two large meltwater channels : these are graded to the present ground level in front of the moraine complex, or to a lower level, and presumably were eroded by pro-glacial rivers, at a time when the low ground to the north and west was occupied by ice or deposits later removed by meltwater or the Amhainn Bhuachaig. The front of the complex reaches a maximum height of 14 m, and upvalley from it the surface of the moraine rises in four rather uneven steps, separated by low breaks of slope. At the back of the complex are two low ridges (4 m high) on its surface that trend approximately west-east over some tens of metres. A river-trimmed section in the back of the moraine at this point shows stratified fluvioglacial deposits rising _ca._ 4 m from the river bed, overlain by another 3 m of hard-packed till. This implies that the Tullich glacier advanced over its own outwash debris, and may in part explain the atypical bulk and form of the moraine. A short fragment of a till ridge, that presumably marks the farthest position of the glacier, emerges just in front of the main deposit : this low round-crested feature was first assumed to be a raised shingle ridge, but on excavation its true composition (till) was revealed. It is therefore possible that, especially to the west, other end moraine fragments in the vicinity are buried beneath outwash and raised beach deposits.

The lateral moraines associated with the end moraine complex are clearly defined features for the first few hundred metres upvalley. On the east side is a broad moraine band draped over the shoulder of Torr na h-Iolaire : two separate low ridges within this belt coalesce at about 100 m O.D. and continue up to the shoulder as a single ridge, here about 7 m high. On top of the shoulder moundy drift with many loose boulders marks the limit, and is continued by a distinct ridge for ca. 200 m, after which only a wide scatter of boulders on the hillside imprecisely records the ice margin. On the western side a low moraine ridge with numerous boulders defines the limit above Tullich House. It reaches upvalley as a bench on the hillside, cut through at one point by a burn draining the south-west slopes of Glas Bheinn. Farther north on both sides of the Amhainn Bhuachaig valley the drift limit must be used where possible to approximate the valley glacier limits, in the absence of lateral moraines. Hummocky drift fills the valley bottom, and higher up elongated mounds trend obliquely downslope; true fluted moraines are relatively scarce, being restricted to the head of the valley where they are best developed on a steep-fronted spur that projects between the valley head and the Bealach a' Ghlas-chnoic.

In the steep, V-shaped valley of the Allt a' Mhuilinn to the east, moraine ridges composed of angular quartzite fragments flute the northern valley side : above these is a very marked limit where the drift gives way to huge striated and plucked slabs of quartzite.

These sharp-angled planes of rock crop out all over the watershed ridge (Carn Cadh an Eididh and its continuation to the south-west), and the impression of tremendous glacial erosion here and on the rounded rock crest above the loch suggests that ice overrode this watershed, moving to the north-west. However, it is not certain that all of the striae and erosion were due to Loch Lomond Readvance ice : in this area the ice-sheet also moved in the same general direction. From the height of the fluted moraines and drift on the south-east side, as well as the evidence presented below, it seems probable that Lateglacial ice did traverse the relatively low watershed, at least at the stage of the Lateglacial maximum. The limited size of the glacier that occupied the Cadh an Eididh basin, and the small basin below it, certainly implies a relatively small supply of ice.

The smooth sandstone floor north of Loch Cadh an Eididh (461906) is littered with quartzite erratics that stream out westward from the cliffed backwall. One particularly dense stripe of these boulders occurs on the 'coire'* floor directly in line with the foot of Carn Cadh an Eididh. If indeed the crest was overridden by ice from the east, the tongue would have been restricted by this hill; hence the dense boulder trail might indicate the resulting ice margin below. The alignment of this erratic train substantiates the hypothesis of an

* : This feature and the An Gorm-loch basin are not named as coires, but the geomorphological term is applicable to them.

ice source to the east ; if ice had been nourished only in the coire itself, the direction of travel of the quartzite would have been downslope (i.e. north-north-east to south-south-west) before swinging east-west and down to An Gorm-loch. Only one large moraine mound occurs in this upper coire. A steep drop of 30 m leads down to the second basin, where An Gorm-loch is surrounded by excellent hummocky moraine. These mounds reach 8 m in height, have a sharply-defined rounded or conical shape, and there are deep kettle holes among them. Quartzite moraine is the principal constituent, though the Cambrian/ Torridonian unconformity runs below the drift. The moraine spread is clearly delimited in this basin, and the northern margin correlates well with the inferred limit in the upper coire. A deep, narrow channel leads out of An Gorm-loch and no further evidence of glacial deposition is present in the wider valley below the gorge. It is therefore inferred that the ice lobe reached 0.5 to 1 km downvalley from An Gorm-loch and terminated there, curiously at approximately the same altitude as the ice tongue in the Bealach a' Ghlas-chnoic.

A drift limit can be traced more or less continuously eastwards from Carn Cadh an Eididh along the south-east flank of An Ruadh-stac, rising north to the col between this peak and Meall nan Ceapairean. More difficult to trace is the marginal position of the ice that crossed the plateau between Amhainn Bhuachaig and the Fionn-amhainn around Loch a' Mhuilinn : good indicators of the former glacier margin are completely lacking in this frost-shattered wilderness, and again logical deduction must largely be relied upon. Flutings and the drift limit on the east side of Amhainn Bhuachaig valley show the ice to have risen and traversed the sidewall via the Allt a' Mhuilinn valley : moraine-like mounds around the loch were probably deposited by it, and to the east begins a series of flutings that descend the wide bench below

An Ruadh-stac. This south-easterly flowing ice joined the Coire Fionnaraich glacier along its eastern margin, and the limits of this confluent ice are well defined on Cnoc na h-Atha, Cnoc nan Each, and in Strathcarron.

Though there is no coire on the south-east face of An Ruadh-stac, the abundant fluted moraines show that snow and neve must have accumulated on the broad, gently-sloping shelf below 530 m. The low col over to Coire an Ruadh-staic was obviously breached by ice, and occupied in the Lateglacial; a cluster of large moraine hummocks occurs high up against this denuded headwall, and a string of stony debris leads north-eastwards over the shoulder of Meall nan Ceapairean. From this gathering ground on the eastern flanks of Maol Chean-dearg ice swept south-eastwards, forming the abundant flutings that are best seen on aerial photographs, since they lack definite relief on the ground.

Coire Fionnaraich is the wide trough head at the end of the Fionn-amhainn valley, encircled by a series of impressive rocky peaks and ridges : Maol Chean-dearg, Meall Dearg, and the Sgorr Ruadh - Fuar Tholl ridge. Lateglacial ice occupied the three cols between these mountains, flowing (presumably) north through the Bealach Ban, ultimately to Glen Torridon, and most probably into the Fionn-amhainn valley from the west via the Bealach na Lice and Bealach a' Choire Ghairbh (the pass between Maol Chean-dearg and Meall nan Ceapairean).

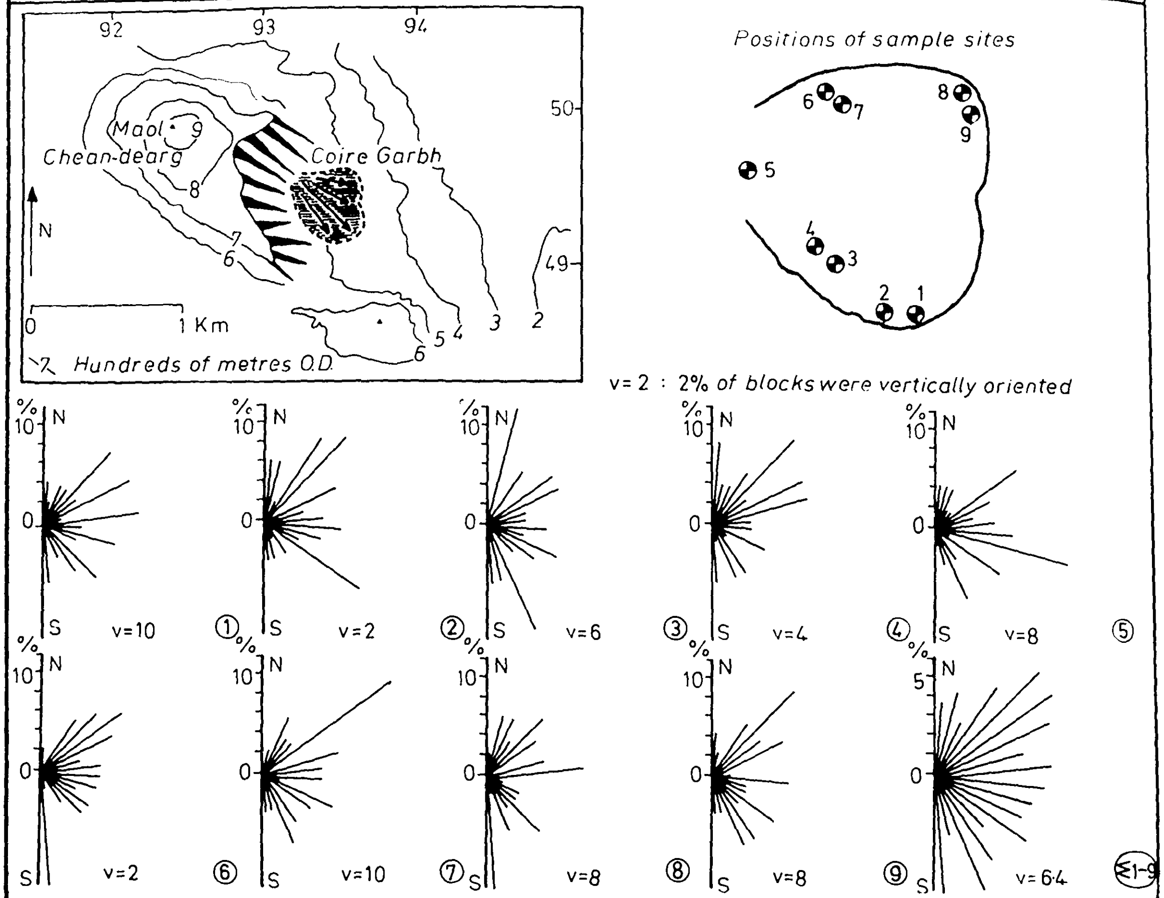
Hummocky moraine occupies large areas of the Fionn-amhainn valley floor and lower valley sides, the mounds in general being under 5 m high. Fluting occurs around Loch Coire Fionnaraich (945497) and on the steeper slopes of the trough head, leading down from the Bealach Ban. The best fluted moraines in this area are those on the eastern slopes of Maol Chean-dearg, descending the steep slope towards the loch : these are broad, round-crested ridges about 1.5 m high and approximately

15 m apart, swinging downvalley for several hundreds of metres. Just above this patch of fluting is a unique feature in the field area, a debris fan covering a few thousand square metres that appears to have resulted from an extensive rock fall (9349) on the cliffs of Coire Garbh. The unusual nature of this landform demanded further investigation, in order to attempt an explanation of its origin.

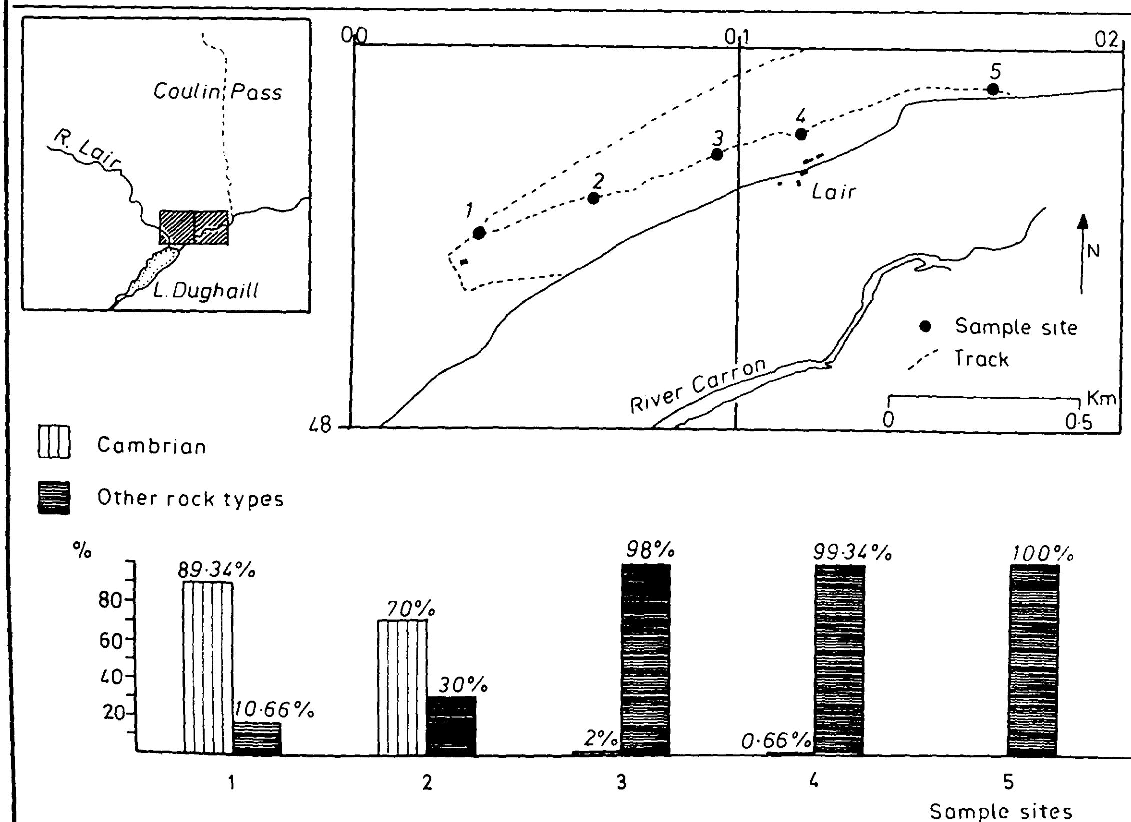
The tongue-shaped deposit consists mainly of Cambrian blocks, that reach 5 m in length and are heaped together in an apparently random fashion. The feature has a very sharply defined margin, and rises from about 450 m to 530 m O.D. below the Maol Chean-dearg summit. The apex of the fan occurs below a scree-choked gully in the cliff above. Most of the debris is unvegetated, but heather has grown up where the surface of the feature dips into small enclosed hollows. No alignment appears to exist in this surface relief of low rises and depressions.

One possibly unconnected, though distinct, feature occurs within the limit of the debris fan on the northern side below the Coire Garbh cliff. The edge of the debris scatter here is marked by a low quartzite debris ridge sitting on Torridon Sandstone bedrock near the steep cliff-foot : below this, following the main break of slope, is a second ridge ca. 7 m high and ca. 60 m long. The composition of this ridge is also largely quartzite blocks, though some Torridon Sandstone is also apparent which may be either bedrock or loose boulders. The surface has scattered quartzite debris, noticeably less than on the ground to either side. The origin of this ridge is not certain, for though the alignment is correct, it seems to be too well-packed to be a protalus rampart, and has the solid appearance of a moraine ridge. Initially this also seems unlikely, however, as the orientation precludes it from being a fluted moraine, yet the situation on the coire floor means that

# Figure 7 : Debris fan




# Figure 8 : Cambrian erratics



it can hardly have been an ice-marginal deposit, unless formed at a very late stage of glaciation.

Various hypotheses have been considered as to the origin of the debris fan. To find out if the blocks are oriented in any particular direction, nine sample sites were chosen systematically over the fan (Fig. 7 ), and the direction of alignment of the a-axis of fifty blocks was recorded at each. In choosing the sample blocks all those on the surface of a small area were measured, until each sample was complete. The diagrams of the results show that no one direction is preferred, the alignments occurring throughout 360° both at individual sites, and overall. However, there does appear to be a slight preference, especially at sites 2, 3, 4, 6, and 7, for alignment of blocks across the slope, i.e. dipping to the north-east and south-west, rather than directly downslope to the east. This may simply reflect the chance influence of micro-topography on the way the blocks settled, e.g. dipping out from minor knolls. But because the fan in general appears to have spread laterally instead of adopting a downhill elongation, lateral extension is suggested.

After this feature on Meall Chean-dearg was mapped, the writer visited the fossil rock glacier at Beinn Alligin ca. 12 km to the north-west (Sissons, 1975). The similarity of form between the two features was striking, and many details listed by Sissons (e.g. the clear edge, the undulating surface, the absence of banking-up against the cliff) describe the Maol Chean-dearg feature equally well. However, transverse or longitudinal ridges did not appear to be present on the latter landform, and its shape is different. Both features occur inside Loch Lomond Readvance limits and originated in east-facing coires. It is the writer's opinion that the Maol Chean-dearg rock debris fan may also be a fossil rock glacier, active in the early post-Stadial period.

If this is so, the moraine-like ridge described above may be a lateral moraine formed by the rock glacier.

This hypothesis seems preferable to accounting for the feature by some normal rock-fall process, since the latter would not explain the morainic ridge, the neat edge and pronounced sideways spread of the fan, nor the lack of banked-up debris.

Throughout most of the Fionn-amhainn valley the drift limit, clearly defined on the smooth valley sides, is assumed to indicate the former margin of the Loch Lomond Readvance glacier. Near Strathcarron lateral moraines are present on both sides, marking the descent of the ice towards the major trough. Ice streamed south off the Fuar Tholl ridge, depositing a lateral moraine along the west side of Carn Eididh. This long moraine is banked against the steeply rising hillside, and reaches 6 m in height in the proximal side. Downvalley the limit is represented by a series of small(4-5 m high) sharply defined moraine ridges and associated stony mounds, perched above the steep drop to the valley floor. The lowest fragment of the lateral limit is a steep terrace on Cnoc nan Each above Coulags, curving up the near-vertical cliff for a short distance.

The western lateral moraine on Cnoc na h-Atha is a much more spectacular feature. It delimited the ice that flowed south-eastward from the Loch a' Mhuilinn area, and is a long, broad, multiple-ridged moraine that meanders downhill to link with the Strathcarron end moraine. Bordering an area of fluted moraines in its upper reaches, it is difficult to differentiate from the flutings. The lateral moraine comprises a suite of long strings of rubble from under 2 to 5 m in height, all trending sub-parallel, though not in such an undeviating fashion as typical flutings. This moraine belt reaches ca. 75 m in width, becoming wider and lower upslope. Its lower end in Strathcarron comprises only two principal ridges, with lesser mounds on the proximal side. A section in the outer ridge shows a compact rubble of quartzite cobbles and boulders in a sandy matrix. As usual, where the valleyside gradient increases the moraine is not present.

The long profile of the Fionn-amhainn valley includes a prominent rock step (952467) at the point where the ice from the west joined the valley glacier : presumably effective erosion of the valley floor increased with the volume of ice channelled along it. Upon descending into the wide trough of Strathcarron, the glacier spread across the valley floor to its terminal position. Unlike all of the glaciers hitherto described, this one appears to have 'died' climatically and dynamically, and downwasted to produce typical dead-ice forms, whereas the others were probably still dynamically active while at the maximum position and retreating. This is inferred (in the latter case) from the presence at the termini of multiple end moraines and the complete lack of such features as kames, kame terraces and eskers, in the area of decay. In Strathcarron, however, all of these features are well represented, and there is only one, albeit large, end moraine.

Kame-and-kettle topography is present on both sides of the Carron river between the end moraine ridge and Loch Dughaill. There are numerous kettle holes, small eskers under 8 m high and several tens of metres long, and flat or gently-rounded mounds of fluvioglacial material, formed in and around the decaying ice. One riverside section (948444) in ice-contact deposits shows the naturally horizontally-bedded sands and gravels to have collapsed, disrupting the strata : proof of the close proximity of the melting ice. Skirting the base of Cnoc na h-Atha is a small meandering esker ridge up to 6 m high, that stretches for several tens of metres. The stream that formed this esker was probably responsible for eroding the small meltwater channel that continues below from the esker: this is incised up to 4 m through bedrock, and opens out downslope into a very shallow and indistinct feature. Perhaps the most spectacular ice-contact features are the kame terraces that on the north side of the valley form a suite of five steps, Coulags village being built upon parts of the upper two. These terraces were levelled, and the results are mapped on Fig.10:1 and tabulated on page ii . Corresponding but less extensive kame terraces fringe the opposite side of Strathcarron.

All these fluvioglacial features extend no farther than the ice limit in the west, beyond which stretches an extensive outwash fan. North of the River Carron a series of very low elongated mounds trends across the valley floor towards the lateral moraine on Cnoc na h-Atha, enclosing one small kettle lochan. The river bed is littered with very large boulders between this area and the large ridge on the opposite bank. Reaching 15 m in height, the end moraine is a steep-fronted ridge with a gentler and lower slope on the proximal side. It has a broad, undulating crest, and is a composite feature with subsiddary mounds and ridges attached. In the east it drops in height, grading into kettled topography and an alluvial fan at the hillside. The moraine limit is continued above these along the valley side as a broad system of linear mounds, rising north-eastwards until the slope steepens.

The continuity of dead-ice deposits, and the traces of lateral moraines above the valley floor (p.71 ) prove that downwasting ice occupied the trough at least as far north-east as Loch Dughaill.

It is hypothesised that the terminus of the Fionn-amhainn valley glacier was in fact confluent with ice emerging from the Lair valley : further discussion of this area will follow the description of the Lair moraines.

The Lair glacier was nourished in the steep-sided trough between Beinn Liath Mhór and Sgorr Ruadh; ice was contributed to the main glacier from the coire and col lying between the latter mountain and Fuar Tholl. Glacier ice was also present on the low watershed between the Lair and Coulin basins (992507), though the lack of clear glacier limits here makes it difficult to define ice movements with certainty. The Lair valley is rather unusual in the respect that only one (relatively short) ice marginal feature exists, despite the excellent flutings, hummocky moraines and small-scale ice-erosional features.

Extremely well-preserved fluted moraines stream down from the head of the valley for several hundreds of metres below the col. These ridges comprise both Torridon Sandstone and Cambrian Quartzite rubble, and are usually several metres high. One abnormally large fluting descends from the conical buttress in the col : this moraine in its lower stretches is a very sharp-crested ridge several metres broad, reaching 12 m in height on its southern side. As it rises westward it loses height, becoming a flat belt of moraine rubble, and is finally lost on the rocky hillside. The altitude this flute attains suggests that ice flowed through the narrow col between Sgorr Ruadh and Beinn Liath Mhór, the glacier then descending the trough to the north-west, to join that emerging from the Bealach Ban and terminating eventually in Glen Torridon. Fluted moraines in the upper Lair valley form a belt that reaches over 1 km along the foot of the Beinn Liath Mhór ridge, indicating ice movement out from the near-vertical valley side and obliquely downvalley.

Such moraines were either not formed, or not preserved, on the southern side of the valley : here, however, are abundant moraine hummocks which continue eastward to cover most of the valley floor. Flutings also occur on the lower valley floor, for instance above and below Loch Coire Lair, and on the steeply dipping rock step that traverses the lower Lair valley. (It is here that fine roche moutonnée forms were eroded by the valley glacier.) Flutings also record former ice movement out of Coire Mainnrichean and the adjacent rocky basin, and more spectacularly, off the southern end of Beinn Liath Mhór, where a triangular patch of short ridges indicates that the ice moved directly south from here. This latter area, however, comprises less typical fluted moraines that are rather round-crested, moundy, and discontinuous, more akin to large aligned moraine hummocks. Both erratics and the local rock type are present in the blocky moraine, and some bedrock knobs are also apparent.

Evidence of ice limits is unfortunately absent in the upper Lair valley as in most of its lower reaches. Beinn Liath Mhór is mantled in magnificent screes from 900 m down to almost the valley bottom, and Sgorr Ruadh is surrounded by cliffs and very steep slopes. On Carn Eite where the ground is level enough to preserve remnants of an ice limit, such evidence is lacking. The hill is mostly bedrock liberally strewn with ablation moraine, and the juxtaposition of Torridon Sandstone and Cambrian rocks allows the spread of erratics to be traced. Sandstone has been carried uphill and deposited on the Cambrian strata, the number of erratics diminishing upslope and becoming very low before sandstone finally disappears from the ground moraine. The limit of these erratics determined by visual scanning falls south at a shallow angle, but is only easily followed for a few hundred metres. This limit gives an indication of the minimal height of the Lair ice on Carn Eite.

The only firm evidence of a former glacier margin occurs to the south east on Carn Odhar. A group of lateral moraines dips downhill from just below the hill crest at 400 m O.D.: there are two main ridges, with several subsidiary ones. The outer ridge is best defined, being a sharp-crested moraine 6 to 10 m high on the proximal side, much lower on the distal side, and running for several hundred metres downslope. About 60 m inside is a second, lower and broader moraine trending parallel. The major and minor ridges disappear on the shoulder of Carn Odhar : deep peat exists there and possibly obscures further moraines. Indications of the former ice margin are also absent from the Allt nan Dearcag valley, although (presumably) the glacier must have occupied at least the head of the valley. The lateral ridges also cease downslope, though they may be present but unobserved in the forested area.

Five sites along a forestry track above the railway in Achnashellach Forest were sampled (Fig. 8 ), in order to demonstrate the decrease eastwards of Cambrian rock in the ground moraine. The sampled sites were cleared faces in the track-side bank, and 150 stones were picked at random at each. Over a distance of 1.4 km the proportion of Cambrian erratics to all other types (principally Torridon Sandstone) decreases rapidly. This increasing scarcity of erratics is of little help in pinpointing the former ice limit, however, since Cambrian rocks would be expected to occur in low numbers beyond the sample limit.

South of the River Carron (outside the field area) no evidence of the former Lair glacier terminus was found. It is possible that any moraines formed on the valley floor have been removed by subsequent river action. It is probable that ice from the hills to the south (if present) joined the Lair glacier, but the extent of any such glaciation during the Loch Lomond Readvance is not known. In the absence of morainic evidence, the spread of the Lair ice might be indicated by the distribution of Torridon Sandstone erratics over the

Moinian rock south of Glen Carron, but this hypothesis is not easily confirmed. Such erratics are recorded on the Six-inch Geological Survey sheet, and one was observed in the field at 335 m, 3 km south-south-west of Lair village. These lie beyond the predictable limit of Lair ice judging by the pattern of valley glaciers observed elsewhere, i.e. one would expect the glacier to have terminated shortly after spreading onto lower ground, in this case Glen Carron. Further geomorphological mapping in the area to the south may one day resolve this problem.

On the south side of the entrance to the Lair valley, a narrow shelf at 400 m on Fuar Tholl was occupied by ice.The corresponding limit on the north-east side proves that this ice at the Stadial maximum was part of the Lair glacier and not an independent tongue, since the ice surface was sufficiently high to override the Sgurr Mhuilinn shelf. However, at a later stage when ice was less extensive, a separate ice lobe probably existed.

Evidence for this small glacier includes a marginal position defined in the north-east by a broad, round-crested ridge under 4 m high, which can be followed several tens of metres, dropping gently westwards. The scatter of boulders is notably denser above the ridge. Higher up, small moraine hummocks and a large accumulation of boulders are present below the very narrow re-entrant on the north-west face of Fuar Tholl. The boulder scatter continues downslope, and the limit (or medial position) is represented by a discontinuous line of large boulders. Fluted moraines descend from Coire Dubh and across Sgurr Mhuilinn : these well-defined rounded boulder ridges trend generally towards the south-east. A single moraine ridge marks the former ice margin here, breaking into a series of mounds farther west, and finally disappearing as the slope steepens. A short distance above here two moraine ridges draped over rocky knolls presumably indicate the westernmost extent of the ice tongue : these too fade out and there is no clear indication of the limit higher up.

Lateral moraines deposited by the Lair ice in Strathcarron occur on the northern valleyside above Balnacra. This wide belt of scattered moraine contains at least two distinct ridges, and it rises gently eastward for about 1 km towards the lower limit of the Sgurr Mhuilinn glacier : it is probably, therefore, related to a late stage of glaciation. Both sandstone and quartzite are present in the moraine, the former clearly being erratics from the Lair valley since no outcrops of sandstone are known east or south-east of Fuar Tholl and the Lair valley. Though the lateral features disappear westward on the steep, gullied hillside, continuation of the line west implies that the Lair glacier was confluent with the Fionn-amhainn terminus, as was shown above by the continuity of kame terraces and other dead-ice landforms in the valley bottom.

Ice spread north from the col that breaches the headwall of the Lair trough, joining the stream from the adjacent Bealach Ban. Both of these cols have a typically 'swept' appearance, preserving the effects of intense glacial erosion, and little moraine is present. Lower down, however, flutings are well developed, especially on the floor of Coire Grannda, where lineations in the morainic drift are very distinct from a distance. Smaller, more closely spaced flutings surround Lochan Dearg Beag (945523), and innumerable fluted moraines stripe the rocky descent towards Lochan Neimhe. In the vicinity of this loch the glacier must have divided, part to flow westward to the Thraill end moraine, and part being destined for Coire a'Cheud-chnoic and Glen Torridon.

Lateral moraines are again scarce in this region. At the entrance to Coire Grannda, following the western slopes of Beinn Liath Mhór is a short fragment of lateral moraine, a low ridge that tails off a rock face, dividing the moraine-strewn valley bottom from bedrock slopes above.

A broad scatter of boulders continues the line for several hundreds of metres before it becomes indistinguishable from the general drift cover. Though no further lateral moraines delimit the glacier that flowed north to Glen Torridon, a clear drift limit traverses the north-west-facing slopes of Sgorr nan Lochan Uaine and Sgurr Dubh. A plastering of drift with an occasional long fluting indicate that ice joined this glacier from the Lochan Uaine basin and Coir' an Leth-uilt : again no lateral moraines are present.

South-east of Lochan Neimhe hummocky moraine begins to proliferate in the valley bottom and on the lower slopes of Sgorr nan Lochan Uaine. This area of hummocky moraine reaches to Glen Torridon, forming what is probably the largest area of such moraines in the field area, and certainly contains the greatest density of hummocks. The mounds are sharply-defined features with steep sides and sharp crests : many are conical or elongated into short ridges, and all are so closely packed that in places they appear to be built up one on top of another. The height varies, being greatest at ca. 15 m near the valley entrance, falling in height up the valley sides. They are copiously strewn with sandstone boulders, and enclose small wet and dry hollows. The predominant alignment is south-north, obliquely downslope : this is evident in the short linear moraines, which are possibly an abbreviated form of fluting. In addition to these moraines are several features of a slightly different form : these occur mainly in two areas above Loch na Frianoch, from the upper drift limit down to the valley floor. These longer ridges meander markedly, but are oriented more directly downslope, running thus at an angle to the hummocky moraine lineation. Though no sections were seen in these ridges, it seems probable that they are fluvioglacial in origin, being sub-glacially engorged eskers related to ice stagnation.

The Coire a' Cheud-chnoic has a clear moraine limit on the south-eastern valleyside : the mounds fall in height, and cease abruptly to give way to shelving sandstone. In places just outside the drift limit these rock ribs are deeply riven into huge blocks, some tumbled together *in situ* to form heaps while others are perched in isolation. It is not known if this destruction was caused by periglacial processes, i.e. frost riving and shattering, or was the result of plucking by the glacier ice and pressure-release upon deglaciation. The latter is perhaps more likely, since the occurrence of these features is restricted to the ice marginal zone in a fashion that periglacial factors would not be. On the north-west side of Coiré a' Cheud-chnoic the hummocky moraine is equally clearly delimited : the drift limit skirts Seana Mheallan and swings into Glen Torridon, ceasing downvalley as a scatter of boulders on the valley side west of Lochan an Iasgaich. South-east of the lochan the moraine mounds grade into a much less hummocky drift spread that is plastered discontinuously along the lower north-western face of Sgurr Dubh. Perched Torridon Sandstone blocks are prolific on the rocky hillside, and the drift limit is still fairly well-defined in this region. The ice descending Coiré a' Cheud-chnoic must have been confluent with the glacier that entered Glen Torridon on the opposite side, from Coire Dubh (J. B. Sissons, pers. comm.). No end moraines exist around Lochan an Iasgaich, but there is a very clear arcuate moraine 3 km downvalley. Where the confluent ice tongues terminated upvalley is a problem, in view of the absence of terminal features. The limit of hummocky moraine lies in the small valley of the burn that drains Sgurr Dubh and enters Loch Bharranch. West of the burn are definite hummocks and many scattered blocks, up to a certain level on the valleyside above which bedrock predominates. East of the burn are drift-mantled slopes below the Sgurr Dubh cliffs, outside a low ridge that parallels the burn on its east bank for several tens of metres. Above the ridge are (apparently) stable scree slopes; to the west stretches the moraine-strewn ground described above. However, this ridge is a small feature and is not continued across the flat floor of Glen Torridon. It can only be surmised that the apparent limit of hummocky drift indicates the maximum extent of the Loch Lomond Readvance glacier, the snout having lain in the vicinity of Loch Bharranch. To the east of this loch are several large mounds of the typically featureless pre-Lateglacial type, and a small branched esker (under 8 m high) meanders across the valley floor. No arcuate moraine ridges, dense boulder accumulations, nor any typical ice terminal deposits are evident here or towards Loch Clair. In this respect the Torridon glacier was like the Lair valley ice that spread eastward, and similar to the final glaciers to be discussed below : all flowed east or north-east, and none formed end moraines.

Three major ice streams covered much of the western Coulin Forest, being nourished in the accumulation areas around Sgurr Dubh, Sgorr nan Lochan Uaine and Beinn Liath Beag, and the Beinn Liath Mhór ridge. The northernmost glacier, that flowing out of Coir' an Leth-uilt towards Loch Clair, presents the most difficult problem of all with regard to the former terminus.

This glacier was nourished on the shelving north-eastern slopes of Sgorr nan Lochan Uaine, as is evidenced by the abundant long fluted moraines that appear on the ground as denser belts of rubble among the ubiquitous drift scatter. The flutings are abundant around Lochan Gobhlach, and descend the slopes beyond into the Allt na Luib valley. At the head of this valley is an area of hummocky moraine, under 5 m high and arrayed in an imperfect chevron pattern. Below this a more vaguely undulating drift spread mantles the valley sides, with many small gullies dissecting the till on both sides. Morainic mounds also occupy the eastern tributary valley, below Meall an Leathaid Mhoir, and fluted moraines reach down to the confluence of the two tributaries. Though drift limits are clear in the upper stretches of both valleys, in the lower Allt na Luib valley the drift merges with that mantling all of the River Coulin trough and the hills beyond. No ice marginal deposits are present.

It is, therefore, without evidence from some other source, impossible to tell if the Coir' an Leth-uilt glacier terminated near the lowest moraines (flutings, in this case), or whether it reached farther, to lochs Coulin and Clair or beyond. There is no unequivocal evidence available yet as to the age of the last ice in the Clair basin : cores of lake sediment extracted from the loch by Dr. W. Pennington for pollen analysis are (so far) inconclusive, as the basal coarse Lateglacial sediments could not be penetrated (Pennington _et al._, 1972). Moraines exist around the loch, those fringing the south-west shore being of a typical Lateglacial appearance : they are steep-sided little knolls, up to 6 m high, interspersed with hollows. The moraine comprises mainly quartzite rubble, but this is not necessarily indicative of a southern origin as the ice-sheet deposits might equally include quartzite from the adjacent mountains. Larger mounds of moraine border the loch on the north-east side, the largest reaching perhaps 12 m in height : again these and the small eskers nearby are of inconclusive age. Three esker-like ridges also descend a short distance to the floor of Glen Torridon west of Loch Clair, these being 8 to 10 m high and a few tens of metres long. Their sudden beginnings and endings imply a fluvioglacial origin, and these features are most probably subglacially engorged eskers. Similar short, broad-crested ridges occur intermittently on the western slopes of the Coulin valley : these certainly lie outside the hypothesised Loch Lomond Readvance limit. It would seem, therefore, that the case for the valley glacier having reached Loch Clair rests solely upon the 'Lateglacial type' hummocky moraines on the western shore, and since despite their appearance these cannot be reliably assigned to the Lateglacial Stadial, the evidence is not considered strong enough to support the hypothesis. The limit of the former glacier must, therefore, be tentatively drawn in the Allt na Luib valley, at the margin of the lowest moraines.

The ice streaming northwards from the Sgorr nan Lochan Uaine and Beinn Liath Beag ridge also in part turned eastward, flowing out of Coire na h-Uamha and curving to the south-east, to terminate just west of Cnoc Daimh. The coire floor is filled with hummocky moraine, and long flutings stripe the headwall. To the south, the ice stream joined that emerging from the Lochan Uaine basin, and to the north-east the lateral limit of ice is marked by a clear drift limit. On the low rocky ice shed, the spur west of Meall an Leathaid Mhoir, the influence of the Loch Lomond Readvance glaciers was mainly erosional, and the denuded Cambrian Quartzite carries only a thin sprinkling of loose debris, whereas east of the former glacier a till sheet mantles the southern flanks of Meall an Leathaid Mhoir. Farther south the ice margin is represented also by the outermost fluted moraine of a series that trails off the watershed spur, the moraines apparently being associated with structural ribs of quartzite trending the same way. Downhill the outer margin of this spread of moraines becomes more diffuse, the major aligned mounds being flanked on the outer side by successively lower and less continuous ridges until the peaty undulating drift of the Coulin valley prevails.

Hummocky moraine covers most of the ground from the Cnoc Daimh area continuously south-westwards into the Coire Beinne Leithe. In the middle reaches rather unusual moraines fill the valley floor : these large, lobate features trend almost at 90° to the valley sides, are about 8 m high, broad and quite flat-topped. Where the valley starts to fall more steeply at the east end of Beinn Liath Beag, the alignment changes to the more common chevron pattern, best developed on the south-facing slope, while still farther downslope no orientation is evident. In this case the gradient of the valley floor appears to have influenced the pattern adopted by the moraines. The upper part of the Coire Beinne Leithe trough, near the rock basin lochs, is floored by a smooth drift sheet, with some faint suggestion of lineation in the moraine along the valley axis. Lateglacial ice certainly spilled out from the western end of the deep trough, though it was not necessarily this most recent ice that created the col by breaching the watershed between Beinn Liath Mhór and Sgorr nan Lochan Uaine. From the altitude of the col (670 m) it seems probable that ice also spilled over the much-eroded col between Sgorr nan Lochan Uaine and Beinn Liath Beag (at 700 m), contributing to the ice accumulating in Coire na h-Uamha.

The distribution of hummocky moraine shows that the ice mantle continued south-westwards into the upper valley of the Easan Dorcha, the slopes north of this river being covered with stone-strewn moraines that continue eastwards to the river confluence and no farther. The south-western slopes of Cnoc Daimh are blanketed in moraine, but it is not hummocky and surface boulders seem to decrease in density downvalley along the southern flank of the hill. Higher up the Easan Dorcha valley, moundy moraine covers the valley floor and the footslopes of Beinn Liath Mhór, but the drift on the south bank is in general much smoother. Several short, low ridges are oriented downslope on this side of the valley: these are under 4 m high, a few metres long, and round-crested. As in other cases described above, these features are most likely to be eskers. (The activity of meltwater is also recorded in this region by small channels on Carn Eite : one joins the Allt nan Dearcag valley, while the other contains the upper reaches of a tributary of the River Lair. These are incised 10 to 15 m vertically through bedrock.) However, fluvioglacial features do not here help to delimit the former valley glaciers, and the problem of the extent of the Loch Lomond Readvance in the upper Easan Dorcha - middle Lair valley remains. The absence of hummocky moraine from the northern slopes of Carn Eite may imply that only a small and shallow lobe of ice occupied the valley, deriving nourishment from the cliff to the north. The clear distinction between the till cover of the two sides of the valley continues to the vicinity of Cnoc Daimh, and downvalley from there both sides of the Easan Dorcha valley are mantled in thick and relatively featureless drift. The situation in this valley is,therefore, similar to that of the Coir' an Leth-uilt glacier in that the limit of moraines is the only remaining guide to the former position of the glacier terminus.

# CHAPTER FOUR.

'Perhaps it may yet be ascertained, that among the agents which in successive geological periods helped in no small degree to alter the surface of the globe were sheets of land-ice and fleets of floes and bergs.'

(Geikie, A., 1865, p. 344)

## The pattern of glaciation in the Stadial.

At the maximum of the Lateglacial Stadial, ice covered about 160 square kilometres, or 28%, of the field area, if the preceding interpretation of landforms is accurate. The glaciers must have dominated the landscape at that time, affecting not only the ground they occupied, but the surrounding regions also, where periglacial processes were active, producing some effects that are still obvious today. Before briefly discussing these periglacial landforms, some general conclusions and inferences will be made concerning the glacial features.

Figures 5a and 5b show the extent of the ice cover in the Eastern and Western areas at the maximum of the Loch Lomond Readvance, contours having been drawn on the hypothetical glacier surfaces. Towards many of the termini lateral and end moraines clearly indicate former ice margins, and contours there are drawn more or less parallel to the outermost terminal moraine. Higher up glaciers the hypothesised limits not based on evidence of landforms were amended slightly where necessary in order to produce the most probable contours : for instance, since ice flow was parallel to fluted moraines (see below), contours should cross them at right angles. No major alterations of hypothesised limits were necessary, because control by ice-marginal moraines is relatively abundant. In the upper reaches of valley glaciers and in accumulation basins, where slight concavity of the ice surface would be expected, the contours were drawn accordingly.

These maps show the general pattern of glaciation to have been one of valley glaciers descending a few kilometres from centres of ice dispersal, from isolated coires or from snow-gathering re-entrants on steep hillsides. The longer glaciers spread out on lower ground, once free of

TABLE ONE

| NAME OF GLACIER | AREA in SQUARE Km. | ALTITUDE of FIRN LINE | NUMBER of END MORAINES | DIRECTION GLACIER FLOWS TOWARDS | POORLY-DEFINED TERMINUS | MULTIPLE LATERAL MORAINES |
|---|---|---|---|---|---|---|
| Coire Muchdarroch | 2.89 | 439 | 0, 1 | NW, E | | x |
| Coire Glas | 0.28 | 370 | 3 | SE | | |
| Meall an Fhuaid | 2.24 | 336 | 0 | E | x | |
| Coire Attadale | 14.23 | 384 | 4 | SW | | x |
| Coire nan Cuileag | 7.00 | 475 | 0 | NW | x | x |
| Coire nan Clach | 0.67 | 571 | 1 | W | | |
| Coire Sgamhadail | 2.89 | 322 | 2 | SE | | x |
| Coire na Ba | 3.51 | 326 | 4 | SE | | x |
| Coire nan Arr | 9.79 | 391 | 4 | SE | | x |
| Beinn Bhan lobe | 6.42 | 429 | 0 | E | x | |
| Coire Toll a' Mheine | 2.27 | 414 | 0 | NE | | x |
| Coire Gorm Beag | 1.35 | 455 | 0 | NE | | |
| Coire Roill | 6.37 | 505 | 0 | NE | | x |
| Strath a' Bhathaich | 11.87 | 519 | 4 | SW | | x |
| Cadh an Eididh | | | 0 | W | | |
| Bealach a' Ghlas-chnoic | | | 0 | W . | | |
| Bhuachaig | 9.59 | 377 | 1 | S | | x |
| Coire Fionnaraich | 23.64 | 447 | 1 | SW | | x |
| Lair | | | 1, 0 | SW, NE | | |
| Coire Beinne Leithe } | 12.85 | 520 | 0 | E | x | |
| Coir' an Leth-uilt } | | | 0 | NE | | |
| Coire a' Cheud-chnoic } | 25.96 | 475 | 0, 1 | NE, W | | |
| Thraill } | | | 4 | NW | | x |

the confining valley sides. The Western Area contained more discrete, small bodies of ice than its eastern counterpart, which at the Stadial maximum comprised an ice-cap of 108 square kilometres feeding nine major outlets and two small overspill tongues (those in the Bealach a' Ghlas-chnòic and the Cadh an Eididh basin). On the Applecross massif some of the valley glaciers issuing from the trough heads were probably linked through cols in the plateau, but the greatest volume of ice was contained in the outlet channels. In the Eastern Area, ice at the Stadial maximum drowned the Interstadial landscape and built up to form a dome, the surface of which lay at an altitude of over 800 m O.D., and through which five nunataks projected.

Table 1 lists the glaciers and some statistics concerning each. The firn line altitudes were calculated using a formula that depends on the spacing of the hypothetical contours (Sissons and Sutherland, 1975). Dr Sissons calculated these with firn lines for other Loch Lomond glaciers in the north-west Highlands for use in palaeo-climatological reconstructions (Sissons and Sutherland, in preparation). In general firn lines tend to be higher in the east than the west of the field area : the mean firn line altitude in the Applecross Peninsula is 409 m, (394 m excluding the anomalous Coire nan Clach tongue), while in the Eastern Area it is 474 m. The simplest explanation of this pattern is that, in spite of the greater build-up of ice in the east, snowfall was heavier in the west, allowing such low-lying and insignificant accumulation areas as Coire Glas and Meall an Fhuaid to harbour small ice tongues.

In the Eastern Area, the firn lines of the ice flowing south on the south-west side of the ice-cap are markedly lower than those on the north, the Bhuachaig glacier having the lowest firn line in this area. The two most southerly glaciers of the Western Area (Coire Sgamhadail and Coire na Bà) have likewise the lowest firn lines of the western group, excepting the Meall an Fhuaid tongue in the north. This suggests that heavy snowfalls during the Stadial were experienced by areas most exposed to the south or south-south-west, their firn lines being depressed below those on glaciers that received relatively less snow. If this reasoning is correct, a preponderance of snow-bearing winds blowing from a southerly direction may be inferred.

Using the firn line altitudes and estimated values for accumulation at the firn lines during the Stadial, inferences about summer temperature can be made. Accumulation is assumed to have been 70% of the present-day annual precipitation (this being the percentage of the annual total that falls during the winter months at present), i.e. about 1,400 mm in the Western Area and 1,600 mm in the Eastern Area, at the respective (mean) firn line altitudes. Using a graph (Liestol, O., unpublished) that relates accumulation at the firn line to the summer temperature there, temperatures of 1.5°C and almost 2°C in the Western and Eastern areas are inferred. These are equivalent to 3.9°C and 4.8°C respectively at sea-level for the period between early May and late September (assuming a lapse rate of 0.6°C/ 100 m). The summer temperature in the field area at the maximum of the Loch Lomond Readvance was, therefore, about 4° C.

The greater area and volume of glacier ice that accumulated in the Eastern Area is presumably a reflection of the availability there of more gathering grounds for snow and névé than existed in Applecross. Initially the glaciers would occupy the coires and trough heads, expanding and eventually coalescing over back walls and utilising the many high-level cols that exist. Few of these have been completely breached ( the former watershed between Beinn Liath Mhor and Sgorr nan Lochan Uaine being a notable exception), and it is difficult to estimate the degree of erosion that may be attributed to the Stadial glaciation. However, the volume of debris contained in moraines and fluvioglacial deposits implies that a relatively small proportion of the material removed from coires, troughs and breached watersheds may be attributed to the Stadial ice, even allowing for debris lost in meltwater rivers. These glaciers would primarily sharpen and trim a landscape eroded in previous glacial stages, all of which presumably began with the growth of coire glaciers.

An interesting pattern that emerges from Table 1 is that only one of the ten glaciers that terminated facing between north and north-east left a well-defined end moraine. (It is assumed that Postglacial destruction of end moraines was not selective, and that where no terminal limit exists today, one had not been formed.) Of the remaining nine glaciers that fall into this category, three poorly-defined termini exist while six glaciers apparently formed no end moraine. The other glaciers, terminating to the west and south, all possess terminal features except for two lobes : those in the Bealach a' Ghlas-chnoic and the An Gorm-loch basin. The steepness of the topography (small V-shaped valleys) might explain the absence of terminal features in the two latter cases, but only one of these facing north-east ended in a similar situation (the Coire Roill glacier), so some other factor must have prevented these glaciers from forming end moraines.

This factor is problematic : there are no obvious reasons why the glaciers in question should not have behaved as their contemporaries and have formed terminal moraines. Topography is in no case (except Coire Roill) prohibitive, nor is it probable that temporary water-bodies existed to create calving conditions. Bedrock types are no different to elsewhere, and with respect to other moraine deposits, abundant hummocky and fluted moraines were formed as normal. The only difference is the orientation of the glaciers, which is the consistent common factor within the group. This implies that the critical distinction between these glaciers and the others is related to aspect, i.e. some climatic control was the causal factor.

The most likely situation in which an end moraine would not be formed would be where the ice front was not stationary at its maximum position for sufficiently long : if the glacier was extremely sensitive to minor climatic fluctuations no one terminal position would be recorded, since the formation of an end moraine requires a relative still-stand of the ice front. This presupposes unstable climatic conditions, for which some evidence is presented below.

Good evidence exists throughout the area for several still- stands of some of the glacier termini while near their maximum positions. Seven glaciers formed multiple end moraines while another six have multiple lateral moraines. Thirteen distinct glacier systems reacted to a maximum of four oscillations, presumably caused by cyclic temperature and/ or precipitation variation. This is not unexpected in view of the behaviour of similar recent and present-day glaciers in Norway, for instance, and the multiple termini of Loch Lomond Readvance glaciers from many other locations in Scotland.

The recessional ridges in the field area all occur within several hundred metres of the outer-most Readvance moraine, but this does not imply that the periodic retreat was fast. No consistent pattern exists in the relative sizes of the moraines : at the Strath a' Bhathaich terminus the outermost moraine is by far the largest feature, whereas the reverse occurs at the Thraill end moraines, the inner ridges exceeding the outer ones. The deduction that can be drawn from these facts is that the amelioration of the climate in the late Stadial was not a simple rise in temperature or decrease in precipitation, but fluctuations in one or both of these factors (or others) during deglaciation caused certain of the glaciers to respond with successive halts during retreat.

Fluted moraines are another type of moraine commonly produced by the Loch Lomond Readvance glaciers throughout the field area. Within Scotland these features, which indicate the direction of ice movement at the time of their formation, are known only inside the Loch Lomond Readvance limits (Sissons, 1967) : the evidence described in the previous chapter substantiates this. Only two of the glaciers did not form fluted moraines, both of these being very small 'overspill' tongues in high positions (Coire nan Clach and the Cadh an Eididh - An Gorm-loch tongue) . Elsewhere flutings were formed in varying forms and abundance, mostly in the upper parts of glacial troughs and valleys, less frequently in all parts, and never only in the lower reaches. As far as could be determined from field sections, the flutings are composed of moraine rubble similar to ground moraine, some being well-packed smooth moraine ridges while others are skeletal constructions comprising boulders of varying dimensions and (apparently) little or no interstitial material. These features seem to be constructional forms, and frequently their material was derived from a steep rock face (e.g. a coire headwall) or rocky spur or knoll. The spacing between flutes is often fairly regular in any particular area, though greater concentrations usually occur below such favourable features as mentioned above. Height and length vary, in general the longest and highest flutings (e.g. in Coire Roill and the Lair valley) being composed of coarse debris, and the more solid forms with finer matrices being lower and rounder. A third type of fluting is that which is at best only vaguely seen on the ground, but easily discerned from a vantage-point : these flutings are linear arrangements of surface moraine blocks amidst a general scatter of ablation or ground moraine (e.g. in Coire Grannda), and therefore have no real relief. It is conceivable that those three forms represent a continuum from little-weathered, compact ridges through the skeletal features to the much-eroded remnant alignments in the scatter of drift. However, detailed fabric analyses would be required to elucidate the relationships between these types of fluting.

Andersen and Sollid (1971) and Sollid et al. (1973) described fluted moraines in Norway that resemble in many ways those found in the field area. In the proglacial region of Mitdalsbreen, fluted moraines are extensively developed in ground moraine, stone-orientation studies showing the long axes of the component debris to be aligned with the axis of the flute, except near main end blocks, where they are turned inwards. Andersen and Sollid inferred from this that the forms were the result of the squeezing of till round rock projections (end blocks) on the glacier bed, the resulting accumulation of till in the lee of the rock being carried down-glacier and consequently forming a flute. Other works support the hypothesis of basal squeezing of till into subglacial cavities (e.g. Paul and Evans, 1974). This explanation seems plausible for those flutings in the study area that are similarly derived from rock projections, though it is not obvious that all are. In Finmark fluted moraines were found to prefer certain types of locality within a glacial valley : they occur on sloping surfaces in preference to flat ones, being particularly numerous on the distal sides of topographic impediments to ice flow (Sollid et al., pp 295-6). This distribution is also evident in the study area, in many instances the flutings being best developed (when away from the headwall) on rocky valley steps, e.g. to the east of Coire na Poite, Beinn Bhàn; in Coire Roill; and in the upper Lair valley. The most extensive area of flutings is on the north-facing cliffs above the Abhainn Thraill valley : a good example of a steep down-glacier slope being favoured.

Sollid et al. concluded from their survey that rapid deglaciation was important for the preservation of flutings, and in Norway they are often found in ice-marginal zones where recent retreat is known to have been rapid. If this was the case in Lateglacial Scotland, it implies that throughout the field area deglaciation was swift, perhaps especially so in those areas where fluted moraines are best preserved. Strangely, the areas of most abundant and well-defined fluted moraines are slopes facing north to east, the opposite of what one might expect in terms of insolation and rapid ice-decay. Flutings also occur on ground facing west, south and south-east, but in general such development is less extensive and individual features more poorly defined (e.g. the three Kishorn glaciers and that in the Fionn-amhainn valley). A wider area would have to be investigated to acertain if such a distribution truly exists and is of general significance. It is interesting that those glaciers that did not form end moraines were among those that produced most fluted moraines : this might imply some connection between rapid deglaciation and the non-formation of terminal features. Such an inference would substantiate the suggestion made previously that the glaciers facing north to north-east were particularly sensitive to environmental change.

Hummocky moraines are as characteristic of the Loch Lomond Readvance glaciers in the field area as are flutings. It will be evident from Chapter 2 that the term covers many different forms of morainic mound, all of which are nevertheless distinctive and typical Lateglacial deposits. However, as exemplified in the case of Loch Clair, the 'typical' hummocky moraines cannot unequivocably be assigned a Lateglacial age purely on appearance. Moraines known to be pre-Lateglacial in origin occasionally preserve the same sharply defined contours and are small, neat features similar to those of more recent origin.

Most hummocky moraine in the field area is of low relief (under 5 m high), and covers valley floors and the lower valley sides, though some occurs high up, e.g. at 495 m just south of the An Ruadh-stac - Meall nan Ceapairean col. Though the distribution of individual mounds in any area is often apparently random, producing a chaotic drainage system and a disordered, undulating landscape, quite frequently alignments are evident in the mounds. The commonest is the orientation of mound crests in an oblique downvalley direction, producing a chevron pattern if it occurs on both sides of the valley. More rarely the major orientation is directly downslope, i.e. at 90° to the valley axis (e.g. as in Strath a' Bhàthaich and the valley between Beinn Liath Mhor and Beinn Liath Beag). Where hummocky moraine is aligned in a downvalley direction, parallel to the valley axis, this is possibly due to the superimposition of flutings (e.g. Coire Attadale).

Gravenor and Kupsch (1959) termed such hummocky landforms 'disintegration moraine', and it is generally accepted that the mounds were formed during deglaciation by ice decaying <u>in situ</u> (Sissons, 1967; Sugden and John, 1976). The presence of occasional kames and eskers among hummocky moraine is, therefore, to be expected. Within the field area hummocks are found in those places where decaying ice would melt last, e.g. in depressions, and valley bottoms.

Two extensive areas of hummocky moraine are particularly remarkable. The head of Strath a' Bhathaich has already been discussed at some length (pp 50- 52 ): the short linear hummocks on the north-western foot-slopes of Maol Chean-dearg are unique in the study area, and no description of similar features has been encountered in the literature. Obviously there may have been as many modes of formation of moraine hummocks as there are different forms, and those in Strath a' Bhathaich were presumably produced by a process or combination of circumstances that were not repeated elsewhere. The other noteable area of hummocky moraines is the well-known Valley of the Hundred Hills (Coir' an Cheud-chnòic) by Glen Torridon. The remarkable profusion of moraines in this 2 km stretch of valley contrasts sharply with the relative absence of moraines on the floor of Glen Torridon, and their much sparser development in the opposite valley entrance. It is probable that the exit of the Coir' an Cheud-chnoic glacier was obstructed by the glacier emerging from Coire Dubh, with which it was confluent, and this damming-back effect may have caused the tremendous build-up of en- and subglacial debris along up-turned debris bands and shear planes, which was dumped during deglaciation to form the innumerable hummocks. The frequently conical or sharply-ridged forms of the moraines may be partly the result of normal sub-aerial erosion at a time when the moraine was newly deposited, and partly due to the collapse of decaying ice contacts and trimming by meltwater. The predominant grain size presumably influenced the final slopes evolved under these and subsequent environmental conditions, and these are largely stabilised now by vegetation.

## The Periglacial Features.

During glaciation in the Lateglacial period 72% of the land was not ice-covered, a greater proportion being exposed during the growth and decay of the glaciers. Periglacial conditions therefore affected this ground for at least 500 years and possibly much longer. The results of periglacial processes are most evident today on the mountain summits and upper valley sides, those areas where climatic conditions have been at all times most severe.

Periglacial features were mapped in the same way as glacial landforms, and dimensions were noted in the field. Where degraded features obscured by later slope movement or vegetation were noticed, these were not mapped, since excavation would have been necessary to confirm their origin. However, because of the harsh conditions still prevailing on the high ground, most solifluction features are well preserved and some (mostly the smaller forms) still appear to be active. No detailed analyses or investigations of the periglacial landforms were attempted since the main interest lay in their distribution.

Some definitions are necessary before describing the periglacial features.

1. A division was made between solifluction terraces and solifluction lobes, using a subjective distinction based on shape, the lobes being markedly elongated downslope while the terraces are wide in relation to length, approximately following the contour of the hillside.

The dimensions of both referred to in descriptions include the height of the front (riser) measured vertically, the depth of the tread (horizontal surface) measured from back to front, and the width of the feature laterally across the tread.

2. Blockfield (felsenmeer) refers to relatively flat areas of frost-shattered bedrock where the resulting regolith is dense enough to obscure the solid bedrock beneath : other areas obviously affected by frost processes to a much smaller degree are referred to as 'disturbed ground', including a greater or lesser quantity of frost-heaved stones. Block slopes are areas of felsenmeer developed on sloping ground, i.e. upper hillsides where the regolith is not derived from a cliff above.

Torridon Sandstone appears to split preferentially into relatively flat platy blocks, and the abundance of felsenmeer developed in it implies that the numerous joints and bedding planes facilitated the freeze - thaw process to produce thick layers of frost-rived debris. Shattered Cambrian Quartzite adopts more blocky forms, usually being extremely angular (unlike the sandstone), and thick periglacial deposits are rarer than on Torridon Sandstone. This may largely be a result of the greater impermeability of the quartzite.

The facility with which periglacial forms are observed is enhanced by the lack of vegetation on most of the mountain summits and upper slopes. Wind is the chief factor in prohibiting the growth of plants here, and in sheltered situations where vegetation does survive, the nature of the ground surface is obscured and (presumably) largely stabilised. The distribution of periglacial features is, therefore, not a reliable guide to the past distribution of active processes : some original features have been degraded, while in other areas more recent activity has produced, or is producing, similar forms. It is believed that all of the major features such as blockfields, block slopes, and the largest lobes and terraces, date from at latest the last period of severe environmental conditions, the Lateglacial Stadial. Development of these massive features under modern or recent climatic conditions is difficult to envisage, and no signs of present activity were observed in them. Areas not ice-covered in the

Stadial may retain elements from former periglacial periods, e.g. the pre-Interstadial deglaciation, though it is probable that these would be modified or removed by more recent processes. Occurrence of periglacial landforms inside Loch Lomond Readvance limits implies a Postglacial age for these features, while some minor forms described below are obviously still active, and were presumably even more so in the Little Ice Age (the 16th. to 19th. centuries), thus further complicating matters.

In the Western Area the central plateau comprises the largest area severely affected by periglacial processes in the Lateglacial period. Intense frost riving has produced a ubiquitous scatter of shattered blocks all over the flat and gently sloping mountain tops : the only area that notably lacks these is the northern part of the Beinn Bhàn ridge which is probably a solifluction sheet, covered with a dense turf of montane grassland. (It is suspected that this part of the northern ridge may comprise vegetated sand deposits such as occur on An Teallach in northern Wester Ross, but no proof of this hypothesis is yet available.)

Beinn Bhàn illustrates most of the periglacial features typical of the study area (Fig. 9). One of the finest areas of blockfield occurs on the spur that descends to the Bealach nan Arr : it is significant in terms of the Loch Lomond Readvance limits that this deposit is not continued across the col, but is clearly developed only above 670 m O.D., the col foot lying at about 610 m O.D. Patches of felsenmeer occur on the minor summits of the ridge and on other exposed rocky areas.

A smooth solifluction sheet showing minor forms of disturbance (e.g. small stones littering the surface, in places standing vertically) covers most of the gently sloping ground. Where solifluction has occurred on steeper slopes the smooth mantle forms terraces or lobes, the size being apparently related, at least in part, to the gradient. At either side of the ridge block slopes on the non-vertical cliffs grade into the fringe of disturbed ground that borders the top of the ridge. The area of largest solifluction features is on the east face of the minor summit above Coir' Each : here there are terraces several tens of metres long and 3 to 4 m deep, with fronts about 1 m high. In general the terrace fronts on the ridge are under 1 m in height, most being turf-fronted, and some having evidence of present-day movement in the spilling of debris from the tread over the riser. With decreasing altitude at both ends of the ridge the ground surface becomes more densely vegetated, but still accumulations of fossil frost-rived boulders appear. One periglacial form not observed elsewhere in the field area is that of turf or earth hummocks, small (ca. 30 cm high) rounded and irregular knobs in turf, covering a small area in a sandy depression near a lochan.

