

THE QUATERNARY OF THE ISLE OF SKYE

Field Guide

COLIN K. BALLANTYNE, DOUGLAS I. BENN,
J. JOHN LOWE and MICHAEL J. C. WALKER

Quaternary Research Association



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Cover Illustration:

Sgurr nan Gillean and the Black Cuillin from Loch nan Eilean.
(Photo: C.K. Ballantyne)

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FIELD GUIDE

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Ordnance Survey maps covering Skye include the 1:50,000 Landranger Series of Great Britain, sheets 23 (Northern Skye), 32 (Southern Skye) and 33 (Loch Alsh and Glen Shiel). An excellent introduction to the geology of Skye is given in: Bell, B.R. and Harris, J.W. (1986) *An Excursion Guide to the Geology of the Isle of Skye*, Geological Society of Glasgow, ISBN 0 902892 08 8.

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1. INTRODUCTION

Colin K. Ballantyne and Douglas I. Benn

The Isle of Skye (57°00'-57°42'N; 5°58'-6°47'W) is the largest island of the Inner Hebrides off the west coast of Scotland (Figure 1.1), and contains some of the most spectacular mountain scenery and varied geology in the British Isles. For the Quaternary scientist Skye is an area of outstanding interest. During the Dimlington Stadial of the Late Devensian (c. 26-13 ka BP) the island experienced a complex pattern of ice-sheet glaciation, with evidence that the mainland ice sheet was deflected around one or more centres of local ice accumulation, and also around mountain peaks that stood proud of the competing ice masses as nunataks. The subsequent Loch Lomond Stadial (c. 11-10 ka BP) witnessed the development of a substantial icefield and a fringe of smaller glaciers in the mountains of central Skye, and a range of now-relict periglacial landforms on high ground. The areas occupied by the glaciers of the Loch Lomond Readvance provide a superb laboratory for investigation of the nature and origin of glacial landforms and deposits. Study of these areas has provided much new information on the entrainment, transport and mode of deposition of debris by former glaciers, and particularly on the origin of the 'hummocky drift' that occupies many upland valleys in Great Britain.

Skye has also been the site of intensive palynological investigations that have thrown light not only on local vegetation changes during the Late Devensian Lateglacial (c. 13-10 ka BP) and Flandrian (c. 10 ka BP - present), but also on the wider environmental aspects of the glacial-interglacial transition on the eastern margin of the North Atlantic area. Changes in sea level during the same period have been partly reconstructed from the evidence of abandoned Lateglacial and Flandrian shorelines. The island also supports the most extensive area of rock slope failure in Great Britain, as well as abundant evidence for less dramatic forms of postglacial landscape change through periglacial activity on high ground, talus accumulation below glaciated rockwalls, debris flow activity and the widespread growth of blanket peat. The almost unparalleled geological variety of the island makes it an ideal location for studying the influence of lithology and structure on glacial, periglacial and postglacial geomorphic activity.

Quaternary research on Skye

The history of Quaternary research on Skye dates back to 1845, when the pioneering Scottish glaciologist J.D. Forbes was sufficiently impressed by the evidence for glaciation on the Cuillin Hills to be converted (though 'most entirely against my will', as he later admitted) to the then contentious notion that Scotland had formerly supported glaciers (Forbes, 1846; Cunningham, 1990). The evidence amassed by Forbes included observations of striated and ice-moulded bedrock, roches

moutonnées, periglacial trimlines and an end moraine at the mouth of Coir' a'Ghrunnda in the southern Cuillins. Bonney (1871) subsequently described evidence for former locally-nourished glaciers, including a 'well-marked lateral moraine', in the Eastern Red Hills. Detailed research on the extent and effects of glaciation on Skye was first initiated by the Officers of the Geological Survey at the end of the 19th century and subsequently published in papers by Harker (1899, 1901) and in two memoirs (Clough & Harker, 1904; Peach *et al.*, 1910). However, later attempts to define the extent of various glacial episodes on Skye (Charlesworth, 1956; Anderson & Dunham, 1966; Birks, 1973; Sissons, 1977a; Walther, 1984) have produced wildly conflicting results.

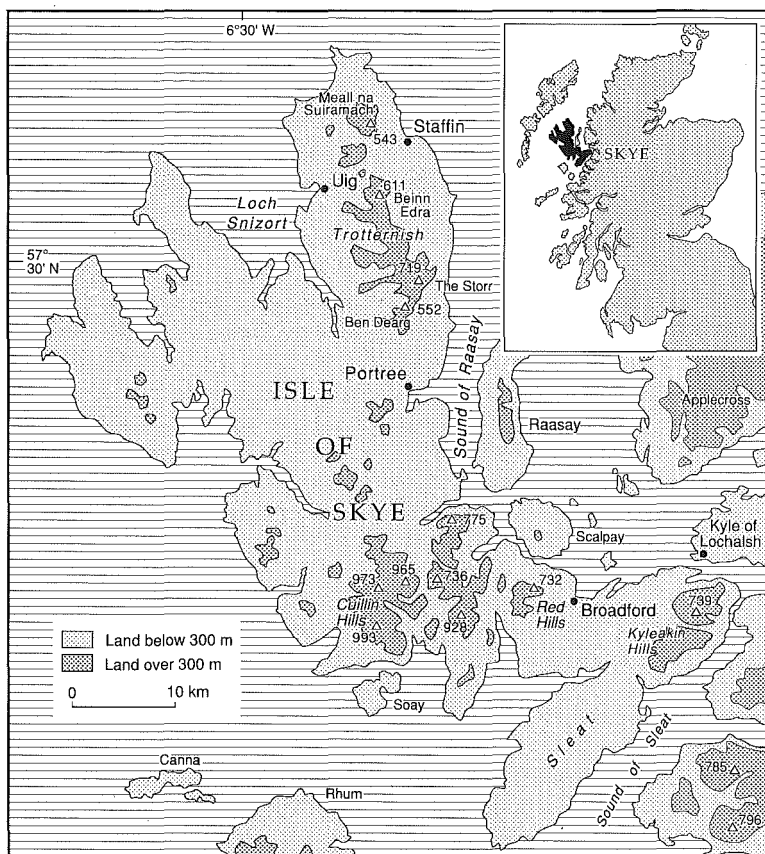


Figure 1.1: The Isle of Skye, Inner Hebrides, Scotland.

In contrast, investigations into the vegetation history of the island have been largely restricted to the last 25 years. Some early pollen-analytical work was carried out on blanket peats in the Sligachan area in the 1920s (Erdtman, 1924, 1928), and a short pollen diagram spanning part of the mid-Flandrian was produced by Blackburn (in Godwin, 1943) from peats on the island of Soay (Figure 1.1). The first detailed pollen diagrams for Skye did not appear until the 1960s and 1970s, when virtually complete Flandrian profiles for a number of lochs on the island were published (Vasari & Vasari, 1968; Williams, 1977). A major study of the vegetation history of Skye was made by Birks (1973), who interpreted pollen-stratigraphic records from five sites on the island as spanning the time interval from the Lateglacial Interstadial to the mid-Flandrian, an interpretation subsequently criticised by Vasari (1977), who suggested that Birks' record may extend only as far back as the Loch Lomond Stadial of c. 11-10 ka BP.

Until recently, other aspects of Quaternary research on Skye have been somewhat neglected. Raised shorelines on the island were briefly described in the early Geological Survey memoirs (Clough and Harker, 1904; Peach *et al.*, 1910) and the evolution of the coastline of northern and western Skye was investigated by Richards (1969, 1971). Short descriptions have been published concerning the periglacial landforms of The Storr in northern Skye and the Red Hills of central Skye (Godard, 1958, Kelletat, 1970), and preliminary analyses of the spectacular rotational landslides of northern Skye were made by Anderson and Dunham (1966) and Richards (1971).

Much of the information presented in this guide, however, arises from interdisciplinary research carried out on the island by the authors and Dr D.G. Sutherland over the past seven years. This research was stimulated partly by inconsistencies in previous accounts of the Late Quaternary environmental history of the island, and partly by an awareness that the full potential for Quaternary research on Skye had been only partly explored. The first results of this recent work were outlined in a multidisciplinary reinterpretation of the Lateglacial environmental history of Skye (Walker *et al.*, 1988), and subsequent publications have dealt in more detail with aspects of the glacial history of the island (Ballantyne, 1988, 1989a, 1990), moraine development (Benn, 1989) and palaeoenvironmental reconstruction of the last glacial-interglacial transition (Walker and Lowe, 1990). In addition, a thesis by Benn (1990) deals with the characteristics of glacial sediment transport and moraine genesis associated with the Loch Lomond Readvance on Skye.

The potential of Skye for future Quaternary research is, however, far from exhausted. About half the island, including the remote peninsulas of Sleat in the SW and Duirinish and Waternish in the NW, has hitherto escaped scrutiny by Quaternary scientists. Even the approximate pattern of ice-sheet and possibly later glaciation in

NW Skye is unknown. Similarly, much of our knowledge of vegetation history is based on relatively limited areas of central, southern and eastern Skye. The pattern of sea-level change on the island has yet to be worked out in detail, and our knowledge of the causes and history of the great landslips of northern Skye is still speculative. Much of interest remains to be learnt about the Quaternary of Skye.

The physical landscape of Skye: relief and pre-Quaternary geology.

Skye supports a rich variety of landscapes that range in character from monotonous peat-blanketed lowlands to the serrated battlements of the Cuillin ridge, the most impressive mountain range in Great Britain. Such variety reflects, often in intricate detail, the resistance and structure of the underlying rocks. For the purposes of description it is convenient to consider the landscapes of Skye in terms of three contrasting areas: South-east Skye, central Skye and northern Skye.

South-east Skye.

South-east Skye is defined as that part of the island lying SE of Strath Suardal, a low though valley that lies between Broadford in the east and Loch Slapin in the west (Figure 1.1). This area is underlain almost entirely by pre-Tertiary metamorphic and sedimentary rocks (Figure 1.2), and consequently it has a character more akin to parts of Sutherland and Ross-shire than to the rest of the island. South-east Skye is itself divisible into three areas: southern Sleat, northern Sleat (the Kyleakin Hills), and the tract of land between Broadford and Loch Eishort. The first two areas are separated by a low neck of land, only 2.2km wide, that lies between Loch Eishort and Loch na Dol, while the second two are separated by a broad peat-mantled strath (Drochaid Airigh na Saorach).

Southern Sleat consists of low (200-300m) irregular hills interspersed with numerous lochs and blanketed by peat. By contrast, the Kyleakin Hills of northern Sleat form a broad SW to NE trending ridge that rises to over 700m. The Kyleakin Hills are breached near their mid-point by the low pass of Bealach Udal (279m), to the north of which lie the highest summits, Beinn na Caillich (733m) and Sgurr na Coinnich (739m). The topographical contrast between northern and southern Sleat reflects differences in the underlying geology. The Kyleakin Hills are underlain entirely by resistant Torridonian grits and arkoses of the Diabeg Group, while southern Sleat consists of thrust sheets of Lewisian Gneiss, Moine Schists, and Torridonian strata abutting a foreland comprising these rocks plus Cambro-Ordovician strata. The thrust faults in southern Sleat are part of the regionally-important Moine and Kishorn Thrusts, which mark the western limit of Lower Palaeozoic tectonic deformation.

The Broadford-Loch Eishort area consists of a low, irregular landscape similar in many respects to southern Sleat. Geologically, the area consists of

Torridonian, Cambro-Ordovician, Triassic and Jurassic strata, and acidic sills that relate to the Tertiary igneous activity in central Skye (see below). The concentric arcuate outcrops of these diverse rocks are reflected in the topography. For example, most of the higher ground is underlain by igneous rocks, while large parts of Glen Suardal and Strath Suardal follow the fault-bounded margins of the Cambro-Ordovician outcrop. Although small, the area occupied by Cambro-Ordovician rocks is of great interest. Much of the succession consists of limestones and dolostones that have given rise to an immature karst landscape, similar to that around Durness in Sutherland. Extensive cave systems are present in places, most notably on the northern flank of Beinn an Dubhaich.

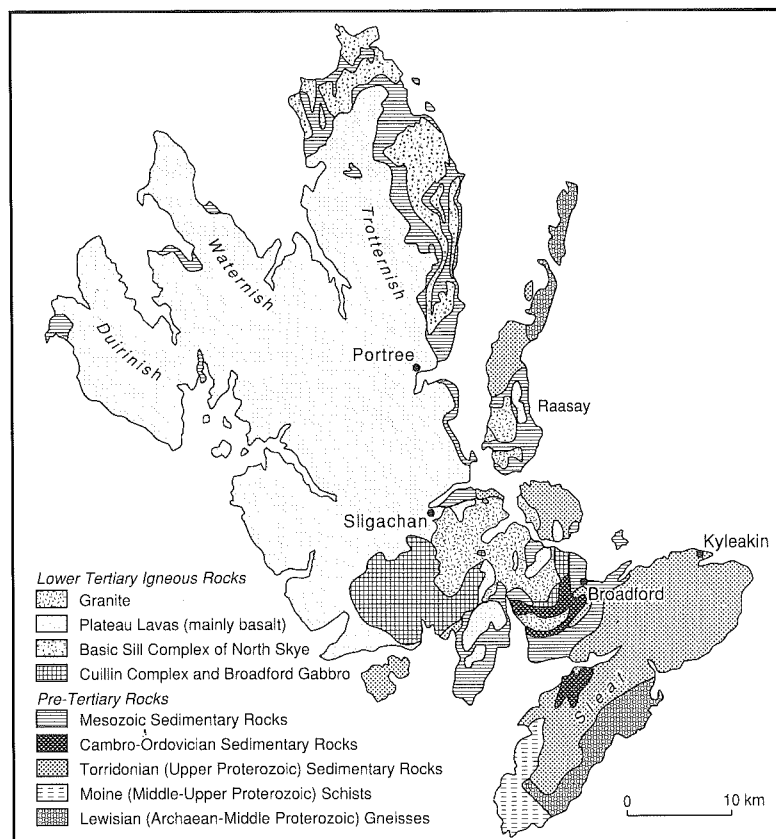


Figure 1.2: The geology of Skye

Central Skye

Central Skye is defined to the north by Loch Sligachan, to the south by Lochs Scavaig and Slapin, to the west by Glen Brittle and to the east by Strath Suardal (Figure 1.1). Although the Strathaird Peninsula, between Loch Scavaig and Loch Slapin, falls within the area so defined, it is both topographically and geologically affiliated with the landscapes of northern Skye, and hence is described in the following section.

Central Skye comprises a compact area of mountains that represent the eroded remnants of a Palaeogene plutonic centre, part of the British Tertiary Igneous Province (Harker, 1904; Emeleus, 1983; Bell and Harris, 1986; Figure 1.2). The igneous activity, which has been dated to *c.* 60-55 Ma BP, occurred in a tensional tectonic setting associated with rifting in the North Atlantic region. The petrological evolution of the Skye Igneous Complex was characterised by increasing acidity, probably as the result of fractionation processes and magma contamination by quartz-rich crustal rocks (Bell and Harris, 1986). This petrological trend was accompanied by migration of the centre of activity to the east, resulting in a series of cross-cutting, roughly circular plutons, the arrangement of which is reflected in the gross form of the landscape. Broadly, four generations of intrusions are represented (Figure 1.3).

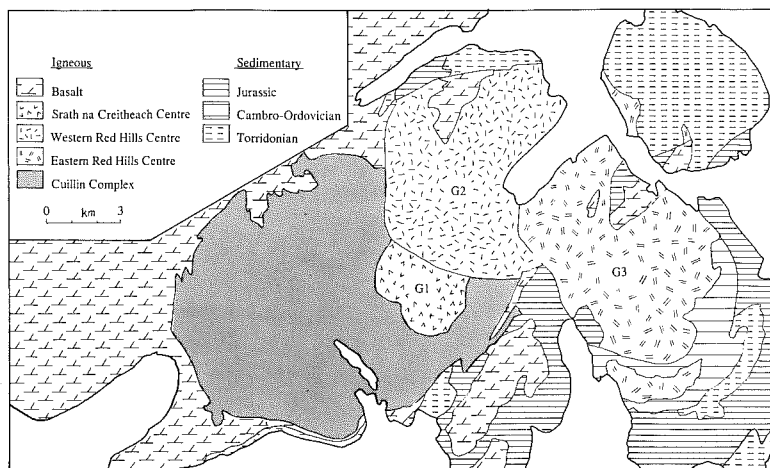


Figure 1.3: The general geology of central Skye.

The earliest, westernmost pluton, known as the Cuillin Complex, consists of several concentric masses of layered basic and ultrabasic rocks that dip inwards to a common focal point. The pluton has been penetrated by a concordant series of thin (c. 1-2m) dolerite cone sheets, discordant swarms of basalt dykes and small, pipe-like masses of agglomerate. The Cuillin Complex underlies two distinct mountain groups which are separated by the deep through valley of Glen Sligachan - Srath na Crèitheach (Figure 1.1). The western group, the Black Cuillin, culminates in Sgurr Alasdair (993m), the highest point on the island, while the eastern group includes Bla Bheinn (928m) and the lesser peaks of Garbh bheinn (806m) and Belig (702m). Both groups consist of steep, bold rock peaks linked by narrow arêtes, the trends of which follow the ring structure of the underlying rocks. The Black Cuillin and Bla Bheinn ridges are indented by numerous steep-sided clefts or *bealachs*, which are often the sites of weathered basalt dykes, as are many of the gullies that incise the area (Harker 1904).

The NE portion of the Cuillin Complex is truncated by two successive intrusive complexes, those of the Srath na Crèitheach and Western Red Hills Centres (G1 and G2 in Figure 1.3). Both of these centres are dominated by epigranites, although felsites and hybrid rocks also occur. The Western Red Hills Centre is cut by further epigranites of the Eastern Red Hills Centre (G3 in Figure 1.3). Each of the three centres comprises more than one generation of intrusion. Large-scale igneous activity in central Skye culminated with the intrusion of the boss-shaped Inner Granite.

Together, the three later igneous centres underlie the Western and Eastern Red Hills (Figure 1.1). The Red Hills nowhere exceed 775m in altitude and present a more rounded, less craggy appearance than the Black Cuillin and Bla Bheinn. The Western Red Hills, which are contiguous with the Bla Bheinn group, form a north-south aligned ridge, consisting of Glamaig (775m), Beinn Dearg Mhór (732m) and Marsco (736m), that forms the western rim of the Loch Ainort basin. The Eastern Red Hills lie to the east of Loch Ainort and comprise the dome of Glas Bheinn Mhór (569m), the isolated summit of Beinn na Crò (572m) and a compact group of hills that culminates in Beinn na Caillich (732m) above Broadford. The three hill masses are separated by two north-south trending troughs, Srath Mór and Srath Beag. The Beinn na Caillich group is underlain by the resistant, massive Inner Granite and has been incised by a radial set of steep-sided corries.

At the margins of the Cuillin Complex, the plutonic rocks are in contact with a variety of older rocks. These include Mesozoic and Palaeozoic strata, extrusive basalts and foundered masses of pyroclastic deposits. In many places, the presence of these rocks has resulted in differential erosion, and has determined the location of some of the through valleys that traverse the mountain area (eg. Srath Beag and Srath Mór, Figure 1.3).

Central Skye is deeply penetrated by fjords (Lochs Scavaig, Slapin, Ainort and Sligachan). Loch Coruisk, the landlocked extension of Loch Scavaig, occupies perhaps the finest example of a glacially-excavated rock basin in Great Britain.

Northern Skye

Almost all of Skye north of a line drawn between Sligachan and Glen Brittle is underlain by gently-dipping flood basalts of Palaeogene age (Figure 1.2). The basalts, which represent the earliest phase of Tertiary igneous activity on Skye (Bell and Harris, 1986), were extruded on to a low-relief terrain cut across Mesozoic and earlier sedimentary rocks (George, 1966). The basalts form laterally-extensive sheets separated by weak tuffs and bole horizons, giving rise to a characteristic trap landscape. In most areas such scenery is subdued and consists of low terraced hills, 200-400m in altitude, that rise above broad peat-filled valleys. On the Duirinish Peninsula of NW Skye, however, the lavas are deeply dissected into a group of steep rocky hills that reach their highest expression in the flat-topped lava-capped peaks of Macleod's Tables, Healabhal Mhor (468m) and Healabhal Beag (488m). The most dramatic scenery in northern Skye, however, occurs on the Trotternish Peninsula, the northernmost part of the island. The peninsula is dominated by the Trotternish Escarpment, which runs north-south for 23km and culminates in The Storr (719m) and eight other peaks over 500m. Geologically, the escarpment consists of westward-dipping plateau lavas, primarily olivine basalts. These overlie Upper Jurassic sedimentary rocks (particularly Oxford Clay, Corallian Limestone and Kimmeridge Clay) into which have been intruded numerous sills (Anderson and Dunham, 1966). Foundering of the relatively incompetent sedimentary rocks under the weight of the overlying lavas has resulted in successive large-scale rotational landslides on the east side of the escarpment. In consequence, the eastern slopes of the escarpment form an almost continuous cliff up to 250m high. East and north of the Trotternish Escarpment, dolerite sills and Jurassic sediments underlie a coastal fringe of undulating peat-covered lowland.

Similar scenery to that of northern Skye occurs on the Strathaird Peninsula between Loch Scavaig and Loch Slapin. Here, basalt caprocks form the bold eastwards-dipping cuestas of An Carnach (331m) and Ben Meabost (346m), which stand proud of a lowland underlain by Jurassic sediments.

Tertiary landscape evolution

No terrestrial sedimentary record exists for the 50 million or so years prior to the last glaciation, and consequently any reconstruction of the evolution of the present landscape of Skye must rely on morphological and structural evidence. In such reconstructions the Palaeogene igneous rocks on Skye provide a useful stratigraphic datum, because they indicate that much of the present landscape must have developed during the Cenozoic Era (Sissons, 1967). Detailed work by Anderson

and Dunham (1966) showed that the basalt flows of northern Skye thin markedly towards the margins of the present outcrop, suggesting that the original lava field did not extend any great distance beyond the present coast. The pattern of erosion of these rocks was strongly structurally controlled: the strikingly rectilinear outlines of parts of the coast and the trend of many of the major valleys follow the lines of faults and dykes (Godard, 1965; Figure 1.4).

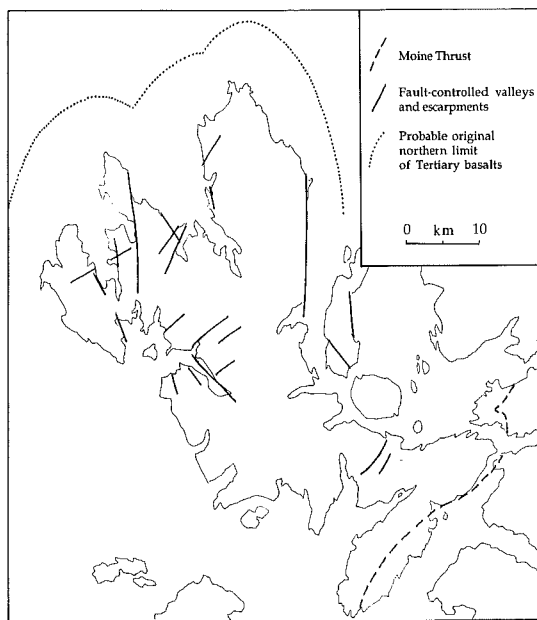


Figure 1.4: Major fault-controlled valleys and scarps on Skye.

Some attempts have been made to interpret the denudation of Skye in terms of a stepped series of 'erosion surfaces' of marine or subaerial origin. George (1966) noted the clustering of summit altitudes around certain values and inferred the existence of dissected, essentially horizontal surfaces that could be 'ascribed without much doubt to marine planation...their stepped form reflecting pulsed fall in sea level' (p. 21). In an effort to demonstrate that Hebridean and mainland Scotland behaved as a single structural unit during denudation, George concentrated on two such 'surfaces' on Skye, both of which he believed to be represented over large areas of the Highlands. According to George the higher of the two, at c. 970m, consisted of 'the residual crowning peaks...of Blaven and the Cuillins' (p. 23), while the lower lay at c. 730m and incorporated the highest summits in the Kyleakin Hills, the Eastern Red

Hills and the Trotternish Escarpment. The inferred periods of marine planation were ascribed to the Neogene, largely because of the apparently undeformed nature of the 'surfaces'. Sissons (1967) regarded the George's insistence on the horizontality of the 'surfaces' as a serious difficulty, and argued that the postulated uplift of the Scottish landmass by over 900m was unlikely to have occurred without significant dislocation and/or tilting.

As part of an extensive study of the evolution of northern Scotland, Godard (1965) delineated four tilted planation surfaces on Skye: (1) a high erosion level (500-700m), incorporating the summits of the Trotternish Escarpment and the Kyleakin Hills; (2) an intermediate surface 400-450m in altitude; (3) the 'surface écosse' at 250-300m; and (4) the so-called Pliocene level (80-120m). Godard considered that these 'surfaces' were mainly of subaerial origin, graded to successive base levels during pulsed uplift, and inferred that tectonic deformation occurred until the end of the Tertiary. No planation surfaces were delineated in the Cuillin Hills, which were regarded as residual summits, the form of which was determined by lithological factors.

Godard's 'Pliocene level' in the Hebrides was regarded by Le Coeur (1988) as part of a very extensive dislocated surface that extends to depths of -25m to -70m offshore. Le Coeur argued that the form and wide distribution of this surface strongly supports its interpretation as a preglacial feature, and concluded that glacial erosion in the Hebrides, including Skye, had been very selective. Furthermore, he inferred that the major lines of drainage on the island had been initiated prior to glaciation as fault-controlled valleys incised into the 'Pliocene' surface.

In support of his contention that large parts of the Hebridean landscape retain their preglacial outlines, Le Coeur (1988, 1989) described several occurrences of rotted mafic rocks which he interpreted as deep weathering horizons. Several such horizons on Skye were described, including dolerite dykes at Tarskavaig, Sleat [NG 593109], ferrodiorite dykes on Marsco [NG 503258] and deep sections in rotted gabbro in Coire na Banachdich [NG 425217]. In addition, Le Coeur (1989) cited extensive areas of 'weathered gneiss' from around Glen Meodal in Sleat [NG 665100] as evidence of interglacial weathering. However, Le Coeur's interpretation of the evidence is open to question. Some of the occurrences of supposedly 'deeply-weathered' rock are located on the sides or floors of deeply-incised troughs and corries (eg. on Marsco and in Coire na Banachdich), sites where glacial erosion is likely to have been most severe. Furthermore, the rotted gabbro in Coire na Banachdich has been interpreted as a hydrothermal alteration product (Bell and Harris, 1986), and need not imply a prolonged period of subaerial chemical weathering. In sum, the uncertainty concerning the interpretation of the rotted rocks on Skye, together with the subjective element in the definition of 'erosion surfaces', means that the nature of landscape evolution during the Tertiary must remain conjectural.

2. THE GLACIAL HISTORY OF THE ISLE OF SKYE

Colin K. Ballantyne and Douglas I. Benn

Introduction

It has long been recognised that Skye supports evidence for both a phase of ice-sheet glaciation, when much of the island was overrun by glaciers from the mainland, and a subsequent episode of locally-nourished valley and corrie glaciers. Moraines and other landforms relating to the later glacial event were observed by Forbes (1846) in the Cuillins and by Bonney (1871) in the Red Hills, and later alluded to by Archibald Geikie (1901, p.300). The first mention of the earlier ice-sheet glaciation was made by James Geikie (1893, p.83), who concluded that during maximum glaciation 'the lofty Coolin Mountains of Skye...formed a centre of dispersion, but the northern parts of the island were overflowed by the ice that crept out of the great glens of Ross'. Subsequent research has refined this basic interpretation. The landforms and deposits of Geikie's 'maximum glaciation' are now attributed to the growth and decay of the last Scottish ice sheet, and of an independent ice cap centred on the mountains of southern Skye, during the Dimlington Stadial of c. 26-13 ka BP. Recent research has confirmed that the subsequent episode of local glaciation occurred during the Loch Lomond Stadial of c. 11-10 ka BP (Walker *et al.*, 1988).

The last ice sheet on Skye.

Much of our knowledge of the pattern of ice-sheet glaciation on Skye dates back to research carried out by the Officers of the Geological Survey nearly a century ago (Harker, 1901; Clough and Harker, 1904; Peach *et al.*, 1910). Only in northern Skye, and particularly on the Trotternish Peninsula, has more recent research contributed to current understanding of the dimensions and patterns of movement of this ice sheet (Anderson and Dunham, 1966; Ballantyne, 1990). It is convenient to summarise current information on the configuration of the last ice sheet in terms of three areas: SE Skye, central Skye and northern Skye.

South-east Skye: The Kyleakin Hills and Sleat Peninsula.

There is general consensus that all of SE Skye was over-ridden by ice from the mainland during the last ice-sheet maximum. Striae on the higher parts of the Kyleakin Hills are oriented westwards or north-westwards, and ice-moulded Torridon Sandstone in the same area shows a similar trend on ground that escaped glaciation during the Loch Lomond Stadial. Erratics of metamorphosed limestone from the mainland are scattered over the eastern slope of Beinn Bhuidhe [NG 776218], and Moine Schist erratics, also derived from the mainland, occur around the summit of Sgurr na Coinnich (739m), the highest point in the Kyleakin Hills. Mainland erratics

are also littered across the low hills of the Sleat Peninsula, and along the shores of Loch Eishort. Striae on southern Sleat show a westerly trend that is consistent with the presence of erratics of Torridon Sandstone on the quartzite of Sgiath-bheinn an Uird [NG 643138], and with that of gneiss boulders derived from the east coast of Sleat on the west coast near Tarskavaig (Peach *et al.*, 1910).

Central Skye: The Cuillins and Red Hills.

Evidence afforded by striae, ice-moulded rock and erratics indicates that the mountain mass of central Skye was not overrun by the last mainland ice sheet, but supported an independent ice cap that diverted the movement of the mainland ice to both the north and south. According to Harker (1901) the point of divergence of the mainland ice stream lay in the vicinity of Broadford (Figure 2.1).

In central Skye, mainland erratics occur only along the coastline below the marine limit, and are encountered only at the surface and not embedded in glacial drift. Such erratics were inferred by Harker (1901) to have been dropped by floating ice. In contrast, mainland erratics occur on Scalpay and Raasay at all altitudes, which suggests that the line of confluence between the mainland ice sheet and the local ice cap followed the narrow strait that separates these islands from Skye (Figure 2.1). In the south, mainland erratics are again absent from drift deposits, but metamorphic erratics on the island of Soay appear to have been derived either from the mainland or from the southernmost part of Sleat (Peach *et al.*, 1910). This suggests that at some stage the mainland ice stream approached within a few kilometres of the south coast of central Skye, but did not encroach upon it.

Harker (1901) estimated that the local ice cap responsible for deflecting the mainland ice was c. 20km long (east-west) and 8-10km wide, and that it completely buried the underlying mountains. From a detailed study of striae and erratic transport he inferred that the former ice shed was aligned north-south along the line of Glen Sligachan - Srath na Crèitheach, and that ice from this centre fed powerful ice streams that moved southwards into Loch Scavaig and northwards into the Sligachan area. Much of the evidence employed in this reconstruction, however, is now known to relate to the development of an icefield during the Loch Lomond Stadial (Ballantyne, 1989a), and hence is of dubious validity as an indication of the dimensions of the earlier ice cap.

Of greater interest is Harker's reconstruction of ice movements outside the area occupied by the later icefield. These show that locally-nourished ice moving southwards into Lochs Slapin and Scavaig was deflected westwards by mainland ice, ultimately joining an ice stream from Glen Brittle that was fed by the western corries of the Cuillins. To the north, Harker inferred from the distribution of Cuillin gabbro and Red Hills epigranite erratics that the Sligachan ice stream was strongly deflected

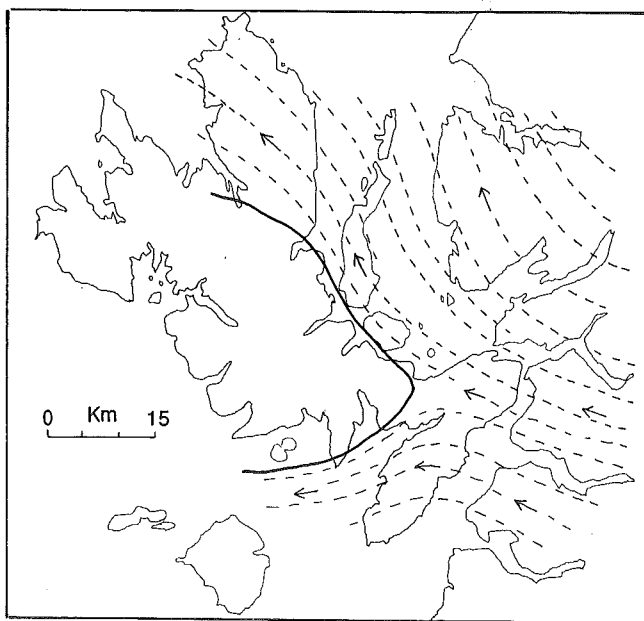


Figure 2.1: Harker's (1901) interpretation of deflection of the Scottish mainland ice sheet around a locally-nourished ice cap in central Skye. The heavy line marks the inferred boundary between local and mainland ice at the glacial maximum. More recent mapping (e.g. Robinson and Ballantyne, 1979; Ballantyne, 1990) indicates that the pattern of flow lines is in error in Wester Ross and northern Skye, but the inferred pattern of ice-sheet movement in south and east Skye appears to be accurate.

first westwards into Glen Dryoch, and then SW towards Loch Eynort. This interpretation poses a conundrum, as it appears to conflict with the evidence from striae that indicate continued northwards movement of the Sligachan ice stream. In part, the pattern of erratic transport outlined by Harker may reflect movement of Sligachan ice into Glen Drynoch during the Loch Lomond Readvance (see below), but this does not account for its inferred continued movement SW to Loch Eynort. Such marked deflection implies near-encirclement of the Skye ice cap by westward-moving mainland ice, an interpretation that conflicts not only with Harker's own map (Figure 2.1) but also with evidence for northwards ice movement across Scalpay, down Glen Varragill (chapter 3) and along the Trotternish Escarpment in northern Skye.