The contrast between the Beinn Bhàn ridge and Carn Dearg is marked in terms of periglaciation. Whereas the former ridge has an extensive vegetation cover in the north, at an altitude of over 760 m O.D., the surface of Carn Dearg at 640 m O.D. consists mainly of bedrock ribs and ridges with a continuous scatter of boulders insufficiently dense to warrant the term 'blockfield'. No solifluction features were observed. The reason for this contrast is not known, but it is possible that environmental conditions were less severe on the lower ridge (despite the greater proximity to the former glacier surfaces), as the ridge is somewhat sheltered by the surrounding higher land. The lack of vegetational growth here by comparison with the Beinn Bhàn ridge could be due to the lack of a suitable substrate : there is no fine solifluction sheet such as the vascular plants of the higher ridge have colonised.

Sgurr a' Chaorachain and Meall Gorm are more akin to Beinn Bhàn in the development of blockfields on the summits, and solifluction features elsewhere. The boulder fields are most extensive and dense in the mantle of platy debris around the 770 m peak of the Sgurr. Meall Gorm has a less thick covering of frost-shattered boulders, and very localised evidence of solifluction including small terraces (the fronts being 0.5 to 0.75 m high) and lobate accumulations of boulders infilling a small valley. Much bare rock is evident on Meall Gorm, and again, extensive solifluction sheets are absent, probably because of the lack of gentle slopes.

Much of the Sgurr a' Chaorachain ridge consists of bedrock projections, some of which are intensely shattered with debris piled up _in situ_. Loose boulders occur everywhere : some of these are doubtless ice-sheet moraine, but the majority are believed to be of local derivation, the products of frost-riving. Solifluction terraces occur on the slopes descending to cols between the minor peaks. These are typically small turf-fronted features anout 10 m long and 0.5 to 1.0 m high and deep. An interesting area above the south headwall of Coire a' Chaorachain comprises a gradation from terraces on the north-east facing side of the col into lobes on the steeper gradient below, which in turn become elongated stripes of more active debris with little relief, tens of metres long, giving a banded appearance to the upper block slopes. Within the lobate form sorting appears to have occurred, the central areas comprising finer debris. An area of particularly well-developed solifluction terraces exists on the south-eastern extremity of the ridge : here a suite of low terraces sweeps for several tens of metres obliquely across the hillside below the steeper slopes on which solifluction lobes are developed.

Solifluction features also exist at a much lower altitude on the plateau than those described above. In Coir' an Fhamhair (809458) terraces form steps where the coire floor begins to fall more steeply eastward : these features are 1.5 m high, 5 m deep, and several metres long, curving round the contour of the slope. The treads are not colonised by plants (though the fronts are completely vegetated) but have some signs of frost disturbance. Similar solifluction terraces also occur several tens of metres lower down, similarly within the well-defined limit of the former ice lobe (p. 33 ). These features and others mentioned below prove that not all of the periglacial forms are Lateglacial or earlier in origin, some dating from the period of deglaciation or the Flandrian.

In the Eastern Area, similar patterns prevail on the narrow ridges and mountain summits, but extensive high areas as in the Applecross plateau do not exist. Sgurr na Bana Mhoraire and Beinn Damh illustrate this : they constitute a narrow ridge, in places knife-edged, mantled in loose shattered quartzite lying *in situ* on the gentler slopes and in places formed into lobes or terraces. True blockfields and block slopes cover all four of the minor peaks, this and a thinner cover merging into the screes and block slopes that drape the precipitous sides of much of the ridge. Solifluction features again appear on sloping ground, especially in the wind-funneling cols. South-east of the central summit are some of the biggest solifluction lobes encountered : these reach 10 m in depth, being a few metres wide, and the steep fronts are 2 m high, sloping at *ca.* 30°. The treads are relatively smooth, and vegetated with a thin mat of grasses and moss, while the fronts consist of coarser rubble with very little interstitial vegetation.

The round top of Maol Chean-dearg is surrounded by precipitous cliffs and screes, and thickly mantled in block slopes on the south-east facing slope. This deposit is formed into a fringe of very large lobes at the base : these features are *ca.* 4 m high at the risers and several metres long. Below them is an area of turf-fronted terraces, and similar features are present on the small flat summit area. Several tens of square metres on the lower south-eastern slopes of Maol Chean-dearg , below the fossil rock glacier described on p. 62 , are occupied by suites of solifluction terraces and lobes, in places well-preserved and possibly active. The largest lobes here are some ten metres deep and two metres high at the fronts, which are turf.

The opposite side of the Fionn-amhainn valley also has abundant evidence of past (and possibly present) downslope movement, but in this case above the hypothesised valley glacier limit. Lobes are developed below the skirts of scree on Sgorr Ruadh and Fuar Tholl, and below the intermediate col. This valley-side illustrates the relationship that sometimes is seen to exist between periglacial features and Loch Lomond Readvance limits : the solifluction forms are present above and down to the drift limit, but not below it. However, the limits of ground affected by periglacial processes cannot here be reliably used as indicators of former ice margins (cf. Sissons and Grant, 1972) because of the evident variation in age of the features.

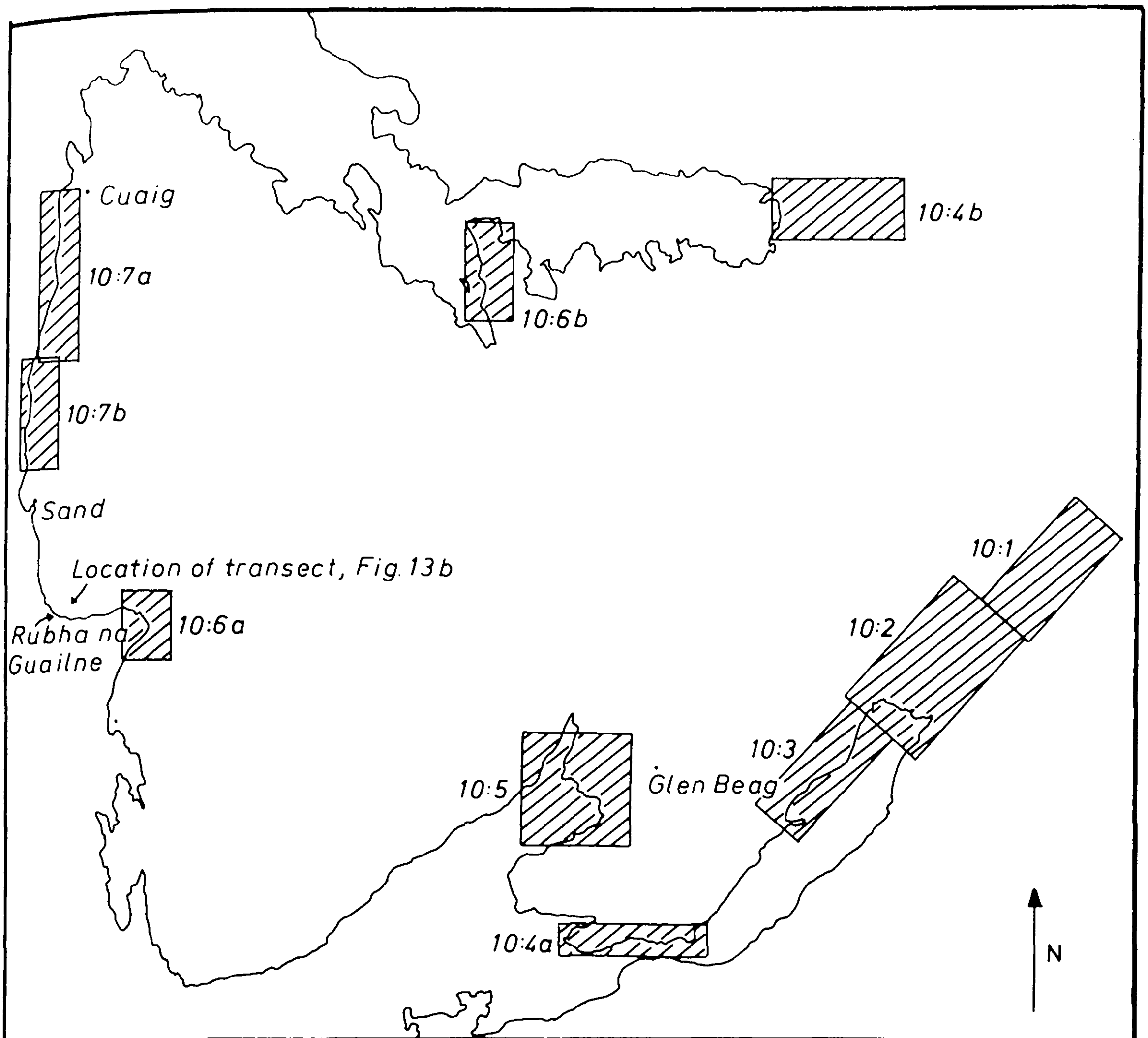
An Ruadh-stac is, like Maol Chean-dearg, a conical hill, and has been subjected to similar conditions as its neighbours. Massive slabs of polished and striated quartzite bedrock on the lower slopes give way higher up to frost-shattered debris, and this division may also reflect the former boundary of glacial and periglacial conditions in the Stadial. The third member of this group of peaks, Meall nan Ceapairean, is lower than the others, but is also liberally strewn with the products of intense frost-riving. This debris contrasts sharply with the smooth drift-strewn slopes below.

The Beinn Liath Mhór ridge to the north-east is spectacularly narrow, with Cambrian Quartzite block slopes and screes descending a few hundred metres on either side. Lack of level ground on the summit ridge precluded extensive development of solifluction features, but small patches of disturbed ground, terraces and stone stripes were noted in the cols. The neighbouring and lower ridge, Beinn Liath Beag, is more remarkable in that an active deflation surface comprising small cobbles 'inlaid' in a gritty matrix covers part of the level eastern summit area (987529). This surface is extremely smooth, and in at least one locality appeared to be actively flowing downslope in a flat tongue-shaped tract with larger stones on its periphery. Boulders are rare here, but include sandstone erratics, and vegetation is almost completely lacking. Solifluction features occur on the steeper slopes below, and blockfield clothes much of the western ridge. The summits of Sgorr nan Lochan Uaine and Sgurr Dubh display much intensely shattered quartzite interspersed with bedrock outcrops, with block slopes and scree mantling the upper hillsides.

# CHAPTER FIVE

'It is interesting to observe that we have, especially in our own islands, good evidence to show that during the glacial period considerable oscillations of the relative level of land and sea took place'

(Geikie, 1893, p. 173)




Positions of Figures 10:1 to 10:7

| | |
|---|---|
| levelled feature & locations of spot heights | B beach |
| rear cliff line of buried platform | R beach ridge |
| depression — kettle-hole or raised lagoon | D delta |
| probable continuation of rock platform cliff | P platform |
| ✱ stack | T terrace |
| channel | F outwash fan |

# Figure 10 : Key for Figs 10:1–10:7

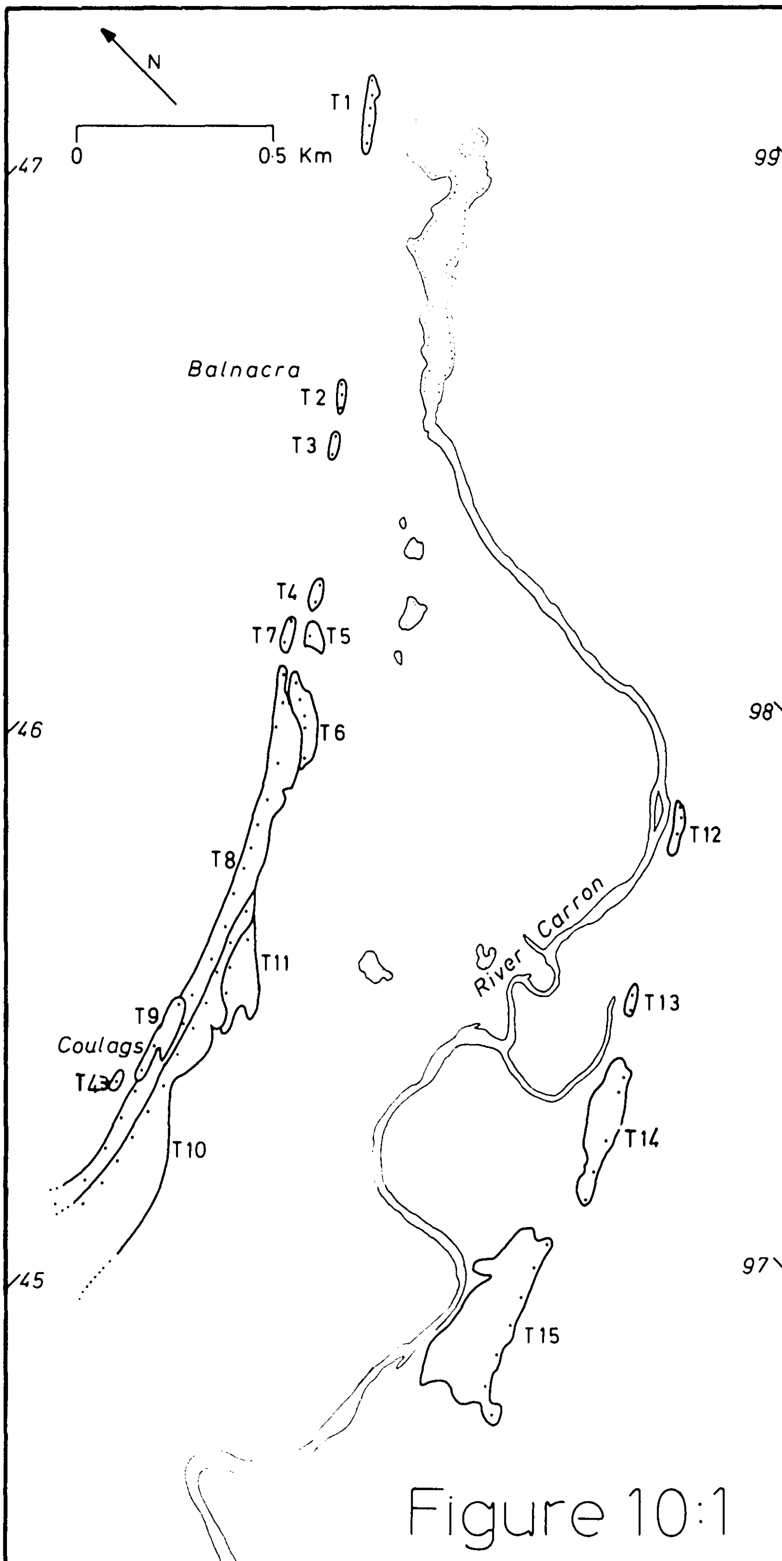

N
0
0·5 Km
T1
47
99
Balnacra
T2
T3
T4
T7
T5
46
T6
98
T12
T8
River Carron
T11
T13
T9
Coulags
T43
T14
T10
45
97
T15
Figure 10:1

TABLE 2 : 2.

| Number of feature | Highest spot height | Lowest spot height | Mean altitude (where relevant) | Number of heights | Reference number in Appendix A. |
|---|---|---|---|---|---|
| T16 | 39.06 | 38.38 | | 3 | 74 to 76 |
| F1 | 21.64 | 3.96 | | 32 | 77 to 108 |
| T17 | 23.14 | 22.51 | 22.83 | 2 | 109, 110 |
| T18 | | | | 1 | 111 |
| T19 | 25.52 | 21.34 | 23.49 | 13 | 112 to 124 |
| T20 | 29.68 | 24.19 | 27.17 | 7 | 733 to 739 |
| T21 | 23.47 | 22.15 | 23.26 | 11 | 125 to 135 |
| T22 | 24.72 | 20.15 | 22.46 | 4 | 136 to 139 |
| T23 | 23.67 | 19.15 | 22.15 | 6 | 140 to 145 |
| T24 | 16.50 | 15.97 | 16.24 | 2 | 146, 147 |
| T25 | 26.87 | 22.46 | 24.17 | 12 | 148 to 159 |
| P1 | 6.22 | 5.00 | 5.48 | 15 | 160 to 174 |
| R1 | 11.27 | 6.00 | 8.34 | 11 | 175 to 185 |
| R2 | 8.42 | 6.50 | 7.39 | 10 | 186 to 195 |
| B1 | 8.83 | 7.97 | 8.36 | 3 | 196 to 198 |
| B2 | 7.01 | 6.00 | 6.41 | 4 | 199 to 202 |
| R3 | 11.10 | 10.02 | 10.38 | 7 | 203 to 209 |
| F2 | 34.47 | 9.64 | | 16 | 210 to 225 |
| R4 | 8.97 | 8.37 | 8.78 | 3 | 226 to 228 |
| R5 | 7.25 | 6.85 | 7.02 | 7 | 229 to 235 |
| R6 | 7.13 | 7.05 | 7.08 | 3 | 236 to 238 |
| R7 | 9.74 | 9.58 | 9.67 | 3 | 239 to 241 |
| R8 | 7.48 | 6.59 | 7.04 | 3 | 242 to 244 |
| R9 | 5.05 | 4.18 | 4.59 | 8 | 245 to 252 |
| R10 | 5.85 | 5.08 | 5.46 | 2 | 253 to 254 |
| R11 | | | | 1 | 255 |
| R12 | | | | 1 | 256 |
| R13 | 7.51 | 7.38 | 7.45 | 3 | 257 to 259 |

TABLE 2 : 2.

| Number of feature | Highest spot height | Lowest spot height | Mean altitude (where relevant) | Number of heights | Reference number in Appendix A. |
|---|---|---|---|---|---|
| T16 | 39.06 | 38.38 | | 3 | 74 to 76 |
| F1 | 21.64 | 3.96 | | 32 | 77 to 108 |
| T17 | 23.14 | 22.51 | 22.83 | 2 | 109, 110 |
| T18 | | | | 1 | 111 |
| T19 | 25.52 | 21.34 | 23.49 | 13 | 112 to 124 |
| T20 | 29.68 | 24.19 | 27.17 | 7 | 733 to 739 |
| T21 | 23.47 | 22.15 | 23.26 | 11 | 125 to 135 |
| T22 | 24.72 | 20.15 | 22.46 | 4 | 136 to 139 |
| T23 | 23.67 | 19.15 | 22.15 | 6 | 140 to 145 |
| T24 | 16.50 | 15.97 | 16.24 | 2 | 146, 147 |
| T25 | 26.87 | 22.46 | 24.17 | 12 | 148 to 159 |
| P1 | 6.22 | 5.00 | 5.48 | 15 | 160 to 174 |
| R1 | 11.27 | 6.00 | 8.34 | 11 | 175 to 185 |
| R2 | 8.42 | 6.50 | 7.39 | 10 | 186 to 195 |
| B1 | 8.83 | 7.97 | 8.36 | 3 | 196 to 198 |
| B2 | 7.01 | 6.00 | 6.41 | 4 | 199 to 202 |
| R3 | 11.10 | 10.02 | 10.38 | 7 | 203 to 209 |
| F2 | 34.47 | 9.64 | | 16 | 210 to 225 |
| R4 | 8.97 | 8.37 | 8.78 | 3 | 226 to 228 |
| R5 | 7.25 | 6.85 | 7.02 | 7 | 229 to 235 |
| R6 | 7.13 | 7.05 | 7.08 | 3 | 236 to 238 |
| R7 | 9.74 | 9.58 | 9.67 | 3 | 239 to 241 |
| R8 | 7.48 | 6.59 | 7.04 | 3 | 242 to 244 |
| R9 | 5.05 | 4.18 | 4.59 | 8 | 245 to 252 |
| R10 | 5.85 | 5.08 | 5.46 | 2 | 253 to 254 |
| R11 | | | | 1 | 255 |
| R12 | | | | 1 | 256 |
| R13 | 7.51 | 7.38 | 7.45 | 3 | 257 to 259 |

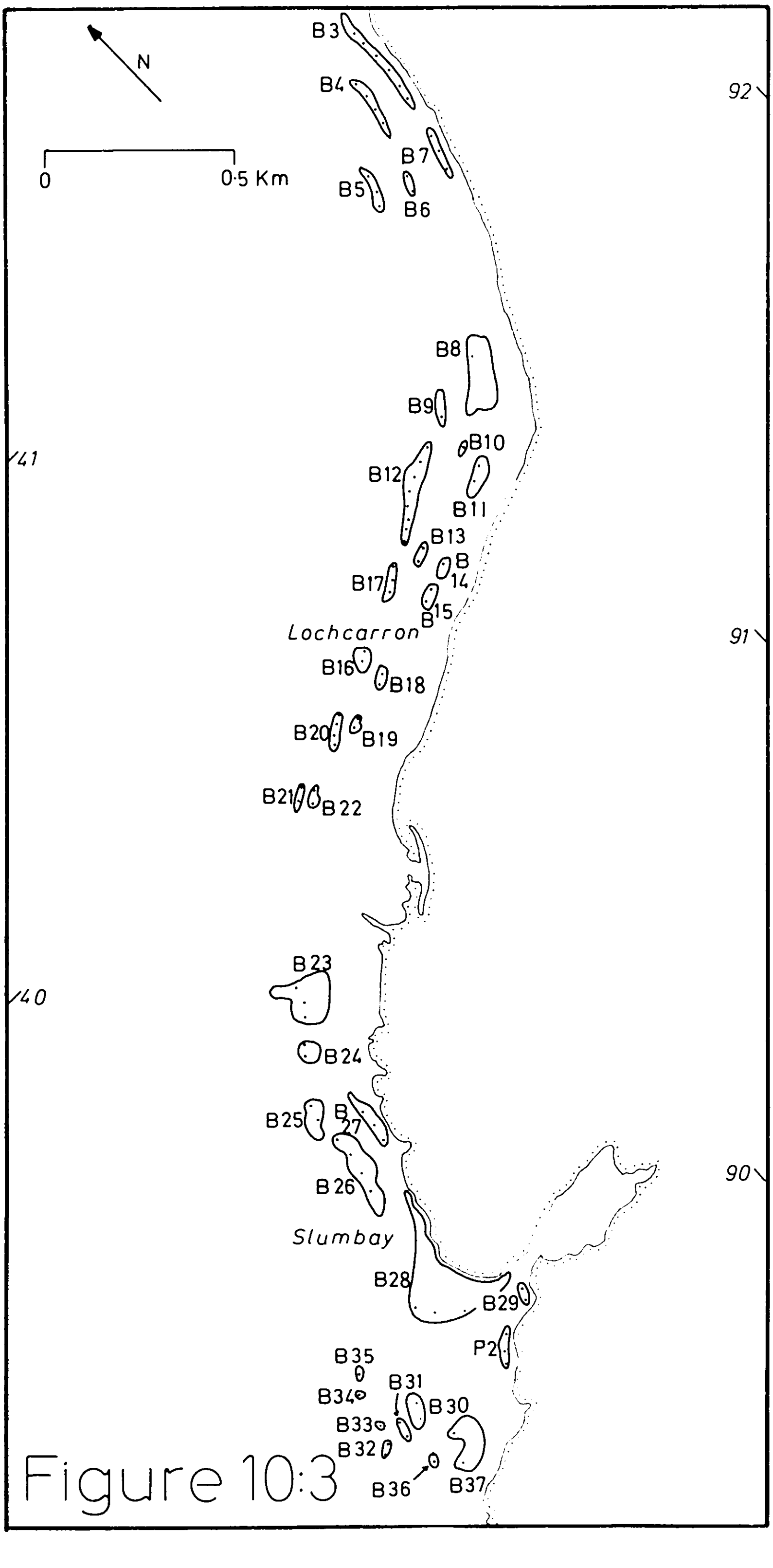

N
0
0·5 Km
B3
B4
B7
B5
B6
B8
B9
B10
B12
B11
B13
B 14
B17
B15
Lochcarron
B16
B18
B20
B19
B21
B22
B23
B24
B25
B 27
B26
Slumbay
B28
B29
P2
B35
B31
B34
B30
B33
B32
B36
B37
92
41
91
40
90

Figure 10:3

TABLE 2 : 3.

| Number of Feature | Highest spot height | Lowest spot height | Mean altitude | Number of heights | Reference number in Appendix A. |
|---|---|---|---|---|---|
| B3 | 6.50 | 5.85 | 6.12 | 6 | 260 to 265 |
| B4 | 20.52 | 19.74 | 20.14 | 5 | 266 to 270 |
| B5 | 33.35 | 32.79 | 33.11 | 3 | 271 to 273 |
| B6 | 26.63 | 25.99 | 26.31 | 2 | 274, 275 |
| B7 | 5.44 | 4.52 | 4.89 | 3 | 276 to 278 |
| B8 | | | | 1 | 279 |
| B9 | | | | 1 | 280 |
| B10 | | | | 1 | 281 |
| B11 | 26.95 | 26.52 | 26.74 | 3 | 282 to 284 |
| B12 | 40.13 | 39.06 | 39.56 | 8 | 285 to 292 |
| B13 | 34.66 | 34.42 | 34.54 | 2 | 293, 294 |
| B14 | | | | 1 | 295 |
| B15 | 27.11 | 26.78 | 26.95 | 2 | 296, 297 |
| B16 | 39.32 | 38.81 | 39.07 | 2 | 298, 299 |
| B17 | 38.59 | 37.33 | 37.76 | 3 | 300 to 302 |
| B18 | 31.59 | 31.07 | 31.33 | 2 | 303, 304 |
| B19 | 37.88 | 37.66 | 37.77 | 2 | 305, 306 |
| B20 | 45.99 | 45.56 | 45.88 | 4 | 307 to 310 |
| B21 | 51.64 | 51.62 | 51.63 | 2 | 311, 312 |
| B22 | 47.12 | 46.45 | 46.79 | 2 | 313, 314 |
| B23 | 25.37 | 24.71 | 25.04 | 3 | 315 to 317 |
| B24 | 26.08 | 25.97 | 26.03 | 2 | 318, 319 |
| B25 | 26.89 | 26.36 | 26.63 | 2 | 320, 321 |
| B26 | 25.36 | 24.40 | 24.88 | 4 | 322 to 325 |
| B27 | 6.13 | 5.96 | 6.02 | 3 | 326 to 328 |
| B28 | 9.96 | 8.06 | 9.32 | 3 | 329 to 331 |
| B29 | 3.91 | 3.82 | 3.87 | 2 | 332,333 |
| P2 | 4.10 | 3.81 | 3.96 | 3 | 334 to 336 |
| B30 | 20.91 | 20.53 | 20.72 | 2 | 337, 338 |
| B31 | 23.74 | 23.47 | 23.61 | 2 | 339, 340 |
| B32 | 45.79 | 45.69 | 45.74 | 2 | 341, 342 |
| B33 | | | | 1 | 343 |
| B34 | | | | 1 | 344 |
| B35 | | | | 1 | 345 |
| B36 | | | | 1 | 346 |
| B37 | 17.91 | 17.04 | 17.48 | 2 | 347, 348 |

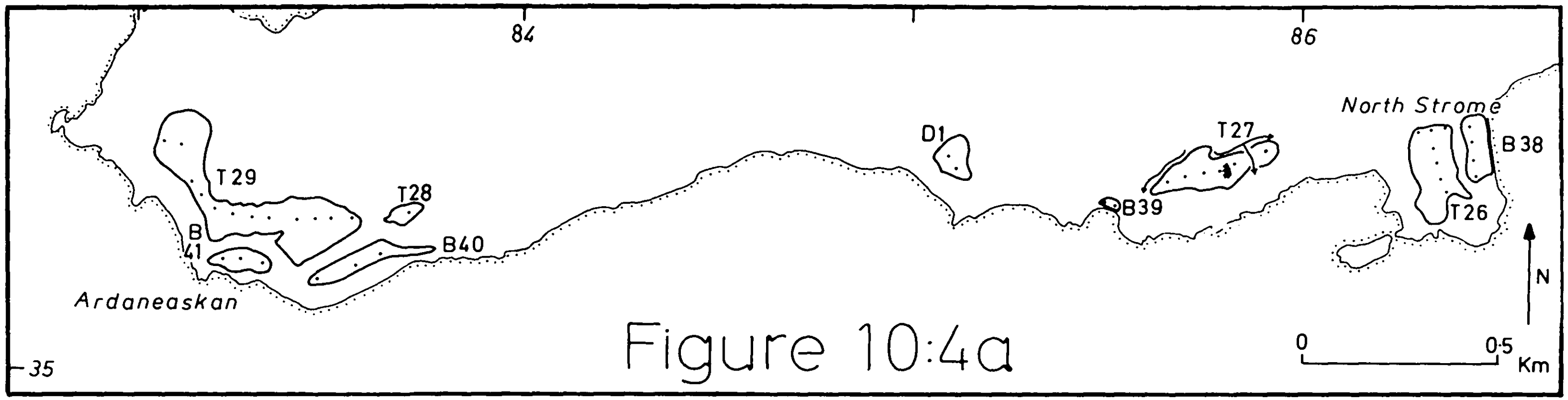



Figure 10:4a

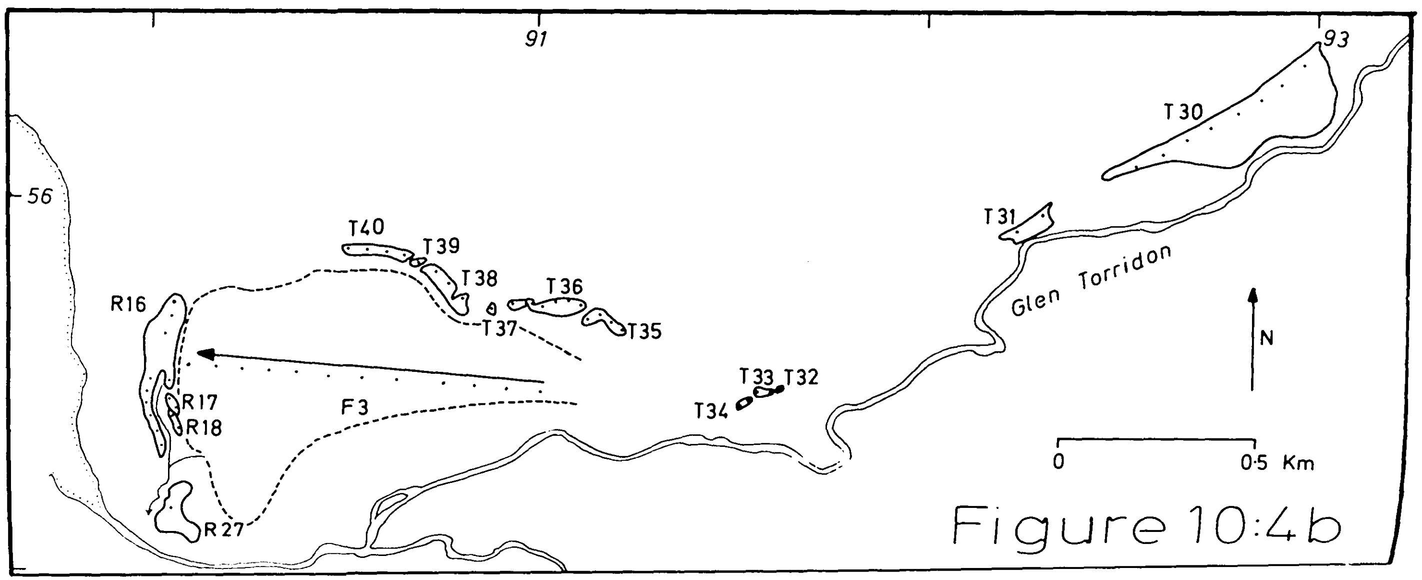



Figure 10:4b

TABLE 2 : 4.

| Number of feature | Highest spot height | Lowest spot height | Mean altitude (where relevant) | Number of heights | Reference number in Appendix A. |
|---|---|---|---|---|---|
| B38 | 7.75 | 7.05 | 7.45 | 4 | 349 to 352 |
| T26 | 16.92 | 15.86 | | 7 | 353 to 359 |
| T27 | 34.90 | 33.40 | 34.51 | 7 | 360 to 366 |
| B39 | 5.79 | 5.13 | 5.46 | 2 | 367, 368 |
| D1 | 38.34 | 37.87 | 38.11 | 2 | 369, 370 |
| B40 | 9.92 | 9.27 | 9.68 | 3 | 371 to 373 |
| B41 | 5.25 | 4.56 | 4.87 | 3 | 374 to 376 |
| T28 | | | | 1 | 377 |
| T29 | 30.49 | 25.93 | | 12 | 378 to 389 |
| T30 | 58.73 | 45.74 | | 8 | 537 to 544 |
| T31 | 41.6 | 39.34 | | 2 | 545, 546 |
| T32 | | | | 1 | 547 |
| T33 | 30.14 | 27.71 | | 2 | 548, 549 |
| T34 | 25.22 | 24.38 | 24.80 | 2 | 550, 551 |
| T35 | 25.02 | 24.13 | 24.56 | 4 | 552 to 555 |
| T36 | 23.63 | 21.36 | 22.33 | 6 | 556 to 561 |
| T37 | | | | 1 | 562 |
| T38 | 20.55 | 19.92 | | 3 | 563 to 565 |
| T39 | | | | 1 | 566 |
| T40 | 19.56 | 18.78 | | 4 | 567 to 570 |
| F3 | 17.52 | 7.20 | | 12 | 571 to 582 |
| R16 | 8.79 | 7.74 | 8.22 | 10 | 583 to 592 |
| R17 | 8.27 | 8.10 | 8.18 | 2 | 593, 594 |
| R18 | 7.67 | 7.18 | 7.42 | 2 | 595, 596 |
| R27 | | | | 1 | 597 |

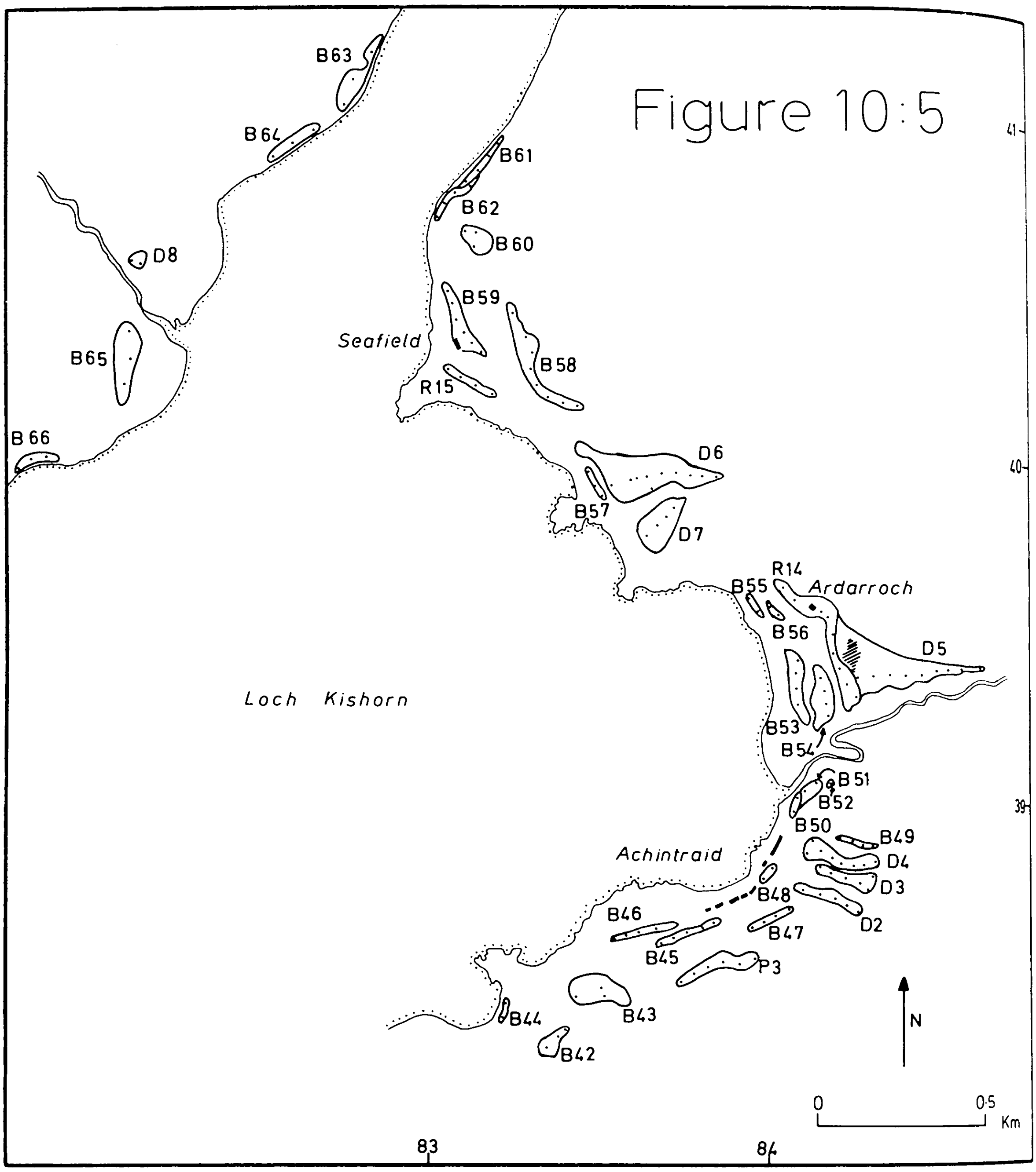


Figure 10:5
B63
B64
B61
B62
B60
D8
B59
Seafield
B58
B65
R15
B66
D6
B57
D7
R14
B55
Ardarroch
B56
D5
Loch Kishorn
B53
B54
B51
B52
B50
B49
Achintraid
D4
D3
B48
D2
B46
B47
B45
P3
B43
B44
B42
N
0
0·5
Km
83
84
41
40
39

TABLE 2 : 5.

| Number of Feature | Highest spot height | Lowest spot height | Mean altitude (where relevant) | Number of heights | Reference number in Appendix A. |
|---|---|---|---|---|---|
| B42 | 24.88 | 23.91 | 24.55 | 3 | 390 to 392 |
| B43 | 24.78 | 23.30 | 24.16 | 3 | 393 to 395 |
| B44 | 5.91 | 5.14 | 5.53 | 2 | 396, 397 |
| P3 | 34.87 | 34.02 | 34.45 | 6 | 398 to 403 |
| B45 | 21.58 | 21.21 | 21.46 | 4 | 404 to 407 |
| B46 | 18.50 | 17.51 | 18.02 | 5 | 408 to 412 |
| B47 | 26.27 | 25.03 | 25.79 | 4 | 413 to 416 |
| B48 | 8.16 | 8.11 | 8.14 | 2 | 417, 418 |
| D2 | 29.49 | 23.92 | | 5 | 419 to 423 |
| D3 | 29.65 | 25.48 | | 6 | 424 to 429 |
| D4 | 29.05 | 25.32 | | 8 | 430 to 437 |
| B49 | 31.51 | 30.69 | 31.27 | 4 | 438 to 411 |
| B50 | 7.04 | 6.68 | 6.86 | 2 | 442, 443 |
| B51 | 6.39 | 5.96 | 6.18 | 2 | 444, 445 |
| B52 | | | | 1 | 446 |
| B53 | 5.71 | 5.61 | 5.66 | 4 | 447 to 450 |
| B54 | 8.09 | 7.67 | 7.88 | 4 | 451 to 454 |
| B55 | 9.40 | 8.58 | 8.99 | 2 | 455, 456 |
| B56 | 18.08 | 17.95 | 18.02 | 2 | 457, 458 |
| R14 | 28.17 | 26.09 | 26.92 | 9 | 459 to 467 |
| D5 | 28.01 | 24.68 | | 9 | 468 to 476 |
| D6 | 25.21 | 17.68 | | 10 | 477 to 486 |
| D7 | 24.53 | 15.98 | | 4 | 487 to 490 |
| B57 | 8.52 | 7.58 | 8.20 | 3 | 491 to 493 |
| B58 | 27.93 | 25.35 | 26.58 | 8 | 494 to 501 |
| R15 | 9.67 | 9.26 | 9.50 | 4 | 502 to 505 |
| B59 | 16.98 | 15.28 | 16.04 | 6 | 506 to 511 |
| B60 | 24.74 | 24.48 | 24.48 | 3 | 512 to 514 |
| B61 | 5.95 | 4.63 | 5.27 | 4 | 515 to 518 |
| B62 | 7.25 | 6.05 | 6.64 | 4 | 519 to 522 |
| B63 | 3.83 | 2.55 | 3.38 | 3 | 523 to 525 |
| B64 | 3.55 | 3.15 | 3.33 | 3 | 526 to 528 |
| D8 | 14.65 | 14.50 | 14.58 | 2 | 529, 530 |
| B65 | 9.01 | 8.86 | 8.94 | 3 | 531 to 533 |
| B66 | 5.46 | 4.67 | 5.07 | 3 | 534 to 536 |

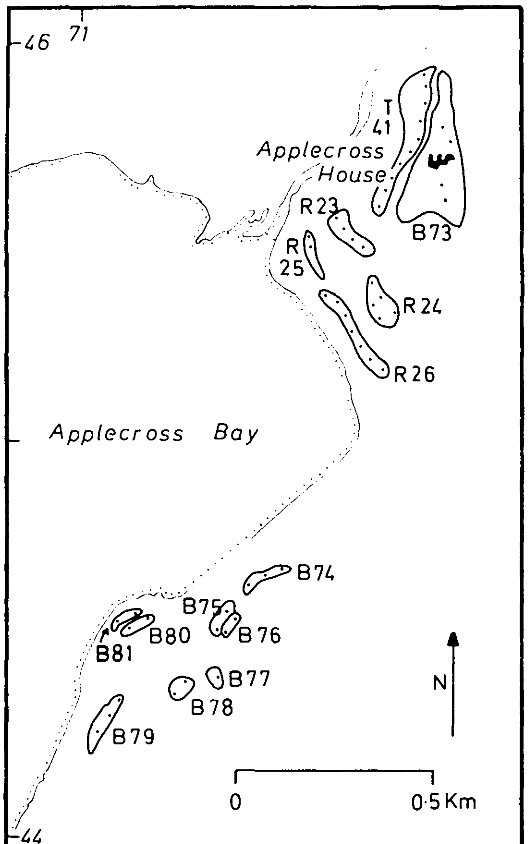



Figure 10:6a

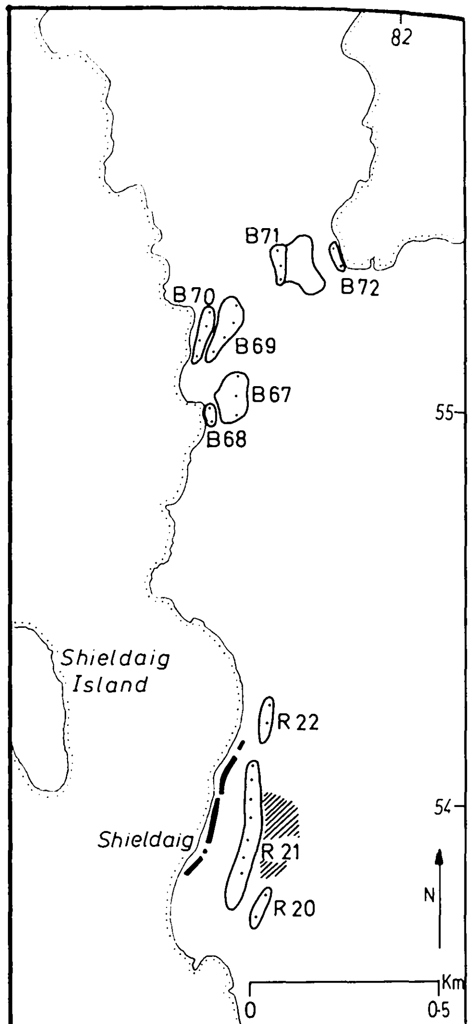



Figure 10:6b

TABLE 2 : 6.

| Number of Feature | Highest spot height | Lowest spot height | Mean altitude | Number of heights | Reference number in Appendix A. |
|---|---|---|---|---|---|
| R20 | 20.95 | 20.94 | 20.95 | 2 | 598, 599 |
| R21 | 21.41 | 20.68 | 20.99 | 7 | 600 to 606 |
| R22 | 22.90 | 22.36 | 22.63 | 2 | 607, 608 |
| B67 | 21.88 | 20.90 | 21.46 | 3 | 609 to 611 |
| B68 | 7.21 | 6.92 | 7.07 | 2 | 612, 613 |
| B69 | 20.22 | 19.78 | 20.08 | 4 | 614 to 617 |
| B70 | 7.04 | 6.40 | 6.83 | 4 | 618 to 621 |
| B71 | 17.62 | 16.74 | 17.31 | 3 | 622 to 624 |
| B72 | 8.77 | 8,74 | 8.76 | 2 | 625, 626 |
| B73 | 8.88 | 8.60 | 8.74 | 6 | 627 to 632 |
| T41 | 7.63 | 5.18 | | 10 | 633 to 642 |
| R23 | 6.58 | 6.31 | 6.46 | 4 | 643 to 646 |
| R24 | 7.75 | 7.31 | 7.46 | 5 | 647 to 651 |
| R25 | 4.67 | 4.62 | 4.65 | 2 | 652, 653 |
| R26 | 7.41 | 5.92 | 6.65 | 7 | 654 to 660 |
| B74 | 30.82 | 30.26 | 30.52 | 3 | 661 to 663 |
| B75 | 31.35 | 31.34 | 31.35 | 2 | 664, 665 |
| B76 | 32.41 | 32.35 | 32.38 | 2 | 666, 667 |
| B77 | | | | 1 | 669 |
| B78 | 31.52 | 31.00 | 31.26 | 2 | 669, 670 |
| B79 | 31.16 | 30.87 | 31.01 | 3 | 671 to 673 |
| B80 | 7.08 | 6.96 | 7.02 | 2 | 674, 675 |
| B81 | 5.72 | 5.38 | 5.55 | 2 | 676, 677 |

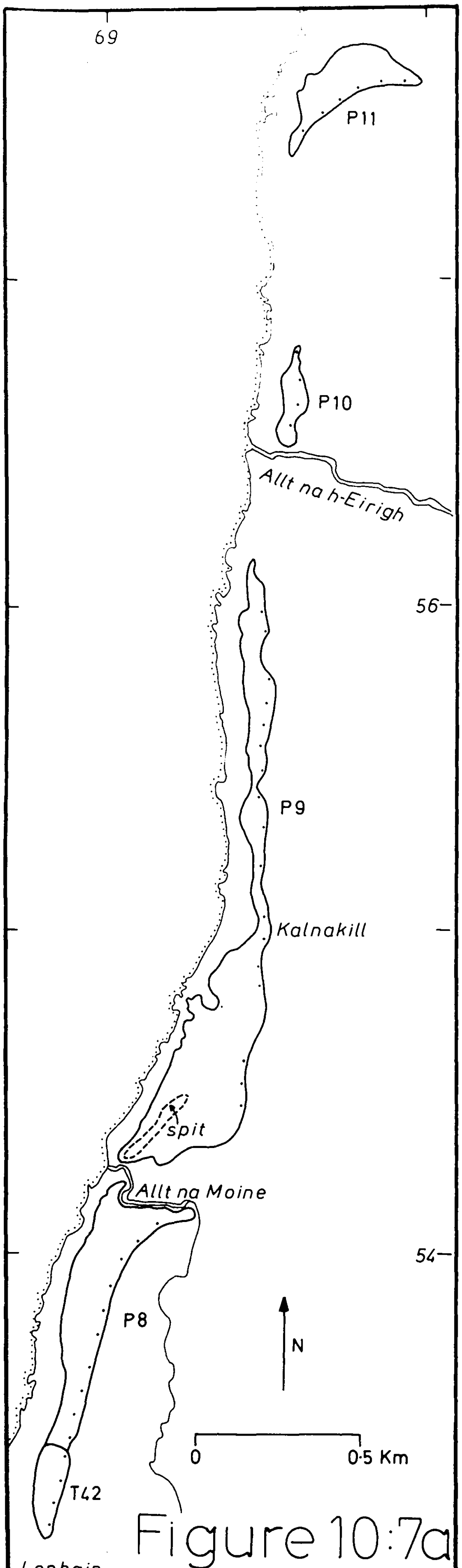



Figure 10:7a

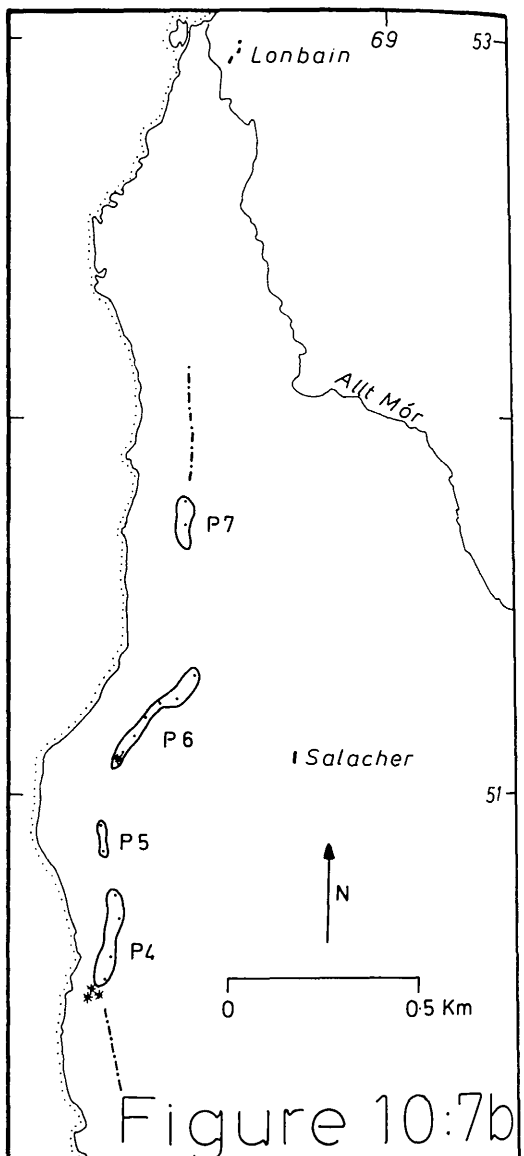



Figure 10:7b

TABLE 2 : 7.

| Number of Feature | Highest spot height | Lowest spot height | Mean altitude (where relevant) | Number of heights | Reference number in Apenndix A. |
|---|---|---|---|---|---|
| P4 | 35.43 | 34.46 | 34.88 | 4 | 679 to 681 |
| P5 | 35.80 | 34.92 | 35.36 | 2 | 682. 683 |
| P6 | 36.67 | 35.18 | 35.89 | 6 | 684 to 689 |
| P7 | 36.42 | 35.57 | 36.00 | 2 | 690, 691 |
| T42 | 30.69 | 28.94 | | 4 | 692 to 695 |
| P8 | 28.68 | 27.45 | 27.81 | 10 | 696 to 705 |
| P9 | 30.79 | 27.38 | 29.16 | 17 | 706 to 722 |
| P10 | 30.16 | 29.12 | 29.62 | 4 | 723 to 726 |
| P11 | 27.32 | 26.14 | 26.79 | 6 | 727 to 732 |

## Former sea-levels in the field area.

The study of former sea-levels in the field area is an integral part of investigating the effects of glaciation, since relative movements of land and sea were largely caused by the growth and decay of glacier ice. The purpose of mapping and measuring the altitudes of raised shorelines was, therefore, to substantiate and add to the story interpreted from glacial landforms.

Former shorelines are best developed at and near the heads of lochs Torridon, Kishorn and Carron, and along the western coast of the Applecross Peninsula. Long stretches of coastline retain only poorly developed raised shorelines or none at all, e.g. north Applecross. The raised features include both depositional and erosional terraces, shingle or sand ridges, and outwash deltas. All areas of relatively flat ground bordering the coast and in valleys above the modern flood plains were morphologically mapped at a scale of 1 : 10,560. Features of non-marine origin such as kame terraces and outwash spreads were, therefore, included: the nature of these landforms was frequently clarified by the results of the subsequent altitude measurements.

The altitudes of the mapped flat areas were determined by instrumental levelling, using Hilger and Watts Autoset levels, and a metric staff graduated to 0.01 m. Traverses were normally opened and closed on Ordnance Survey bench marks, all of which excepting one are related to the Newlyn Datum. In the one exception (indicated in Appendix A), an older bench mark related to the Liverpool Datum was used, so a conversion factor was added, being equal to the difference between Newlyn- and Liverpool-related heights listed for a nearby bench mark.

Where no O. S. bench marks existed, temporary bench marks were used.

In western Applecross the road surveyor's heights were utilised in levelling the features between Sand and Cuaig. These temporary bench marks were established in 1975, and were based on previous survey work by Ross and Cromarty County Council between Applecross village and Sand, related to the O. S. bench mark at Applecross House. The closing error of the Sand to Lonbain section was of the order of 0.010 m (J. Musto, road engineer, pers. comm.). In another case where no O. S. bench marks are available, a synchronous sea-level mark was used following the method described by Gray (1972, 1975). On a calm day two marks were chiselled simultaneously to record the sea-level at Achintraid and Ardaneaskan (under 4 km apart): the altitude of both was then established by levelling from a convenient bench mark at Achintraid to the nearby chisel mark. The mark at Ardaneaskan was subsequently used to level features there.

The coastal landforms were classified during mapping as beaches, beach ridges, platforms, and deltas. Definitions of these forms and the term 'sea-level' are given below.

Sea-level : The mean position of the water's edge between ordinary High and Low Spring Tides. According to Zenkovich (1967) mean sea-level divides the coastal area into two parts :

1. The coast, a strip of land above mean sea-level, the relief features of which were created by the sea.
2. The submarine beach slope, a shallow area of sea bed extending from mean sea-level down to an imprecise lower limit.

Beach : A deposit of loose material formed by swash, stretching from the upper limit reached by the oversplash of storm waves to an undefined depth on the submarine beach slope. The beach is thus divided into portions lying above and below mean sea-level.

Beach ridge : A deposit of loose material formed between mean sea-level and the upper limit reached by storm waves. Beach ridges in exposed parts of north Norway investigated by Moller and Sollid (1972)frequently occur 2.5 m above mean sea-level, but have been recorded at up to 6 m above sea-level. Included in the term are sand spits and shingle ridges : owing to the lack of field sections more precise definition was usually not possible.

Platform : A gently sloping shelf eroded by the sea which may or may not be backed by a cliff. In tidal seas the cliff foot where present lies between the levels of mean High Water Spring and mean High Water Neap tides, the precise level being subject to local variation due to lithological and other influences (Trenhaile, 1974).

Delta : A deposit of alluvium formed by a river in the sea, its surface lying partly above and partly below mean sea-level. The delta surface slopes gently seaward to the depth at which wave attack ceases to be effective. Below this, the delta front falls more steeply.

The difficulties involved in precisely relating present-day coastal features to contemporary mean sea-level exist also when dealing with fossil landforms. Abrasion platforms were levelled near the junction of cliff and platform so the altitudes obtained probably over-estimate contemporaneous mean sea level by between 5.2 and 3.8 m, if the levels of mean High Water Spring and High Water Neap tides were as they are today.

Raised beaches are less easily related to mean sea-level. Zenkovich found transverse beach profiles of equilibrium on present shores to be straight on shingle, and concave where particle size decreases with increasing depth below sea-level. In tidal seas the smooth concave gradient begins at the upper limit of Spring Tides, and above mean sea-level a beach berm or beach ridge is developed. Since raised beaches were levelled along the back of the terrace at or close to the rear break of slope, it is assumed that the heights relate to some level nearer High than Low Tide mark, but the exact relationship to mean sea-level is not known. Fossil beach ridges present the same problem in estimating contemporaneous sea-level. These features were levelled along their crests, and are likely to overestimate mean sea-level by at least 2.45 m (i.e. half the present inter-tidal range, ridges being deposited between mean sea-level and High Spring Tide level or above).

The surfaces of deltas were usually measured normal to the coastline, and across any ridges or flat areas developed upon them. Contemporaneous sea-level was of the same order of altitude as the levelled surface heights, but the exact position of the former shoreline is not known. Part of the delta front may have been removed by later marine action, which may add further complications.

It is, therefore, evident that estimation of former mean sea-levels from levelled altitudes on raised features cannot be precise. Steps taken to reduce inaccuracy included the use of Hiller rods to penetrate peat overlying features, the staff being placed on one or more rods pushed vertically through the peat at a representative point. Areas likely to have been affected by the deposition of colluvium, or by stream erosion, were avoided during traverses.

Altitudes were usually recorded every 50 paces ( ca. 42.5 m); on exceptionally long features with little surface variation (e.g. the Torridon and Carron outwash fans) a hundred-pace interval was used. The error that is acceptable in a closed traverse depends both on the length of the traverse and the desired accuracy. Gray (1975) suggests 15 cm as the maximum acceptable error. In the course of levelling over 800 points in the field area no large closing errors were incurred, the greatest being 0.220 m over 6.5 km, the majority being under 0.030 m and about 66% under 0.010 m. Height values were 'corrected' by spreading the error in the accepted manner if the closing error divided by the number of backsights exceeded 0.001 m. Since First and Second Edition Ordnance Survey base maps were used, reference features for locating measured points were sometimes scarce, especially in uninhabited areas. However, it is believed that the most dubious of measured points are within 20 m of the true point.

The levelled features are mapped on Fig. 10:1 to 10:7, the accompanying Tables give details of each levelled fragment, and Appendix A lists individual spot heights with their grid references. Shoreline equidistant diagrams, Figs 11 and 15, were used to attempt correlation of shoreline fragments. Before discussing these diagrams and the evidence for distinct shorelines, some previous work on sea-level change in Scotland will be summarised.

The most detailed studies of former sea-levels involve south-east Scotland, in particular the Forth and Tay estuaries. The basic sequence of sea-level change as demonstrated there is summarised in Sissons (1974a). In outline, sea-level fell relative to the land from the marine limit in early Lateglacial times to reach a minimum sometime before 10,300 B.P., this minimum now being below sea-level throughout much of the Forth estuary. Thereafter sea-level rose a few metres to a maximum at about 10,300 to 10,100 B.P. In the early Postglacial the sea regressed to a minimum at 8,500 B.P., followed by the major Postglacial transgression which culminated between 6,900 and 6,600 B.P. Minor still-stands or transgressions interrupted the subsequent retreat to present-day sea-level. A much earlier sea-level is indicated at Dunbar by a high-level rock platform known to pre-date the last ice-sheet by its relationship to a crag and tail (Sissons, 1967).

This changing sequence presumably affected all of Scotland, and evidence of some comparable former sea-levels has been found on the west coast. Shorelines associated with ice-decay are here rarely well-developed, a fact attributed by Gray (1974b) to the steepness of the west coast and relatively fast uplift upon deglaciation. Lateglacial shorelines have been described and measured by King and Wheeler (1963) on the north coast, where they are said to range between 15 and 24m in a westward-sloping zone, and by Kirk, Rice and Synge (1966) in the north-west, where the marine limit was measured at 19 m at the mouth of Loch Broom, falling westward to 14 m in Coigach. McCann, and McCann and Richards (1963; 1964; 1969) measured the Lateglacial marine limit at 29 to 32 m O.D. in lochs Kishorn and Carron, at 28 m on Rhum, and up to 37 m on Jura. The highest Lateglacial shoreline measured by Gray (1974b) lies at 40 m O.D. in Loch Feochan, Lorn, while in the south-west Sutherland measured the marine limits in Loch Fyne, Glendaruel and Loch Long at 36, 37 and 40 m O.D. respectively. From these heights it appears that in general the Lateglacial marine limit falls northwards up the west coast.

Lateglacial shorelines below the local marine limit are less-well documented on the west coast. The '50-foot'beach correlated by Peach(1913) with the latest valley glaciation and later by Donner (1957) with the Highland (i.e. Loch Lomond) Readvance, is recorded at the heads of lochs Torridon and Carron (Hinxman, 1898; Peach et al., 1913). McCann also measured the '50-foot' beach in Strathcarron, obtaining values between 12 and 18 m O.D., but his work on similar features elsewhere on the west coast produced no evidence of synchronous shorelines between 7 and 30 m O.D. King and Wheeler grouped terraces that they related to Pollen Zones III to IV in a westward dipping zone at 11 to 14 m, while Kirk et al. found Strandline B (by implication a Lateglacial feature) to reach 12 m in

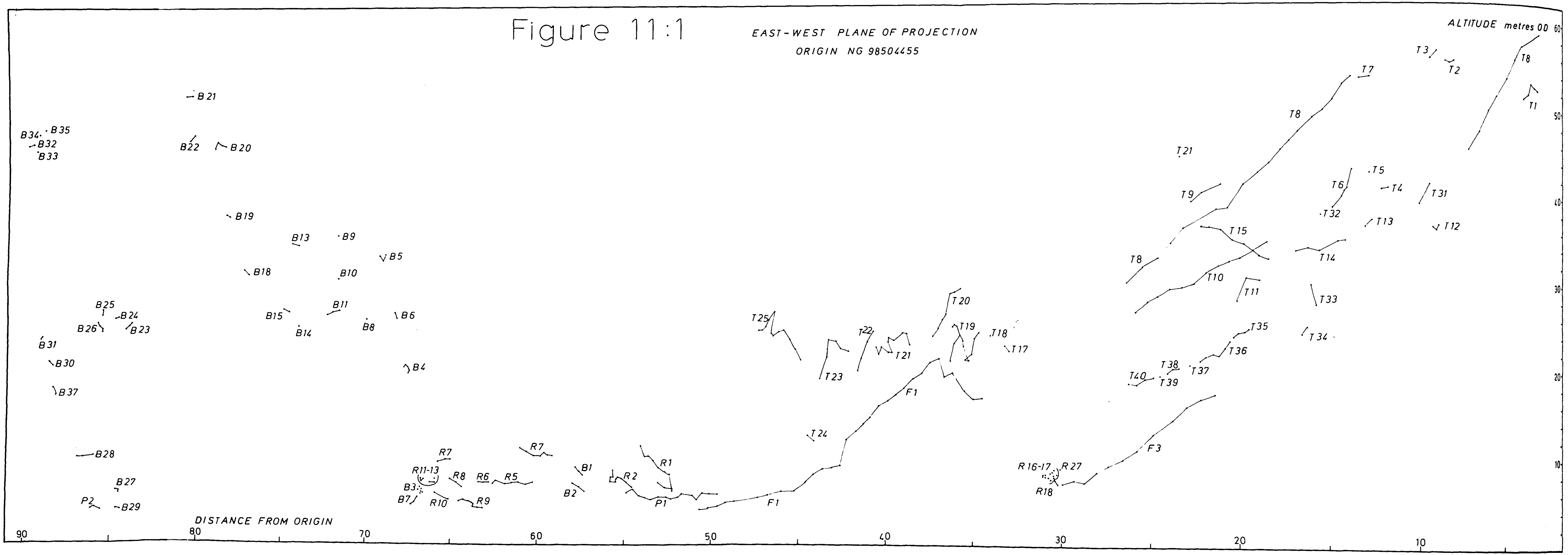
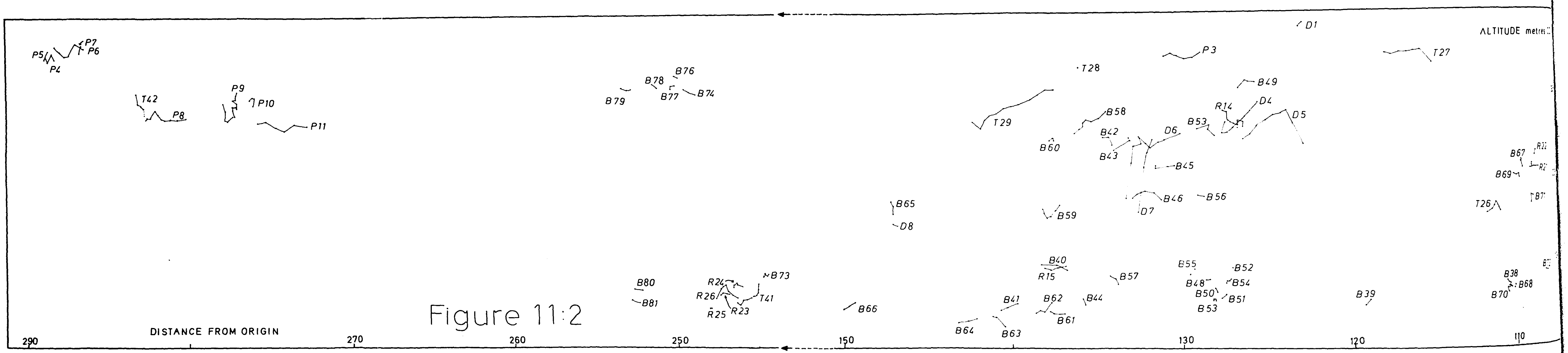


Figure 11:1
EAST-WEST PLANE OF PROJECTION
ORIGIN NG 98504455
ALTITUDE metres OD
DISTANCE FROM ORIGIN
90
80
70
60
50
40
30
20
10
B21
B34
B35
B32
B33
B22
B20
B19
B13
B9
B5
B18
B10
B25
B24
B26
B23
B15
B11
B14
B8
B6
B31
B30
B4
B37
B28
B27
P2
B29
R7
R11-13
R8
R6
R5
B3
B7
R10
R9
B1
B2
R2
R1
P1
F1
T24
T25
T23
T22
T21
T20
T19
T18
T17
R16-17
R27
R18
F3
T40
T38
T39
T37
T36
T35
T34
T33
T11
T10
T14
T15
T8
T9
T21
T7
T6
T5
T4
T32
T13
T31
T12
T3
T2
T1

inner Loch Broom. More recent, detailed work by Gray (1974b; in press) and Sissons (1974b) strongly suggests that the Lateglacial Stadial sea-level was at or below 13 to 14 m O.D. in Loch Creran , 11 to 12 m O.D. north of Oban and in Loch Feochan, and at least as low as 10 or 11 m O.D. in glens Forsa and Ba on Mull. The gradient of the Main Lateglacial platform in Lorn and south-east Scotland (Sissons, 1974b, 1976a; Gray, 1974a, in press)suggests that although this shoreline will be below sea-level round much of Scotland, it will maintain its position at or near present sea-level along much of the west coast, falling below this level at some unspecified point in the north.

The Main Postglacial beach produced by the major Flandrian transgression is generally the best-developed raised shoreline on the Scottish coast. In the north it lies between 7 and 9 m O.D. according to King and Wheeler, is at 9 m O.D. in upper Loch Broom (Kirk et al.), between 7 and 11 m O.D. in lochs Kishorn and Carron, over 12 m O.D. along Loch Linnhe and reaches up to 15 m O.D. in this region (McCann,1966a), is at 11 m O.D. on Rhum (McCann and Richards), and 9 or 10 m O.D. on Islay (McCann, 1964). Working in the Lorn - eastern Mull area Gray (1974b) produced isobases for the Main Postglacial shoreline aligned north 4 east - south 4 west, showing a slope westward at 0.05 m/km from 14 m O.D. in Upper Loch Etive to 11.5 m O.D. at Salen, Mull.

Minor Postglacial shorelines on the north coast range between 4 and 6m O.D. (King and Wheeler), lie at 6 m O.D. in Loch Broom (Kirk et al.), and between 4 and 5 m O.D. at the head of Loch Carron (McCann, 1963). Gray (1974b) discerned two clear shorelines at 8 and 4 m O.D., and two uncertain features at about 10 to 11 m O.D. and 6 m O.D., all in the Lorn and Mull area. The latter features are almost horizontal, having gradients of only 1 cm/ km.



ALTITUDE metres
DISTANCE FROM ORIGIN
290
270
260
250
150
130
120
110

Figure 11:2

The Field Evidence : 1. Shoreline Fragments.

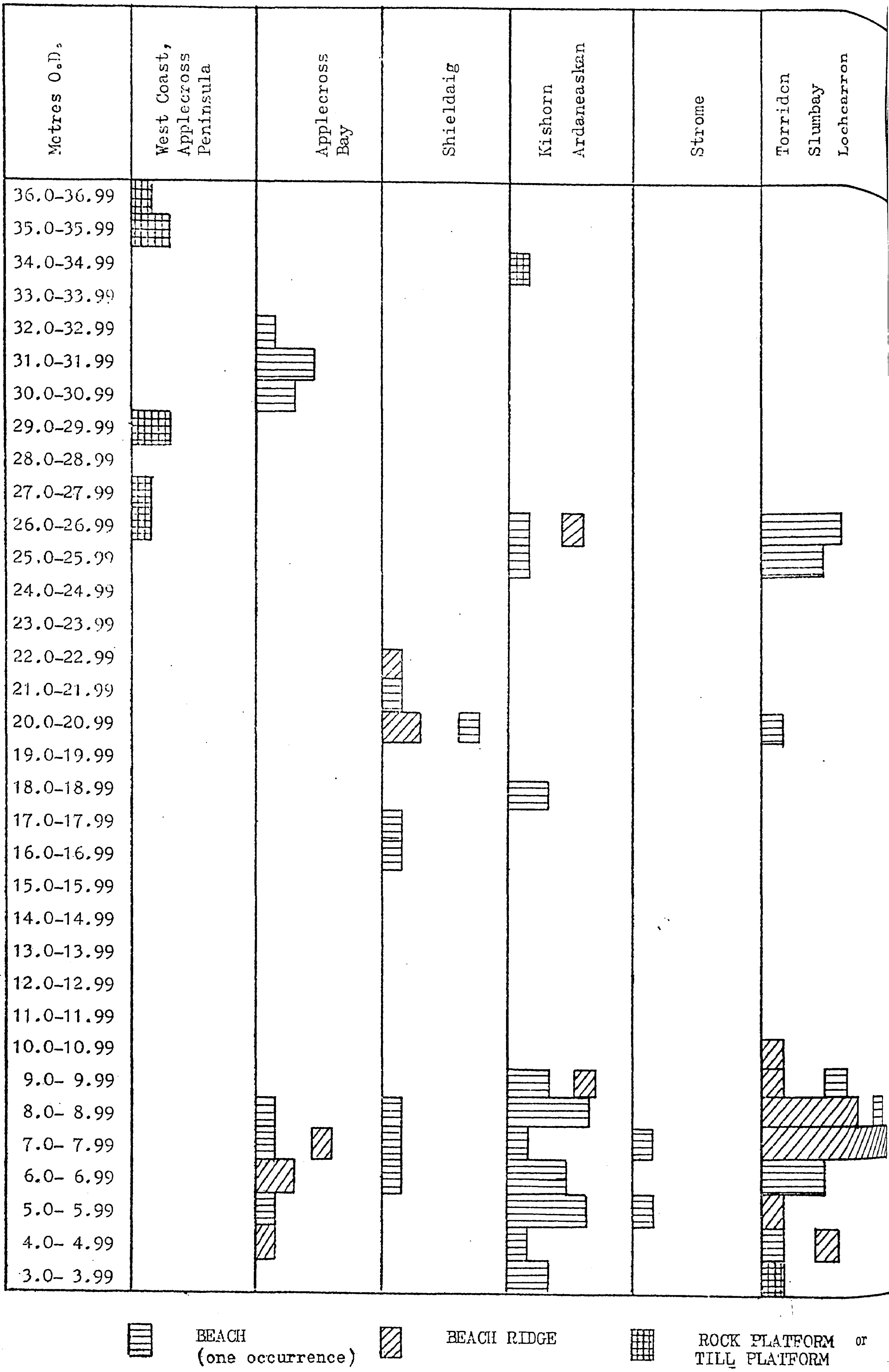
The aim of levelling former coastal features was to record heights on these landforms throughout the field area, and to use these data to attempt to distinguish specific shorelines. If such shorelines were sufficiently well developed, regional gradients on them could be established, isobases constructed, and thus the pattern of isostatic recovery further clarified.

The first step in interpreting the levelling data involved drawing height-distance diagrams. These allow inspection of the heights displayed on a vertical plane, and any marked lineations of points to be noted. The ideal height-distance diagram uses a plane of projection lying at 90° to the isobases, thereby maximising any gradient on shorelines. Since the isobases for the field area were not already known, an east-west plane of projection was considered a reasonable approximation, in view of the evidence available for Scotland as a whole. This direction is particularly suitable for data from lochs Torridon and Carron, since they are aligned approximately east-west, but is less satisfactory for coastlines oriented north-south. The main height-distance diagram, Fig. 11, is oriented east-west, and it is supplemented by a separate diagram using a north-south plane for the west coast of the Applecross Peninsula (Fig. 15).

Inspection of Fig. 11 shows no strong linear patterns among the scatter of points. The fluvioglacial features (kame terraces and outwash fans) in Strathcarron and Glen Torridon emerge clearly as individual sloping features, but raised beach fragments are not markedly grouped into linear bands, either horizontal or sloping. Therefore, the disparate fragments do not initially appear to constitute distinct shorelines.

An attempt to clarify the pattern on Fig. 11 resulted in Fig. 12. This diagram records occurrences of shoreline fragments (vertical axis)

FIGURE 12.


Metres O.D.
West Coast, Applecross Peninsula
Applecross Bay
Shieldaig
Kishorn
Ardaneaskan
Strome
Torridon
Slumbay
Lochcarron
36.0-36.99
35.0-35.99
34.0-34.99
33.0-33.99
32.0-32.99
31.0-31.99
30.0-30.99
29.0-29.99
28.0-28.99
27.0-27.99
26.0-26.99
25.0-25.99
24.0-24.99
23.0-23.99
22.0-22.99
21.0-21.99
20.0-20.99
19.0-19.99
18.0-18.99
17.0-17.99
16.0-16.99
15.0-15.99
14.0-14.99
13.0-13.99
12.0-12.99
11.0-11.99
10.0-10.99
9.0- 9.99
8.0- 8.99
7.0- 7.99
6.0- 6.99
5.0- 5.99
4.0- 4.99
3.0- 3.99
BEACH (one occurrence)
BEACH RIDGE
ROCK PLATFORM or TILL PLATFORM

against their altitudes (horizontal axis), using the arithmetic mean height for each levelled feature. Separate histograms are drawn for six areas, the fragments being grouped thus according to their distribution along an east-west axis through the field area.

The most obvious distinction on Fig. 12 is the gap in occurrences of fragments between 11m and 16 m O.D. : the features are divided broadly into a higher and a lower group. The lower group covers a smaller altitudinal range, and more shoreline fragments occur within it; the higher features are less concentrated altitudinally and are fewer in number. The highest fragments are rock platforms, whereas at lower altitudes such shoreline types are rare, beach terraces and beach ridges predominating.

A. Postglacial Features.

By analogy with other parts of Scotland, the lower group of beaches relates to the Postglacial period : their existence within Loch Lomond Readvance limits confirms this, e.g. in lochs Kishorn and Carron. The results of previous work on Postglacial shorelines in western Scotland have been summarised above, where it was shown that normally the Main Postglacial Shoreline and several subsidiary lower features can be discerned. However, in the field area no distinct shorelines are evident on the diagrams, and the only consistent factor among the histograms (Fig. 12) is that the highest beach occurs in three areas at 8.5 to 8.99 m and in one at 9.0 to 9.49 m O.D. This suggests that the highest Postglacial sea-level reached a fairly consistent altitude throughout the field area, forming these beaches and presumably also the beach ridges at up to 10.99 m O.D. A further indication of the 'Postgacial marine limit' lying at about 9 m O.D. is the presence of a break of slope in the Strathcarron outwash fan (Fig. 18a) at 9.1 m O.D. Such a pronounced change of gradient in this

# TABLE 3.

| B44 | B48 | B57 | B55 | B53, 54 | B61, 62 | B50 - 52 |
|---|---|---|---|---|---|---|
| | | | | | | 9.46 |
| | | | 8.99 | | | |
| | 8.14 | 8.20 | | | | |
| | | | | 7.88 | | |
| | | | | | | 6.86 |
| | | | | | 6.64 | |
| | | | | | | 6.18 |
| 5.53 | | | | 5.66 | | |
| | | | | | 5.27 | |

All beach fragments occur in the Loch Kishorn area.

The mean altitudes of the fragments are in metres O.D.

Possible correlations are suggested with arrows.

otherwise evenly-sloping feature is most rationally explained by marine erosion subsequent to formation of the fan. However, although in the absence of further evidence the contemporaneity of these features cannot be assumed, it is considered probable that they were formed simultaneously by the culmination of the major Flandrian transgression that in some other parts of Scotland created the Main Postglacial Shoreline. If the fragments described above do collectively represent one shoreline, its gradient may be calculated approximately using the appropriate heights from Applecross Bay and Strathcarron : a rise eastward of 0.018 m/km is indicated.

Lower Postglacial beach fragments are widespread in the field area, but again reliable correlation of these among different localities is impossible. In several places successive features occur one below another, suggesting the presence there of separate shorelines. This staircase constraint (Cullingford, 1972) can be applied wherever more than one feature occurs, but does not solve the problem of areal correlation. An example of suites of raised beaches in Loch Kishorn is given below, which illustrates the difficulties encountered in correlating features even over small distances (Table 3 ).

Beach ridges formed by the Postglacial sea occur at various levels, and are most abundant at the heads of lochs Torridon and Carron and in Applecross Bay. In the field these features are in general rounded broad swells separated by slight dips, and were presumably formed in low-energy environments where river-transported sand and gravel was in plentiful supply, i.e. from rivers Torridon, Carron and Applecross. Longer and more sharply crested ridges also occur in the same regions, for instance R26 at Applecross House, R1 and R2 near Lochcarron are all sand spits or shingle ridges, the last-mentioned being a small multiple spit system with recurved branches.

Eight of these beach ridges (seven being near the head of Loch Carron) occur at between 7.0 and 7.49 m O.D. : obviously a period of extensive ridge formation occurred when the mean sea-level lay somewhere below 7 m O.D. It is interesting to note that a second erosional notch occurs at between 6 and 7 m O.D. on the Strathcarron outwash fan : though much less pronounced than the upper step, it appears to confirm the evidence of a second relatively well-marked period of marine activity.

Only one stretch of coastal rock platform on the Postglacial height range was mapped and levelled (P2), its mean altitude being 4.0 m O.D. Fragment P1 is also likely to be a marine-eroded platform: although obscured by deep peat the bedrock fronting the cliff proved on levelling to be horizontal at 5.5 m O.D. No other low rock platforms were levelled, although other fragments are undoubtedly present. At various localities around the coast a marine cliff fronted by an inter-tidal platform is present, for instance at the head of Loch Kishorn, around Shieldaig Island, and along parts of the west coast of Applecross. Extensive planated rock also occurs in the inter-tidal zone at Camusterrach (7141). The presence of modern beach deposits on these fragments precluded accurate levelling of the rock platforms. With one exception there is no evidence of the age of these fragments. At the head of Loch Kishorn a finger of rock platform cut in Cambrian limestone extends for a few hundred metres south-south-west of the shore at Seafield Farm, and is backed by a cliff about 6 m high. Exposure at low tide shows this platform and the adjacent shore to be littered with erratic blocks of Torridon Sandstone that probably mark the farthest extension of the Coire nan Arr glacier during the Lateglacial Stadial (see p. 28 ). In this case, therefore, the rock platform was eroded prior to the glacial maximum of the Stadial, when sea-level stood very near its present level.

B. Lateglacial Features.

In considering the group of low shoreline fragments, the final question concerns the relative position of the sea during the Lateglacial Stadial. Farther south on the west coast, this sea-level is represented by a rock platform lying at 11 to 12 m O.D. north of Oban (Gray, 1974a; in press). The pattern of isostatic uplift in Scotland suggests that the corresponding shoreline in Wester Ross would be lower, as is confirmed by the evidence of the Loch Lomond Readvance outwash profiles in the study area. These indicate (Fig. 18a) that the meltwater rivers descended to about 10 m O.D., where the effects of Postglacial marine activity interrupt the profiles : hence it can be stated that the sea to which the rivers were graded lay at a maximum of 10 m O.D. It is tempting to suggest that the fragments of inter-tidal rock platform described above constitute a single shoreline that correlates with the Main Lateglacial Shoreline of south-east Scotland and Argyll. The age of the Loch Kishorn fragment is known to predate the Loch Lomond Readvance maximum, and in view of evidence presented below ( which shows the early Lateglacial shorelines to be relatively high), this rock platform was probably formed in one of two periods. It may be an ancient feature, preglacial or interglacial in age, or it may have been formed in the mid- to late- Lateglacial period. Levelling of the platform fragments in the field area, and of similar features between there and Lorn, will be necessary to demonstrate any conclusive association with the Main Lateglacial Shoreline.

Shoreline fragments in the upper group on Fig. 12 range between 16 m and 37 m O.D. The highest features, i.e. those over 30 m O.D. will be discussed as a separate group later.

Evidence of a Lateglacial marine limit exists around the coast in the form of erosional platforms, beaches, and large raised deltas formed by a high sea-level. The reasons why these features are considered to relate to the period of deglaciation (very early Interstadial) are best discussed after the field evidence has been described.

The best-developed high shoreline fragments are on the west coast of the Applecross Peninsula, between Lonbain and Cuaig (Fig. 10 7a). The longest feature (P8, P9, P10) covers almost 4 km, and reaches a maximum width of 0.3 km. This feature is a platform cut into till, and is divided by the Allt na Moine and Allt na h-Eirigh into three sections. The measured altitudes reveal a further division (Fig. 15) : between Lonbain and Kalnakill the platform has a mean altitude of 27.9 m O.D., whereas north of Kalnakill the mean altitude is 29.6 m O.D. Since no discontinuity of form is apparent in the ground at Kalnakill, the terrace fragments P8 to P10 are regarded as being contemporaneous, and are thus referred to as a single feature. Possible reasons for the altitudinal discontinuity are presented below.

The platform is backed by a sloping cliff formed by the till-mantled hill slopes; only in one place does bedrock occur in this cliff, though in several areas small outcrops of planated rock occur on the platform itself. By contrast, the frontal cliff is frequently steep and occasionally vertical (where bedrock forms the cliff). Slumping of till from the platform has occurred along much of the frontal cliff, and lower raised beaches are largely absent. Shelving bedrock is common on the shore despite its scarcity in the cliff above, although it may be present at some depth under the slumped deposits (see Fig.14).

Natural sections in the seaward cliffs show that at least in places the planated till is overlain by beach deposits. Such surficial deposits are most abundant between the Allt na Moine and Kalnakill :

they range from rounded cobbles and small boulders, with little interstitial material, to coarse sand with few larger inclusions. The depth of beach deposits overlying till is commonly under 1 m. Natural sections and pits dug north of Kalnakill and south of the Allt na Moine failed to locate surficial deposits over the till, though this need not imply their total absence here. Hiller rods were used in levelling these stretches to penetrate the peat (which never exceeded 2 m), since unlike the middle stretch south of Kalnakill, most of the ground has not been cleared for crofting purposes. The apparent distribution of beach deposits over the till platform is most probably related to the incidence of streams and rivers. In the middle section the Allt na Moine and several smaller un-named streams debouch onto the platform and turn north in crossing it to the coast. During the former period of high sea-level these rivers presumably transported much material lately released from decaying ice, some of which would be deposited locally by the sea. A large sand spit (or beach ridge) is developed on top of the platform at the former mouth of the Allt na Moine, suggesting that it provided abundant debris. By contrast, north of Kalnakill only very minor streams cross the platform, which correspondingly appears to lack loose deposits. Around Lonbain alluvial deposits related to the Allt Mor form river terraces that grade into the coastal platform (T42), but north of Lonbain to the Allt na Moine till again seems to predominate.

The magnitude of these erosional platforms implies a former period of considerable marine activity. The coast is open to wave attack from the north-west, the fetch being over 60 km, but is relatively sheltered by Skye and Raasay to the west and south-west. In no other part of the field area are related features so well-developed : the Lateglacial marine limit is represented at Shieldaig by much smaller,

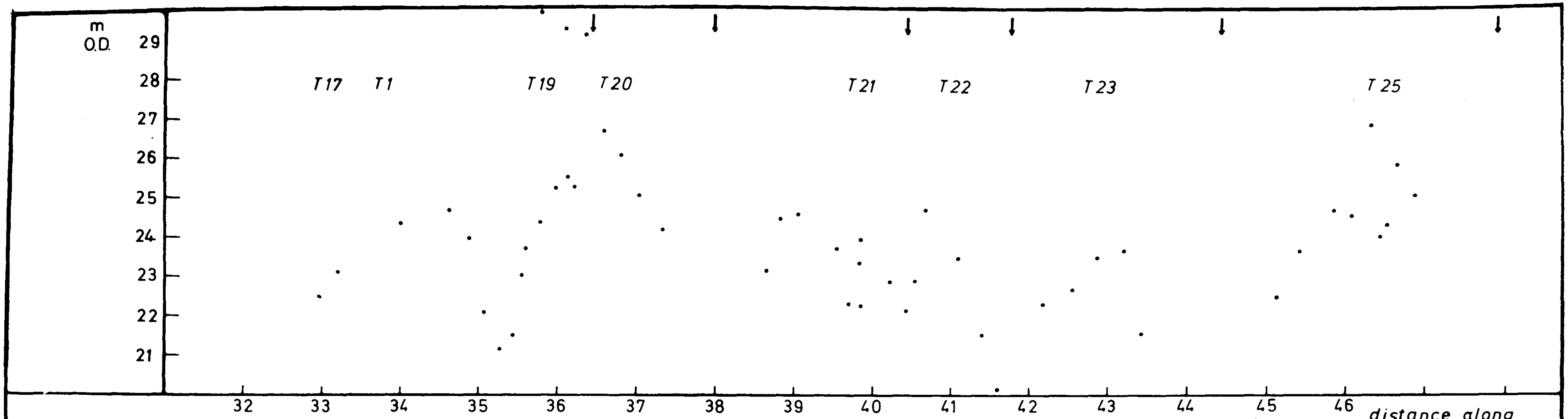



Figure 13a : The Achintee terrace

↓ : river or stream valley
T17 : number of fragment

distance along east-west plane of projection

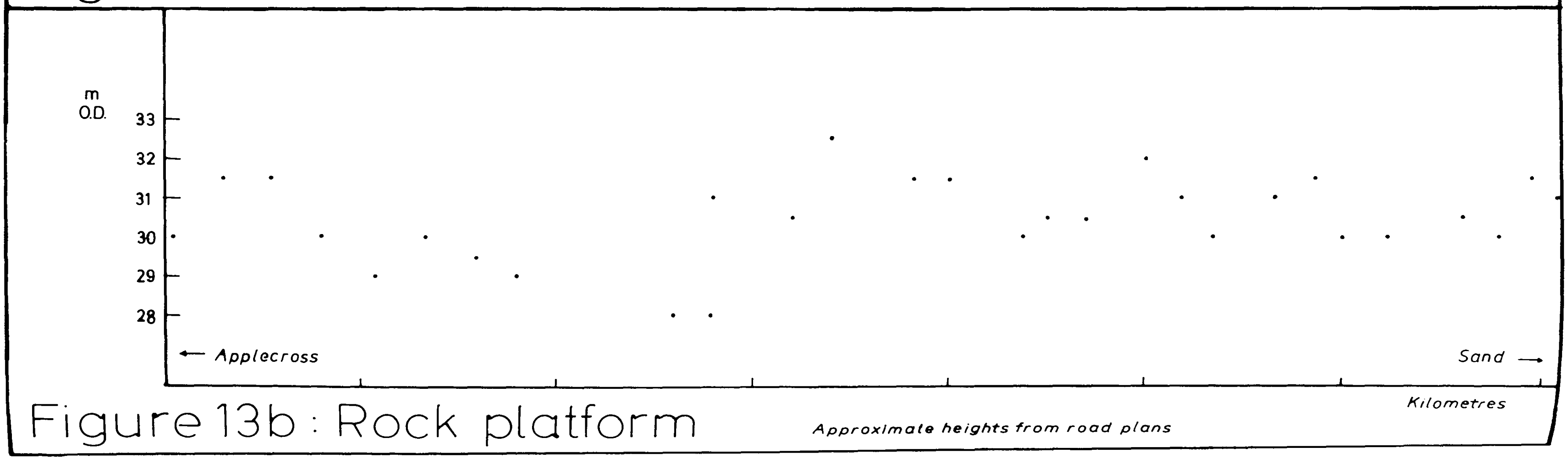



Figure 13b : Rock platform

Approximate heights from road plans

disparate fragments at 21 m O.D., while even less-clearly defined fragments above Lochcarron village were heighted at about 26 m O.D. (B6, B8, B11, B15), and similarly at a maximum of 26 m O.D. in Loch Kishorn (B47, B58). In the Lochcarron area the features form narrow shelves on the till-covered hillside, never reaching more than a few hundred metres in length, and again being at least in places veneered with beach gravels.

On the south shore of Loch Carron a very distinctive terrace skirts the lochside and valley-edge for over 2.5 km (Figs 10:2 and 13a). Despite the initial horizontal appearance of the terrace, levelling showed it to possess a very uneven surface, resembling a linked series of cones, the apices of which in places coincide with river and stream channels. A section in the river bank north of Achintee village (which is built upon the terrace) revealed deltaic bedding in the deposit, with large foreset beds of rounded debris dipping to the north-west, capped by a topset bed ca. 1 m thick. In view of the surface morphology of the whole terrace and the presence of deltaic structures in one part of it, it is probable that the feature was formed by a series of streams depositing deltas that merged laterally to form the continuous feature. Despite the altitudinal variation of the surface, the mean height of 23.7 m O.D. suggests that the deltas were formed when Loch Carron stood at or near the Lateglacial marine limit (26 m O.D.). Again, large quantities of alluvial debris are implied at the time of delta formation.

McCann (1963) gave the altitude of the Achintee terrace as 24.7 m O.D. (81 feet O.D.), which is a reasonable approximation, but noted erroneously that 'this height is maintained with little variation along the whole length' (op. cit., p. 167). He considered it to be a strand-line, deposition having occurred in an ice-marginal lake, since no

Fig. 14:1. The till platform, looking north to Kalnakill.

Fig. 14:2. The till platform, looking south to Lonbain.

evidence of marine re-working of the fluvial fabric is apparent. In view of the general absence of any such alteration in sections through marine-deposited deltas observed elsewhere, it is considered more likely that the deltas were simply built in the Lateglacial sea as described above. Moreover, no kettle holes are evident on the terrace surface, as might have been expected if the terrace had originated in an ice-marginal lake.

High-level deltas are most commonly associated with the Lateglacial marine limit in Loch Kishorn. The long profiles of deltas were levelled, usually down both (or all) sections where the original feature has been divided by modern rivers. Any conspicuous flat areas or ridges were also measured : these usually lay at ca. 90 to the long axis. Which, if any, of the resulting heights related to the associated sea-level is doubtful (see p. 101 ). However, as at Achintee a general altitudinal range is indicated (Fig. 18b) : the delta tops occur at over 24 m O.D., the highest points recorded on them being ca. 29 m O.D.

The Ardarroch delta (D5) is particularly interesting for several reasons. It is bounded by a spit that runs parallel to the delta front, enclosing a small wet depression behind it on the delta surface, which was presumably a lagoon. The delta rises evenly upvalley until it reaches 28 m O.D. : the feature then stops abruptly, the ground falling to recent river terraces at below 15 m O.D. This probably implies that during formation of the delta glacier ice was present in the wide, low-lying basin around Glen Beag, the surrounding hills constricting the escape of meltwater and forcing it to exit at Ardarroch and Kishorn village, the large deltas forming where the meltwaters entered the sea. Similar features were built above Achintraid village and at Seafield Farm (D2, D3, D4, B58).

The highest corresponding beach in Loch Kishorn (B58, part of a

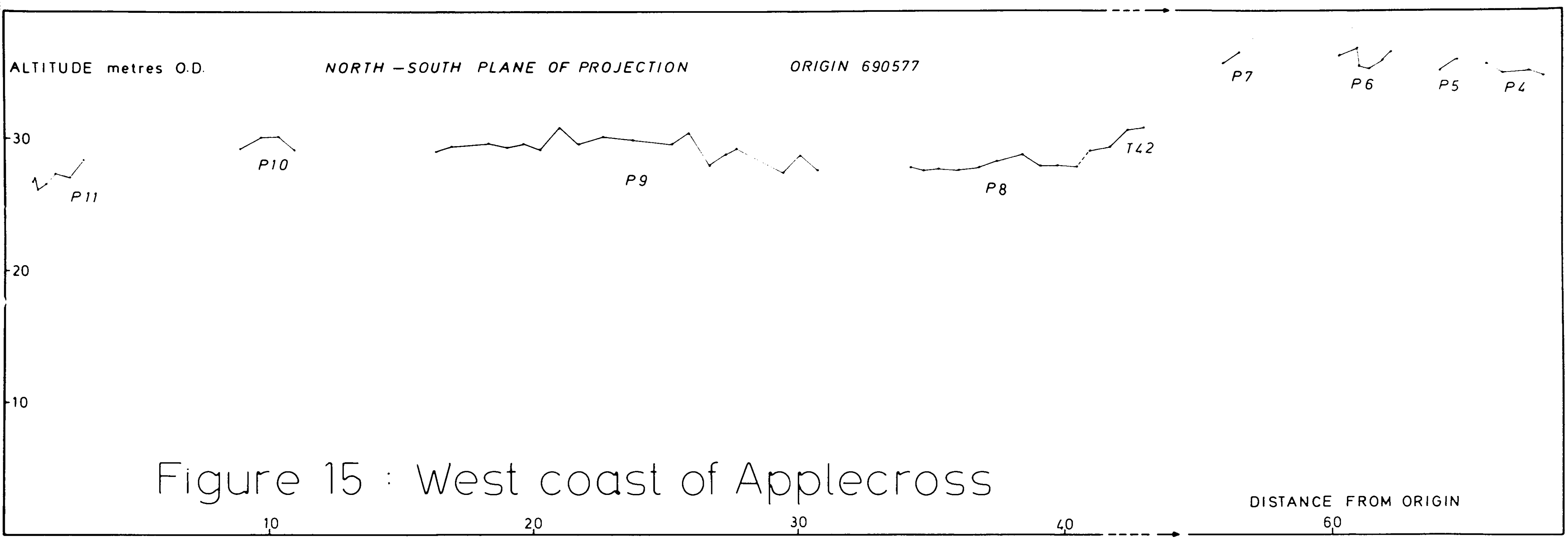



Figure 15 : West coast of Applecross

small raised delta) lies at 25.8 m O.D., once again implying a marine limit of around 26 m O.D. Here, as in Loch Carron, various fragments occur at lower altitudes above the Postglacial beaches, but they are too infrequent to allow areal correlations or any reliable reconstructions of lower Lateglacial shorelines. These fragments were presumably formed during regression of the sea from the Lateglacial maximum.

Such prominent landforms as the raised deltas were deposited by rivers carrying considerable loads of debris, as revealed in modern sections showing bedded gravel and cobbles. Two of the Loch Kishorn deltas (D2-4, D6) are situated at present on relatively insignificant streams. The most probable period of delta formation was during and after deglaciation, when initially meltwater rivers heavily charged with debris from downwasting ice would exist for perhaps relatively short periods as the local ice decayed. After the disappearance of the ice slope-wash and stream erosion would continue to supply much material to the rivers, until vegetation stabilised the ground and reduced run-off. The situation described above at Ardarroch supports this hypothesis.

The beach fragments that fall within the height range of the delta surfaces logically belong to the same period. Such high features do not occur anywhere inside the limits of coastal Loch Lomond Readvance glaciers : the contrast between the north-west and south-east coasts of Loch Kishorn is notable in this respect. A third indication of association with a very early Lateglacial period is the variation in altitude of the marine limit at different localities in the field area. This implies that no true single shoreline is present, but a series of diachronous shoreline fragments formed as the ice shrank landwards, accompanied by isostatic rebound. The west coast of Applecross was deglaciated first, in the Lonbain to Allt na h-Eirigh area where the Lateglacial marine limit reaches 28.8 m O.D. (mean of P8-10). The ice then disappeared in the lochs Kishorn and Carron region (marine limit of ca. 26 m O.D.) during which time the north-west Applecross Peninsula around Cuaig was also vacated. The Shieldaig peninsula appears to have undergone relatively late deglaciation, since the marine limit here is at only 21 m O.D.

The evidence for later ice retreat in the Loch Torridon trough corresponds with the evidence of glacial landforms and striae discussed previously (pp 17 – 20). The lower marine limit at Cuaig lies well within the area of till drumlinoid hills which, it was postulated, are probably associated with the Applecross moraine. It therefore seems that the Applecross substage ice existed in the Torridon trough while or after deglaciation proceeded to the south. This can explain the still lower marine limit at Shieldaig, and possibly also the absence of high shoreline fragments around upper Loch Torridon (at least on the south and east shores) : uplift as the ice retreated eastwards would create a successively lower marine limit.

Two explanations of the lower marine limit at Cuaig are possible. These are :-

1. That ice disappeared from the Torridon trough during ice-sheet decay, allowing the marine limit at about 29 m O.D. to form there as in the south. Susequently, the Applecross substage ice readvanced and destroyed the shorelines within its limits. The 26 m O.D. platform at Cuaig was cut after the retreat of the Applecross substage ice.

2. That the Applecross substage landforms and striae were produced by a still-stand of the (active) ice in the Torridon fjord during deglaciation elsewhere. In this case no '29 m' shoreline could be formed inside the readvance limit. The implication of the lower marine limit at Cuaig is that sea-level fell during the Applecross substage from 29 to 26 m O.D.

The problematic fragment of till platform P10 is relevant in

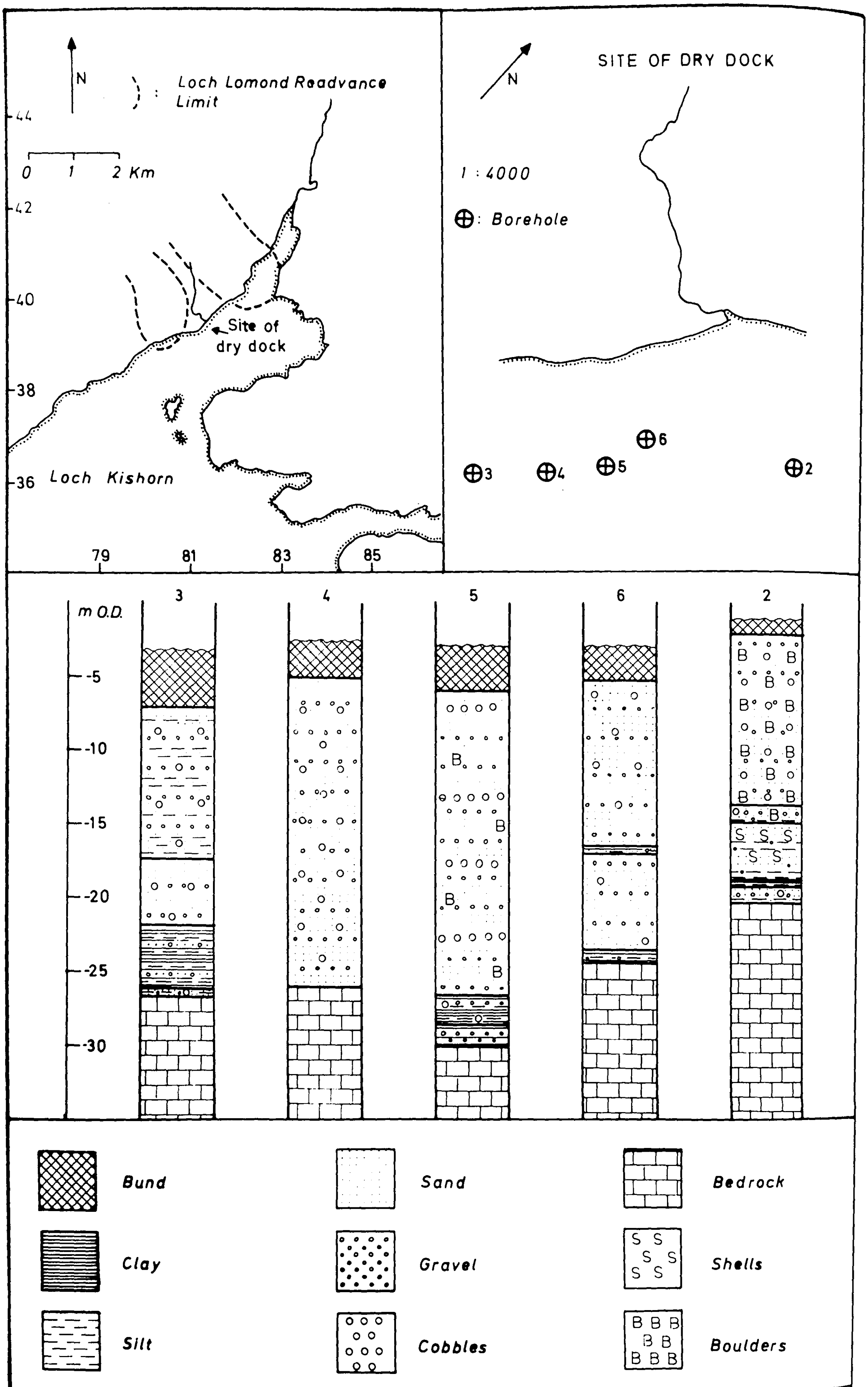



Figure 16 : Kishorn borehole data

this connection. This feature lies marginally inside the hypothesised readvance limit (being within the margin of the till hills), yet attains the altitude of the Lateglacial marine limit (29 m O.D.) immediately to the south, i.e. beyond the hypothesised readvance limit. If the limit is correctly positioned, this anomaly can only be explained by assuming the later ice from Torridon to have overridden P10 without destroying it, which in the light of a situation described below is not impossible. Explanation 1 is therefore preferred.

A final consideration concerning the Lateglacial marine limit in western Applecross involves the raised platform between Lonbain and the Allt na h-Eirigh (P8 and P9). Despite the continuity of the shoreline on the ground, Fig. 15 clearly shows the break in height near Kalnakill, the platform to the north being on average 1.7 m higher than that to the south, while the individual sections are horizontal. The break coincides with a decrease in width (northwards) of the platform, and a change from once cultivated crofting land underlain in part or whole by beach deposits, to a peat-covered till platform. These differences may be purely coincidental : the height difference between the two sections remains difficult to explain. The platform was almost certainly formed contemporaneously in both sections, the surfaces then being altered, or the underlying rock structure faulted near Kalnakill to produce the discontinuity evident today.

Further information about the Lateglacial marine environment was provided by identification of marine shells from the bed of Loch Kishorn (Fig. 16 and Table 4 ). The samples of shelly sediment were derived from borehole cores extracted during investigation for the Kishorn oil rig construction. The shells occurred in a stratum of grey sandy silt underlying sand, gravel, cobbles and boulders, and lay 5 m above

TABLE 4 : LATEGLACIAL SHELL ASSEMBLAGE FROM LOCH KISHORN.

Astarte borealis (Schumacher)

Astarte montagui (Dillwyn)

Astarte sulcata (da Costa)

Balanus cf. balanus (L.)

Buccinum cf. tenue Gray

Chlamys islandica (Muller)

Cingula sp.

Crenella decussata (Montagu)

Echinoderm spines

Gibbula cineraria (L.)

Littorina saxatilis agg (Olivi)

Lora decussata agg (Couthouy)

Lora turricula (Montagu)

Macoma calcarea (L.)

Margarites helicinus (Fabricius)

Moerellia costulata (Moller)

Natica sp.

Nuculana pernula (Muller)

Parvicardium scabrum (Philippi)

Rissoa sp.

Yoldiella amblia

Yoldiella fraterna

rock head. In view of the position of the borehole (see Fig. 16), the coarse debris can be confidently identified as till and/or outwash deposits from the Coire nan Arr and Coire na Ba Loch Lomond Readvance glaciers, both of which terminated only several tens of metres from the borehole site. The grey silt resembles typical Lateglacial marine sediment (Peacock, 1975) of either the 'Errol' or 'Clyde' beds type. Dr. Sheelagh Smith who identified the shells (pers. comm.), described the material as 'distinctly boreal or arctic' in character, and richer than usual for a Scottish Pleistocene marine deposit. The wide variety of genera present in the assemblage implies that the deposit belongs to the 'Clyde beds' type, but Dr. Peacock (pers. comm.) noted that the usual warmer indicators of this group are absent. The arctic species Buccinium tenue has hitherto been unknown in British Lateglacial deposits. As the shells form a detrital deposit, the relation of the stratum to contemporaneous mean sea level is not known. The fossils accumulated sometime after deglaciation of Loch Kishorn, and before the Stadial glaciers reached their maximal positions: further precision would necessitate absolute dating.

C. Pre-Lateglacial Features.

Of the remaining high features mapped and levelled as shoreline fragments, only those shown on Fig. 11 will be discussed. Other fragments marked with an asterix in Appendix A were treated in the same manner as all flat terrace-like forms encountered during mapping, but for various reasons they are discounted in the interpretation of the data. The fragments are classed as 'poor' because they are of dubious origin, and lack evidence of a coastal genesis. They are in general short and narrow fragments, and do not correlate with other levelled features, some occurring at abnormally high altitudes (over30 m and up to 50 m O.D.). Therefore, they will not be discussed further.

The highest recognisable shoreline is a rock platform on the west coast of the Applecross Peninsula (F4-7). Unfortunately, several kilometres of this marked feature have been utilised by the new road between Applecross village and Sand : the road works entailed blasting of the rear cliff in places, and raising and smoothing of the original platform surface. Since any precise measurements on this could not reflect the true level of the feature, levelling of this altered stretch was not undertaken. An approximation of the altitude here is given by Fig. 13b : the spot heights represent the break of slope at the back of the platform, having been extracted from the 1:500 plans for the road ( courtesey of Ross and Cromarty County Council, Dingwall).
The points were recorded from the plans wherever a clear topographic break in slope appeared below the cliff, and their distribution along the horizontal axis of Fig. 13b is as accurate as possible. Since the original ground surface is plotted on the plans using a 0.5 m contour interval, and the feature has a very marked rear cliff, the approximated elevation in Fig. 13b is believed to be reasonably accurate. However,

superficial deposits on the platform such as peat or colluvium may have been measured, thereby giving erroneously high altitudes for the feature at some points.

Farther north on the west coast the road abandons the rock platform, which after disappearing at Sand recurs intermittently south and north of Salacher. These stretches of platform were levelled. Beyond P7 the platform could not be traced, but the probable continuation of the old cliff is indicated on Fig. 10 7b; here and north of Sand traces of the cliff are best observed on aerial photographs, as in the field the appearance of both cliff and platform are not sufficiently convincing to warrant mapping and levelling.

Fig. 15 shows that the disparate shoreline fragments near Salacher (P4-7.) form a linear band of heights dipping to the south. The gradient over this stretch is 0.817 m/km : if this is produced 5km south to Rubha na Guailne, the rock platform would be expected to occur there at 30.38 m O.D. Reference to Fig. 13b shows that this predicted height corresponds well with the spot heights from the road plans, therefore the north-south gradient appears to be maintained.

The rock platform consists of a relatively narrow platform (25 to 75 m wide) backed by a rock cliff. Surficial deposits on the platform are in general thin, bedrock frequently cropping out and in places replacing the platform with rocky projections (e.g. between P5 and P6). Fallen rock or other loose material is only present at the rear cliff-foot in small quantities, being most abundant on the south-facing section. In this area the platform is narrow, the rear cliff very steep, and in places vertical, and it is fronted by precipitous slopes to sea-level. The gradient of both cliffs tends to diminish north of Rubha na Guailne, where the rear cliff (in rock) is also much lower, and the platform wider, appearing in places to be veneered with beach

Fig 17:1. The rock platform and rear cliff, south of Salacher.

Fig. 17:2. Stack on the rock platform near Salacher.

deposits. At Salacher the feature is less sharply defined, the rear cliff rising more gently and having a very old, degraded appearance (Fig. 17:1). The platform itself is not in general abruptly delimited by sea-cliffs as farther south, but forms a gently inclined shelf that drops seawards in stepped fashion, finally ending in vertical cliffs. Since the coast here follows the strike of the Torridon Sandstone, whereas in the south it truncates it, such differences of form are not unexpected.

On P4 south of Salacher excellent rock stacks are present on the platform. At the southern extremity of this fragment several massive blocks of sandstone are separated by narrow, winding clefts up to 6 m deep and about 1 to 3 m across. These presumably are stacks at an early stage in formation : they occur beside what formerly would be a headland, marine erosion having been arrested before further separation took place. By contrast, the stack on P6 (Fig. 17:2) is isolated, standing well away from the former cliff, and its mushroom shape testifies to the degree of undercutting achieved by the sea.

The ancient nature of this rock platform is implied by its appearance, and confirmed by at least two factors. The demonstrated tilt from north to south is opposed to the gradient that would be expected from the pattern of isostatic recovery. The existence of glacial striations on the platform surface, near the undercut stack described above and onthe seaward slopes below it mean that ice traversed the platform, thus suggesting formation before the last stage of extensive glaciation. These striae (mapped by Horne on the 1:10560 geological map) comply with the general course of ice movement as indicated by many other striations in this area. Farther north, the platform may be present but obscured by the thick till mantle which is absent in the south : this predominance of till over bedrock equally helps explain the presence of the Lateglacial till platform in the north and its absence in the south.

The implication of this comparison is that the Lateglacial sea eroded less efficiently than that which carved the rock platform. The time period involved in the latter case was probably much greater than that available in early Lateglacial times, when relatively fast land and sea movements prohibited extensive marine erosion, most of all in rock. Until more is known of the Pleistocene chronology in Scotland it is possible only to suggest an Interstadial or Interglacial age for the rock platform.

Other features levelled in the field area may correlate with this shoreline. Some small features occur on the south-east coast of Applecross Bay (B74 to 79) under 2 km from the rock platform on the opposite shore. These small but distinct fragments might be either erosional or depositional forms (or a combination) ; unfortunately no sections in them were observed. More convincing is a fragment near Achintraid (P3) which is backed by a cliff, and gave very consistent heights of ca. 34 m O.D. for over 200 m. Several of the 'poor' features above Lochcarron referred to previously are of the same order of height as the rock platform farther west, though again correlations are dubious.

Elsewhere on the west coast high-level rock platforms are known to occur, having initially been reported in detail by Wright (1911), and subsequently by McCann (1964; 1968) and McCann and Richards (1969). Such features ranging between 25 and 45 m O.D. are reported in the literature from the majority of the islands in the Inner Hebrides between Islay and Skye, and on the mainland in the Ardnamurchan and Applecross peninsulas. McCann believed that in Rhum, Skye and Mull there is evidence of distinct levels produced by more than one phase of erosion; Peacock (1969) also reported two distinct features on Rhum, and believed that the evidence from the island implies that the platform(s) has been tectonically warped in the past.

A rock platform that stretches for over 2 km in south-west Raasay (opposite the southern part of the Applecross Peninsula) lies between 15 and 30 m O.D., with a well-developed cliff backing the platform, which is littered with erratic blocks. A stack was observed on the platform, and glacial striations were noted (Dr. D. E. Smith, Lanchester Polytechnic, pers. comm.). Wright observed till on the rock platform on Islay underlying beach gravels : McCann has confirmed the former presence of glacier ice on the platforms in reporting ice-moulding, striations, and till in various localities. Peacock (1969) also noted till on the Rhum rock platform reaching over 3 m deep in surficial rock hollows. From the various accounts of high-level rock platforms in the western islands and mainland it appears, therefore, that one or more shoreline is present throughout the area, and that evidence exists for some of the features having been glaciated and tectonically warped. The rock platform in Applecross apparently has been affected by both events.

Summary of sea-level change in the field area.

1. A high-level rock platform at 32 to 37 m O.D. in the western Applecross Peninsula is the earliest record of a former sea-level, believed to have been formed in an interstadial or interglacial period older than the culmination of the last major glaciation at ca. 20,000 to 18,000 years B.P.

2. Raised shoreline fragments including deltas that range from 21 to 28 m O.D. record the diachronous decay of the ice in various parts of the field area, during the early Lateglacial Interstadial.

3. Low-level, inter-tidal rock platforms occur in various localities around the coast. The ages of these are not known, but it is suggested that the Kishorn fragment (and possibly others) may represent the Main

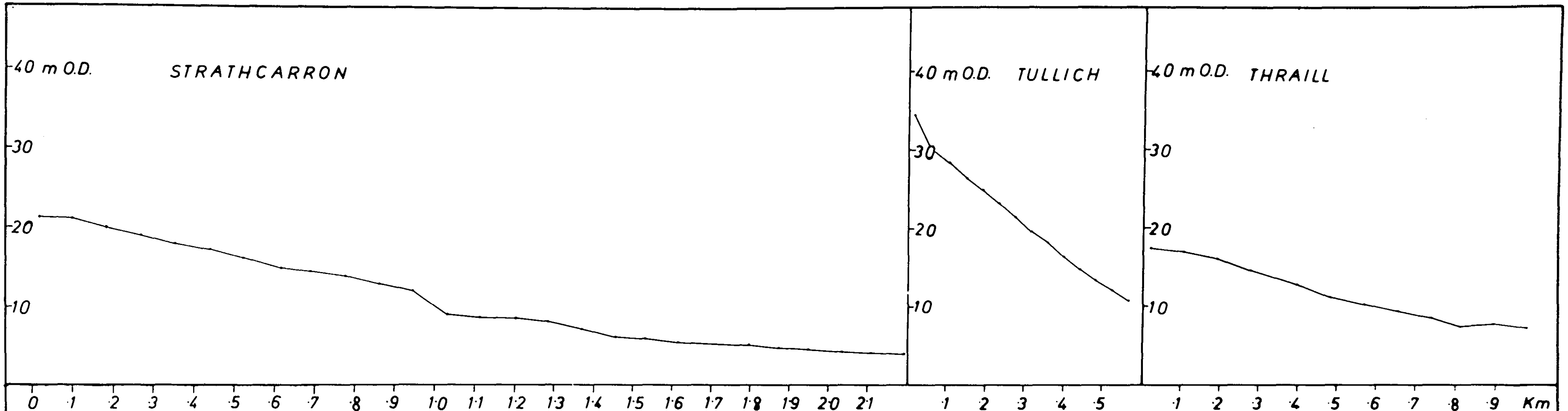



Figure 18a: Profiles of outwash fans

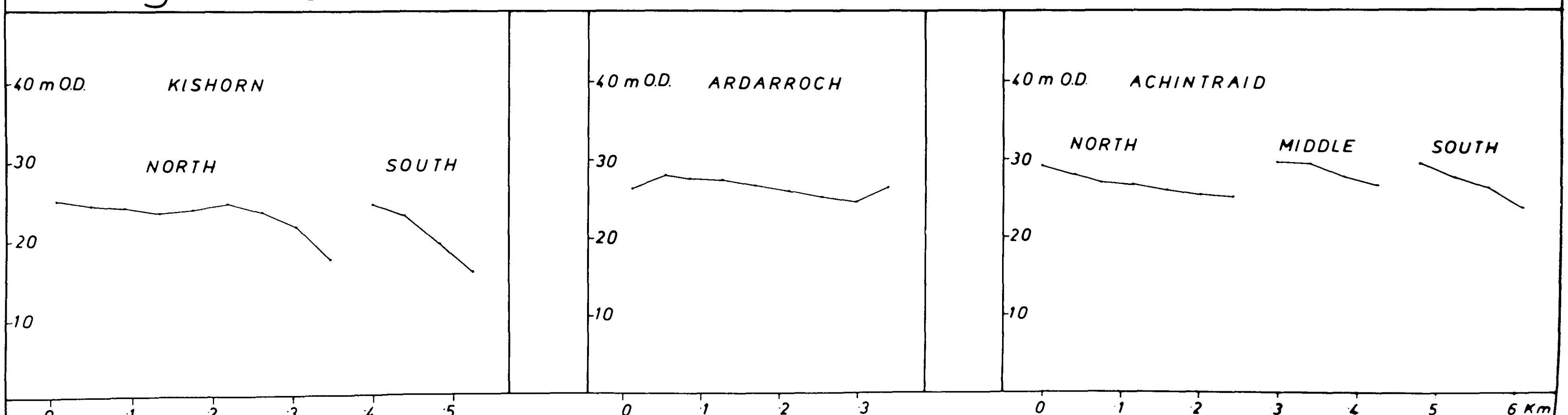



Figure 18b: Profiles of raised deltas

Lateglacial Shoreline formed during the Interstadial and/or Stadial.

4. The Postglacial marine limit represented by raised beaches, beach ridges, and breaks of slope on Lateglacial outwash fans occurs at _ca._ 9 m O.D. Collectively these disparate fragments may constitute the Main Postglacial Shoreline described in other parts of Scotland.

5. Various lower raised depositional features represent later positions of the Postglacial sea, but no distinct shorelines can be discerned.

## 2. Fluvioglacial Features.

The final section in this chapter will deal with features of non-marine origin that were levelled, and are included on Fig. 11.

Kame terraces constitute the largest group of fluvioglacial landforms that were measured. These features are commonest in Strathcarron (T1-15), and are important in the interpretation of local deglaciation, as previously explained (p. 66 ). The slopes on the two major terraces (T8, T10) are 15.9 m/km and 9.8 m/km respectively, suggesting that either the gradient of the ice-surface decreased as it down-wasted, or that considerably variation in fluvial conditions took place through time. Those terraces on the south side of the valley are less extensive features, and this contrast may be connected with the different aspects of the two valley-sides. The south side is shaded, and it is possible that during deglaciation less meltwater was released there, hence the paucity of ice-marginal deposits. One kame terrace (T15) possesses an up-valley dip : the consistency of slope over 400 m, and lack of obvious disturbance, implies that this gradient truly reflects the slope of the former ice-surface. In view of the hypothesised merging of glacier snouts at Coulags (p. 71 ) this reversed dip is interesting. The simplest explanation is that T15 marks the margin of the former Coire Fionnaraich glacier snout where it sloped north-east to merge with the Lair ice, T12-14 having formed against the westward-dipping margin of the latter glacier. The escape of meltwater presumably took place by en- or supra-glacial drainage, since no channel or esker exists to record a sub-glacial route.

Related to the same period of ice-decay are the outwash fans (Fig. 18a). Loch Lomond Readvance outwash fans have frequently in the past been confused with the '50-foot' raised beach : Hinxman (1898) in Glen Torridon, Peach _et al_. (1913) and more recently McCann (1963) in Strathcarron failed to note the respective gradients. As noted previously, a smooth descent from the end moraines down to the highest Postglacial beaches prevails, below which the fans have been affected by later coastal processes. In all cases only the steep proximal parts of the fans remain, the distal parts having been removed and reworked by the sea. Originally these fans would probably have ended in deltas, their concave long profiles assuming the form of a parabolic curve (Church, 1972). River erosion and aggradation since deglaciation have, however, altered the original profiles such that estimation of the contemporaneous base-level (i.e. the Stadial sea-level) is impossible.

In Glen Torridon the situation is somewhat complicated with regard to outwash fans. Two Stadial glaciers terminated in the glen, their meltwater draining west to Loch Torridon. The highest river terrace adjoining the moraine in the glen (930564) constitutes a remnant of outwash: farther downvalley subsequent river erosion has removed the fan, and only fragments remain of which T31 may or may not be part. Farther downvalley is the locally-named 'old beach' (T35-40) that skirts the valley-side opposite the Thraill end moraines. This sloping terrace is clearly higher than the outwash fan from the latter terminus (see Fig. 11), and therefore must pre-date the Thraill outwash. None of the other Glen Torridon fragments can be reliably correlated with T35-40, although the small terrace fragment T33 might belong to this or the river terrace sequence described above. The 'old beach' comprises a high percentage of non-local Moinian lithologies probably derived from ice-sheet or Applecross substage till or outwash, compared to the abundant Torridon Sandstone and Cambrian Quartzite present in Loch Lomond Readvance deposits. The simplest explanation of this feature is that it also is part of a former outwash fan (hence the similar gradients), but is related to a pre-Lateglacial stage of deglaciation. It may be suggested that the

Fig. 19:1. Section in the Ardaneaskan terrace showing convoluted strata.

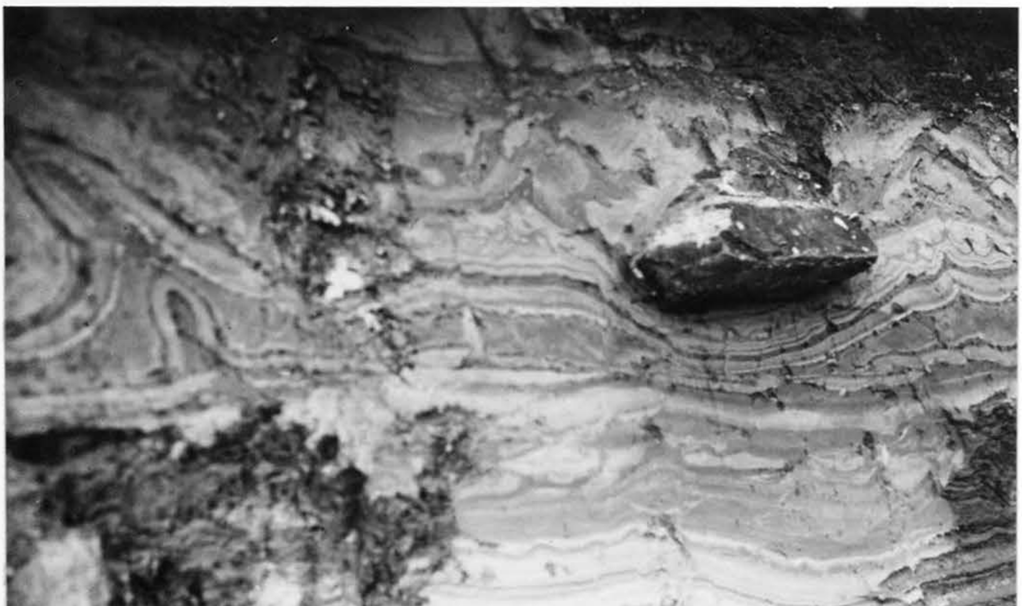


Fig. 19:2. Small boulder among fine sediments in the Ardaneaskan section.

outwash was in fact produced by the decaying Applecross substage glacier, since this was presumably the glacial stage preceeding the Loch Lomond Readvance.