Northern Skye consists of three peninsulas, Duirinish in the NW, Waternish in the north and Trotternish in the NE. Little is known of the glaciation of Duirinish and Waternish, or indeed any part of Skye NW of a line drawn between Portree and Glen Brittle. A confused account is given by Anderson and Dunham (1966), who surmised that a second locally-nourished ice mass existed in Duirinish, on the hilly terrain dominated by MacLeod's Tables, and that this diverted ice moving from the SE into Bracadale Bay in the west and Loch Snizort in the north. This reconstruction, however, appears to be based solely on their contention that 'there is no evidence that the area between Loch Bracadale and Loch Dunvegan has ever been overridden by Highland ice'. They also considered that mainland ice moving northwards up the Sound of Raasay turned northwestwards at Portree and thus occupied Loch Snizort. No supporting evidence is given for this interpretation.

More is known about the glaciation of Trotternish. Mapping of the Trotternish Escarpment (Figure 2.2) indicates that the last ice sheet moved northwards across the peninsula, parallel to the escarpment, but that the ice lay higher to the west than to the east and traversed cols in the escarpment in a northeasterly direction. Such cols support evidence for the passage of glacier ice in the form of roches moutonnées and ice-moulded bedrock, but all the Trotternish peaks over 500m from The Storr northwards support a thick cover of *in situ* frost-weathered regolith. The upslope transition from ice-scoured cols to slopes covered by frost-weathered debris occurs over an altitudinal range of at most 30m, and descends in altitude from 580-610m at the southern end of the escarpment to 440-470m at its northern end (Figure 2.3). This weathering limit was interpreted by Ballantyne (1990) as a periglacial trimline that represents the maximum altitude of the last ice sheet, an interpretation which implies that the peaks of Trotternish remained above the surface of the ice and hence experienced prolonged periglacial conditions of great severity (chapter 4; site 4.1). Calculations based on the altitude and gradient of the inferred upper limit of the last ice sheet in this area suggest that it extended 25-40km north of Trotternish and was probably confluent with an independent Outer Hebridean ice cap. It is also of interest that linear extrapolation of the trimline gradient southwards indicates an ice surface altitude of 750-800m for central Skye, sufficient to bury the Red Hills but suggesting that some of the higher summits of the Black Cuillin may have remained above the ice as small nunataks. Ballantyne (1990) calculated basal shear stresses of 30-39 kPa for the ice sheet in the Trotternish area, and suggested that such low values reflected drainage of ice from Trotternish by adjacent low-gradient ice streams flowing over deforming sediments in Loch Snizort and the Sound of Raasay (*cf.* Chesher *et al.*, 1983).

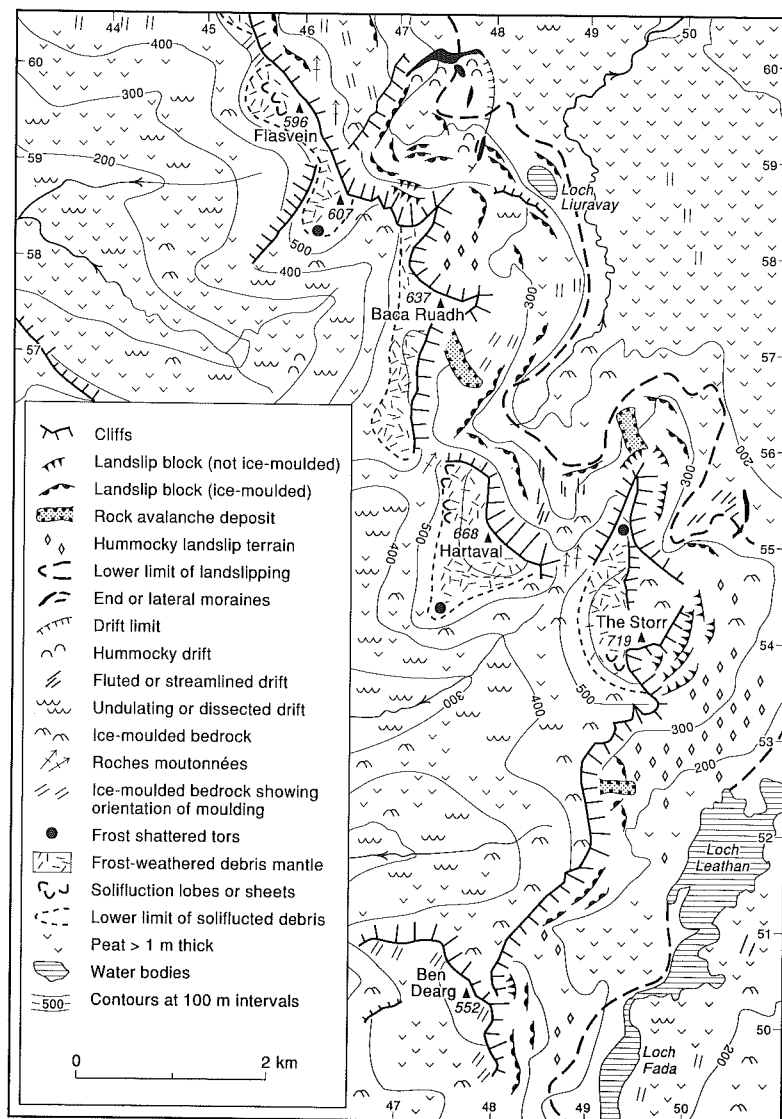


Figure 2.2: Geomorphological map of the southern half of the Trotternish Escarpment. From Ballantyne (1990).

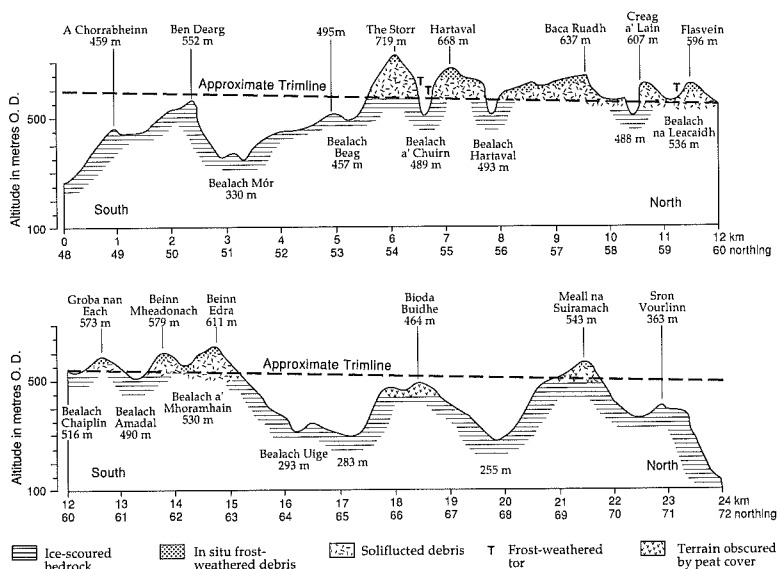


Figure 2.3: Relief of the Trotternish Escarpment plotted against a north-south projection plane, and showing the lower limits of frost-weathered regolith and soliflucted debris, the upper limit of ice-scoured bedrock and the level of the trimline inferred from this evidence. From Ballantyne (1990).

The overall pattern of ice-sheet glaciation.

The pattern of ice-sheet glaciation outlined above refers for the most part to ice flow directions when the last Scottish ice sheet reached its maximum dimensions on Skye. It is not known when this occurred as the culmination of the last (Late Devensian) ice-sheet expansion has not been dated in Scotland. In England, the maximum extension of the southern margin of the same ice sheet has been dated at c. 18-17 ka BP (Bowen *et al.*, 1986). There is evidence, however, that the culmination of ice-sheet expansion in southern Scotland and England occurred *after* the ice nourished in the Scottish Highlands reached its maximum extent (Sutherland, 1984a). This asynchronous behaviour may represent a response to the southerly migration of a zone of increased precipitation associated with the oceanic polar front (Sissons, 1981), and raises the possibility that the culmination of the last Scottish ice sheet (and associated locally-nourished ice masses) on Skye may have occurred markedly earlier than the date established for the last ice sheet maximum in England.

Little is known of the pattern of build-up of local ice masses on Skye during the Dimlington Stadial, but if it is assumed that it resembled that of glacier expansion during the Loch Lomond Stadial (see below) some interesting inferences are possible. During the Loch Lomond Stadial a substantial icefield 155 km² in extent developed in the mountains of central Skye, and smaller glaciers formed elsewhere on the island (see below). At the same time, the margins of the mainland icefield lay no nearer than the upper reaches of Loch Alsh and the mouth of Loch Hourn, over 30km east of the central Skye icefield. If ice cover during the Loch Lomond Stadial represents a valid analogue for glacial build-up during the Dimlington Stadial, the icefield in central Skye must have reached impressive proportions before becoming confluent with the mainland ice sheet. Possible evidence for the southeastwards extension of this central icefield during its build-up occurs in Glen Ord, south of Loch Eishort, where Peach *et al.* (1910) discovered erratics indicative of ice transport from the NW mingled with Lewisian gneiss erratics from the east.

Various interpretations have been proposed for the pattern of ice retreat. Harker (1901) suggested that withdrawal of the mainland ice from the island allowed the outlet glaciers of the central Skye ice cap to resume a pattern of radial movement out from the Cuillins and Red Hills. It is now evident, however, that much of the evidence he used to infer such a radial pattern relates not to the period of ice-sheet retreat, but to the movement of glaciers during the Loch Lomond Stadial (*cf.* Ballantyne, 1989a). Anderson and Dunham (1966) proposed that ice-sheet retreat in Trotternish was interrupted by 'four main pauses', each associated with the cutting of overspill channels that controlled the drainage of lakes dammed up in the valleys to the west of the Trotternish Escarpment by glacier ice that occupied Loch Snizort. This proposal was refuted by Ballantyne (1990), who found no evidence in Trotternish to indicate interruption of general deglaciation.

Indeed, across most of Skye the wasting ice sheet appears to have left little evidence of its retreat, except in the form of a smooth undulating till sheet of variable thickness, now in many areas obscured by a blanket of peat. Moraine ridges deposited by the last ice sheet have been identified at only two sites. The first is located c. 1km west of Strollamus, where a double moraine ridge composed largely of erratic granite boulders descends in a northwesterly direction from 150m [NG 584270] to 70m [NG 581276] over a distance of 600m. This feature was initially interpreted by Ballantyne (1988) as a lateral moraine marking the southern margin of a lobe of ice that formerly occupied the sound between Skye and Scalpay. However, Benn (1990) has argued convincingly that this deposit should be interpreted as a medial moraine related to the confluence of ice streams in the area (site 3.5 below).

The second ice-sheet moraine identified by Ballantyne (1988) is located at c. 450m to the NW of Beinn na Caillich [NG 770230] in the Kyleakin Hills, where four or five arcuate boulder-covered moraine ridges cross the mouth of a shallow corrie.

Ballantyne interpreted these as having been deposited at the margin of a lobe of the retreating mainland ice sheet (site 2.9 below).

The Loch Lomond Readvance.

Evidence for former local glaciers on Skye was first reported by Forbes (1846) and Bonney (1871), in the form of corrie moraines in the Cuillin and Red Hills respectively. Harker (1901) and Clough and Harker (1904) outlined further evidence for a local glaciation during which corrie and valley glaciers radiated outwards from the central mountain area, and end moraines marking the limits of this glaciation were identified in the southern Cuillin (Harker, 1901) and the Red Hills (Peach *et al.*, 1910). The latter also attributed hummocky moraines in Kylerhea Glen (Kyleakin Hills) to deposition by a locally-nourished glacier moving eastwards down to the sea (i.e. against the direction of ice-sheet movement in his area) and noted the absence of the '100 foot' or Lateglacial shoreline in the area occupied by this glacier. Similar hummocky drift was observed by Harker (1901) to be abundant on low ground fringing the mountains of central Skye, but was attributed by him to deposition by stagnant ice during ice-sheet deglaciation rather than by later local glaciers, even though the boundary of such drift with the surrounding smooth till sheet is often sharply defined (Clough and Harker, 1904, p. 40; Peach *et al.*, 1910, p. 159).

Later attempts to define the limits of local glacier advances on Skye produced widely differing interpretations. Charlesworth (1956) envisaged the development of an independent icefield in the Cuillins and Red Hills with outlet glaciers extending into neighbouring glens and fjords, and the development of numerous small glaciers in the Kyleakin Hills and east of the Trotternish Escarpment, but he did not substantiate this reconstruction with field evidence. Anderson and Dunham (1966) published a map depicting a much more extensive 'Lateglacial readvance' than that envisaged by Charlesworth, but also provided no supporting evidence. In contrast, Birks (1973, p.365) favoured two Lateglacial readvances on the island, involving an extensive local glaciation of the central mountain area prior to c. 12 ka BP and regeneration of small corrie glaciers in the Cuillins during the Loch Lomond Stadial of c. 11-10 ka BP.

Mapping by Sissons (1977a) appeared to vindicate the conclusions of Birks regarding the limited extent of glacier ice in central Skye during the Loch Lomond Stadial. Sissons inferred the existence at this time of 12 corrie glaciers, 8 in the Black Cuillin and 4 in the Red Hills, and a valley glacier that occupied Coir'uisg to the east of the Cuillin ridge. There are, however, several inconsistencies in Sissons' reconstruction: (1) the absence of glaciers in topographically-suitable locations within the central mountain area; (2) the presence of abundant 'hummocky drift' outside his proposed glacier limits, even though such drift was used in some instances to delimit corrie glaciers; (3) selective use of striae to delimit some corrie glaciers; and (4) part of the supposed accumulation area of his 'Coruisk Glacier' lies over 200m below his reconstructed equilibrium line altitude for that glacier. Walther (1984)

subsequently proposed that during the Loch Lomond Stadial glacier ice occupied Glens Sligachan, Drynoch and Varragill, implying that the Loch Lomond Readvance in this area was much more extensive than Sissons envisaged. Walther also suggested that there had been a limited readvance of some small corrie glaciers in the Cuillins during the Preboreal (c. 10-9 ka BP).

In an attempt to resolve the above conflict of opinion, Ballantyne (1989a, 1990) carried out detailed geomorphological mapping of the mountains of central Skye, Kyleakin and Trotternish. The results indicate the former existence of fourteen independent locally-nourished ice masses: a major icefield (the Cuillin Icefield, 155km² in area) and ten corrie glaciers in the mountains of central Skye; a small icefield c. 10km² in area in the Kyleakin Hills; and two small corrie glaciers on the east side of the Trotternish Escarpment. The evidence for these former glaciers is summarised briefly below.

The Cuillin Icefield and associated outlet glaciers (Figures 2.4 and 2.5)

Abundant striae, roches moutonnées and streamlined or fluted moraines, together with the transport of gabbro and granite erratics (Harker, 1901) indicate former movement of glacier ice northwards down Glen Sligachan into Glen Drynoch, Glen Varragill and Loch Sligachan (Figure 2.4; site 3.2). The former extent of these outlet glaciers is defined mainly by drift limits, though the southern margin of the Sligachan Glacier is marked by a pronounced lateral moraine, the Sconser moraine (site 2.1). The former margins of the Glamaig, Moll, Ainort, Srath Mór and Srath Beag outlet glaciers are defined not only by the upslope limits of thick drift (sites 2.2, 3.6 and 3.8), but also by abrupt changes in the orientation of striae and ice moulding, and by lateral moraines along the former northern margin of the Ainort Glacier (site 2.3) and the eastern margin of the Srath Beag glacier. End moraines, lateral moraines and changes in the orientation of ice-moulding and striae define the former lateral extent of the Slapin and Kilmorie glaciers (site 2.4). A pronounced lateral moraine marks the former eastern limit of the Crèitheach Glacier (site 2.5), but the terminus of the Coruisk Glacier occupied an area of drift-free bedrock, and its position had to be reconstructed from changes in the direction of ice-moulding and striae (site 3.9).

The upper limits of the Cuillin Icefield are locally represented by periglacial trimlines. Erosional trimlines are well developed on the resistant basic intrusive rocks, for example on the sides of Coir' Uisg. On the scree-covered granite slopes of the Red Hills erosional trimlines are rare, however, and the upper limits of the icefield and its outlet glaciers in this area are more often represented by an upslope transition from a thick glacial drift cover to frost-weathered bedrock or scree (site 2.2).

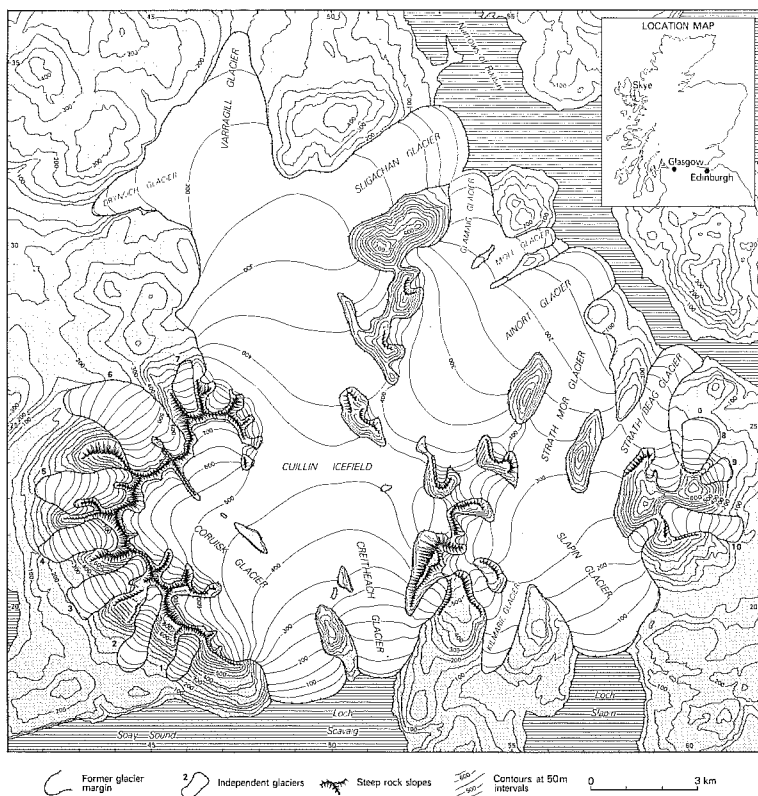


Figure 2.4: Reconstruction of the dimensions of the Cuillin Icefield and other former glaciers in the area of the Cuillin Hills, Bla Bheinn and Red Hills (Ballantyne, 1989a).

The Cuillin Hills corrie glaciers.

Evidence for seven former corrie glaciers on the western side of the Cuillin Ridge was first described and mapped by Sissons (1977a). Remapping by Ballantyne (1989a) supported Sissons' interpretation, but suggested that three of these glaciers (3, 4 and 7 in Figure 2.4) may have been more extensive than Sissons envisaged. Benn (1990), however, has accepted Sissons' original interpretation of the maximum dimensions of glacier 3 (Coire Lagan; site 2.6) and glacier 4 (Coire na Banachdich) following a detailed reassessment of the field evidence. The limit to glacier 7 (Fionn Choire) is equivocal. Striae and ice-moulded rock beyond the mapped terminus of this glacier indicate former westwards glacier movement across the mouth of the corrie, and this evidence was employed to constrain the dimensions of the glacier as depicted

in Figure 2.4. However, Harker (1901) noted that erratics of a distinctive silicified trachyte that crops out in the corrie (Thompson, 1967) can be traced north-eastwards in the direction of Sligachan. This north-eastwards carry of trachyte erratics has been confirmed by the authors, and suggests that the Fionn Choire glacier may have been more extensive than is depicted in Figure 2.4, and possibly confluent with the glacier that occupied Glen Sligachan.

The remaining six corrie glaciers to the west and south of the Cuillins (1-6 in Figure 2.4) are all at least partly defined by end or lateral moraines, and by drift limits, periglacial trimlines and ice-moulded bedrock or striae aligned in directions at variance with those produced at the time of the Late Devensian ice-sheet maximum. The detailed evidence for the limits of four of these glaciers is described below (sites 2.6, 2.7, 3.10 and 3.11).

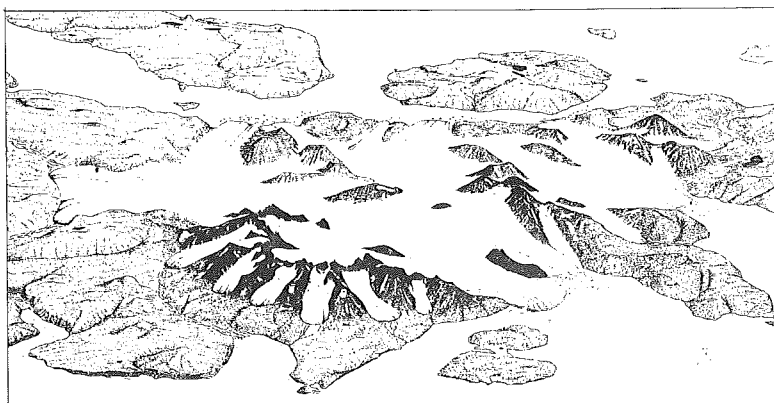


Figure 2.5: An oblique reconstruction of the Cuillin Icefield and surrounding corrie glaciers, based on the glacial limits depicted in Figure 2.4.

The Eastern Red Hills Corrie Glaciers.

Sissons (1977a) mapped evidence for four corrie glaciers in the Eastern Red Hills. Remapping confirmed the accuracy of his reconstruction of three of these (glaciers 8-10, Figure 2.4), all of which are delimited by clear end and lateral moraines. The bouldery moraines marking the limit of the glacier that occupied Coire Fearchair (glacier 9; site 3.4) are visible from Broadford, and the massive end moraine of the Coire Gorm Glacier (10) extends down to only 60m above sea level at NG 613219 and can be seen from the A881 road in Strath Suardal. However, the lateral moraine and drift limit that mark the eastern limit of Sissons' fourth 'corrie glacier' (NW of Beinn na Caillich) continue downvalley to near the coastline, demonstrating that ice from this corrie was confluent with the Strath Beag Glacier (Figure 2.4).

The Kyleakin Hills glaciers (Figure 2.6).

Former local glaciation of the Kyleakin Hills is indicated by striae and ice-moulded bedrock in Kylerhea Glen that indicate former eastwards movement of a small outlet glacier, the Kylerhea Glacier. In addition, Kylerhea Glen, upper Glen Arroch and Coire nan Cuilean all support thick valley-floor deposits of hummocky and fluted drift, yet similar drift deposits are absent from lower Glen Arroch and neighbouring valleys (Peach *et al.*, 1910). Ballantyne (1989a) employed the downvalley and upslope limits of this drift to define the limits of former locally-nourished glaciers in the Kyleakin Hills (Figure 2.6). The presence of eastwards-oriented striae near sea level suggests that the Kylerhea Glacier extended a short distance beyond the present coastline. The upper limits of this small icefield are defined by periglacial trimlines on the slopes of Sgurr na Coinnich and Ben Aslak.

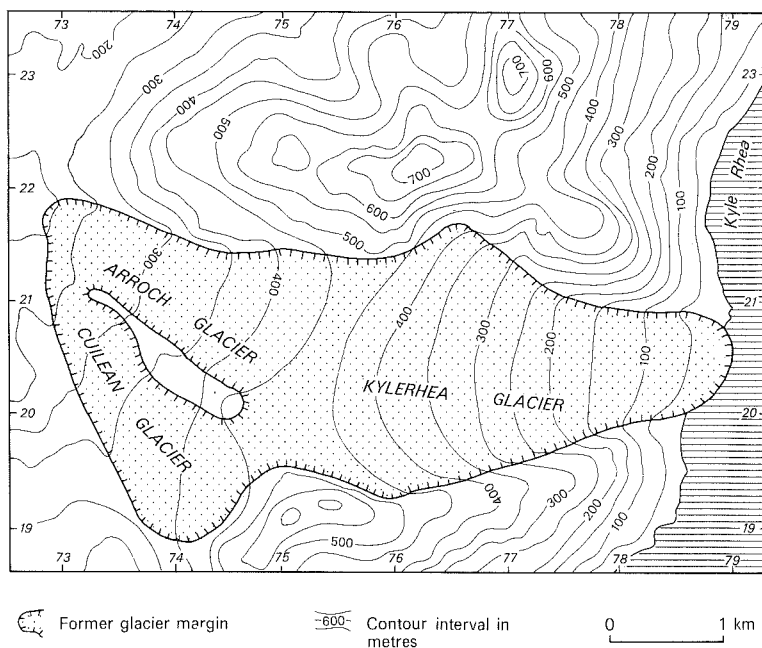


Figure 2.6: Reconstruction of the dimensions of the Kyleakin Hills glaciers at their maximum extent. From Ballantyne (1989a).

The Trotternish Glaciers.

Ballantyne (1990) found evidence for only two locally-nourished glaciers in Trotternish, both on the east side of the escarpment. At Coire Cuithir (site 2.8) this

takes the form of an extensive lateral moraine and related drift limit. At Coire Scamadal, NE of The Storr, a low moraine ridge [NG 506554] marks the eastern limit of an area of NE-oriented streamlined moraines and ice-moulded rock knolls.

The age of the local glaciation

The results of the geomorphological mapping summarised above provide evidence for only one readvance of locally-nourished glaciers on Skye. Immediately outside the limits of this readvance, erratics, striae and ice-moulded rock reflect the movement of the last ice sheet over the area. No evidence was found by Ballantyne in support of the much more extensive 'Lateglacial readvance' of Anderson and Dunham (1966), nor Birks' (1973) concept of two readvances of local ice, nor Walther's (1984) supposedly 'Preboreal' boulder moraines in certain corries of the Cuillins. The reconstruction outlined above most closely resembles that proposed by Charlesworth (1956), though some of the outlet glaciers are less extensive than those he depicted, and no evidence was found for the numerous corrie glaciers believed by him to have occupied the Kyleakin Hills and the Trotternish Escarpment.

Three lines of argument are pertinent to establishing the age of the glacial readvance (Walker *et al.*, 1988). First, the absence of *in situ* frost-shattered bedrock within the mapped limits of local glaciation indicates a Loch Lomond Stadial (c. 11-10 ka BP) age for this event, as bedrock exposed to the severe climate of the stadial is likely to have experienced at least limited frost weathering (chapter 4). Second, high-level (> 15m OD) Lateglacial raised shorelines occur only outside the readvance limits (Figure 2.7). This relationship suggests that the readvance occurred during a period of relatively low sea level well after ice-sheet deglaciation, and was responsible for destroying earlier high-level Lateglacial shorelines, an interpretation again consistent with a Loch Lomond Stadial age (chapter 6). Finally, the hypothesis that the readvance occurred during the Loch Lomond Stadial was tested by Walker *et al.* (1988) by means of pollen analysis and radiocarbon dating of cores obtained from infilled enclosed basins in central and eastern Skye. Ten cores were recovered from inside the mapped limits of the readvance and five from outside these limits (Figure 2.7; chapters 7 and 8). Whereas the 'outside' sites all yielded Lateglacial organic sediments, only Flandrian sedimentary sequences were encountered in cores from the 'inside' sites, a result strongly indicative of a Loch Lomond Stadial age for the readvance.

Similarly, organic sediment from the base of a core recovered from inside the limit of the Cuithir Glacier in Trotternish (site 2.8) yielded a radiocarbon age of $10,060 \pm 270$ yr BP and a pollen assemblage characteristic of the Lateglacial/Early Flandrian transition (Vasari and Vasari, 1968; Vasari, 1977; chapters 7 and 8). The absence of older organic sediments in this core indicates that the local glaciers on Trotternish are also of Loch Lomond Stadial age.

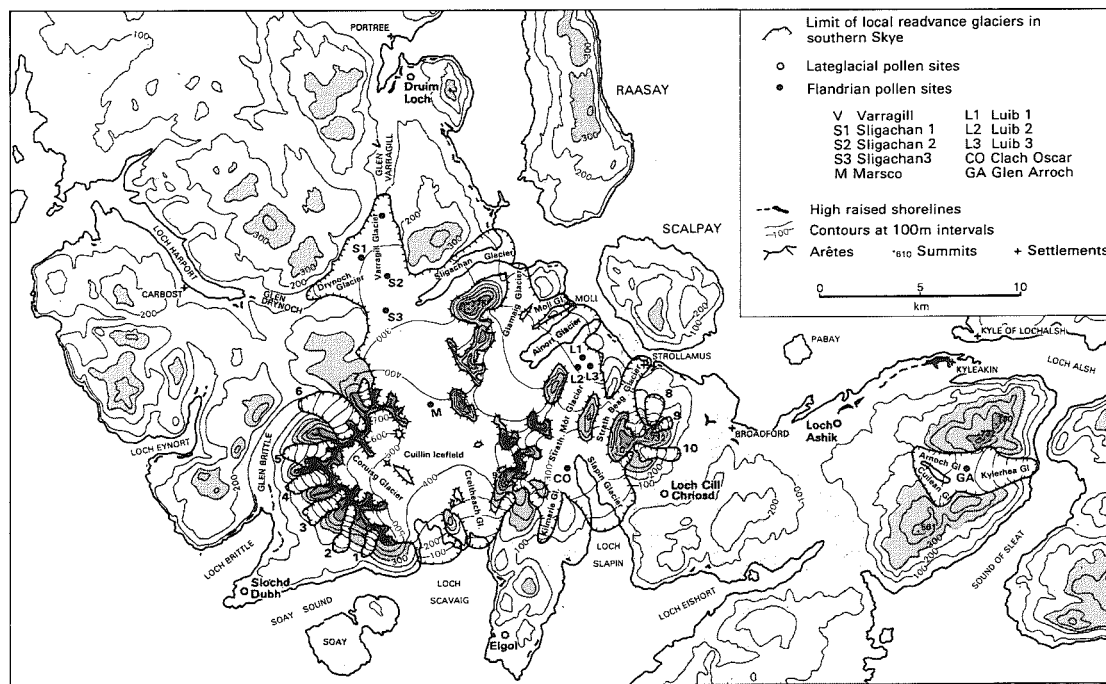


Figure 2.7: High raised shorelines, pollen sites and Loch Lomond Readvance limits in central Skye.

In sum, the absence of evidence for Lateglacial periglacial activity, Lateglacial shorelines and Lateglacial pollen sites inside the mapped readvance limits, taken together with the presence of all three immediately outside these limits, indicates that the readvance described above occurred during the Loch Lomond Stadial of c. 11-10 ka BP, and therefore represent the Loch Lomond Readvance on the island.

Palaeoclimatic and glaciological implications of the readvance glaciers.

Palaeoclimatic implications.

The area-weighted mean equilibrium line altitude (ELA) for the reconstructed Loch Lomond Readvance glaciers of central and eastern Skye was calculated by Ballantyne (1989a) to be 319m. This value conforms with wider evidence for a regional eastwards rise in ELAs across NW Scotland that indicates dominant westerly airstreams during the Loch Lomond Stadial (*cf.* Sissons, 1979, 1980). However, the reconstructed ELAs for individual outlet glaciers of the Cuillin icefield decline in a north-easterly direction (Figure 2.8) from 433m to 235m. This trend was interpreted by Ballantyne as indicating easterly transfer of snow across ice sheds by strong westerly winds. The trend of corrie glacier ELAs suggests that the dominant snow-bearing (as opposed to snow-blowing) winds may have been southerlies. Overall, this interpretation provides support for Sissons' (1979, 1980) proposal that snowfall during the Loch Lomond Stadial was associated with southerly airstreams preceding warm and occluded fronts, but that south-westerly winds were nonetheless prevalent and were responsible for blowing snow on to and across glacier surfaces.

By using a relationship between mean summer temperature and average accumulation established for ten Norwegian glaciers (Sutherland, 1984b) and by assuming that mean annual stadial precipitation values for the Cuillin Icefield lay in the range 2700-3700 mm, Ballantyne (1989a) calculated that the reconstructed ELA for the icefield at its maximum extent (308m) implies a contemporaneous mean July sea-level temperature of c. 6°C. This figure is consistent with previous estimates of 7.5°C for the English Lake District and 7.0°C for the Western Grampians (Sissons, 1979, 1980).

Implications of icefield asymmetry.