The fluvioglacial features at Ardaneaskan and North Strome (lower Loch Carron, Fig. 10:4 ) are also related to pre-Lateglacial events. Varied opinions exist in the literature about these prominent features : the Geological Survey 1:10,560 sheet designates T26 and D1 as fragments of the '100-foot' beach. Wright (1937) believed the 'gravel embankments' to be part of the outwash fan of the 'Loch Carron Glacier', and described them as lying at 40 m (130 feet) at Strome Ferry and at 18 m (60 feet) in its 'distal portions' - presumably meaning Ardaneaskan, although it is not certain to which shore of the loch Wright was referring. McCann (1963) observed that in the Strome area no feature attains 40 m O.D. and that the deposits lack the gradient typical of an outwash fan. However, his contention that the features are related to the Lateglacial maximal sea-level (which he claims to be 28 - 32 m O.D.) is not tenable either. Only one terrace (T27) is horizontal at ca. 34 m O.D.; the Ardaneaskan terrace (T28,29) rises east at 9.8 m/km and is certainly not a raised shoreline. Nor is this terrace likely to be part of a former outwash fan as suggested by Wright : it is highly improbable that such a feature deposited proglacially from an ice-front in upper Loch Carron, attaining a total thickness of ca. 55 m at Strome, could have been so deeply incised in the subsequent time available to produce the basin now present.

Most of the terrace at Ardaneaskan appears to comprise relatively coarse pebbles and cobbles, but at one point in a roadside clearing (838354) rather unusual sediments were observed in the terrace front (Fig. 19). The lowest metre consists of massively bedded silty sands containing few larger inclusions. These sands become finer upwards, grading into 3.5 m of stratified silty sand and clays, the texture varying among the strata. Many of the layers are convoluted : waves, pointed ripples and flame structures all being represented within bands several centimetres deep. Where recumbent structures occur, they point westwards in general. Interspersed with the rippled beds are relatively undisturbed strata. Near the top of the fine section is a single large stone (Fig. 19:2) ca. 40 cm long, under which the fine strata are bent, and are contorted into a large recumbent fold to the left-hand side. This stone obviously settled into the fine sediments while they were still fluid : indeed, it is probable that the convolutions were produced by superimposition of the coarser material, i.e. pebbles and cobbles, that forms the top of the section and most of the terrace. This section shows that quiet water deposition was followed by a much more active phase. The stratified structure proves a fluvial origin for the terrace, and both the relatively steep gradient of the surface and the evidence of a fluctuating depositional regime imply association with glacier ice. The most plausible explanation of this feature is therefore, that it is a kame terrace.

Between Ardaneaskan and Strome further road-side sections reveal horizontally-bedded sands, gravels and cobbles clinging to the very steep loch-shore. No surface expression of these deposits remains, but their nature and position again indicate origin in an ice-marginal position.

The features at North Strome are more problematic. T27 is horizontal, the kettled surface being both backed by and crossed by meltwater channels. A large section in the terrace shows a structure-less fabric of crudely sorted round or sub-rounded clasts ranging from pebble to cobble size, along with some sand lenses. The feature corresponds in altitude with the rock platform at 34 m O.D. at Loch Kishorn, but if it were a fragment of raised shoreline, the glacial origin of the Strome feature could hardly be reconciled with the suggested interglacial or interstadial age of the other. In spite of the absence of clear fluvial bedding and a typical inclined surface, the terrace is believed to have formed as a kame terrace in close proximity to decaying ice.

The other terrace at Strome (T26) forms the small peninsula at ca. 16 m O.D. projecting south into the loch and terminating against a small bed-rock rise. The long (north-south) profile of this feature shows that it is not flat, and though it is backed by a stream channel draining east, the rear of the terrace slopes gently west. A section through the deposit shows deltaic bedding, the foreset beds dipping landwards from a source lying to the south. The strata are well sorted into grades that vary from grit (rare) up to very rounded cobbles. A bed, 0.5 m deep and apparently horizontal, defines the top of the feature. This landform appears to be another kame terrace, or ice-marginal delta, deposited by ice lying in the Carron trough. Since its surface is below the Lateglacial marine limit (26 m O.D.), it is probable that in the early Interstadial it was covered by the sea : some alteration of the upper strata may therefore have occurred (e.g. to produce the uppermost bed). However, it is also possible that the terrace was formed at a later stage of ice decay; hence the lower altitude. The upper stratum in this case would be the topset bed of the former delta.

To summarise, the large fluvioglacial features in lower Loch Carron record the former existence there of a down-wasting ice-lobe. No evidence of former (early) sea-levels is present here, but does exist in upper Loch Carron : the very steep loch-side slopes were probably responsible for their absence in the west. The decaying ice most probably belonged to the youngest pre-Lateglacial stage in the loch, i.e. the declining Late-Devensian ice-sheet or Applecross substage ice, if the latter phase was represented here.

# CHAPTER SIX.

'The succession of cold and warm, or wet and dry, periods represented by the deposits above the Boulder Clay can be decided by an examination of the contents of the ancient peat-mosses and similar strata.'

(Geikie, A., 1901, Progress 1892- 1900,
Geological Survey of the United Kingdom, p. 156.)

## The Pollen Analyses.

Another aspect of the Lateglacial environment is revealed by pollen analysis. Unlike the glacial landforms, vegetation is not static, but a record of the changes in past plant life is preserved as macro- and micro-fossils in peat and other deposits. Despite many constraints, the major patterns within the pollen record allow the reconstruction of past vegetation types and the recognition of successional vegetation development. The relevance of pollen analyses to the present study is two-fold : the biotic and minerogenic characteristics of the kettle-hole deposits provide information about the past environment, and secondly, the hypothesised Lateglacial age of the valley glaciers described in Chapters 2 and 3 is substantiated. Donner (1957) was the first to use pollen analysis to demonstrate a Zone III (Loch Lomond Readvance or Stadial) age for valley glaciers in Scotland : he analysed cores from sites positioned inside and outside terminal moraines, inferring from the presence of Lateglacial sediments outside and their absence within that Lateglacial ice deposited the moraines. The same technique has since been applied elsewhere (Walker, 1974; Lowe, 1977) and the proliferation of Lateglacial sites has helped delimit the Loch Lomond Readvance glaciers throughout the country (Sissons, 1974). In the field area, therefore, pollen sites were sought in the vicinity of clear end moraines, in order to locate a pair of suitable sites related to the former ice limit.

Experimental coring in Strathcarron around the Blackwood moraine (terminus of the joint Coire Fionnaraich and Lair glaciers) established that Lateglacial sediments are buried (if present) under deep outwash sand and gravel, and therefore this area was abandoned. The next area visited yielded better results, both Lateglacial and Postglacial sites being discovered in Strath a' Bhàthaich, within 2.0 and 0.2 km respectively of the major end moraine (Fig. 1). Both sites are infilled kettle -holes a few tens of square metres in area, the Lateglacial site Glasscnock (called after the locality) being in a large morainic deposit situated at the entrance of the valley. The Postglacial site Druim Dubh (named after the main end moraine ridge) lies between the second and third end moraines of the complex on the gently-sloping valley floor : experimental probing established this as the deepest site in the area.

The same technique was used to locate the deepest point in each basin to obtain the maximum depth of sediment : it was hoped thus to ensure sampling the oldest deposits. It was assumed that the presence of the tripartite stratigraphy, namely minerogenic material between organic deposits, which overlay impenetrable minerogenic sediment, implied a Lateglacial sequence of deposition with associated plant fossils. That such a sequence was not found inside the end moraines strongly suggests the absence there of Lateglacial deposits, accumulation having begun in the Postglacial, though such negative evidence is not proof that Lateglacial ice deposited the moraines.

Both kettle-hole sites were cored with a modified Dachnowski piston corer (or Abbey Corer), which produces cylinders of sediment about 60 cm long and 5cm in diameter. Each series of cores was extracted by using alternately two holes close together on the bog surface, in order to minimise stratigraphic disturbance. The method of using an instrumental level to ensure extraction of cores from the correct depths is outlined in Walker (1974), and in Walker and Lowe (1976). At Glasscnock five complete series of cores were collected to provide sufficient sediment for both pollen analysis and radiocarbon dating. The cores were expelled onto plastic semi-cylindrical containers, and sealed immediately in polythene sheeting. In Edinburgh they were stored in a cold cupboard: samples were extracted as soon as possible from the cores and stored in small glass tubes until required.

Since only two sites were being studied, detailed analysis of the cores was possible. Each core was measured, and the sampling interval altered in accordance with the amount of change from 60 cm. All samples are the equivalent of 1.0 cm in thickness, allowing for any unavoidable compression or contraction of the core after expulsion from the chamber. Contiguous samples were extracted from the cores, the sediment being packed into small glass tubes and immediately sealed with wax prior to storage.

Laboratory Techniques.

The laboratory method of preparing pollen slides basically follows Faegri and Iversen (1975). This involves :-

1. Dispersing the sample in hot 5% sodium hydroxide solution.
2. Sieving to remove coarse particles and macro-fossils.
3. Treatment (if necessary) in hot 50-60% hydrofluoric acid to remove minerogenic sediment. In the case of silt and clay samples, overnight soaking in cold 50-60% hydrofluoric acid followed by up to 120 minutes at boiling point was found to be effective.
4. Treatment with cold 5% hydrochloric acid.
5. Dehydration with glacial acetic acid, prior to acetolysis using Erdtman's technique (1934), followed by further dehydration.
6. Mounting in a mixture of glycerine and safranine.

No sample required further chemical treatment to clarify the slides. In the early stages much experiment was necessary to discover the optimum length of treatment with hydrofluoric acid : this is best kept to a minimum to reduce the distortion of pollen grains.

Since absolute pollen counting was used throughout the analyses, some extra steps were required in the pollen preparations. The method described by Bonny (1972) was followed, except in one respect. It was decided to add the exotic pollen suspension (*Ailanthus altissima* grains in glycerol) at the beginning of the preparation instead of at the end, thus allowing any accidental loss of grains, e.g. in decanted liquids, on stirring rods etc., to be in proportional quantities. The additional steps at the beginning of the preparation are as follows :-

1. 1cc of sample sediment is measured by displacement of dilute sodium hydroxide solution in a 5ml measuring cylinder. This is then washed into a boiling tube, made up to *ca*. 75% full with more alkaline solution, and weighed accurately (to three decimal places of a gram).
2. Several drops of the stirred and homogenised exotic suspension are added to the boiling tube, which is then re-weighed.

The normal preparation is then commenced as described above.

The calculation of absolute pollen values depends upon knowing how many exotic grains are added to each sample : this is calculated from the known weight of exotic suspension added. Exact measurement of the 1cc sample volume depends upon the sediment being in its natural water-saturated state. Organic sediments presented no problem in this respect, but the Lateglacial silts and clays were found, after the return journey from the sampling area, to have partially dried in the central 12 cm of this stratum. The fluid nature of these sediments caused them partially to flow out of stratigraphic position, creating an air space above those clays remaining *in situ*. Samples from the partially dried sediments could not, therefore, be measured using the displacement method, and an alternative technique was used. The texture of the silts and clays appeared homogeneous throughout (see p. 148 ). A sample of wet, unflowed minerogenic sediment was used to displace 1 ml of distilled water in a small cylinder, the contents of which were then dried in an oven. When cool, the sample was weighed accurately. All the samples for pollen analysis from the flowed section of the core were then dried, 1cc of each being measured by weighing out the standard quantity as determined above.

A Baker Patholette microscope with x10 Complan oculars was used to count the prepared slides. Routine identifications were made using the medium-power (x40) microplan objective, while the high-power (x90) oil-immersion objective was required for difficult identifications. Grains were counted in regularly-spaced traverses across the slide, until a sum of 1000 grains was reached. This rarely required a complete slide, and never more than one : even in sparsely fossiliferous sediments the sum was achieved relatively quickly due to the exotic pollen component. At the time of starting pollen counting the conclusions of Brooks and Thomas (1967) concerning the non-random distribution of grains on slides were not known, so it is possible that a bias is present in all the counts as complete slides were rarely counted. However, this potential error is only one in the chain of sampling procedures involved in producing a representative sample of each stratum of the coring sites (see Chapter 8).

Identification of pollen grains was most frequently made to the family level where non-arboreal pollen was concerned. Certain families (e.g. Rosaceae) were subdivided into several distinct genera and a composite class (Rosaceae undifferentiated). Only rarely were plant species identified : the state of grain preservation and the equipment used would not permit observation of many of the features necessary for critical identifications, e.g. as listed in the key of Faegri and Iversen. Comparison of fossil grains with a type-slide collection was the most useful aid to identification, while the volumes of Erdtman, Berglund and Praglowski (1961), and Erdtman et. al. (1963) were frequently consulted.

Further comments are necessary about the following elements included in the pollen diagrams :-

1. Betula. Despite the great value of knowing whether tree birches (most probably Betula tortuosa or B. pubescens, c.f. Clapham, Tutin and Warburg, 1962) or only dwarf birch (B. nana) was present in Lateglacial sediments, no objective distinction between them was attempted during pollen counting. Birks (1968) has shown that two measurements are necessary on every grain to separate reliably B. nana, B. pubescens, B. pendula and B. tortuosa : time did not permit this. The use of hydrofluoric acid can cause grain distortion, possibly with a differential effect among the grains, therefore rendering inferences based upon measurement somewhat unreliable. It is also possible that B. nana and B. pubescens may have hybridised in the past as they are known to at present (Godwin, 1975), with unknown results concerning the pollen produced. However, a subjective judgement was made during counting, those grains believed to be B. nana being counted and expressed as a percentage of the total Betula count.

2. Corylus/Myrica. No attempt was made to distinguish Corylus avellana grains from Myrica gale pollen : either or both plant fossils may therefore be present under this term.

3. Salix. The various species were not differentiated, though different types of grain were observed. The dwarf willows (Salix herbacea and/or S. reticulata ) were almost certainly present in the Lateglacial.

4. Empetrum. Measurement of the grains would have been necessary to distinguish between E. hermaphroditum and E. nigrum. This would not have been possible in many Lateglacial samples where the tetrads were crushed or shrunken. Since there are no major ecological differences between the species, identification to generic level is sufficient.

5. Ericaceae. Grains of Vaccinium species and of Calluna vulgaris were believed to be the most frequent components of this group, the latter not

appearing in Lateglacial sediments.

6. Myriophyllum. The great majority of pollen throughout the diagrams was M. alterniflorum, but a few of the M. spicatum or M. verticillatum type were also observed.

7. Unidentified grains were recorded in the pollen sum. Most of this category comprises badly damaged grains, i.e. corroded, degraded, torn or crushed pollen grains or spores. Few were indeterminable due to concealment by debris, and even fewer were distinctive but unknown pollen types.

The calculation of absolute numbers of pollen grains follows Bonny. For the purpose of calculating numbers of grains per square centimetre per annum, a series of five samples from the Lateglacial site were sent for radiocarbon dating at the Palaeoecology Laboratory of the Queen's University of Belfast. Multiple-shot coring as described above was necessary to provide bulked samples for each of the points to be dated : the four series of cores were all located within a small area (ca. 1 square metre) around the cores extracted for pollen analysis. Once the main pollen counting was completed, four of the points selected for dating were located in each core by rapid counts of 500 grains. In the case of the basal organic sediment, the lowest 2 cm of organic deposits were removed. The use of absolute counting simplified the task of correlating the various levels, since three of the points necessitated only counting fossil against exotic pollen to locate the major change being dated, while the fourth, the Corylus rise, involved looking for the appearance of hazel pollen and then the rational limit (sensu Smith and Pilcher, 1973). This matching procedure was essential at the Glasscnock site, in view of the uneveness of lithostratigraphic boundaries in the kettle-hole. Once the relevant points on the cores were located, thin (1.0 to 2.0 cm) slices of each were cut out, the circumference trimmed, and wrapped in tinfoil paper and polythene. The results of the dating are listed in Table 5 and discussed

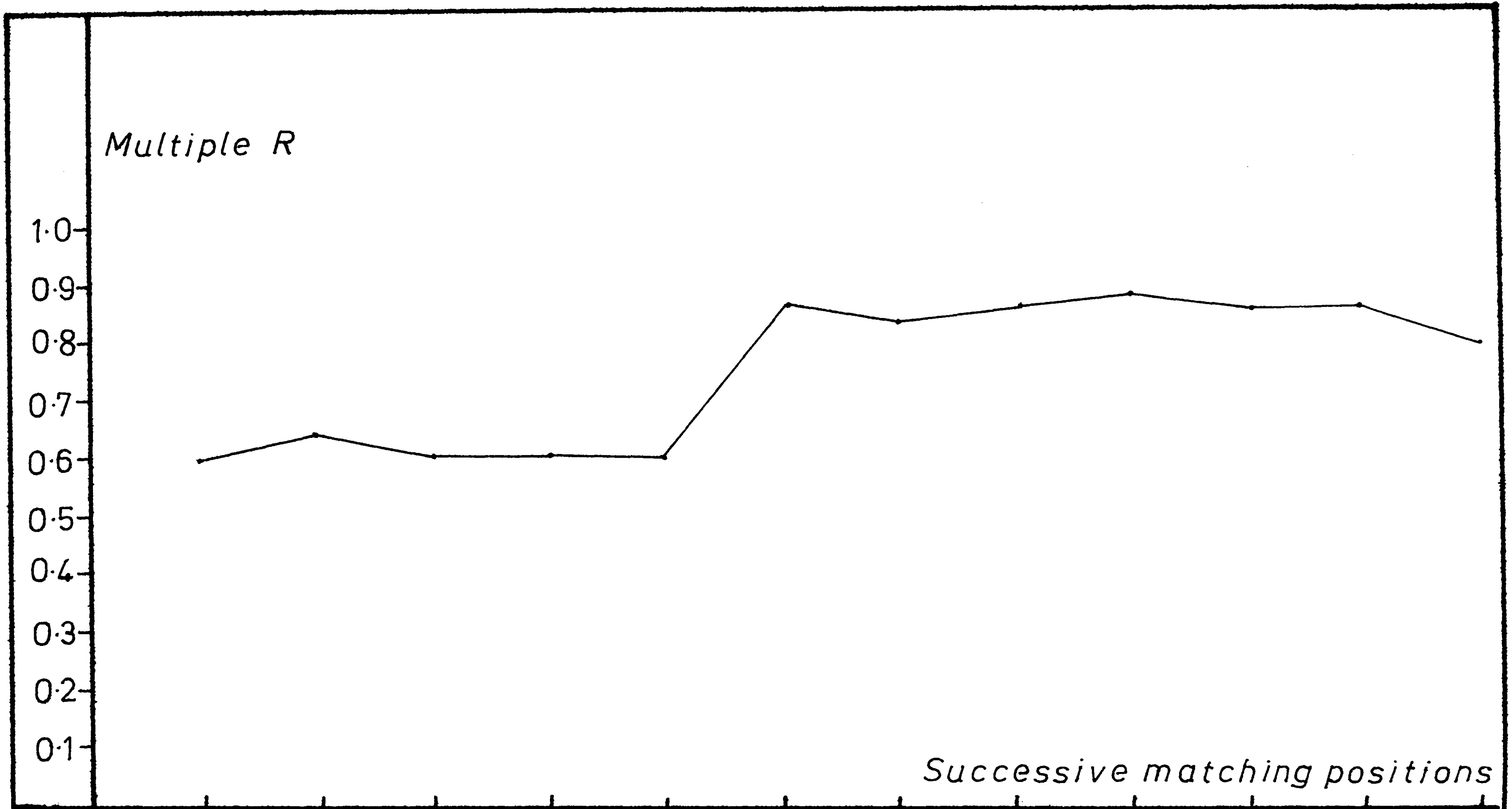



Figure 22 CORRELATION OF POLLEN CORES, GLASSCNOCK

later (see the last section of Chapter 7). Anomalous results in two cases, and lack of precision in a third prevent the use of the series as a time scale to calculate pollen influx per square cm per annum. The pollen data are, therefore, presented on the diagrams as numbers of grains of each taxon per cc of sediment.

The pollen diagrams are presented in Figs 20 and 21. The vertical scale on each shows depth and lithostratigraphy of the cores used for pollen analyses : in Druim Dubh the early Postglacial sequence from the first organic deposits to the incoming of the trees is contained in 6 cm of a single core. The situation at Glasscnock was more complicated, and in order to cover the required depth of sediment three cores were necessary. These were extracted alternately from a pair of coreholes, the sampling depths being chosen to ensure sufficient overlap to match the core ends and obtain an unbroken vertical sequence. The lower junction of cores occurred in the early Stadial deposits (at 5.415 m on Fig. 20), and the large overlap of 19 cm allowed the two ends to be matched by lithostratigraphy and comparison of the levelled depths. The upper junction (at 5.125 m) occurred in Postglacial gyttja, and because of the short overlap (4.6 cm) and the lack of distinctive lithology, the core ends could not be matched by eye. Normal pollen analyses were continued to the ends of both overlapping cores, and the data from these were used in a simple regression analysis to find the 'best fit' point in the cores. The amalysis program was run on the Edinburgh computer, using data from twelve successive levels ( at 1.0 cm intervals) with values for thirty-two taxa at each level. The highest correlation reached (multiple R=0.88759, R square = 0.78781) was assumed to be the point where the two cores were most perfectly matched. Fig. 22 shows the multiple R scores for each pairing position. The correlation of the cores is high over 6 cm, reflecting the similarity in the pollen assemblages between levels from that section of the cores. In order to clarify the pollen diagram the depth values on the vertical axis of Fig. 20 continue upwards in sequence from the two lower cores, ignoring the true depth levels of the upper core (which differed by several centimetres due to the uneven stratigraphy).

Zonation of the Diagrams.

Pollen diagrams are divided into zones to facilitate description and interpretation, and to allow comparison with other sequences. Such zones are conventionally delimited by eye, the pollen analyst assessing changes in either (or both) the lithology of the core or the pollen spectra, and placing zone boundaries at levels of significant change.

Zones defined on the basis of lithostratigraphy are not commonly used by pollen analysts, since their prime interest lies not in the sediment but in its microfossils, and changes in lithology do not always coincide precisely with changes in pollen content. In Scottish Lateglacial diagrams minerogenic sediment has been used to define 'pollen' zones I and III (Donner, 1957), but normally all pollen zones are delimited consistently on the basis of biostratigraphic change.

Biostratigraphy is concerned with the fossil content of sediment, pollen, spores and macro-fossils being most relevant in the study of vegetational development. Where pollen spectra are used to zone a diagram, the object is to isolate the major floristic assemblages present, from which reconstruction of the former vegetation types may be attempted. Such zones may represent periods of change, or relatively static phases. Boundaries of pollen zones are usually based on (more or less) synchronous behaviour of several taxa, but in some cases significant changes in one taxon alone are used, e.g. the boundary between traditional zones VIIa and VIIb at the 'elm decline', or the division of the early Lateglacial into zones Ia, Ib and Ic on the Continent, based on the Betula curve.

The zones used in the Glasscnock and Druim Dubh diagrams are pollen assemblage zones as defined by Birks (1973) quoted on p.144 below. These constitute local zones, but may be compared with zones in other diagrams, in particular with the Regional Pollen Assemblage Zones and the chronozones from north-west Scotland described by Pennington *et al.* (1972). The absence of reliable radiocarbon dates from Glasscnock precluded the delimitation of chronozones, which is the ultimate objective in standardisation of pollen diagrams in order to elucidate regional vegetational history (Mangerud *et al.*, 1974).

The subjectivity involved in zoning by eye is difficult to avoid : ecological, climatic and temporal associations are not easily disregarded. 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. In an attempt to achieve this three zonation techniques using the Newcastle I.B.M. computer were applied to the pollen data. The program 'Zonation' was supplied by A. D. Gordon (Department of Statistics, University of St. Andrews), who with H. J. B. Birks devised the program for use on percentage pollen diagrams (Gordon and Birks, 1972). Slight modification of the program allowed it to be used with absolute data.

'Zonation' incorporates three programs, each designed to group the pollen data in such a way that the optimum groups, i.e. pollen zones, may be discerned. Where all three programs give similar results, 'one can have....considerable faith in the reality of zones so defined within the data' (Gordon and Birks, 1974, p. 243). It is interesting to observe the degree of consistency between zones produced with and without the aid of a computer : in most cases the work of an experienced pollen analyst should be expected to show little discrepancy.

Eighteen pollen types were used in the initial zonation of both sites, this being the maximum number specified in the program. These included all the major contributors to the pollen sum, those types that occurred least and in low concentrations being excluded. Pinus was also excluded, for reasons explained below (p. 173 ). The taxa on which the initial'Zonation' program was based are, for Glasscnock : Artemisia, Betula, Compositae undiff., Corylus/Myrica, Cyperaceae, Empetrum, Ericaceae, Filicineae, Filipendula, Gramineae, Juniperus, Lycopodium selago, Myriophyllum, Plantago undiff., Ranunculaceae, Rosaceae, Rumex, and Salix. For the zonation of Druim Dubh, Lycopodium selago and Compositae were not used, Caryophyllaceae and Liguliflorae being substituted.

The results of 'Zonation' are shown on Figs 23 a,b,c and d. The first program, CONSLINK, is tabulated as a dendrogram, where all the levels are progressively amalgamated into one group. The sooner that two elements (i.e. levels or groups of levels) link up, the more similar they are in terms of pollen types and proportions present, whereas the final amalgamations fuse the most different groups. A contiguity constraint operates in this program ( and the other two) restricting amalgamations to adjacent elements. Values on the x-axis of the dendrogram represent the measures of dissimilarity between elements. Dissimilarity coefficients are calculated for every pair of contiguous elements by the formula :

$$\sum_{k=1}^{t} (p_{ki} - p_{kj})$$

where i and j are contiguous levels in the diagram, t is the number of pollen types, and $p_{ki}$ is the proportion of the total pollen sum in level i which is of type k. In other words, each measure of dissimilarity is the sum of a series of subtractions, where the proportion of pollen of each taxon is subtracted from the corresponding value in the level above. This procedure is therefore affected by both changes in the taxa present (i.e. within the eighteen types considered), and in their proportions. At any value on the x-axis of the dendrogram, a number of groups have been formed, which is related to that level of dissimilarity : the final choice of zones is therefore reduced to a choice of how many divisions are required. (This is assuming that meaningful groups have been detected in the data.) Further groupings below the chosen measure of dissimilarity may indicate sub-zones.

The other two programs are divisive procedures, starting with a single group of, for instance, sixty-two levels at Glasscnock, and subsequently splitting it into an increasing number of groups until ultimately the sixty-two levels are separated. The major divisions appear first, and constitute the zones : further subdivision indicates potential sub-zones. The program SPLITINF uses information theory in order to measure the initial total variability, in terms of information content, within the group. It proceeds by binary division to reduce that initial variability eventually to zero after sixty-one divisions have been made. The information content of a group is measured by the information statistic I, I being large where very dissimilar objects (e.g. levels) constitute a group.

$$I = \sum_{j=1}^{t} ((\ n\log n - aj\ \log aj - \ (n-aj)\ \log(n-aj))$$

Here j is the pollen type, n is the number of levels, aj is the number of levels in the group containing the jth. type (Poole, 1974). The use of presence/ absence data in SPLITINF means that changes in abundance of the taxa are disregarded, the formation of groups depending upon the vertical distributions of each pollen type throughout the diagram. SPLITLSQ, the third technique, works by a similar procedure, but a different measure of variability is used, based on the sum of squared deviations method.

SPLITINF and SPLITLSQ are represented in Figs 23b and 23c by a series of contiguous boxes, which are progressively subdivided as the splitting proceeds. The x-axis indicates the decreasing total variability, each value plotted along it being the percentage of the initial variation that remains at that point. As can be seen from the decrease in both information content and this percentage of total variability, the decline is not steady, hence a log graph paper base was used to draw Figs 23b and 23c to improve their clarity.

# CHAPTER SEVEN.

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

(Birks, H.J.B., 1973, p. 273)

## The Pollen Diagrams.

### A. GLASSCNOCK.

The kettle-hole basin from which the Glasscnock cores were extracted lies at 75 m O.D. on the east side of a large morainic mass that occupies the lower Strath a' Bhàthaich. The surface of the infilled kettle-hole covers several tens of square metres, and in spite of its eastward slope no surface drainage was observed : it is therefore believed that the stratigraphy of the basin should have remained largely undisturbed.

The surface vegetation of the kettle-hole comprises a community similar to the '*Molinia* - *Calluna* bog' described by McVean and Ratcliffe (1962, p. 108). The dominant species observed were *Molinia caerulea*, *Calluna vulgaris*, and *Sphagnum* mosses. *Erica tetralix* and *Carex* species were also well-represented, and smaller angiosperms such as *Narthecium ossifragum*, *Potentilla erecta*, and *Pinguicula vulgaris* were present. The Mollinieto-Callunetum occurs widely on the gently sloping hillsides below 460 m in the Western Highlands, often being present on small hollows and flat areas. It can be viewed as either part of the western blanket bog system, or as a wet grass-shrub heath.

#### 1. Lithology.

The lithology at Glasscnock is a tripartite sequence, consisting of a stratum of silts and clays under- and overlain by organic deposits. Coring could not proceed beyond 5.6 m (depth) due to an impenetrable layer of fine white or pale grey clay : this was assumed to be the base of the kettle-hole.

In the following description, the term 'gyttja' is used to indicate a finely-divided limnic deposit derived from the flora and fauna of the eutrophic lochan that occupied the basin. At certain levels the gyttja is purely organic : elsewhere a greater or lesser proportion of minerogenic sediment is present, this being termed clay-gyttja, although silt as well as clay may exist. No telmatic or terrestrial peat is believed to be present below 4.86 m, indicating that open water persisted in the kettle-hole throughout the time-span of the analysed section.

The lithology of the pollen cores is shown on the left-hand side of Fig. 20. In the basal centimetre, purely minerogenic material in the form of white clay graded upward into clay-gyttja, which in turn was quickly superseded by a fine pale greenish-brown gyttja. Within the 12 cm stratum of this organic deposit (5.60 to 5.49 m) macrofossils are present in the form of very small moss fronds, which become abundant between 5.52 and 5.50 m. At 5.51 m a minerogenic inclusion was noted during the sieving process : this was a rounded grain, probably of sandstone, ca. 2 mm in diameter.

At 5.48 m the gyttja became less purely organic, and from there to 5.41 m the mineral content increased. Within this clay-gyttja macrofossils were noted to be less frequent than previously. Coarse grains of minerogenic debris were recorded first at around 5.42 m. Light grey fine sediment of an almost completely minerogenic nature commenced at 5.41 m, forming a homogeneous stratum 16 cm thick that contained very few macrofossils. It was noted in the field that this sediment was thixotropic, and although complete cores were satisfactorily extracted from the coring site, the sediment tended to flow during transit.

Unlike the lower transition between organic and mineral sediment, the upper boundary of the grey sediment was extremely sharp : it ceased abruptly at 5.245 m, giving way to a pale yellowish gyttja that turned brown on exposure to air. Very fine stem or root fibres were present throughout this gyttja : at 5.14 m Potamogeton drupes were first noted, and these continued to appear over the next few centimetres. At 5.04 m the gyttja became darker in colour, and at 4.99 m many fragments of fossil leaves were noted.

Further information about the character of the cores from the Glasscnock kettle-hole was provided by (1) laboratory testing of samples for organic carbon content, and (2) particle-size analysis of samples from the minerogenic layer.

1. The carbon content was tested only in the region of the levels to be radiocarbon dated, using cores extracted for that purpose. The laboratory method used was a modification of the Walkley-Black colorimetric technique (Walkley and Black, 1934). Samples weighing about 0.25 g were dispersed in 15 ml sodium dichromate solution, 30 ml concentrated sulphuric acid then being added. After ten minutes the solution was diluted with 100 ml distilled water and allowed to stand for two to three hours. After this period had lapsed, the supernatant from each sample was centrifuged, the solution then being tested in the E. E. L. colorimeter. The reading for each sample was used to derive the percentage organic carbon value from a standard curve.

The results showed the basal clay-gyttja ( at around 5.60 m on the pollen diagram) to contain ca. 2% carbon, this percentage rising rapidly to over 10% in the overlying gyttja at around 5.51 m. The upper clay-gyttja was again poor in carbon, containing ca. 1% near the transition to pure minerogenic sediment (around 5.42 m). Above the latter stratum the junction with gyttja gave a value of 1 to 3% carbon, and this rose within a centimetre to 6%, and presumably continued to maintain high values or increase as the gyttja graded upward into peat (at about 4.86 m ).

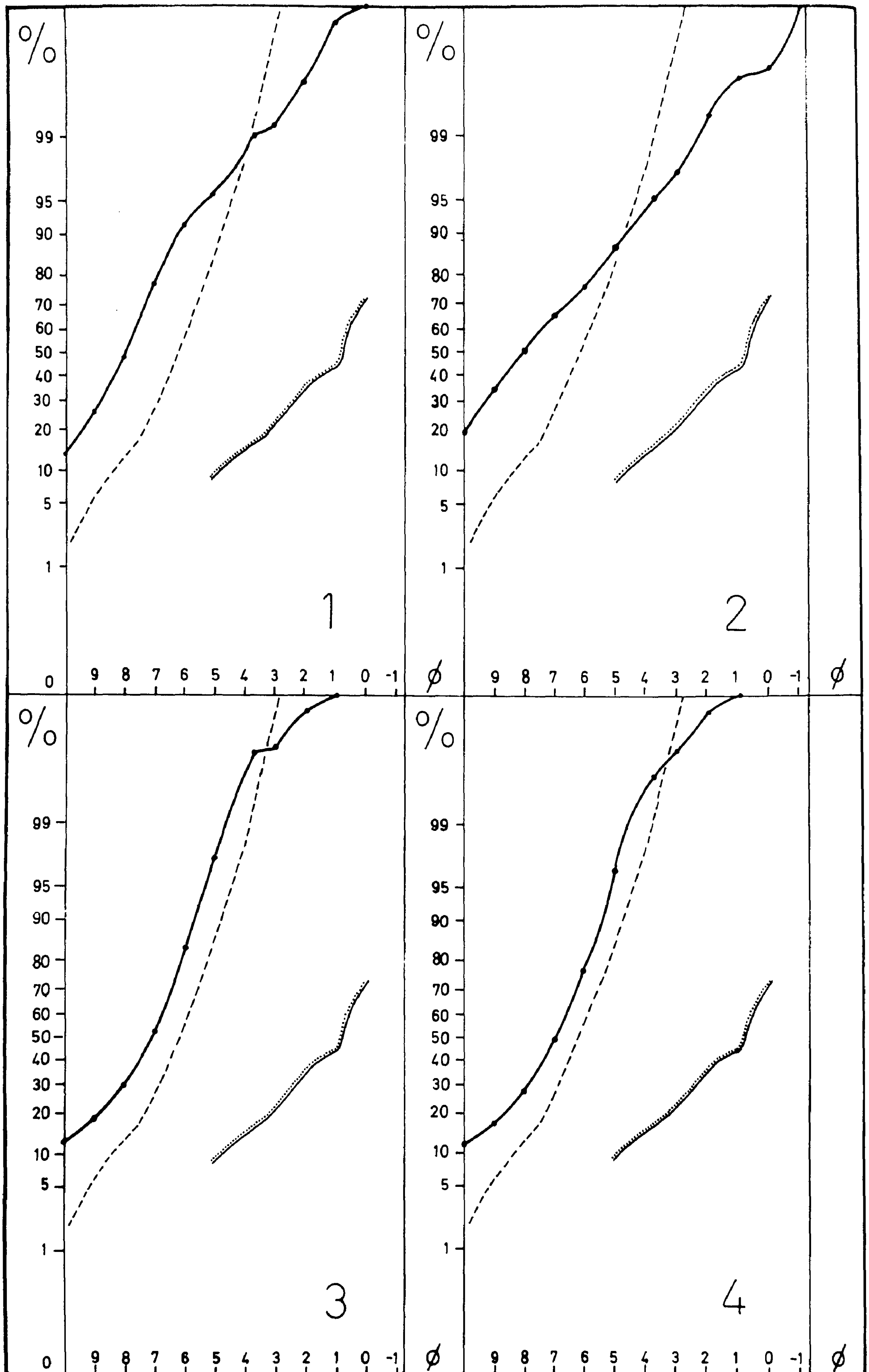



Figure 24: Particle-size Distributions

: SAMPLE 1 to 4 : TYPICAL LOESS FROST-HEAVING NON-FROST-HEAVING SOIL

2. Particle-size analyses were performed on four samples from the minerogenic layer of one of the cores from Glasscnock. Sample 1 was from the basal sediment overlying the clay gyttja, samples 2, 3, and 4 being extracted successively at 7 cm intervals above the first, thereby sampling the complete stratum. The laboratory method described in Folk (1968) was followed, the coarse fractions (i.e. -1, 0, 1, 2, 3, and 4 ø) being separated in a nest of seives, and the fine fractions being subjected to pipette analysis. The results of the analyses are presented on Fig. 24. The curves show that samples 1 and 2 (from the lower section) are finer than samples 3 and 4, the former being classed as silty-clays under the U. S. D. A. system. Samples 1 and 2 comprise 1.5 and 5% sand, 49.5 and 43% silt, and 49 and 52% clay respectively. The upper two samples are silts (U. S. D. A. system), comprising 1% sand, 70 and 72% silt, and 29 and 27% clay respectively. Further reference to the nature and origin of these sediments is made in Chapter 8.

The alternation of organic and minerogenic deposits in the tripartite pattern described above can be interpreted with reference to previous literature as showing a Lateglacial and Postglacial sequence, similar to stratigraphies found at many sites in Scotland that lie outside the limits of the Loch Lomond Readvance (Sissons, 1974). Elsewhere, the intermediate minerogenic layer has been shown to have accumulated during the Lateglacial Stadial, reflecting the more severe environmental conditions of that time that resulted in the cessation of vegetational and soil development, and initiated instability and mass-movement beyond the glaciated areas. The preceding sediments, which are usually predominantly though variably organic, accumulated prior to the onset of Stadial conditions during the Interstadial. The upper organic sediment overlies the Stadial deposits, thus being of Postglacial age. It was hoped that the series of radiocarbon dates from the organic sediment at Glasscnock would confirm

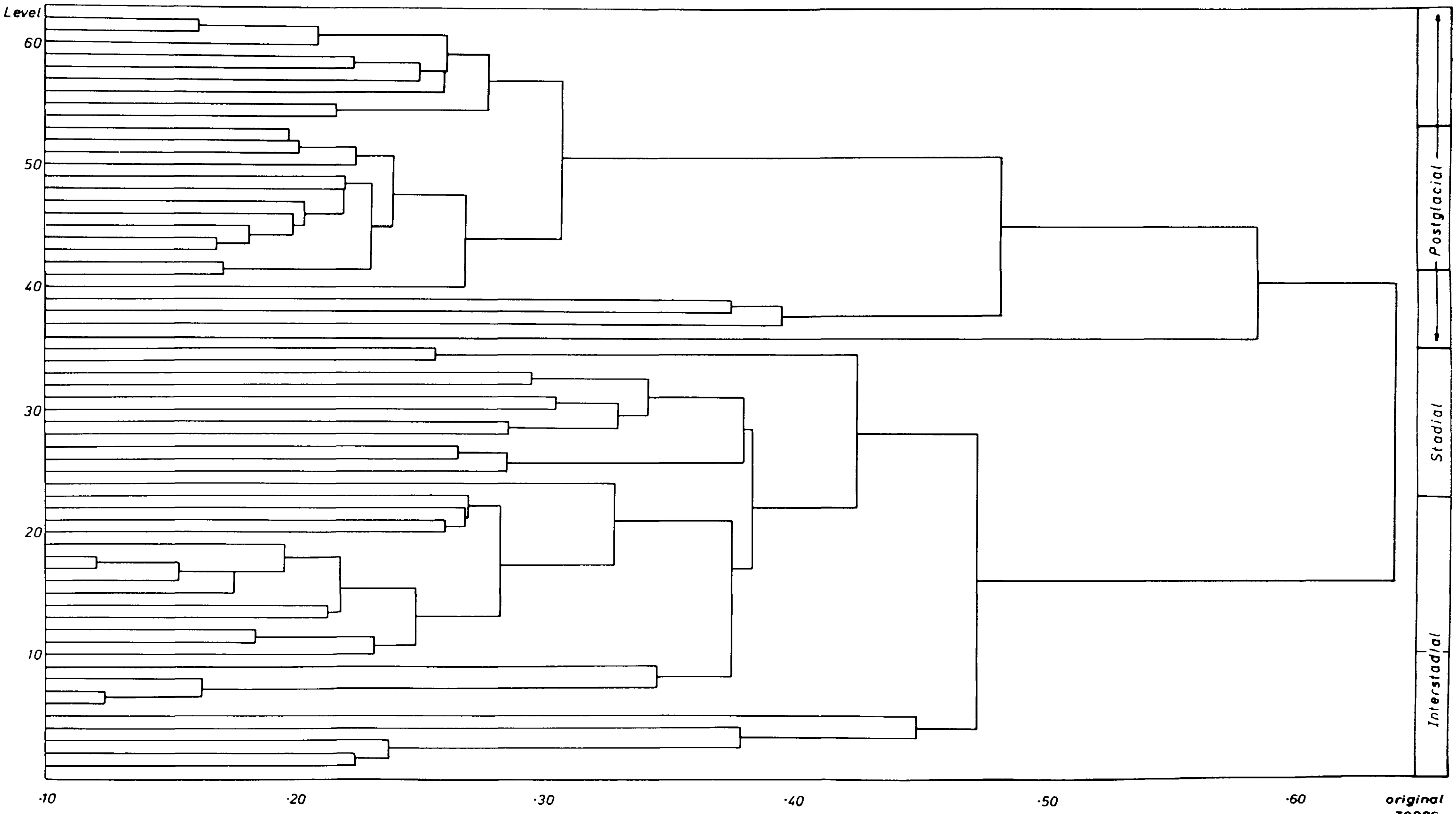



Figure 23a : CONSLINK dendrogram — Glasscnock the hypothesised chronology, but the results were so anomalous (with reference to dates of the same events elsewhere) that they are considered unreliable (see discussion at end of Chapter). The degree to which the pollen analyses corroborate this interpretation of the lithology is discussed after the following description of the pollen zones.

2. The Pollen Zones.

The Glasscnock diagram is divided vertically into a series of pollen zones that were based on the results of the computer program 'Zonation', described in the previous chapter. Diagrams of the group hierarchies produced by CONSLINK, SPLITINF and SPLITLSQ (Figs 23a-c) show that all three techniques select similar major groupings of levels, suggesting that important differences in the pollen flora exist within the 61 cm of core analysed.

Though the positions of group boundaries are objectively indicated by the three techniques, the subjective choice of the number of groups (zones) remains. There is no simple method of deciding how many groups should be selected as pollen zones : in SPLITINF and SPLITLSQ the decline of total (initial) variability associated with an increasing number of groups is relatively smooth with no sudden fall-off to indicate the point where the optimum number of groups is reached. The choice of number of zones therefore depends upon the aims of the analyst. Since the purpose of zonation is usually to simplify the description and interpretation of a complex set of data, a minimum number of zones that fulfils this purpose must be found initially. In the case of Glasscnock, three major floristic divisions might be expected from lithological implications, i.e. the Interstadial, Stadial and Postglacial divisions. Further major sub-divisions can be made with reference to the pollen diagrams, in particular to the curve showing total influx. For the purposes of a seminar given almost a year before the diagram was zoned by computer, six major pollen

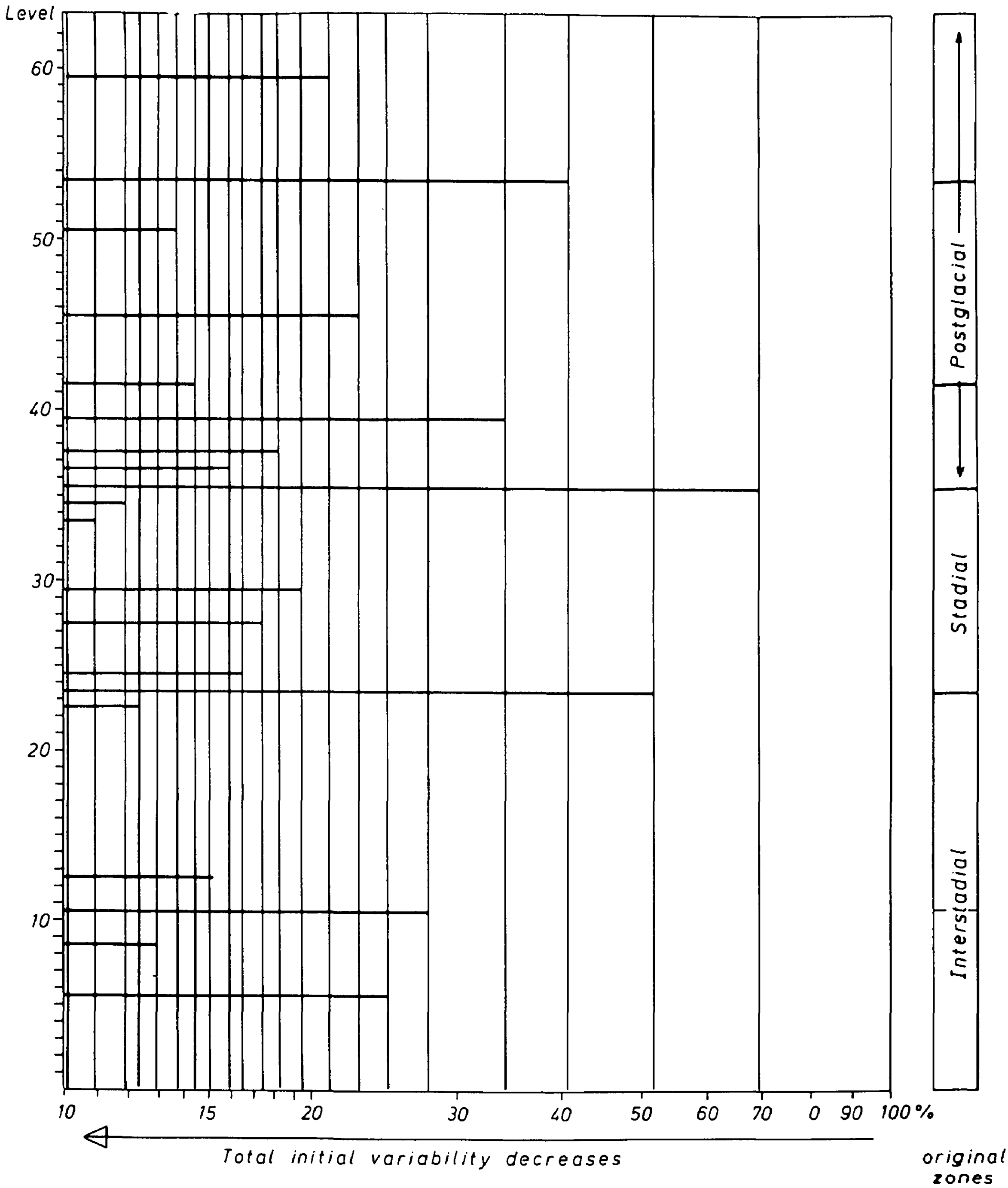



Figure 23b: SPLITINF diagram
Glasscnock

assemblage zones were defined (by eye) on the Glasscnock diagram. These zones were believed to represent the major floristic units present, and are shown on Fig. 23. Comparison with the SPLITINF and SPLITLSQ hierarchies shows that the five zone boundaries correspond with the first five divisions produced by these techniques, four coinciding precisely while the fifth is displaced by 1 cm. It was therefore, decided to treat the zones as the principal subdivisions of the diagram. The six groupings reduce by over 70% the initial total variability of the complete sequence as measured in SPLITINF, and similarly by over 80% that measured in SPLITLSQ. Further subdivisions within these groups are considered in association with the pollen spectra, some being consequently designated sub-zones. It should be stressed that the number of divisions chosen is a purely subjective choice : the numerical zonation techniques used cannot indicate the optimum number of groups (for this will vary with the object of the exercise), but can only show the optimum situations of the group boundaries.

Both CONSLINK and SPLITINF select as the principal two groups levels 1 to35, and 36 to 62 (levels will here be referred to by the sample number, instead of its depth in metres, for the sake of brevity; the levels are numbered 1 to 62 from 5.60 m upwards as shown on Fig. 20). These groups amalgamate last in CONSLINK, and are therefore of maximum dissimilarity, whereas in SPLITINF the first division falls above level 35. This boundary falls near the top of the minerogenic stratum in the core, and is interpreted below with reference to the pollen spectra as representing the Lateglacial/ Postglacial boundary.

The second major division in SPLITINF is selected by SPLITLSQ as being of prime importance : this produces groups 1 to 23, 24 to 35, and 36 to 62. Level 23 lies near the base of the grey silts and clays, and marks a very clear decrease in total fossil pollen influx (see Fig. 20)

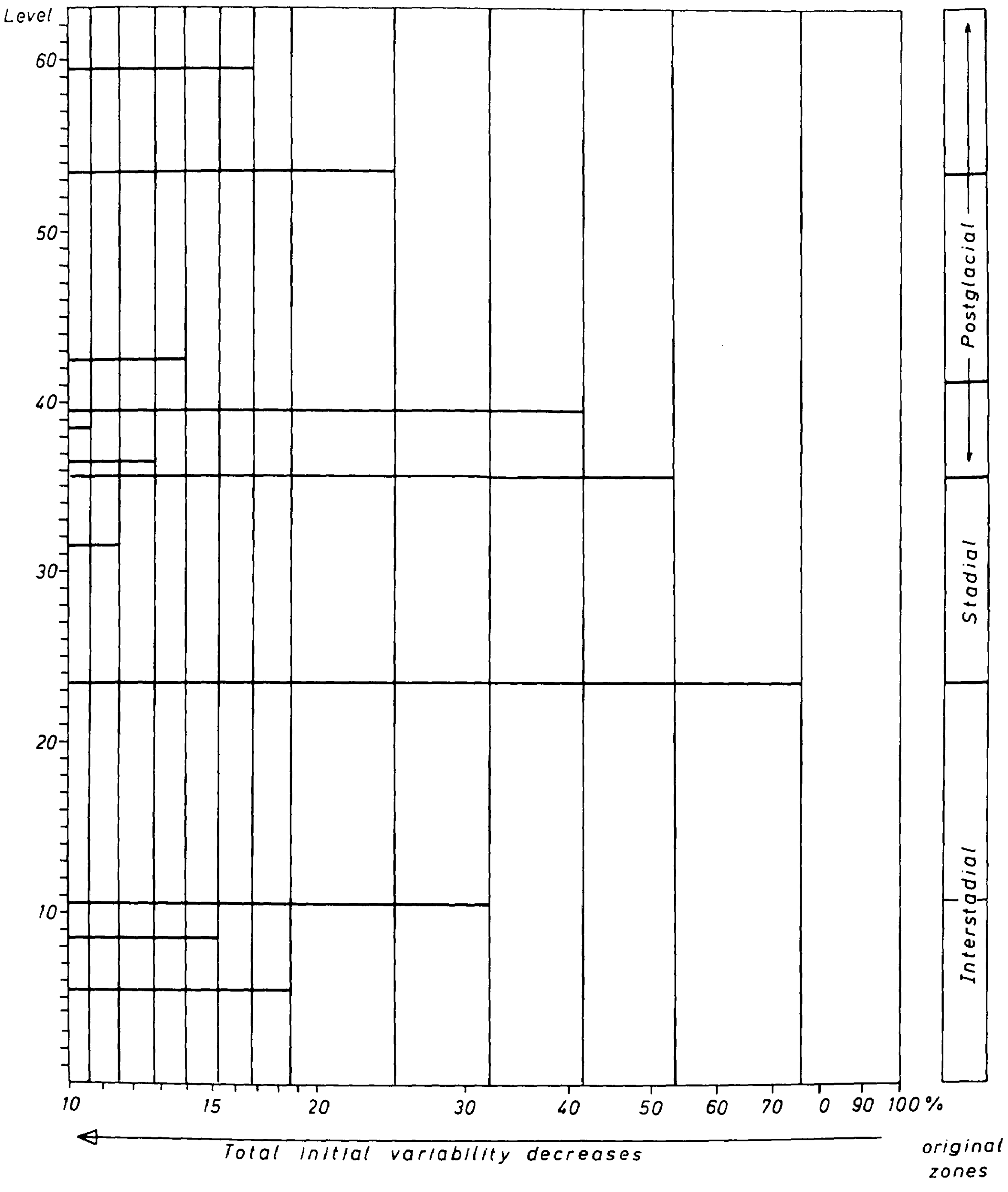



Figure 23c : SPLITLSQ diagram
Glasscnock

that is interpreted as marking the Interstadial/ Stadial junction. CONSLINK considers level 24 to be more similar to groups below it than the overlying elements, and levels 25 to 33 are grouped with 34 and 35 relatively late in the procedure. In palynological terms markedly dissimilar elements such as 34 and 35 probably represent transitional stages between different, more distinct pollen assemblages, CONSLINK being particularly sensitive to such levels (Gordon and Birks, 1972, p. 974), and therefore amalgamating them relatively late. Level 36, the lowest in the Postglacial section,illustrates the point perfectly : this single level joins in the penultimate amalgamation with the remainder of the Postglacial levels, and is clearly regarded by CONSLINK as being intermediate in character between the Lateglacial and Postglacial groups.

SPLITLSQ and CONSLINK select as the third most significant division that above level 39,indicating it to be the most important subdivision of the Postglacial section. In the early Postglacial group (levels 36 to 39) the pollen influx, i.e. grains per c.c., is rising steadily from the Stadial minima, and the whole zone is transitional in pollen taxa and concentrations between the Lateglacial and the later Postglacial.

SPLITINF awards third place to the division at level 53; this is picked out in fifth place by SPLITLSQ and is also detected by CONSLINK (dissimilarity coefficient = 0.30). This group of levels was originally chosen during zonation by eye as it includes the great simultaneous expansions of the Betula and Corylus/Myrica curves, and the slightly later expansion of Salix.

The final major zone boundary of the five lies between levels 10 and 11, splitting the Interstadial section into a lower and upper part. CONSLINK again varies slightly here, joining level 10 to 11 and selecting level 9 as being intermediate between the adjacent groupings. The suggested boundary at 10/11 almost coincides with the lithological transition between gyttja and clay-gyttja (5.495 m), and is associated with a sharp increase in pollen influx in many taxa.

The six zones described above are labelled G-1 to G-6 on the Glasscnock diagram, from the base upwards. The dendrogram Fig. 23a shows that, in general, the Stadial zone G-3 has the greatest internal consistency in terms of the measured dissimilarities between contiguous elements. All of the amalgamations in it are concentrated in the range (of dissimilarity coefficients) 0.25 to 0.38, i.e. the individual elements comprising the group display very consistent ( and relatively large) measures of dissimilarity.

Greater internal variation is seen in G-1 and G-2, where small sub-groupings of very similar levels (e.g. 6, 7, and8) amalgamate at later stages with far less similar neighbouring elements (e.g. 5 and 9). This is presumably indicative of greater floristic variability through the Interstadial : the presence of very late-amalgamating levels (e.g. 5 and 9) between distinct sub-groups implies alternating stability and transition in the pollen flora. In the Postglacial, however, each zone shows a fairly high internal consistency in the degree of similarity of its elements. G-4 comprises four rather different levels, due to its transitional position. G-5 and G-6 are more homogeneous in character, the bulk of amalgamations within each falling within the range 0.16 to 0.26 (dissimilarity coefficients), although alternation does exist to a lesser extent between highly similar sub-groups, e.g. levels 41 and 42, and more heterogeneous neighbouring elements.

ZONE G-1. (levels 1 to 10)

This covers the basal 10.5 cm of gyttja from the kettle-hole. The total fossil pollen and spore concentration varies among the levels from under 50,000 to over 100,000 grains per c.c. This range compares well with those quoted by Pennington(1973) for Zone Bb in north-west England, where values range from 60,000 to 100,000 grains per c.c. at Blea Tarn and Low Wray Bay respectively. Pennington's zone Bb is early Lateglacial Interstadial in age, and follows the basal pollen zone Ba.

The major contributors to the pollen and spore influx in zone G-1 are Rumex, Lycopodium and Filicineae, all of which attain their maximal values in this zone. Salix, Betula, Gramineae and Cyperaceae are continuously present, and many herbs are well-represented, especially Helianthemum, Artemisia, and Compositae. Aquatic types are present, Myriophyllum appearing consistently but with very low concentrations. Zone G-1 is named the Rumex-Lycopodium Assemblage Zone (A. Z.) because of the dominance of these taxa in this part of the sequence. (Filicineae is not included in the name since the values attained by the fern spores, including Polypodiaceae, are superseded in the following zone).

Subdivision of G-1 is indicated by SPLITINF and SPLITLSQ between levels 5 and 6 ; CONSLINK detects the same two major sub-groups, level 5 being very late in amalgamating with those below it. Above the transitional level exists a group of very similar levels, 6, 7, and 8, with level 9 appearing as another anomalous level intermediate between zones G-1 and G-2. The sub-groups indicated by the numerical techniques are therefore 1 to 5 and 6 to 10. This division ranks sixth in both SPLITINF and SPLITLSQ,and is therefore worthy of attention.

The curve for total fossil pollen and spore influx shows in general a rising trend in sub-zone G-1a, and decreasing values throughout G-1b. (The basal sample in G-1a has a higher pollen concentration than the succeeding samples and is therefore anomalous). The decline through G-1b to a minimum at level 9 preceeds the large increase in pollen influx in zone G-2. There are no striking differences in floristic composition or pollen concentrations between the two sub-zones. The herbs are intermittently or continuously present throughout both, Plantago and

Rosaceae undiff. showing a preference for the earlier period. Juniperus, Gramineae and Cyperaceae all decline in G-1b from slightly higher concentrations in G-1a. Lycopodium undiff. and L. selago reach maxima for the complete sequence of 62 levels at the boundary between the sub-zones, their values rising towards it and falling off again through G-1b. Empetrum reaches an early peak in G-1a, thereafter maintaining very low concentrations until the beginning of Zone G-2. The Rumex curve is interesting in that it has two peaks, one in each sub-zone, each coinciding with levels (4 and 11) where the other taxa contribute relatively less pollen (c.f. the curve for total fossil influx).

ZONE G-2. (levels 11 to 23)

The lithology of this section is mainly clay-gyttja, with 4 cm of minerogenic material being included at the top. The total microfossil influx reaches over 160,000 grains per c.c. at level 19, higher than any other sample in the sequence. From this maximum concentration values decline sharply to under 10,000 grains per c.c. at the opening of zone G-3. The mean concentration in G-2 is 86,000 grains per c.c.; concentrations of the same order (100,000 grains per c.c.) are recorded by Pennington (1973) at Blea Tarn in zone Bd, which precedes the Stadial zones.

All taxa except Rumex and Helianthemum register increased values in zone G-2, and many reach maxima for the Interstadial at level 19. The most dramatic change involves Empetrum, which at its maximum exceeds by more than ten times its concentrations in G-1b, rising from 14,000 grains per c.c. (level 12) to a maximum of 56,700 grains per c.c. Because of the dominance of this genus, zone G-2 is named the Empetrum A. Z. Other taxa that are particularly well-represented in this zone are Juniperus, Salix, Gramineae, Cyperaceae, Filicineae and Epilobium. Single grains of Koenigia islandica were recorded in two successive levels in the zone, the only occurrences of this species. Rumex again behaves in a contrary manner : it declines from high values at the top of sub-zone G-1b and maintains relatively low concentrations through most of G-2.

Strong indications of sub-zones are lacking within G-2. CONSLINK shows levels 11 to 19 to have much mutual similarity (levels 17 and 18 being the least dissimilar pair of levels out of 62), whereas the top four levels form a distinct, separate group that is internally less homogeneous. This again probably indicates a small transitional sub-group near a zone boundary. Since SPLITINF and SPLITLSQ do not give high priority to any subdivision of the group, no sub-zones are distinguished.

ZONE G-3. (levels 23 to 35)

This zone occurs within the minerogenic section of the core sequence, and is characterised by extremely low pollen concentrations at every level. The total fossil influx ranges from 4,200 to 12, 400 grains per c.c., intermediate between values from Be and Bf at Low Wray Bay and Blelham Bog, where they reach under 1,000 and 20,000 grains per c.c. respectively.

All pollen spectra maintain minimal values throughout G-3, some disappearing altogether, i.e. Chenopodiaceae, Plantago, Polypodium vulgare, Selaginella, Equisetum, and Menyanthes. Most taxa present only have sporadic occurrences through the zone, although Empetrum, Gramineae, Cyperaceae and Polypodium undiff. give continuous records, Betula, Rumex and Filicineae being absent only at one level. Gentiana is the only type that actually occurs more frequently in this zone (and the uppermost levels of G-2) than elsewhere, and two of the three records of Hippophae are from this zone. Although it is difficult to choose dominant taxa in this zone, grasses and sedges contribute more to the pollen influx than any other types, therefore G-3 will be referred to as the Gramineae-Cyperaceae A.Z.

The relative lack of similarity among the elements comprising this distinctive group has already been pointed out. The first sub-division of G-3 according to SPLITINF occurs (as the 9th. split) above level 29, presumably because several taxa reappear at this level, but SPLITLSQ and CONSLINK do not assess this as an important division. Zone G-3 is therefore not sub-divided.

ZONE G-4. (levels 36 to 39)

In the smallest zone in the diagram influx values rise steadily, total fossil pollen content climbing from 25,500 to 83,700 grains per c.c. in only 3 cm of sediment. The matrix is organic throughout this and the subsequent two zones.

The zone is named the Rumex A.Z. after the remarkable rise in Rumex concentrations, the curve having a symmetrical peak that culminates at level 19 ; within the preceding 2 cm the influx of Rumex pollen increases 18-fold. Other spectra also show rapid increases in this zone, e.g. Salix, Myriophyllum and Equisetum, while some taxa appear in the diagram for the first time (Filipendula, Potentilla, Dryas, Plantago lanceolata, and Typha). Many of the herbs present throughout zones G-1 to G-3 maintain increased concentrations in G-4, regaining values similar to those in G-2.

ZONE G-5. (levels 40 to 53)

Influx values attained in G-4 are maintained at fairly constant levels through this zone (59,000 to 111,000 grains per c.c.), while the floristic composition changes in several important respects.

Many of the taxa that characterize zones G-1 to G-4 continue to appear, some in sustained higher concentrations than previously, including Ericaceae, Liguliflorae, Menyanthes, Potamogeton and Equisetum. Several pollen types appear for the first time : Urtica, Caltha, Sphagnum, Plantago maritima, Cruciferae, Populus, Alnus, Quercus, and Corylus/ Myrica. The latter occurs sporadically in the middle of G-5, its rational limit being at the top of the zone, above which level it continues to rise steadily. Conversely, Plantago undiff., Caryophyllaceae, Rubus, Helianthemum, Epilobium, Gentiana and Juniperus are all recorded for the last time in this zone. Filicineae sustains high levels throughout, but begins to decline at the top of the zone. Few rapid changes in abundance are evident, the main exception being Plantago maritima which is first recorded at level 44 and increases seven times within as many centimetres. Betula exceeds values reached in G-1 and G-2, increasing to an early maximum before falling again slightly towards the upper boundary. Zone G-5 is called the Betula A.Z. since it is probable that birch was a dominant feature of the vegetation at this stage (see p. below).

Definition of sub-zones is not considered helpful here : SPLITINF suggests a division into sub-groups 40 to 45, 46 to 53, but neither CONSLINK or SPLITLSQ detect these groupings, and subdivision does not appear necessary to aid description and interpretation of the spectra.

ZONE G-6. (levels 53 to 62)

Pollen and spore influx is similar in this final zone to the values consistently present in G-5, rising gradually above level 57, but the curve for total fossil influx masks strong trends that are evident in certain individual taxa.

The most marked changes are the rapid, simultaneous rises of Betula, Salix, and Corylus/ Myrica above level 56 : hence G-6 is named the

Betula-Corylus A.Z. , assuming the majority of Corylus/Myrica grains to belong to hazel (c.f. similar zones reported by Birks, 1973, and H. H. Birks, 1972). Birch shows the swiftest increase, multiplying its influx four times over in six centimetres, and all three types reach their highest recorded values at level 62. Sorbus aucuparia appears for the first time, while the rational limit of Alnus occurs at level 57. Empetrum declines steadily as Ericaceae increase, the ferns and Plantago maritima decrease, while most of the remaining terrestrial taxa continue to be recorded. Increased representation of Artemisia is evident, Cruciferae flourish rather briefly, and Sphagnum begins to increase slowly. The aquatic plants Myriophyllum, Potamogeton and Menyanthes are still present, though much less abundant than in earlier zones. A single grain of Nuphar was found at the base of the zone.

SPLITLSQ and SPLITINF place a dividing line ( 8th. in rank order) between levels 59 and 60, creating sub-groups 53 to 59 and 60 to 62, and CONSLINK also regards the upper three levels as constituting a separate sub-group. However, it was decided not to designate these sub-groups as sub-zones since, in general, the upper levels only continue (and, in some cases, magnify) trends already established in the lower part of G-6.

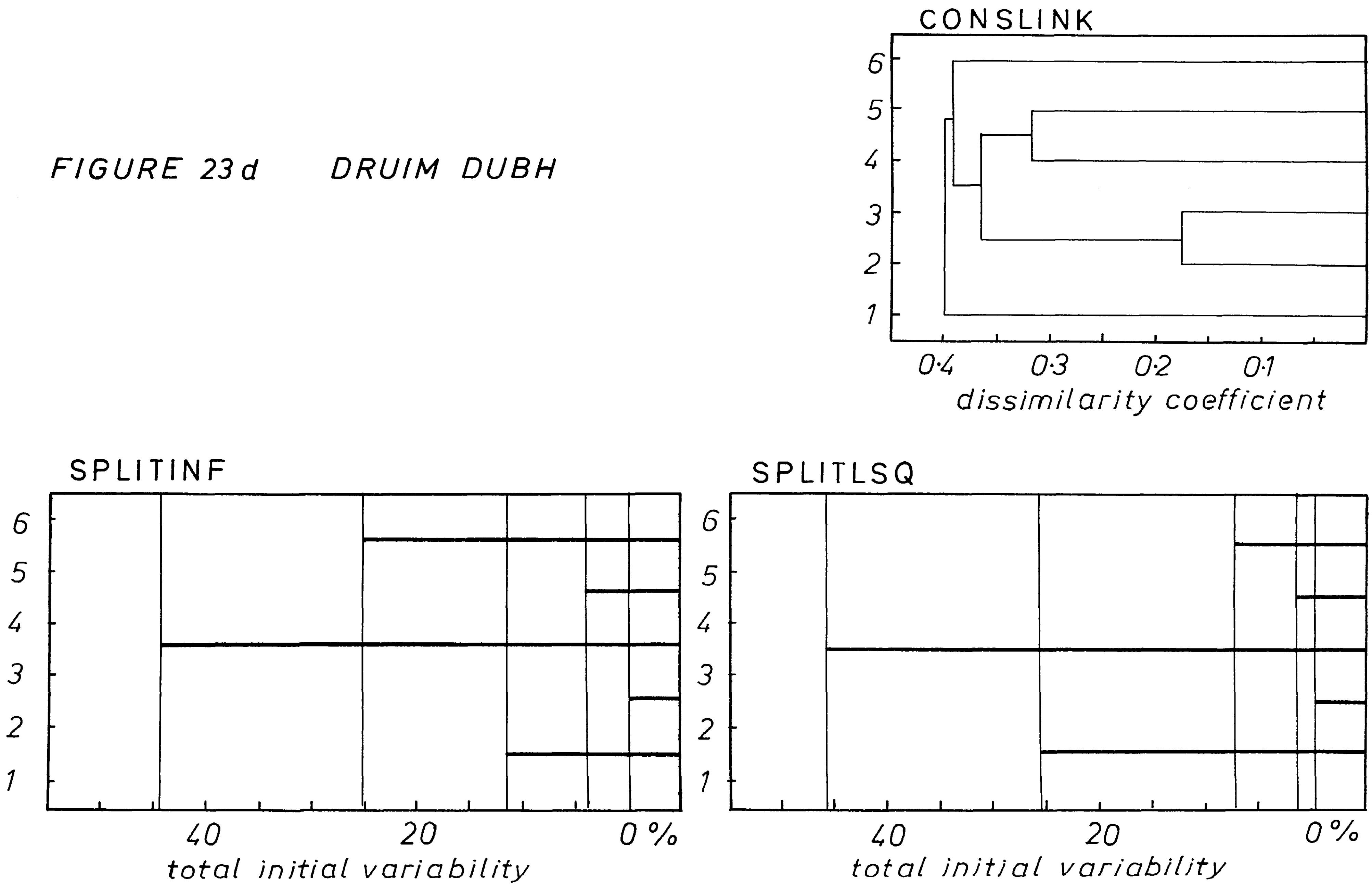
B. DRUIM DUBH.

The second series of cores for analysis was extracted from another kettle-hole site, lying at 152 m O.D., about 2 km north-east of Glasscnock in Strath a' Bhathaich. The site is several hundred metres inside the large end moraine (Druim Dubh) described in Chapter 3, which was interpreted as marking the maximal extent of the Loch Lomond Readvance ice in this valley. The kettle-hole selected for coring lies between two of the subsidiary terminal moraine ridges, which record the positions of the second- and third-oldest termini. No surface drainage channels were observed on the infilled basin surface, although it slopes very gently to the south-east, and the bog vegetation is arranged across it in a small-scale aapamire or string-bog form with alternating elongated hummocks and flarks (Moore and Bellamy, 1974).

The dominant components of the present vegetation on the infilled kettle-hole are _Sphagnum_ mosses, _Carex_ species and _Calluna vulgaris_. _Erica cinerea_ and _E. tetralix_, _Molinia caerulea_, and _Myrica gale_ are frequent, and _Eriophorum_, _Drosera_, _Narthecium ossifragum_ and _Menyanthes trifoliata_ are among others present. The vegetation appears to correspond closely with the Trichophoreto-Eriophoretum typicum described by McVean and Ratcliffe (1962) as being 'one of the most widespread vegetation types in the Western Highlands on ground below 1500 feet (457 m) and on slopes of less than 10° (op. cit., p. 102).

The deepest part of the basin was located, and cores for pollen analysis extracted by the methods described previously. Coring could not proceed below a depth of 6.17 m, where impenetrable minerogenic sediment with a high clay content was encountered. The lithostratigraphy of the analysed cores is shown on the left of Fig. 21. All the sediment was organic, the basal centimetre having a low mineral content that was

FIGURE 23d DRUIM DUBH



not evident (to the eye) above this level. Sample 1 at 6.17 m was light greyish green in colour, a finely divided clay-gyttja lacking macro-fossils. Above this the gyttja was pale greenish-brown, becoming darker at 6.12 m where small fibrous inclusions were noted for the first time.

This sediment strongly resembled the gyttja present in the Glasscnock basin, and is similarly interpreted as being detritus derived from the fauna and flora living in and around the kettle-hole lochan. No laboratory tests were applied to the Druim Dubh samples to investigate the lithology further. Visual inspection of the cores extracted suggested that homogeneous gyttja formed a layer 22 cm thick that was overlain by fine highly humified peat at 5.93 m.

The pollen diagram from Druim Dubh is presented in Fig. 21, and the computed zonation hierarchies are illustrated in Fig. 23d. The program 'Zonation' was applied to the six analysed levels using eighteen taxa (see p. 141 above). Both SPLITINF and SPLITLSQ select the major groups 1 to 3, and 4 to 6 : this division reduces the initial total variability by over 50% in both cases. The next divisions separate from the initial groups level 6 in SPLITINF and level 1 in SPLITLSQ ; from the third division onwards the groups selected are the same. The CONSLINK dendrogram displays a slightly different pattern : pairs of levels from the middle of the diagram (2,3 and 4,5) are amalgamated before the basal and uppermost levels join the group. Levels 2 and 3 are measured as being the most similar elements present, while levels 1 and 6 are most dissimilar. Despite the limited length of core investigated, a distinctive pattern of floristic change is indicated, and the six levels cannot be regarded as a single zone. Two major assemblage zones are defined with reference to the numerical zonation techniques and the observed changes in the pollen taxa.

ZONE DD-1. (levels 1 to 3)

Throughout the basal pollen zone the total fossil pollen influx rises steadily towards a peak early in the following zone. Betula, Empetrum, Gramineae and Filicineae are the largest contributors to the pollen influx, while Salix, Cyperaceae and Rumex are also well-represented. Most taxa register maintained or increasing concentrations throughout the zone, the exceptions being Rumex and Lycopodium selago : the latter declines steadily above its initial maximum values in level 1, while Rumex attains its peak at level 2 and its concentrations are reduced thereafter. The zone is named the Empetrum-Gramineae A.Z. because these taxa reach maxima here.

Juniperus has a small peak (prior to disappearing in level 4) that coincides with the maximum Empetrum and Gramineae values at the top of DD-1. Several taxa present here appear only intermittently, or not at all, in DD-2, i.e. Cruciferae, Epilobium, Caryophyllaceae and Thalictrum. The only records of Dryas octopetala and Selaginella selaginoides occur in level 1.

Subdivision of DD-1 early in the SPLITLSQ procedure creates groups 1, and 2 to 3 : this is probably largely a reflection of the lower pollen concentration in the basal sediment. CONSLINK regards level 1 as being the most dissimilar element of the six levels, and amalgamates it last. Because of its markedly different character level 1 is separated from the pair of levels 2 and 3, and both are designated sub-zones (DD-1a and DD-1b) in spite of the small size of DD-1.

ZONE DD-2. (levels 4 to 6)

Fossil concentrations decline from the maximum in level 4, over 200,000 grains per c.c., to almost half that value by level 6. Despite the overall decrease in pollen influx, some taxa maintain or increase values in this zone. Betula and Filicineae are the dominant types present throughout, while Salix, Gramineae and Filipendula also record large concentrations. Betula, Salix, Ranunculaceae, Artemisia, Filipendula, Menyanthes and the ferns all reach maxima for the six levels in level 4, where Juniperus is recorded for the last time. Two taxa hitherto unrecorded appear in DD-2 : these are Corylus/ Myrica and Ericaceae, both of which increase toward the top of the zone.

Zone DD-2 is named the Betula A.Z. because of the sustained high values of this taxon. Subdivision of the zone produces sub-zones 4 to 5 (DD-2a), and level 6 (DD-2b) : the uppermost level is treated by the numerical techniques as being akin to level 1 in DD-1, rather unlike the other components of its group.

TABLE 5.

The Radiocarbon Dates from Glasscnock.

| Reference number. | Sample number | Depth in metres. | Age B.P. | Sc 13 |
|---|---|---|---|---|
| UB 2031 | Glasscnock 5 | 5.097 to 5.082 | 10,430 ± 210 | -26.3 ±0.6 |
| UB 2012 | Glasscnock 4 | 5.267 to 5.247 | 8,785 ± 1950 | -23.2 ± 0.3 |
| UB 2011 | Glasscnock 3 | 5.432 to 5.417 | 10,060 ± 560 | -20.9 ± 0.2 |
| UB 2010 | Glasscnock 2 | 5.515 to 5.505 | 11,165 ± 350 | -19.4 ± 0.2 |
| UB 2009 | Glasscnock 1 | 5.612 to 5.592 | 7,355 ± 280 | -18.0 ± 0.3 |

The Radiocarbon Dates.

UB 2009 represents the basal organic sediment from the kettle-hole. The sediment is clay-gyttja, poor in carbon (less than 2%), and is the remnant of the first plant and animal life to accumulate in the basin. The expected age of this deposit would therefore be Lateglacial, probably early Interstadial (although the ice block that eventually created the kettle-hole may have lingered for centuries or more after deglaciation : Florin and Wright, 1969). The result is Postglacial and out of chronological order in the series, and is therefore doubly anomalous.

The second result, UB 2010, is Lateglacial as anticipated, and dates the low point on the curve for total fossil influx, summarising minima in many taxa. The sediment dated was gyttja, relatively rich in organic content (ca. 10% carbon).

The third sample of Lateglacial sediment, UB 2011, is clay-gyttja from the transition between organic (Interstadial) and minerogenic (Stadial) deposits. The point dated is the major decline from maximal Interstadial values on the total fossil influx curve, i.e. the traditional pollen zone II - zone III junction. This abrupt decline in pollen frequencies is not matched by a sharp stratigraphic change : the increase cf minerogenic content is gradual throughout the late Interstadial sediment and into the Stadial silts and clays. As expected the date is Lateglacial, though somewhat younger than anticipated (see below).

The fourth dated sample, UB 2012, has a very large error factor of 1950 years, meaning that at the 66% probability level the age lies anywhere between 10,735 and 6,835 B.P. The point dated is the clear lithostratigraphic transition from Lateglacial minerogenic to Postglacial organic sediment, which coincides with an abrupt rise in pollen influx.

The fifth result, UB 2031, relates to gyttja from the Postglacial <u>Corylus</u> rise, where influx of hazel pollen begins to rise to sustained high values, yet the age indicated is Lateglacial, and is therefore anomalous.

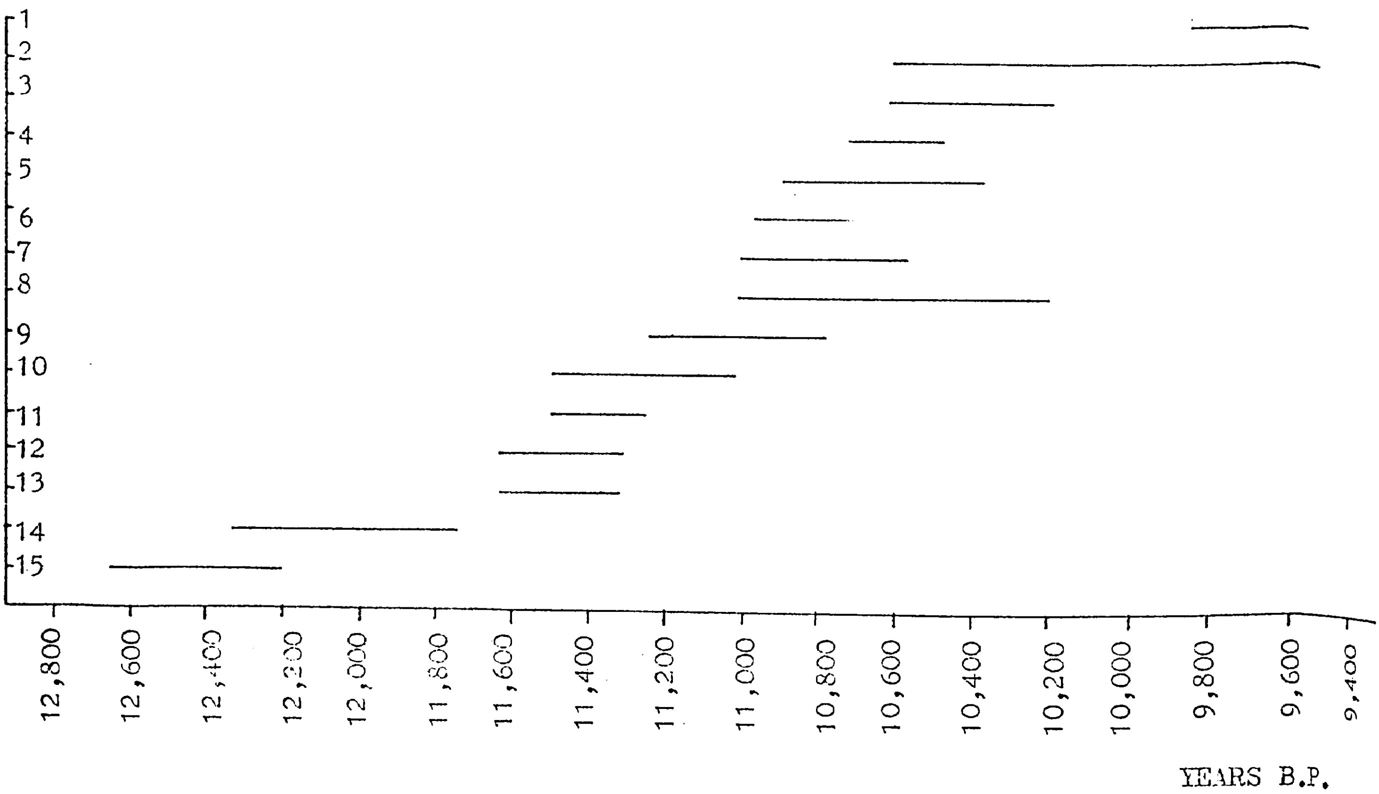
Of the five radiocarbon dates two (UB 2009 and UB 2031) are obviously wrong, one is so imprecise as to be of little value (UB 2012), while the remaining two may be correct.

There are many possible reasons for samples giving anomalous radiocarbon ages. Because of the necessity of minimising the time span represented by the thickness of each sample, they were deliberately kept as thin (vertically) as possible, since there is little point in attempting to date very precisely a sample that took several hundred or thousand years to accumulate. In spite of the multiple-shot coring, the total carbon content of the bulked samples proved very low, and all carbonaceous material had to be utilised in the dating process. This included the humic acid component, which is one potential source of contamination due to downward penetration of younger acids into older sediment. Another possible cause of the error that makes dates too young is the presence of roots from plants that grew above the dated horizon : no large roots were observed during routine preparations for pollen analyses, but throughout the gyttja small macrofossils including roots were abundant, and it is conceivable that some of these were not contemporaneous with the matrix. A third possibility is that during the coring operation some sediment from higher up in the bog was carried downwards with the piston corer, though the care taken in the field to avoid this, and the subsequent removal of the outer layer of the dated samples, make this rather unlikely. The absence of obviously Postglacial pollen (e.g. <u>Corylus</u> grains) in the Lateglacial samples examined also implies no such contamination occurred.

The date 10,430 $\pm$ 210 B.P. for the rational Corylus limit is obviously affected by a different sort of error to the others, for it is too old rather than too young. One possible cause is the hard water error, the result of the incorporation by organisms of old bicarbonate derived from inert sources, e.g. limestone. The presence of carbonaceous rocks in Strath a' Bhathaich and north and east of the valley (Fig. 2) makes it probable that the kettle-hole is situated in morainic debris containing a proportion of these rocks. However, it is strange that only the uppermost date appears to have been thus affected : it would be reasonable to expect the earliest life, having closest contact with the debris forming the depression, to have been most susceptible. The fact that UB 2031 was not affected by the same type of contamination as the lower dated sediments is perhaps significant : level 5.097 to 5.082 presumably was not significantly affected by percolating humic acids or either of the other two sources of error discussed above. It is possible that several types of error were effective in varying proportions and in different directions throughout the cores. Another possible source of 'old' carbon in the kettle-hole deposits is the product of slopewash or rill erosion of surrounding soils, but this is improbable for several reasons. The dated sediment was highly organic, and contained very little minerogenic material. The pollen spectra here show no evidence of secondary deposition of grains, which would inevitably accompany soil movement and might be reflected in unusual numbers of deteriorated grains and pollen tetrads (see Chapter 8). Finally, slope wash is least likely at that stage of vegetational development when plant cover was presumably denser than at any previous time. Whatever the causal factor may have been, an estimate of the proportion of the sample that was contaminated can be made from Olsson's graph dealing with samples being made too old (Olsson, 1974). These curves show that to produce an error of 1,500 years

FIGURE 25 : a.

Dates at or near the Pollen Zone II / III boundary.




| | | |
|---|---|---|
| 1 | Q-956 | Switsur, V.R., and West, R.G. 1972 <u>Radiocarbon</u>, 14, 239- 46. |
| 2 | UB-2011 | |
| 3 | Q-66 | Godwin, H., and Willis, E.H. 1959 <u>Radiocarbon</u>, 1, 63- 75 |
| 4 | Q-61 | " " " " |
| 5 | | Vasari unpub. |
| 6 | Birm-128 | Shotton, F.W., Blundell, D.J., and Williams, R.E.G. 1970 <u>Radiocarbon</u>, 12, 385- 99. |
| 7 | Q-104 | Godwin, H., and Willis, E.H., as above. |
| 8 | SRR-249 | Pennington, 1975a* |
| 9 | Q-207 | Godwin, H., and Willis, E.H., as above. |
| 10 | | Vasari unpub. |
| 11 | | Lowe, J.J., unpub. |
| 12 | Q-365 | Godwin, H., and Willis, E.H., 1961 <u>Radiocarbon</u>, 3, 60- 76. |
| 13 | I-3595 | Pennington, 1975a * |
| 14 | | Vasari, unpub. |
| 15 | SRR-250 | Pennington, 1975a* |

*indicates that the reference is included in the bibliography.

(i.e. the probable discrepancy in UB 2031, see p. 170 ) 30% of the sample would have had to be almost 7000 years older than the true age, or 18% too old by about 23, 000 years. The proportion of contaminant is therefore relatively large.

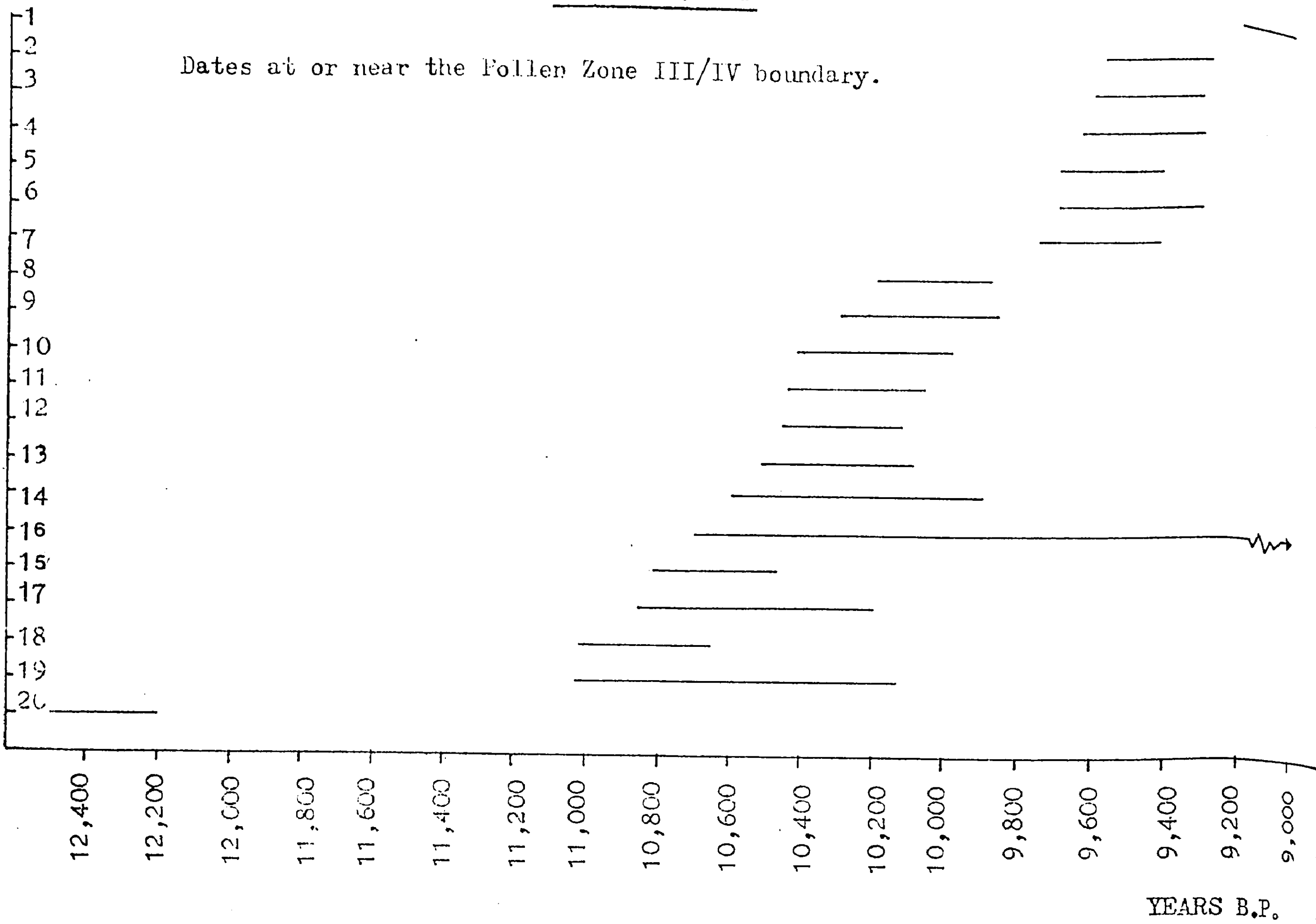
Of the five dates there can be little doubt that the lowest and uppermost (UB 2009 and UB 2031) are wrong, but the other three cannot be dismissed. In order to help place these results among others recorded in Britain for the same events, Figs 25a–c have been compiled from the relevant data in Radiocarbon volumes 1 to 17. Dates referring to marine deposits are not included, and most are associated with pollen or coleoptera analyses of the dated sediment.

The interpretation of the pollen record implies that the organic sediment at the base of the kettle-hole accumulated in the Lateglacial Interstadial at an early phase of vegetational development, prior to the incoming and dominance of *Empetrum*. The early Interstadial does therefore appear to be represented at Glasscnock, above white clays of the pre-Interstadial period. Dates for the earliest Lateglacial organic deposits from north-west Scotland include 12,810 ± 155 years (Kirk and Godwin, 1963), 10,254 ± 220 years (Birks, 1973), and 12,956 ±240 years (Pennington, 1975). In view of the mounting evidence for deglaciation at around or prior to 13,000 B.P. in western Britain (Coope and Brophy, 1972; Pennington and Bonny, 1970; Switsur and West, 1973) and in the central Scottish Highlands (Sissons and Walker, 1974), it is probable that the study area was not exceptional and that ice had largely disappeared by 13,000B.P.

The second date (UB 2010) refers to sediment 10 cm up from the basal organic deposit. If two assumptions are made, i.e. that organic sedimentation commenced at 13,000 B.P. and that it continued at a steady rate until 11,000 B.P., the age of the oscillation dated at 11,165

FIGURE 25 : b

Dates at or near the Pollen Zone III/IV boundary.




| | | |
|---|---|---|
| 1 | Q-1021 | Switsur, V.R., and West, R.G. 1973, Radiocarbon, 15, 156- 64. |
| 2 | Q-957 | " " 1972, " 14, 239-46. |
| 3 | Q-1320 | " " 1975, " 17, 301- 12. |
| 4 | Q-697 | Godwin, H., and Willis, E.H., 1964, " 6, 116- 37. |
| 5 | UB-411 | Smith, A.G., Pearson, G.W., and Pilcher, J.R. 1973, Radiocarbon, 15, 212- 28. |
| 6 | Q-925 | Switsur, V.R., Hall, and West, R.G., 1970, Radiocarbon, 12, 590- 8. |
| 7 | Q-697 | Godwin, H., and Willis, E.H., as above. |
| 8 | Birm-452 | Harkness, D.D., and Wilson, H.W. 1974, Radiocarbon, 16, 238- 51. |
| 9 | Q-980 | Switsur, V.R., and West, R.G., 1973, as above. |
| 10 | Q-930 | " " 1972, as above. |
| 11 | SRR-247 | Pennington, 1975a* |
| 12 | Birm-92 | Shotton, F.W., Blundell, D.J., and Williams, R.E.G., 1968, Radiocarbon, 10, 200- 06. |
| 13 | Q-1240 | Switsur, V.R., and West, R.G. 1975, as above. |
| 14 | Q-151 | Godwin, H., and Willis, E.H. 1959, Radiocarbon, 1, 63- 75. |
| 15 | I-3597 | Pennington, 1975a* |
| 16 | UB-2012 | |
| 17 | Birm-723 | Lowe, J.J., unpub. |
| 18 | Q-144 | Godwin, H., and Willis, E.H., as above. |
| 19 | SRR-248 | Pennington, 1975a* |
| 20 | Q-1080 | Switsur, V.R., and West, R.G., Radiocarbon, 15, 534- 44. |

* indicates that the reference is included in the bibliography.

$\pm$ 350 B.P. can be calculated. If the 20 cm of Interstadial sediment accumulated over 2000 years, level 5.515 - 5.505 formed at 12,000 B.P., implying that once again the radiocarbon age is too young. The derived age of 12,000 years is interesting : if the decline in pollen influx were interpreted as a result of a climatic oscillation similar to the Older Dryas period of the Continent, the age would accord with this hypothesis. The Younger Dryas oscillation has been dated at 12,000 - 11,800 B.P. and 11,900 - 11,750 B.P. (Van der Hammen et al., 1971; Morner, 1971), and more recently has been recognised in western Britain (Pennington, 1975) and dated in Cumbria and Sutherland at 12,000 - 11,800 B.P. However, in the absence of a reliable basal date at Glasscnock it is not wholly justifiable to discount the radiocarbon age of UB 2010 : it is quite possible that the oscillation in the pollen curves occurred here in the late 12th. millenium B.P.

The third point to be dated is the traditional pollen zone II/III boundary, based here on the marked decline from maximal Interstadial pollen values. The range of available dates for this event in Britain is shown on Fig. 25a. Iversen (1953) stated that this boundary was the clearest horizon in Danish pollen diagrams, and that it was definitely synchronous in that country, five radiocarbon assays from the site at Ruds Vedby giving a mean of 10,830 $\pm$ 200 years. The onset of pollen zone III, or of minerogenic sedimentation, has been dated to around 10,800 B.P. in different English and Scottish sites, the modal age range on Fig. 25a being 11,000 to 10,400 B.P., but many earlier and later dates are also recorded. This variation in dates, here of over 3000 years, deserves further explanation. Several reasons can be suggested to account for it.

1. Some of the dated samples were contaminated and are therefore incorrect. Where dates were believed to be suspect and an appropriate comment was made in Radiocarbon, these were not included in Figs 25a-c.

2. The thickness of dated samples varies greatly. The depth of core or section sampled is relevant in relation to deposition rate : some dates are averages of a large number of sedimentation years whereas others are much more accurately related to the boundary concerned. The depth must be particularly critical where the carbon content varies throughout the core, since the 'average' date on a thick sample will presumably be unduly influenced by the carbon-rich component.

3. Different criteria are chosen to represent the zonal boundary, e.g. lithological or biostratigraphical changes, which are not always clearly defined. Also, where the 'boundary' is dated, it is frequently sediment on either the lower or the upper side of the junction that forms the sample.

4. The event being dated need not be synchronous throughout the country.

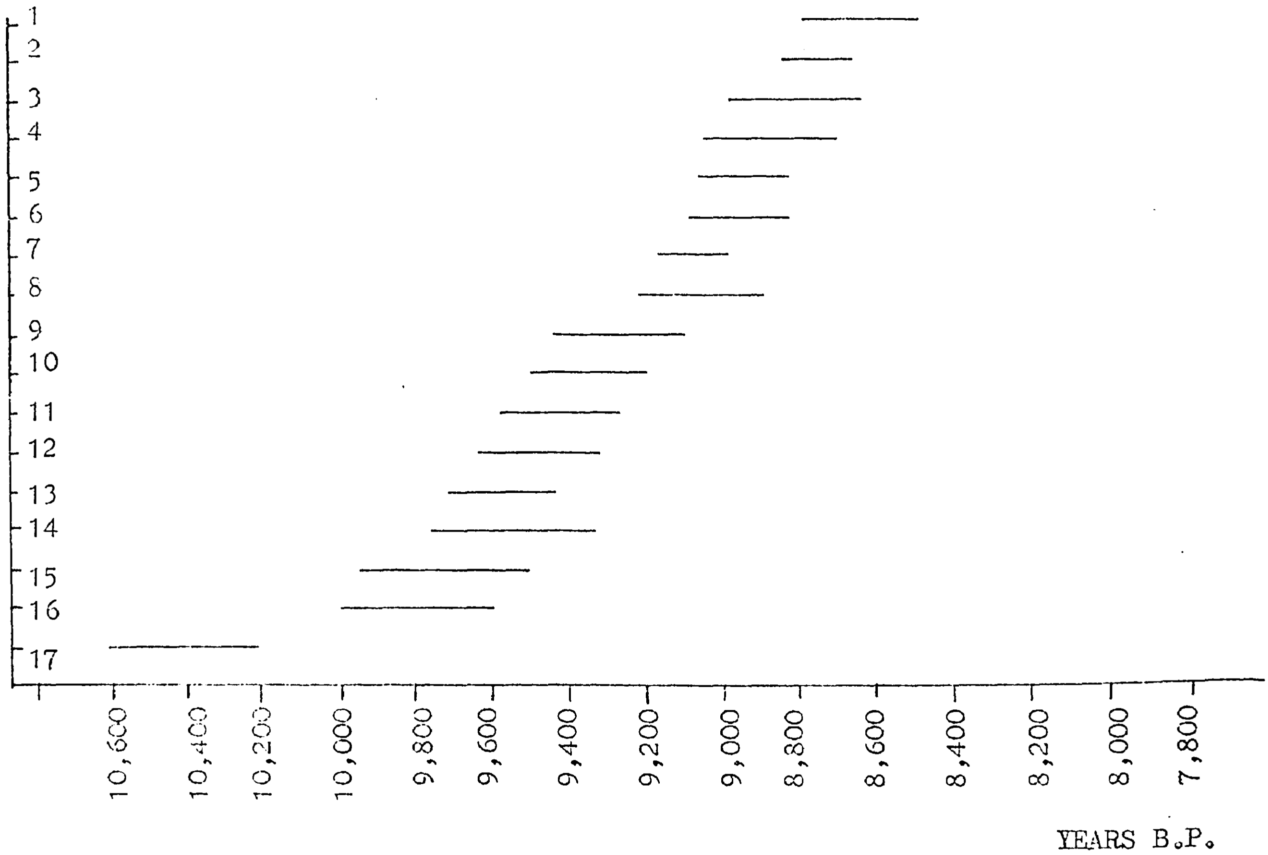
The final point is possibly the most important. Whatever criteria are selected as being significant in choosing zonal boundaries or delimiting vegetational events, it is probable that the environmental response did not occur simultaneously over Britain. With reference to Fig. 25a, if the dates are not affected by errors, it appears that the onset of glacial conditions produced environmental change at different places for over 2,000 years. Presumably upland areas would be affected before the lowlands by either (or both) falling remperatures or increasing precipitation. However, vegetational response would be swiftest where critical environmental thresholds for plants were first crossed (Smith, 1965), and this need not necessarily have been in upland areas. Once vegetational development was arrested, associated soil development would cease, and at some stage slope wash and soil destruction would result from the reduction of ground cover. The precise timing of these events would depend upon the local severity of climatic change and the sensitivity of the environment towards it.

The date on the Interstadial/Stadial boundary from Glasscnock (UB 2011) appears rather extreme by comparison with the other dates in Fig. 23a, although it overlaps with the most frequently occurring age range (11,000 to 10,400 B.P.). In view of the continuum of ages for this event, it may perhaps be concluded that it was diachronous in Britain over several hundred or more years, but that from the evidence presently available the onset of periglacial conditions affecting coring-site basins was in many cases first apparent early in the 12th. millenium B.P.

The same factors as listed above (1 -4) apply to the dating of the Lateglacial/Postglacial transition, for which there is a narrower scatter of recorded British dates (Fig. 25b). The core from Glasscnock implies that environmental change was abrupt at this time, organic deposition being swiftly substituted for mineral sedimentation , and the vegetation flourishing after a period of reduced species diversity and plant cover. Geomorphological evidence also implies rapid deglaciation (Chapter 4). The effects of quickly rising temperatures and/or reduced precipitation in the early Postglacial are more likely to have been reflected in a widespread, contemporaneous environmental response than that induced by the more gradual onset of glaciation. Excluding the anomolous date (Q-1080) on Fig. 25b, the Lateglacial/Postglacial boundary lies between 11,000 and 9,000 B.P., with the greatest concentration of dates between 10,400 and 10,000 B.P. The date from Glasscnock includes this modal range, but because of its great imprecision it is not possible to suggest a date for deglaciation of the site. Again, the reaction of the environment to climatic amelioration probably varied with locality : slope movement would presumably continue longest into upland basins surrounded by steep slopes, and colonisation and stabilisation of the ground would occur last in the centres of previously glaciated regions.

FIGURE 25 : C

Dates at the *Corylus* rise.




| | | |
|---|---|---|
| 1 | Q-958 | Switsur, V.R., and West, R.G., 1972, *Radiocarbon*, 14, 239- 46. |
| 2 | UB-280 | Smith, A.G., Pearson, G.W., and Pilcher, J.R., 1971 *Radiocarbon*, 13, 450- 67. |
| 3 | Q-896 | Switsur, V.R., and West, R.G., 1973 *Radiocarbon*, 15, 156- 64. |
| 4 | Q-921 | Switsur, V.R., Hall, and West, R.G., 1970, *Radiocarbon*, 12, 590- 8. |
| 5 | Q-1009 | Switsur, V.R., and West, R.G., 1973, as above. |
| 6 | | Pennington, W., *et al.*, 1972*. |
| 7 | SSR-106 | Harkness, D.D., and Wilson, H.W., 1973 *Radiocarbon*, 15, 554- 65. |
| 8 | Q-1020 | Switsur, V.R., and West, R.G., 1973, as above. |
| 9 | Q-1076 | " " " |
| 10 | UB-443 | Smith, A.G., Pearson, G.W., and Pilcher, J.R., as above. |
| 11 | Q-366 | Godwin, H., and Willis, E.H., 1964 *Radiocarbon*, 6, 116-37. |
| 12 | Q-960 | Switsur, V.R., and West, R.G., 1972, as above. |
| 13 | Q-1229 | Harkness, D.D., and Wilson, H.W., 1973, as above. |
| 14 | Q-14 | Walker, D., and Godwin, H., 1954* |
| 15 | Q-931 | Switsur, V.R., and West, R.G., 1972, as above. |
| 17 | UB-2031 | |
| 16 | Q-677 | Godwin, H., and Willis, E.H., 1964, as above. |

* indicates that the reference is included in the bibliography.

Fig. 25c depicts the recorded age ranges for the Corylus rise, i.e. the rational limit. Since few pollen analysts differentiate hazel from Myrica in their diagrams, it is possible that this horizon represents more than one type of vegetational change. However, the range of dates associated with this event is under 1,500 years, reaching from ca. 10,000 to 8,500 B.P. Two major groups of dates appear in Fig. 25c : an earlier concentration between 9,600 and 9,200 B.P., and a later one at 9,200 to 8,800 B.P. Lochs Clair and Maree near Glasscnock gave very similar dates for the Corylus rise (8,960 ± 130 and 8,951 ± 120 B.P.), while two from Skye were not in agreement at 9,482 ± 150 and 8,650 ± 150 B.P. While the latter seems anomalously young, (on Fig. 25c), the former corresponds with the earlier dates from farther south. It is likely therefore that hazel immigrated to the Glasscnock area between 9,600 and 8,800 years ago, and in view of the closely corresponding dates from nearby to the north-east, a date around 9,000 B.P. is highly probable.

# CHAPTER EIGHT.

'What are the roots that clutch, what branches grow
Out of this stony rubbish ?'

(T.S. Eliot, The Wasteland )

## Interpretation of the Pollen Diagrams.

In Chapter 8 pollen assemblage zones were defined in both diagrams, and brief descriptions given of each, and of the trends of the component taxa. Interpretation of the patterns may now be attempted, and inferences made about the local conditions of vegetation and climate prevailing throughout the Lateglacial and early Postglacial. There are, however, many problematic factors to be borne in mind when trying to reconstruct the past environment from a pollen diagram : some of these are considered below.

One major question is the extent to which the pollen record at each level is a true representation of the pollen rain that existed at that time. Physical changes in the sediment after deposition may have altered the original influx ; for instance, pollen grains differ in their ability to withstand the various forms of chemical and biological destruction potentially active in sediment (Cushing, 1967). *Populus* is particularly susceptible to crumpling and thinning of the exine, but was found by Cushing to be relatively well preserved in peaty deposits. Stratigraphic disturbance of lake sediment may occur through the activities of fauna, or the inversion in spring of ice floes to which bottom sediment has adhered (Nichols, 1967), or the normal resuspension and redistribution of sediment by lake currents (Davis, 1968; Davis *et al.*, 1973). The problem of mixing by frost-heave in frozen sediments should also be considered, especially with reference to the frost-susceptible Stadial silts and clays (see p. 194 ).

The issue of representative sampling is relevant in this context. The pollen sum counted is the final sample in a succession of sampling procedures that starts with the choice of coring site. Allowance is made for the sampling errors inherent in the pollen count of each slide (Faegri and Ottestad, 1948) by calculating the 90% confidence limits for each result (Bonny, 1971), and expressing each value as a range on the diagram. Consideration of these ranges, instead of the mid-points, permits greater confidence in assessing the patterns of change through the diagram. However, another possible error at the counting stage exists in assuming a random distribution of grains on a slide : Brooks and Thomas (1967) have shown that this does not necessarily follow, and since in no case was every grain on a slide counted, an unknown bias in the pollen counts may exist.

The next major question to be considered is the degree to which the pollen influx (represented more or less truthfully by each sample) reflected at the time of deposition the composition of the existing vegetation around the coring site. Janssen (1966) described the pollen rain at any point as comprising local, extra-local and regional components, the variability of input from each decreasing with distance from the source to the basin. The pollen record can therefore include grains from tens or hundreds of kilometres distant as well as those of plants growing in the basin itself. Tauber (1965) also described patterns of pollen dispersion, and investigated the trajectories of pollen grains and the influence of air currents over and through forests on the type of grains deposited in different situations. Small light grains that are shed prior to tree leafing, e.g. Corylus, Populus, some Salix, or at the same time as leafing (Betula) have the greatest opportunity for widespread dispersal, whereas large grains released later in the season are restricted in travel. Pollen from anemophilous plants dominates the extra-local and regional components of the pollen rain, Pinus being one of the important examples found in Scottish Lateglacial diagrams (Birks, 1973; Walker, 1975b). It is believed that all of the pine recorded in this work at Glasscnock and Druim Dubh is the result of long-distance transport from the south or south-east, since pine forest did not develop in the area until about 8,250 B.P. (Birks, H.H., 1972 ). For this reason Pinus was excluded from consideration in Chapter 7. The occasional grains of Ulmus, Quercus and Tilia that were encountered during counting of the Lateglacial section are also attributed to long-distance transport since these thermophilous trees did not enter Scotland until the Flandrian. According to Birks (1973), the grains of Hippophae rhamnoides found on Skye were somewhat dubious evidence for the local presence of the shrub in Lateglacial times, and the three grains from Glasscnock should similarly be viewed with caution, if it is not a native plant of northern Britain as suggested by Birks (op.cit., p. 316). Further indication of long-distance transport is the presence of Ambrosia/ Xanthium type grains (classed under Compositae undiff.) in the very early Interstadial at Glasscnock (R. Andrew, pers. comm.). The distribution of these genera today is confined to the Mediterranean area and North America, and the sporadic occurrence of such grains in Scottish diagrams has generally been attributed to long-distance travel (Godwin, 1975).

The sources of other pollen types in the diagrams are less easy to pinpoint. Large ornate grains (e.g. as in Tubuliflorae) tend to be produced by the insect-pollinated flowers of herbaceous plants, and are less liable to be carried long distances, their chief contribution therefore being to the local element of pollen rain.

The relative amounts of pollen produced by different plants are equally relevant to the question of interpretation. Anemophilous species tend to produce large quantities of pollen, causing a tendency towards over-representation in a pollen diagram. Modern pollen rain studies have begun to elucidate the relationship between vegetational composition and that of local pollen influx (Davis, 1963; Birks, 1973), but generalisations applied to the same plants in different areas and associations may never be reliable. Reference to the likelihood of over- or under-representation is made below in connection with specific taxa.

Some elements of the vegetation may not be reflected at all in the pollen influx, due to very low pollen production, ineffective pollen dispersal, or failure of the writer to recognise certain grains. The last is liable to cause the most serious error : such a 'blind spot' (Davis, 1963) exists in the present study in the absence of cryptogam spore records. Mosses, liverworts and lichens are abundant in Arctic communities (Churchill and Hanson, 1958) and presumably also existed in the field area, but the pollen of vascular plants only was counted.

The relative contributions made by local, extra-local and regional pollen may be subject to change through time. Such variables as the direction of the prevailing wind and vegetational change (e.g. immigration of forest) may have a profound effect on the composition of the pollen rain, particularly the regional contribution. Alteration of a recognised long-distance influx may, therefore, be of significance in environmental terms, and one example of its potential use is given below (p. 192 ).

Problems of a different sort arise in interpretation of the pollen-floristic assemblages. Identification of pollen and spores is not sufficiently precise in most cases to distinguish plant species, which would be desirable in order to glean the maximum information from the samples. Degradation, corrosion and crumpling of grains was fortunately not common in the analysed sediment, but where such effects occur they can unavoidably reduce accuracy in identification. Conversely, they might also aid interpretation under certain circumstances : for instance the incidence of shrunken Empetrum tetrads in zone G-2 may corroborate other evidence for increased soil inwash at this time, a matter that is further discussed below.

The reconstruction of past vegetation from pollen data usually precedes inferences made concerning the environmental conditions prevailing at the time : here the geological maxim that 'the present is the key to the past' is assumed to hold, though the possibility exists that evolution has produced in species of modern plant communities somewhat different ecological tolerances and requirements from those under investigation. Inferences concerning the composition of vegetational assemblages are equally tenuous : comparison with present-day analogues elsewhere introduces change in both time and space, and it is possible that assemblages now unknown existed in the past. Modern pollen rain studies may ultimately assist the understanding of pollen floristic assemblages, but the wide variation of plant communities in any area (and especially in tundra landscapes) makes comparisons difficult, and even more so when place as well as time is altered.

The greatest difficulty in the interpretation of the Glasscnock and Druim Dubh diagrams is one not commonly encountered by palynologists, being a result of the problem of fitting a credible time scale to data expressed in absolute quantities. The pollen curves represent numbers of grains per c.c. instead of grains per square centimetre per annum, the latter being the desirable and usual way of presenting absolute data. A diagram using data in both forms has been published by Pennington (1975a) and previously Brush (1967) used a 'density diagram' to present pollen data as numbers of grains per unit weight of sediment. Both types of diagram, in lacking time control, are liable to misinterpretation if the rate of sedimentation of the matrix was not constant throughout the analysed section. This factor is likely to be particularly serious in a Lateglacial diagram, where different types of sediment are usually encountered, and one would expect different rates of accumulation under very varied environmental conditions. Fig. 8 in Pennington(1975a) shows the variation of age with depth throughout Lateglacial sediments : in both Blelham Bog and Cam Loch the basal sediment accumulated considerably more slowly than younger deposits. Comparison of the pollen diagrams (Figs 4 and 5) in this paper is interesting : selected taxa from Blelham Bog are shown expressed as concentrations and as annual deposition rates, and in general the curves are remarkably similar in pattern. The outstanding difference occurs in the basal sediments, where deposition of the matrix was abnormally slow. Here the 'concentration' curves exaggerate the influxes, which are reduced to extremely low values when corrected for the rate of sedimentation. Therefore, although accumulation rates are not known at Glasscnock and Druim Dubh, it may be suggested that the major trends in the pollen curves indicate true changes in pollen influx, the actual patterns of change remaining essentially true although in certain sections of the cores values may consistently under- or over-estimate influxes in terms of grains deposited per unit area.

Speculation on the 'true' ages of the dated Glasscnock samples (see the final section of Chapter 7) would produce an accumulation rate of 1 cm/ 100 years over zones G-1 and G-2, given a basal age of 13,000 years and an upper date of 10,800 B.P. Approximately the same value is produced (1 cm/ 108 years) for the 12 cm of Postglacial gyttja of zones G-4 and G-5, given a date of 10,300 B.P. for the base of the Postglacial and 9,000 B.P. for the rational Corylus limit (Birks, H.H., 1972 ; Pennington _et al._, 1972) in the field area. The intermediate lithological unit, 12 cm of silt and clays, took 500 years to accumulate using these dates, which implies a deposition rate of _ca._ 1 cm/ 40 years, more than twice that of the gyttja. Assuming these calculations are correct, the very low concentration values throughout the Stadial zone G-3 would appear relatively higher on an annual pollen influx diagram. It is possible that the sedimentation rate was not constant throughout the

Interstadial : the lithological boundary at 5.5 m coincides with the increase in total fossil pollen influx (Fig. 20), implying that at this level either the rate of accumulation of the matrix decelerated, or the input of pollen grains accelerated, or both occurred simultaneously. This important question and its implications are discussed in detail below.

Examination of the Glasscnock diagram for the purpose of zonation showed the major division to lie between G-3 and G-4. The basic reasons for the division are quantitative and qualitative changes in the pollen floristic assemblages present. The taxa comprising these assemblages in the Interstadial, Stadial, and Postglacial sections of the cores will now be discussed, and inferences made concerning the conditions of vegetation, soil and climate prevailing in each of those periods.

## THE INTERSTADIAL.

Throughout the Lateglacial section of the diagram most taxa present appear in all three zones, but in significantly varying quantities. Consistently present are the herbs : Ranunculaceae, Compositae undiff. and Liguliflorae, Caryophyllaceae, Umbelliferae, *Plantago*, *Helianthemum*, *Thalictrum*, *Epilobium*, *Artemisia* and *Rumex*. These pollen types are frequently found in Lateglacial diagrams (Pennington, 1974) except at sites where woodland predominated. Many of these are represented today in the category of ruderal plants (e.g. *Plantago major*, *Rumex acetosella*) growing by waysides and on derelict land where their demands for maximum light and minimum competition from other plants are fulfilled (Salisbury, 1964). These heliophytes proliferated during the Lateglacial, when conditions were apparently very favourable. Certain genera are recognised colonisers of unstable, disturbed soil, e.g. *Oxyria digyna* (included here in the taxon *Rumex*), a plant capable of very rapid re-establishment of its root system following disruption by frost heave (Churchill and Hanson, 1958). Artemisia has also been associated with substrate disturbance (Matthewes, 1970) but this genus is less-well represented at Glasscnock than at sites in eastern Scotland (Walker, 1975a, 1975b) or farther north in Sutherland (Pennington et al., 1972). This probably reflects the plant's preference for rather drier continental conditions than prevailed in this oceanic area (see below). Helianthemum flourished at Glasscnock especially in the early Interstadial, a pattern also reported from Denmark (Krog, 1954) : this suppression may be due to increased competition later, or less suitable edaphic conditions as the pH decreased (see below).

Annual plants are less commonly represented in the pollen diagram (although some of the herbaceous taxa, e.g. Ranunculaceae, may include both annuals and perennials). The only certain annual type present is Koenigia islandica, which was recorded twice in G-2. This plant is also reported from the Lateglacial at Loch Droma (Kirk and Godwin, 1963), and on Skye (Birks, 1973 ) besides other sites in Scotland, and was apparently much more widespread in its distribution then than at present. It is believed (Dahl, 1963) that sensitivity to high summer temperatures (over 24°C) is the limiting factor in its geographical range; Vasari and Vasari (1968) deduce from Dahl's work that the mean annual maximum temperature in north-west Scotland was not greater than 20°C during the Lateglacial. A paucity of annual plants is to be expected in the Lateglacial, since a severe environment demands of plants economy of production, and that is best achieved by the perennial habit. Billings and Mooney (1968, p. 493) stated that 'in most arctic or alpine locations, annual species constitute only 1 to 2% of the flora'. Although it is likely that the Interstadial at Glasscnock was low-arctic in character rather than arctic, a similar situation probably prevailed.

Pollen of the dwarf shrub Empetrum dominates the later part of the Interstadial. This type is generally believed to be E. nigrum in British diagrams, and is a common component of Lateglacial assemblages, being most abundant in northern Scotland (Godwin, 1975). E. nigrum is heliophilous and chionophobous, but has a wide ecological range on stable, non-water-logged soils (Dahl, 1957; Hafsten, 1963). The production of litter under the preferred oceanic conditions leads to the initiation and maintenance of an acidic soil. Empetrum acts as a pioneer dwarf shrub on open, mineral soils, spreading rapidly to form a thick mat, stabilising the soil and modifying it so that other woody plants (e.g. Calluna) can then enter the succession (Gimingham, 1972). Conditions in the Interstadial at Glasscnock were favourable for the development of Empetrum : the critical influential factors were probably climatic and edaphic (Brown, 1971). Brown investigated the British records of Empetrum in the Lateglacial and early Postglacial, and concluded that high frequencies in the pollen records were associated with the oceanic climate that characterises north-west Europe, particularly the low summer temperatures and sunshine duration, a small annual temperature range, and high relative air humidity. Where light is too intense, Empetrum favours north and north-east facing slopes or requires shelter from taller plants. The implications of a large Empetrum influx are, therefore, significant in terms of Lateglacial climate. Although the plant is wind-pollinated and might be expected to produce pollen prolifically, investigations in Iceland (Rymer, 1973) showed it to be only slightly over-represented in contemporary pollen rain, while in Scotland according to Birks (1972) dispersal is poor. Thus, large quantities in a diagram probably indicate abundant local Empetrum.

Juniperus communis frequencies are discontinuously present throughout zones G-1 and G-2, apparently favouring the beginning and end of the Interstadial and being rather poorly represented in the middle. A flourishing of Juniperus prior to the onset of the Stadial, as happened at Glasscnock, is not uncommon in pollen diagrams (Iversen, 1954; Vasari and Vasari, 1968; Pennington et al, 1972; Walker, 1975). Increases in the juniper curve are usually interpreted (following Iversen) as indicating climatic amelioration, causing increased flowering and pollen production from tall dense juniper scrub, although Crabtree (1972) pointed out that a rise in temperature is not the only favourable change that might increase production of Juniperus pollen. The plant is sensitive to frost and wind, needing the protection of a snow cover in low- and sub-arctic areas (Hafsten, 1956), yet is intolerant of prolonged snow-lie. A dwarf sub-species, J. communis ssp. nana, occupies snow-bed sites, and is relatively common today on mountain screes, especially on Cambrian rock, in the field area. Juniperus pollen is believed to indicate the local presence of the plant, pollen dispersal being ineffective, especially from the prostrate form (Seddon, 1961).

The other major woody taxa present in G-1 and G-2 are Salix and Betula. Both genera include a range of species that vary in stature from the dwarfed up to the tree life-form, and in neither case was differentiation of the pollen grains attempted (see p. 136 above). However, it is believed that most Betula grains in G-1 and G-2 belonged to the species B. nana, which is in accord with evidence from nearby Skye where Birks (1973) has recorded pollen and macrofossil evidence for the occurrence of birch woodland restricted prior to 10, 000 B.P. to the Sleat peninsula (southern Skye), although scattered copses may have occurred elsewhere on the island. In Sutherland during the Interstadial the landscape lacked birch woodland (Pennington, 1975), although in northern Wester Ross birch woodland is suggested by the high Betula percentages at Loch Droma (Kirk and Godwin, 1963) where apparently only a relatively small proportion of B. nana was found. Interstadial tree birch is also reported from north-east Scotland

(Vasari and Vasari, 1968), and from the south-east (Newey, 1970). The low and fluctuating concentrations of Betula pollen in G-1 and G-2 imply that this genus in any form was not a dominant member of the vegetation, and the tremendous increase in Betula in Flandrian zone G-5 indicates that the establishment of birch woodland took place only at this relatively late stage.

Salix presents a similar problem in that the different species were not distinguished. It seems highly improbable that tall tree willows were present during the Lateglacial, and the most likely contributors were the shrubby and dwarf species, several of which are native. Salix purpurea, S. caprea, S. cinerea, S. aurita, S. nigricans, S. phyllicifolia all might have been present as scrub in sites with deficient drainage in the Interstadial (c.f. present-day distributions in Clapham, Tutin, and Warburg, 1962), whereas the shorter forms S. repens, S. lapponum, S. arbuscula, S. myrsinites, and the dwarf species S. herbacea and S. reticulata might equally be represented. The latter two species are chionophilous plants favouring areas of prolonged snow-lie, being especially confined to snow-beds in Scotland and in the low-alpine belt in Norway today (Conolly, 1961). Dwarf Salix can also survive on disturbed soils, such as on solifluction terraces (Churchill and Hanson, 1958). Edaphic conditions do not appear to be critical for Salix species other than the preference for soils where there is impeded drainage.

Pteridophyta are represented in zones G-1 and G-2 by Lycopodium, Polypodium vulgare, Polypodiaceae undiff., and Filicineae. The former genus flourishes in the basal zone, indicating very favourable conditions at this period. Some Lycopodium species are heliophytes, and appear to be capable of growing on a wide range of substrates in mountain areas including solifluction soils (Dahl, 1957), although Pennington et al. (1972, p. 275) believed that 'the percentages of L. selago increase with the amount of scree and bare rock ...' L. selago is still a common plant in the higher parts of the field area. L. alpinum is a snow-bed species, and along with L. selago can show a very strong representation in modern pollen rain despite relatively low cover in the vegetation (Degerbøl and Iversen, 1954; Birks, 1973).

The flourishing of ferns throughout the Interstadial is another indication of a degree of climatic and edaphic high moisture levels, since these plants are drought-sensitive, and Polypodium vulgare is listed by Seddon (1962) as being indicative of oceanity. This species grows today in dwarf shrub heath in Scotland, often above the tree-line, and ferns may grow on rock ledges and scree as well as in their common habitat in woodland subordinate societies. Ferns are also associated in northern Norway with snow-beds, dominated by Athyrium alpestre (Polypodiaceae), being found in ravines, along water-courses and on gravel and stony ground (Gjaerevoll, 1965).

The final group of plants to be considered comprises the littoral genera. A typical taxon of the Lateglacial is Myriophyllum, the majority found here being M. alterniflorum, which is continuously present in low quantities through G-1, but occurs only intermittently in G-2. M. alterniflorum is an obligate aquatic, indicating the presence of open oligotrophic water. M. spicatum was noted very infrequently : this is probably because of its requirement for alkaline water not normally found in areas of acidic rock. Another obligate aquatic is Potamogeton, which was not well represented in the Interstadial. Sparganium, which grows in marginal reedswamp, was recorded only once. Menyanthes trifoliata is a typical member of British and Scandinavian Lateglacial assemblages (Godwin, 1975) occurring from the time of deglaciation onwards; it is continuously present in G-1a, and sporadically present throughout the rest of the Interstadial. It is highly probable that this plant frequented the margins of kettle-holes, including the Glasscnock lochan.