The reconstructed Cuillin Icefield (Figure 2.4) displays pronounced north-south asymmetry. The Coruisk and Crèitheach Glaciers descended steeply southwards towards Loch Scavaig, with average gradients of 5.6° and 3.5° respectively. In contrast, the Drynoch-Varragill and Sligachan Glaciers extended northwards much farther beyond the icefield accumulation area, with overall gradients of only 2.4° and 2.0° respectively. A section across the icefield (Figure 2.9) shows that the Varragill Glacier began to steepen north of the former ice shed, then flattened out to an almost

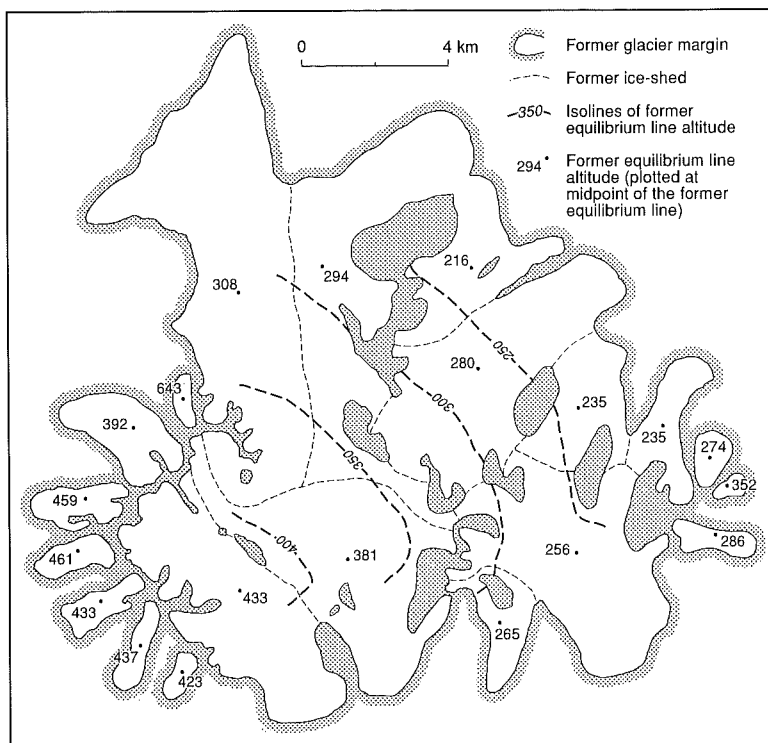


Figure 2.8: Reconstructed ice-sheds and equilibrium line altitudes in metres for the Cuillin Icefield and surrounding glaciers. The isolines pertain to the icefield glaciers only (Ballantyne, 1989a).

constant slope of 1.6° that continued almost to the glacier snout. Such a profile appears inconsistent with that of a glacier moving over a rigid bed, and Ballantyne (1989a) suggested that the anomalously low gradient of the northern outlet glaciers reflected deformation of subglacial sediment, (cf. Boulton and Jones, 1979). Two points of evidence favour this interpretation: first, flattening of the glacier profile coincides with an area of strongly fluted or streamlined drift (Donner and West, 1953); second, drift exposed in section in this area comprises a thin veneer of supraglacial debris overlying a much greater thickness of subglacially-sheared till (chapter 3; site 3.2). Both lines of evidence confirm that the bed of the Varragill Glacier in the area of low surface gradient consisted of deformable sediment.

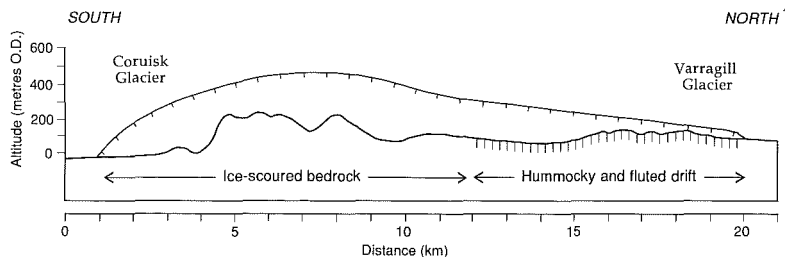


Figure 2.9: North-south section across the Cuillin Icefield, showing the correspondence between the low gradient surface of the Varragill Glacier and the zone of hummocky and fluted drift.

Sites of particular scientific interest.

Most of the sites described below consist of locations where the limits of the Loch Lomond Readvance are particularly well defined. The only known land-based limit of the Late Devensian ice sheet on Skye is represented by the periglacial trimline on the hills of Trotternish. The field evidence for this is described in greater detail in chapter 4 (site 4.1). The stratigraphic evidence for the age of the Loch Lomond Readvance is considered in detail in Chapters 7 and 8.

2.1 The Sconser moraine [NG 529317]

About 400m south of the Sconser Lodge Hotel a pronounced moraine ridge *c.* 550m long and up to 5m high on its distal side climbs the hillslope in a WSW direction. In places the ridge is a complex feature that is interrupted by several kettle holes indicating the former presence of buried ice. The moraine is continued westwards by discontinuous ridge fragments and by a pronounced drift limit that extends to 200m altitude before becoming obscured by scree. The moraine marks the southern boundary of an area of elongate WSW-ENE aligned drift ridges and ice-moulded bedrock.

The Sconser moraine was interpreted by Ballantyne (1989a) as a lateral moraine marking the southern limit of an outlet glacier, the Sligachan Glacier, at the culmination of the Loch Lomond Readvance (Figure 2.4). This view is supported by the absence of Lateglacial shoreline fragments within Loch Sligachan.

2.2 Loch Ainort Viewpoint [NG 532283].

From the head of Loch Ainort the A850 road climbs northwards. At the crest of the hill a car park south of the road offers a panoramic view over much of the Ainort

basin and the surrounding hills. Amongst the features of geomorphic interest are two excellent drift limits, one on the slopes of Beinn Dearg Mhór to the west, the other across the loch on the NW slopes of Glas Bheinn Mhór.

The Beinn Dearg Mhór drift limit [NG 523285; see also site 4.2].

On the SE slope of Beinn Dearg Mhór the upslope limit of thick glacial drift descends northeastwards from c. 400m to c. 350m across the flank of the mountain. This drift limit coincides both with the approximate upslope limit of continuous vegetation cover, and with the downslope limit of frost-weathered granitic bedrock and scree. The thickness of drift banked against the slope is exposed in gullies cut by streams and debris flows. This drift limit and trimline was interpreted by Ballantyne (1989a) as marking the northern margin of a glacier (the Glamaig Glacier; Figure 2.4) that occupied Gleann Torra-mhichaig at the culmination of the Loch Lomond Readvance. Below the level of the drift limit are two or three moraine ridges that descend obliquely to the ENE. These moraines have a maximum altitude of c. 300m at NG 524280 and extend down to c. 140m at NG 522284, 100m west of the A850 road. They were interpreted by Benn (1990) as recessional moraines that record the breakup of the eastern Cuillin Icefield into separate valley glaciers.

The Glas Bheinn Mhór drift limit [NG 552263].

A very similar drift limit and trimline to that described above descends northeastwards across the NW flank of Glas Bheinn Mhór from c. 310m to c. 230m. The drift forms a broad bench, heavily dissected by gullying and debris flows, that is succeeded upslope by periglacial scree deposits. At the SW end of this drift limit, the glacier that formerly occupied the Ainort basin during the Loch Lomond Stadial was fed by a small tributary glacier emanating from a corrie on the NE side of Belig (Figure 2.4). Predominantly angular basalt and agglomerate erratics transported by this tributary glacier from the corrie are scattered across the col between Belig and Glas Bheinn Mhór, and are incorporated in the drift bench described above.

2.3 The Loch Ainort lateral moraine [NG 555293].

From the south shore of Loch Ainort near Luib [NG 564279], a lateral moraine and drift limit can be seen cutting obliquely across the upper part of the slope opposite (Leathad Chrithin). This former ice limit descends northeastwards from c. 200m [NG 549290] to c. 140m [NG 55929], and consists for most of its length of a drift bench rather than a ridge, although it impounds a small lochan at 185m near the summit of the hill. This lateral moraine was interpreted by Ballantyne (1989a) as marking the northern margin of the Ainort Glacier (Figure 2.4) at the culmination of the Loch Lomond Readvance.

2.4 Camas Malag [NG 583190]

At Camas Malag on the eastern shore of Loch Slapin, two to three moraine ridges are banked against a steep-sided granite escarpment (Figure 3.7). The moraines form the southern extremity of a moraine belt that extends for c. 3km from the slopes of Beinn Dearg Bheag in the Eastern Red Hills (A-D in Figure 3.7), and mark the eastern limit of a large glacier system that drained into Loch Slapin (Ballantyne, 1989a). The ridges at Camas Malag stand up to 5m high and are littered with boulders of locally-derived granite. Granite boulders are uncommon on the ground to the south, and those in the moraines were probably derived by plucking below the margin of the Slapin glacier. The composition of pebble-sized material in the outermost moraine also indicates a predominantly local origin: 68% granite, 28% Cambro-Ordovician limestone, and 4% basalt.

The seaward end of the moraines at Camas Malag is truncated by the Main Postglacial Raised Beach, which has a maximum altitude of c. 10m at this locality. The absence of higher (Lateglacial) raised shorelines at Camas Malag provides strong evidence that the moraines were deposited during the Loch Lomond Stadial.

Scuba divers have reported that a submarine boulder-littered ridge trends directly across Loch Slapin from Camas Malag to the intertidal shingle spit at Rubha Cruaidhlinn [NG 570190]. The ridge, which is apparently the continuation of the onshore moraines, has a gentle proximal slope and a steep distal slope, and may represent the grounding line of the Slapin glacier at the Loch Lomond Readvance maximum (*cf.* Barnett and Holdsworth, 1974).

2.5 The Camasunary moraine [NG 524191].

From a point on the track about 300m east of Camasunary, at the head of Loch Scavaig, a fine moraine ridge and drift limit can be traced northwards almost uninterruptedly from c. 30m above sea level for a distance of over 1km to c. 160m. In places this feature takes the form of a drift bench, but elsewhere it rises up to 6m above the adjacent ground. A meltwater channel runs along the eastern side of the ridge for part of its length and has captured and diverted southwards the drainage from the slope to the east. To the east of the moraine, striae reflect westward movement of the last ice sheet across Strathaird, but striae west of the ridge on ice-moulded rock outcrops around Camasunary are aligned southwards, reflecting the later movement of locally-nourished glaciers from Srath na Crèitheach and Bla Bheinn. The moraine also marks the boundary between strongly fluted drift to the west and ice-scoured bedrock to the east.

Ballantyne (1989a) interpreted the Camasunary moraine as delimiting the eastern margin of a small glacier that flowed SSW from Bla Bheinn to become confluent with the much larger Crèitheach Glacier (Figure 2.4). The point of

confluence of the two glaciers is marked by a boulder-stewn medial moraine at NG 551192. The absence of Lateglacial shorelines within the sheltered bay at Camasunary provides evidence in favour of a Loch Lomond Stadial age for the Camasunary moraine, and hence for the readvance of the Crèitheach Glacier that it delimits.

2.6 The Coire Lagan moraines [NG 431201]

The moraines in the lower part of this corrie have a complex morphology and distribution, and disagreement has arisen concerning the precise limit of the Loch Lomond Readvance. Sissons (1977a) placed the northern and western glacier limit at an arcuate belt of boulders, ridges and mounds that descends from c. 460m to 200m (A to E in Figure 2.10). On the southern side of the corrie the belt is less distinct (F,G,H). The features at I lie beyond the glacier limit envisaged by Sissons and may represent the fluvially-dissected remnants of a formerly continuous drift cover. According to Sissons, the limit is marked by the bouldery ridges at E and the massive round-crested spur at H.

Ballantyne (1989a) considered that part of an area of boulders, hummocks and discontinuous ridges to the west of the moraine arc lay within the limits of the Loch Lomond Readvance, and drew the maximum position of the glacier along the line A, B, I, F shown on Figure 2.10. However, it is notable that the area of boulders and hummocks continues for c. 1 km to the north of the revised glacier limit, and any line drawn within the deposits in this area must be considered to be arbitrary. Consequently, Benn (1990) argued that unless further evidence is forthcoming, there is no compelling reason to revise the limits originally proposed by Sissons. The debris outside the arcuate moraine belt was considered by Sissons (1977a) to record deposition by the Late Devensian ice sheet.

2.7 Coir' a'Ghrunnda [NG 448191].

Coir' a'Ghrunnda exhibits several of the glacial landforms typical of basins that are underlain by massive, resistant rocks, and the limit of the Loch Lomond Readvance at this site is one of the clearest in Britain. A continuous arc of boulders defines the margin of a piedmont lobe that extended on to the open ground below the narrow corrie mouth (Figure 2.10). The boulders, which are up to 6m in length, are arranged in a series of ridges and mounds linked by more diffuse spreads. To the west, three distinct belts are present (K in Figure 2.10), the outermost of which consists of a discontinuous ridge that stands up to 10m above the adjacent ground. By contrast, to the east a single belt of large mounds of boulders is present (M), and linear elements are less evident. This contrast may reflect aspect-related differences in the activity of the glacier margin, although it is also possible that it is the result of asymmetries in the volume or distribution of debris. By analogy with modern glaciers, it is probable that the Coir' a'Ghrunnda moraines formed by a combination of dumping and ice push

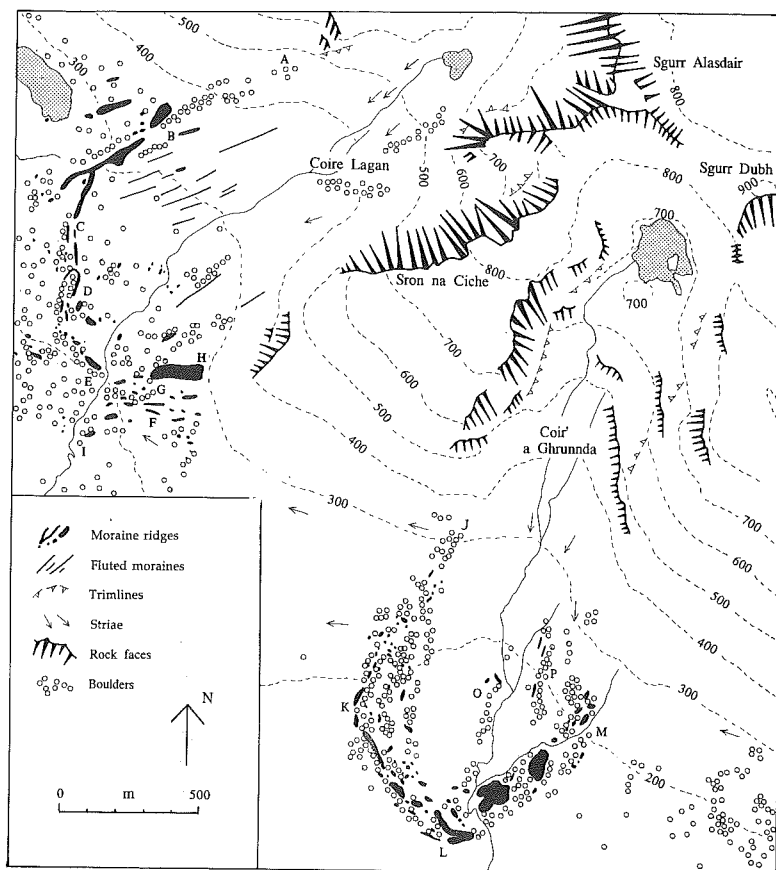


Figure 2.10: Glacial landforms of Coire Lagan and Coir' a'Ghrunnda.

(cf. Eyles 1989; Sharp 1984). There is no evidence for stillstands or readvances of the retreating glacier at distances greater than 200m from its maximum position.

Most of the boulders in the moraines are of gabbro, allivalite or eucrite, lithologies that underlie large parts of the catchment and are not readily traceable to particular source areas. However, on the eastern side of the moraines, boulders of a distinctive brown careous-weathered peridotite are common (up to 40%). The peridotite is derived from the Layered Peridotite Series that crops out on Sgurr Dubh above the upper corrie (Figure 2.10), and it appears probable that the boulders were entrained supraglacially following rockfalls. Two longitudinally-oriented trains of boulders, including peridotite, occur within the moraine arc (O,P), in alignment with

the two largest boulder mounds in the moraine. The boulder trains are interpreted as 'avalanche-type' medial moraines that resulted from rockfalls in the upper parts of the basin.

Subglacial erosional forms are exceptionally clear in Coir' a'Ghrunnda, and well-preserved striae and friction cracks may be observed at many localities. Striae recording westwards flow of the last ice sheet around the Cuillin Hills are visible on several bedrock outcrops both west and east of the moraine arc.

2.8 Coire Cuithir, Trotternish [NG 4759]

Coire Cuithir is a low altitude embayment flanked by impressive cliffs midway along the length of the Trotternish Escarpment, and formed by rotational landslipping of the scarp NE of Creag a'Lain (607m). The floor of the corrie is partly occupied by a small loch, Loch Cuithir, that is dammed by a landslide block. The site is accessible by vehicles via an unmetalled road from Lealt [NG 508609].

The principal evidence for the formation of a local glacier in Coire Cuithir following the withdrawal of the last ice sheet across Trotternish takes the form of a pronounced lateral moraine nearly 1km long and rising up to 15m above the adjacent terrain on its distal side. This moraine descends from 270m [NG 471600] to 170m [NG 478601] across the limit of landsliding, and marks the northern boundary of an area of thick hummocky drift. The south-east margin of the same glacier is delimited by a low lateral moraine 80m long that descends from 230m to 210m [NG 478592]. The position of the former glacier terminus is represented by an indistinct limit to hummocky drift a short distance east of the landslide block that dams Loch Cuithir.

Ballantyne (1990) concluded that the Coire Cuithir moraines represent the limits of a glacier 1.67km² in area that developed during the Loch Lomond Stadial. In support of this interpretation he pointed out that the reconstructed equilibrium line altitude for this glacier (291m) is similar to those of Loch Lomond Readvance glaciers with similar aspects in the Eastern Red Hills, and that there is no evidence for stadial frost weathering within the limits of the glacier. In addition, organic sediment at the base of a core recovered from Loch Cuithir by Vasari and Vasari (1968) yielded a radiocarbon age of 10,060 ± 270 yr BP and a pollen assemblage characteristic of the Lateglacial/Flandrian transition (Vasari, 1977). The absence of Lateglacial Interstadial organic sediments in this core is consistent with occupation of Coire Cuithir by glacier ice during the Loch Lomond Stadial.

Loch Cuithir is also of interest as the site of the most extensive diatomite deposits on Skye. According to Anderson and Dunham (1966), the diatomite rests directly on till but is itself overlain by peaty soil (site 8.6 below). The diatomite deposits of Loch Cuithir were commercially exploited early in the present century.

2.9 Glas Choire, Kyleakin Hills [NG 7624].

An arcuate belt of four or five moraine ridges interspersed with kettle holes crosses the mouth of Glas Choire at an altitude of *c.* 450m (Figure 2.11). This moraine belt is continued to the SW on the flanks of Beinn na Caillich by a pair of lateral moraines and then by a drift limit that becomes obscured under scree at 540m. The ridges support lines of boulders aligned parallel to the ridge crests. The moraine belt marks the limit of a small area of hummocky drift; immediately downvalley from the moraines the terrain consists of ice-moulded Torridon Sandstone bedrock with only a patchy drift cover.

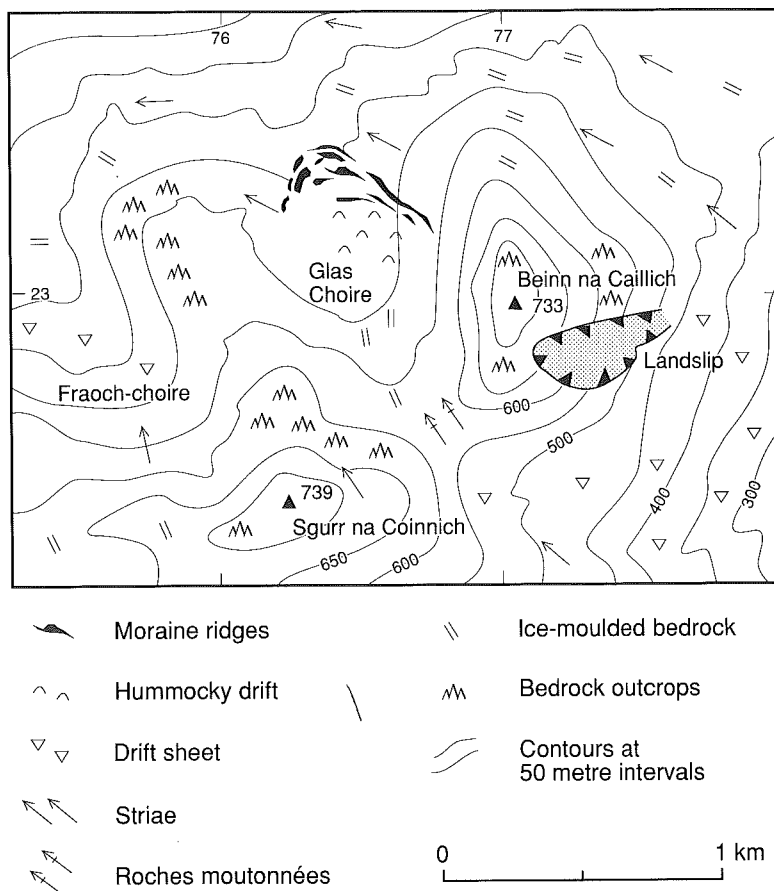


Figure 2.11: The Glas Choire moraines and related landforms in the Kyleakin Hills

Roches moutonnées at the head of Glas Choire, in the col at c. 570m between Sgurr na Coinnich and Beinn na Caillich, suggest that the moraines were deposited not by a small locally-nourished glacier, but by a lobe of ice that crossed the col from the SE, particularly as Glas Choire lacks a headwall that could have acted as a source area for the development of a small local glacier. This interpretation is consistent with the presence on the moraines of erratics of schist and gneiss carried westwards from the adjacent mainland. Ballantyne (1988) therefore interpreted the Glas Choire moraines as having been deposited at the margin of a lobate extension of the last mainland ice sheet during the period of overall ice-sheet retreat. The presence of kettle holes between the concentric arcuate ridges of the moraine belt may indicate that these ridges represent controlled ice disintegration features, possibly formed when glacier ice in Glas Choire was cut off from its source as the last mainland ice sheet downwasted below the level of the col between Beinn na Caillich and Sgurr na Coinnich.

3. GLACIAL LANDFORMS AND SEDIMENTS ON SKYE

Douglas I. Benn

Introduction

The Island of Skye contains a wide range of glacial landforms, some of which are among the most spectacular in the British Isles. The landforms and sediments of Loch Lomond Stadial age are of exceptional clarity, and have been the subject of intense study in recent years (Ballantyne, 1989a, 1990; Benn, 1989, 1990). In consequence, many of the geological and topographical controls on glacial deposition have been identified, and the pattern and style of deglaciation is known in great detail. In addition, work is in progress on the glaciomarine sediments associated with the Loch Lomond Readvance glaciers (Dix, unpublished; site 3.7). By contrast, landforms relating to ice-sheet conditions have received relatively little attention, although they are not without interest (Ballantyne, 1988, 1990; Benn, 1990).

Ice-sheet landforms and deposits

The offshore sediment record indicates that the Island of Skye has been glaciated on several occasions in the recent geological past (*cf.* Davies *et al.*, 1984; Bowen and Sykes, 1988). It is therefore probable that the large-scale glacial erosional features on the island, such as breaches, troughs and rock basins, formed as a result of successive episodes of glacial erosion. The extent of former glacial erosion is perhaps best appreciated in Coir' Uisg in the Black Cuillin (site 3.9), although the deep breaches of Srath Mór (site 3.6) and Glen Sligachan - Srath na Creatheach (Site 3.2) are also worthy of mention. In many places, glacial erosion has clearly been most effective in lithologically or structurally weak areas, although in others, such as the head of Loch Scavaig, great thicknesses of resistant rocks have been removed. Well-formed corries occur in many parts of the Cuillin Hills. The mis-match of the volume of the corries and the amount of material in the Loch Lomond Readvance moraines within them indicates that the corries are ancient features. It is notable that subsidiary corries and free faces are preferentially developed on north- and east-facing slopes (Harker, 1901). Benn (1989, 1990) suggested that this phenomenon is a consequence of the preferential development of firn basins on the lee side of ridges during the Pleistocene, resulting in the efficient removal of debris.

Outside the limits of the Loch Lomond Readvance, the medium- and small-scale glacial landforms on Skye appear to have formed during the Dimlington Stadial. Most of these landforms are subglacial in origin, and there are only scattered occurrences of supraglacially-deposited sediments, possibly reflecting a paucity of debris at high levels within the last ice sheet. Examples of ice-marginal sediments include arcuate

moraines in Glas Choire in the Kyleakin Hills, irregular ice-stagnation topography in Glen Brittle and at Strollamus, and the Strollamus boulder moraine (Walker *et al.*, 1988; Ballantyne, 1988; Benn, 1990; sites 2.9 and 3.5). The last mentioned was interpreted by Ballantyne (1988) as a lateral moraine marking a readvance or stillstand that interrupted ice-sheet deglaciation, but Benn (1990) argued that it was a medial moraine, and hence lacks stage significance. A full description of the moraine is given below (site 3.5).

Ice-sheet erosion has produced an irregular mammilated terrain in some parts of the island. Such terrain is most strikingly developed on the Precambrian and Palaeozoic rocks on the Sleat peninsula, where 'cnoc and lochain' topography is widespread. By contrast, much of the basalt terrain in the north and west of the island has been eroded into a subdued trap landscape. In many places, small-scale erosional features have been destroyed by weathering. Consequently, striae tend to be best preserved where drift cover has only recently been removed, or on hard, massive rocks, such as the gabbro in the Black Cuillin (Site 2.7) and the Torridonian and Palaeozoic rocks of the Kyleakin Hills and Sleat.

In general, basal tills have a patchy distribution, although they can attain considerable thicknesses locally, particularly on low ground. Unfortunately, good intact exposures are uncommon. In addition, tills developed on basalt bedrock tend to be heavily oxidised, and primary sedimentary structures are commonly obscured as a result. However, good examples of intact lodgement tills can be examined around Staffin bay in the north of the island (site 6.1), on the south bank of the Eas Mór gorge above Glen Brittle (NG 419214) and in Glen Varragill (NG 475367; site 3.1).

Loch Lomond Readvance landforms and deposits

An exceptionally wide range of glacial landforms is present within the limits of the Loch Lomond Readvance on Skye, a diversity primarily due to the richly varied geology and topography of the island (chapter 1). In particular, an important division can be made between those areas that are underlain by massive, resistant rocks (*e.g.* the basic plutonics in the Black Cuillin and Bla Bheinn group, and the Inner Granite in the Eastern Red Hills) and those underlain by closely-jointed or weak lithologies (*e.g.* Mesozoic sedimentary rocks and certain basalts and epigranites). The two groups of areas contain contrasting suites of glacial landforms, due to differing bedrock response to glacial and subaerial erosion, and consequent differences in the quantity and character of debris that was transported by the former glaciers.

This point is well illustrated by the contrasting landforms of subglacial erosion in areas underlain by resistant rocks and those underlain by 'weak' lithologies. Subglacial erosion of massive rocks has resulted in large areas of smooth, striated rock surfaces (*e.g.* Coir' a' Ghrunnda, Coir' Uisg and Coire Lagan; sites 2.7, 3.9, 3.12). Evidence for discontinuous rock-mass failure (*e.g.* joint-bounded failure surfaces) on

massive rocks is limited to the lee faces of roches moutonnées, suggesting that subglacial erosion of coarse debris was of minor importance. By contrast, on closely-jointed rocks subglacial plucking was widespread, and more important than abrasion in releasing material from bedrock. Large numbers of subglacially-eroded clasts of Jurassic shale and sandstone are present in moraines and lodgement till around Loch Slapin (site 3.3), Strollamus and Loch Sligachan, while an excellent exposure of subglacially-sheared epigranite can be examined near Luib (site 3.6). In places, the glaciers over-rode unconsolidated sediments, which provided an easily-entrained source of debris. Evidence for such over-riding exists in the Sligachan area (site 3.2) and at Strollamus.

Basal tills are present on all rock types. Such tills are commonly matrix-supported and overconsolidated, with a sub-horizontal platy structure (sites 3.2, 3.12). The contained clasts are typically sub-rounded and faceted, characteristics indicative of modification during active subglacial transport (*cf.* Boulton, 1978; Ballantyne, 1982; Vere and Benn, 1989). In many areas (such as around Sligachan, site 3.2) the clast component is dominated by local material, although in others far-travelled clasts are abundant (*e.g.* on the east side of Loch Slapin, site 3.3, NG 574210). The surface expression of the till deposits is varied. In places, the deposits form low-relief sheets that occupy topographic lows, while elsewhere longitudinally-lineated forms are developed. Two major types of such linear forms are present: (a) fluted moraines 1-2m high and up to 400m long; and (b) larger 'drumlinoid' ridges. Some fluted moraines occur on the lee side of large rock knobs (*e.g.* in Coire na Banachdich, NG 430218, and Coire Lagan, site 3.12), while others occur in 'swarms' and are apparently unrelated to local topography. Fine examples of the latter occur in Coire na Seilg (NG 534245), Harta Corrie (NG 467240) and on Nead na h-Iolaire south of Sligachan (NG 483270). Large 'drumlinoid' moraine ridges occur on the low ground around Sligachan. Ballantyne (1989a) suggested that the Sligachan ridges reflect subglacial sediment deformation during the Loch Lomond Readvance, and argued that such deformation could account for the anomalously low gradient of the reconstructed glacier surface (chapter 2; *cf.* Boulton and Jones, 1979). The landforms around Sligachan, and their constituent sediments, are discussed below (site 3.2). Subglacial deformation of basal till was also invoked by Benn (1990) to account for the large amounts of abraded clasts and rock flour in end moraines above Glen Brittle (*e.g.* Coire na Banachdich, Coire a' Ghreadaidh, site 3.11).

A wide variety of moraine types was deposited at glacier margins during the Loch Lomond Readvance. The characteristics of the moraines vary with (a) the lithology and structure of the source material, (b) the local slope gradient, and (c) the activity of the former glacier margins.

In corries that are underlain by massive rocks, glacier stillstands or readvances are recorded by arcuate, sharp-crested moraine ridges. Such moraines sometimes consist entirely of large boulders (*e.g.* Coir' a' Ghrunnda and Coire Fearchair, sites 2.7 and 3.4,

Active-ice moraines

The most frequently-occurring moraines in basins underlain by weak or well-jointed rocks consist of ridges and hummocks arranged in closely-spaced chains oriented obliquely downvalley. The moraines are commonly 2-4m high, but can be up to 20m in height. Individual ridges commonly have a beaded long profile, which enhances the hummocky appearance of the landform assemblages. Fine examples of such moraines occur around Loch Slapin (site 3.3), and in northern Srath Mór (site 3.6), Gleann Torra-mhichaig (site 3.8), Kilmarie Glen and Coire Mór (Figure 3.2).

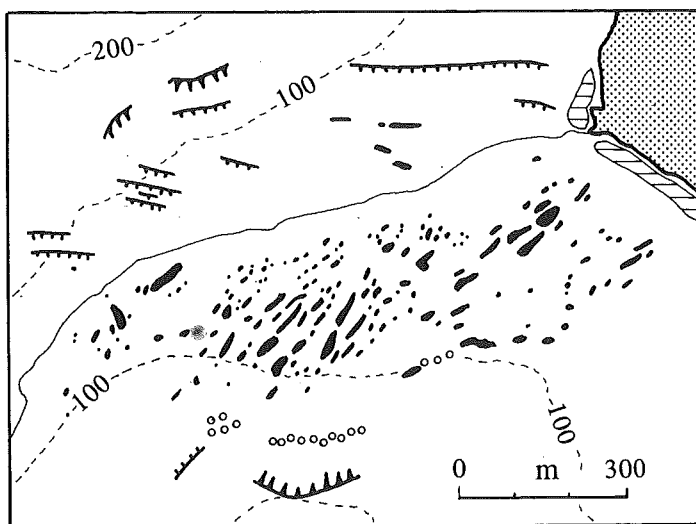


Figure 3.2: Map of the Loch Lomond Readvance moraines in Coire Mór, showing numerous closely-spaced chains of ridges and hummocks. For key see Figure 2.10.

Sissons (1967) suggested that such moraine patterns record deposition in crevasses during ice stagnation. However, this hypothesis is untenable because the typical pattern of crevasses in valley glaciers is a series of incomplete chevrons oriented upglacier (Nye, 1952; Sharp, 1988), while the moraine patterns suggest fragmentary chevrons oriented downglacier. Furthermore, the patterns cannot record the dissection of thick deposits by subglacial meltwater channels: sections invariably expose subaerially-deposited sediments, showing that the deposits did not originate subglacially. A third possibility, that the moraines record deposition at active ice margins is supported by two lines of evidence. First, the moraine ridges often have asymmetric cross-profiles, with steep distal slopes and gentler proximal slopes (*eg.*

in Coire Mór and in northern Srath Mór, site 3.6), suggesting that ice push was of at least local importance in moraine formation. Second, direct structural evidence for glaciotectonism can be examined in sections to the north of Loch Ainort [NG 557292] and in Coire Mór [NG 556303]. Sections in the moraines usually expose gently deformed sediment-gravity flows (including 'flow tills') interbedded with sands and gravels, showing that subaerial sediment reworking was important during moraine formation.