The different types of plants present during the Interstadial and some of their ecological preferences have been discussed, therefore an attempt at reconstruction of their changing environment may now be made. Three major elements will be considered : soil conditions, climate, and vegetation.

At the opening of the Interstadial little or no organic soil would exist, the landscape consisting of expanses of bare rock and stretches of glacial deposits. The predominant rock type (sandstone) is acidic, but Cambrian outcrops and till or fluvioglacial deposits containing a high percentage of Cambrian debris would be calcareous in character (Chapter 1), and capable of forming fertile soils. An abundance of meltwater and the initiation of new drainage systems during deglaciation would mean that extremely ill-drained ground conditions prevailed; as the ice disappeared more ordered drainage patterns would become established and the coarse-textured morainic deposits would begin to dry out. Leaching of bases such as calcium and potassium, together with clay minerals, would commence with the downward percolation of rainwater, although upward movement would also occur in a soil susceptible to frost heave (i.e. where fine fractions existed, Fig. 24). The most potentially fertile base-rich minerogenic soils existed, therefore, during the earliest stages of the Interstadial. The absence of stabilising vegetation would allow slope wash, rill erosion and solifluction processes to operate. The pale grey basal clays at Glasscnock probably represent inwashed fine sediment from the surrounding slopes of moraine.

When sufficient time had elapsed after ice decay to allow the immigration of flora and fauna (this is discussed in detail later), organic production would replace mineral sedimentation in the kettle-hole lochan, recorded at Glasscnock by the sharp transition from purely minerogenic to highly organic sediment at 5.60 m. At this time Rumex, Lycopodium, Gramineae and Cyperaceae, and the heliophytic herbs were present, indicating very open conditions with unstable soils. This situation appears to have persisted for perhaps 1,000 years (if the gyttja accumulated at ca. 1 cm/ 100 years). Over this period humus would gradually accumulate in the soil, adding such elements as nitrogen, sulphur and phosphorus in which inorganic soils are lacking. Pedogenesis and the development of an increasingly closed vegetation cover would inhibit large-scale soil surface movement, but some movement apparently did occur, hence the appearance of mineral debris in the lochan sediment at 5.49 m, half-way through the Interstadial. The implication of the pollen record in G-2 is that Empetrum and many other taxa increased steadily, in all probability being associated with increasing acidification of the soil, especially under Empetrum stands. The avoidance of disturbed soils by these dwarf shrubs (Seidenfaden, 1931; Berglund, 1966) implies that some areas around Glasscnock no longer experienced soil movement, yet the growth to dominance of Empetrum in G-2 coincides with an increasing minerogenic content of the sediment, presumably due to soil inwash in some form.

The problem of sedimentation rates must be reconsidered here. It was pointed out previously that the large increase in fossil pollen influx above 5.5 m could be explained by either, or both, a decreasing rate of (matrix) sedimentation or an increased pollen input. Pollen influx can include two elements : those deposited directly from the air, and grains lodged in soil that is subsequently eroded and redeposited elsewhere. It is therefore conceivable that part of the growth in fossil concentration in G-2 is the result of inclusion of secondarily deposited grains : this would be expected if the increased minerogenic content does indicate renewed soil instability. At the same time, the sedimentation rate either remained constant or slowed down. The behaviour of the Pinus influx may be of some significance here : if the long-distance supply of

*Pinus* pollen remained more or less constant, fluctuations in its value in the diagram imply changing conditions of sedimentation at the coring site. The consistently increased values of *Pinus* through G-2 corroborate the hypothesis of a decreased rate of sedimentation and/ or supplementation of the influx with redeposited grains. Another point of possible significance is the incidence of crushed *Empetrum* grains encountered during counting : the basal sample, and then the series from 5.47 to 5.41 m contained notably large quantities of such grains. Pennington *et al*. (1972) also recorded quantities of *Empetrum* tetrads associated with inwashed sediment in north-west Scotland. (The reason why *Empetrum* grains alone should thus indicate secondary deposition may be connected with their morphology : these tetrads are relatively large grains, difficult to disperse effectively, and may tend to be deposited very near their source, e.g. in the litter and upper layers of soil underlying the canopy of dwarf shrubs). The less frequent occurrence of *Myriophyllum* in zone G-2 may indicate a reduced availability of clear, open water. Increased numbers of macrofossils were noted in this area of the core, but the significance of these is somewhat obscure. All of these points strengthen the case for deterioration of soil structure around the kettle-hole in the second part of the Interstadial, reulting in soil movement and secondary deposition of pollen, therefore reducing the likelihood that the increased pollen influx of G-2 was simply the result of a flourishing and expanding vegetation.

The question remains as to the extent of the soil inwash. It is possible that the effect was purely local, e.g. a small brook may have changed course and begun to contribute material to the basin when the basal sediment reached 5.5 m (below the present surface). The continuously low values of *Rumex* throughout G-2 indicate that no sudden expansion of this species took place, although *Artemisia* does show slightly higher values than in the early Interstadial, possibly indicating increased availability of open, mobile soils.

Chemical analyses of Lateglacial sediment from Loch Sionascaig (Pennington _et al._, 1972) indicate that the maximum humus accumulation occurred early in the Interstadial zone B1 (_Empetrum_-juniper assemblage zone). Zone B2 however reverts to a situation more like the basal pre-Interstadial zone A, in both of which (A3 and B2) the chemical composition 'suggests increased erosional transport of clay minerals' (op. cit., p. 225). The subsequent zone B3 contains no visible organic remains, yet maintains high carbon values. In later papers Pennington (1973; 1975) argues that soil erosion took place during the 'Allerod' (i.e. upper Interstadial) in various sites in western Britain and in Ireland, despite earlier work of her own where the upper Interstadial was interpreted as being the period of maximum soil stability (Pennington, 1970; Pennington _et al._, 1972). Support therefore exists in recent work for the hypothesis that at Glasscnock the beginning of soil erosion occurred in the mid-Interstadial, and instability increased towards the onset of the Stadial. The depth of clay-gyttja in G-2 implies that the process of deterioration was a slow one, taking at least several hundred years. Although some of the pollen recorded in G-2 is almost certainly re-deposited on this hypothesis, the lack of obvious damage to types other than _Empetrum_ implies that the majority of the grains were aerially transported, and an expanding population of plants might be inferred. The peak of pollen influx is rapidly superseded by a decline towards the Stadial. Throughout the 8 cm of clay-gyttja the increasing mineral content suggests gradually increasing erosion of stable soils, culminating at level 5.41 m in pure minerogenic deposits when presumably organic production on the basin had ceased and inwash of mineral 'soil' prevailed, repeating the conditions existing before the Interstadial.

Climatic change over this period has already been implied in discussion of the pollen flora and of the stratigraphy. The climate obviously ameliorated in pre-Interstadial times to initiate the widespread decay of glacier ice, but the pattern of temperature rise and decline through the Lateglacial is not known. Thermophilous plants such as Typha and Filipendula do not appear at Glasscnock until the Postglacial, and although arguments based on the absence of pollen types are rather tenuous in view of the sampling errors discussed above, this might indicate that climatic conditions favourable for such species did not prevail in the Lateglacial.

Inferences concerning precipitation are more abundant. The flourishing of Empetrum suggests that in early zone G-1 and in G-2 an equable cool temperate climate prevailed, with a high relative humidity throughout the year. The abundance of Filicineae pollen corroborates this. The rise of Empetrum pollen through G-2 may be solely due to decreasing soil pH as leaching proceeded, and the resultant expansion of this dwarf shrub, but it is tempting to suggest that climatic conditions also became more suitable, possibly an increased cloudiness favouring Empetrum by shortening sunshine duration and reducing temperature fluctuation (Brown, 1971). Increased rainfall would also accelerate podzolisation, and beyond a certain point it might initiate increased rill erosion despite a relatively closed vegetation cover, and thus account for the apparent inwash of soil fines that began early in zone G-2.

The greater influx of Salix pollen in upper G-2 might reflect increased availability of suitable sites, due to either the creation of more sites suffering from impeded drainage, or to an expansion of snow-bed sites harbouring more dwarf willow. It has been suggested that an increase in the juniper curve on a diagram might reflect greater snowfall, by affording greater shelter in winter to this frost-sensitive plant (Crabtree, 1972), but the more usual explanation of such a pattern invokes temperature amelioration, and Pennington (1970) states specifically that increased snowfall has an adverse affect on the flowering of juniper. In view of such uncertainty no reliable interpretation of the zone G-2 Juniper rise can be made.

The pollen floristic evidence from Glasscnock therefore may be interpreted as indicating relatively mild and dry conditions early in the Interstadial, followed by a cloudier and wetter regime during the second half of the period. It can be surmised that at some stage the mean annual temperature must have started to fall, in order to allow the build-up of glacier ice that advanced to its maximum position during the Stadial. Evidence from western Britain in coleopteran assemblages analysed by Coope (1970), Coope et al.,(1971), and Coope and Brophy (1972) indicates that the Lateglacial optimum for insects occurred in the early Interstadial, prior to 12,000 B.P., when the mean July temperature was estimated to be at least 17°C. Using the present-day distribution of coleoptera, Coope infers that temperature fell from 16° to 12° or 13°C through traditional pollen zone II, declining to or below 10°C during the Stadial. This model of Lateglacial temperature fluctuation is probably the best available at present, insects largely being independent of the problems of inter-specific competition and immigration that hamper and complicate the movement of plants. There is no reason to believe that this general pattern is inapplicable in north-west Scotland, although the mean temperature values might expectably be somewhat lower than those mentioned above.

Consideration of the pollen flora leads to speculation about the types of vegetation that produced it. It is not certain that the basal organic sediment records the initial pioneer vegetation at Glasscnock, since the underlying clay was not sampled and may have contained evidence of the earliest plants to arrive. For this reason discussion of plant immigration and succession is better related to early Postglacial vegetation (section C).

Zone G-1 differs most markedly from G-2 in the relative concentrations of Empetrum, Salix and Betula pollen. The early Interstadial pollen record implies derivation from a herb-rich, open vegetation with much Rumex and Lycopodium, and grasses and sedges. Rumex and Artemisia presumably frequented the more unstable slopes, while Salix scrub and Betula nana probably grew with Carex species in boggy hollows and along water courses. Stable ground would attract dwarf scrub, including Empetrum and Juniperus, and the ferns may have been associated with the latter as an understorey (McVean and Ratcliffe, 1962) or have grown in damp shaded places or in snow-bed communities. Lycopodium was apparently a common member of communities around the kettle-hole, L. selago probably favouring well-drained shallow soils in association with the perennial herbs and grasses.

Empetrum emerges as a dominant in G-2, suggesting the spread of dwarf-shrub heath similar to that described in the present-day 'Low Alpine' vegetation belt of Norway (Dahl, 1957). Although the plant occurs in a wide variety of community types, such apparent abundance of it in Late-glacial north-west Scotland (Kirk and Godwin, 1963; Pennington et al., 1972) implies successful establishment of a widespread, dominant vegetation type. In Scandinavia and the northern Scottish Highlands above 600 m the Vaccineto-Empetrum association occupies large tracts of ground, forming a dwarf shrub heath (although much of the present range of this formation has been produced by deforestation). In Scotland, Carex bigelowii, Rhacomitrium lanuginosum, and abundant liverworts and lichens are members of the association : C. bigelowii pollen may be included under 'Cyperaceae', but the other three plants constitute a potential blind spot in the diagram. Empetrum- Vaccinium heath is found commonly in large shallow snow-beds in the central Highlands, but not where snow is late in melting (Bell and Tallis, 1973). Records of pure Empetrum stands in modern vegetation are less common, although such do exist, e.g. Watt and Jones (1948) reported an almost pure community of E. hermaphroditum on Mount Keen. The apparent absence of Vaccinium from most levels in the Lateglacial diagram might be explained by the plant's poor representation in the pollen rain : Tinsley and Smith (1974, p. 564) state that 'it appears that the status of Vaccinium in former heath communities cannot be deduced from its representation in fossil pollen diagrams', following work on modern pollen rain. Birks (1973) also found Vaccinium pollen to underestimate the local plant cover in modern Scottish alpine summit vegetation. Another reason might be mis-identification of the shrunken tetrads in G-2, some of which conceivably could have been types other than Empetrum. The Lateglacial dwarf-shrub heath was therefore not necessarily dominated by a single species.

In the same zone Rumex appears to decline in importance, and similarly (but to a lesser extent) Lycopodium, while the herbs, grasses and sedges continue to flourish. Willow and (dwarf) birch scrub persisted and Juniperus expanded : the ligneous elements in the vegetation were therefore better represented in the later Interstadial, although much open ground must still have existed since no diminution of the heliophytic herbs is apparent.

The final question to be considered with regard to the Interstadial concerns the general pattern of pollen floristic change and its environmental implications : whether or not there is evidence for an Interstadial climatic oscillation.

The curve for total fossil influx on the Glasscnock diagram has a decided double peak in the Lateglacial : the first maximum occurs in mid-zone G-1, while the second precedes the decline towards zone G-3. The intervening trough occupies sub-zone G-1b, and its lowest point (5.51 m) was radiocarbon dated at 11,165 $\pm$ 350 B.P. As described previously, many taxa decline in G-1b, birch and Empetrum showing particularly clear minima, while Rumex registers increased influxes. These changes occur within a homogeneous matrix of gyttja, and hence probably reflect changes in pollen production unaffected by major alterations of the sedimentation rate. The pollen record of G-1a shows in general increasing values that culminate at level 5.55 m in the first Interstadial maximum, and this would imply an increasing density of plants. Throughout G-1b the reverse tendency prevails as pollen concentrations in general decline, suggesting a reduction in pollen production. The absence of records of Pinus pollen in early G-1b is perhaps significant : this could be a consequence of statistical errors, but the occurrence of three consecutive samples with no pine pollen (the largest gap in the Pinus curve) suggests that long-distance influx was at least reduced at that time.

It is most likely that some change in the climatic pattern caused this negative oscillation in the pollen records, some critical threshold (of temperature or rainfall) being crossed and initiating the decline registered by many taxa. The cessation of the Pinus input implies that either the distant source of the pollen was similarly affected, or that a change of wind direction interfered with the transport of the pollen. As far as the writer is aware there is no evidence of an Interstadial Pinus decline in these areas where pine was then present ( e.g. Vasari and Vasari, 1968), thus the suggestion of a changed direction of the prevailing wind appears more plausible. If it is accepted that the source of the pine pollen lay to the south and south-east (Aberdeenshire) of Wester Ross, the wind during sub-zone G-1b must have blown predominantly from between the north-west and north-east, to effectively prevent or reduce the influx. Wind from this quarter is associated with cold air at all seasons, and could easily account for the deterioration in vegetation that apparently took place in G-1b. The effects of this hypothesised climatic oscillation were not sufficiently severe, however, to initiate soil instability (i.e. solifluction) at least in the Glasscnock basin.

Pollen influx values in G-2 are complicated by lithological considerations and by the inestimable contribution made by secondary pollen. However, the implications of the pollen flora are that cloudy, wet weather prevailed while the cover of dwarf-shrub and herb-rich grass - sedge heaths was maintained or increased. <u>Pinus</u> pollen is once more in evidence. The simplest explanation of these changes involves a return of more temperate weather patterns, probably involving south-westerly or westerly winds and their associated depressions.

It is therefore proposed that evidence does exist for a climatic oscillation during the early Interstadial. The absence of reliable radiocarbon dates precludes accurate estimation of the age and duration of this colder spell, but if 1 cm of gyttja took 100 years to accumulate, it was not less than three hundred years. Oscillations in Lateglacial Interstadial deposits are reported in the literature from many places in Britain, although causes other than climatic could account for some or all. The nearest to Glasscnock are in Sutherland and the Great Glen (Pennington <u>et al</u>., 1972; Pennington, 1975a; Haworth, 1976) and the Grampian region (Donner, 1957; Vasari and Vasari, 1968; Clapperton <u>et al</u>., 1975). Fluctuations are also recorded in north-west England (Smith, 1958; Oldfield, 1960; Evans, 1970; Pennington, 1973, 1975a), north-east England (Walker and Godwin, 1954; Bartley, 1962), Wales (Crabtree, 1969) and Ireland (Watts, 1963). Where climatic causes are invoked for these oscillations, reference is usually made to the Older Dryas period (<u>ca</u>. 12,700 to 12,450 B.P., Pennington, 1970)of the Continent. Pennington (1975b) summarises the situation thus : (the Lateglacial) ' interstadial .... is clearly divided by evidence for a minor recession in the more continental parts of Britain and on the mainland of Europe, but almost imperceptibly divided in the most oceanic areas of western Britain' (op. cit., p. 561). It seems logical to assume that if a minor climatic oscillation is recorded in zone G-1b at Glasscnock, it probably correlates with this event that differentially affected all of north-west Europe.

B. THE STADIAL.

During zone G-3 the local coire and valley glaciers advanced to their maximum positions, forming the two ice caps illustrated on Figs 5a and 5b. Although glacier ice may have started accumulating during the Interstadial, it is logical to assume that the silts and clays of G-3 represent the period of most severe climate immediately preceding and contemporaneous with the glacial maximum. Pollen influx is consistently very low throughout the inorganic deposits.

Lithostratigraphical implications are probably more useful than the pollen record in G-3 with reference to climate. The homogeneous grey sediment, lacking fossil content except for pollen and spores, replaces the organic products of the Interstadial and indicates a drastically changed environment. The source of the minerogenic deposits was probably two-fold : (1) the local slopes surrounding the kettle-hole, and (2) more distant expanses of open ground susceptible to aeolian action.

Particle-size analyses described previously show that the deposits are predominantly fine-grained, the coarsest fraction present being coarse sand. Reference to Fig. 24 shows that an increase in silt content occurs upward through the stratum, while clay content is highest in the lower samples. Comparison of the particle-size curves with Williams's curve separating frost-susceptible from non-frost-susceptible morainic soils (Williams, 1957) shows that all four samples would be liable to frost-heave. The most probable local source for the sediment is the surrounding slopes of moraine, where it is probable that such periglacial processes as frost-heave, solifluction and soil creep besides normal slope wash and rill erosion would operate during the Stadial, and at least some of the affected debris would be deposited in the kettle-hole. The lack of coarse material may reflect preferential movement of fines, but it is more likely that any larger debris moved downslope would be deposited first at or near the margin of the pool, while silt and clay would travel farther and settle out through deeper water. Ice-rafting of large clasts presumably did not occur. Although the fine Stadial deposits were frost-susceptible,it is unlikely that frost action would occur in them because of the insulating effect of the water, unless the lochan was less than 2 m deep (Sellman et al., 1975). Evidence for the existence of permafrost just after, and by implication during, the Loch Lomond Readvance has been found elsewhere in western Scotland (Sissons, 1974), and frozen ground in Strath a' Bhàthaich, surrounded by glacierized mountains, seems a strong possibility. Vertical mixing of the Stadial deposits would result from frost-heave, reducing the chances of a chronologically-ordered sequence being preserved. Moreover, the almost certain inclusion of redeposited grains, and the disturbance of the Stadial sediment during transportation from Wester Ross, mean that the pollen record from G-3 is likely to contain little or no information about vegetational change throughout the period, and all of these factors may help account for the very consistent dissimilarity coefficients measured between the successive Stadial samples.

The other possible source of at least a proportion of the Stadial deposits was the outwash plain of the Strath a' Bhàthaich glacier, and any other open expanses of 'soil' or glacial deposits susceptible to deflation. Wind-transported suspended sediments have characteristic particle-size distributions, the silt size range being favoured (Chepil, 1957; Embleton and King, 1968; West, 1968). Comparison of the four sample curves with one for loess from Kansas (Swineford and Frye, 1945) shows that samples 3 and 4 approximate most closely the loess curve, and both comply with the observation that in loess normally between 70 and 85% of all particles (by weight) lie within the size range 0.07 to 0.003 mm (i.e. ca. 3.75-11.5 ϕ), and that some fine or very fine sand is present (Embleton and King, 1968). It is therefore conceivable that wind-transported material did contribute to the kettle-hole deposits, especially in the later part of the Stadial. Strong katabatic winds blowing down Strath a' Bhàthaich from the eastern ice cap would almost certainly lift and redistribute clay and silt from the outwash plain during the period of extensive ice-cover, but the results of such activity compared to contemporaneous soil movement are not known.

Evidence of sand-grain morphology argues against an aeolian origin for the larger particles present in the samples. Grains from all sand-size classes present in the samples were examined under a microscope, and appeared to be typical glacial sands, lacking the surface alterations usually incurred during wind or water transport (Krinsley and Doornkamp, 1973). The grains were angular or sub-angular in shape with very sharp edges, numerous fractures produced by shattering including conchoidal breakages, and lacked a frosted appearance. The implication is that no alteration of the original surfaces of these grains had occurred during transport, presumably because the source was very local (e.g. the moraine in which the kettle-hole lies) and insufficient time or distance prevented modification of the glacial sands. This lack of characteristics does not, however, deny the possibility that the smaller particles (silt and clay) may have been derived from sources other than the kettle-hole basin itself.

The Stadial deposits, whether of local or more distant origin, indicate that little or no organic soil remained on the slopes at Glasscnock by the beginning of G-3 : the erosion that started in G-2 culminated in the removal of mature soil, a process that must have been greatly accelerated with the onset of freeze-thaw cycles and associated periglacial activity. Where podzolised strata were not removed, e.g. on flat ground or at the base of slopes, they may have been buried. The overall result was probably a return to early-Interstadial conditions with fresh, base-rich mineral 'soil' replacing the leached and acidic horizons developed under a more temperate climate.

The Stadial climate was discussed in Chapter 4, using glaciological inferences, and the pollen taxa cannot contribute information to this topic.

Pollen production during the Stadial was very low compared with values recorded in the Interstadial. If a sedimentation rate of 1 cm per 50 years is assumed (see p. 177 ), and 10,000 grains per c.c. taken as an approximation to the Stadial pollen concentration, a deposition rate of 200 grains/ square centimetre/ annum is estimated. Very similar values for pollen influx (and concentration) are reported from basal sediment in Blelham Bog and Blea Tarn (Pennington, 1973) and the figure also compares well with modern pollen influx in mid-Arctic Canada recorded by Ritchie and Lichti-Federovich (1967). Allowing for the inclusion of redeposited grains, by these calculations the pollen rain must have been very sparse indeed.

This is hardly surprising in view of the proximity of the valley glaciers and the widespread movement of soil that apparently occurred. A much-reduced vegetation cover is implied, and the interruptions and severe reductions in the records of many taxa suggest an impoverished flora that was dominated by those types with a continuous (or nearly so) representation, i.e. <u>Rumex</u>, grasses, sedges, <u>Empetrum</u>, and <u>Betula</u>. One can only speculate on the vegetation types that produced this combination of pollen taxa : open moss-heath communities such as are found today on

Scottish mountain summits, e.g. Rhacomitrium-heath with Carex bigelowii and grasses; montane grassland; and snow-bed associations probably accounted for most of the sparse vegetation cover (Pearsall, 1970). Grass- and sedge- dominated communities would grow in the more wind-exposed areas, while chionophilous plants such as Salix herbacea, S. reticulata, Vaccinium, and Nardus stricta would favour areas of prolonged snow-lie. The persistence of Betula (almost certainly dwarf birch), Empetrum, and juniper indicate the continued existence of the dwarf shrub and scrub vegetation, in a very much reduced form.

Aquatic vegetation was practically non-existent, judging by the extremely low Myriophyllum concentrations and the complete lack of pollen of other water and littoral plants. This is probably a reflection of the absence of clear water : throughout G-3 frequent freezing and the deposition of fine minerogenic debris must have disrupted the normal growth of aquatic plants, micro-flora and micro-fauna, that had been established in the Interstadial.

## C. THE POSTGLACIAL.

Information about Strath a' Bhàthaich after the Stadial is contained in the pollen diagram from Druim Dubh, and in the upper section of the Glasscnock diagram. For the purpose of interpreting the development of vegetation over this period the diagrams will be referred to together, although certain differences exist in the pollen records.

Comparison of the two diagrams is made difficult by the unequal lengths of core involved : the complete Postglacial sequence that is represented by about 18 cm of gyttja at Glasscnock is contained within only 6 cm at Druim Dubh. This implies that at the point sampled the deposition rate of Postglacial gyttja was three times slower in the Druim Dubh kettle-hole, and concentration values of pollen and spores possibly three times higher as a consequence. The pollen record is therefore less precise and more generalised at Druim Dubh : minor fluctuations in the pollen concentrations were not identified. Despite this difference, the general pattern of change might be expected to follow a similar course, and any notable differences may be attributed to purely local variations. The extra-local and regional components of the pollen rain should have been common to both sites since they are only 2 km apart. It should be noted that the spectrum at 6.17 m in Druim Dubh does not necessarily represent the earliest vegetation at the site, since the unsampled basal sediment may contain micro-fossils.

The basal zones G-4 and DD-1a include typical Lateglacial taxa, Gramineae, Cyperaceae, Betula, Rumex, Salix, Empetrum, and the heliophytic herbs all being well-represented. Aquatic plants were present at both sites, Myriophyllum registering a very large increase in G-4. In addition, new taxa appear in the early Postglacial : Filipendula, Potentilla, and Typha. Filipendula probably represents F. ulmaria (Berglund, 1966), which is found today in the Scandinavian sub-alpine belt (Iversen, 1954), and grows in poorly-drained habitats including marshes, tall herb meadows, and river banks. Iversen noted a Filipendula rise characterising the early Postglacial, caused by a rise in temperature, and Chanda (1965) believed that its presence in a pollen diagram was indicative of sub-arctic temperatures. Potentilla is another (mainly) perennial genus, but as it grows in a great range of habitats, it is of little use as a climatic indicator. Typha, however, is distinctly thermophilous (Iversen, 1954; Hafsten, 1956) and in Scandinavia has a range limited by the 14°C (July) isotherm. The plant becomes locally dominant in many sites in reedswamp, especially on inorganic substrata around lake margins (Clapham et al., 1962).

The sudden cessation of minerogenic deposition at Glasscnock at 5.24 m indicates a rapid recovery of organic production in the basin, inwash of mineral 'soil' being halted. Pollen influx starts rising 2 cm below this lithological boundary, implying that climatic amelioration had commenced some tine before, and that plant life was then beginning to recover after suppression during the Stadial. Climatic inferences based on the lithological evidence suggest that air temperatures rose rapidly in the early Postglacial, halting soil movement and initiating organic production in the basin : this contrasts with the gradual period of environmental change inferred at the onset of the Stadial. Air and ground temperatures rose, and clear, open water prevailed as in the Interstadial lochans, allowing Myriophyllum to flourish. If the botanical implications of the presence of Typha are correct, a mean temperature of at least 14°C in July was reached early in G-4. Little inwash of mineral debris took place, although sparsely vegetated ground probably predominated. Relatively warm conditions with moderate precipitation are therefore implied. Coope's work in England and the Isle of Man (Coope, 1970; Coope *et al.*, 1971) indicates a rapid amelioration of climate at the close of the Stadial, July temperatures approaching 17°C in traditional pollen zone IV.

The pattern of plant immigration at Glasscnock and Druim Dubh is the most interesting aspect of Postglacial vegetational development. It is best illustrated at the Lateglacial site where a complete stratigraphic sequence is almost certainly preserved, and changes in the taxa are more accurately recorded. The re-establishment of vegetation around Glasscnock would presumably begin with the hardiest pioneer plant types that had survived in closest proximity to the ice : the pollen record in G-4 indicates that such taxa as *Lycopodium*, *Saxifraga*, *Rumex*, *Artemisia*, Gramineae, Cyperaceae, Caryophyllaceae, Ranunculaceae and *Juniperus* were prominent in the earliest stages. It is difficult to select a dominant member of the earliest assemblage, but willow and juniper may have formed localised thickets in a landscape of open, grass-sedge heath rich in herbs, including *Lycopodium* and saxifrages. A little later *Rumex* flourished : this may represent a purely local phenomenon, but also indicates a relatively rapid transition occurring in the vegetation. The swift rise to dominance of *Rumex* is followed by its equally rapid decline, and contrasts strongly with the behaviour of the curve in the early Interstadial where it maintained a relatively high influx over hundreds of years in a similar pollen assemblage. This difference is almost certainly due to a continued climatic amelioration in the Postglacial, allowing the immigration of more competitive plants that deposed *Rumex*, and were later succeeded themselves. During the Interstadial, climatic deterioration presumably prevented this succession progressing so far. In upper G-4 and DD-1 the ligneous plants show increased influxes, *Salix* rising to an early Postglacial maximum at about the same time as the highest concentrations of *Juniperus* are recorded. Increasing density of the vegetation is therefore indicated, probably accompanied by a reduction in light under woody scrub and ericaceous heath.

This sequence of colonisation may be compared with those recorded in front of present-day retreating glaciers, notably Storbreen in Jotunheimen, Norway (Matthews, 1976). In the gletschervorfeld of Storbreen, Matthews found Arabis alpina and Saxifraga groenlandica to be particularly common on the youngest ground nearest the retreating glacier, while Cerastium species, Saxifraga stellaris and Deschampsia alpina formed the core of the pioneer group of species defined by multi-dimensional scaling. Poa alpina and Trisetum spicatum were two other common grasses, the former constituting the dominant pioneer species. Although at Glasscnock Cruciferae were not in evidence so early in the Postglacial, Saxifraga species, and members of Caryophyllaceae and Gramineae were present, and may have included these pioneer species. Cruciferae and Caryophyllaceae appear in low concentrations in DD-1a, and Gramineae in very high concentrations throughout the zone. At Storbreen Oxyria digyna tended to appear on slightly older ground than the other pioneers, and since the category Rumex on the pollen diagrams includes this type, much of the large increase in upper G-4 may in fact record a period of abundant Oxyria. Rumex also reaches its peak at Druim Dubh just above the basal organic sediment.

Matthews (1976; in press) described vegetational development on the glacier forefield as constituting a series of waves of species invasions, and a similar concept was also applied by Stork (1963) to immigration in front of northern Swedish glaciers, where colonisation of barren ground took place by sudden incursions of swarms of species. After about five decades at Storbreen the initial colonisers were superceded by late successional types, including heath species such as Empetrum hermaphroditum, Vaccinium uliginosum and Betula nana. Other relatively late immigrants included snow-bed species such as Salix herbacea, and members of the

Gramineae and Compositae families (e.g. Anthoxanthium odoratum and Gnaphalium species). All of the early pioneers were herbs, and only after suitable modification of the newly deglaciated ground could the dwarf shrubs successfully colonise. Similarities are evident between this pattern and that described for Lateglacial and early Postglacial Glasscnock, despite the lack of precision in pollen identification and the numerous pitfalls inherent in interpreting vegetation from a pollen diagram.

The trends established in G-4 are continued in G-5 : heath plants and birch increase their concentrations, although Salix registers a slight but steady decline, and juniper disappears. The herbs are still present, Rumex maintaining a fairly steady influx. Similar patterns appear in DD-2 at the Postglacial site.

The Betula curve for the first time exceeds values reached in the Interstadial, and it is believed that at this time tree birches were near, and possibly present in, the field area. It is probable that as birch spread into new territory, seed dispersal ahead of the established woodland would give rise to scattered small populations, which on maturity would then increase the local density of trees and farther advance the tree-line (Watts, 1973). It is suggested that the initial rise of birch in G-5 reflects the arrival of the first trees in the area, but also includes a certain extra-local component. The establishment of closed woodland in Strath a' Bhathaich occurs in the following zone.

The decline of Juniperus in mid-zone G-5 and DD-2 strengthens this hypothesis : the shrub is known to be supressed by woodland (pollen production being reduced in shaded conditions), but grows luxuriantly at the forest limit in Scandinavia (Iversen, 1954; Berglund, 1966). A pronounced peak in the Juniperus curve in the early Postglacial often precedes the arrival of woodland in the area (Pennington, 1969). Such juniper rises are recorded in north-west Scotland in lochs Sionascaig and Clair (Pennington et al., 1972), Loch Maree (Birks, H.H., 1972), and at Loch Mealt, Lochan Coir a' Ghobhainn and Lochan Cill Chriosd on Skye (Birks, 1973). The absence of a definite juniper rise preceding its decline in G-4 or G-5 is puzzling, especially since the plant did flourish locally in the pre-Stadial period. A possible explanation lies in juniper's susceptibility to rust fungi, Gymnosporangium species, and Lophodermium juniperinum, that attack the conducting tissues of the stem and can cause severe destruction of the plant. Such disease may have affected juniper at Glasscnock in early Postglacial times, thus preventing it from flourishing.

Throughout the Betula assemblage zones at Glasscnock and Druim Dubh Empetrum declines or maintains a rather fluctuating influx while the pollen of Ericaceae rises steadily from its rational limit near the lower zonal boundaries. The decline of Empetrum is probably related to the development of a taller, more closed vegetation (Empetrum being strongly heliophilous) Vaccinium species, e.g. V. myrtillus and V. vitis-idaea, are relatively shade-tolerant, and at least some of the Ericaceae category is believed to represent Vaccinium that grew as an understorey in the developing mixed woodland. This may have resembled the modern Vaccinium -rich birchwood association of the Scottish uplands described by Burnett (1964) where ferns, mosses, grasses and Vaccinium dominate the woodland floor. Juniperus occasionally forms a tall-shrub layer in such associations, and may have done so in early G-5 and DD-2a before increased competition for light excluded it. Other trees possibly present in these pioneer copses are aspen and hazel : both pollen curves show sporadic occurrences that are somewhat unconvincing in view of long-distance transport possibilities. It is highly probable that Populus and Corylus were in the vicinity of the field area at that time, the former migrating ahead of the closed woodland as it is a light-demanding pioneer species (Iversen, 1960).

The paucity of Populus pollen may be a result of either poor pollen representation (Birks, 1973) or loss from the sediment.

Alongside the newly established copses it is probable that tall herb-rich meadow vegetation predominated, especially on the deeper and richer soils. This is indicated by the presence of Filipendula, which reaches a peak in early DD-2, Urtica (probably U. dioica), and more abundant Valeriana than hitherto : this perennial is often associated with Filipendula (Berglund, 1966), and all three plants commonly grow in tall herb communities. The herbaceous genera and families present in the area since the Lateglacial continue to be represented, although it is probable that new, more thermophilous species would add to the richness of the vegetation.

Aquatic plants were relatively abundant and diversified at this time, Potamogeton flourishing for the first time at Glasscnock, Myriophyllum maintaining high concentrations, Menyanthes increasing, and Caltha and Sparganium being recorded. This abundance of water plants presumably reflects increasingly favourable conditions that resulted in prolification of previously established types and the immigration of new species.

An interesting aspect of vegetational development in G-5 is the rise in the Plantago maritima pollen influx, which commences early in the zone and rises somewhat erratically to reach a maximum at the G-5/G-6 boundary, then declines through the latter zone. P.maritima is wind-pollinated, an obligate halophyte that occurs in alpine locations as well as coastal sites. Although it was apparently the commonest plantain in the British Lateglacial (Godwin, 1975), its sudden abundance in Postglacial Glasscnock implies that some new habitat became available to it in G-5, and the general development of vegetation towards a closed cover implies that coastal territory was the scene of the tremendous Plantago expansion.

P. maritima is frequently the dominent species in salt-marsh vegetation of north-western Scottish sea lochs (Burnett, 1964), forming a turf with the grass Puccinellia maritima. It also occurs on rocky coasts, e.g. in the basal cliff zone where salt sea-spray is a dominant influence. It is tempting to relate this event recorded at Glasscnock to some maritime regression that resulted in exposure of extensive estuarine deposits, for instance at the head of Loch Kishorn, 3.5 km south-west of the pollen site. Seral succession at such a site almost certainly would include a phase of domination by Plantago sward.

Evidence of sea-level change in south-east Scotland (Sissons, 1974a) suggests that in the very early Postglacial sea-level was falling from a late-Stadial maximum, some 7 m (in the Forth estuary) above the Main Late-glacial Shoreline, towards a minimum reached about 8,500 B.P. If, as was tentatively suggested in Chapter 5, the Main Lateglacial Shoreline in this part of Wester Ross lay near present sea-level, a late-Stadial sea at ca. 7 m O.D. would have covered at least half of the present marshy valley of the River Kishorn, and subsequent regression would have exposed estuarine flats at the head of the loch. Dating of the G-5/G-6 zonal boundary at ca. 9,000 B.P. is provided by radiocarbon dates from Loch Clair (Pennington et al., 1972) and Loch Maree (Birks, H.H., 1972) on the rational Corylus limit, which coincides with the zonal boundary at Glasscnock, and the maximum of the P. maritima curve. This hypothesis implies a strong extra-local component in the pollen rain, the dominant wind direction having been west-south-west to south-west.

Vegetational development at Glasscnock in G-6 was dominated by tremendous expansions of Betula, Corylus/ Myrica, and a little later, Salix. The high influx values (approaching 100,000 grains per c.c. at 4.99 m) are of the same order of magnitude as values reported for forested regions in north-west Scotland and England at ca. 5,000 B.P. (Pennington, 1973). The pollen record implies the growth locally in G-6 of a relatively closed mixed woodland, dominated by Betula, but containing a large proportion of Corylus. The records of rowan, oak, elm, alder and pine are difficult to interpret because of the possibility of long-distance transport. It is probable that Sorbus aucuparia did grow in the early mixed woodland since it is a pioneer tree suited to the environment of the north-west Highlands, and is known to be poorly represented in pollen diagrams (Birks, H.H., 1972). Quercus and Ulmus are less likely to have been present in the north at this relatively early stage, and are recorded only sporadically, whereas Alnus, with a continuous curve above 5.04 m may have been locally present. The absence of an increased Pinus influx in G-6 implies that no local pine yet existed. The simultaneous and sustained increases in birch, willow, hazel and alder above 5.04 m suggests that at that time the trees extended their territories, forming an increasingly closed canopy. Heliophytes such as Empetrum and Lycopodium suffered as a result, but the herb-rich meadow communities present in G-5 probably persisted, some plants such as members of the Cruciferae and Umbelliferae being better represented here than in any other zone. The expansion of Artemisia to concentrations that exceed Lateglacial values is somewhat anomalous in view of its accepted role in the Lateglacial 'flora of opportunists' (Raven and Walters, 1965, p. 84). One can only assume that environmental conditions were sufficiently diverse to allow the continued growth of such herbs at the same time as woodland developed. The known preference of Artemisia for open, dry conditions (Iversen, 1954; Hafsten, 1956) may indicate a greater abundance of dry soils than existed hitherto.

The aquatic flora continued to flourish, Nuphar being recorded for the first time. Some suggestion of a local hydrosere exists in upper G-5 and G-6 : deep, open-water plants like Potamogeton and Myriophyllum flourished initially, followed by shallow-water genera such as Sparganium, *Typha*, *Caltha* and *Menyanthes*. Finally, *Sphagnum* appears and is continuously present above 5.02 m, indicating the beginning of the final terrestric phase of the hydrosere (Hafsten, 1956; Tansley, 1968). It is probable that the sequence indicates the gradual infilling of the Glasscnock basin, which at some level above the analysed sediment would contain terrestrial peat alone.

# CHAPTER NINE.

'Of the general correctness of the theory there seems little doubt; but, like every other drawn from Nature, it will be still further developed and improved, by observation and experience.'

(Steuart, H., 1828, The Planter's Guide, William Blackwood, Edinburgh, p. 93.)

# Lateglacial and early Postglacial vegetational development in north-west Scotland.

The patterns of early vegetational change in Strath a' Bhàthaich were described and analysed in the previous chapters, and an attempt will now be made to compare this sequence with the general vegetational development in north-west Scotland. This has been elucidated by Kirk and Godwin (1963), Vasari and Vasari (1968), Moar (1969), H.H. Birks (1972), Pennington *et al.*, (1972), Birks (1973), and Pennington (1975 a).

Pennington *et al.* investigated loch cores from Sutherland and Wester Ross, and defined six Postglacial Regional Pollen Assemblage Zones , NSI to NSVI. Using time scales provided by radiocarbon dates from lochs Clair and Sionascaig these were designated as chronozones for north-west Scotland (NWSI to NWSVI). The Lateglacial portions of the pollen diagrams are divided into three zones : A (pre-Interstadial), B (Interstadial), and C (post-Interstadial). These zones were not radiocarbon dated at those sites. A more recent Lateglacial pollen diagram from Cam Loch, Sutherland is divided by Pennington into seven assemblage zones, their relationship to the earlier zones A, B and C being indicated (Fig. 2, Pennington, 1975 a).

The pre-Interstadial zone A is a *Rumex* zone, subdivided into periods of abundant *Lycopodium selago*, *Empetrum*, and *Artemisia* (oldest to youngest), and is interpreted as indicating open communities of pioneer vegetation on skeletal soils. Implications of the three sub-zones were uncertain because of the possibility of a purely statistical effect in the percentage diagram.

Interstadial zone B is dominated by *Empetrum*, and (in some cases) by juniper. At three sites it is divided into sub-zones defined by an Empetrum maximum (B1) then slight recession (B2), followed by a Juniperus maximum in B3. The lower boundary of zone B is equated with the date from Loch Droma of 12,870 ± 155 B.P. This zone is dominated by woody plants which are believed to have formed closed communities. Post-Interstadial zone C is an Artemisia zone, with particularly high percentages of the pollen being found in the more eastern sites (lochs Craggie and Tarff). This distinctive assemblage includes taxa characteristic of open, disturbed soils.

Between the Lateglacial and Postglacial pollen zones is a transitional Rumex-Lycopodium selago zone, preceding the rise of Betula at ca. 8,900 B.P. that forms the lower boundary of NSIII, the birch-hazel zone. NSIV is defined at the rise of Pinus, ca. 7,900 B.P. : since the Glasscnock and Druim Dubh diagrams do not cover this period, the mid- and late-Postglacial vegetation will not be considered.

The similarities between this sequence and those described using the evidence from Strath a' Bhàthaich are marked. The pollen assemblages from the field area bear a strong resemblance to those found at Loch Clair, 15 km to the north-east of Strath a' Bhàthaich, and to those from ca. 80 km to the north. Zones A and B may be correlated with G-1 and G-2 in terms of their pollen floras, in both cases Rumex and then Empetrum dominating in assemblages that include high Lycopodium, ferns, grasses, sedges, birch and willow. Subdivision of the zones is more complex in Pennington's diagrams, but at lochs Sionascaig and Borralan a double Empetrum peak with intervening recession (and slight expansion of Rumex) is present, as at Glasscnock. An oscillation in Cb at Cam Loch where juniper and Empetrum rise, then decline as Artemisia increases, is interpreted by Pennington as having climatic significance related to the Bolling - Older Dryas fluctuation.

Although Zone C is named the Artemisia zone, values for this genus remain at or below 5% in Loch Sionascaig, and evidence from Glasscnock and Skye confirms the fact that Artemisia was a relatively unimportant plant during the Stadial in the oceanic west coast area. Otherwise the assemblages in zones C and G-3 are not unalike, Cyperaceae being more important and Betula, Salix and Empetrum much less so at Glasscnock. Such variation may have been the result, among other factors, of the relative proximities of the sites to glacier ice during the Stadial : it is fairly certain that the local climate at Glasscnock would be among the most severe.

The Transition zone at Loch Sionascaig with high Cyperaceae, Rumex, Lycopodium selago and Salix may be equated with G-4 and DD-1a, both indicated to be transitional in character by their admixture of typical Lateglacial taxa and newly-appearing Postglacial types. Empetrum did not regain its Interstadial importance at Glasscnock in G-4 or G-5 as in NSI and II at Loch Clair and farther north, nor is the succeeding zone of Juniperus dominance (NSII) represented here. However, birch is high in NSII at Loch Sionascaig, and rapidly rising at Loch Clair as at Glasscnock in G-5, so in this respect the zones are very similar.

Pennington's zone NSIII, the Betula - Corylus zone, is equated with G-6 and upper DD-2. The beginning of the Corylus expansion is dated in Loch Maree (Birks, H.H., 1972) at 8,951 ± 120 years B.P., although a continuous (low) hazel curve is present on the diagram below the sample dated at 9,085 ± 120 B.P. In Loch Clair the rational Corylus limit and expansion are dated at 8,960 ± 130 B.P. Such close agreement implies that hazel was becoming established in this part of Wester Ross at about 9,000 B.P. An interesting difference is apparent between Glasscnock, Druim Dubh, Loch Clair, and Loch Sionascaig : in the south, Betula attains high values (rising to over 40% at Loch Clair, to almost 7,000 grains/ c.c. at Glasscnock, and to over 45,000 grains/ c.c. at Druim Dubh), before the rational *Corylus* limit in NSIII, G-6 and DD-2b. In the north, there appears to have been no period of pure birch woodland, but instead a mixed (hazel - birch) woodland is present in, and succeeds, the juniper zone. In this respect Glasscnock, Druim Dubh and Loch Clair resemble Pennington's more easterly sites (lochs Craggie and Borralan) where she noted less juniper, and birch expanding before hazel (Pennington *et al.*, p. 280). Further regional comparisons may be made with diagrams from Loch Maree and Skye : at the former birch has started to rise (in upper LME-1) before the marked *Corylus*/ *Myrica* expansion, whereas on Skye this occurred at two sites only (Loch Cuithir and Lochan Coir' a' Ghobhainn) and the other four diagrams of Birks show more or less simultaneous expansions of hazel and birch. (However, it should be noted that the two diagrams of Birks and Vasari and Vasari for Loch Fada differ inexplicably in this respect.)

The reasons for these two distinct patterns of woodland colonisation are not known, but it is suggested here that since *Betula* is capable of faster migration than *Corylus*, because of its having light, wind-borne seeds, environmental obstacles to migration may have operated to retard the spread of hazel in certain areas. Prohibitive factors may have included an absence of basic or neutral soils which hazel prefers (Clapham *et al.*, 1962), or a lack of distributive agencies such as streams or rivers, and rodents, to transport the seeds. Hazel will spread more quickly down-valley than up-valley, where the seeds are distributed by rivers, whereas birch is not affected to such a degree by topography, and in fact may have spread faster up the major east-west valleys of the north-west Highlands if westerly winds prevailed. If Deacon (1974) is correct in hypothesising a Postglacial spread in Britain of hazel from western refugia, this factor of retarded up-valley migration may explain the slightly later arrival of Corylus at the more inaccessible (inland and upland) sites.

The pollen diagram from Loch Droma (Fig. 7, Kirk and Godwin) also appears to fit the pattern described for northern Scotland, although it is not zoned. The date (12,870 $\pm$ 155 years) at the base of the more organic layer within the silt monolith proves the deposits to be Lateglacial, and examination of the pollen spectra suggests that Pennington's zones A, B and C may be represented. At Loch Droma the basal few centimetres are dominated by Lycopodium species, Selaginella and Filicales, with high Rumex, Artemisia and Compositae, similar to Pennington's zone A1 and the writer's zone G-1a. Empetrum swiftly gains dominance above this 'zone', reaching its maximum at 12,870 B.P., after an initial early peak, while Rumex and Artemisia are very low. This assemblage resembles B, the period of woody-plant domination. The top of the analysed section, above 35 cm, reverts to very high Lycopodium percentages and much-increased Artemisia, although Empetrum is also still high : this assemblage may reflect the Stadial conditions of zone C.

Two Postglacial diagrams from the north-west substantiate the general pattern of vegetational development as described by Pennington et al. At Loch Maree, the sequence of pollen assemblage zones can be equated with the NS Regional Zones. LME-1 is a Juniperus zone like NSII, birch rising as juniper declines. The succeeding zone LME-2 is the equivalent of the Betula - Corylus zone (NSIII, G-6 and DD-2b), with very similar trends in Empetrum, Ericaceae and other taxa. Oak and elm have continuous records from LME-1 and LME-2 respectively, which Birks believed may indicate local presence of these trees in favourable situations (e.g. on basic soils and south-facing slopes). These trees are first noted in low quantities at Glasscnock in G-5 and G-6, in lochs Clair and Borralan in NSIII, Loch Sionascaig in NSII (oak) and III (elm), and at Loch Craggie in NSIII (oak) and IV (elm). Pennington stated that even in later times (NSIVand Vi) they can only have formed 'very small areas of oak-elm woodland' in north-west Scotland (Pennington et al., p. 281) , if indeed the pollen was local in origin.

Farther north, in Sutherland, Moar (1969) discerned a basal zone of Lateglacial character, with very high Empetrum, Gramineae, Cyperaceae, Rumex and Pteridophytes, followed by a zone of expanding tree pollen and much-reduced N. A. P. Moar's zones FII and FIII probably correlate with NSI to IV, although differences exist, e.g. the early continuous presence of Alnus compared to Pennington's and H.H. Birks's diagrams. At Glasscnock alder pollen was found in G-6, much earlier than at Loch Clair, where the rational limit in NSIV was dated at 6,570 $\pm$ 145 B.P. and at Loch Maree where an almost simultaneous alder rise occurred at 6,513 $\pm$ 65 B.P., in both cases well after the major Pinus expansion. Alnus was noted in very low quantities at Loch Maree in LME-2 (equivalent of G-6), but the continuous low curve in the Glasscnock diagram appears to be somewhat premature by comparison with the other diagrams.

The development of Lateglacial and early Postglacial vegetation therefore seems to have followed a fairly consistent pattern throughout the mainland of north-west Scotland. The Lateglacial is characterised by an initial period of herb-rich grass or sedge heath succeededby treeless dwarf-shrub heath, Empetrum being abundant and widespread. Revertance during the Stadial to an open vegetation dominated by ruderals, grasses and sedges was followed by a sequence similar to that of the Interstadial : dwarf-shrub heath and Juniperus preceded the arrival of trees and the establishment of mixed deciduous woodland.

The remaining pollen diagrams to be considered are those from Skye (Vasari and Vasari, 1968; Birks, 1973). Despite the proximity of the sites to Glasscnock and the mainland, considerable differences are evident between them in the evolution of vegetation.

Birks's five diagrams cover the Lateglacial and early Postglacial period, and are from widely spaced sites on the island, ranging from 20 m to 135 m O.D. in varied geographical areas. Vasari and Vasari investigated two Postglacial sites, one of which (Loch Fada) was also studied by Birks.

Birks defined four pollen assemblage zones, three being recognisable in all five diagrams and one occurring only in one diagram. The Betula - Corylus zone appears at the top of every diagram, and appears to be the equivalent of NSIII. In each case it is preceded by a Gramineae - Rumex zone of varying depth, in turn normally preceded by a Lycopodium - Cyperaceae zone which at lochs Fada and Mealt forms the basal zone. Variations on this pattern include repetition of the last two zones, and the insertion of a Betula assemblage zone between two Gramineae - Rumex zones (Loch Meodal). Subdivisions within the Lycopodium - Cyperaceae and Gramineae - Rumex zones include Betula, B. nana, Ericaceae, Juniperus and Selaginella sub-zones. No attempt was made to divide the diagrams into Interstadial, Stadial and post-Stadial sections, although correlations are made in the text where appropriate, e.g. the Ericaceae sub-zone of the Lycopodium - Cyperaceae zone at Lochan Coir' a' Ghobhainn is equated with the Stadial period.

Although a degree of similarity exists among the diagrams (since comparable assemblages occur in all), Birks showed that the flora and vegetation of Skye were as varied areally in the past as they are today. In spite of this diversity, the major trends in vegetational development on the island can be summarised.

Before ca. 10,000 B.P. the commonest assemblages were tall herb communities, with grassland, Juniperus and shrub heath being locally important at different times (Fig. 32, op. cit.). The oldest assemblage zone is normally the Lycopodium - Cyperaceae assemblage, where Cyperaceae exceed 30% and L. selago is consistently 5% or more, and Ericaceae may be important. This zone was not recognised at Glasscnock, where Cyperaceae apparently never assumed the importance it did on Skye. The Gramineae - Rumex zone is a herb-rich zone dominated by grasses (at over 30%) where Rumex acetosa forms at least 3% throughout. Again, this zone was not recognised at Glasscnock and Druim Dubh, where Rumex was the dominant member of two assemblages and very much more abundant than in any of the Skye diagrams. The Betula assemblage zone, peculiar to Loch Meodal, (Lateglacial Interstadial) is most akin to Postglacial G-5 since tree birch were present, and A.P. exceeds 30%. Pinus, Corylus, and Populus tremula pollen occur in the assemblage, and grasses and sedges dominate the N. A. P. The final zone is the Betula - Corylus assemblage zone, the equivalent of G-6, DD-2b, NSIII and LME-2. After 10,000 B.P. tall herb communities were the most important vegetation type at most sites before the arrival and dominance of the woodland. Lochan Coir' a' Ghobhainn differs, and is superficially more akin to the mainland : shrub heath dominated this upland area throughout the Stadial and early Post-glacial, and was replaced by Juniperus shortly before the establishment of woodland.

Several marked differences are apparent in vegetational history between Skye and the mainland. The most striking feature is the relative unimportance of Empetrum on the island : the greatest amounts recorded are at Loch Cill Chriosd and Lochan Coir' a' Ghobhainn, both in the Lateglacial Lycopodium - Cyperaceae zone, where percentages reached just over 10%, a paltry contribution by comparison with the diagrams discussed previously. The reasons for this are not certain, but at lochs Mealt and Meodal the presence of tree birches may have helped suppress Empetrum at those periods when woodland existed. Ericaceae, on the other hand, is present in all the diagrams in percentages equal to and excelling Empetrum, therefore implying communities of Calluna, Vaccinium, and

Empetrum. Climatic conditions on Skye were presumably as favourable for the plant as those of the mainland, the island being probably more oceanic in character than the west coast, and would therefore be suited to prolific Empetrum growth (Brown, 1971). Birks tentatively ascribed the lack of ericaceous heath on Skye to the predominance of basic soils (due to base-rich bedrocks). However, if this were the sole limiting factor one would have expected much higher values for Empetrum and Ericaceae at Loch Meodal, situated in an area of Torridon Sandstone and Lewisian Gneiss. This variance in distribution of dwarf shrub heath remains at present without a satisfactory explanation.

Another major difference between Skye and Glasscnock, mentioned above, is the low percentages of Rumex recorded on the island. Although R. acetosa is recorded continuously or discontinuously in all five sites, only at Lochan Coir' a' Ghobhainn is a Rumex peak recorded with a maximum percentage of about 15% (LCG-1), where very abundant Oxyria digyna was also noted. This un-named basal zone is most similar to the lowest zone at Glasscnock, zone A1 of Pennington, and possibly the lower part of Ca at Cam Loch. The characteristic unimportance of Rumex in Late-Devensian Skye may reflect a more closed vegetation cover where mobile soils were less common than on the mainland.

The establishment of tree birch copses in the Sleat peninsula (Skye) before the Loch Lomond Readvance is another distinguishing factor : southern Skye is some 35 km south of the field area, and if Betula spread through Britain from the south or west one would expect the trees to have colonised the Sleat peninsula at a relatively early stage in migration through north-western Scotland. Pennington (1975 a) stated that nowhere on the Scottish mainland north of the Great Glen were birchwoods present in the Lateglacial, but since tree birches apparently did colonise south-east Skye during the Interstadial, presumably the tree-line did reach beyond the Great Glen in the extreme west before the Stadial.

It therefore appears that in the Lateglacial much of Skye experienced less severe conditions than occurred in Wester Ross and Sutherland. Where dwarf-shrub heath was dominant on the mainland, tall herb vegetation with woodland copses existed on Skye. Similar tall herb assemblages were not recorded at Glasscnock until G-5, in the Postglacial, and it is thought unlikely that tree birch was present before then. It is possible that the apparently greater climatic severity at Glasscnock during the Interstadial may have been a purely local effect, but the general similarity in the pollen flora of Glasscnock to those from the other sites in Wester Ross and Sutherland suggests that the trends on the mainland were regional. Even at the site in Skye that in many ways most closely resembles the Glasscnock diagram (Lochan Coir' a' Ghobhainn) tall herb communities flourished and *Juniperus* was well represented in the early Interstadial. It can, therefore, be concluded that vegetational development as reflected in the diagrams from Strath a' Bhàthaich was representative of patterns established throughout the north-western Highlands, which differed in several important respects from contemporaneous evolutionary trends on the nearby Isle of Skye.

## Summary.

This final section is concerned with summarising the sequence of environmental changes in the field area as illustated by the evidence described in previous chapters.

The earliest evidence relates to a pre- or inter-glacial sea-level that carved a rock platform on the west coast of the Applecross Peninsula at between 32 and 37 m O.D. Ice of the last major glaciation crossed the platform, striating it but apparently achieving no major erosion of this stretch of coastline : several stacks still survive on the platform.

During ice-sheet decay the coast was once more exposed to marine processes, and because of isostatic uplift, the land earliest deglaciated preserved the highest shoreline fragments. Between Lonbain and the Allt na h-Eirigh in western Applecross the marine limit, in the form of an extensive platform cut in till, lies at ca. 28 m O.D., while elsewhere in the field area it is lower, indicating later deglaciation. The Torridon fjord has a notably depressed marine limit, features at Shieldaig reaching about 21 m O.D. (the lowest marine limit in the field area) while on the northern west coast 12 km to the west, the till platform is at 26 m O.D., ca. 2 m lower than its counterpart immediately to the south. This implication of later deglaciation in the Loch Torridon area accords with evidence of glacial landforms and striations, as a major lateral moraine at Loch Gaineamhach, drumlinoid till mounds near Cuaig, and striae aligned west-south-west (as opposed to north-west of the ice-sheet) all indicate that ice-sheet decay was interrupted by an advance in the Torridon fjord. The amelioration of climate that caused the disappearance of the hypothesised Applecross substage ice is considered to mark the beginning of the Lateglacial period.

A more detailed reconstruction of the Lateglacial landscape is provided by pollen analysis of deposits from a kettle-hole in ice-sheet moraine, as well as by geomorphological evidence pertaining to the Stadial. As sea-level fell from the marine limit to or just below present sea-level (the hypothesised Stadial sea-level), the landscape regained a cover of soil and vegetation. In the first part of the Interstadial the heliophytic and ruderal-type herbs predominated in an open vegetation of herb-rich, grass or moss-sedge heath possibly similar to montane heaths of today. The absence of mineral debris in the early Interstadial sediments from the kettle basin implies a relatively stable environment with no solifluction occurring at least in the vicinity of the lochan, although the importance of Rumex pollen near the base of the diagram indicates the existence then of some disturbed ground. Pedogenesis would be proceeding, with a progressive decline in base-status of the maturing soils as leaching occurred in a predominantly acidic and humid environment.

A minor climatic oscillation is implied in the first part of the Interstadial (zone G-1b) by a brief decline in the pollen representation of woody plants and many herbs, while Rumex increases : this is attributed to a cooler climatic regime, possibly under the influence of more northerly air streams, arresting the expansion and development of vegetation. The degree of temperature change involved was, however, insufficient to initiate soil movement into the kettle-hole, and the oscillation probably lasted four hundred years at most (if the sedimentation rate was 1 cm/ 100 years). This event may reflect the minor changes experienced in north-west Scotland during the Older Dryas climatic recession of continental north-west Europe, which occurred at around 12,000 B.P.

The later part of the Interstadial appears to have been rather different from the first part in terms of climate. Despite the maturation of soils under the dwarf-shrub heath that characterised the later

Interstadial, an increasing minerogenic component in the kettle-hole deposits probably indicates the onset of wetter climatic conditions. The apparent flourishing of Empetrum would corroborate this, as the plant favours an oceanic climate with equable temperatures and cloudy skies. The vegetation at this period was dominated by willow and juniper scrub, Empetrum heath being very important, and herb-rich grassland probably still playing a part.

At some point during the Interstadial, average temperatures must have fallen low enough to permit the accumulation of snow fields in the mountains. By the onset of the Stadial, solifluction was occurring in Strath a' Bhathaich and sedimentation of silt and clay had replaced organic production in the Glasscnock basin. The pollen influx was drastically reduced, presumably due to a reduction in vegetation cover and pollen production as well as an increased rate of matrix sedimentation. The impoverished vegetation probably comprised communities dominated by grasses and sedges, with chionophilous species and those capable of growing on disturbed ground being particularly abundant. Pedogenesis was halted as the landscape reverted to one of instability and swifter change. The acidic soils that were developing throughout the Interstadial were probably churned up by frost-heave, moved downslope by solifluction, or completely removed by erosion.

At the maximum extent of the Stadial glaciation 28% of the area was covered by ice, leaving five nunataks and a fringing periglaciated area. Glaciation was most intense in the eastern area, where valley glaciers radiated from an elliptical ice cap that reached to over 800 m O.D. The Applecross plateau of the Western Area supported a smaller ice cap and several small individual glaciers. The firn line rose in general from a mean of 409 m in Applecross to 474 m in the eastern field area, and since the firn lines on glaciers on the southern parts of the two ice caps tended to be low, a south-westerly origin of snow-bearing winds can be inferred. Using Liestol's unpublished graph of accumulation at the firn line against temperature, a mean sea-level summer temperature of about 4°C at the Stadial maximum is inferred.

It is likely that local winds from the ice caps would affect proglacial areas. Some of the minerogenic Stadial deposits in the Glasscnock basin may have originated in the Strath a' Bhathaich outwash plain : particle-size analysis showed the similarity of these sediments to typical loess. Another probable source was the slopes immediately surrounding the basin, from whence material susceptible to frost-heave would be washed down into the kettle-hole.