On Skye, the 'active ice' moraines can be divided into two sub-types, according to whether the dominant debris component was derived supraglacially or subglacially. Supraglacial entrainment was dominant where the former glacier surfaces were overlooked by slopes over *c.* 20° (*e.g.* Gleann Torra-Mhichaig, site 3.8, and the northern side of Coire Mór), while subglacial entrainment was more important in the central parts of valleys (*e.g.* the east side of Loch Slapin, site 3.3). Where the slope of the valley sides exceeds 10-20°, slope deposits are widespread, and often interdigitate with glacial sediments (*e.g.* Gleann Torra-mhichaig, site 3.8). In such cases, the continuity of glacial landforms has often been broken by continued slope activity following deglaciation, and the apparently chaotic appearance of the moraines has been further enhanced. Slope activity was particularly high during the retreat of the Loch Lomond Readvance glaciers, as the result of (a) the abundance of freshly-exposed unconsolidated sediment, and (b) slope adjustment to subaerial conditions. Landslipped blocks can be observed in moraine sections in Gleann Torra-mhichaig (site 3.8).

Stagnant-ice moraines

Chaotic assemblages of moraines occur on some valley floors (*eg.* central Srath Mór, Gleann Torra-mhichaig, site 3.8, and the head of Loch Ainort, site 3.7, Figure 3.3). The most commonly-occurring forms in such assemblages are single or composite hummocks, rim-ridges, discontinuous non-aligned ridges, and fluvial terraces. Longitudinally-oriented boulder trains and chains of hummocks occur in places, marking former debris concentrations in the ice (Figure 3.3).

The chaotic planform of the moraines suggests that they were deposited at stagnant ice margins (*cf.* Boulton, 1972; Sharp, 1985), an interpretation that is further supported by sedimentological evidence. Sections in chaotic moraine assemblages commonly expose superimposed sediment flows, sands and gravels. Some hummocks have an anticlinal structure, and normal faults and sag folds have been observed in many exposures (*eg.* site 3.8). Such sequences record the repeated reworking of debris in contact with stagnant ice cores (Boulton, 1972; Eyles, 1979). Ice-stagnation topography tends to occur where supraglacially-derived debris was dominant, apparently because the presence of abundant debris on the ice surface encouraged uneven glacier ablation (*cf.* Eyles, 1983).

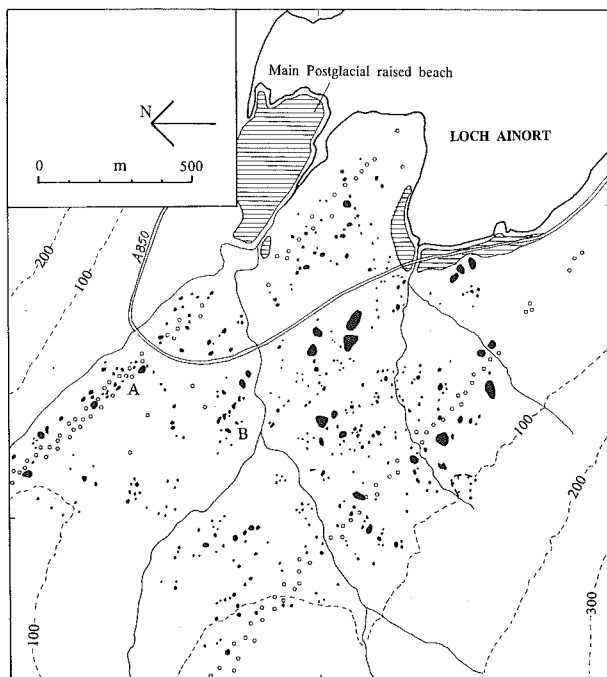


Figure 3.3: Moraine pattern around the head of Loch Ainort. The moraines are described in detail as site 3.7 below. For key, see Figure 2.10.

In some places, the juxtaposition of lateral moraines and hummocky terrain suggests that ice stagnation was confined to the marginal areas of otherwise active glaciers (eg. northern Srath Mór, site 3.6, and Gleann Torra-mhichaig, site 3.8). In one area, central Srath Mór, there is evidence for extensive *in situ* glacier stagnation (Benn, 1990; Figure 3.5). In the strath, the valley sides support staircases of parallel terrace fragments interspersed with moraine hummocks. The distribution of the terraces suggests that a mass of ice, c. 2.5km long and 750m across, stagnated *in situ* on the floor of the strath in the final stages of deglaciation. The floor of central Srath Mór nowhere exceeds 10m OD, and it is inferred that during deglaciation the ice surface declined until snow accumulation was insufficient to maintain an active system. A second area where extensive ice stagnation may have occurred, at the head of Loch Ainort, is described below (site 3.7, Figure 3.3).

The distribution of moraines has been used to reconstruct the pattern of retreat of some of the Skye glaciers (Benn, 1990; Figures 3.4 and 3.5).

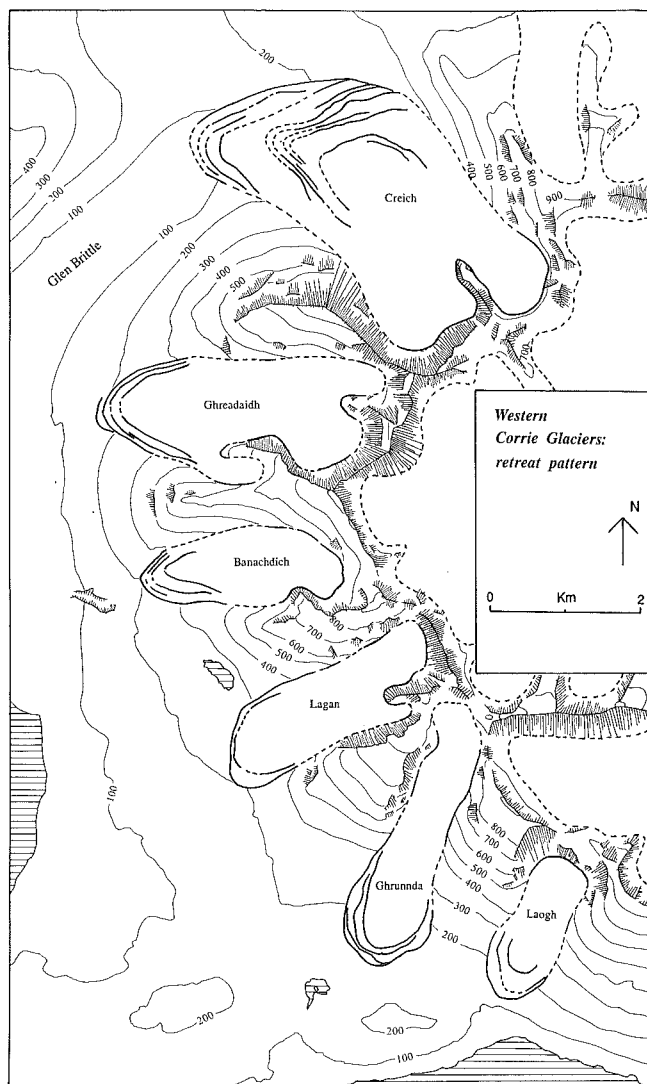


Figure 3.4: The retreat stages of the Loch Lomond Readvance glaciers in the western Black Cuillin, based on lateral and frontal moraines.

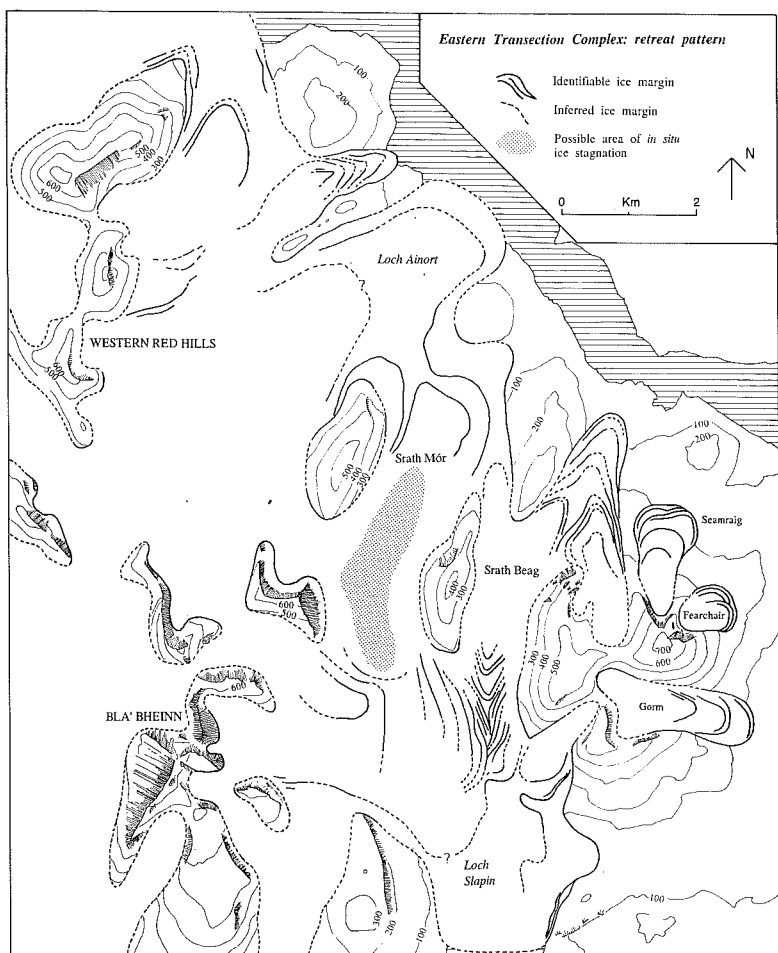


Figure 3.5: The retreat stages of the Loch Lomond Readvance glaciers in the eastern Cuillin Hills, based on moraine distribution.

In all areas, lateral and frontal moraines indicative of readvances and/or stillstands are confined to the lower parts of the corries and valleys. In places, such moraines occur only within 200-300m of the Loch Lomond Readvance maxima, while in others belts of moraines up to 4.3km wide occur. In other parts of the NW Highlands, recessional moraines of Loch Lomond Readvance age are similarly confined to the outer areas of basins (Sissons, 1977b; Robinson, 1977; Ballantyne and Wain-Hobson, 1980; Lawson, 1986). On Skye, the positions of the up-valley limits to recessional moraines are apparently unrelated to geological controls on debris supply, and it is probable that such moraine limits reflect changes in glacier activity. It is therefore suggested that, following an initial period of ice-margin fluctuation, final deglaciation was characterised by relatively rapid and uninterrupted retreat (Benn, 1990). This model of deglaciation is compatible with biostratigraphic and geochemical data that suggest that around the North Atlantic temperatures rose extremely rapidly at the end of the Loch Lomond Stadial (Bard *et al.*, 1987; Atkinson *et al.*, 1988; Dansgaard *et al.*, 1989). However, Bennett and Boulton (in press) have argued that retreat of the large Loch Lomond Readvance icefields on mainland Scotland was interrupted by stillstands throughout deglaciation. This apparent anomaly may reflect the more maritime climate of the west coast of Scotland, or the much greater size of the mainland icefields.

Sites of particular scientific interest

3.1 Glen Varragill till section

Basal tills of probable pre-Loch Lomond Stadial age are exposed in a large section on the west bank of the Varragill River [NG 475367], 100m west of the A850 Sligachan to Portree road. The section is approximately 1km north of the Loch Lomond Readvance limit as determined by Ballantyne (1989a), and consists of 9-10m of till capped by 3-3.5m of sand and gravel. The till is a massive, matrix-supported diamicton with occasional deformed 'streaked-out' lenses of laminated silt and sand. The clasts in the diamicton are commonly faceted and striated, and have strong preferred orientations (Figure 3.6). Most of the clasts are of basalt, although a small proportion are of gabbro, derived from the Cuillin Hills to the south. The diamicton is interpreted as a lodgement till, which has possibly undergone subglacial deformation *en masse* (cf. Boulton, 1987). Vertical variations in the orientation of clast fabric modes may record minor changes in ice flow direction during the accumulation of the till. The gravel and sand that cap the till form a series of laterally extensive lenses, and were probably deposited in a braided river environment. A dark horizon is often visible at the base of the gravel and sand sequence, immediately above the contact with the till. The horizon appears to mark a perched water table caused by the relative impermeability of the till and is not a buried soil, as it may first appear. There is therefore no evidence for a significant time lapse between deglaciation of the site and the deposition of the gravels and sands.

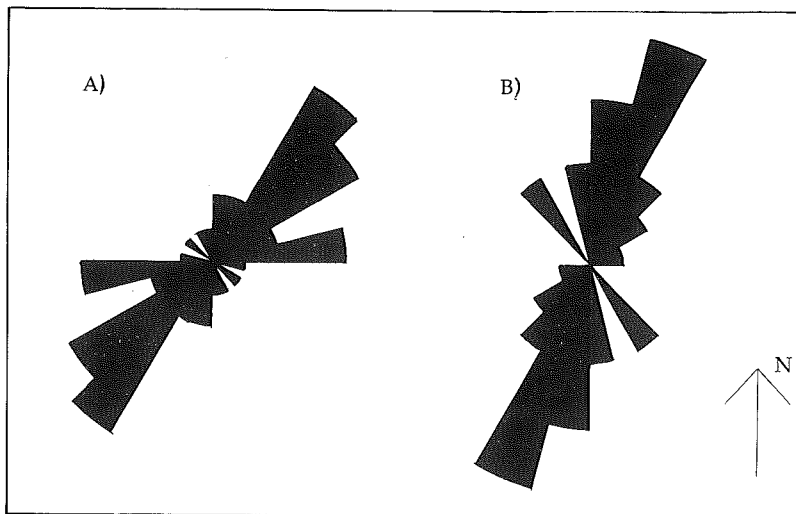


Figure 3.6: Orientation of clast long axes in the Varragill till section. The samples were taken from 9m (A) and 8m (B) below the top of the till. $N=25$.

3.2 Sligachan moraine suite

The area around Sligachan [NG 486299] contains some of the most impressive moraines on the Island of Skye. The moraines were described as 'hummocky drift' by Harker (1901), who attributed them to deposition from stagnant ice during ice sheet decay, an interpretation that was repeated by Clough and Harker (1904) and Sissons (1977a). An alternative view was expressed by Donner and West (1955), who interpreted the moraines as a 'drumlin field' on the basis of preferred landform and clast fabric orientations. The moraines have yet to be studied in detail, although recent mapping by Ballantyne (1989a) and unpublished work by the present author tends to support the 'drumlin' hypothesis. Ballantyne (1989a) confirmed the presence of longitudinal linear elements in the moraines, which he attributed to subglacial deformation (chapter 2; cf. Boulton, 1987). A subglacial origin is also strongly suggested by the composition of the moraines: sections almost invariably reveal basal tills capped by only a thin veneer of subaerially-deposited sediment. The moraines occur within the limit of the Loch Lomond Readvance as determined by Walker *et al.* (1988) and Ballantyne (1989a).

The linear pattern in the moraines is not clearly visible from the valley floor, and is most readily appreciated from the adjacent hills in low light, or on aerial photographs. However, the elongate form of individual moraine elements and their distinctive steep lee slopes are visible from a number of localities, most notably the Coruisk footpath about 500m south of the Sligachan Inn [NG 489293]. Numerous sections occur in the moraines. Three of the clearest and most accessible are described below.

The first section is located on the north side of the A863 (Sligachan to Dunvegan road), about 500m west of the Inn [NG 481297]. The section exposes *in situ* till resting on basalt bedrock and overlain by a variable thickness of slumped sediment. The deposit has several characteristics typical of Highland lodgement tills (*cf.* Benn, 1989, 1990): (1) it is matrix supported and shows little lateral or vertical structural variation; (2) the matrix is very compact and is traversed by numerous anastomosing sub-horizontal joints, giving the till a platy appearance; (3) the contained clasts are dominantly sub-angular and sub-rounded, and are frequently blocky in form; and (4) the clasts have a strong preferred orientation parallel to probable former ice flow directions. The most abundant clast lithology in the till is basalt, derived from the low ground to the south. Gabbro from the Black Cuillin and acidic rocks from the Western Red Hills occur in smaller quantities.

A second good section exists in the west bank of the Allt nan Ime [NG 491310], where a 5m thickness of grey lodgement till is exposed. The clast content (%) of the till at three levels is as follows:

	Depth below surface		
	1m	2m	4m
Basalt	84	72	76
Porphyry	8	12	4
Granite	8	16	0
Gabbro	0	0	20
Total	100	100	100

The granite and gabbro clasts are derived from the hills to the east and west of Glen Sligachan respectively, suggesting that ice flow directions changed during the period of till deposition. It is not certain whether all of the till was deposited during a single glacial event.

Evidence for the incorporation of pre-existing sediments in basal till exists in a third section, in the south-west bank of the Allt Dubh [NG 480314]. At this site, sheared lacustrine deposits crop out below compact lodgement till. The lacustrine

The shale clasts in the moraines are commonly angular and unmodified, suggesting that much of the debris was entrained in sub-marginal positions and underwent only limited subglacial transport prior to deposition. Because no large exposures are available and the internal structure of the moraines is not known, the mechanism of moraine formation is uncertain. One possibility is that the moraines consist of pushed masses of weak submarginal and proglacial materials (*cf.* Krüger, 1985; Humlum, 1985). It is notable in this respect that the moraine ridges are most continuous where the glacier abutted reverse slopes and drainage would have been impeded (*e.g.* O,Q,R; *cf.* Boulton, 1986). Shallow exposures of sediment-gravity flow deposits show that superficial debris reworking was locally important.

Similar areas of moraines, also composed largely of locally-derived Jurassic material, occur on the west side of Loch Slapin (*e.g.* NG 558220), in Kilmorie Glen north of Kirkibost [NG 551178], around the Abhainn nan Leac north-east of Camasunary [NG 516187], and south of Strollamus [NG 593270].

3.4 Coire Fearchair boulder moraines

Coire Fearchair is a small, shallow corrie located on the north-east side of Beinn na Caillich in the Eastern Red Hills [NG 602233]. Moraines marking the limit of a small Loch Lomond Readvance glacier (Sissons, 1977a; Ballantyne, 1989a) form a prominent arc around the corrie mouth (Figure 3.1), and are clearly visible from Broadford village. The moraines are composed entirely of large boulders of coarse granite. In most places the ridges stand 1-2m high, but in the south-east the debris forms a massive rampart with a distal slope of 20m (A, Figure 3.1). At its margins (B, C) the rampart oversteps and incorporates a smaller, earlier ridge showing that the rampart is, at least in part, a composite feature.

The pattern of moraine ridges on the corrie floor shows the position of the glacier at five stages of retreat. Retreat of the glacier was spatially uneven: the moraines record retreat of the northern margin (D) of 250m while no corresponding net retreat occurred on the southern side. This pattern may be due to topographic control exerted by the bedrock spur at D. Evidence for a readvance during deglaciation exists at E, where one moraine ridge oversteps two earlier ones. Such truncation of earlier moraines demonstrates that the ridge at E was formed, at least partly, by 'bulldozing' of proglacial boulders.

The floor of the inner corrie is littered with a chaotic spread of boulders, which suggests that the later stages of deglaciation were not interrupted by stillstands or readvances.

On the upper corrie floor, polished bedrock slabs are widespread. The upper limit of the slabs is abrupt, and is interpreted as a periglacial trimline. The backwalls of the corrie consist of a series of unstable and deeply-jointed buttresses, towers and gullies, and rockfalls probably constituted the principal source of debris to the glacier. The preferential occurrence of rockwalls on the north-facing slopes may have contributed to the large size of the moraine rampart at A (*cf.* Benn, 1989).

3.5 Strollamus boulder moraine

The Strollamus boulder moraine lies on the slopes of Glas Bheinn Bheag and Am Meall in the Eastern Red Hills, and can be easily examined from the track leading from Strollamus to Luib (Figure 3.8).

The Strollamus moraine, which is truncated at its southern and northern ends by moraines of Loch Lomond Stadial age, was interpreted by Ballantyne (1988) as a lateral moraine that marks the southern margin of an ice lobe that flowed north-westwards up Loch na Cairidh. Ballantyne argued that the position of the lobe implied contemporaneous ice cover over Loch Ashik [NG 691232; site 8.5], from which Lateglacial pollen has been recovered (Walker *et al.*, 1988; Walker and Lowe, 1990). Consequently, he inferred that the Strollamus moraine delimited a glacial readvance or stillstand that antedates the Lateglacial Interstadial of *c.* 13 - 11 ka BP, and suggested that it may correlate with the Wester Ross Readvance on the mainland to the north-east (*cf.* Robinson and Ballantyne, 1979; Sissons and Dawson, 1981). Almost all of the boulders in the train are of granite derived from the north-western ridge of Beinn na Caillich [NG 602233]. Lines of such boulders also occur on that ridge, and were interpreted by Ballantyne (1989a) as lateral moraines marking the eastern margin of a Loch Lomond Readvance glacier that flowed out of Coire Reidh.

While confirming that the Strollamus moraine pre-dates the Loch Lomond Readvance, Benn (1990) argued that it is not a lateral, but a medial moraine. The evidence for this re-interpretation lies in the planform and long profile of the moraine. Adjacent to the northern limit of the Loch Lomond Readvance in Srath Beag [NG 587266], the moraine consists of a diffuse boulder spread with a maximum altitude of *c.* 150m. From this point, the upslope limit of the boulders rises to *c.* 200m on the northern ridge of Glas Bheinn Bheag [NG 585269], from which point the moraine descends directly downslope to *c.* 70m OD as two parallel ridges. Thereafter, the upper edge of the train maintains a generally constant altitude of *c.* 70m OD for 1.2 km, to where it is truncated above Loch Ainort (A, Figure 3.8). The *c.* 50m rise then 130m fall in the altitude of the moraine would appear to rule out its interpretation as a lateral moraine. Furthermore, the moraine descends the northern slopes of Glas Bheinn Bheag with a gradient of over 1:5, yet no westwards deflection of the moraine is evident, as would be expected if the area to the west had been ice free. These difficulties are removed if the moraine is reinterpreted as a medial feature, the planform of which reflects the orientation of flow lines within a laterally-extensive

ice sheet. Benn (1990) concluded that the moraine was initiated in a zone of convergent ice flow in the lee of Beinn na Caillich. It is not possible to ascertain whether the summit of Beinn na Caillich stood above the ice surface as a nunatak at the time of formation of the moraine.

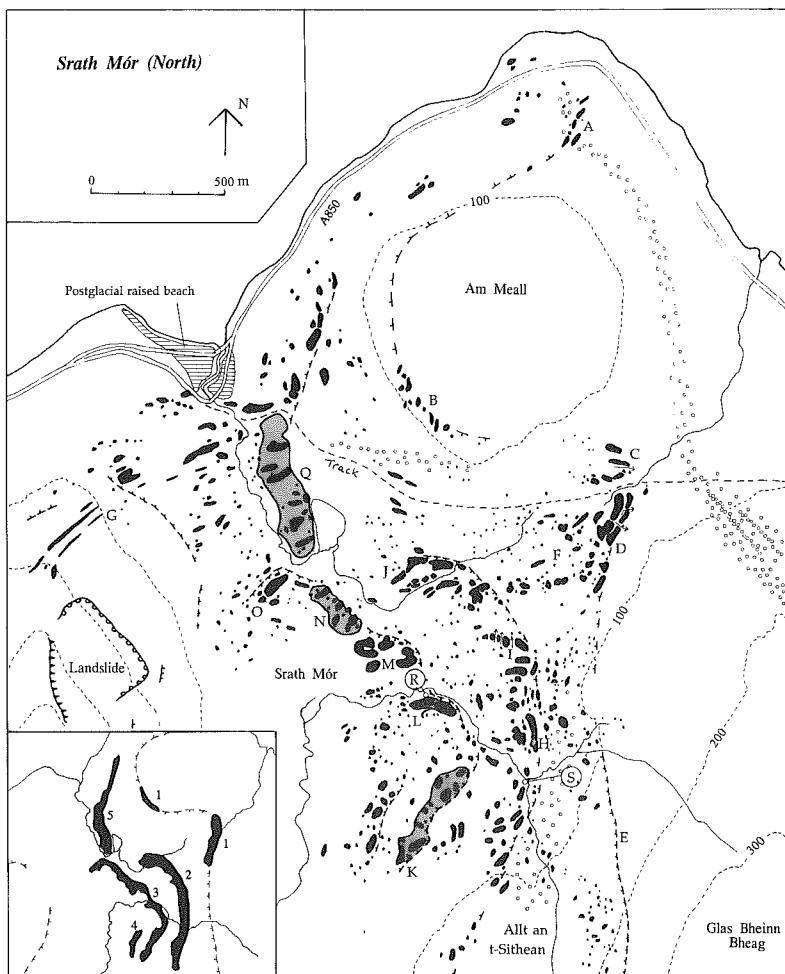


Fig. 3.8 Geomorphological map of the Luib and Dunan area.

3.6 Recessional moraines in northern Srath Mór

A striking series of moraines occurs in the northern part of Srath Mór, south of Luib (Figure 3.8). The moraines record the retreat of confluent glaciers that flowed from Srath Mór and Loch Ainort during the Loch Lomond Readvance (Ballantyne, 1989a; Benn, 1990). The limit of the confluent glaciers extends intermittently from the northern termination of the Strollamus moraine at Ard Dorch (A, Figure 3.8) to the western slopes of Glas Bheinn Bheag (E). The glacier limit is clearest on the col between Am Meall and Glas Bheinn Bheag, and is easily accessible from the summit of the track between Luib and Strollamus [NG 579274; C,D, Figure 3.8]. Two to three parallel chains of moraines are present, and delineate a lobe of ice that spilled north-eastwards from Srath Mór. The chains have a beaded form which is at least partly the result of incision by melt-water channels (*eg.* D). To the west of the col lies an area of low conical hummocks (F). In low light, fluted morainic ridges can be seen on the northern ridge of Glas Bheinn Mhór on the opposite side of the valley (G). The ridges are interpreted as medial features formed at the confluence of Loch Ainort and Srath Mór ice at the Loch Lomond Readvance maximum.

Within the limit of the Loch Lomond Readvance, the moraines in northern Srath Mór form a series of pronounced belts (numbered 2 to 5 on Figure 3.8), between which lie areas of small, scattered hummocks. The overall form of the belts is best appreciated from the northern ridge of Beinn na Crò in low light. In detail, the moraines in the belts are varied in form. The most frequently-occurring forms are ridges, some of which have beaded long profiles (*eg.* H, Figure 3.8). Most of the ridges are oriented parallel to the trend of the belts (*eg.* H, J, K, L, N, Q), although transversely-oriented ridges occur (*eg.* I). A variety of hummocky forms occur in association with the ridges, including small one- or two-topped cones and large composite mounds. Some composite mounds partially enclose central depressions (*eg.* M), and are morphologically similar to the *rim ridges* described by Gravenor and Kupsch (1959) and attributed to deposition in association with stagnating blocks of ice. The largest moraines are the beaded ridges on the valley floor, which are up to 500m long and 18m high (Q). Ridges N and Q have asymmetric cross-profiles, with the steeper slopes lying to the north-east (N) and east (Q).

Numerous shallow sections are present in the moraines in northern Srath Mór. The most widely-exposed material consists of sediment-gravity flow deposits, sometimes interbedded with fluvial gravels, sands or silts. The finest section is located on the northern flank of a large beaded ridge in moraine belt 3 (R, Figure 3.8, Figure 3.9).

Two principal facies associations are exposed. The lower association consists of horizontally-bedded granule and cobble gravels that interdigitate with trough-bedded gravels and sands. Thin units of diamicton sometimes crop out in the lower left of the section, but due to limited exposure, neither their origin nor their relationship to the

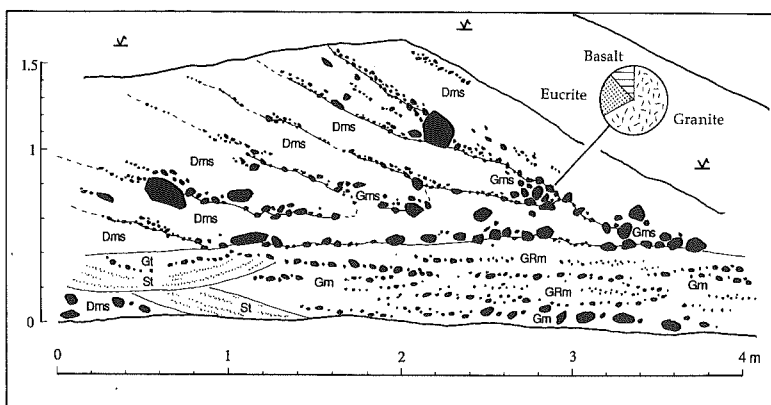


Figure 3.9: Exposure of sediment-gravity flows and outwash gravels in moraine belt 3 (R in Figure 3.8). For key, see Figure 3.10.

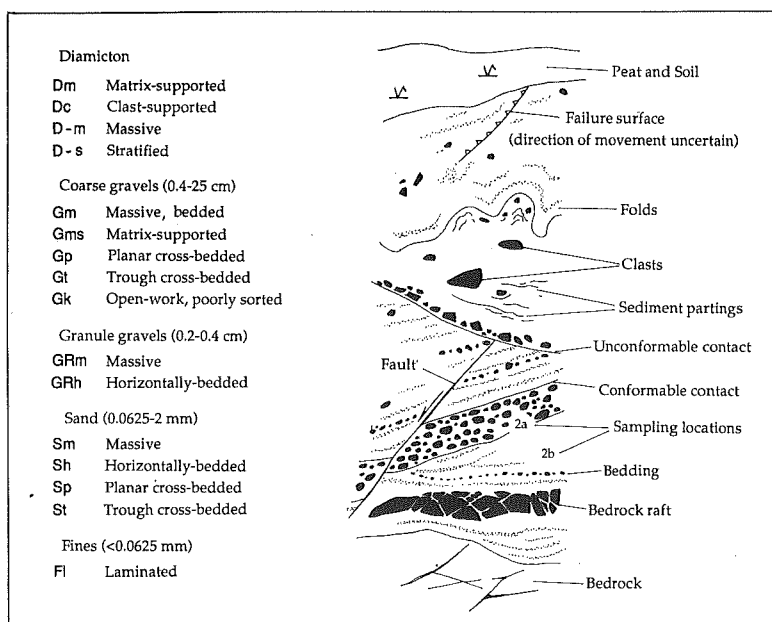


Figure 3.10: Key to symbols and lithofacies codes used in Figures 3.9, 3.14 and 3.15.

overlying sediment have been established. The gravels and sands are interpreted as a bar and channel association, probably part of a proglacial outwash sequence. The upper bounding surface of the association is sub-horizontal, undeformed, and does not appear to be erosional. Above the bounding surface, the upper association consists entirely of a conformable sequence of diamicton units with apparent dips of 15-30° to the north-west. Basal clast concentrations clearly delineate the form of the diamicton units, which progressively overstep the sand and gravel association below. The diamictons are interpreted as sediment-gravity flows (*cf.* Lawson, 1982, 1988), and it is concluded that the section records the progradation of a debris fan over the proglacial surface. The beaded form of the ridge suggests that the moraine belt in this area consists of a series of such ice-marginal debris fans.

Unfortunately, available exposures are too limited to establish whether glaciotectonic thrusting played a role in the formation of the moraine belts in northern Srath Mór, although some evidence for glaciotectonism is provided in a stream section in moraine belt 2 (S, Figure 3.8). At this site, the stream has cut through *c.* 8m of slumped sediment and *c.* 1m of the subjacent rock. The rock is a fine-grained facies of the Glas Bheinn Mhór epigranite, and is traversed by numerous closely-spaced joints. Several of the joints, particularly those with a sub-horizontal disposition, are occupied by bands of compact, foliated diamicton. In places, the disaggregation of the rock between the bands has yielded lines of angular clasts, the *a-b* planes of which are oriented parallel to the foliae in the diamicton. To the left (east) of the section, the bands are narrower and infilled with laminated silts. Tight folds within the silts indicate that deformation occurred following deposition. The material in the section is interpreted as an immature glaciectonite (*cf.* Pedersen 1988), and illustrates the former efficacy of subglacial erosion of well-jointed rock.

The planform and morphology of belts 2-4 indicates that they record successive retreat positions of the Srath Mór glacier. Clast lithological evidence and the position of moraine belt 5 indicate that it was deposited by Loch Ainort ice, either immediately before or after it became separated from the Srath Mór glacier.

The juxtaposition of the moraine belts and areas of hummocky ice-stagnation topography is similar to that reported from the forelands of surging glaciers in Iceland and Svalbard (Clapperton, 1975; Croot, 1978; Sharp, 1985). However, similar landform assemblages have been described from the margins of non-surging glaciers (*e.g.* Humlum 1985). Therefore, in the absence of corroborative evidence, such as 'crevasse-fill' ridges or looped medial moraines, the possibility of palaeosurges cannot be established.

3.7 The Loch Ainort basin

The Loch Ainort basin is of particular interest for two reasons. First, the sea-floor deposits below Loch Ainort and the adjacent waters have been the subject of a recent geophysical study by Justin Dix at the University of St. Andrews, and have yielded important data on glaciomarine sedimentation. Second, the basin contains one of the largest areas of ice-stagnation topography on Skye, study of which has shed light on the style of deglaciation at the end of the Loch Lomond Stadial.

Submarine deposits

The detailed bathymetry of the floor of Loch Ainort has been established by echosounding, and 97.8km of pinger surveys have been collected and used to determine the distribution of the major sediment bodies (J. Dix, unpublished; Figure 3.11).

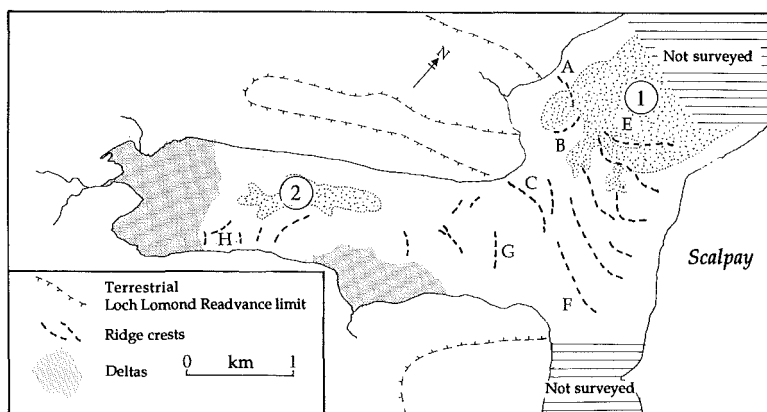


Figure 3.11: Major relief elements and bottom sediments, Loch Ainort (after Dix, unpublished)

The surveys indicate the presence of numerous ridges, some tens of metres high, which typically have steep southern or western slopes and gentle northern or eastern slopes (A-H in Figure 3.11), and which have seismic characteristics indicative of a diamictic composition. The ridges at A, B and C correspond closely to the Loch Lomond Readvance limits as determined from terrestrial evidence, and are interpreted as end moraines. Ridges E to F, in the sound between Scalpay and Skye, are more difficult to interpret, and two possibilities may be suggested. First, the ridges may be

of a similar age to those at A, B and C, implying that the Loch Lomond Readvance limit may have lain farther offshore than the terrestrial evidence suggests. Second, ridges E to F may be older recessional moraines associated with the southward retreat of the last ice sheet. Difficulties exist with both interpretations, and further data are clearly required. The series of ridges within Loch Ainort (G-H) apparently represent Loch Lomond Readvance retreat stages.

A distinctive stratified seismic facies occurs in two areas (1 and 2 in Figure 3.11). The facies characteristics suggest coarse, bedded sediment, interpreted as proximal subaqueous outwash (*cf.* Boulton, 1986). In the outer waters the sediment body overlies parts of ridges A and B, indicating that it formed, at least in part, in association with the Loch Lomond Readvance glaciers. The occurrence of the facies within Loch Ainort is interpreted as proximal outwash deposited during glacier retreat.

In Loch Ainort the stratified seismic facies grades upwards into apparently massive material, probably reflecting a transition to more distal sedimentation. The massive material is thicker on the northern side of the basin, possibly indicative of asymmetric sediment supply. In the outer waters the stratified unit is directly overlain by a strong, thin reflector. One interpretation of this reflector is that it represents clay deposition from meltwater plumes.

Postglacial sedimentation in the Loch Ainort basin has resulted in the progradation of large deltas at Luib and Kinloch Ainort (Figure 3.11).

Terrestrial deposits

Large numbers of moraine mounds cover the low ground at the head of Loch Ainort, and can be well seen from the A850 Broadford to Portree road. Little pattern is evident in the arrangement of the moraines, and there is a complete absence of transversely-oriented features (Figure 3.3). However, longitudinal concentrations of moraines occur in places, for example, along the line of a prominent boulder train that descends from Coire nam Bruadaran (A in Figure 3.3).

The Bruadaran boulder train, which can be seen from the A850 [NG 534268], consists of large (up to 4m a-axis) blocks of Marsco epigranite. The epigranite contains distinctive blue feldspars, and can be traced to a source area which is known from trimline evidence to have occupied a supraglacial position at the Loch Lomond Readvance maximum (Figure 2.4). The nature of the source area and the large size of the boulders indicates that the debris was probably released from bedrock in a series of rockfalls, and that the boulder train is an 'avalanche-type' medial moraine.

In general, the moraines around the head of Loch Ainort contain large proportions of debris derived from the basin backwalls, and relatively small amounts of subglacially-eroded local rocks. An exception to this pattern is the area of moraines south-east of the Bruadaran erratic train (B), where most of the debris is locally-derived Loch Ainort epigranite. This anomaly is attributable to the closely-jointed nature of the bedrock, which would have facilitated subglacial plucking (*cf.* Addison, 1981).

Small sediment exposures can be found in stream cuts through the moraines. All such exposures examined to date contain interbedded sediment-gravity flows and water-sorted sediments, some of which show evidence of multiple reworking episodes. Together with the distribution and morphology of the moraines, the sedimentological evidence is indicative of deposition from ablating glacier ice.

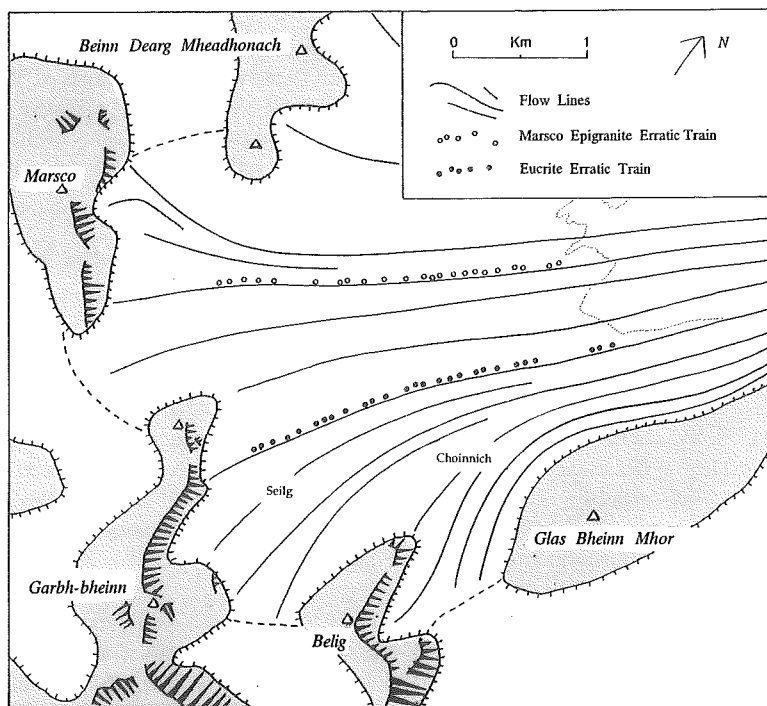


Figure: 3.12: Reconstructed glacier flow lines in the Loch Ainort basin.

Although often adduced as evidence for *in situ* glacier downwasting (*e.g.* Sissons, 1967; Clapperton and Sugden, 1977; Gray, 1982), areas of chaotic 'hummocky' moraine are also known to form at the stagnant margins of otherwise active glaciers

(e.g. Eyles, 1983). One line of evidence regarding the style of deglaciation of the Loch Ainort basin is the pattern of ice flow-lines shown in Figure 3.12. The diagram, based on the distribution of erratics and the alignment of fluted moraines and striae, reveals a single coherent pattern of ice flow that reflects conditions when the glacier extended into tidewater in the lower part of the basin. Significantly, there is no evidence for later realignment of ice flow in the upper parts of the basin. Of particular relevance is the orientation of a train of eucrite boulders, the upper reaches of which cut obliquely across the axes of Coire na Seilg and Coire Choinnich. The lack of deflection of the train in these two corries implies that ice was not reoriented under topographic control during deglaciation, and consequently that ice retreat in the upper parts of the basin was not interrupted by readvances or significant stillstands. Although not conclusive evidence that the Loch Ainort glacier downwasted *in situ*, the lack of evidence of stillstands suggests that the later stages of deglaciation were relatively rapid.

3.8 Gleann Torra-mhichaig: moraines and paraglacial deposits

The moraines and associated landforms in Gleann Torra-mhichaig are typical of areas underlain by closely-jointed rocks. Sub-parallel chains of moraines and drift benches occur on both sides of the valley, and are particularly clear on the east side, above the A850 (Figure 3.13). By contrast, the moraines on the valley floor lack any preferred pattern, and consist of randomly-oriented hummocks and ridges. The moraines on the valley sides are similar to those that mark the Loch Lomond Readvance limit in the glen (A,B and C, Figure 3.13), and are interpreted as closely-spaced 'active-ice' moraines (Benn, 1990).

The principal sources of the debris in the moraines were the long debris-mantled slopes of Beinn Dearg Mhór and Glamaig to the west and the shorter slopes of Druim nan Cleoich to the east. Good sections are available on the east side of the valley, in cuttings beside the A850.

The finest section is located opposite a lay-by at NG 537298 (D, Figure 3.13, Figure 3.14). The section exposes up to 2m of interbedded diamictons and gravels, which record subaerial deposition by sediment-gravity flow and fluvial activity respectively. Bedrock slabs up to 3m in length occur interbedded between diamicton units. The blocks are of a blue-grey fine-grained chill facies of the Glamaig epigranite that crops out locally and on the slopes above the exposure. Partial disaggregation of the well-jointed blocks has occurred at their lateral margins. The blocks are in conformable, non-erosional and undeformed relationship with the underlying beds, indicating that they are landslipped masses of local material.

A striking feature of the diamicton and gravel units is a marked compositional stratification. Most of the units are composed of the local Glamaig epigranite,

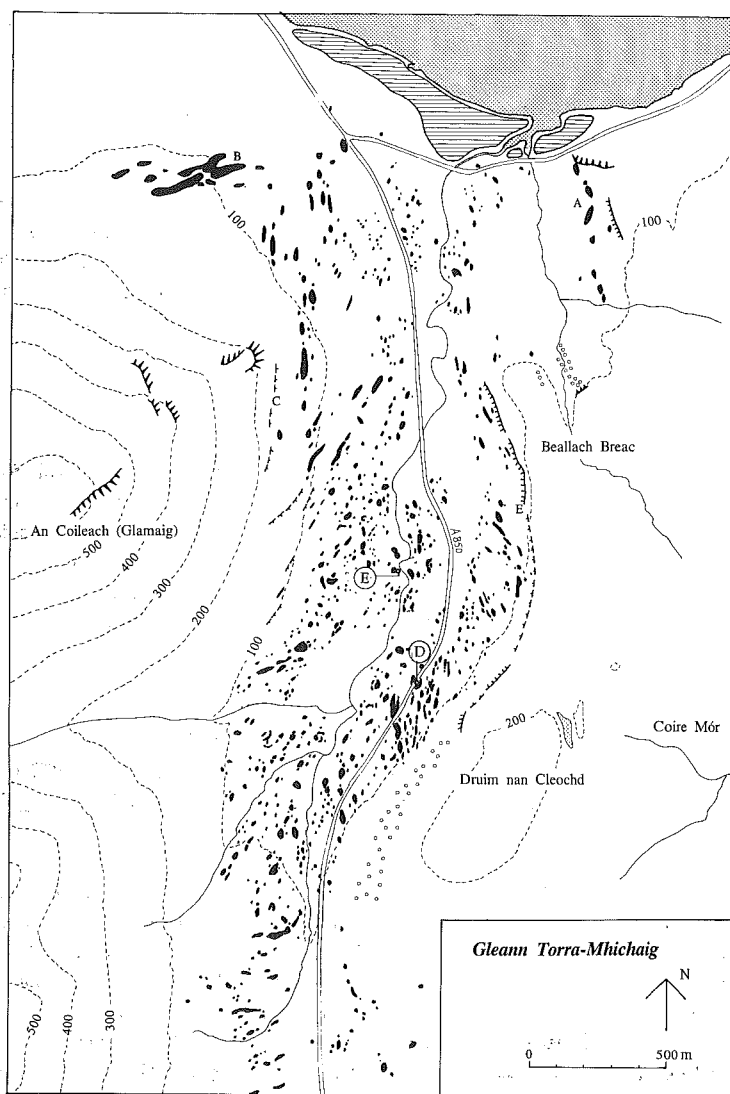


Figure 3.13: Geomorphological map showing the pattern of Loch Lomond Readvance moraines in Gleann Torra-mhichaig.

although some units are largely composed of the Beinn Dearg epigranite that underlies a large area upvalley. The contact between the two rock types trends across the axis of the valley and lies c. 80m upvalley from the exposure. The clasts in the exposure thus consist of local material in addition to a smaller quantity of glacially-transported debris from an unknown distance upvalley. The lack of depositional mixing of the material suggests that the debris was released penecontemporaneously from the deglaciated valley side and from glacier ice, and that subsequent reworking did not occur. There is no evidence of subsequent glacigenic deformation. The evidence from this section and from others in the valley (Benn, 1990) shows that ice retreat was accompanied by slope instability on the newly-deglaciated valley sides. Thus, the sites provide important examples of *paraglacial* sedimentation at the margins of a retreating glacier (*cf.* Church and Ryder, 1972).

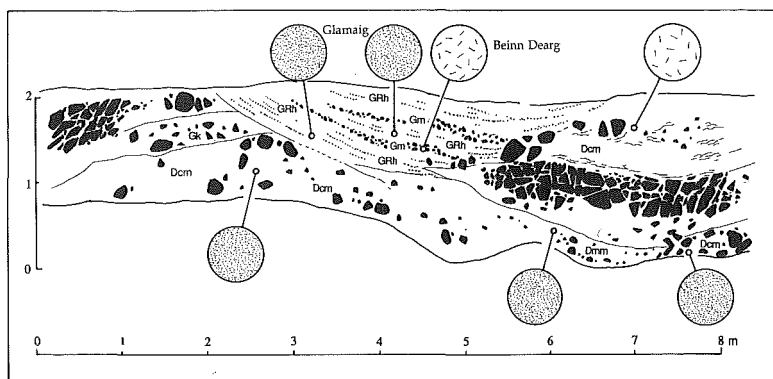


Fig. 3.14 Section in the moraines on the east side of Gleann Torra-mhichaig (D in Figure 3.13). See Figure 3.10 for key.

The moraines on the floor of Gleann Torra-mhichaig lack the linear pattern that is evident on the valley sides, and consist of non-oriented groups of ridges and hummocks. Most of the moraines stand 2-3m above the adjacent ground, although some attain 5m in height. The morphology of individual moraines is variable. Most are simple conical forms with approximately elliptical planforms, although two- and three-topped variants are relatively common. Such features suggest that sedimentation occurred on and adjacent to inactive glacier ice.

An excellent and accessible exposure in the west bank of the Abhainn Torra-mhichaig at NG 536303 (E in Figure 3.13; Figure 3.15) shows the internal structure of a 3m high hummock. The lithofacies in the exposure consist of lenses of matrix-supported diamicton, clast-supported diamicton, pods of openwork gravels, bedded gravels, and bedded medium- and coarse-grained sands, and are interpreted as interbedded sediment-gravity flows, colluvium, and water-sorted deposits. The clasts in the section consist of angular grey epigranite and basalt from the slopes of Glaomaig,

although some units are largely composed of the Beinn Dearg epigranite that underlies a large area upvalley. The contact between the two rock types trends across the axis of the valley and lies c. 80m upvalley from the exposure. The clasts in the exposure thus consist of local material in addition to a smaller quantity of glacially-transported debris from an unknown distance upvalley. The lack of depositional mixing of the material suggests that the debris was released penecontemporaneously from the deglaciated valley side and from glacier ice, and that subsequent reworking did not occur. There is no evidence of subsequent glacigenic deformation. The evidence from this section and from others in the valley (Benn, 1990) shows that ice retreat was accompanied by slope instability on the newly-deglaciated valley sides. Thus, the sites provide important examples of *paraglacial* sedimentation at the margins of a retreating glacier (*cf.* Church and Ryder, 1972).

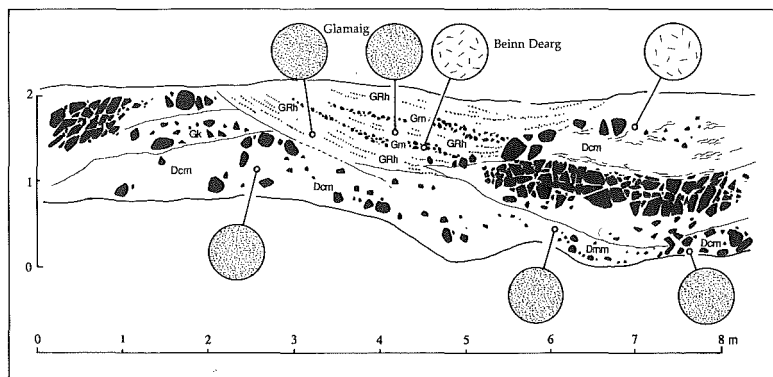


Fig. 3.14 Section in the moraines on the east side of Gleann Torra-mhichaig (D in Figure 3.13). See Figure 3.10 for key.

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and sub-angular and sub-rounded epigranite from Beinn Dearg Mhór or the floor of the valley. Some compositional stratification is evident.

The structures in the exposure record a complex history of syndepositional deformation and reworking. The gravels, sands and flow deposits in the lateral parts of the exposure have dips that parallel the hummock surface, while the lower central portion is largely structureless. The contacts between the central portion and the flanking lithofacies are gradational and minor folds are present in places. The upper central part of the exposure consists of a block of bedded sands and gravels overlain by a massive diamicton unit. The lower left bounding surface of the block is a concave-up curvilinear failure plane, while to the right, sands have been deformed into an isoclinal fold. The suite of structures suggest that the hummock was originally ice-cored, and that the faulting, folding and destruction of sedimentary structures in the central part of the exposure record the melt of buried ice.

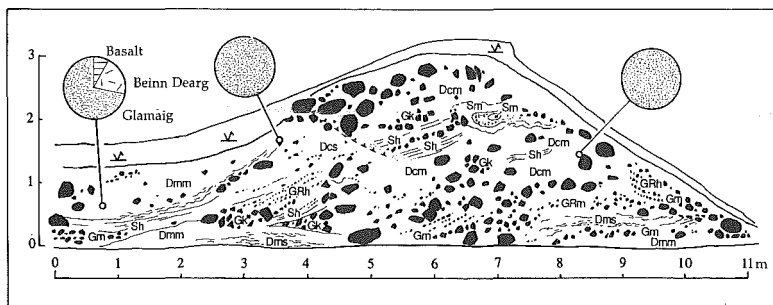


Figure 3.15: Section through a hummock on the floor of Gleann Torra-mhichaig (E in Figure 3.13). See Figure 3.10 for key.

The evidence for deposition in association with stagnant glacier ice is compatible with that from other minor sections in the area and the overall pattern of moraines on the valley floor. The sediment-landform assemblage of hummocks and rim ridges indicates that ice stagnation and multiple reworking of debris were typical of the environmental conditions during the final stages of deglaciation of the low ground.

It was stated above that the moraines on the valley sides were formed at the margins of a retreating but active glacier. This conclusion is not incompatible with the evidence for ice stagnation on the valley floor. Areally-restricted development of hummocky ice-stagnation topography is known to occur at the margins of modern debris-laden temperate glaciers (Eyles, 1979; Gordon and Birnie, 1986). It is possible that on the floor of Gleann Torra-mhichaig, masses of sediment-covered ice became

dynamically isolated from the retreating glacier, and that the stagnation topography developed as a time-transgressive assemblage during active retreat.

3.9 Coir' Uisg

Coir' Uisg, in the heart of the Black Cuillin, is one of the most striking examples of a glaciated trough in the British Isles. The floor of the trough, which lies over 900m below the adjacent mountain summits, has been overdeepened and is occupied by Loch Coruisk. The loch, which has a maximum depth of c. 38m (Harker, 1901), is separated from the sea at Loch Scavaig by a low rock bar. The western side of the trough is indented by several perched corries, between which are text-book examples of truncated spurs.

Coir' Uisg also has a place in the history of Quaternary studies, for it was a visit in 1845 that convinced J.D. Forbes of the former existence of glaciers in Scotland, and helped to further the acceptance of the glacial theory in Britain (Cunningham, 1990). Forbes (1846) was much impressed by the stoss and lee form of the roches moutonnées on the trough floor, and described the periglacial trimline which marks the upper limit of glacial erosion. Forbes also produced a remarkably accurate sketch map of the Black Cuillin on which he marked areas of 'conspicuous glacier markings' in Coir' Uisg, 'Coire Laghain' (Coire Lagan, site 3.12) and 'Bottomless Corry' (Coir' a' Ghrunnda, site 2.7).

The finest approach to Coir' Uisg is by boat: regular and chartered sailings run from Elgol [NG 516136] in the summer months. An arduous alternative is to follow the signposted track from Sligachan [NG 485299] along the deep breach of Glen Sligachan and over Druim Hain (10km, 300m of ascent, 2-3hrs). One advantage of the latter approach is the fine view of Coir' Uisg that is obtained from Druim Hain (weather permitting!). If one arrives by boat, a good viewpoint is the summit of Meall na Cuilce [NG 483199], which can be reached by a rough scramble from the outfall of the River Scavaig.

During the Loch Lomond Readvance, a large glacier occupied the trough, fed by ice from the subsidiary corries to the west and from Harta Corrie to the north. The distribution of striae around Loch Scavaig indicates that the glacier terminated in tidewater in the vicinity of grid northing 18 (Figure 2.4), although the limit has not been positively identified. Clough and Harker (1904) described a spread of gabbro boulders on the north-east of the island of Soay, which was considered by Charlesworth (1956) to mark the limit of the Loch Lomond Readvance (his Stage M). However, this intriguing interpretation conflicts with the terrestrial evidence around Loch Scavaig (Ballantyne, 1989a), and the boulders probably relate to ice-sheet deglaciation.

No lateral or frontal moraines are to be found in Coir' Uisg, and their absence suggests that the deglaciation of the trough was uninterrupted.

3.10 Coire na Creiche

Coire na Creiche is the most northerly and largest of the corries in the western Black Cuillin, with an estimated volume of 1.633 km^3 (Sissons, 1977a). The corrie consists of a broad, low-floored basin above which lie two perched corries, Coir' a' Tairneilear and Coir' a' Mhadaidh, separated by the bold rock peak of Sgurr an Fheadain (Figure 3.16). The upper corries are rock floored, and glacial deposits are largely confined to the ground below 300m, where they form an extensive area of moraines. The principal features of the corrie can be viewed from the Glen Brittle road (convenient car parking is available at NG 424258), or the corrie floor can be gained by a footpath that follows the north bank of the Allt Coir' a' Mhadaidh.

The limit of the Loch Lomond Readvance in Coire na Creiche is not marked by continuous end moraines, but by a diffuse arc of boulders, mounds and marginal terraces (A, B, C, D in Figure 3.16). Most of the boulders are of a coarse pyroxene-rich gabbro, and were probably derived from the backwalls of the corrie. Moraines are rare in the axial portion of the valley, which is occupied by a series of fluvial terraces. The relationship of one of the terraces with a bouldery moraine ridge (C in Figure 3.16) shows that at least part of the terrace sequence was deposited during the Loch Lomond Stadial.

An impressive suite of moraines occupies the northern half of the corrie floor, and can be well seen from the road, particularly in low light. The moraines consist of a series of broadly concentric chains of ridges between which lie bouldery hummocks. The largest moraines occur below the north-east wall of the corrie, where they attain 6m in height. Elsewhere, the moraines are more usually 2-3m high. It is notable that the band of moraines is considerably broader than is usual in the corries of the Black Cuillin (up to 1.5km instead of 200-300m), and it therefore appears that the Creiche glacier retreated actively for a greater distance upvalley than did the other Cuillin glaciers. The reasons for this anomaly are not known, although differences in glacier aspect, geometry and size may have been important (Benn 1990).

The clast content of the moraines is highly variable. On the low ground, material from the corrie backwalls is not well represented, and the most commonly-occurring lithologies are dolerite, basalt, porphyritic rhyolite and acid breccia. In places, the material can be matched with bedrock that crops out in nearby stream beds, and it is concluded that the moraines contain significant amounts of subglacially-entrained debris. However, below a large debris fan in the north-eastern part of the corrie (E in Figure 3.16) the moraines contain large amounts of basalt, gabbro and trachyte derived from the slopes of Bruach na Frithe.

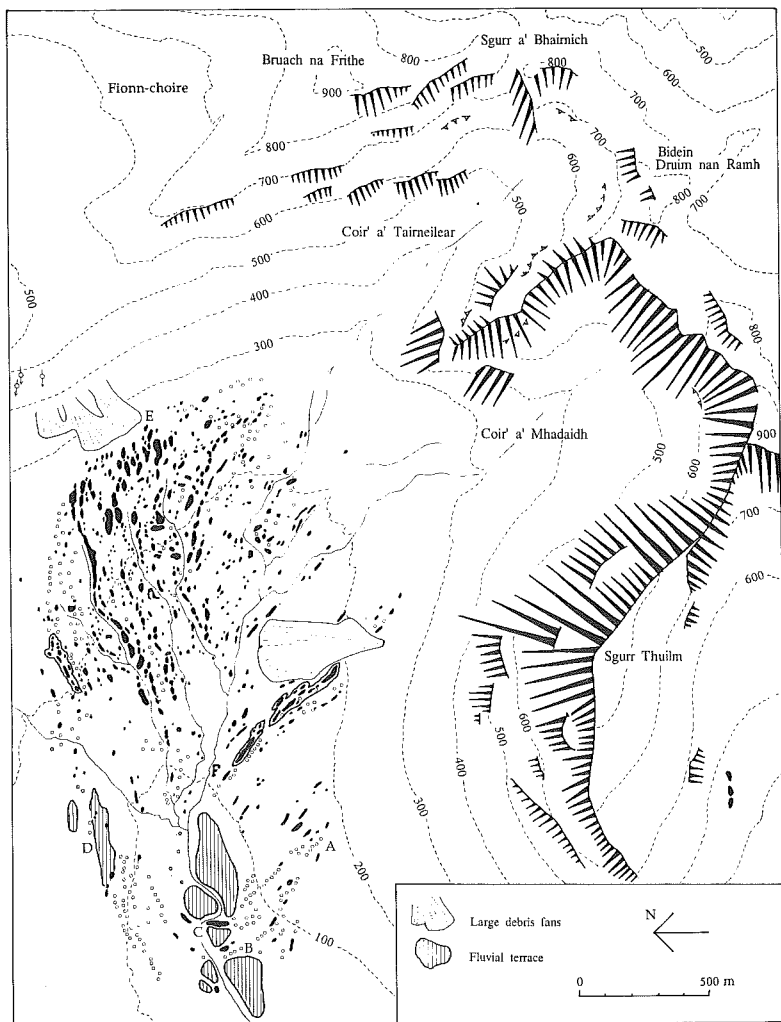


Figure 3.16: Geomorphological map showing the distribution of Loch Lomond Readvance moraines in Coire na Creiche.

A further point of interest in Coire na Creiche is the Fairy Pools in the Allt Coir' a' Mhadaidh [NG 433257; F in Figure 3.16], a series of impressive water-scoured rock bowls that floor a deep gorge. The control exerted by rock structure on the

location of the pools is very striking, particularly at a point close to the lower end of the gorge, where a basalt dyke forms a natural bridge between two linked pools.

3.11 Coire a' Ghreadaidh

Coire a' Ghreadaidh is a well-formed west-facing corrie bounded by narrow ridges that project from the Cuillin Main Ridge. Two spurs divide the upper corrie into three basins that stand above pronounced rock steps. Ice-moulded bedrock is widespread on the floors of the upper basins and in the upper reaches of the main corrie floor. The lower part of the corrie contains large areas of lodgement till and a number of clear arcuate moraines (Figure 3.17). The corrie floor can be reached easily by following the footpath that starts at the Glen Brittle Youth Hostel [NG 409225].

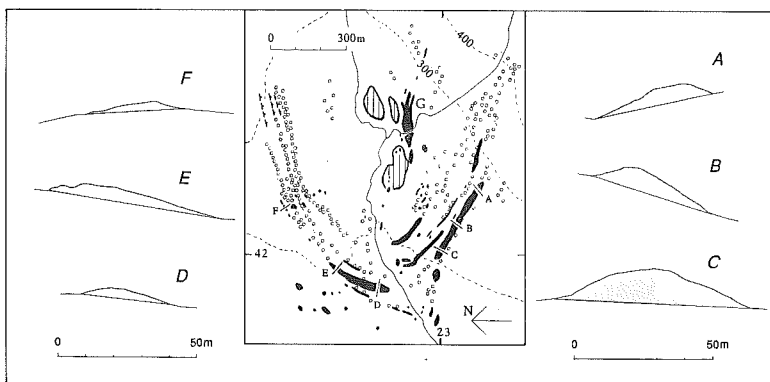


Figure 3.17: Moraine pattern and cross-profiles in Coire a' Ghreadaidh.

The footpath crosses the limit of the Loch Lomond Readvance at c. 170m [NG 419232]. The glacier limit and later retreat positions are marked by a band, some 200-300m across, of sharp-crested moraine ridges and lines of boulders which rise up the valley sides to c. 290m (Figure 3.17). The outermost moraine on the southern valley side is markedly larger than that on the northern. The asymmetric development of the moraines was attributed by Benn (1989) to differential rates of debris supply from rock walls and debris-mantled slopes during the Loch Lomond Stadial. The preferential occurrence of rock walls on north-facing slopes in the corrie is clearly visible from the footpath: the extensive cliffs on Sgurr nan Gobhar and An Diallyad contrast sharply with the discontinuous crags and scree-strewn slopes of Sgurr Thuilm.

A further interesting feature is a longitudinally-oriented moraine ridge some 500m up-corrie from the outermost moraines [NG 425232; G in Figure 3.17]. The ridge is sharp-crested and is 16m high on the north side and 3-5m high on the south, where deposition of fluvial sediments has formed a small terrace. Exposures in the ridge show it to be composed of coarse bouldery diamicton, gravels, and laminated sand and silt, recording subaerial and subaqueous reworking processes. The ridge is interpreted as a medial moraine that formed at the confluence of ice that flowed from the main corrie and that from Core an Eich.

3.12 Upper Coire Lagan

Coire Lagan, in the southern Black Cuillin, is bounded by extensive rock walls and narrow, pinnacled arêtes, and contains large areas of well-preserved ice-moulded bedrock and a rock basin loch (Figure 2.10). Footpaths into the corrie start from the Glen Brittle campsite [NG 413205] and the British Mountaineering Council hut [NG 412215]. The footpaths converge close to the belt of moraine ridges that marks the Loch Lomond Readvance limit (site 2.6; B, Figure 2.10). A considerable area within the arcuate moraine belt is occupied by a longitudinally-lineated sheet of overconsolidated lodgement till. The till thickens distally, and at its up-valley limit is confined to the depressions between roches moutonnées.

A number of lines of large angular boulders may be viewed from the footpath into the upper corrie [NG 438206]. Some are longitudinally-oriented, and are interpreted as 'avalanche-type' medial moraines. By contrast, one boulder line [NG 442205] is aligned directly downslope, oblique to the former glacier flow lines as recorded by striae. The boulders exhibit pronounced proximal to distal coarsening, and probably record a postglacial rock-slope failure from the rockwall of Sron na Ciche.

Impressive areas of ice-scoured bedrock can be examined *en route* to the upper corrie. A small rock basin loch lies at 565m [NG 444209], above an abrupt rock step. This coincides with the outcrop of the massive Border Zone Eucrite, one of several arcuate masses of basic rocks that underlie the Black Cuillin (Bell and Harris, 1986).

4. PERIGLACIAL FEATURES ON THE MOUNTAINS OF SKYE

Colin K. Ballantyne

Introduction

In common with mountains elsewhere in the British Isles, those on Skye support both active periglacial features and relict landforms that developed under a much colder climate than that of the present. The periglacial phenomena on Skye fall into three broad age groups: pre-Late Devensian, Late Devensian and Holocene.

Pre-Late Devensian periglacial features

On the Trotternish Peninsula of northern Skye, all high ground over 500m supports a cover of frost-weathered regolith, with only occasional shattered rock outcrops protruding through such debris. In contrast, the ice-moulded bedrock in the intervening cols displays little evidence of frost weathering. The transition from ice-scoured terrain to slopes covered by frost-weathered debris is not gradual, but in places occurs over an altitudinal range of 30m or less. This weathering limit descends northwards in conformity with the regional movement of the last ice sheet across Trotternish, and has been interpreted as a periglacial trimline marking the upper surface of this ice sheet at its maximum thickness (Ballantyne, 1990; Figures 2.2 and 2.3). This interpretation implies that the higher summits of Trotternish remained as nunataks above the level of the last ice sheet, and were exposed to severe periglacial conditions throughout the Devensian and possibly earlier.