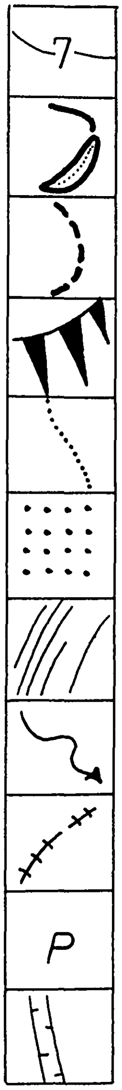
Near their maximal positions, the margins of 13 of the Loch Lomond Readvance glaciers are known to have fluctuated within the space of several hundred metres, implying a sensitive reaction to changing climatic conditions. Multiple end and lateral moraines indicate that there were at least three still-stand or readvance positions after the maximum. In other cases only one broad end moraine was formed, while in 13 cases ( 9 of them facing between north and east) no terminal moraine is present. Fluvioglacial deposits (except proglacial fans) are uncommon in the field area. The major exception to this is the Strathcarron valley, where ice stagnation in the wide trough is indicated by the preservation of kame terraces, kames, eskers, and kettle-holes.

During the Stadial the mountain summits and ridges surrounded by ice must have been exposed to very severe conditions, and it is (subjectively) believed that the blockfields and block slopes that occur on the highest ground, as well as the largest solifluction lobes, date from this period. Smaller features such as solifluction terraces, turf hummocks, and patterned ground are believed to be more recent in origin.

Mineral sedimentation ceased abruptly in the Glasscnock basin at the beginning of the Postglacial period, organic production re-commencing there and starting also in the Druim Dubh kettle-hole lochan formed by Stadial ice. Re-colonisation of the pro-glacial area proceeded in much the same order as in the early Interstadial, with an initial period of dominance by pioneer ruderal and heliophytic herbs, superseded by woody scrub and dwarf-shrub heath. Before the arrival of trees it is probable that the soil again underwent podzolisation, reducing any tendency to base-richness inherited from the Stadial period. Into this landscape tree birch immigrated, first forming isolated stands, and later a more continuous cover. Tall herb-rich meadow vegetation existed at that time beside the stands of birch, and thermophilous plants such as _Typha_ and _Filipendula_ indicate the prevalence of warmer (over 14°C in July) temperatures than existed hitherto. The final development of vegetation recorded was the large simultaneous expansion of birch and hazel, indicating the establishment of mixed deciduous woodland in Strath a' Bhathaich. Aspen and rowan were probably also present in this community, and an understorey rich in Ericaceae (probably _Vaccinium_ species) is inferred. The early Postglacial was therefore, a period of relatively swift vegetational change, with a favourable climate and increasingly stable soils, characterised by succession from an open landscape towards closed woodland.

The early Postglacial sea apparently left no visible raised shorelines, as would be expected from evidence in south-east Scotland where shorelines below present sea-level related to the late Stadial and early Postglacial period are buried beneath later marine and estuarine deposits. An oscillation of sea-level in the Kishorn estuary at about 9,000 B.P. may have been responsible for the large expansion of _Plantago maritima_ pollen at Glasscnock. The highest Postglacial shoreline features lie at about 10 m O.D., and probably relate to the culmination of the Main Postglacial transgression, but the lack of long, continuous raised beaches and the predominance of short beach ridges makes the identification of distinct shorelines at this altitude impossible in the area. Raised beach ridges and minor beaches below the Postglacial marine limit indicate subsequent formation of shoreline features, which again lack continuity and cannot be reliably related to mean sea levels over a wide area.

## KEY FOR FIGURES 4a AND 4b : GLACIAL LANDFORMS RELATED TO THE LOCH LOMOND READVANCE




altitude, in hundreds of metres O.D.

end and lateral moraine ridges

hypothesised margin of former glacier

coire backwall, or other very steep slope

drift limit

hummocky moraine

fluted moraine

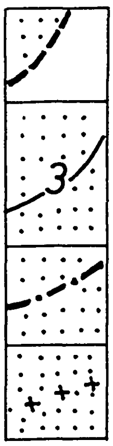
meltwater channel

esker

periglacial features within glacier limits

medial moraine

## KEY FOR FIGURES 5a AND 5b : RECONSTRUCTION OF THE STADIAL ICE-CAPS




ice margin

altitude, in hundreds of metres, of the hypothesised ice-surface

firn line

arbitrary division between adjacent glaciers

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# APPENDIX A.

Altitudes and locations of levelled points.

B = beach

D = delta

P = platform

R = beach ridge

T = terrace

B1* denotes a dubious feature.

xB1 denotes features levelled using bench mark related to the Liverpool Ordnance Datum.

All grid references are prefixed NG.

| FEATURE NUMBER | SPOT HEIGHT NUMBER | ALTITUDE in METRES O.D. | GRID REFERENCE |
|---|---|---|---|
| T1 | 1 | 52.38 | 98394651 |
| | 2 | 52.73 | 98374649 |
| | 3 | 53.16 | 98344647 |
| | 4 | 51.87 | 98314644 |
| | 5 | 51.43 | 98274641 |
| T2 | 6 | 55.53 | 97794602 |
| | 7 | 55.32 | 97774600 |
| | 8 | 55.53 | 97744599 |
| T3 | 9 | 56.58 | 97694595 |
| | 10 | 55.75 | 97654592 |
| T4 | 11 | 41.07 | 97394570 |
| | 12 | 40.97 | 97354568 |
| T5 | 13 | 42.80 | 97284563 |
| T6 | 14 | 43.20 | 97174557 |
| | 15 | 41.13 | 97154553 |
| | 16 | 40.73 | 97124549 |
| | 17 | 40.17 | 97104547 |
| | 18 | 38.84 | 97054542 |
| T7 | 19 | 53.67 | 97274569 |
| | 20 | 53.64 | 97234566 |
| T8 | 21 | 53.73 | 97164561 |
| | 22 | 52.85 | 97114556 |
| | 23 | 51.09 | 97054552 |
| | 24 | 49.97 | 96994546 |
| | 25 | 49.15 | 96914544 |
| | 26 | 47.53 | 96854538 |
| | 27 | 46.54 | 96794536 |
| | 28 | 45.46 | 96744533 |
| | 29 | 43.92 | 96684531 |
| | 30 | 42.83 | 96604526 |
| | 31 | 41.45 | 96524522 |
| | 32 | 38.80 | 96424519 |
| | 33 | 38.76 | 96354516 |
| | 34 | 36.49 | 96144512 |

| FEATURE NUMBER | SPOT HEIGHT NUMBER | ALTITUDE in METRES O.D. | GRID REFERENCE |
|---|---|---|---|
| | 35 | 34.76 | 96074510 |
| | 36 | 33.01 | 95994507 |
| | 37 | 31.02 | 95904505 |
| | 38 | 30.21 | 95804506 |
| T9 | 39 | 41.48 | 96394520 |
| | 40 | 40.47 | 96264517 |
| | 41 | 39.53 | 96204515 |
| T10 | 42 | 34.94 | 96674525 |
| | 43 | 33.90 | 96584522 |
| | 44 | 33.14 | 96514519 |
| | 45 | 32.63 | 96434515 |
| | 46 | 32.12 | 96364513 |
| | 47 | 31.34 | 96294511 |
| | 48 | 30.18 | 96204508 |
| | 49 | 29.66 | 96134506 |
| | 50 | 29.57 | 96064504 |
| | 51 | 28.66 | 95994503 |
| | 52 | 28.00 | 95924502 |
| | 53 | 26.86 | 95854501 |
| T11 | 54 | 30.56 | 96624519 |
| | 55 | 30.82 | 96544518 |
| | 56 | 28.23 | 96494514 |
| T12 | 57 | 36.91 | 97644466 |
| | 58 | 36.28 | 97634463 |
| | 59 | 36.60 | 97594461 |
| T13 | 60 | 37.48 | 97224440 |
| | 61 | 36.81 | 97194438 |
| T14 | 62 | 35.04 | 97054427 |
| | 63 | 34.98 | 97024425 |
| | 64 | 33.90 | 96904419 |
| | 65 | 34.19 | 96824415 |
| | 66 | 33.87 | 96764411 |
| T15 | 67 | 32.93 | 96614410 |
| | 68 | 33.33 | 96554408 |

| | | | |
|---|---|---|---|
| | 69 | 34.65 | 96474405 |
| | 70 | 35.10 | 96494402 |
| | 71 | 36.42 | 96324400 |
| | 72 | 36.60 | 96254396 |
| | 73 | 36.71 | 96204390 |
| T16 | 74 | 39.06 | 95504331 |
| | 75 | 38.38 | 95464330 |
| | 76 | 38.41 | 95434327 |
| F1 | 77 | 17.17 | 94914439 |
| | 78 | 16.97 | 94864435 |
| | 79 | 17.93 | 94804432 |
| | 80 | 18.65 | 94754427 |
| | 81 | 19.92 | 94734424 |
| | 82 | 19.53 | 94674420 |
| | 83 | 21.57 | 94644417 |
| | 84 | 21.17 | 94594412 |
| | 85 | 19.95 | 94534407 |
| | 86 | 19.21 | 94484401 |
| | 87 | 18.08 | 94434396 |
| | 88 | 17.40 | 94374390 |
| | 89 | 16.61 | 94324385 |
| | 90 | 16.01 | 94264380 |
| | 91 | 14.68 | 94204374 |
| | 92 | 13.98 | 94174370 |
| | 93 | 13.09 | 94124365 |
| | 94 | 12.13 | 94074360 |
| | 95 | 9.14 | 94024355 |
| | 96 | 8.84 | 93964349 |
| | 97 | 8.75 | 93904344 |
| | 98 | 8.05 | 93844338 |
| | 99 | 7.15 | 93784333 |
| | 100 | 6.10 | 93714325 |
| | 101 | 6.02 | 93644318 |
| | 102 | 5.59 | 93564310 |
| | 103 | 5.23 | 93484301 |
| | 104 | 4.94 | 93344288 |
| | 105 | 4.64 | 93294281 |
| | 106 | 4.21 | 93234275 |
| | 107 | 4.05 | 93174270 |
| | 108 | 3.96 | 93114264 |
| T17 | 109 | 22.51 | 95024294 |
| | 110 | 23.14 | 95024291 |
| T18 | 111 | 24.39 | 94904278 |
| T19 | 112 | 24.72 | 94834266 |
| | 113 | 23.97 | 94814264 |
| | 114 | 22.08 | 94784261 |
| | 115 | 21.34 | 94764257 |
| | 116 | 21.45 | 94.754254 |
| | 117 | 23.05 | 94734251 |
| | 118 | 23.71 | 94714247 |
| | 119 | 24.38 | 94694244 |
| | 120 | 23.38 | 94674246 |
| | 121 | 21.26 | 94644249 |
| | 122 | 25.22 | 94684241 |
| | 123 | 25.52 | 94664237 |
| | 124 | 25.31 | 94654233 |
| T20 | 733 | 29.68 | 94664217 |
| | 734 | 29.27 | 94634214 |
| | 735 | 29.17 | 94604211 |
| | 736 | 26.75 | 94574208 |
| | 737 | 26.07 | 94554205 |
| | 738 | 25.07 | 94524201 |
| | 739 | 24.19 | 94494198 |
| T21 | 125 | 23.17 | 94344190 |
| | 126 | 24.44 | 94324186 |
| | 127 | 24.59 | 94294183 |
| | 128 | 23.96 | 94264180 |
| | 129 | 23.72 | 94244177 |
| | 130 | 23.47 | 94214162 |
| | 131 | 22.30 | 94214159 |
| | 132 | 22.28 | 94194156 |
| | 133 | 22.88 | 94164148 |

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|---|---|---|---|
| | 134 | 22.15 | 94134446 |
| | 135 | 22.88 | 94124142 |
| T22 | 136 | 24.72 | 94104137 |
| | 137 | 23.45 | 94064133 |
| | 138 | 21.51 | 94034132 |
| | 139 | 20.15 | 94004130 |
| T23 | 140 | 22.32 | 93934127 |
| | 141 | 22.65 | 93904125 |
| | 142 | 23.50 | 93874123 |
| | 143 | 23.67 | 93834120 |
| | 144 | 21.58 | 93794118 |
| | 145 | 19.15 | 93764116 |
| T24 | 146 | 15.97 | 93704113 |
| | 147 | 16.50 | 93674111 |
| T25 | 148 | 19.26 | 93644108 |
| | 149 | 22.46 | 93614405 |
| | 150 | 23.63 | 93584102 |
| | 151 | 24.71 | 93554100 |
| | 152 | 24.58 | 93524097 |
| | 153 | 24.04 | 93484095 |
| | 154 | 24.35 | 93474092 |
| | 155 | 26.87 | 93484088 |
| | 156 | 2583 | 93454085 |
| | 157 | 25.07 | 93434082 |
| | 158 | 24.58 | 93414077 |
| | 159 | 24.70 | 93394074 |
| P1 | 160 | 5.69 | 93254336 |
| | 161 | 5.68 | 93214333 |
| | 162 | 5.76 | 93164330 |
| | 163 | 5.08 | 93144328 |
| | 164 | 5.49 | 93104325 |
| | 165 | 5.72 | 93044323 |
| | 166 | 5.22 | 93004321 |
| | 167 | 5.11 | 92964319 |
| | 168 | 5.35 | 92934318 |
| | 169 | 5.37 | 92894318 |
| | 170 | 5.00 | 92854317 |
| | 171 | 5.22 | 92814314 |
| | 172 | 5.52 | 92784312 |
| | 173 | 6.22 | 92744310 |
| | 174 | 5.83 | 92714308 |
| R1 | 175 | 7.01 | 92894292 |
| | 176 | 6.41 | 92934291 |
| | 177 | 6.22 | 92994297 |
| | 178 | 6.00 | 92984294 |
| | 179 | 7.97 | 92964289 |
| | 180 | 8.29 | 92934284 |
| | 181 | 8.83 | 92894281 |
| | 182 | 9.59 | 92864278 |
| | 183 | 10.08 | 92834275 |
| | 184 | 10.08 | 92814272 |
| | 185 | 11.27 | 92784270 |
| R2 | 186 | 8.42 | 92594254 |
| | 187 | 7.66 | 92594251 |
| | 188 | 7.59 | 92624249 |
| | 189 | 7.64 | 92584249 |
| | 190 | 7.47 | 92614248 |
| | 191 | 7.58 | 92644247 |
| | 192 | 7.06 | 92574247 |
| | 193 | 7.02 | 92604246 |
| | 194 | 6.50 | 92694246 |
| | 195 | 7.00 | 92664246 |
| B1 | 196 | 7.97 | 92384237 |
| | 197 | 8.29 | 92364234 |
| | 198 | 8.83 | 92344230 |
| B2 | 199 | 6.00 | 92394226 |
| | 200 | 6.22 | 92374222 |
| | 201 | 6.41 | 92364219 |
| | 202 | 7.01 | 92324217 |
| R3 | 203 | 10.14 | 92194208 |
| | 204 | 10.22 | 92174205 |
| | 205 | 10.42 | 92144201 |
| | 206 | 10.11 | 92114199 |
| | 207 | 10.02 | 92074197 |
| | 208 | 10.64 | 92034195 |
| | 209 | 11.1- | 92004194 |

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|---|---|---|---|
| F2 | 210 | 9.64 | 91964196 |
| | 211 | 10.88 | 91944199 |
| | 212 | 12.12 | 91944203 |
| | 213 | 13.41 | 91934206 |
| | 214 | 14.76 | 91914210 |
| | 215 | 16.46 | 91904215 |
| | 216 | 18.15 | 91894218 |
| | 217 | 19.59 | 91884221 |
| | 218 | 21.45 | 91864225 |
| | 219 | 23.12 | 91854229 |
| | 220 | 24.85 | 91844233 |
| | 221 | 26.64 | 91834237 |
| | 222 | 28.33 | 91814241 |
| | 223 | 30.32 | 91804245 |
| | 224 | 32.09 | 91784249 |
| | 225 | 34.47 | 91774253 |
| R4 | 226 | 8.37 | 91914191 |
| | 227 | 8.94 | 91874190 |
| | 228 | 8.97 | 91834188 |
| R5 | 229 | 7.02 | 92074189 |
| | 230 | 6.87 | 92024187 |
| | 231 | 7.18 | 91984185 |
| | 232 | 7.03 | 91944185 |
| | 233 | 6.85 | 91904184 |
| | 234 | 7.25 | 91844182 |
| | 235 | 6.95 | 91834180 |
| R6 | 236 | 7.05 | 91804178 |
| | 237 | 7.05 | 91774174 |
| | 238 | 7.13 | 91734172 |
| R7 | 239 | 9.74 | 91604477 |
| | 240 | 9.70 | 91534168 |
| | 241 | 9.58 | 91384165 |
| R8 | 242 | 6.59 | 91634163 |
| | 243 | 7.06 | 91594160 |
| | 244 | 7.48 | 91564156 |
| R9 | 245 | 4.18 | 91754160 |
| | 246 | 4.20 | 91724157 |
| | 247 | 4.30 | 91704161 |
| | 248 | 4.44 | 91704157 |
| | 249 | 4.64 | 91694154 |
| | 250 | 4.98 | 91664150 |
| | 251 | 5.05 | 91634146 |
| | 252 | 4.93 | 91604143 |
| R10 | 253 | 5.08 | 91534142 |
| | 254 | 5.85 | 91454134 |
| R11 | 255 | 7.02 | 91454144 |
| R12 | 256 | 7.07 | 91434140 |
| R13 | 257 | 7.51 | 91374139 |
| | 258 | 7.38 | 91374135 |
| | 259 | 7.46 | 91354134 |
| B3 | 260 | 5.98 | 91364113 |
| | 261 | 5.85 | 91354110 |
| | 262 | 5.94 | 91354105 |
| | 263 | 6.21 | 91354100 |
| | 264 | 6.50 | 91344096 |
| | 265 | 6.21 | 91344092 |
| B4* | 266 | 19.74 | 91264103 |
| | 267 | 19.81 | 91264099 |
| | 268 | 20.33 | 91254096 |
| | 269 | 20.52 | 91244092 |
| | 270 | 20.32 | 91234089 |
| B5* | 271 | 33.35 | 91124085 |
| | 272 | 32.79 | 91114081 |
| | 273 | 33.20 | 91094077 |
| B6 | 274 | 25.99 | 91204077 |
| | 275 | 26.63 | 91174074 |
| B7 | 276 | 5.44 | 91324080 |
| | 277 | 4.72 | 91304076 |
| | 278 | 4.52 | 91284071 |
| B8 | 279 | 25.89 | 90984033 |
| B9* | 280 | 35.69 | 90814027 |
| B10* | 281 | 30.55 | 90804017 |
| B11 | 282 | 26.52 | 90804011 |
| | 283 | 26.76 | 90764009 |
| | 284 | 26.95 | 90724007 |
| B12* | 285 | 39.23 | 90734024 |
| | 286 | 39.29 | 90694023 |
| | 287 | 39.22 | 90654021 |

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|---|---|---|---|
| | 288 | 40.07 | 90624019 |
| | 289 | 39.85 | 90594017 |
| | 290 | 39.06 | 90564014 |
| | 291 | 39.60 | 90544013 |
| | 292 | 40.13 | 90514011 |
| B13* | 293 | 34.42 | 90544006 |
| | 294 | 34.66 | 90504004 |
| B14 | 295 | 25.01 | 90544000 |
| B15* | 296 | 26.78 | 90483998 |
| | 297 | 27.11 | 90443997 |
| B16* | 298 | 39.32 | 90243998 |
| | 299 | 38.81 | 90223997 |
| B17* | 300 | 38.59 | 90454008 |
| | 301 | 37.37 | 90424006 |
| | 302 | 37.33 | 90394004 |
| B18* | 303 | 31.07 | 90233991 |
| | 304 | 31.59 | 90213990 |
| B19* | 305 | 37.66 | 90103987 |
| | 306 | 37.88 | 90083987 |
| B20* | 307 | 45.80 | 90073992 |
| | 308 | 45.99 | 90053990 |
| | 309 | 46.16 | 90033989 |
| | 310 | 45.56 | 90013987 |
| B21* | 311 | 51.62 | 89873985 |
| | 312 | 51.64 | 89843983 |
| B22* | 313 | 47.12 | 89883982 |
| | 314 | 46.45 | 89863980 |
| B23 | 315 | 25.37 | 89483948 |
| | 316 | 25.05 | 89473945 |
| | 317 | 24.71 | 89453942 |
| B24 | 318 | 26.08 | 89393937 |
| | 319 | 25.97 | 89373934 |
| B25 | 320 | 26.89 | 89293924 |
| | 321 | 26.36 | 89283920 |
| B26 | 322 | 24.40 | 89283913 |
| | 323 | 24.72 | 89273908 |
| | 324 | 25.04 | 89263902 |
| | 325 | 25.36 | 89243897 |
| B27 | 326 | 5.97 | 89383913 |
| | 327 | 5.96 | 89373908 |
| | 328 | 6.13 | 89363904 |
| B28 | 329 | 9.96 | 89113867 |
| | 330 | 9.95 | 89133862 |
| | 331 | 8.06 | 89203857 |
| B29 | 332 | 3.82 | 89353850 |
| | 333 | 3.91 | 89333847 |
| P2 | 334 | 3.81 | 89233844 |
| | 335 | 4.10 | 89193842 |
| | 336 | 3.98 | 89163838 |
| B30* | 337 | 20.53 | 88933848 |
| | 338 | 20.91 | 88913845 |
| B31* | 339 | 23.74 | 88863849 |
| | 340 | 23.47 | 88853844 |
| B32* | 341 | 45.79 | 88803847 |
| | 342 | 45.69 | 88773845 |
| B33* | 343 | 44.52 | 88823851 |
| B34* | 344 | 47.02 | 88843861 |
| B35* | 345 | 47.46 | 88883865 |
| B36* | 346 | 22.00 | 88863834 |
| B37* | 347 | 17.04 | 88943836 |
| | 348 | 17.91 | 88903829 |
| B38 | 349 | 7.75 | 86423564 |
| | 350 | 7.59 | 86433560 |
| | 351 | 7.05 | 86443555 |
| | 352 | 7.42 | 86443551 |
| T26 | 353 | 16.33 | 86363564 |
| | 354 | 16.08 | 86323563 |
| | 355 | 15.76 | 86293562 |
| | 356 | 16.50 | 86333558 |
| | 357 | 16.92 | 86.343555 |
| | 358 | 16.57 | 86353550 |
| | 359 | 15.86 | 86373547 |
| T27 | 360 | 33.40 | 85903558 |
| | 361 | 34.90 | 85833556 |
| | 362 | 34.87 | 85793552 |
| | 363 | 34.72 | 85753552 |
| | 364 | 34.67 | 85703551 |
| | 365 | 34.41 | 85663550 |

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| | 366 | 34.61 | 85623547 |
| B39 | 367 | 5.79 | 85523544 |
| | 368 | 5.13 | 85593545 |
| D1 | 369 | 38.34 | 85113553 |
| | 370 | 37.87 | 85093556 |
| B40 | 371 | 9.27 | 83623530 |
| | 372 | 9.84 | 83563527 |
| | 373 | 9.92 | 83463524 |
| B41 | 374 | 5.25 | 83323528 |
| | 375 | 4.81 | 83263529 |
| | 376 | 4.56 | 83213529 |
| T28 | 377 | 33.12 | 83703541 |
| T29 | 378 | 30.49 | 83553540 |
| | 379 | 30.46 | 83493539 |
| | 380 | 29.81 | 83453539 |
| | 381 | 29.34 | 83413539 |
| | 382 | 28.74 | 83333539 |
| | 383 | 28.57 | 83293540 |
| | 384 | 28.29 | 83243540 |
| | 385 | 27.76 | 83203542 |
| | 386 | 27.44 | 83163545 |
| | 387 | 26.99 | 83133549 |
| | 388 | 25.93 | 83113558 |
| | 389 | 26.72 | 83063559 |
| B42* | 390 | 23.91 | 83403833 |
| | 391 | 24.88 | 83383831 |
| | 392 | 24.86 | 83353828 |
| B43* | 393 | 23.30 | 83433842 |
| | 394 | 24.78 | 83513843 |
| | 395 | 24.42 | 83513845 |
| B44 | 396 | 5.14 | 83233841 |
| | 397 | 5.91 | 83223837 |
| P3 | 398 | 34.31 | 83743847 |
| | 399 | 34.77 | 83783849 |
| | 400 | 34.48 | 83823851 |
| | 401 | 34.02 | 83863853 |
| | 402 | 34.26 | 83913852 |
| | 403 | 34.87 | 83963854 |
| B45 | 404 | 21.56 | 83683858 |
| | 405 | 21.21 | 83723860 |
| | 406 | 21.48 | 83763861 |
| | 407 | 21.58 | 83803863 |
| B46 | 408 | 17.51 | 83833864 |
| | 409 | 18.22 | 83673862 |
| | 410 | 18.50 | 83613861 |
| | 411 | 18.12 | 83583860 |
| | 412 | 17.77 | 83543860 |
| B47 | 413 | 25.03 | 84063868 |
| | 414 | 25.86 | 84023866 |
| | 415 | 26.27 | 83983864 |
| | 416 | 25.98 | 83953863 |
| B48 | 417 | 8.11 | 84013880 |
| | 418 | 8.16 | 83983877 |
| D2 | 419 | 29.49 | 84213867 |
| | 420 | 27.74 | 84233870 |
| | 421 | 26.48 | 84203872 |
| | 422 | 25.07 | 84153873 |
| | 423 | 23.92 | 84103874 |
| D3 | 424 | 29.65 | 84293874 |
| | 425 | 29.34 | 84313878 |
| | 426 | 27.78 | 84273876 |
| | 427 | 26.76 | 84223877 |
| | 428 | 25.48 | 84183879 |
| | 429 | 25.48 | 84153881 |
| D4 | 430 | 29.05 | 84313882 |
| | 431 | 28.06 | 84283881 |
| | 432 | 27.31 | 84253881 |
| | 433 | 26.87 | 84213882 |
| | 434 | 26.05 | 84193883 |
| | 435 | 25.39 | 84153885 |
| | 436 | 25.32 | 84123885 |
| | 437 | 26.62 | 84133889 |
| B49* | 438 | 31.40 | 84303887 |
| | 439 | 31.48 | 84283887 |
| | 440 | 31.51 | 84253888 |
| | 441 | 30.69 | 84213889 |
| B50 | 442 | 7.04 | 84073898 |
| | 443 | 6.68 | 84083901 |
| B51 | 444 | 5.96 | 84103903 |
| | 445 | 6.39 | 84143906 |

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| B52 | 446 | 9.46 | 84183906 |
| B53 | 447 | 5.71 | 84093942 |
| | 448 | 5.70 | 84083937 |
| | 449 | 5.61 | 84083933 |
| | 450 | 5.63 | 84093928 |
| B54 | 451 | 7.67 | 84153936 |
| | 452 | 7.85 | 84163932 |
| | 453 | 7.90 | 84173928 |
| | 454 | 8.09 | 84183925 |
| B55 | 455 | 8.58 | 83943960 |
| | 456 | 9.40 | 83973956 |
| B56 | 457 | 18.08 | 84003957 |
| | 458 | 17.95 | 84033955 |
| R14 | 459 | 26.86 | 84043963 |
| | 460 | 26.71 | 84073959 |
| | 461 | 28.17 | 84153956 |
| | 462 | 27.97 | 84173954 |
| | 463 | 26.93 | 84193949 |
| | 464 | 26.79 | 84193943 |
| | 465 | 26.44 | 84213939 |
| | 466 | 26.30 | 84233934 |
| | 467 | 26.09 | 84263930 |
| D5 | 468 | 24.03 | 84633940 |
| | 469 | 26.59 | 84573939 |
| | 470 | 28.01 | 84533939 |
| | 471 | 27.74 | 84493938 |
| | 472 | 27.51 | 84453937 |
| | 473 | 26.86 | 84403937 |
| | 474 | 26.18 | 84363937 |
| | 475 | 25.24 | 84313937 |
| | 476 | 24.68 | 84263936 |
| D6 | 477 | 25.21 | 83853995 |
| | 478 | 24.51 | 83813995 |
| | 479 | 24.25 | 83773995 |
| | 480 | 23.57 | 83733996 |
| | 481 | 24.04 | 83693996 |
| | 482 | 24.86 | 83653995 |
| | 483 | 24.01 | 83653992 |
| | 484 | 23.77 | 83613995 |
| | 485 | 21.80 | 83603994 |
| | 486 | 17.68 | 83553993 |
| D7 | 487 | 24.53 | 83723986 |
| | 488 | 23.03 | 83703983 |
| | 489 | 19.28 | 83673981 |
| | 490 | 15.98 | 83643978 |
| B57 | 491 | 7.58 | 83523990 |
| | 492 | 8.24 | 83493993 |
| | 493 | 8.52 | 83473997 |
| B58 | 494 | 27.93 | 83444015 |
| | 495 | 27.12 | 83404017 |
| | 496 | 26.73 | 83364018 |
| | 497 | 26.91 | 83324022 |
| | 498 | 26.58 | 83314026 |
| | 499 | 26.13 | 83314031 |
| | 500 | 25.85 | 83294036 |
| | 501 | 25.35 | 83254043 |
| R15 | 502 | 9.67 | 83194019 |
| | 503 | 9.60 | 83154021 |
| | 504 | 9.26 | 83104024 |
| | 505 | 9.46 | 83064026 |
| B59 | 506 | 16.98 | 83164031 |
| | 507 | 16.20 | 83134034 |
| | 508 | 15.50 | 83114037 |
| | 509 | 15.28 | 83094041 |
| | 510 | 15.90 | 83084046 |
| | 511 | 16.39 | 83064049 |
| B60 | 512 | 24.53 | 83144062 |
| | 513 | 24.74 | 83154066 |
| | 514 | 24.48 | 83124067 |
| B61 | 515 | 4.63 | 83214092 |
| | 516 | 5.0 | 83184088 |
| | 517 | 5.48 | 83154084 |
| | 518 | 5.95 | 83124081 |
| B62 | 519 | 6.05 | 83134080 |
| | 520 | 6.40 | 83084078 |
| | 521 | 6.85 | 83054075 |
| | 522 | 7.25 | 83034071 |
| B63 | 523 | 2.55 | 82844119 |

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|---|---|---|---|
| | 524 | 3.76 | 82784111 |
| | 525 | 3.83 | 82764104 |
| B64 | 526 | 3.55 | 82674096 |
| | 527 | 3.29 | 82614092 |
| | 528 | 3.15 | 82554088 |
| D8 | 529 | 14.65 | 82134059 |
| | 530 | 14.50 | 82164058 |
| B65 | 531 | 8.86 | 82134038 |
| | 532 | 8.95 | 82134030 |
| | 533 | 9.01 | 82114022 |
| B66 | 534 | 5.46 | 81884001 |
| | 535 | 5.08 | 81834000 |
| | 536 | 4.67 | 81793998 |
| T30 | 537 | 58.73 | 92965634 |
| | 538 | 57.37 | 92905629 |
| | 539 | 55.68 | 92855625 |
| | 540 | 53.65 | 92795621 |
| | 541 | 51.58 | 92725618 |
| | 542 | 49.87 | 92665615 |
| | 543 | 47.50 | 92605611 |
| | 544 | 45.74 | 92535607 |
| T31 | 545 | 41.60 | 92295595 |
| | 546 | 39.34 | 92225591 |
| T32 | 547 | 38.14 | 91625550 |
| T33 | 548 | 27.71 | 91605550 |
| | 549 | 30.14 | 91575550 |
| T34 | 550 | 25.22 | 91545548 |
| | 551 | 24.38 | 91525546 |
| T35 | 552 | 25.02 | 91215565 |
| | 553 | 24.60 | 91185567 |
| | 554 | 24.50 | 91165569 |
| | 555 | 24.13 | 91135568 |
| T36 | 556 | 23.63 | 91105572 |
| | 557 | 22.92 | 91075573 |
| | 558 | 21.98 | 91045572 |
| | 559 | 22.19 | 91015571 |
| | 560 | 21.87 | 90975572 |
| | 561 | 21.36 | 90935572 |
| T37 | 562 | 20.94 | 90885571 |
| T38 | 563 | 20.55 | 90805573 |
| | 564 | 20.45 | 90775577 |
| | 565 | 19.92 | 90735580 |
| T39 | 566 | 19.67 | 90695583 |
| T40 | 567 | 19.56 | 90655584 |
| | 568 | 19.31 | 90605585 |
| | 569 | 18.68 | 90555586 |
| | 570 | 18.78 | 90505586 |
| F3 | 571 | 17.52 | 91005549 |
| | 572 | 16.95 | 90925550 |
| | 573 | 16.07 | 90835550 |
| | 574 | 14.55 | 90755551 |
| | 575 | 12.85 | 90635552 |
| | 576 | 11.13 | 90545553 |
| | 577 | 10.16 | 90455553 |
| | 578 | 9.28 | 90375554 |
| | 579 | 8.58 | 90305555 |
| | 580 | 7.38 | 90235555 |
| | 581 | 7.67 | 90165556 |
| | 582 | 7.20 | 90095556 |
| R16 | 583 | 8.79 | 90055573 |
| | 584 | 8.56 | 90045569 |
| | 585 | 8.51 | 90035564 |
| | 586 | 8.34 | 89995552 |
| | 587 | 7.90 | 90035552 |
| | 588 | 8.24 | 89985549 |
| | 589 | 8.12 | 89975546 |
| | 590 | 8.02 | 89995543 |
| | 591 | 7.96 | 90005539 |
| | 592 | 7.74 | 90015535 |
| R17 | 593 | 8.10 | 90035547 |
| | 594 | 8.27 | 90055545 |
| R18 | 595 | 7.67 | 90045543 |
| | 596 | 7.18 | 90065540 |
| R27 | 597 | 8.87 | 90045518 |
| R20 | 598 | 20.94 | 81655379 |
| | 599 | 20.95 | 81625372 |
| R21 | 600 | 20.84 | 81595383 |
| | 601 | 20.68 | 81595387 |
| | 602 | 20.99 | 81605392 |
| | 603 | 20.88 | 81615397 |

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|---|---|---|---|
| | 604 | 21.15 | 81625401 |
| | 605 | 21.41 | 81615406 |
| | 606 | 20.95 | 81615410 |
| R22 | 607 | 22.36 | 81655420 |
| | 608 | 22.90 | 81665425 |
| B67 | 609 | 21.81 | 81585508 |
| | 610 | 21.66 | 81575503 |
| | 611 | 20.90 | 81575498 |
| B68 | 612 | 6.92 | 81505499 |
| | 613 | 7.21 | 81515497 |
| B69 | 614 | 19.78 | 81575525 |
| | 615 | 20.17 | 81565520 |
| | 616 | 20.13 | 81545517 |
| | 617 | 20.22 | 81515513 |
| B70 | 618 | 6.97 | 81515524 |
| | 619 | 7.04 | 81495520 |
| | 620 | 6.40 | 81485517 |
| | 621 | 6.89 | 81475512 |
| B71 | 622 | 16.74 | 81675539 |
| | 623 | 17.56 | 81685535 |
| | 624 | 17.62 | 81685531 |
| B72 | 625 | 8.74 | 81825540 |
| | 626 | 8.77 | 81835534 |
| B73 | 627 | 8.61 | 71924582 |
| | 628 | 8.88 | 71914578 |
| | 629 | 8.60 | 71944574 |
| | 630 | 8.72 | 71914564 |
| | 631 | 8.87 | 71924560 |
| | 632 | 8.74 | 71954556 |
| T41 | 633 | 7.63 | 71864591 |
| | 634 | 6.94 | 71874588 |
| | 635 | 6.48 | 71864584 |
| | 636 | 6.25 | 71854580 |
| | 637 | 6.23 | 71854575 |
| | 638 | 5.99 | 71834572 |
| | 639 | 5.76 | 71804569 |
| | 640 | 5.70 | 71784566 |
| | 641 | 5.18 | 71774563 |
| | 642 | 5.42 | 71754558 |
| R23 | 643 | 6.31 | 71644556 |
| | 644 | 6.58 | 71664553 |
| | 645 | 6.51 | 71684550 |
| | 646 | 6.43 | 71714548 |
| R24 | 647 | 7.47 | 71734539 |
| | 648 | 7.56 | 71634536 |
| | 649 | 7.31 | 71794532 |
| | 650 | 7.75 | 71754530 |
| | 651 | 7.34 | 71734534 |
| R25 | 652 | 4.67 | 71574551 |
| | 653 | 4.62 | 71584548 |
| R26 | 654 | 5.92 | 71614536 |
| | 655 | 7.03 | 71644534 |
| | 656 | 7.28 | 71664531 |
| | 657 | 7.41 | 71674527 |
| | 658 | 6.69 | 71704524 |
| | 659 | 6.27 | 71734521 |
| | 660 | 5.98 | 71764517 |
| x B74 | 661 | 30.26 | 71504468 |
| | 662 | 30.49 | 71464466 |
| | 663 | 30.82 | 71424464 |
| x B75 | 664 | 31.34 | 71364457 |
| | 665 | 31.35 | 71344453 |
| x B76 | 666 | 32.35 | 71394455 |
| | 667 | 32.41 | 71364452 |
| x B77 | 668 | 30.98 | 71354441 |
| x B78 | 669 | 31.00 | 71264439 |
| | 670 | 31.52 | 71234436 |
| x B79 | 671 | 30.99 | 71104434 |
| | 672 | 30.87 | 71074430 |
| | 673 | 31.16 | 71044426 |
| B80 | 674 | 6.96 | 71174456 |
| | 675 | 7.08 | 71124453 |
| B81 | 676 | 5.38 | 71144457 |
| | 677 | 5.72 | 71094454 |
| P4 | 678 | 34.46 | 68285051 |
| | 679 | 34.87 | 68295057 |
| | 680 | 34.75 | 68315068 |
| | 681 | 35.43 | 68305074 |
| P5 | 682 | 35.80 | 68275086 |
| | 683 | 34.92 | 68265092 |

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|---|---|---|---|
| P6 | 684 | 36.31 | 68325112 |
| | 685 | 35.70 | 68345116 |
| | 686 | 35.18 | 68375120 |
| | 687 | 35.32 | 68405124 |
| | 688 | 36.67 | 68455126 |
| | 689 | 36.16 | 68505132 |
| P7 | 690 | 36.42 | 68485171 |
| | 691 | 35.57 | 68485178 |
| T42 | 692 | 30.69 | 68835316 |
| | 693 | 30.47 | 68845323 |
| | 694 | 29.26 | 68865330 |
| | 695 | 28.94 | 68885337 |
| P8 | 696 | 27.66 | 68895344 |
| | 697 | 27.84 | 68905350 |
| | 698 | 27.78 | 68925357 |
| | 699 | 28.68 | 68965365 |
| | 700 | 28.18 | 68985375 |
| | 701 | 27.69 | 69005382 |
| | 702 | 27.45 | 69025390 |
| | 703 | 27.58 | 69055399 |
| | 704 | 27.53 | 69095404 |
| | 705 | 27.68 | 69165409 |
| P9 | 706 | 27.44 | 69435446 |
| | 707 | 28.60 | 69435453 |
| | 708 | 27.38 | 69435460 |
| | 709 | 28.75 | 69485483 |
| | 710 | 27.91 | 69485489 |
| | 711 | 30.35 | 69495498 |
| | 712 | 29.55 | 69495504 |
| | 713 | 29.83 | 69485520 |
| | 714 | 30.12 | 69495532 |
| | 715 | 29.46 | 69485541 |
| | 716 | 30.79 | 69495550 |
| | 717 | 29.12 | 69485557 |
| | 718 | 29.46 | 694955564 |
| | 719 | 29.24 | 69505570 |
| | 720 | 29.49 | 69515576 |
| | 721 | 29.31 | 69505592 |
| | 722 | 28.92 | 69495599 |
| P10 | 723 | 29.12 | 69575656 |
| | 724 | 30.16 | 69595663 |
| | 725 | 30.01 | 69615670 |
| | 726 | 29.19 | 69595679 |
| P11 | 727 | 27.04 | 69625746 |
| | 728 | 27.32 | 69675751 |
| | 729 | 26.53 | 69735761 |
| | 730 | 26.14 | 69795758 |
| | 731 | 26.98 | 69865761 |
| | 732 | 26.73 | 69925761 |
| T43 | 740 | 44·64 | 96134518 |

# APPENDIX B.

THE POLLEN COUNTS 1. GLASSCNOCK.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alnus | | | | | | | | | | | | | | | |
| Armeria | | | | | | | | | | | | | | | |
| Artemisia | 2 | 3 | 3 | 8 | 3 | 8 | 5 | 7 | 6 | 6 | 5 | 3 | 8 | 10 | 3 |
| Betula | 31 | 18 | 10 | 35 | 7 | 5 | 6 | 1 | 6 | 13 | 20 | 15 | 6 | 4 | 2 |
| B. nana | 5 | | 1 | 4 | 1 | 2 | 1 | 1 | | 1 | 2 | 4 | 3 | | |
| Caltha | | | | | | | | | | | | | | | |
| Caryophyllaceae | | | 1 | 1 | | 1 | 1 | | 1 | | 2 | 1 | | 2 | |
| Chenopodiaceae | | | | | | | | 1 | | 1 | | 1 | | | |
| Compositae undiff. | 2 | 3 | 1 | 1 | 2 | | 4 | 4 | 4 | | 2 | 1 | 3 | 1 | 3 |
| Corylus/Myrica | | | | | | | | | | | | | | | |
| Cruciferae | | | | | | | | | | | | | | | |
| Cyperaceae | 106 | 67 | 75 | 70 | 76 | 29 | 16 | 6 | 26 | 42 | 57 | 62 | 92 | 74 | 87 |
| Drosera | | | | | | | | | | | | | | | |
| Dryas | | | | | | | | | | | | | | | |
| Dryopteris | | | | | | 6 | | | | | | 12 | | | |
| Empetrum | 204 | 28 | 27 | 199 | 73 | 18 | 34 | 14 | 12 | 40 | 159 | 118 | 199 | 185 | 147 |
| Epilobium | 1 | 1 | 1 | | | 1 | 2 | 5 | 9 | | 6 | | 9 | 8 | 10 |
| Equisetum | | 6 | 11 | 1 | 2 | | | | | 16 | | 5 | | | |
| Ericaceae | | | | | | | | | | | | | | | |
| Filipendula | | | | | | | | | | | | | | | |
| Filicineae | 9 | 23 | 45 | 20 | 32 | 29 | 14 | 31 | 29 | 10 | 3 | 11 | 9 | 15 | 30 |
| Galium | | | | | | | | | | | | | | | |
| Gramineae | 48 | 26 | 53 | 36 | 42 | 43 | 34 | 22 | 53 | 39 | 49 | 36 | 59 | 47 | 25 |
| Helianthemum | | 6 | 6 | 1 | 2 | 1 | 14 | 8 | 9 | 7 | 1 | 3 | 1 | 1 | |
| Hippophae | | | | | | | | | | | | | | | |
| Juniperus | 15 | 8 | 3 | 3 | | | 2 | 1 | | 3 | | 1 | | 2 | |
| Koenigia | | | | | | | | | | | | | | | |
| Labiatae | | | | | | | | | | | 1 | | | | |
| Leguminosae | | | | | | | | 1 | | | | | | | |
| Liguliflorae | | | 1 | 2 | 3 | 4 | 3 | 5 | | 1 | 2 | 1 | | 1 | |
| Lycopodium undiff. | 17 | 3 | 15 | 6 | 58 | 28 | 22 | 30 | 16 | 15 | 24 | 8 | 11 | 12 | 3 |
| L. selago | 24 | 20 | 25 | 18 | 40 | 34 | 30 | 34 | 36 | 30 | 17 | 15 | 13 | 16 | 15 |
| Menyanthes | 4 | 5 | 1 | 2 | | | | 1 | | | | | 1 | | |
| Myriophyllum | 7 | 9 | 16 | 10 | 7 | 2 | 2 | 6 | 10 | 12 | 3 | 5 | 1 | | 1 |
| Nuphar | | | | | | | | | | | | | | | |
| Nymphaea | | | | | | | | | | | | | | | |
| Pinus | 9 | 1 | 2 | 2 | 3 | | | | 2 | 1 | 3 | 1 | 7 | 4 | 2 |
| Plantago undiff. | 1 | 3 | 1 | 1 | 1 | 3 | | | 1 | | | | | | |
| P. maritima | | | | | | | | | | | | | | | |
| Polygonum | | | | | | | | | 2 | 1 | | | | | |
| Polypodiaceae | 145 | 119 | 145 | 166 | 129 | 379 | 352 | 336 | 218 | 178 | 168 | 134 | 120 | 163 | 175 |
| P. vulgare | 21 | 19 | 23 | 11 | 36 | 43 | 46 | 46 | 43 | 22 | 29 | 18 | 38 | 70 | 75 |
| Populus | | | | | | | | | | | | | | | |
| Potamogeton | 2 | | | | | 1 | 1 | | 2 | | | | | | |
| Quercus | | | | | | | | | | | | | | | |
| Ranunculaceae | 1 | 4 | | | 2 | 2 | 1 | 1 | | 3 | 1 | | | 4 | |
| Rosacae | 1 | | 1 | | 1 | | | | | | | | 1 | 1 | 1 |
| Rubus | | | | | | | | | | | | | | | |
| Rumex | 41 | 55 | 99 | 60 | 33 | 35 | 42 | 33 | 60 | 88 | 22 | 38 | 12 | 7 | 3 |
| Salix | 3 | 16 | 12 | 10 | 4 | 4 | 4 | 4 | 4 | 6 | 19 | 4 | 6 | 5 | 6 |
| Saxifraga | | | | | | | | | | | | | | | |
| Scheuchzeria | | | | | | | | | | | | | | | |
| Selaginella | | | | | | | | | | | | | 2 | | 2 |
| Sparganium | | | | | 1 | 1 | | | | | | | | | |
| Succisa | | | | 1 | | | | | | | | | | | |
| Thalictrum | 2 | 3 | | 2 | 3 | | | 1 | 2 | 2 | 6 | 1 | 5 | 7 | 1 |
| Tilia | | | | | | | | | | | | | | | |
| Typha | | | | | | | | | | | | | | | |
| Ulmus | 1 | 1 | | | 1 | | | | | 1 | | | | | |
| Umbelliferae | | | | | | 1 | | | 1 | | | 2 | 1 | 2 | |
| Urtica | | | | | | | | | | | | | | | |
| Valeriana | | | | | | | | | | | | | | | |

| | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alnus | | | | | | | | | | | | | | | |
| Armeria | | | | | | | | | | | | | | | |
| Artemisia | 6 | | 6 | 5 | 4 | 8 | 6 | 1 | | | | | | | |
| Betula | 3 | 5 | 10 | 4 | 2 | 2 | 6 | 1 | 2 | | 1 | 4 | 2 | 1 | 4 |
| B. nana | 1 | 2 | 2 | 2 | 4 | 2 | 1 | 1 | | | | | | | |
| Caltha | | | | | | | | | | | | | | | |
| Caryophyllaceae | | 2 | 1 | 2 | 1 | 2 | 3 | 1 | | 3 | | 1 | | | 3 |
| Chenopodiaceae | | | | | | | | | | | | | | | |
| Compositae undiff. | 2 | 1 | 3 | 4 | 2 | | 4 | 5 | 3 | | | 2 | 2 | 2 | 1 |
| Corylus/Myrica | | | | | | | | | | | | | | | |
| Cruciferae | | | | | | | | | | | | | | | |
| Cyperaceae | 67 | 81 | 95 | 97 | 88 | 41 | 67 | 35 | 29 | 41 | 33 | 53 | 49 | 52 | 40 |
| Drosera | | | | | | | | | | | | | | | |
| Dryas | | | | | | | | | | 1 | | | | | |
| Dryopteris | | 1 | | 1 | | | | | | | | | | | |
| Empetrum | 213 | 244 | 223 | 267 | 136 | 167 | 153 | 29 | 7 | 3 | 2 | 4 | 9 | 7 | 9 |
| Epilobium | 6 | 13 | 12 | 17 | 1 | 5 | 7 | | | 1 | | | | | |
| Ericaceae | | | | 2 | | | 1 | | | | | | | | |
| Filipendula | | | | | | | | | | | | | | | |
| Filicineae | 30 | 62 | 47 | 42 | 33 | 60 | 48 | 19 | 1 | 2 | 2 | 1 | 4 | 2 | 3 |
| Gramineae | 73 | 64 | 72 | 112 | 98 | 52 | 82 | 35 | 22 | 20 | 29 | 18 | 38 | 43 | 20 |
| Gentiana | | 2 | | | 4 | 2 | 2 | 2 | 2 | 1 | | | 1 | | |
| Helianthemum | 1 | 1 | 2 | | 1 | | | | | | | 1 | | | 1 |
| Hippophae | | | | | | | | | | | | | | | |
| Juniperus | 1 | 6 | 3 | 11 | 5 | 3 | | 1 | | 1 | 2 | | 1 | 5 | 4 |
| Koenigia | 1 | 1 | | | | | | | | | | | | | |
| Labiatae | | | | | | | | | | | | | | | |
| Leguminosae | | | | | | | | | | | | | | | |
| Liguliflorae | | 2 | | | 2 | | 2 | 1 | 1 | 1 | | | | | |
| Lycopodium undiff. | 10 | 4 | 10 | 12 | 21 | 10 | 7 | 3 | | | 1 | 1 | | 1 | |
| L. selago | 12 | 14 | 14 | 11 | 19 | 12 | 13 | 4 | | | | | | 1 | 1 |
| Menyanthes | | 1 | | 1 | | | 1 | | | | | | | | |
| Myriophyllum | 2 | | | 3 | | | | | | | | | | | |
| Nuphar | | | | | | | | | | | | | | | |
| Nymphaea | | | | | | | | | | | | | | | |
| Pinus | 7 | 1 | 9 | 1 | 4 | 4 | 3 | 5 | 2 | 2 | | 1 | | 1 | 3 |
| Plantago undiff. | | | | | | | | | | | | | | | |
| P. maritima | | | | | | | | | | | | | | | |
| Polygonum | | | | | | | | | | | | | | | |
| Polypodiaceae | 167 | 148 | 142 | 107 | 94 | 154 | 133 | 40 | 7 | 6 | 8 | 2 | | 3 | 7 |
| P.vulgare | 51 | 34 | 33 | 18 | 10 | 24 | 18 | 7 | | | | | | | |
| Populus | | | | | | | | | | | | | | | |
| Potamogeton | | | 1 | | | | | | | | | | | | |
| Quercus | | | | | | | | | | | | | | | |
| Ranunculaceae | 1 | 1 | | 2 | 4 | | 2 | | | 2 | 1 | 2 | 1 | | |
| Rosaceae | | 1 | 1 | 1 | 1 | 1 | | 1 | | 1 | | | | | |
| Rubus | | | | | | | | | | | | | | | |
| Rumex | 1 | 6 | 5 | 5 | 14 | 2 | 6 | 3 | | 1 | 3 | 6 | 1 | 2 | 3 |
| Salix | 23 | 15 | 17 | 18 | 23 | 10 | 10 | 4 | | 2 | | 2 | 6 | 3 | |
| Saxifraga | | | | | 4 | 1 | 2 | 2 | 2 | | | | | 2 | 1 |
| Scheuchzeria | | | | | | | | | | | | | | | |
| Selaginella | 2 | | 2 | | | | | | | | | | | | |
| Sphagnum | | | | | | | 2 | | | | | | | | 1 |
| Succisa | | | | | | | | | | | | | | | |
| Thalictrum | 5 | 5 | 2 | 3 | | 1 | 1 | 2 | | | | 1 | | 1 | |
| Tilia | | 1 | | | | | | | | | | | | | |
| Typha | | | | | | | | | | | | | | | |
| Ulmus | | | | | | | | | | | | | | | |
| Umbelliferae | | 1 | | 1 | | | | | | | | | | | 1 |
| Urtica | | | | | | | | | | | | | | | |
| Valeriana | | | | | | | | | | | | | | | |

| | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alnus | | | | | | | | | | | | | | | | |
| Armeria | 1 | | | | | | | | | | | | | | | |
| Artemisia | | 1 | 3 | | 2 | 6 | 2 | 1 | 1 | 5 | 1 | 1 | 1 | 1 | 1 | |
| Betula | 1 | 1 | 2 | 2 | 2 | 4 | 4 | 2 | 8 | 5 | 15 | 24 | 25 | 28 | 40 | 53 |
| B. nana | | | | | | | | | | | | | | | | |
| Caltha | | | | | | | | | | | | | | | | |
| Caryophyllaceae | 1 | 1 | 1 | 1 | | 14 | 1 | 1 | | 1 | | | | | | |
| Chenopodiaceae | | | | | | | | | | | | | | | | 1 |
| Compositae undiff. | 4 | 3 | 1 | | 1 | | | 2 | 2 | 1 | 1 | 1 | 1 | 2 | | |
| Corylus/Myrica | | | | | | | | | | | | | | | 1 | |
| Cruciferae | | | | | | | | | | | | | | | | |
| Cyperaceae | 48 | 35 | 43 | 42 | 31 | 77 | 61 | 40 | 59 | 54 | 45 | 37 | 47 | 33 | 40 | 45 |
| Drosera | | | | | | | | | | | | | | | | |
| Dryas | | | | | | | 1 | | | | | | | | | |
| Dryopteris | | | | | | | | | | | | | | | | |
| Empetrum | 6 | 3 | 6 | 15 | 13 | 11 | 10 | 9 | 21 | 21 | 41 | 57 | 66 | 89 | 84 | 74 |
| Epilobium | | 1 | 3 | 1 | | | | | | | | 2 | 1 | 1 | | |
| Equisetum | | | | | | 2 | 6 | 7 | 10 | 31 | 29 | 10 | 13 | 11 | 7 | 1 |
| Ericaceae | 1 | | 2 | | | | 2 | | | | | 4 | 3 | | 2 | 4 |
| Filipendula | | | | | | | 6 | 9 | 13 | 10 | 10 | 8 | 4 | 3 | 1 | 9 |
| Filicineae | | 1 | 1 | 3 | 3 | 2 | 1 | 13 | 24 | 48 | 78 | 47 | 48 | 20 | 27 | 24 |
| Gramineae | 22 | 34 | 39 | 35 | 16 | 38 | 50 | 27 | 31 | 22 | 33 | 39 | 70 | 72 | 68 | 65 |
| Gentiana | 1 | 1 | 3 | 1 | 1 | | | | | | 2 | | | | 2 | |
| Helianthemum | | | 1 | | | | 2 | 1 | | | | | | | | |
| Hippophae | | | | 1 | | | | | | | | | | | | |
| Juniperus | 1 | 4 | 2 | 1 | 2 | 3 | 4 | 1 | 3 | 4 | 4 | | 4 | | 1 | 1 |
| Koenigia | | | | | | | | | | | | | | | | |
| Labiatae | | | | | | | | | | | | | | | | |
| Leguminosae | | | | | | | | | | | 1 | | | | | |
| Liguliflorae | 1 | | 1 | | | | | 3 | 1 | 4 | 3 | 3 | 1 | 4 | 3 | |
| Lycopodium undiff. | 2 | 3 | 1 | 4 | 5 | | 2 | 3 | 2 | 3 | 6 | 4 | 7 | 5 | 2 | 3 |
| L. selago | | | 1 | | 4 | 4 | | 4 | 11 | 10 | 6 | 2 | 10 | 4 | 3 | 1 |
| Menyanthes | | | | | | | | | | | 1 | 1 | 1 | 1 | | |
| Myriophyllum | | 2 | 2 | 17 | 1 | 97 | 348 | 326 | 238 | 193 | 123 | 142 | 95 | 101 | 102 | 114 |
| Nuphar | | | | | | | | | | | | | | | | |
| Nymphaea | | | | | 1 | | | | | | | | | | | |
| Pinus | 1 | 1 | 1 | 4 | | 1 | 2 | 3 | | 1 | 3 | 4 | 3 | 7 | 6 | 4 |
| Plantago undiff | | | | | | 3 | | | 1 | | | | | 5 | 4 | 4 |
| P. maritima | | | | | | | | | | | | | | | 2 | |
| P. lanceolata | | | | | 1 | | | | | | | | | | | 2 |
| Polypodiaceae | 11 | 11 | 12 | 33 | 7 | 12 | 12 | 19 | 35 | 133 | 133 | 189 | 193 | 149 | 177 | 136 |
| P. vulgare | | | | 1 | 1 | 2 | | 2 | 6 | 6 | 11 | 14 | 4 | 6 | 2 | 4 |
| Populus | | | | | | | | | | | | | | 1 | 4 | 1 |
| Potentilla | | | | | | | | 1 | 2 | 2 | | | 1 | 5 | 1 | |
| Potamogeton | | | | | | | | | | | | | | 4 | 5 | 8 |
| Ranunculaceae | | 3 | 4 | 1 | | 8 | 7 | 4 | 3 | 4 | 1 | 2 | 1 | 3 | | |
| Rosacae | 1 | | 2 | 1 | | | 1 | | | | 1 | | 1 | 2 | | |
| Rubus | | | 1 | | | | 1 | | | | 1 | | | | | |
| Rumex | 5 | 5 | 3 | 2 | 3 | 17 | 5 | 90 | 140 | 70 | 28 | 31 | 23 | 19 | 12 | 21 |
| Salix | 2 | 7 | 7 | 1 | 4 | 13 | 6 | 16 | 29 | 22 | 17 | 20 | 16 | 13 | 16 | 17 |
| Saxifraga | 3 | 3 | 2 | 1 | 1 | 5 | 4 | 3 | 2 | | 2 | 1 | | | | |
| Scheuchzeria | | | | | | | | | | 1 | | | | | | |
| Selaginella | | | | | | | | | | | | | | | | |
| Sphagnum | | | | | | | | | | | 1 | | | | | |
| Succisa | | | 1 | | | | 2 | | | | | | | | | |
| Thalictrum | | | | 1 | | 2 | 1 | 1 | | 1 | 2 | | | 1 | 2 | 1 |
| Tilia | | | | | | | | | | | | | | | | |
| Typha | | | | | | 1 | | | | | 1 | | | | | |
| Ulmus | 1 | | | | | | | | | | | | | | | 1 |
| Umbelliferae | | | | | | | | | | | 1 | | | | | |
| Urtica | | | | | | | | | | | | 1 | 2 | | | |
| Valeriana | | | | | | | | | | | | | | | | |

| | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alnus | | | | | | | | | | | | | | | | |
| Armeria | | | | | | 1 | | | | 1 | | 6 | 2 | 3 | 4 | 2 |
| Artemisia | 3 | | 2 | 2 | 2 | 1 | 3 | | 1 | 2 | 3 | 3 | 6 | 10 | 14 | 13 |
| Betula | 43 | 38 | 31 | 29 | 20 | 25 | 35 | 61 | 66 | 87 | 103 | 109 | 109 | 174 | 182 | 236 |
| B. nana | | | | | | | | | | | | | | | | |
| Caltha | 1 | 1 | | | | | | | | | 1 | | | | | |
| Caryophyllaceae | | | 2 | | 1 | | | | | | | | | | | |
| Compositae undiff. | 1 | 1 | 3 | | | | | 1 | | | | | 1 | | | |
| Corylus/Myrica | 5 | 4 | | | | | 2 | 5 | 14 | 5 | 17 | 43 | 17 | 31 | 37 | 43 |
| Cruciferae | | | | | 1 | | | | 1 | 3 | 6 | 17 | 20 | 4 | 2 | 1 |
| Cyperaceae | 42 | 33 | 49 | 72 | 33 | 38 | 33 | 62 | 55 | 97 | 80 | 68 | 63 | 45 | 38 | 59 |
| Drosera | | | | | | | | | | | | | | | | |
| Dryas | | | | | | | | | | | | 1 | | | | |
| Dryopteris | | | | | | | | | | | | | | | | |
| Empetrum | 101 | 103 | 78 | 83 | 101 | 76 | 68 | 79 | 67 | 53 | 74 | 85 | 53 | 40 | 15 | 11 |
| Epilobium | 1 | 1 | | | | | 1 | | | | | | | | | |
| Equisetum | 3 | 2 | 6 | 1 | 9 | 8 | 6 | 5 | 3 | 4 | 1 | 1 | | | 2 | 1 |
| Ericaceae | 2 | 2 | 1 | 18 | 5 | 12 | 1 | 17 | 6 | 24 | 8 | 19 | 18 | 17 | 23 | 29 |
| Filipendula | | 1 | 9 | 3 | 2 | 6 | 3 | | 4 | | 2 | 4 | 4 | 5 | 7 | 8 |
| Filicineae | 24 | 30 | 40 | 34 | 60 | 43 | 29 | 41 | 24 | 55 | 51 | 59 | 22 | 14 | 17 | 12 |
| Gramineae | 84 | 100 | 81 | 88 | 100 | 128 | 71 | 101 | 97 | 170 | 188 | 119 | 94 | 121 | 92 | 86 |
| Gentiana | | | | | | | | | | | | | | | | |
| Helianthemum | | | | | | | | | | | | | | | | |
| Hippophae | | | | | | | | | | | | | | | | |
| Juniperus | | | | | | | | | | | | | | | | |
| Koenigia | | | | | | | | | | | | | | | | |
| Labiatae | | | | | | | | | | 1 | | | | | | |
| Liguliflorae | | 3 | 2 | 1 | 2 | | | | 3 | 5 | 2 | 3 | 1 | | 2 | 1 |
| Lycopodium undiff. | 3 | | 2 | 4 | 6 | 5 | 3 | 2 | 3 | 2 | 1 | | | 1 | | |
| L. selago | 1 | | 2 | 4 | 2 | 5 | 6 | 4 | 3 | 3 | 1 | 1 | | 1 | | |
| Menyanthes | | 2 | 1 | 4 | 2 | 14 | 6 | 4 | 8 | 4 | 2 | 1 | 2 | | | 5 |
| Myriophyllum | 94 | 67 | 103 | 167 | 92 | 121 | 83 | 63 | 50 | 65 | 26 | 47 | 25 | 26 | 23 | 15 |
| Nuphar | | | | | | | | 1 | | | | | | | | |
| Nymphaea | | | | | | | | | | | | | | | | |
| Pinus | 2 | 3 | 7 | 8 | 4 | 3 | 6 | 9 | 6 | 6 | 3 | 8 | 1 | 5 | 3 | 7 |
| Plantago undiff. | | | | | | | | | | | | | | | | |
| P. lanceolata | | 1 | | | | | 1 | 4 | | | 1 | | | | | |
| P. maritima | 20 | 29 | 5 | 12 | 53 | 45 | 52 | 81 | 36 | 33 | 31 | 53 | 33 | 20 | 12 | 12 |
| Potamogeton | 33 | 49 | 5 | 27 | 46 | 10 | 3 | 15 | 16 | 24 | 7 | | | 1 | 3 | 1 |
| Polypodiaceae | 137 | 145 | 173 | 160 | 114 | 151 | 91 | 92 | 97 | 103 | 88 | 59 | 59 | 67 | 78 | 81 |
| Polypodium vulgare | 2 | 3 | 3 | 1 | | 1 | 2 | 4 | 2 | 2 | | 1 | 4 | | | |
| Populus | | | | | 1 | | | | | | | | | | | |
| Potentilla | | 1 | 4 | | 3 | 3 | 2 | 2 | 1 | 3 | | 2 | 1 | 3 | | |
| Quercus | | | | | | | | 2 | 1 | | | | 1 | | 4 | |
| Ranunculaceae | 2 | 4 | 3 | | 3 | 3 | 2 | 1 | 2 | 3 | 5 | 2 | 1 | 2 | 1 | 2 |
| Rosacae | 1 | | | | 1 | 1 | 1 | | | 1 | | | | 1 | | |
| Rubus | | | | | | | | | | | | | | | | |
| Rumex | 10 | 16 | 18 | 18 | 15 | 24 | 16 | 12 | 9 | 18 | 18 | 12 | 5 | 8 | 6 | 9 |
| Salix | 10 | 5 | 11 | 5 | 6 | 10 | 10 | 8 | 8 | 4 | 14 | 20 | 25 | 37 | 33 | 49 |
| Saxifraga | | | | | 2 | | 2 | 2 | 1 | | 1 | | | | | |
| Scheuchzeria | | | | | | | | | | | | | | | | |
| Selaginella | | | | | | | | | | | | | | | | |
| Sorbus | | | | | | | | | | | 1 | | 1 | | | 1 |
| Succisa | | | | | | | | | | | | | | | | |
| Thalictrum | 1 | 3 | 3 | 6 | 1 | 1 | 4 | 2 | 4 | 3 | 6 | 3 | 2 | 3 | 1 | 3 |
| Tilia | | | | | | | | | | | | | | | | |
| Typha | | | | | | | | 1 | | | | | | | | |
| Ulmus | | | | | 1 | 2 | | | | | 1 | 3 | | | 4 | 1 |
| Umbelliferae | | | | | | | | | 2 | 4 | 4 | 2 | 2 | | 1 | 2 |
| Urtica | 1 | 1 | | | | | | | | | | | | | | |
| Valeriana | | | 1 | | 1 | | | 2 | | | | | | | | |

2. DRUIM DUBH.

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Alnus | | | | 2 | | |
| Artemisia | 3 | 5 | 6 | 8 | 2 | 5 |
| Betula | 45 | 166 | 188 | 193 | 231 | 254 |
| Caryophyllaceae | 1 | 1 | 1 | | | |
| Compositae undiff. | | | | | 1 | |
| Corylus / Myrica | | | | | 3 | 39 |
| Cruciferae | 1 | 1 | | | | 2 |
| Cyperaceae | 52 | 45 | 30 | 24 | 24 | 9 |
| Drosera | | | | | | 1 |
| Dryas | 1 | | | | | |
| Empetrum | 115 | 164 | 149 | 101 | 73 | 29 |
| Epilobium | 2 | 1 | 1 | | | 1 |
| Ericaceae | | | | 6 | 22 | 52 |
| Filicineae | 25 | 8 | 14 | 15 | 10 | 10 |
| Filipendula | 3 | 5 | 11 | 45 | 19 | 7 |
| Gramineae | 168 | 144 | 164 | 96 | 136 | 90 |
| Helianthemum | | | 1 | | | |
| Juniperus | 5 | 6 | 11 | 1 | | |
| Labiatae | | 1 | | | | |
| Liguliflorae | 6 | 5 | 3 | 3 | 2 | |
| Lycopodium undiff. | 5 | | 1 | | 1 | 1 |
| Lycopodium selago | 2 | 1 | 1 | 1 | | 1 |
| Menyanthes | 2 | 4 | 1 | 4 | 2 | 3 |
| Myriophyllum | 5 | 4 | 2 | | 6 | 3 |
| Pinus | 6 | 8 | 11 | 9 | 13 | 8 |
| Plantago undiff. | | 3 | 3 | 19 | 32 | 27 |
| Polypodiaceae | 136 | 133 | 130 | 212 | 155 | 104 |
| Polypodium vulgare | 4 | 2 | 2 | 2 | 2 | |
| Potamogeton | | | | 1 | | 1 |
| Potentilla | | | | 2 | | |
| Quercus | | | 2 | | | |
| Ranunculaceae | 7 | | 3 | 5 | 1 | 2 |
| Rosacae | 2 | | 3 | 2 | | 2 |
| Rumex | 15 | 14 | 9 | 10 | 5 | 5 |
| Salix | 24 | 42 | 44 | 58 | 54 | 28 |
| Sanguisorba | | 1 | | | | |
| Saxifraga | | 4 | | 2 | 3 | |
| Selaginella | 1 | | | | | |
| Sorbus | | | | 2 | | |
| Thalictrum | | 1 | 6 | | 1 | |
| Ulmus | | 3 | 1 | | | 1 |
| Umbelliferae | | | 6 | 1 | 1 | |
| Valeriana | | 2 | | 2 | | |

# APPENDIX C.

The computed results of the SPLITINF and SPLITLSQ programs.