The mantle of basaltic mountain-top detritus on the Trotternish Hills locally takes the form of blockfields, for example near the summits of Hartaval (668m) and Creag a'Lain (565m). The thickness of the regolith contrasts markedly with the limited evidence for periglacial weathering on rock surfaces that were abraded by the passage of the last ice sheet. Despite the exposure of such surfaces to severe periglacial conditions following ice-sheet downwastage and again during the Loch Lomond Stadial, evidence for frost weathering of ice-scoured rock in cols crossed by the last ice sheet is limited to surface roughening by granular disaggregation, joint dilation and the spalling of occasional slabs. This contrast suggests that the basalts of Trotternish are resistant to frost weathering, and that the formation of a thick regolith cover reflects very prolonged exposure to severe periglacial conditions.

This conclusion is supported by analyses of the clay mineral content of soils developed on the higher parts of the Trotternish Escarpment (Ballantyne and Mellor, unpublished). Samples recovered from three sites above the weathering limit revealed traces of gibbsite, but gibbsite was not detected in five samples

extracted from soils below the weathering limit. As gibbsite in Scottish mountain soils has been interpreted as a pedorelict derived from interglacial or preglacial regolith formed under humid warm or subtropical conditions (*e.g.* Mellor and Wilson, 1989), the presence of this mineral in the mountain soils of Trotternish suggests that these represent prolonged weathering of the underlying basalt, dating back to at least the last interglacial. A long period of sustained frost weathering on the Trotternish nunataks is also indicated by the presence of frost-shattered tors, for example on The Storr at 580m [NG 493550], on Hartaval at 560m [NG 474544] and on Creag a'Lain at 565m [NG 461581].

In places, the mountain regolith on the Trotternish hills terminates abruptly downslope at the lower limit of soliflucted frost-weathered debris. This frequently coincides with a springline, where water draining through the permeable frost-weathered deposits emerges at the surface, and consequently with the upper limit of gullying and the lower limit of xerophytic vegetation. Such solifluction limits are particularly well developed on the SW slopes of Beinn Edra [NG 450622] and The Storr (Figure 4.1; site 4.1). In places, they descend slightly lower than the general level of the ice-sheet trimline, and thus indicate solifluction of frost-weathered regolith after the downwastage of the last ice sheet.

Late Devensian periglacial features

A distinctive range of periglacial features developed on the mountains of Skye in the interval between ice-sheet downwastage and the end of the Loch Lomond Stadial at *c.* 10 ka BP. Such features occur on ground that was actively glaciated by the last ice sheet but not subsequently occupied by ice during the Loch Lomond Readvance (*cf.* Ballantyne, 1984). Four types of Late Devensian periglacial features are represented in such areas, namely frost-weathered bedrock and mountain-top detritus, relict solifluction landforms, fossil patterned ground phenomena, and relict talus accumulations.

The effects of Late Devensian frost weathering on the mountains of Skye have been highly discriminatory. In general, such weathering has been most effective on the epigranites of the Red Hills, which support a widespread shallow regolith of clasts embedded in a coarse sandy matrix, interrupted only locally by bedrock outcrops. A widespread cover of frost-weathered diamictic regolith also occupies some plateaux underlain by gabbro or eucrite in the Black Cuillin, for example on Meall Odhar (630m), the northernmost point on the Cuillin ridge. In contrast, as noted above, basaltic uplands exhibit limited evidence of frost weathering except on hills that apparently remained above the level of the last ice sheet. The Torridon Sandstones of the Kyleakin Hills have also been little affected by Late Devensian frost weathering, and preserve numerous ice-moulded rock knolls and striae relating to the passage of the last mainland ice sheet over the area (Peach *et al.*, 1910).

The lower limits of Late Devensian frost weathering and *in situ* weathered regolith in the Cuillins are often defined by periglacial trimlines that mark the upper limits of Loch Lomond Readvance glaciers (Forbes, 1846; Harker, 1901; Ballantyne, 1989a). The gentler slopes of the Red Hills, however, are in most areas mantled by a shallow cover of granitic scree that extends downslope into areas occupied by glacier ice during the Loch Lomond Stadial. Such scree apparently represents debris transported downslope in the wake of deglaciation rather than *in situ* weathering. Periglacial trimlines nonetheless occur on granitic rocks on the western slopes of Beinn na Crò at c. 300m and on the eastern slopes of Beinn Dearg Mhór at 350-400m (site 2.2). Within the limits of the Loch Lomond Readvance, bedrock weathering under the milder conditions of the Holocene has been limited to localised joint dilation and the rounding of exposed rock by granular disaggregation. On the Red Hills, granitic boulders embedded in the underlying sandy regolith are rounded on their exposed surfaces, but angular underneath, a characteristic of stable upland regolith that has experienced prolonged microgelivation under the relatively mild periglacial conditions of the Holocene (Ballantyne, 1987).

Developed on some gentle debris-mantled slopes are relict solifluction sheets and lobes with degraded, often bouldery, risers. Such features are best developed on the relatively abundant granitic regolith of the Red Hills, particularly on Druim na Ruaige [NG 505283]. Similar lobes also occur, however, on Torridon Sandstone regolith at c. 450m in Fraoch-choire, in the Kyleakin Hills [NG 756230], and on basaltic regolith in the Trotternish Hills, for example at 580m on the northern ridge of Hartaval [NG 476558] and at a similar altitude near the summit of Flasvein. The origin of such 'boulder lobes' is contentious (*cf.* Ballantyne, 1984), but it seems likely that they represent gelifluction of vertically frost-sorted regolith. Evidence of Late Devensian solifluction is not confined to high ground, however, but is also apparent in the form of head deposits developed on the Jurassic rocks of the Strathaird Peninsula. Sections in such deposits are exposed along the Elgol road.

Relict patterned ground phenomena are rare on Skye, though the higher parts of the Trotternish Escarpment support nonsorted patterned ground in the form of vegetated earth hummocks 0.1-0.3m high and 0.4-1.2m in diameter. Such hummocks occur on summit plateaux above 600m, for example on The Storr and Beinn Edra, and on slopes of 5° or more grade into nonsorted relief stripes. Birks (1973) implied that such features are currently active, but similar hummocky microrelief on other Scottish mountains is relict, and probably of Lateglacial origin (Ballantyne, 1986a).

The upland areas of Skye support numerous impressive talus slopes (Statham, 1976). Some of these occur in corries that were occupied by glaciers during the Loch Lomond Stadial, and hence presumably accumulated during the Holocene. Others, however, are located outside the limits of the Loch Lomond Readvance, and represent relict accumulations of probable Lateglacial age (Godard, 1965, p. 402; Ballantyne, 1990). Particularly fine examples of the latter skirt the basalt scarps of Ben

Meabost and An Carnach in Strathaird, and much of the Trotternish Escarpment. Such relict taluses support a closed vegetation cover, and have been modified by translational landslides, debris flows and gullying, features which indicate that erosion has replaced accumulation as the dominant mode of geomorphic activity on these slopes.

Survey of the relict talus slopes of Ben Meabost, An Carnach and The Storr at sites not affected by debris flows have shown that these possess characteristics of unmodified rockfall talus, namely an upper rectilinear slope, a basal concavity and a general downslope increase in the size of surface clasts. Those on the Strathaird Peninsula are 'mature' taluses, with talus height : overall slope height ratios of 0.58-0.75 (Ben Meabost) and 0.52-0.54 (An Carnach). The equivalent ratios for relict taluses at the foot of The Storr, however, range from only 0.19 to 0.28 (Fraser, 1990). Such differences probably reflect the greater rock mass strength of the Storr lavas, which dip gently into the slope, rather than any difference in talus age. Intriguingly, active gullies cut into relict talus on Trotternish reveal that some of these are composed mainly of fine, sandy sediment rather than clast-sized debris. This suggests that the dominant mode of sediment supply from cliffs upslope may have been granular disintegration rather than rockfall.

Holocene periglacial activity

The present 'maritime periglacial' climate of the higher parts of British mountains is dominated by strong winds and high precipitation rather than low temperatures and deep ground freezing (Ballantyne, 1987), and it is likely that similar conditions persisted throughout most of the Holocene. The Holocene periglacial features on Skye strongly reflect the characteristics of this climatic regime.

The action of wind on high ground is most evident on the granitic summits of the Red Hills and on the cols and summits of the Trotternish Escarpment. On the former, strong winds have stripped away the vegetation mat and the underlying fine soil, exposing widespread deflation surfaces that are carpeted by lag gravels and armoured by flat-lying granite clasts. On Trotternish, wind erosion has been more selective, stripping away the turf cover to expose deflation scars of variable size. It is generally agreed that such erosion reflects detachment of soil particles by needle ice and their subsequent removal by strong winds, and that erosion is triggered by rupture of the vegetation mat (*cf.* King, 1971). The initial cause of breakage in the vegetation cover is less well understood. Research elsewhere in the Highlands, however, suggests that such erosion of mountain soils is a fairly recent phenomenon triggered either by climatic deterioration during the 'Little Ice Age' of the 16th-19th centuries AD or through overgrazing by sheep introduced to high ground (Ballantyne, 1991a).

4.1 The Storr [NG 496540]

The Storr (719m; Figure 4.1) is the highest peak in Trotternish, and is underlain by flood basalts that dip gently westwards. Rotational sliding has removed much of the east side of the mountain, producing one of the most spectacular areas of landslip in Britain (Anderson and Dunham, 1966; chapter 5). From the west, however, The Storr appears as a regular cone, evenly mantled by vegetated frost-weathered regolith. Periglacial landforms on The Storr have previously been described by Godard (1958), Kelletat (1970), Birks (1973) and Ballantyne (1990). Access to the higher parts of the Storr is easiest from the south. A steep path ascends the escarpment to Bealach Beag (457m), from which the mountain is readily traversed.

Relict periglacial features

The Storr supports clear evidence for an ice-sheet trimline. The flanking cols, Bealach Beag (457m) and Bealach a'Chuirn (489m) both support ice-moulded rock outcrops, and on the former striae marking the passage of the last ice sheet have been found on bedrock under a cover of peat. In contrast, the upper slopes of the summit cone support a thick and complete cover of frost-weathered detritus. The lower limit of this detritus dips northwards from *c.* 570m to *c.* 550m, and is in places represented by the lower limit of a sheet of gelifluctate. On the SW slope of the mountain such debris obscures the outline of the underlying stepped lava flows, whereas farther downslope these tend to protrude boldly despite a cover of peat and vegetation. Excavation of the regolith has revealed a diamicton comprising angular basalt clasts embedded in a fine sandy matrix of weathered basalt. Gibbsite recovered from samples of soil on the Storr suggests very prolonged weathering, as does the presence of frost-shattered tors at 580m altitude approximately 1km north of the summit [NG 493550]. These features, together with the clarity of the trimline and its consistent northwards descent across Trotternish, have been interpreted as indicating that The Storr remained a nunatak when the last ice sheet achieved its maximum thickness (Ballantyne, 1990).

Earth hummocks (thufur) up to 0.3m high occupy the higher parts of The Storr, and in places grade into nonsorted 'ridge and furrow' relief stripes. Both types of microrelief support a closed vegetation cover. Such features have been interpreted by Kelletat (1970) and Birks (1973) as active periglacial forms, but their characteristics suggest otherwise. Unlike the thufur of Iceland, the earth hummocks on The Storr are domed rather than knob-shaped, which suggests that they represent degraded forms. Moreover, excavation of a hummock near the summit revealed soil horizons sub-parallel to the hummock surface. These indicate that recent cryoturbation has been minimal and suggest that the earth hummocks and relief stripes of The Storr are essentially relict features. Unlike relief stripes elsewhere in Scotland (*cf.* Ballantyne, 1986a), those near the summit of The Storr do not follow the direction of maximum slope, but run obliquely across-slope.

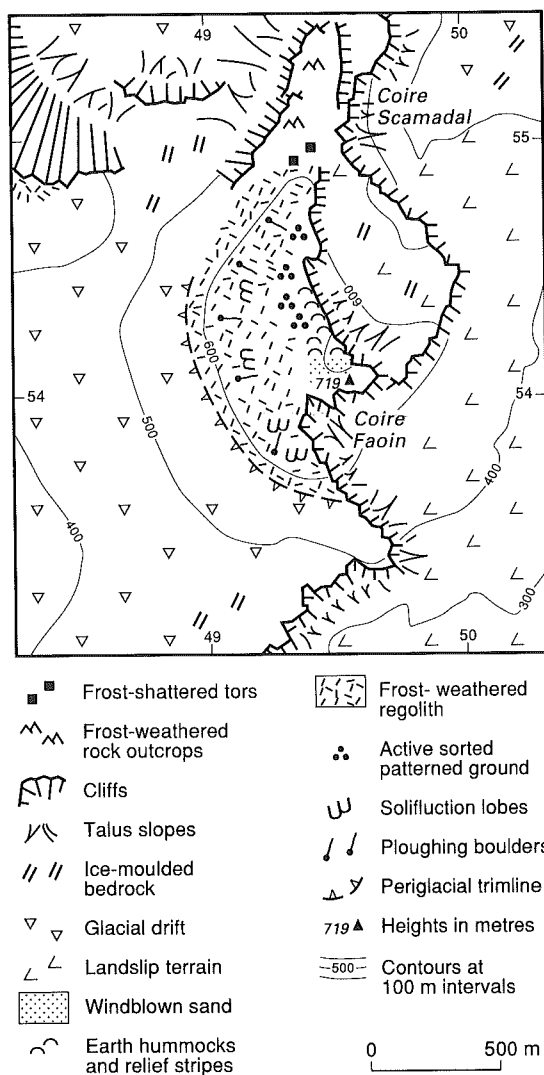


Figure 4.1: Geomorphological map of The Storr, the highest peak in Trotternish

The cliffs of the Trotternish Escarpment to the east and north of The Storr are skirted by impressive taluses that achieve heights of up to 100m. The complete vegetation cover of these slopes indicates that they are relict, and it has been suggested by Godard (1965) and Ballantyne (1990) that they represent Lateglacial debris accumulations. These slopes are scarred by debris flows and shallow translational slides, indicating that they are now predominantly subject to erosion and reworking of sediment rather than debris accumulation. Sections in gullies at the heads of debris flows reveal that these talus slopes contain an abundant matrix of fine sand, presumably washed from the cliffs upslope. A 2.3m deep section logged by Innes (1983b) in Coire Faoin [NG 497535] revealed two buried organic soil horizons at depths of c. 165-155cm and c. 140-125cm. These soils yielded radiocarbon ages of 2450 ± 40 yr BP and 1990 ± 70 yr BP for the base and top respectively of the lower soil horizon, and 1240 ± 40 yr BP and 720 ± 40 yr BP for the upper. Innes interpreted the stratigraphy of this site as indicative of episodic burial of organic soils by slopewash during the Late Holocene, with periods of stability (represented by the soil horizons) alternating with episodes of enhanced slopewash.

Active periglacial features

The operation of three sets of processes is evident on The Storr: wind action, superficial cryoturbation and solifluction.

The effects of wind erosion are most evident in the removal of soil and vegetation from the exposed ridge north of the summit. The resultant deflation scars are carpeted by lag gravels and surrounded by eroding soil scarps. On gentle slopes, accelerated mass movement of vegetation-free deflation scars has resulted in the formation of step-like terraces with vegetated (turf-banked) risers and broad, vegetation-free treads. In addition to such evidence for recent deflation, pits excavated near the summit of The Storr revealed 0.7m of poorly-sorted, structureless windblown sand overlying frost-weathered regolith. Such sand deposits are protected from erosion by an unbroken vegetation mat. The age of these deposits is unknown, though similar windblown sand on An Teallach (66km NE of The Storr) is believed to represent a niveo-aeolian deposit that began to accumulate in the early Holocene (Ballantyne & Whittington, 1987).

The current operation of superficial cryoturbation is evident in the formation of small-scale sorted patterns on the deflation scars described above. These include irregular nets, circles and polygons, elongate nets and circles, sinuous stripes and straight stripes. Pattern widths range from 0.1m to 0.6m (Godard, 1958; Kelletat, 1970; Birks, 1973). Cell centres and fine stripes are composed of fine sandy brown soil with few or no clasts, and show signs of recent frost disturbance. Sorted clasts do not exceed 15cm in length. On individual deflation scars, coarse stripes tend to converge downslope against soil scarps, giving garland-like patterns. Godard (1958) argued that such patterns are active as they have survived trampling by grazing sheep.

Active solifluction is evident in the form of shallow vegetated lobes with risers up to 1m high on the thick regolith above 580m. The same slopes support ploughing boulders with furrows up to 4m long; recent movement is indicated by an unvegetated zone immediately upslope of some boulders (Kellett, 1970). Stratigraphic evidence for Holocene solifluction on The Storr is evident in a section on the south side of the mountain at 610m [NG 494537]. At this site 0.6m of gelifluctate overlies a peat horizon up to 0.2m thick, which in turn overlies a buried soil. Although this peat has not been dated, its thickness suggests that it is of Flandrian rather than interstadial age. Peat, plant remains and organic soils buried under solifluction lobes in the Scottish Highlands have hitherto yielded radiocarbon ages ranging from 5541 ± 55 yr BP to 530 ± 90 yr BP (Sugden, 1971; Mottershead, 1978; Ballantyne, 1986b).

4.2 The Beinn Dearg ridge, Western Red Hills [NG 5127, 5128]

The Beinn Dearg ridge (Figure 4.2) lies to the west of Loch Ainort, and culminates in the peaks of Beinn Dearg Mhór (732m) and Beinn Dearg Mheadhonach (656m). It is underlain for most of its length by granitic rocks, and epitomises the periglacial landscapes developed on such lithologies. The ridge is easily accessible from the A850 road.

Relict periglacial features

Although it is likely that the Red Hills were completely ice covered at the last ice-sheet maximum (Chapter 2), the Beinn Dearg ridge remained a nunatak above the level of the Loch Lomond Readvance glaciers (Ballantyne, 1989a; Figure 2.4) and hence was exposed to frost weathering both during ice-sheet downwastage and throughout the Loch Lomond Stadial. The products of such periglacial weathering take the form of a shallow mantle of regolith comprising clasts embedded in a coarse sandy matrix. Bedrock outcrops are generally well-rounded by granular disaggregation (microgelivation). On the crest of the ridge the regolith is *in situ*, but the debris mantle on the surrounding slopes has experienced mass movement as a consequence of Lateglacial gelifluction and subsequent debris flow. As a result, granitic scree frequently extends downslope into areas occupied by glacier ice during the Loch Lomond Stadial. A superb periglacial trimline is, however, visible from the road on the east slope of Beinn Dearg Mhór, where the former upslope limit of the Glamaig Glacier (Figure 2.4) is defined simultaneously by the upper limit of glacial drift and the lower limit of periglacial scree and frost-weathered bedrock (site 2.2).

Inactive boulder lobes ('stone-banked lobes') of presumed Lateglacial age occur on moderate slopes flanking the two main summits, but are best developed on the NE slope of Druim na Ruaige, where they extend down to the Loch Lomond Readvance limit at c. 300m.

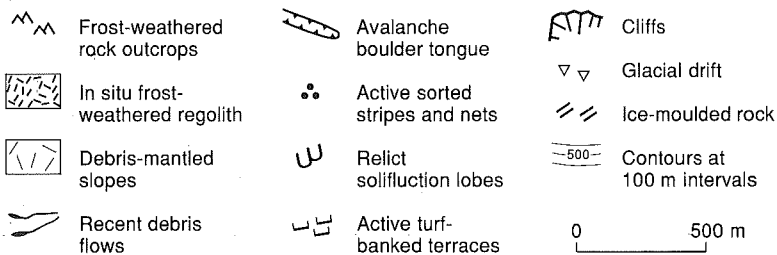
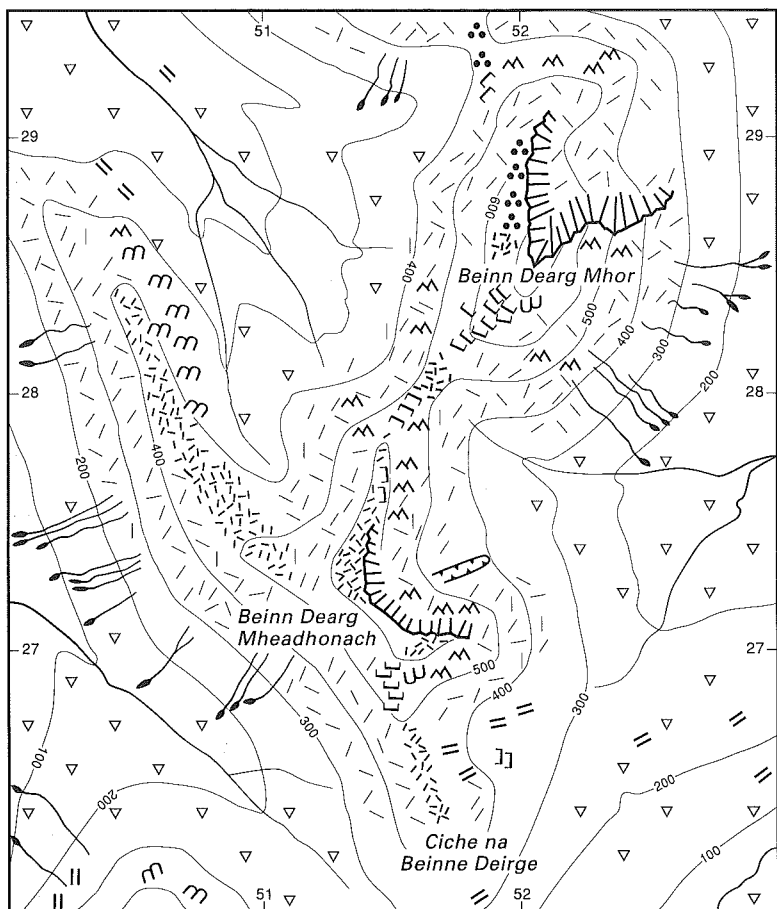


Figure 4.2: Geomorphological map of the Beinn Dearg ridge, Western Red Hills.

Of particular interest is a relict (vegetated) avalanche boulder tongue that extends downslope from the cliffs of Beinn Dearg Mheadhonach. This terminates at a long, low ramp of boulders, *c.* 1m high, that runs across the slope at 410m [NG 519274]. This ramp has a steep proximal slope and gentle distal slope, and was interpreted by Benn (1990) as a relict avalanche impact rampart similar to those recently discovered on Ben Nevis (*cf.* Ballantyne, 1989b). This interpretation implies that powerful avalanche activity occurred at this site after the wastage of the Loch Lomond Stadial glaciers, though there is no geomorphic evidence for recent snow avalanches in the Western Red Hills.

Active periglacial features

The effects of wind erosion take the form of an extensive deflation surface that occupies most of the ridge crest. Eroded scarps of soil at the margins of this surface suggest a formerly more extensive soil and vegetation cover. Widespread frost creep is evident in the formation of extensive flights of turf-banked terraces with vegetated risers 0.3-0.6m high (Kelletat, 1970; Figure 4.2). These represent a response to the combined action of wind and slow mass-movement: creeping debris becomes stabilised behind a turf bank that increases in height as debris accumulates, thus providing further shelter from the wind. Small active sorted patterns up to 0.4m wide are locally present on the ridge, but occur only where there are concentrations of particularly fine (frost-susceptible) regolith.

5. THE LANDSLIDES OF SKYE

Colin K. Ballantyne

Introduction

'Skye', wrote J.B. Whittow (1977), 'is an island of superlatives'. Nowhere is this more evident than in a consideration of the landslides of the island. These are, by common consensus, the most spectacular in Great Britain. The reason for this is largely geological. In the north of Skye, a thick cap of Tertiary igneous rocks (primarily flood basalts) overlies a great thickness of relatively incompetent Jurassic sediments. Where these rocks form an escarpment or marine cliff, foundering of the sediments under the weight of the overlying lavas has resulted in extensive and impressive rotational landslides, often of great complexity. The archetypal examples fringe the great escarpment of Trotternish and the cliffed coastline of northern Skye.

The Trotternish landslides

The Trotternish Escarpment consists of Tertiary plateau lavas (primarily olivine basalts) of the Beinn Edra group. These overlie Upper Jurassic sedimentary rocks, particularly Oxford Clay, Corallian Limestone and Kimmeridge Clay, into which have been intruded numerous dolerite sills. The original scarp face probably developed in late Tertiary times as a consequence of westwards tilting and faulting (Anderson and Dunham, 1966).

Slipped rock masses extend continuously along the scarp slope for 23km (Figure 2.2), with subsidiary areas of scarp failure on the cliffs of Suih'a'Mhinn [NG 403685] in NW Trotternish and those in Glen Uig to the west of the Trotternish hills. Slope failure in all these areas predominantly took the form of successive rotational slides of lava-capped blocks that extend up to 2.2km from the scarp crest. Several different landslide forms are present. Nearest the escarpment are incipient failures, where blocks have become detached from the crest without slipping downwards. Resting against the scarp are slipped blocks of intact rock, such as those of Dùn Dubh [NG 441666], Coire Cuithir [NG 470586] and Baca Ruadh [NG 478576]. Farther out from the scarp are isolated tabular blocks such as Cleat [NG 447669] and shattered pinnacles such as the Old Man of Storr (Figure 5.1; site 5.1) and the Quiraing Needle (site 5.2). Beyond this inner area of landsliding lies a zone of imbricate back-tilted blocks, but in contrast to the bold angular forms of the inner zone these are rounded and subdued in appearance. From this contrast, Godard (1965) and Ballantyne (1990) inferred that the rounded landslip blocks of the outer zone have been modified by the passage of the last ice sheet, whereas the tabular and pinnacled forms of the inner zone represent failure since the withdrawal of the ice

sheet from this area. Significantly, patches of till occur amid the blocks of the outer zone (Anderson and Dunham, 1966), and at Coire Cuithir ice-moulded landslip blocks are crossed by Loch Lomond Readvance moraines.

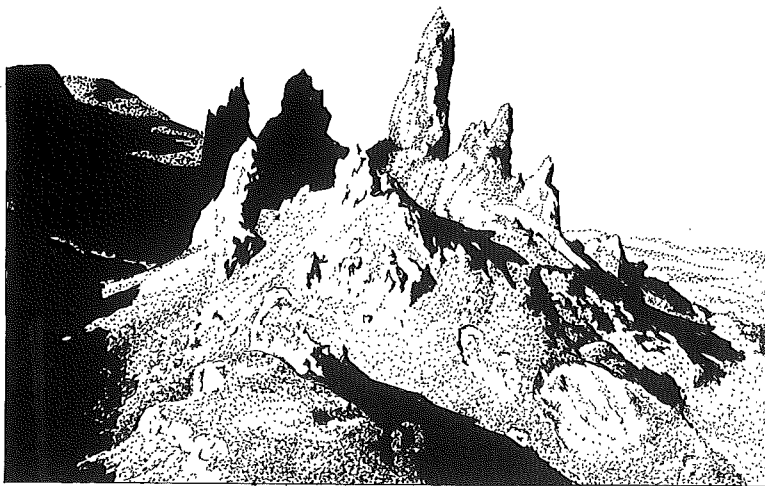


Figure 5.1: *The Old Man of Storr and other pinnacles of slipped rock, Coire Faoin, The Storr.*

The age of the inner zone failures is unknown, but many of the detached blocks and pinnacles are fringed by mature (vegetated) talus slopes that are now extensively gullied and eroded. On the assumption that such slopes are of Lateglacial origin, Godard (1965) proposed that most of the inner zone failures occurred fairly soon after the retreat of the last ice sheet from the area, and suggested that they represent collapse of glacially-steepened cliffs following the withdrawal of a supporting buttress of glacier ice. A number of *a priori* arguments also favour failure during the Lateglacial: (1) unloading of ice would be expected to result in joint dilation; (2) under severe periglacial conditions, freezing of the scarp face may have resulted in the build-up of high (rectangular) cleft-water pressures in the basaltic cap and the underlying sediments; and (3) differential isostatic recovery may have resulted in localised seismic activity of a magnitude sufficient to trigger failure.

Not all of the rock slope failures of the Trotternish Escarpment are rotational landslides. South of Baca Ruadh (at NG 476568) there is evidence for an ancient flowslide in the form of subdued vegetated ridges of debris aligned downslope and terminating in a broad lobe, c. 100m wide, of bouldery mounds and hummocks. A

smaller but similar deposit occurs NE of Druim na Coilre [NG 441651]. Nearby, a jumble of limestone boulders [NG 449646] covers an area of nearly 0.2km² and records the collapse of the cliff upslope. The most impressive nonrotational failure occurs at Carn Liath [NG 494563]. This is described more fully below (site 5.4).

The coastal landslides of northern Skye

The coastline of northern Skye is extensively cliffed, particularly where it is developed in resistant basalts or dolerite sills. In places, where Jurassic sediments are exposed at the base of such igneous rocks, large-scale failure has occurred, producing coastal landslides of impressive dimensions. A total of 18 coastal landslides have been identified in northern Skye (Ballantyne, 1986c), occupying areas of up to 2km². Seven of these have been described in detail by Richards (1971).

The nature of rock slope failure, however, differs from site to site, as do the geological circumstances. East of Ben Tianavaig [NG 511410], foundering of an estimated thickness of c. 300m of Jurassic sediments between a thick lava cap and an underlying dolerite sill has resulted in complex rotational failure of the entire hillslope, producing the most extensive coastal landslide on Skye if one discounts the Quiraing (Anderson and Dunham, 1966). Farther north, along the east coast of Trotternish between Portree and Staffin, are several failures that involve only Jurassic sediments (particularly shales) interbedded with and underlain by the separate leaves of a bifurcating dolerite sill. Examples include the landslides at Valtos [NG 517636], Rubha Garbhaig [NG 501673] and Tote [NG 521614]. All of these are complex failures, involving a rotational component but also rockfall and slab failure induced by undermining of relatively weak sedimentary strata by the sea. Failure of undermined Jurassic sediments not overlain by lavas is also evident in a large landslide north of Waterstein Head [NG 1447]. Elsewhere, however, failed sediments are overlain by lavas, for example on the west shore of Loch Bay, Watnish [NG 2554, 2455], at Score Horan (site 5.5) and, farther south, at Càrn Mór on the Strathaird Peninsula [NG 520157].

The age of such coastal landslips appears to be variable. Richards (1971) has noted that at several sites subdued landslide blocks occur adjacent to or seawards of angular slipped blocks, which suggests that the former may represent failure before the passage of the last ice-sheet and the latter failure after ice-sheet retreat. This relationship, however, can be confirmed only at Score Horan (site 5.5). Holocene landslide activity is indicated at Valtos [NG 517636] on the east coast of Trotternish, where, according to Richards, landslide debris partly buries the Main Postglacial Raised Beach. At some sites where steep cliffs are currently subject to marine erosion intermittent failure may still be occurring, as at Tote [NG 521614].

Landslides in central and eastern Skye

Large-scale rock-slope failures are much less frequent in those parts of Skye where Jurassic sediments are absent, though the identification of a number of 'avalanche-type' medial moraines amongst the drifts deposited by glaciers during the Loch Lomond Stadial suggests that sizeable cliff collapses were not uncommon at this time (chapter 3), even though the related failure scars can no longer be identified. Major landslides have been found at only three locations in central and eastern Skye. One of these occupies the NE slope of Glas Bheinn Mhór [NG 560270], and is described below (site 5.6). The others occur on the Torridon Sandstones of the Kyleakin Hills.

The larger of the Kyleakin landslides is located between 450m and 670m on the SE side of Beinn na Caillich [NG 776227; Figure 2.11], and takes the form of a translational failure along steeply-dipping bedding planes (Peach *et al.*, 1910). The slide block has remained largely intact, having moved little more than 5m at its southern end. Both the slide scar and the trailing edge of the slipped mass form conspicuous features, the latter taking the form of an obsequent scarp of shattered rock aligned obliquely down the hillslope. The smaller landslide forms 'Coire an Fraoich', a hollow on the flank of Beinn Bhuidhe at an altitude of 370m [NG 773217]. Again, translational failure appears to have been favoured by the dip of the underlying beds, and the slipped mass forms a conspicuous obsequent scarp at its upslope edge.

Sites of particular scientific interest

5.1 The Storr landslide

Few landforms in Great Britain are more impressive than the Storr landslide, 'cette topographie anarchique' as Godard (1965) aptly described it. The entire SE face of The Storr (719m) has collapsed to produce a great hollow, Coire Faoin, that is bounded to the NW and SW by the towering basalt scarp that marks the line of failure. The undercliff zone of slipping is a confusion of lava-capped blocks, narrow canyons and weird shattered pinnacles of basalt, dominated by the 49m high pinnacle of the Old Man of Storr. The most impressive view of this landslide assemblage is obtained from an altitude of 600m on the SE ridge of The Storr [NG 495537; Figure 5.1], but for the less agile a pleasant footpath winds upwards through forestry plantations from a car park at NG 503526 and gives access to the labyrinth of Coire Faoin. Below 350m the path crosses ancient ice-moulded landslip blocks that represent failure before the passage of the last ice sheet, though it is conceivable that the easternmost and oldest of these have survived several glacial episodes. Above 350m, the terrain is dominated by angular postglacial landslip blocks and spires.

Anderson and Dunham (1966) have attempted a schematic reconstruction of the Storr landslide. They estimated that before the most recent (i.e. postglacial) collapse the scarp face lay c. 600m east of its present position, and that failure involved the foundering of a thickness of up to 300m of Jurassic sediments and palagonite tuffs under a similar thickness of basalts (Figure 5.2). They inferred that a thick dolerite sill, the Armishader sill, underlies the base of the lower area of landslide, but that the postglacial slides took place over the higher, thinner Creag Langall sill. The formation of pinnacles during postglacial sliding may imply that movement was rapid and violent, and resulted in the widespread shattering of the basalt caps of detached blocks.

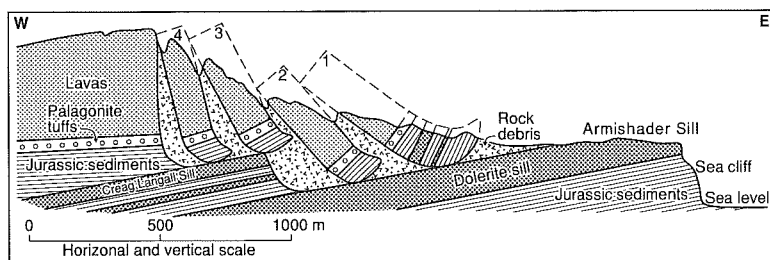


Figure 5.2: Reconstructed cross-section through the Storr landslide. Based on Anderson and Dunham (1966).

5.2 The Quiraing landslide

To the Quiraing landslide at the northern end of the Trotternish Escarpment belongs the distinction of being the largest landslide in Great Britain (Anderson and Dunham, 1966). It occupies an area of c. 8.5 km² and extends 2.2 km from the crest of the scarp to the sea. Like the Storr landslide, it consists of an inner zone of tabular landslide blocks, with narrow intervening corridors and pinnacles of shattered rock, and an outer zone of ice-moulded landslide blocks (Godard, 1965, p.402). Access to the upper part of the slide is by a path from the car park on the crest of the escarpment at NG 440679.

A geological cross-section through the slide by Anderson and Dunham (1966) suggests that a thickness of c. 200m of Jurassic sediments have failed under the weight of a lava pile c. 300 m thick, and that successive rotational failures are underlain by a thick, stepped, transgressive dolerite sill that crops out offshore as Eilean Flodigarry and Staffin Island (Figure 5.3). The forward thrust of the toe of the landslide has profoundly disturbed the Jurassic sediments exposed in sections west of Staffin Bay, which reveal strata dipping westwards at high angles with marked overthrusts.

There is some conflict of opinion regarding the present stability of this great landslide. According to Anderson and Dunham (1966), the slide is 'stable for the most part...though in the north near Flodigarry where the toe is being actively removed by the sea there is continuous though not extensive movement. The main road near Flodigarry is frequently dislocated'. The same authors claim that the landslide toe has in places over-ridden the Main Postglacial Raised Beach. Conversely, Richards (1971, p.242) found that deformed shales at the landslide toe are overlain by raised beach deposits, and that 'at least two fragments of the low-level Post-glacial raised beach shoreline are eroded into the front of the landslide'. Richards also pointed out other indicators of current stability, including the accumulation of over 3.5m of peat in a basin near the toe of the slide.

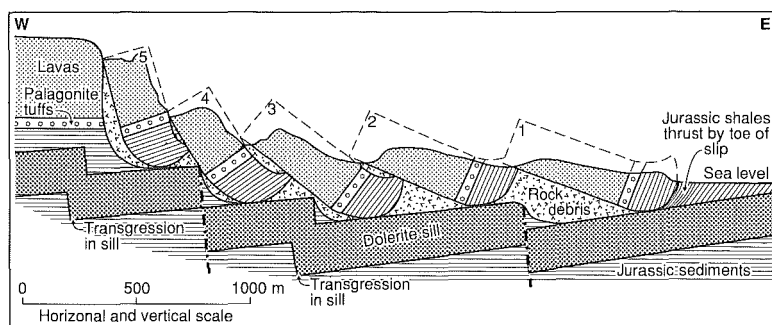


Figure 5.3: Reconstructed cross-section through the Quiraing landslide. Based on Anderson and Dunham (1966).

5.3 The Glen Uig landslides [NG 4163, 4263]

Glen Uig comprises an inlier of Corallian and Kimmeridge clay shales overlain by lavas that rise as steep cliffs from the valley floor. The flanks of this valley replicate, albeit on a much smaller scale, the great rotational slides of the Trotternish Escarpment as they again reflect failure of the sedimentary rocks under the weight of the overlying lavas. On the north side of this natural amphitheatre, detached blocks have undergone only limited displacement, but on the south side of the valley, below the cliffs known as Castle Ewen [NG 414629], landslide blocks form a remarkable landscape of chaotic steep-sided hummocks.

5.4 The Carn Liath landslide [NG 464593]

The Carn Liath landslide is the most dramatic of the nonrotational rock-slope failures on Trotternish. It takes the form of a tongue of rock debris, 260m wide and

500m long, that descends from 400m to 260m. The visible debris consists entirely of large angular boulders, many exceeding 2m in length. The lower part of this tongue extends for 250m over a slope of only 8-9°, and appears to be about 10m thick. The debris tongue results from collapse of the lava scarp upslope, apparently in the form of a rock avalanche. The extended runout of the tongue over gentle slopes indicates an element of flow (debris flow or cohesionless grainflow) in the movement of the failed debris. The limited lichen cover on the source area rockwall suggests that this failure occurred within the past few centuries.

5.5 The Score Horan landslide [NG 2859]

The largest of the coastal landslides on Skye is located at Score Horan, near Gillen on the Watnish Peninsula. The slipped mass covers an area of c. 1km² and forms a headland south of Loch Losait. It is accessible by footpath from Gillen [NG 268598], but unfortunately much of the slide area is now forested.

The Score Horan slide is typical of many of the coastal landslides on Skye in that it involved complex rotational slip of igneous rocks over less competent Jurassic sediments. According to Richards (1971), the stratigraphy at Score Horan comprises a lower dolerite sill overlain in turn by Jurassic clays and limestones, an upper sill then Tertiary basalts and tuffs. The last-mentioned form a cliff up to 60m high at the rear of the slipped mass. The most conspicuous feature of this landslide is a 40m high ridge of slipped rock (Cirein Mór) that extends northwards across the slide zone and supports deposits of till on its western side. The inner part of the landslide consists of backtilted blocks. Those abutting the backwall are angular and in places pinnaced, and thus indicative of postglacial failure; those farther seaward are rounded and subdued, and probably represent failures that occurred before the advance of the last ice sheet over the area. This area of subdued landslide topography grades northwards into an outermost zone dominated by raised shorelines. The main shore platform cut across the landslide is at 12.5-14.0m OD, and raised beach deposits related to this shoreline overlie land-slipped rock. A fragmentary lower terrace at c. 5.5m OD is developed seaward of the higher shoreline (Richards, 1971).

The evidence provided by the till deposit on Cirein Mór, rounded (ice-moulded?) landslide blocks and the presence of high-level (Lateglacial) raised beach deposits on the outermost landslide blocks indicates that most of the Score Horan landslide antedates the passage of the last ice sheet over this area. Only the angular and pinnaced blocks adjacent to the slide backwall appear to represent postglacial failure. As these are now mantled by mature, vegetated talus slopes, Richards (1971) suggested that the last episode of failure at his site occurred during the Lateglacial, a conclusion consonant with those of Godard (1965) and Ballantyne (1990) regarding the ages of the rotational slides on the Trotternish Escarpment.

5.6 The Glas Bheinn Mhór landslide [NG 560270]

From the hamlet of Luib [NG 565279] can be viewed a large landslide that occupies much of the NE face of Glas Bheinn Mhór. The slide comprises an arcuate crown scar, c. 0.5km across, below which a hummocky mass of boulders and partly disaggregated rock descends as a broad tongue to the valley floor, over-riding the drifts of the Loch Lomond Readvance. Benn (1990) found that three joint sets occur in the epigranite of the crown scar: one approximately parallel to the surface slope (30°); one aligned downslope at $75-85^\circ$; and the third aligned at c. 20° into the slope. Failure probably took the form of translational sliding of the rock mass along the plane of the slope-parallel joint set.

The age of the slide is unknown, but its relationship with the Loch Lomond Readvance drifts demonstrates that it occurred after the withdrawal of the Srath Mór Glacier at the end of the Loch Lomond Stadial. The proximity of the slide to the Loch Lomond Readvance limit is of interest, as many major rock-slope failures in the Scottish Highlands occupy similar locations. Holmes (1984) has suggested that the close association between rock-slope failures and former glacier limits reflects progressive rock-slope weakening induced by fluctuating cleft-water pressures raised above 'normal' levels by the proximity of glacier ice. There is growing evidence, however, that the relationship may reflect the influence of seismic activity triggered by differential isostatic unloading near former glacier margins (*cf.* Ballantyne, 1991b).

6. RAISED SHORELINES ON SKYE

Douglas I. Benn

Introduction

The Island of Skye has one of the most varied and spectacular coastlines in Britain. The island is deeply indented by numerous sea-lochs, resulting in a coast some 600km long, although no part of Skye lies more than 12km from the sea. Large parts of the coast, particularly in the north and west of the island, are fringed by steep cliffs which rise in places to well over 300m, and in many embayments raised shorelines occur up to c. 30m OD. However, relatively little is known about the history of sea-level change on Skye, and the raised shorelines on the island have never been the subject of systematic, detailed studies such as those conducted elsewhere in Scotland (*cf.* Sissons, 1983a).

The following account is based largely on the work of Richards (1969, 1971) in northern and western Skye, and a brief reference to the evidence adjacent to the Cuillin Hills in Walker *et al.* (1988). For convenience, the raised shorelines are discussed below under four categories: (1) high rock platforms; (2) low rock platforms; (3) raised beaches associated with ice-sheet deglaciation; and (4) Postglacial raised beaches.

High rock platforms

Rock platforms occur at several localities around the coast of Skye at altitudes of 17-30m (Figure 6.1). McCann (1968) argued these platforms are the equivalents of the benches developed between 25 and 51m OD on Mull, Jura, Islay and adjacent islands (Wright, 1911), and inferred an interglacial age from evidence suggestive of glacial over-riding. This interpretation was upheld by Richards (1969, 1971), who gave detailed descriptions of the platforms that occur in parts of northern and western Skye. The platforms studied by Richards are most extensive on the east coast of Trotternish between Portree and Staffin, and locally attain 150m in width (*e.g.* at Rubha Garbhaig, NG 497677, site 6.1). In places, platforms cut in drift occur at similar altitudes to the rock platforms (*e.g.* at Staffin, site 6.1). Shingle overlies the rock platforms in several places at altitudes up to 21m (*e.g.* Holm, NG 518512).

Richards attributed the till-cut platforms and shingle deposits to limited Lateglacial coastal activity, and argued that they bear only a coincidental altitudinal relationship to the supposedly much older platforms. Richards' interpretation of the age of the platforms hinged on the presence of 'till' on the platform surfaces at two localities, Rubha Garbhaig and Rigg [NG 522565]. However, no detailed descriptions

of the material were given, and it is possible that the 'till' consists of non-glacial diamicton (see site 6.1).

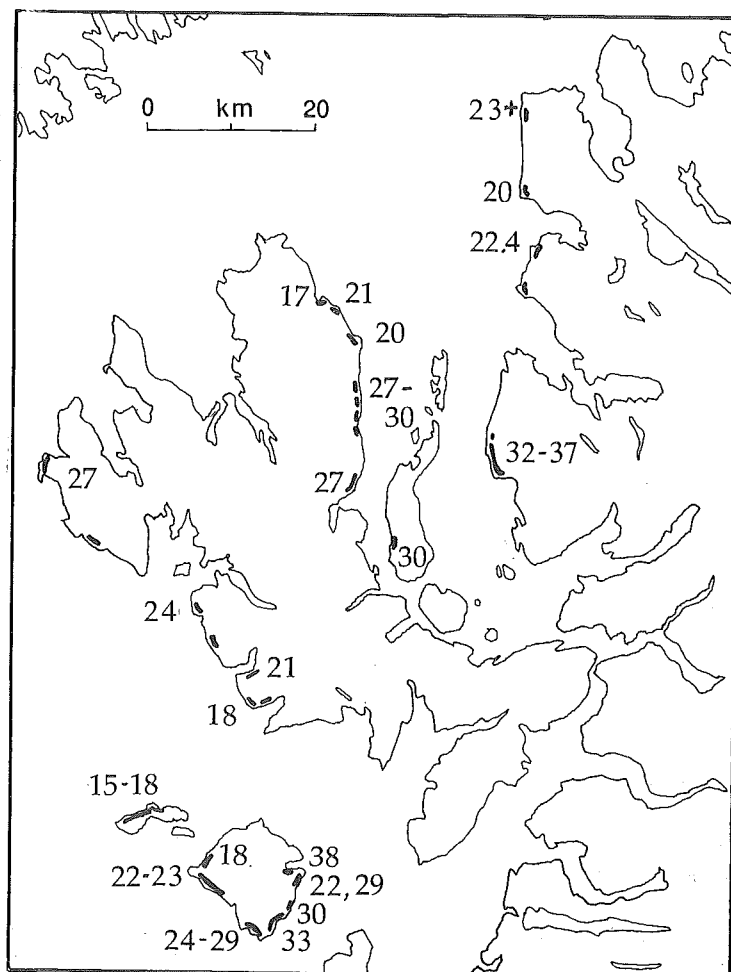


Figure 6.1: The distribution and approximate altitudes (in metres) of high rock platforms on Skye and the adjacent area. Compiled from McCann (1968), Richards (1969) and Sissons (1982).

According to Richards, high rock platforms are poorly represented on the west coast of Skye, possibly due to effective coastal erosion subsequent to platform formation. No high rock platforms have been found in southern or eastern Skye (*e.g.* Peach *et al.*, 1910).

Sissons (1982, 1983b) questioned the interglacial origin of the high rock platforms in the Inner Hebrides, and suggested that platform erosion was effected during the Late Devensian and earlier glaciations, at times when parts of the coast were unglaciated (*cf.* Sutherland, 1981). The platforms were argued to be composite, isostatically-uplifted shorelines, parts of which had been over-ridden during oscillations of the ice-sheet margins. In support of this hypothesis Sissons pointed to the predominantly westerly distribution of high rock platforms and argued that '...it is probable that there was a considerable period during the last glaciation when the margin of the Scottish ice-sheet occupied a relatively stable position amidst the Inner Hebrides' (1982, p. 212). Although the distribution of ice-sheet moraines on some islands lends some support to Sissons' ideas (*e.g.* Dawson, 1982), no unequivocal evidence for stable ice-sheet margins has been found on Skye apart from the high-level periglacial trimline on the Trotternish Hills (chapters 2 and 3).

Low rock platforms

Rock platforms at or close to present sea-level are developed on several stretches of the coast of Skye. Richards (1969, 1971) described a number of narrow platforms that occur between Portree and Staffin at 2-7m OD. In places, cemented beach gravels occur on the platform surfaces and within associated caves [*e.g.* NG 506667]. In a cave approximately 500m south of Inver Tote [NG 523598] such cemented gravels were said to be overlain by a clay-rich matrix-supported diamicton, interpreted as 'till'. On the basis of this evidence Richards interpreted the platforms as interglacial in age (*cf.* McCann, 1968), and suggested that they represent a period of marine erosion that post-dated the formation of the high rock platforms. Although the evidence he presented would appear to be equivocal, it is notable that a low ice-moulded rock platform of possible interglacial age is present in many parts of the Hebrides (Dawson, 1980).

Low rock platforms occur around much of the coasts of central and south-east Skye, and are particularly prominent around Sleat and the Strathaird peninsula. The platforms have a fresh appearance and are often associated with raised geos, caves and stacks. A particularly fine raised stack, some 25m high, occurs near Glasnakille [NG 541132]. It is possible that such features reflect coastal erosion (or at least retrimming) during the Postglacial, as has long been suggested for similar landforms elsewhere (*e.g.* McCann, 1968). An alternative hypothesis is that the low platforms in southern Skye are correlatives of the Main Rock Platform of Argyll, Bute and Ayrshire, which is attributed, at least in part, to erosion during the Loch Lomond Stadial (*cf.* Sissons, 1974b; Gray, 1978). Two lines of evidence lend support to this

view. First, the pattern of isobases established for the Main Rock Platform in south-west Scotland (Gray, 1978; Dawson, 1983) indicate that an equivalent shoreline may be expected at 0-5m OD in southern Skye. Second, low rock platforms are conspicuously absent from Loch Sligachan, Loch Ainort (site 3.7) and the inner part of Loch Slapin (site 3.3), areas which were occupied by Loch Lomond Readvance glaciers (Figure 2.4), implying that the platforms were formed prior to or during the Loch Lomond Stadial.

It has been suggested that the Main Rock Platform formed entirely during the Loch Lomond Stadial as the result of severe periglacial weathering in the intertidal zone (Sissons, 1974b; Dawson, 1983). However, there is evidence that the Main Rock Platform in the Firth of Lorne is in part a much older feature that was re-occupied during the Loch Lomond Stadial (Gray and Ivanovich, 1988). Therefore, the possibility that the low rock platforms on Skye are composite features resulting from more than one period of coastal erosion cannot be rejected.

Raised beaches associated with ice-sheet deglaciation

High raised beach gravels (up to c. 30m OD) occur at numerous localities around the coast of Skye (Clough and Harker, 1904; Peach *et al.*, 1910; Richards, 1971; Walker *et al.*, 1988). The gravel deposits frequently form distinct terraces, although occasionally the surface form is indistinct (*e.g.* NG 558320). Terraces are particularly well developed between Kyleakin and Broadford [NG 733262] where they are currently quarried as a source of aggregate. Raised beach gravels occurring on high rock platforms near Staffin are described below (site 6.1).

The highest beach deposits represent the Lateglacial marine limit, which marks the maximum sea-level during ice-sheet deglaciation. Walker *et al.* (1988) noted that the marine limit in central Skye slopes westwards from over 30m OD near Kyleakin to c. 15m OD around Loch Harport, a gradient of c. 0.4m km⁻¹. This gradient, which is the result of differential isostatic uplift, is similar to that of the highest Lateglacial raised beaches in Wester Ross (Sissons and Dawson, 1981). The presence of high raised beaches around Sleat and Kyleakin shows that sea-level remained high at least until mainland ice had disappeared from Skye. However, in Glen Brittle there is evidence that considerable uplift occurred prior to the final decay of locally-nourished ice at the end of the Dimlington Stadial (Walker *et al.*, 1988; site 6.3).

High shorelines (*i.e.* above c. 15m OD) are not present inside the limits of the Loch Lomond Readvance, as determined from morphological and pollen-stratigraphic evidence (Walker *et al.*, 1988; chapters 2 and 8). For example, no high shorelines occur around Loch Sligachan, Loch Ainort (site 3.7), the inner parts of Loch Scavaig and Loch Slapin (site 2.4), and the mouth of Kylerhea Glen. The relationship between the distribution of high Lateglacial shorelines and the Loch Lomond Readvance limits is particularly clear in the Loch Sligachan area. Raised

beach gravels occur at c. 30m OD at Braes (site 6.2), 1km to the north of the margin of the former Sligachan glacier (Figure 2.4). Inside the margin, the highest raised shorelines occur at c. 7m OD (e.g. at Peinchorran, NG 528335; Sconser, NG 535322; and Sligachan, NG 487305), and are attributable to the Main Postglacial Transgression (see below). The absence of high shorelines within the glacier limits shows that by the Loch Lomond Readvance maximum relative sea-level had fallen to or below the altitude of the Main Postglacial Raised Shoreline, indicating rapid isostatic emergence during the Lateglacial.

Postglacial raised beaches

Raised beaches formed during or following the culmination of the Main Postglacial Transgression are widespread on Skye, where they occur up to c. 10m OD (Richards, 1971; Walker *et al.*, 1988). The highest such features, known collectively as the Main Postglacial Shoreline (Sissons, 1983a), are often very well developed, and have varied forms depending on the configuration and aspect of the coast. For example, fossil shingle ridges occur in exposed locations (e.g. Staffin Bay, site 6.1), and raised tombolos are found connecting former islands to the shore (e.g. at Ard Mór, NG 220610; and Braes, site 6.2). Within the limits of the Loch Lomond Readvance, the Main Postglacial Shoreline often consists of an erosional platform cut across moraines (e.g. Camas Malag on Loch Slapin, site 2.4; and Loch Ainort, site 3.7).

No evidence is available concerning the timing of the Main Postglacial Transgression on Skye, although data from elsewhere in western Scotland suggest that it may have occurred between 7 and 5.5ka BP (Dawson, 1983). Similarly, the tilt of the Main Postglacial Shoreline on Skye is unknown. However, generalised isobases for the shoreline in western Scotland suggest that it slopes north-westwards from c. 10m near Kyleakin to c. 6m in Duirinish, Waternish and northern Trotternish, a gradient of c. 0.07m km⁻¹ (Sissons, 1983b).

Unlike many Hebridean islands, Skye generally does not support large areas of *machair*, lush grassland developed on fossil coastal sand dunes. This is probably due to the lack of suitable source material on the rocky Skye coasts. An exception, at the mouth of Glen Brittle, is described below (site 6.3).

Sites of particular scientific interest

6.1 Staffin Bay and Rubha Garbhaig

A variety of raised coastal landforms occur in the vicinity of Staffin [NG 475683] in Trotternish. In Staffin Bay a well-developed erosional platform occurs at c. 18m OD (Richards, 1971; A in Figure 6.2). The platform is up to 500m wide and is cut largely in till, sections in which can be examined in the banks of the River

Brogaig. No occurrences of gravels have been reported from the platform surface, although Richards described gravels exposed in cliff sections near Digg (B in Figure 6.2). These gravels lay above a gently-undulating erosion surface cut in Oxford Clay, and had a maximum altitude of c. 18m.

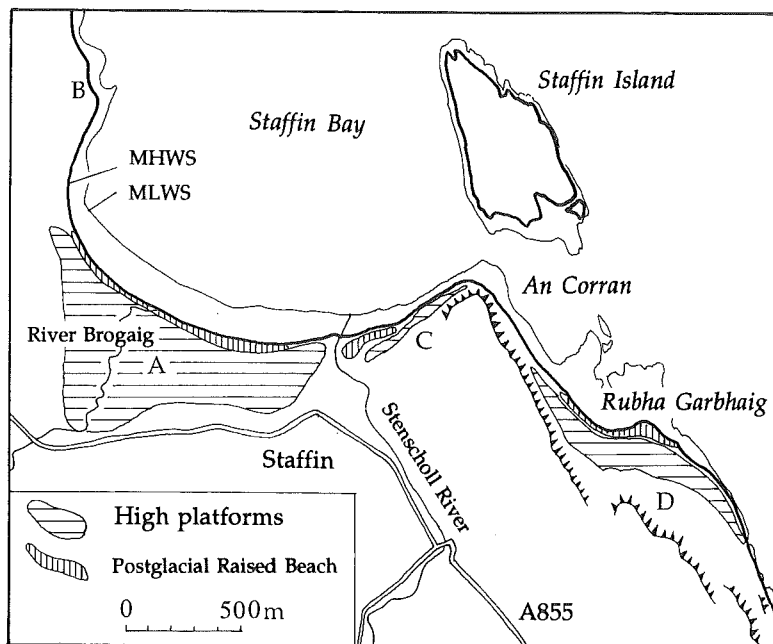


Figure 6.2: Raised shorelines in the vicinity of Staffin.

The Main Postglacial Shoreline is well developed in Staffin Bay, where it has an altitude of c. 6-7m OD. The beach consists of vegetated shingle ridges, and is similar in morphology to the modern beach. Fragments of the Main Postglacial Shoreline also occur to the north of B (Figure 6.2), where they are cut into landslipped material, and around Rubha Garbhaig.

East of the Stenscholl River the upper parts of the coastal slopes consist of cliffs of columnar dolerite, below which a high rock platform occurs (C and D, Figure 6.2). The inner edge of the platform is generally overstepped by coarse blocky talus, and varies in altitude from c. 17m west of An Corran to c. 21m south of Rubha Garbhaig. The flat-lying surface of Staffin Island is at a similar altitude. According to Richards, parts of the Rubha Garbhaig platform are covered by till. However, the

deposit as described by Richards consists entirely of weathered local material, and a non-glacial origin cannot be ruled out. Patchy beach gravels occur on the platform surface south-east of An Corran.

Richards contended that the rock platform predated the last glaciation. However, the similarity in altitude of the rock platform and the till-cut platform and beach gravels in Staffin Bay suggest that all of the features may have originated during the Late Devensian (*cf.* Sissons, 1982).

6.2 Braes: raised tombolo [NG 530349]

An unusual raised tombolo composed of Lateglacial and Flandrian beach gravels occurs near Braes, about 12km south of Portree. The tombolo links the main part of the coast to An Aird, a low rocky knoll underlain by an acidic sill. Two levels of raised beach are present at the site: a lower vegetated gravel spit, and an upper, eroded beach terrace. The upper beach forms a steep-sided promontary at the western (landward) end of the tombolo and is not represented on the eastern end. Sections in the deposit reveal coarse, well-sorted gravels and occasional lenses of sand. Abundant clasts of Glamaig epigranite and Torridonian Sandstone, derived from the south, occur in the gravels suggesting that the deposit consists of reworked glacially-transported material. No shells have been discovered in the deposits. The inner edge of the high terrace lies at approximately 30m OD, which is the Lateglacial marine limit on this part of the coast of Skye (Walker *et al.*, 1988). It is notable that the limit of the Loch Lomond Readvance lies 1km south of Braes (Figure 2.4), and that within this limit no raised beaches occur at altitudes greater than *c.* 10m.

The low fossil spit has a maximum altitude of *c.* 7m, and forms part of the Main Postglacial Raised Beach. Where the northern part of the spit abuts An Aird vegetated shingle ridges are evident, the innermost of which dams up a small pond. Raised beaches at similar altitudes occur near Peinchorran [NG 530335] and Sconser [NG 536320] to the south, within the limits of the Loch Lomond Readvance.

A rock platform occurs close to sea-level on the eastern side of An Aird, backed by caves and a natural arch [NG 535353]. An Aird also provides fine views northwards to Ben Tianavaig, the eastern slopes of which comprise one of the most extensive areas of landslip in Britain (chapter 5).

6.3 Glen Brittle

A good general view of the varied raised coastal landforms around the mouth of Glen Brittle can be obtained from the footpath on the east side of Loch Brittle [NG 415200]. High shorelines (18m-22m OD) occur above the shores of the loch, and are particularly clear around Bualintur [NG 407207] where, according to Richards (1971), they are cut in till. Such high shorelines, which mark the Lateglacial marine

limit, only extend 1km upvalley, although the floor of the Glen Brittle lies below this altitude for over 3km. A short distance upvalley from the inland limit of the high shorelines, a small group of morainic hummocks occurs [NG 406222]. These are quite distinct from the clear arcuate end moraines of the Loch Lomond Readvance (sites 2.6 and 2.7). Walker *et al.* (p. 141) noted that '...the existence of these moraines close to the termination of the high shorelines suggests that during ice-sheet decay either a dead-ice-mass became isolated in lower Glen Brittle or a minor readvance occurred'. Since this interpretation implies a drop in the marine limit of at least 10m, the site may be of considerable importance for the deglacial chronology of Skye.

Intertidal rock platforms are developed in many places around the shores of Loch Brittle. The platforms are backed by low sea-cliffs and have a fresh appearance, indicating that significant erosion has occurred since ice-sheet deglaciation. Part of this erosion may have occurred during the Loch Lomond Stadial, when relative sea-level probably lay close to that of the present.

The head of Loch Brittle is backed by an extensive area of fossil sand dunes [NG 410207]. The age of the initiation and stabilisation of the dunes is not known. Similar areas of fossil dunes elsewhere in the Hebrides were initiated following the Main Postglacial Transgression as large areas of sand were exposed by the falling sea (Ritchie, 1979).

The dunes overlie a surface composed of well-bedded sand and gravel that can be examined section in the east bank of the River Brittle opposite Bualintur [NG 408209]. The deposits are horizontally-bedded, and were interpreted by Richards (1971) as Lateglacial outwash. However, it is perhaps more likely that they are an aggradational fluvial sequence associated with the Main Postglacial Transgression. To date no shells or other organic remains have been discovered in the section.

7. VEGETATIONAL HISTORY OF THE ISLE OF SKYE

I. THE LATE DEVENSIAN LATEGLACIAL PERIOD (13-10 ka BP)

Michael J.C. Walker & J. John Lowe

Introduction

Although the Isle of Skye has long been regarded as an area of outstanding interest to geologists and glacial geomorphologists, over the past three decades the palaeoecology of the island has also become a particular focus of attention. More than 20 pollen diagrams are now available from sites on Skye, and these data form the basis for a reconstruction of the sequence of vegetational changes that have occurred over the last 13,000 years. In addition, pollen evidence has been used to establish a chronology of glacial events at the last glacial/interglacial transition (chapter 8).

The pattern of Lateglacial vegetational changes presented in this chapter is based largely on the results of the most recent research on the island (Walker *et al.*, 1988; Walker and Lowe 1990), and differs in a number of respects from that described in previous publications (Birks, 1973; Walther, 1984). It does however conform to the Lateglacial and early Flandrian vegetational sequence that has been inferred from pollen analytical investigations on other Hebridean islands and adjacent areas of the Scottish mainland (Lowe and Walker, 1986a, 1986b; Robinson, 1987; Tipping, 1984, 1986; Walker and Lowe, 1982, 1985, 1987).

Pollen-stratigraphic investigations

Some of the earliest pollen records from Scotland were obtained during the 1920s from blanket peats in the Glen Sligachan area (Erdtman, 1924, 1928). Thereafter, however, apart from a short mid-Flandrian pollen record from the island of Soay (Blackburn in Godwin, 1943: Figure 7.1), no further pollen diagrams from Skye appeared until the late 1960s when detailed Flandrian profiles were published from Loch Cuithir and Loch Fada in the Trotternish area of northern Skye (Vasari and Vasari, 1968). During the 1970s the pollen-stratigraphic sequences from five sites, Loch Meodal, Loch Cill Chrìosd, Lochan Coir' a'Ghobhainn, Loch Fada and Loch Mealt (Figure 7.1) were described by Birks (1973), who interpreted these records as spanning the time interval from the Lateglacial (Windermere) Interstadial through to the early Flandrian period. Subsequently, Williams (1977) presented a pollen diagram from the Flandrian part of the Loch Meodal profile, as well as two new Flandrian records from Loch Ashik in south-east Skye and Loch Cleat in the extreme north of the island (Figure 7.1). Data from a number of these sites were later synthesised to produce a history of vegetational changes on the Isle of Skye over the

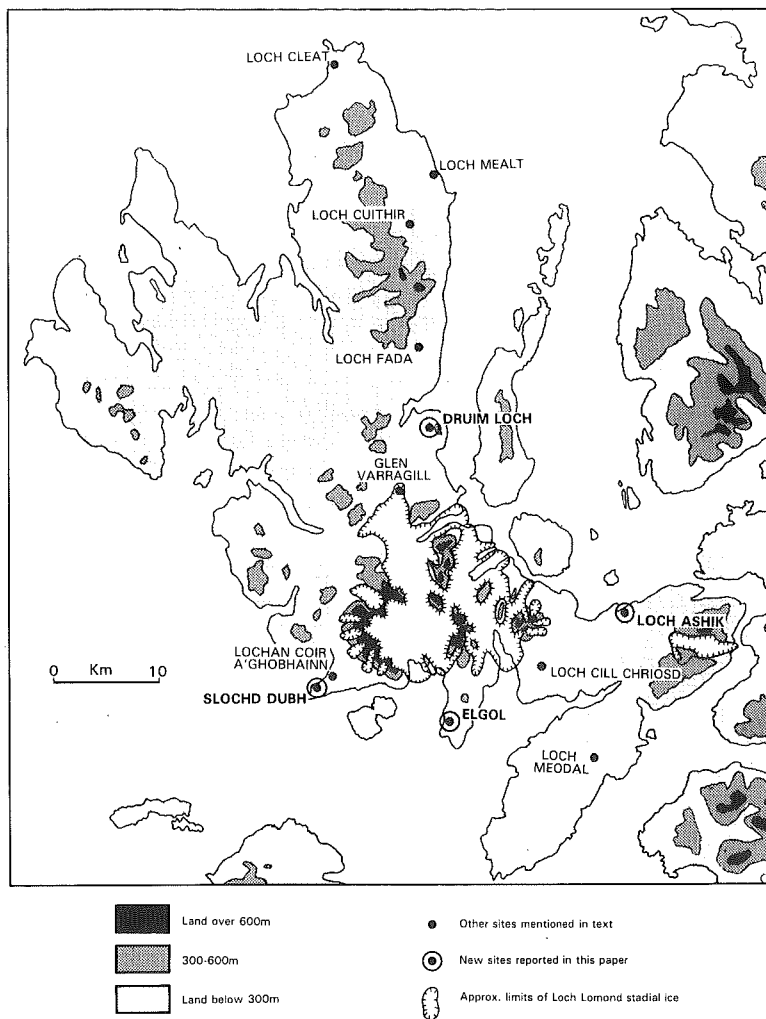


Figure 7.1: The Isle of Skye showing the location of pollen sites and the limits of the Loch Lomond Stadial glaciers in central Skye and the Red Hills.