1. Glasscnock.

```
61        0.161
62

RESULTS OF SPLITINF

INF CONTENT     PERCENT OF TOTAL          MARKERS
  31.083618
  21.554779           69.34            35
  16.114014           51.84            23  35
 ** INVESTIGATE  29  28 IN GROUP   24 -  35
CONTENTS ARE    2.0142     2.0160
  12.711808           40.90            23  35  53
  10.639928           34.23            23  35  39  53
   8.651712           27.83            10  23  35  39  53
   7.699548           24.77             5  10  23  35  39  53
   7.093519           22.82             5  10  23  35  39  45  53
   6.523995           20.99             5  10  23  35  39  45  53  59
   6.050472           19.47             5  10  23  29  35  39  45  53  59
   5.711591           18.37             5  10  23  29  35  37  39  45  53  59
   5.409766           17.40             5  10  23  27  29  35  37  39  45  53  59
   5.133287           16.51             5  10  23  24  27  29  35  37  39  45  53  59
   4.911988           15.80             5  10  23  24  27  29  35  36  37  39  45  53  59
   4.692193           15.10             5  10  12  23  24  27  29  35  36  37  39  45  53  59
   4.476602           14.40             5  10  12  23  24  27  29  35  36  37  39  41  45  53  59
   4.268931           13.73             5  10  12  23  24  27  29  35  36  37  39  41  45  50  53  59
   4.062318           13.07             5   8  10  12  23  24  27  29  35  36  37  39  41  45  50  53  59
   3.863705           12.43             5   8  10  12  22  23  24  27  29  35  36  37  39  41  45  50  53  59
   3.667489           11.80             5   8  10  12  22  23  24  27  29  34  35  36  37  39  41  45  50  53  59
   3.400719           10.94             5   8  10  12  22  23  24  27  29  33  34  35  36  37  39  41  45  50  53  59

   3.157855           10.16             5   8  10  12  22  23  24  27  29  31  33  34  35  36  37  39  41  45  50  53
                                           59
   2.985517            9.60             5   8  10  12  22  23  24  26  27  29  31  33  34  35  36  37  39  41  45  50
                                           53  59
   2.819825            9.07             5   8  10  12  22  23  24  25  26  27  29  31  33  34  35  36  37  39  41  45
                                           50  53  59
   2.674835            8.61             5   8  10  12  22  23  24  25  26  27  29  31  33  34  35  36  37  39  41  45
                                           50  53  56  59
```

| | | |
|---|---|---|
| 2,536562 | 8,16 | 5 8 10 12 22 23 24 25 26 27 28 29 31 33 34 35 36 37 39 41 45 50 53 56 59 |
| 2,400242 | 7,72 | 5 8 10 12 22 23 24 25 26 27 28 29 30 31 33 34 35 36 37 39 41 45 50 53 56 59 |
| 2,274407 | 7,32 | 1 5 8 10 12 22 23 24 25 26 27 28 29 30 31 33 34 35 36 37 39 41 45 50 53 56 59 |
| 2,029284 | 6,53 | 1 3 5 8 10 12 22 23 24 25 26 27 28 29 30 31 33 34 35 36 37 39 41 45 50 53 56 59 |
| 1,911895 | 6,15 | 1 3 5 8 10 12 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 45 50 53 56 59 |
| 1,797249 | 5,78 | 1 3 4 5 8 10 12 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 45 50 53 56 59 |
| 1,688784 | 5,43 | 1 3 4 5 8 9 10 12 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 45 50 53 56 59 |
| 1,589339 | 5,11 | 1 3 4 5 8 9 10 12 15 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 45 50 53 56 59 |
| 1,499977 | 4,83 | 1 3 4 5 8 9 10 12 15 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 45 49 50 53 56 59 |
| 1,404530 | 4,52 | 1 3 4 5 8 9 10 12 15 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 45 46 49 50 53 56 59 |
| 1,325491 | 4,26 | 1 3 4 5 8 9 10 12 15 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 45 46 47 49 50 53 56 59 |
| 1,249772 | 4,02 | 1 3 4 5 8 9 10 12 15 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 45 46 47 48 49 50 53 56 59 |
| 1,175303 | 3,78 | 1 3 4 5 8 9 10 12 15 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 45 46 47 48 49 50 53 54 56 59 |
| 1,107606 | 3,56 | 1 3 4 5 8 9 10 12 15 19 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 45 46 47 48 49 50 53 54 56 59 |
| 1,025709 | 3,30 | 1 3 4 5 8 9 10 12 15 19 20 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 45 46 47 48 49 50 53 54 56 59 |
| 0,958434 | 3,08 | 1 3 4 5 8 9 10 12 15 19 20 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 42 45 46 47 48 49 50 53 54 56 59 |
| 0,891672 | 2,87 | 1 3 4 5 8 9 10 12 15 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 41 42 45 46 47 48 49 50 53 54 56 59 |

| | | |
|---|---|---|
| 0,830023 | 2,67 | 1 3 4 5 8 9 10 12 15 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 40 41 42 45 46 47 48 49 50 53 54 56 59 |
| 0,770054 | 2,48 | 1 3 4 5 8 9 10 12 15 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 40 41 42 45 46 47 48 49 50 53 54 56 57 59 |
| 0,710203 | 2,28 | 1 3 4 5 8 9 10 12 15 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 39 40 41 42 45 46 47 48 49 50 53 54 56 57 59 60 |
| 0,651191 | 2,09 | 1 3 4 5 8 9 10 12 15 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 45 46 47 48 49 50 53 54 56 57 59 60 |
| 0,592361 | 1,91 | 1 3 4 5 8 9 10 12 15 16 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 45 46 47 48 49 50 53 54 56 57 59 60 |
| 0,536445 | 1,73 | 1 3 4 5 8 9 10 12 15 16 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 45 46 47 48 49 50 53 54 55 56 57 59 60 |
| 0,480702 | 1,55 | 1 3 4 5 8 9 10 12 13 15 16 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 45 46 47 48 49 50 53 54 55 56 57 59 60 |
| 0,425188 | 1,37 | 1 2 3 4 5 8 9 10 12 13 15 16 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 45 46 47 48 49 50 53 54 55 56 57 59 60 |
| 0,376539 | 1,21 | 1 2 3 4 5 8 9 10 12 13 15 16 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 45 46 47 48 49 50 52 53 54 55 56 57 59 60 |
| 0,332232 | 1,07 | 1 2 3 4 5 6 8 9 10 12 13 15 16 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 45 46 47 48 49 50 52 53 54 55 56 57 59 60 |
| 0,287928 | 0,93 | 1 2 3 4 5 6 8 9 10 12 13 15 16 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 44 45 46 47 48 49 50 52 53 54 55 56 57 59 60 |
| 0,244590 | 0,79 | 1 2 3 4 5 6 8 9 10 12 13 15 16 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 44 45 46 47 48 49 50 52 53 54 55 56 57 59 60 |

```
0.204846      0.66      1  2  3  4  5  6  8  9 10 12 13 15 16 18 19 20 21 22 23 24
                          25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42
                          43 44 45 46 47 48 49 50 52 53 54 55 56 57 59 60
0.166169      0.53      1  2  3  4  5  6  8  9 10 11 12 13 15 16 18 19 20 21 22 23
                          24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41
                          42 43 44 45 46 47 48 49 50 52 53 54 55 56 57 59 60
0.127828      0.41      1  2  3  4  5  6  8  9 10 11 12 13 14 15 16 18 19 20 21 22
                          23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
                          41 42 43 44 45 46 47 48 49 50 52 53 54 55 56 57 59 60
0.095627      0.31      1  2  3  4  5  6  8  9 10 11 12 13 14 15 16 18 19 20 21 22
                          23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
                          41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 59
                          60
0.065138      0.21      1  2  3  4  5  6  8  9 10 11 12 13 14 15 16 18 19 20 21 22
                          23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
                          41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58
                          59 60
0.035612      0.11      1  2  3  4  5  6  8  9 10 11 12 13 14 15 16 17 18 19 20 21
                          22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39
                          40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
                          58 59 60
0.014426      0.05      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20
                          21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38
                          39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
                          57 58 59 60
0.000995      0.00      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20
                          21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38
                          39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
                          57 58 59 60 61

URTHER SPLITS ARE
  0.013431    0.04     61 62 61
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SULTS OF SPLITLSQ

M OF SQUARES    PERCENT OF TOTAL     MARKERS
 4.672584
** INVESTIGATE  23  22 IN GROUP   1 - 62
NTENTS ARE   3,5612    3,5634
 3,561233        76,22     23
 2,505476        53,62     23 35
 1,940651        41,70     23 35 39
 1,512598        32,37     10 23 35 39
 1,143772        24,48     10 23 35 39 53
 0,868528        18,59      5 10 23 35 39 53
 0,783415        16,77      5 10 23 35 39 53 59
 0,712039        15,24      5  8 10 23 35 39 53 59
 0,650024        13,91      5  8 10 23 35 39 42 53 59
 0,592898        12,69      5  8 10 23 35 36 39 42 53 59
 0,538362        11,52      5  8 10 23 31 35 36 39 42 53 59
 0,494907        10,59      5  8 10 23 31 35 36 38 39 42 53 59
 0,457028         9,78      5  8 10 22 23 31 35 36 38 39 42 53 59
 0,428894         9,18      5  8 10 22 23 31 35 36 38 39 42 50 53 59
 0,402920         8,62      1  5  8 10 22 23 31 35 36 38 39 42 50 53 59
 0,364640         7,80      1  3  5  8 10 22 23 31 35 36 38 39 42 50 53 59
 0,340725         7,29      1  3  5  8 10 15 22 23 31 35 36 38 39 42 50 53 59
 0,323066         6,91      1  3  5  8 10 15 22 23 31 33 35 36 38 39 42 50 53 59
 0,304040         6,51      1  3  5  8 10 15 22 23 31 33 34 35 36 38 39 42 50 53 59
 0,287789         6,16      1  3  4  5  8 10 15 22 23 31 33 34 35 36 38 39 42 50 53 59

 0,272620         5,83      1  3  4  5  8 10 15 22 23 31 33 34 35 36 37 38 39 42 50 53
                              59
 0,257592         5,51      1  3  4  5  8 10 15 22 23 29 31 33 34 35 36 37 38 39 42 50
                              53 59
 0,241758         5,17      1  3  4  5  8 10 15 22 23 27 29 31 33 34 35 36 37 38 39 42
                              50 53 59
 0,221037         4,73      1  3  4  5  8 10 15 22 23 26 27 29 31 33 34 35 36 37 38 39
                              42 50 53 59
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| | | |
|---|---|---|
| 0,207040 | 4,43 | 1 3 4 5 8 10 15 22 23 26 27 29 31 33 34 35 36 37 38 39 42 50 53 55 59 |
| 0,194067 | 4,15 | 1 3 4 5 8 10 15 22 23 26 27 29 31 33 34 35 36 37 38 39 42 50 53 55 57 59 |
| 0,182638 | 3,91 | 1 3 4 5 8 10 15 19 22 23 26 27 29 31 33 34 35 36 37 38 39 42 50 53 55 57 59 |
| 0,166767 | 3,57 | 1 3 4 5 8 10 15 19 20 22 23 26 27 29 31 33 34 35 36 37 38 39 42 50 53 55 57 59 |
| 0,156218 | 3,34 | 1 3 4 5 8 10 15 19 20 22 23 24 26 27 29 31 33 34 35 36 37 38 39 42 50 53 55 57 59 |
| 0,144768 | 3,10 | 1 3 4 5 8 10 15 19 20 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 42 50 53 55 57 59 |
| 0,134399 | 2,88 | 1 3 4 5 8 10 12 15 19 20 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 42 50 53 55 57 59 |
| 0,124208 | 2,66 | 1 3 4 5 8 10 12 15 19 20 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 42 49 50 53 55 57 59 |
| 0,114120 | 2,44 | 1 3 4 5 8 10 12 13 15 19 20 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 42 49 50 53 55 57 59 |
| 0,104267 | 2,23 | 1 3 4 5 8 9 10 12 13 15 19 20 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 42 49 50 53 55 57 59 |
| 0,095444 | 2,04 | 1 3 4 5 8 9 10 12 13 15 18 19 20 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 42 49 50 53 55 57 59 |
| 0,086649 | 1,85 | 1 3 4 5 8 9 10 12 13 15 18 19 20 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 42 45 49 50 53 55 57 59 |
| 0,079087 | 1,69 | 1 3 4 5 8 9 10 12 13 15 18 19 20 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 40 42 45 49 50 53 55 57 59 |
| 0,073381 | 1,57 | 1 3 4 5 8 9 10 12 13 15 18 19 20 21 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 40 42 45 49 50 53 55 57 59 |
| 0,067938 | 1,45 | 1 3 4 5 8 9 10 12 13 15 18 19 20 21 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 40 42 45 49 50 53 55 57 59 60 |
| 0,062710 | 1,34 | 1 3 4 5 8 9 10 12 13 15 18 19 20 21 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 40 42 45 46 49 50 53 55 57 59 60 |
| 0,058164 | 1,24 | 1 3 4 5 8 9 10 12 13 15 18 19 20 21 22 23 24 25 26 27 29 31 33 34 35 36 37 38 39 40 42 45 46 48 49 50 53 55 57 59 60 |

| | | |
|---|---|---|
| 0,053775 | 1,15 | 1 3 4 5 8 9 10 12 13 15 18 19 20 21 22 23 24 25 26 27 28 29 31 33 34 35 36 37 38 39 40 42 45 46 48 49 50 53 55 57 59 60 |
| 0,049477 | 1,06 | 1 3 4 5 8 9 10 12 13 15 18 19 20 21 22 23 24 25 26 27 28 29 31 32 33 34 35 36 37 38 39 40 42 45 46 48 49 50 53 55 57 59 60 |
| 0,045377 | 0,97 | 1 3 4 5 8 9 10 12 13 15 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42 45 46 48 49 50 53 55 57 59 60 |
| 0,041495 | 0,89 | 1 3 4 5 8 9 10 12 13 14 15 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42 45 46 48 49 50 53 55 57 59 60 |
| 0,037760 | 0,81 | 1 2 3 4 5 8 9 10 12 13 14 15 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42 45 46 48 49 50 53 55 57 59 60 |
| 0,034067 | 0,73 | 1 2 3 4 5 8 9 10 12 13 14 15 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42 45 46 48 49 50 53 55 56 57 59 60 |
| 0,030674 | 0,66 | 1 2 3 4 5 8 9 10 12 13 14 15 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42 45 46 47 48 49 50 53 55 56 57 59 60 |
| 0,027309 | 0,58 | 1 2 3 4 5 8 9 10 12 13 14 15 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42 45 46 47 48 49 50 53 54 55 56 57 59 60 |
| 0,024358 | 0,52 | 1 2 3 4 5 8 9 10 12 13 14 15 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42 45 46 47 48 49 50 52 53 54 55 56 57 59 60 |
| 0,021360 | 0,46 | 1 2 3 4 5 8 9 10 12 13 14 15 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42 45 46 47 48 49 50 51 52 53 54 55 56 57 59 60 |
| 0,018558 | 0,40 | 1 2 3 4 5 8 9 10 12 13 14 15 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42 43 45 46 47 48 49 50 51 52 53 54 55 56 57 59 60 |
| 0,015821 | 0,34 | 1 2 3 4 5 8 9 10 12 13 14 15 16 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42 43 45 46 47 48 49 50 51 52 53 54 55 56 57 59 60 |

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0.013132    0.28     1   2  3  4  5  8  9 10 12 13 14 15 16 18 19 20 21 22 23 24
                        25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42 43
                        45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
0.010662    0.23     1   2  3  4  5  8  9 10 11 12 13 14 15 16 18 19 20 21 22 23
                        24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42
                        43 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
0.008250    0.18     1   2  3  4  5  8  9 10 11 12 13 14 15 16 18 19 20 21 22 23
                        24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 42
                        43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
0.005974    0.13     1   2  3  4  5  7  8  9 10 11 12 13 14 15 16 18 19 20 21 22
                        23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
                        42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59
                        60
0.003778    0.08     1   2  3  4  5  7  8  9 10 11 12 13 14 15 16 18 19 20 21 22
                        23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
                        41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58
                        59 60
0.002027    0.04     1   2  3  4  5  7  8  9 10 11 12 13 14 15 16 18 19 20 21 22
                        23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
                        41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58
                        59 60 61
0.000969    0.02     1   2  3  4  5  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21
                        22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39
                        40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
                        58 59 60 61
-0.000072  -0.00     1   2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20
                        21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38
                        39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
                        57 58 59 60 61

URTHER SPLITS ARE
 0.001041   0.02     6   7  6
```
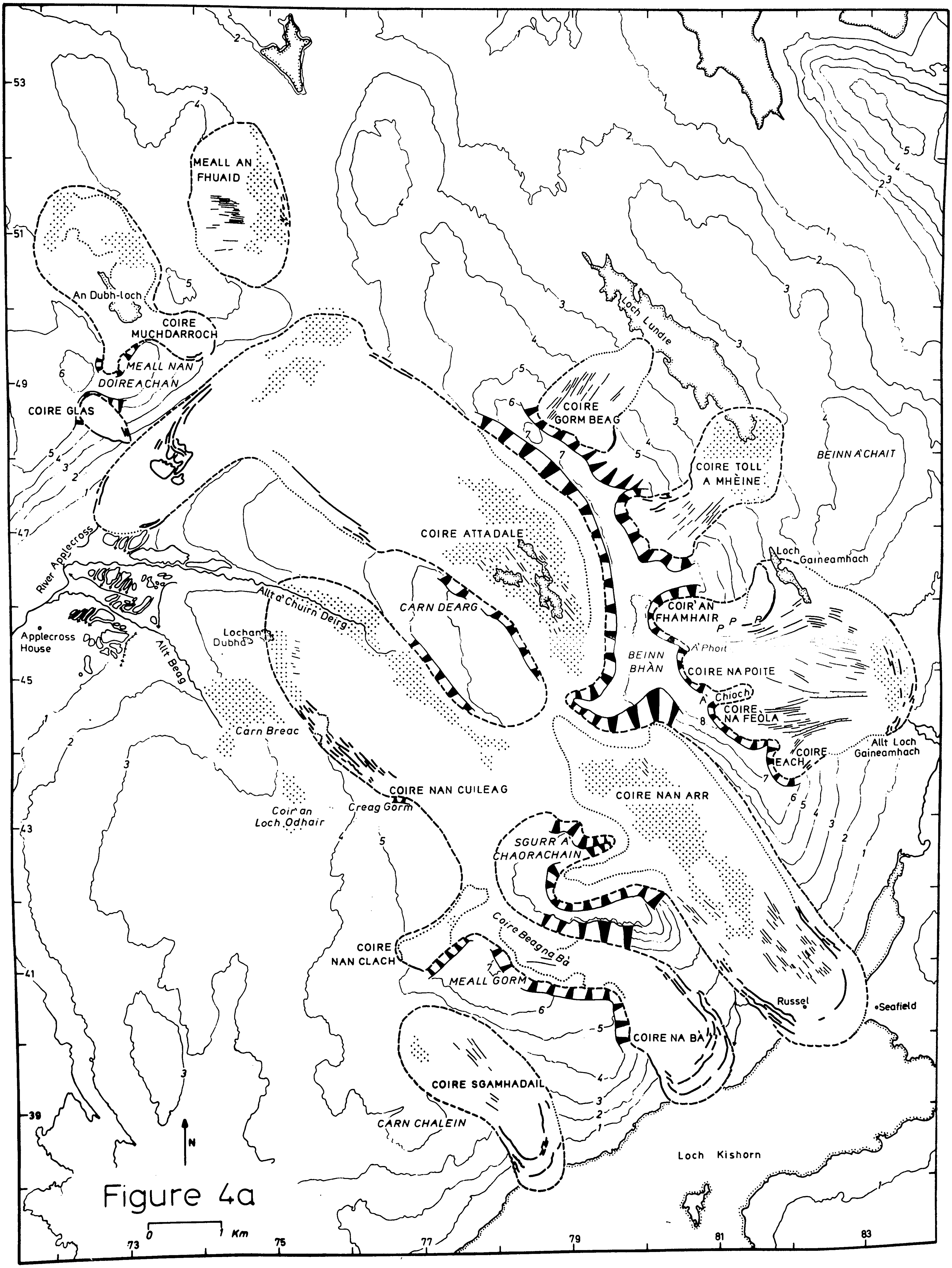

2. Druim Dubh.

```
RESULTS OF SPLITINF

INF CONTENT    PERCENT OF TOTAL        MARKERS
   1.034344
   0.459679        44.44          3
   0.200725        25.21          3   5
   0.119892        11.59          1   3   5
   0.043102         4.17          1   3   4   5
   0.000007         0.00          1   2   3   4   5
   0.000007         0.00          0   1   2   3   4   5
   0.000007         0.00          0   0   1   2   3   4   5
   0.000007         0.00          0   0   0   1   2   3   4   5
   0.000007         0.00          0   0   0   0   1   2   3   4   5
   0.000007         0.00          0   0   0   0   0   1   2   3   4   5

FURTHER SPLITS ARE

IHC208I IBCOM - PROGRAM INTERRUPT (P) -  UNDERFLOW   OLD PSW IS  FFA50000820C5B88

TRACEBACK  ROUTINE  CALLED FROM ISN   REG. 14   REG. 15   REG.  0   REG.  1

           SPLINF                     420C2136  000C5258  00000003  00000000

           MAIN                       00018592  010C2010  FF000018  000DAF48

ENTRY POINT=  010C2010

STANDARD FIXUP TAKEN , EXECUTION CONTINUING
   0.000000           0.0             0   0   0
```

```
RESULTS OF SPLITLSQ

SUM OF SQUARES     PERCENT OF TOTAL      MARKERS
   0,107975
   0,049587          45,92           3
   0,027790          25,74           1    3
   0,008008           7,42           1    3    5
   0,001629           1,51           1    3    4    5
   0,000000           0,00           1    2    3    4    5
   0,000000           0,00           0    1    2    3    4    5
   0,000000           0,00           0    0    1    2    3    4    5
   0,000000           0,00           0    0    0    1    2    3    4    5
   0,000000           0,00           0    0    0    0    1    2    3    4    5
   0,000000           0,00           0    0    0    0    0    1    2    3    4    5

FURTHER SPLITS ARE

IHC208I IBCOM - PROGRAM INTERRUPT (P) -  UNDERFLOW   OLD PSW IS  FFA5000D820C71A8 .

TRACEBACK  ROUTINE  CALLED FROM ISN   REG. 14    REG. 15    REG.  0    REG.  1

           SPLSQ                      420C2140   000C6818   00000002   00000000

           MAIN                       00018592   010C2018   FF000018   000DAF48

ENTRY POINT=  010C2010

STANDARD FIXUP TAKEN , EXECUTION CONTINUING
   0,000000           0,0            0    0    0
```


MEALL AN FHUAID
An Dubh-loch
COIRE MUCHDARROCH
MEALL NAN DOIREACHAN
COIRE GLAS
River Applecross
Applecross House
Allt Beag
Lochan Dubha
Allt a' Chuirn Deirg
CARN DEARG
COIRE ATTADALE
Loch Lundie
COIRE GORM BEAG
COIRE TOLL A MHÈINE
BEINN A' CHAIT
Loch Gaineamhach
COIR' AN FHAMHAIR
A' Phoit
BEINN BHÀN
COIRE NA POITE
A' Chioch
COIRE NA FEOLA
COIRE EACH
Allt Loch Gaineamhach
Carn Breac
COIRE NAN CUILEAG
Creag Gorm
Coir' an Loch Odhair
COIRE NAN ARR
SGURR A' CHAORACHAIN
Coire Beag na Bà
COIRE NAN CLACH
MEALL GORM
COIRE NA BÀ
Russel
Seafield
COIRE SGAMHADAIL
CARN CHALEIN
Loch Kishorn
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0
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51
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47
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41
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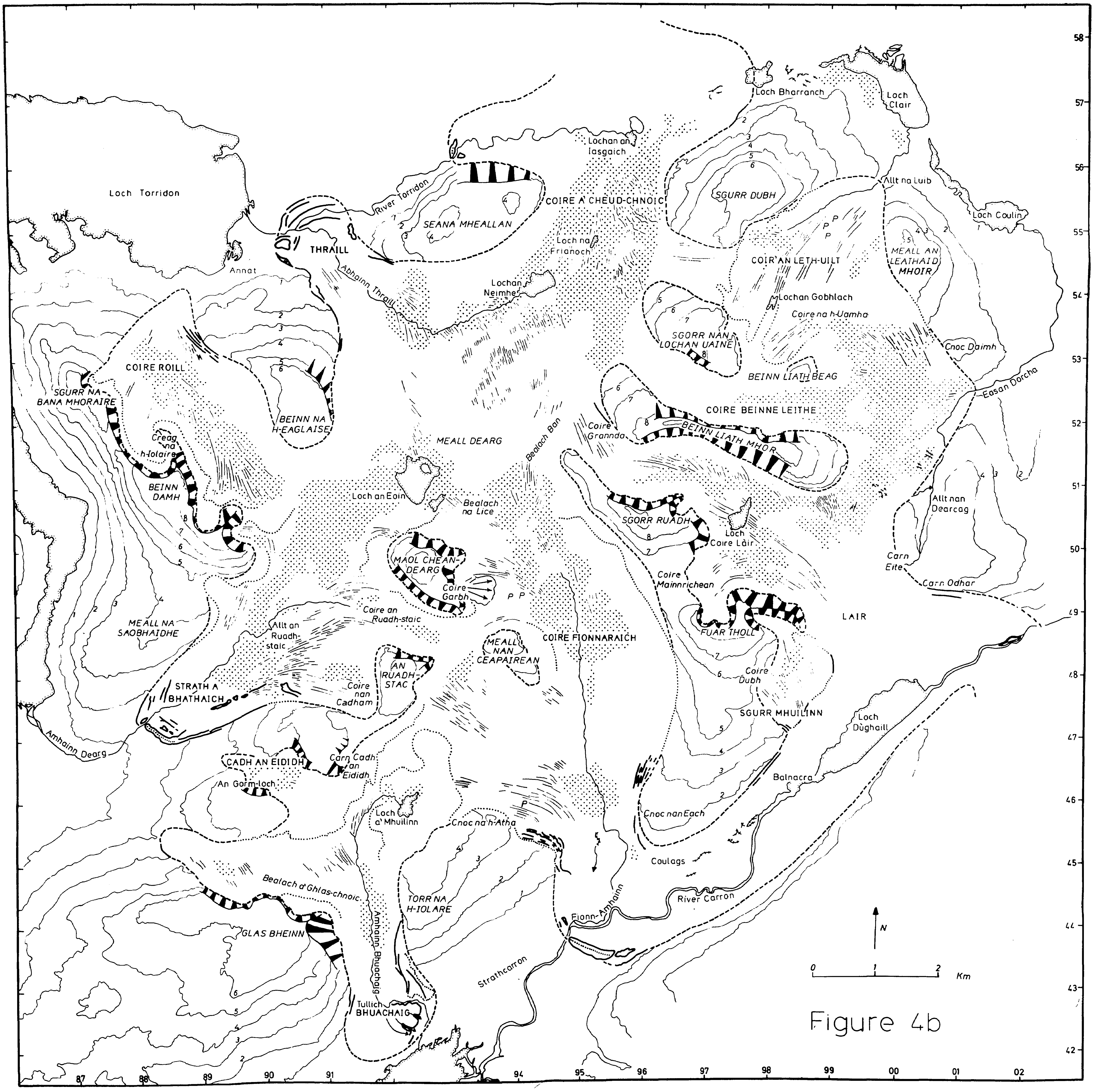
73
75
77
79
81
83

Figure 4a


Loch Torridon
River Torridon
SEANA MHEALLAN
THRAILL
Annat
Abhainn Thraill
COIRE A' CHEUD-CHNOIC
Lochan an Iasgaich
Loch na Frianach
Lochan Neimhe
Loch Bharranch
Loch Clair
SGURR DUBH
Allt na Luib
Loch Coulin
COIR' AN LETH-UILT
MEALL AN LEATHAID MHOIR
Lochan Gobhlach
Coire na h-Uamha
SGORR NAN LOCHAN UAINE
BEINN LIATH BEAG
Cnoc Daimh
Easan Dorcha
COIRE BEINNE LEITHE
BEINN LIATH MHOR
Coire Grannda
Bealach Ban
COIRE ROILL
SGURR NA BANA MHORAIRE
BEINN NA H-EAGLAISE
MEALL DEARG
Creag na h-Iolaire
BEINN DAMH
Loch an Eoin
Bealach na Lice
SGORR RUADH
Loch Coire Làir
Allt nan Dearcag
Carn Eite
Carn Odhar
MAOL CHEAN-DEARG
Coire Garbh
Coire Mainnrichean
LAIR
MEALL NA SAOBHAIDHE
Coire an Ruadh-staic
Allt an Ruadh-staic
MEALL NAN CEAPAIREAN
COIRE FIONNARAICH
FUAR THOLL
Coire Dubh
AN RUADH-STAC
Coire nan Cadham
STRATH A BHATHAICH
SGURR MHUILINN
Loch Dùghaill
Amhainn Dearg
CADH AN EIDIDH
Carn Cadh an Eididh
An Gorm-loch
Balnacra
Loch a' Mhuilinn
Cnoc na h-Atha
Cnoc nan Each
Coulags
Bealach a' Ghlas-chnoic
TORR NA H-IOLARE
River Carron
Fionn-Amhainn
GLAS BHEINN
Amhainn Bhuachaig
Strathcarron
Tullich
BHUACHAIG
N
0
1
2
Km
87
88
89
90
91
94
95
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98
99
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01
02
58
57
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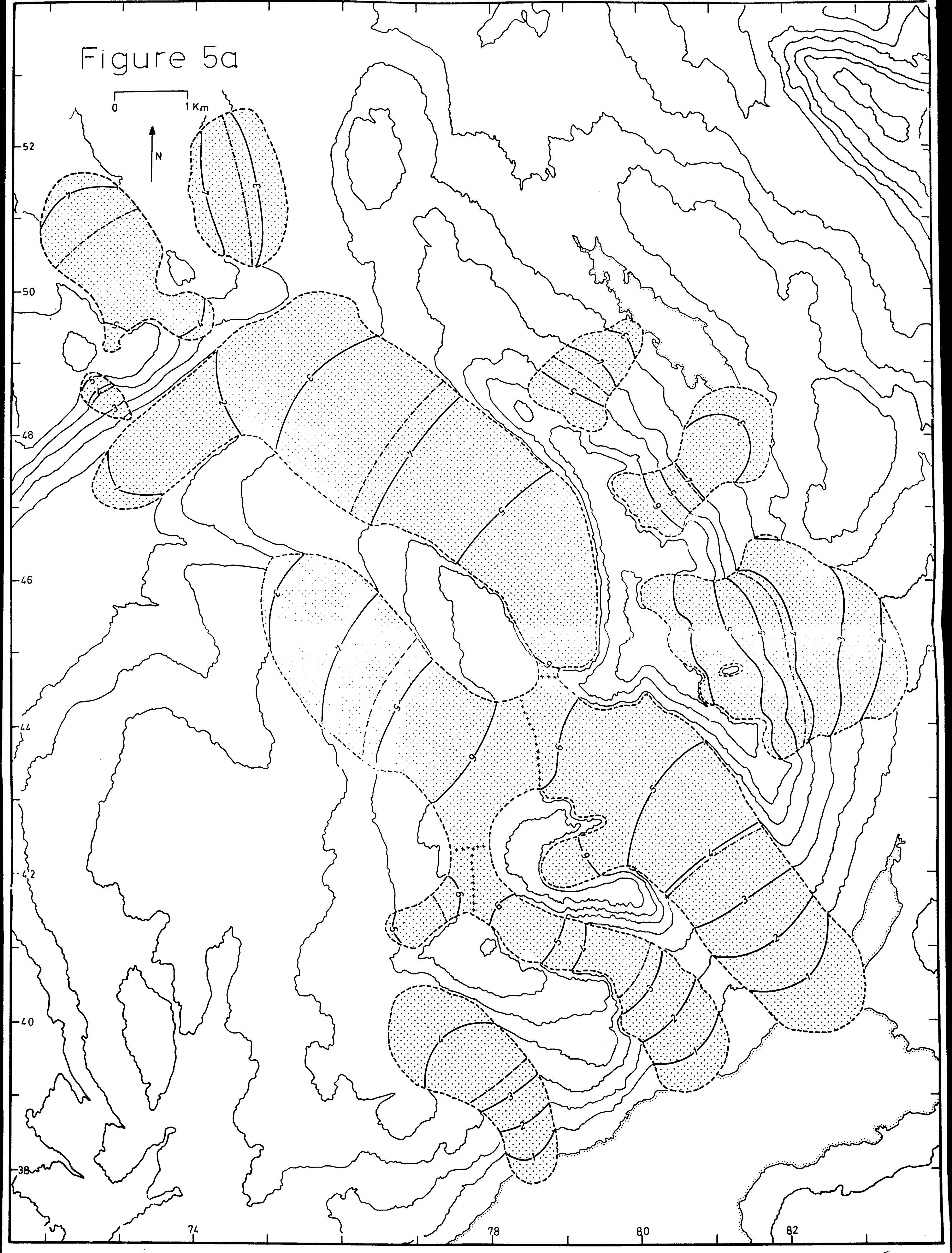
42

Figure 4b

# Figure 5a



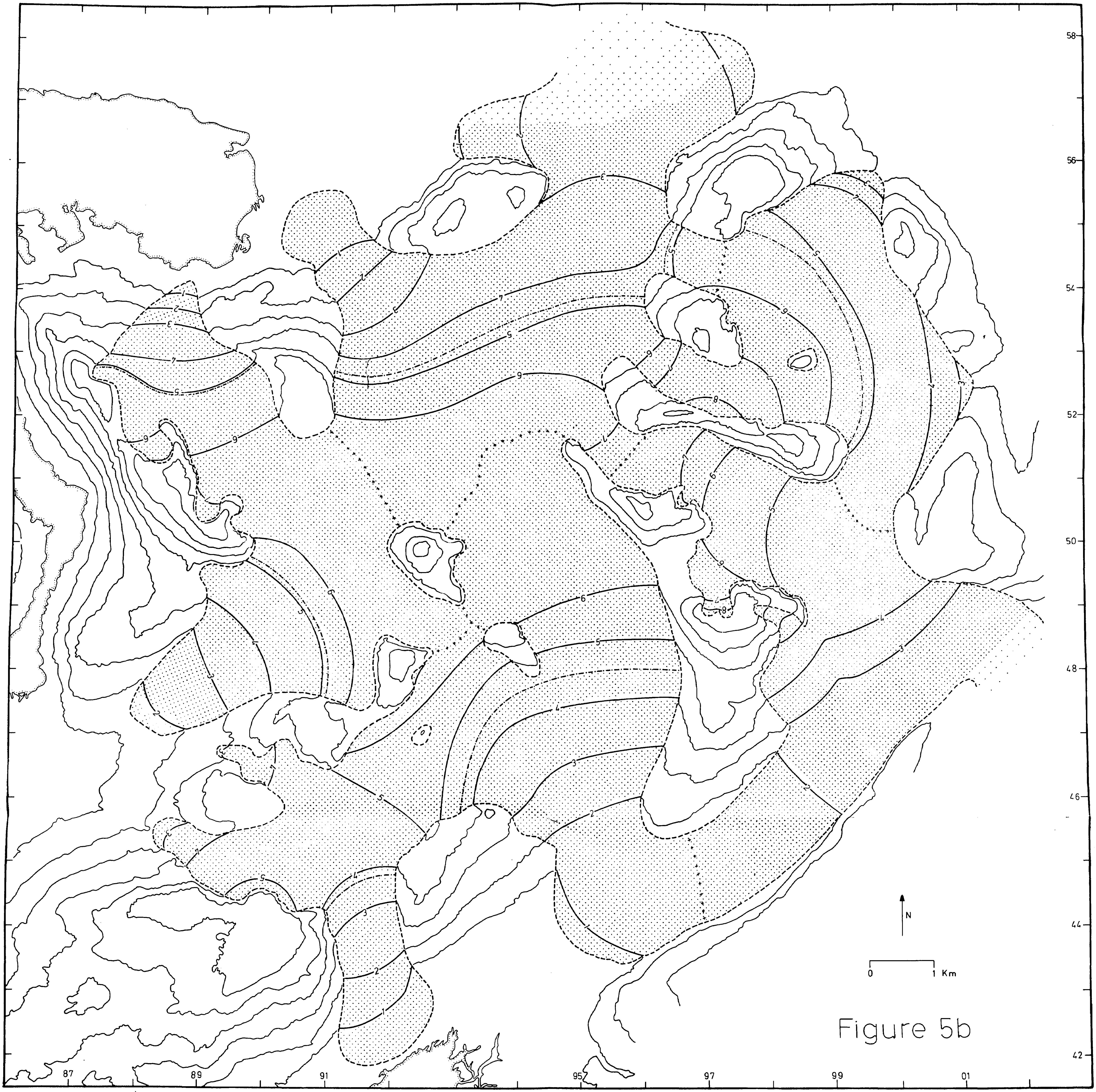



Figure 5b

# Figure 20 : Glasscnock

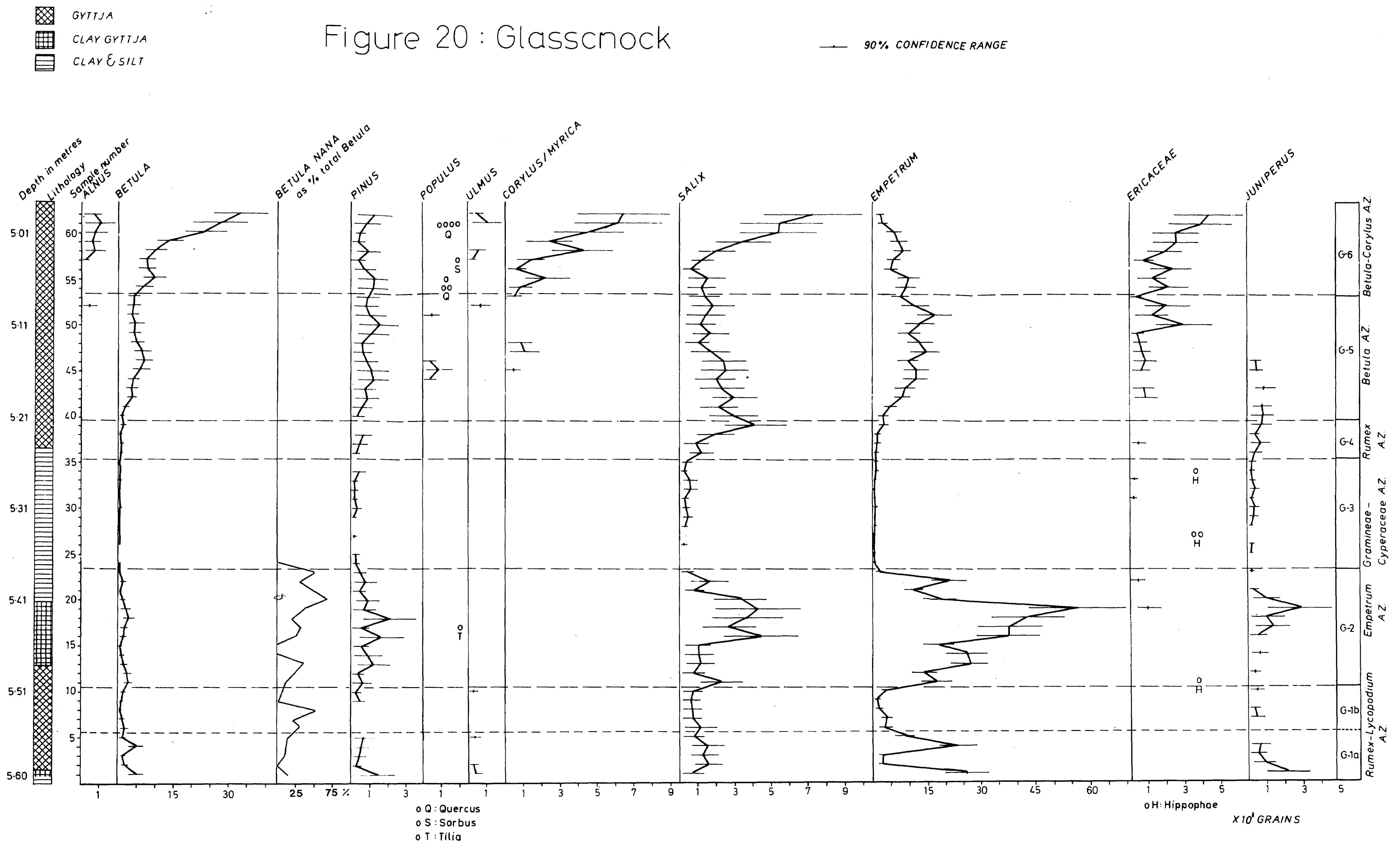
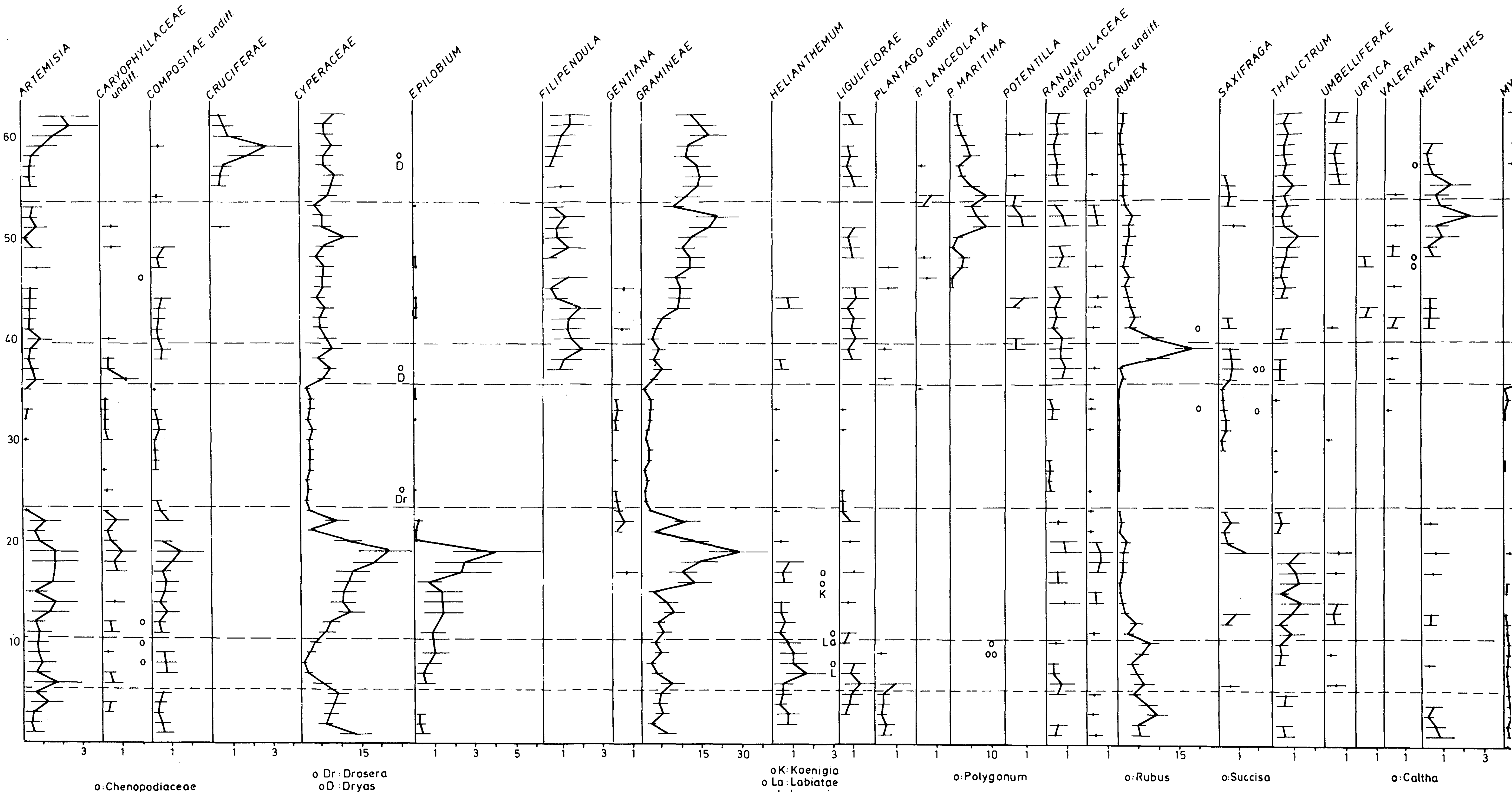
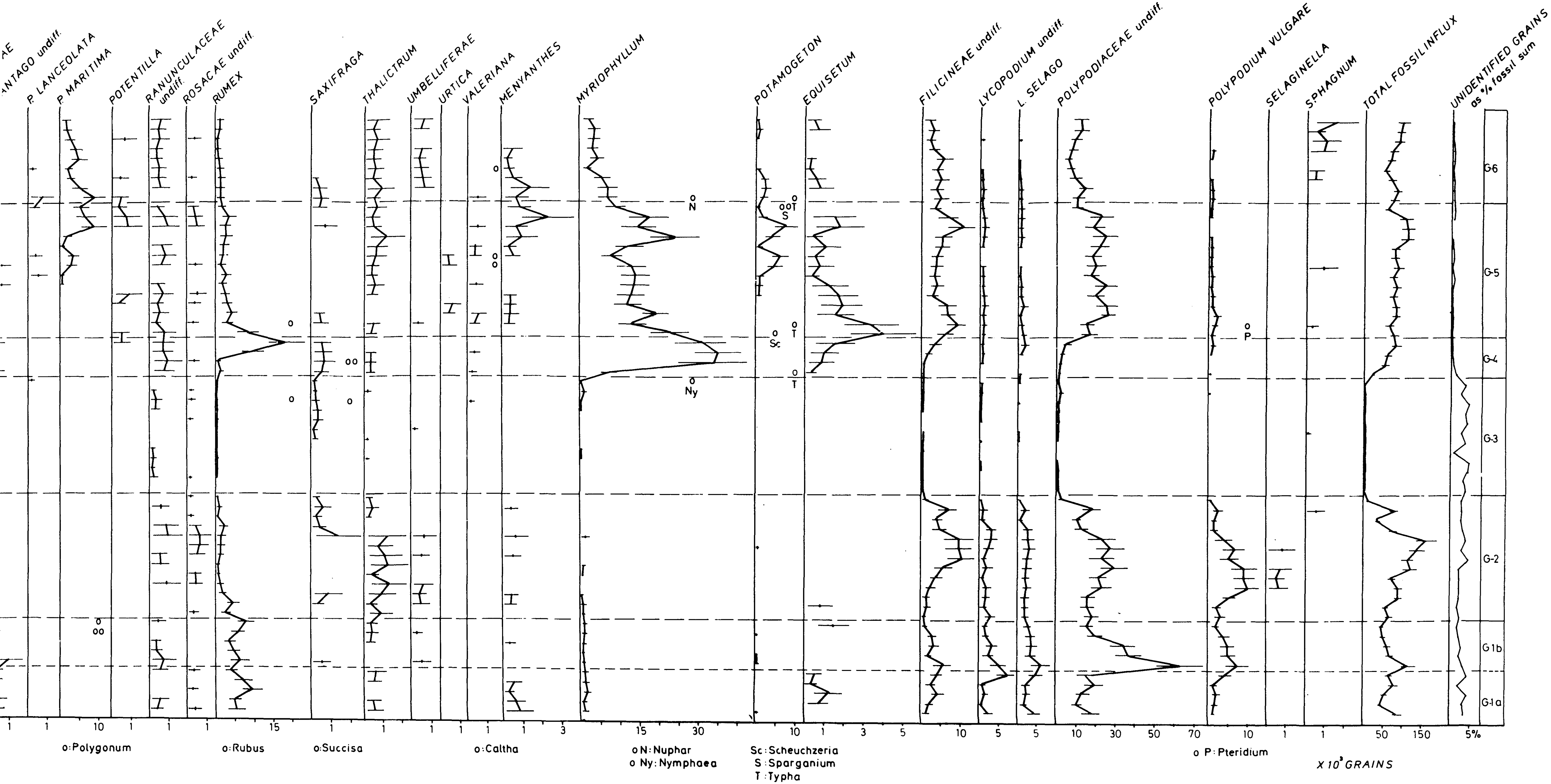


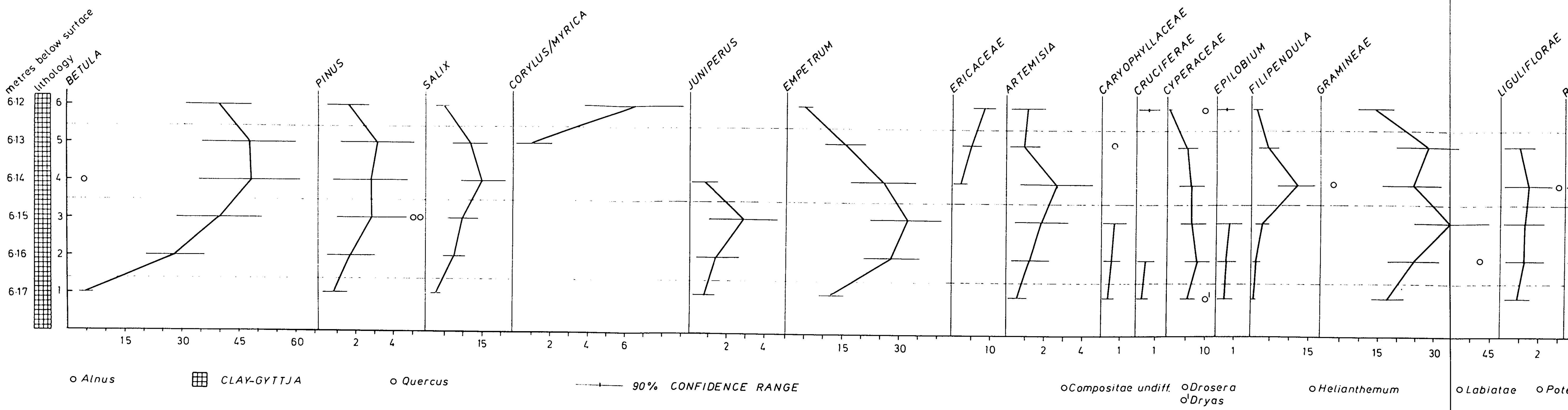
Figure 20 continued

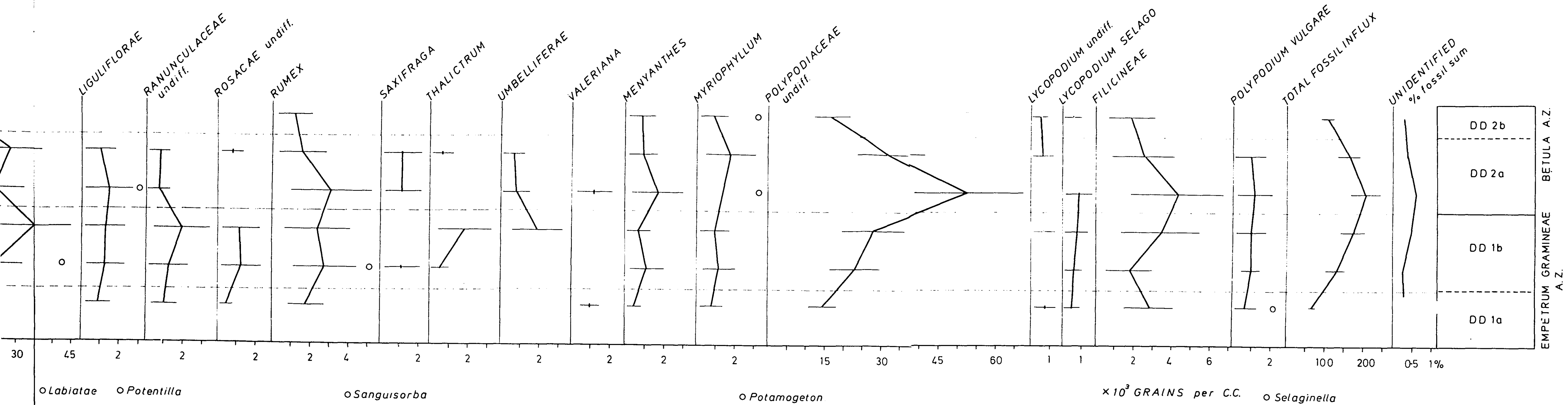




PLANTAGO undiff.
P. LANCEOLATA
P. MARITIMA
POTENTILLA
RANUNCULACEAE undiff.
ROSACEAE undiff.
RUMEX
SAXIFRAGA
THALICTRUM
UMBELLIFERAE
URTICA
VALERIANA
MENYANTHES
MYRIOPHYLLUM
POTAMOGETON
EQUISETUM
FILICINEAE undiff.
LYCOPODIUM undiff.
L. SELAGO
POLYPODIACEAE undiff.
POLYPODIUM VULGARE
SELAGINELLA
SPHAGNUM
TOTAL FOSSIL INFLUX
UNIDENTIFIED GRAINS as % fossil sum
G-6
G-5
G-4
G-3
G-2
G-1b
G-1a
o: Polygonum
o: Rubus
o: Succisa
o: Caltha
o N: Nuphar
o Ny: Nymphaea
Sc: Scheuchzeria
S: Sparganium
T: Typha
o P: Pteridium
X 10³ GRAINS
5%

Figure 21: Druim Dubh




LIGULIFLORAE
RANUNCULACEAE undiff.
ROSACAE undiff.
RUMEX
SAXIFRAGA
THALICTRUM
UMBELLIFERAE
VALERIANA
MENYANTHES
MYRIOPHYLLUM
POLYPODIACEAE undiff.
LYCOPODIUM undiff.
LYCOPODIUM SELAGO
FILICINEAE
POLYPODIUM VULGARE
TOTAL FOSSIL INFLUX
UNIDENTIFIED % fossil sum
DD 2b
DD 2a
DD 1b
DD 1a
BETULA A.Z.
EMPETRUM GRAMINEAE A.Z.
30
45
2
2
2
2 4
2
2
2
2
2
2
15 30 45 60
1
1
2 4 6
2
100 200
0·5 1%
o Labiatae
o Potentilla
o Sanguisorba
o Potamogeton
× 10³ GRAINS per C.C.
o Selaginella