	Pollen-stratigraphic 'events'	LOCHAN COIR A GHOBHAINN NG 417183	LOCH CILL CHRISO NG 605203	LOCH FADA NG 494467	LOCH MEODAL NG 656113	LOCH CUITHIR NG 476598	LOCH CLEAT NG 416674	LOCH ASHIK NG 690233	GLEN SLIGACHAN NG 476598	LOCH DUBH NG 485282	COIRE LAGGAN NG 431189	GLEN VARRAGILL NG 469328
		Birks (1973)			Williams (1977)	Vasari (1977)	Williams (1977)	Harkness (1981)	Walther (1984)			
Early Flandrian	<u>Corylus</u> rise	8650±150 (Q-958)	9655±150 (Q-959)	7500±120 (Q-961)	9482±150 (Q-960)	9400±210 (HEL-502)	9000±100 (SRR-938)	9540±70 (SRR-811)	9460±154 (HV-11932)		7780±180 (HV-11931)	8175±85 (HV-11937)
	<u>Betula</u> phase					9680±250 (HEL-503)	9760±150 (SRR-939)	10,090±90 (SRR-812)		10,155±305 (HV-11935)		
	<u>Juniperus</u> maximum						9990±130 (SRR-940)					
	<u>Empetrum</u> maximum					10,060±270 (HEL-504)		10,330±80 (SRR-813)				9930±1600 -1250 (HV-11938)
	<u>Gramineae-Rumex</u> phase	9420±150 (Q-957)										
Loch Lomond Stedial												
Lateglacial Interstadial	?	9691±150 (Q-956)										
	?	10,254±220 (Q-955)										

Table 7.1: Radiocarbon dates from sites on the Isle of Skye.

past 13,000 years (Birks and Williams, 1983). Walther (1984) subsequently produced a series of pollen diagrams from sites around the Cuillin Hills, the majority of which span the early and mid-Flandrian, but one (from Glen Varragill) was considered to extend back into the Lateglacial.

Although radiocarbon dates have been obtained from a number of these sites (Table 7.1), none provides evidence of a Lateglacial age *sensu stricto*. Hence, previous interpretations concerning the Lateglacial chronology of sedimentary sequences have been based entirely on pollen-stratigraphic correlations (Birks, 1973; Walther, 1984). More recently, data from three new sites, Druim Loch, Elgol and Slochd Dubh (Figure 7.1), as well as from the Loch Ashik site previously investigated by Williams (1977), have provided a detailed and consistent series of Lateglacial biozones for the Isle of Skye (Walker and Lowe, 1990; Table 7.2). This new evidence suggests that some of the previously published profiles, notably Loch Meodal, Loch Fada and Loch Mealt, are unlikely to be of Lateglacial age. On the other hand, the diagram from Loch Cill Chriosd does contain biozones that correlate with those in Table 7.2, while a Lateglacial sedimentary record may also be present at Lochan Coir' a' Ghobhainn, despite the fact that the dates on the 'Lateglacial' horizons in that profile are no older than early Flandrian (Table 7.1).

Lateglacial vegetational changes

After the wastage of the Late Devensian ice sheet the Isle of Skye was characterised by pioneer vegetational communities on skeletal mineral soils. Typical open-habitat taxa included species of Gramineae, Cyperaceae, *Rumex*, Caryophyllaceae, Compositae and *Artemisia*, along with the clubmosses (*Lycopodium*), typically *L. selago* and *L. annotinum*. Of the woody plants, only *Salix* appears to have been present, probably the northern forms *S. glauca*, *S. polaris* or *S. reticulata*. Following the initial episode of plant succession, a landscape of dwarf shrub heath and open grassland developed throughout the island, the dominant heathland elements being *Juniperus*, *Empetrum*, and species of Ericaceae. To the north and east of the Cuillin Hills, where some degree of shelter could be obtained from the south-westerly winds, a mosaic of juniper scrub, *Empetrum* and *Erica* heath, open grassland, and stands of tree birch developed, while on the more exposed south- and west-facing slopes heathland and grass-sedge communities with only occasional stands of birch and juniper were to be found.

In climatic terms, this vegetational succession reflects a response to rapidly rising temperatures at the beginning of the Lateglacial Interstadial as the atmospheric Polar Front swung northward. Evidence suggests that the Polar Front lay off Ireland at c. 13,000 yr BP (Duplessy *et al.*, 1981) but thereafter migrated to a position between Iceland and Greenland (Ruddiman and McIntyre, 1981). The subsequent terrestrial warming began around 13,300 yr BP and by 12,500 yr BP summer temperatures in the British Isles reached 17°C (Atkinson *et al.*, 1987). Cooling

Table 7.2a

Correlation between pollen assemblage zones. 1: Eastern Skye

	REGIONAL POLLEN ZONES: EASTERN SKYE	DRUIM LOCH	LOCH ASHIK
Flandrian	ESK-11: <i>Betula-Corylus</i>	DL-11: <i>Betula-Corylus</i>	
	ESK-10: <i>Betula</i>	DL-10: <i>Betula</i>	LA-11: <i>Betula</i>
	ESK-9: <i>Betula-Juniperus</i>	DL-9: <i>Betula-Juniperus</i>	LA-10: <i>Juniperus</i> -Gramineae
	ESK-8: <i>Juniperus</i> -Gramineae	DL-8: <i>Juniperus</i>	
	ESK-7: <i>Empetrum</i> -Gramineae	DL-7: <i>Empetrum</i> -Gramineae	LA-9: Gramineae- <i>Empetrum</i> -Ericaceae- <i>Rumex</i>
	ESK-6: Cyperaceae- <i>Rumex</i>	DL-6: Cyperaceae- <i>Rumex</i>	LA-8: <i>Rumex</i> -Gramineae-Cyperaceae
Loch Lomond Stadial	ESK-5: <i>Rumex-Artemisia</i>	DL-5: <i>Artemisia-Rumex</i>	LA-7: Cyperaceae-Gramineae- <i>(Empetrum-Ericaceae)</i>
	ESK-4: Gramineae-Cyperaceae- <i>(Empetrum-Ericaceae)</i>	DL-4: Gramineae-Cyperaceae- <i>(Empetrum)</i>	
	ESK-3: <i>Empetrum-Ericaceae</i> -Gramineae-Cyperaceae	DL-3: <i>Empetrum-Ericaceae</i> -Gramineae-Cyperaceae	LA-6: <i>Empetrum-Ericaceae</i> -Cyperaceae
			LA-5: Gramineae- <i>Rumex-Juniperus</i>
Lateglacial Interstadial	ESK-2: <i>Juniperus-Empetrum</i> -Gramineae- <i>Rumex</i>	DL-2: <i>Juniperus-Empetrum</i> -Gramineae- <i>Rumex</i>	LA-4: <i>Rumex</i> -Gramineae LA-3: <i>Juniperus-Empetrum</i> -Gramineae- <i>Rumex</i>
	ESK-1: <i>Rumex-Salix</i> -Gramineae	DL-1: <i>Rumex</i> -Gramineae- <i>Salix</i>	LA-2: Gramineae- <i>Rumex</i> LA-1: <i>Rumex</i> -Gramineae- <i>Salix</i>

Table 7.2b

Correlation between pollen assemblage zones. 2: SW Skye

	REGIONAL POLLEN ZONES: SW SKYE	SLOCHD DUBH	ELGOL
Flandrian	SWSK-7: <i>Betula-Corylus</i> -Gramineae	SLD-8: <i>Betula-Corylus</i> -Gramineae	ELG-9: <i>Betula-Corylus</i> -Gramineae
	SWSK-6: <i>Betula-Empetrum</i> -Gramineae- <i>Rumex</i> -(<i>Juniperus</i>)	SLD-7: <i>Betula-Empetrum</i> -Gramineae- <i>Rumex</i>	ELG-8: <i>Betula-Juniperus</i> -Gramineae ELG-7: Gramineae-Cyperaceae- <i>Empetrum</i>
Loch Lomond Stadial	SWSK-5: <i>Artemisia-Rumex</i> -Cyperaceae-(<i>Empetrum</i>)	SLD-6: Cyperaceae- <i>Artemisia-Rumex</i> - <i>Lycopodium</i>	ELG-6: <i>Rumex-Artemisia</i> -Cyperaceae- <i>Lycopodium</i>
	SWSK-4: Cyperaceae- <i>Selaginella</i> -(<i>Empetrum</i>)	SLD-5 Cyperaceae- <i>Selaginella</i> -(<i>Empetrum</i>)	ELG-5: <i>Selaginella</i> -Cyperaceae- <i>Lycopodium</i> ELG-4: Gramineae-Cyperaceae- <i>Rumex</i>
	SWSK-3: <i>Empetrum</i> -Cyperaceae	SLD-4: <i>Empetrum</i> -Gramineae-Cyperaceae	ELG-3: <i>Empetrum</i> -Cyperaceae
	SWSK-2: Gramineae- <i>Rumex</i> - <i>Empetrum</i>	SLD-3: <i>Rumex</i> -Gramineae- <i>Salix-Artemisia</i>	ELG-2: <i>Empetrum</i> -Cyperaceae- <i>Rumex-Lycopodium</i>
	SWSK-1: <i>Salix-Rumex</i> -Gramineae	SLD-2: <i>Rumex</i> -Gramineae- <i>Salix-Artemisia</i> SLD-1: Graminae- <i>Salix</i> -Compositae	?ELG-1: <i>Rumex</i> -Gramineae-Cyperaceae- <i>Lycopodium</i>
Lateglacial Interstadial			

appears to have begun around 12,000 yr BP, with winter temperatures in particular falling by more than 10°C over the next 1000 years.

These temperature inferences, based on fossil insect assemblages, are supported by the pollen-stratigraphic data from Skye. In all the pollen diagrams, *Juniperus* pollen declines markedly during the mid-Interstadial. This cannot be interpreted as the shading out of juniper (as may have been the case at sites farther south) for there is no indication in the pollen records for a subsequent increase in tree pollen. Rather, the decline in *Juniperus* after c. 12,000 yr BP appears to be a climatic signal indicating, as in the Irish pollen records, a lowering of temperature (cf. Watts, 1985). Hence, the decline in *Juniperus* scrub and the expansion of acidophilous heath and grassland which is a feature of all of the mid- and late-Interstadial pollen records from Skye is a clear reflection of climatic deterioration resulting, perhaps, from the renewed southward expansion of cold Atlantic waters around the coast of north-west Britain (Broecker *et al.*, 1985; Atkinson *et al.*, 1987).

A characteristic feature of the recently published biostratigraphic data from Skye is evidence for the occurrence during the Lateglacial Interstadial of what appears to have been a short-lived reversion episode (Walker and Lowe, 1990). This is typically reflected in a lithostratigraphic change from organic to more minerogenic sediment which is accompanied in the pollen record by a decline in woody plants (*Juniperus* and *Betula*), a rise in the curves for Ericaceae and *Empetrum*, and a complementary increase in pollen of open-habitat taxa and plants indicative of disturbed soils including, for example, species of Caryophyllaceae, *Rumex*, *Artemisia* and *Lycopodium selago*. Subsequently, *Juniperus* and especially *Empetrum* and *Erica* increase once more. A similar lithostratigraphic and biostratigraphic oscillation in Interstadial sediments has been noted at a number of sites in Scotland (Walker, 1984), and has been widely interpreted as reflecting a break-up of the vegetation cover and increased soil erosion as a consequence of a short-lived climatic deterioration. At Cam Loch in northern Scotland, this event was estimated to have occurred around 11,800-12,000 yr BP (Pennington, 1975), and a similar date has been inferred for Ireland (Watts, 1985). On the Isle of Mull, the subsequent rise in *Empetrum* has been dated to c. 11,860 yr BP (Lowe and Walker, 1986a). Coleopteran evidence suggests a fall of almost 10°C in temperatures of the coldest months of the year from 12,300-11,800 yr BP after which winter temperatures rose by 4-5°C (Atkinson *et al.*, 1987). Hence, the vegetational reversion episode recorded in the Skye profiles may well reflect this significant climatic oscillation, which might have been linked to a short-lived infusion of cold waters into the North Atlantic, perhaps due to rapid melting of coastal glaciers as the Polar Front swung northwards during the early Interstadial.

The Loch Lomond Stadial on the Isle of Skye was a period of arctic severity. This climatic episode, which may have lasted for up to 1000 years, is represented in all of the profiles by a lithostratigraphic change from organic to minerogenic sediment accumulation reflecting a marked increase in soil erosion around the basin catchments

following the break-up of the Interstadial vegetation cover. The pollen evidence shows that the *Empetrum-Erica* heaths that had characterised much of the island during the later part of the Interstadial were replaced by a tundra vegetation dominated by grasses, sedges, and taxa associated with bare and unstable soils including species of *Artemisia*, *Rumex*, *Thalictrum*, Caryophyllaceae, Chenopodiaceae and Compositae, along with the clubmosses, *Lycopodium* and *Selaginella*. Some heathland taxa (*Empetrum* and *Erica*) may have survived throughout the Stadial, particularly in eastern areas where more extensive snow cover in the lee of the central hill mass may have afforded some protection from low winter temperatures (cf. Bell and Tallis, 1973).

Further indications of permanent or semi-permanent snow in sites to the north and east of the Cuillin and Red Hills may be reflected in the relatively low frequencies of *Artemisia* and *Rumex* pollen in stadial sediments from the Druim Loch, Loch Ashik and Loch Cill Chriosd profiles, for a number of species of these genera are known to be either chionophobous or associated with xeric habitats. Hence, the higher counts for pollen of these two genera in profiles to the south and west of the main hill mass (Elgol, Slochd Dubh) are perhaps indicative of more restricted snow cover in areas exposed to strong onshore winds. In those areas, heathland communities were almost entirely absent during the stadial, the vegetation having been reduced to a sedge and grass tundra, with extensive areas of bare soils which were continuously being disturbed by gelifluction processes. Upon such sites species of Compositae, Caryophyllaceae, *Lycopodium* and *Selaginella* were the most successful competitors. The inference of increased snow cover in areas to the north and east of the Cuillins is consistent with Ballantyne's (1989a) reconstruction of a northeastward decline in equilibrium line altitudes across the Cuillin Icefield (chapter 2).

Palaeoclimatic reconstructions based on equilibrium-line altitudes indicate a mean July temperature at sea level of around 6°C for the Loch Lomond Stadial (Ballantyne, 1989a), an estimate that is in broad agreement with that derived from coleopteran evidence (Atkinson *et al.*, 1987) once the latitudinal difference between lowland Britain and Skye is taken into account. The coleopteran data also indicate winter temperatures of -17°C to -20°C, figures which are similar to estimates derived from periglacial evidence (Ballantyne, 1984). These very low temperatures support the view that the oceanic Polar Front lay to the south of Ireland during much of the stadial (Ruddiman and McIntyre, 1981), and that cold surface waters surrounded the British Isles. The pollen-stratigraphic record from Skye, which shows maximum *Artemisia* and *Rumex* frequencies during the mid- and late-stadial, suggests that the heavy snowfall required to generate glaciers in the Cuillins occurred during the early part of the stadial as the Polar Front moved southwards. Thereafter, with the spread of cold surface waters along the western seaboard, precipitation levels would have diminished. Hence, glacier wastage would probably have begun prior to the rise in temperature at the onset of the present interglacial, which is so clearly reflected in the pollen stratigraphy. This evidence is considered in the following chapter.

Lateglacial sites

7.1 Loch Ashik [NG 691232]

Loch Ashik is situated 4km east of Broadford in an area of Torridonian sandstones and arkoses that are occasionally intruded by Tertiary dykes. The loch lies at around 40m OD and, at its maximum, is 175m long and 125m wide. The deepest and most accessible infilled area around the loch occurs in an embayment beside an inflowing stream at the western end. In a core taken from this locality in 1986 (Walker *et al.*, 1988; Walker and Lowe, 1990), the lithostratigraphy of the basal sediments was as follows:

474-507 cm Green-brown organic lake mud (gyttja)
507-523 cm Grey-purple plastic silt-clay
523-526 cm Clay gyttja
526-550 cm Green brown gyttja
550-552 cm Pink-grey clay gyttja
552-567 cm Green brown gyttja
567-569 cm Green-grey gyttja
569-573 cm Grey-green clay gyttja
573 cm Gravel

The following Local Pollen Assemblage Zones (LP AZs) were identified in the corresponding pollen diagram (Figure 7.2):

LA-11 *Betula*
LA-10 *Juniperus*-Gramineae
LA-9 Gramineae-*Empetrum*-Ericaceae-*Rumex*
LA-8 *Rumex*-Gramineae-Cyperaceae
LA-7 Cyperaceae-Gramineae-(*Empetrum*-Ericaceae)
LA-6 *Empetrum*-Ericaceae-Cyperaceae
LA-5 Gramineae-*Rumex*-*Juniperus*
LA-4 *Rumex*-Gramineae
LA-3 *Juniperus*-*Empetrum*-Gramineae-*Rumex*
LA-2 Gramineae-*Rumex*
LA-1 *Rumex*-Gramineae-*Salix*

LP AZ's LA-1 to LA-6 are of Lateglacial Interstadial age, LA-7 represents the Loch Lomond Stadial, while LA-8 to LA-11 date from the early Flandrian.

Radiocarbon dates from the Loch Ashik profile are shown in Table 7.3. By comparison with radiocarbon age determinations on comparable biostratigraphic horizons at other sites in northern Britain, most of these dates appear to be too old. Only SRR-3118 appears to be consistent with the currently accepted radiocarbon

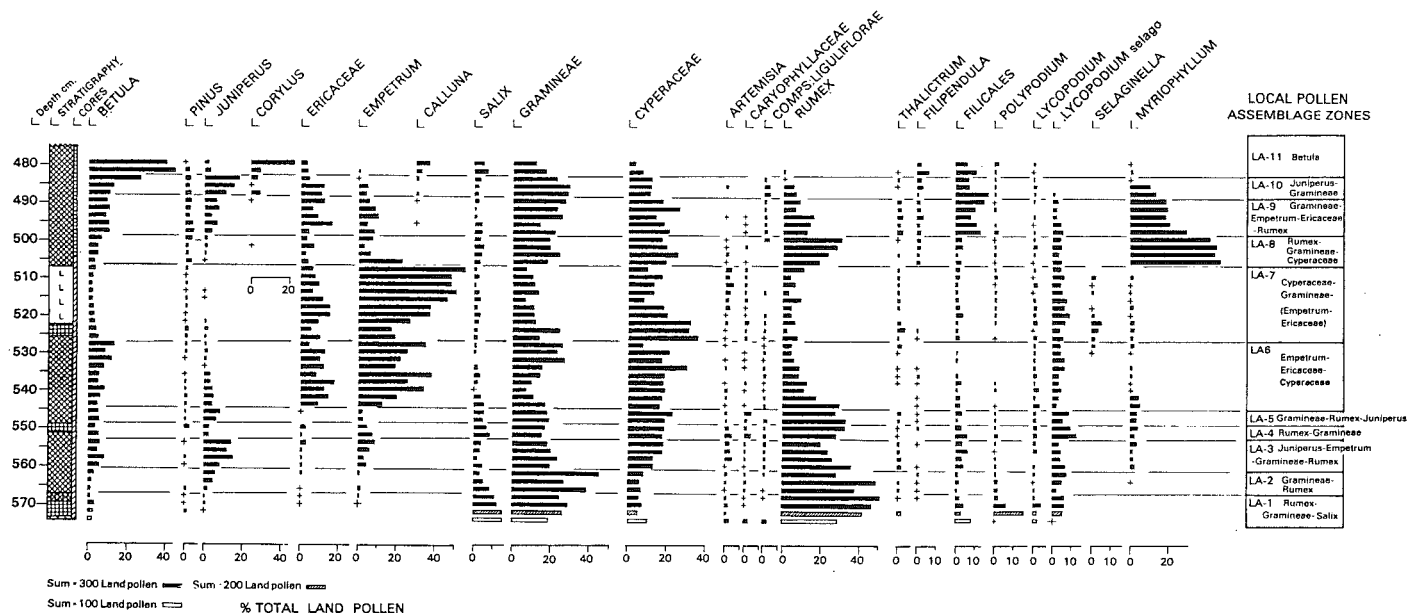


Figure 7.2: Lateglacial pollen diagram from Loch Ashik.

chronology of Lateglacial biozones (Walker and Harkness, 1990). The measured ages most probably reflect the inwash of inert carbon residues into the lake basin, although the source of this inert material is difficult to establish. There are no obvious outcrops of carbonaceous rocks in the basin catchment, and while limestones crop out in the Broadford Beds some 1.5km to the north of the site, both the regional drainage pattern and former direction of ice movement (as indicated by glacial striae) would not permit transport of these rocks into the Loch Ashik basin. One possibility is that the sediments have been contaminated by the accumulation of older organic carbon residues, either from the break-up of soils around the lake catchment or from the inwashing of other carbon detritus (plant remains, peats etc). This 'reservoir effect' (Olsson, 1979; 1986) would have been most likely to have occurred during the later part of the interstadial as climate deteriorated and soil erosion accelerated. Increased numbers of deteriorated pollen in that part of the profile (Figure 7.3) lend some support to this hypothesis.

Table 7.3

Radiocarbon dates from Loch Ashik

SURRC Reference No.	Mean sample depth	Radiocarbon age (yr BP)
SRR-3116	506 cm	11,240 \pm 120
SRR-3117	526 cm	11,760 \pm 190
SRR-311	545 cm	11,590 \pm 160
SRR-3119	548 cm	12,400 \pm 200
SRR-31	553 cm	12,550 \pm 280
SRR-3121	572 cm	13,870 \pm 190

The Loch Ashik pollen record is significant in a number of respects. First, the site is located in a critical position relative to the mapped ice limits in SE Skye. It lies approximately 7km east of the Loch Lomond Stadial glacier that developed in Coir Gorm in the Eastern Red Hills and just over 4km NW of the Loch Lomond Readvance limit in Glen Arroch. The site is therefore a key element in the establishment of a glacial chronology for this part of Skye (chapter 2). Second, the site provides a high resolution pollen record of the Lateglacial and early Flandrian for eastern Skye. It shows clearly the early Lateglacial pioneer vegetational stage (LA-1 to LA-2), the *Juniperus* maximum (LA-3), the expansion of *Empetrum* and *Erica* heathland communities (LA-5), the development of a grass-sedge tundra with some heathland stands during the Loch Lomond Stadial (LA-7), and finally the early Flandrian vegetational succession to birch and hazel woodland (LA-8 to LA-11). Third, the profile shows unequivocal evidence of the mid-interstadial 'revertance' episode, reflected both in the sediment stratigraphy between 553cm and 549cm, and the

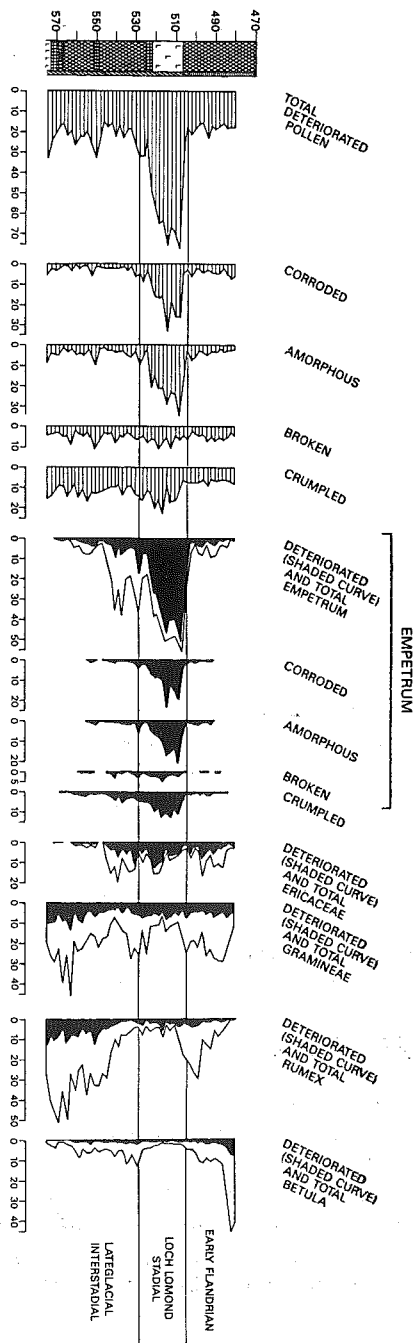


Figure 7.3: Deteriorated pollen diagram from Loch Ashik.

pollen-stratigraphic changes from LA-3 to LA-5. The decline in *Juniperus* and *Empetrum* values in LA-4 is accompanied by increases in *Rumex*, Caryophyllaceae, *Salix* and *Lycopodium*, and also by a peak in the curve for deteriorated pollen (Figure 7.3). Fourth, the site is important for demonstrating the significance of deteriorated pollen analysis in palaeoecological reconstructions. The very high counts for *Empetrum* pollen in paz LA-7 may be taken to indicate extensive heathland communities around the basin catchment during the Loch Lomond Stadial, and certainly the rising curve for this taxon is indicative of some local *Empetrum* presence. However, deteriorated pollen counts show that the majority of the *Empetrum* pollen exhibit signs of exine damage and hence are most likely to be of secondary derivation from eroding soils around the catchment.

7.2 Loch Cill Chrìosd [NG 605203]

Loch Cill Chrìosd is located beside the A881 road in Strath Suardal, some 4km SW of Broadford and 3km east of Loch Slapin. It lies at an altitude of 20m OD on the geological contact between Durness Limestone to the south and east and the epigranite of the Beinn na Caillich range to the north and west. The loch is almost 1.5km in length at its maximum and some 500m across at the widest point. An extensive fen has formed near an inflowing stream at the western end, and in 1967 a series of cores was taken from this area (Birks, 1973; Birks and Williams, 1983). The stratigraphy was as follows:

345-400 cm Dark brown slightly fibrous detritus mud
 400-430 cm Grey silty fine detritus mud
 430-432 cm Brownish-grey coarse sand
 432-441 cm Medium grey silty fine detritus mud with fine sand
 441-443 cm Brownish-grey coarse sand
 443-453 cm Grey silt
 453-498 cm Brownish grey sandy silt, interbedded and interlaminated with coarse sand laminae.
 498-516 cm Grey brown coarse sand and silt
 516 cm + Pale brown coarse sand. Base not seen

The pollen diagram from the site (Figure 7.4) was divided into seven LPAZ's:

LCC-7 Arboreal pollen abundant: *Betula* and *Corylus* > 20% TLP
 LCC-6 Herb pollen abundant: Gramineae > 20%; *Juniperus* > 10%
 LCC-5 Herb pollen abundant: Cyperaceae > 20%
 LCC-4 Herb pollen abundant: Gramineae > 30%; *Betula* 7.5-10%
 LCC-3 Herb pollen abundant: Gramineae > 20%; Cyperaceae 10-20%
 LCC-2 Herb pollen abundant: Cyperaceae > 20%; Ericaceae > 10%
 LCC-1 Dominated by deteriorated pollen - mainly Cyperaceae

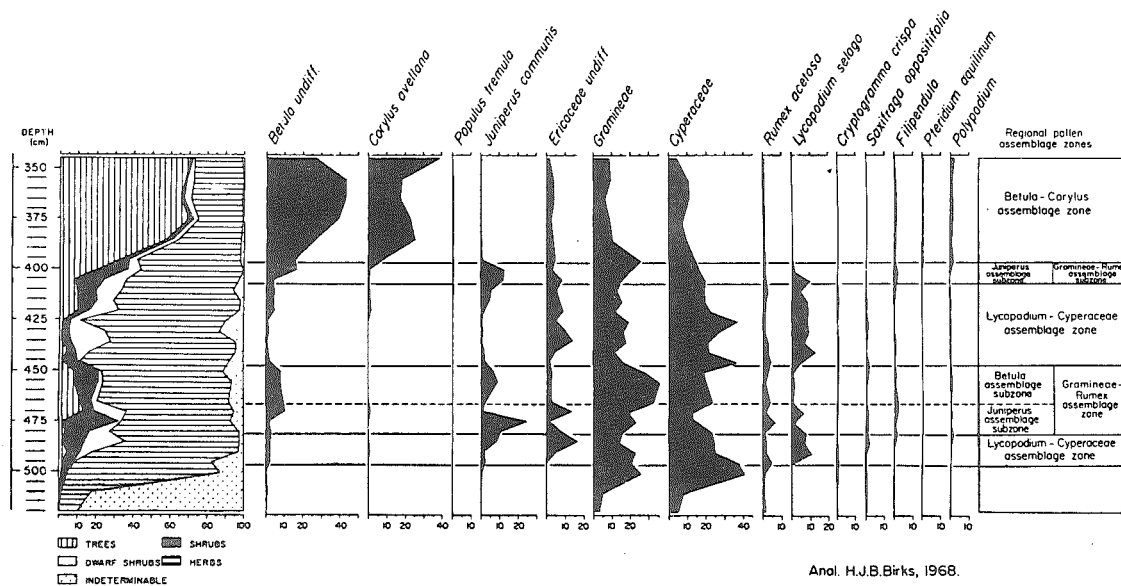


Figure 7.4: Lateglacial pollen diagram from Loch Cill Chrìosd (from Birks and Williams, 1983).

Pollen assemblage zones LCC-1 to LCC-4 represent the Lateglacial Interstadial, LCC-5 the Loch Lomond Stadial and LCC-6 and LCC-8 the early Flandrian. A single radiocarbon date of 9655 ± 150 BP (Q-959) was obtained on the increase in *Corylus* pollen in upper part of LPAZ LCC-6.

The pollen diagram from Loch Cill Chriosd is similar in a number of respects to that from Loch Ashik (above) in showing (a) the early interstadial plant succession from an open tundra landscape to *Juniperus* scrub, *Erica*- and *Empetrum* heath and grassland (LCC-1 to LCC-3); (b) a sharp fall in juniper values at the LCC-3/4 boundary, possibly reflecting the interstadial reversion episode; (c) a recovery in juniper in LCC-4 accompanied by *Betula* expansion; (d) the re-establishment of tundra vegetation during the Loch Lomond Stadial (LCC-5) with Cyperaceae, *Lycopodium* and *Selaginella* as key floristic elements; and (e) the early Flandrian vegetational succession from open grassland to the establishment of birch-hazel woodland (LCC-6 to LCC-8). The pollen record differs from that at Loch Ashik, however, in terms of the higher *Juniperus* frequencies recorded during the early Lateglacial Interstadial, lower *Erica*/*Empetrum* percentages during the later interstadial, and especially in sediments of Loch Lomond Stadial age, and lower counts for certain herbaceous taxa such as *Artemisia* and particularly *Rumex* throughout the Lateglacial period. In terms of vegetational history, the Loch Cill Chriosd record appears to be transitional between sites to the north and south of the central hill mass.

The lithostratigraphy of the Loch Cill Chriosd profile contains a number of features of interest. In a core recovered in 1986, marine mollusca were discovered in the lowermost sands and silts, confirming the original interpretation (Birks, 1973) of a relative sea-level of at least 15m OD during the Late Devensian. Indeed, on the basis of dinoflagellate evidence, Birks suggested that marine incursions may have continued at Loch Cill Chriosd throughout the Lateglacial. Within the Loch Lomond Stadial sediments of the 1986 core (cf. 405-450cm of Figure 7.4) laminations were recorded, and these may reflect sedimentation influenced by the Slapin Glacier, which lay only 2km west of Loch Cill Chriosd at the Loch Lomond Readvance maximum (Figure 7.1).

7.3 Slochd Dubh [NG 403170]

Slochd Dubh (The Black Cleft) is a deeply-incised valley cutting through Tertiary basalts on the promontary between Loch Brittle and Soay Sound. The valley has a maximum width of 100m but it narrows to less than 20m at the SE end. The site lies approximately 4km to the SW of the clearly-defined terminal moraine and boulder limit that marks the former extent of the Loch Lomond Readvance glacier that flowed out of Coir' a'Ghrundha on the south side of the Cuillin ridge (Ballantyne, 1989a; site 2.7).

The valley of Slochd Dubh has become infilled with a considerable thickness of limnic muds and peats. A core taken in 1987 from the northern end of the site by Walker and Lowe (1990) revealed the following lithostratigraphic succession:

720-742 cm Green-grey gyttja
 742-743 cm Green-grey clay gyttja
 743-754 cm Grey clay
 754-759 cm Green-grey clay gyttja
 759-776 cm Green-brown gyttja
 776-779 cm Green-grey clay gyttja
 779-783 cm Green-brown gyttja
 783-788 cm Green-grey clay gyttja
 788-794 cm Grey plastic laminated clay
 794-797 cm Grey silty clay
 797 cm Gravel

The pollen diagram from the site (Figure 7.5) has been divided into eight local pollen assemblage zones:

SLD-8 *Betula-Corylus*-Gramineae
 SLD-7 *Betula-Empetrum*-Gramineae-*Rumex*
 SLD-6 Cyperaceae-*Artemisia-Rumex-Lycopodium*
 SLD-5 Cyperaceae-*Selaginella*-(*Empetrum*)
 SLD-4 *Empetrum*-Gramineae-Cyperaceae
 SLD-3 Gramineae-*Rumex-Empetrum*
 SLD-2 *Rumex*-Gramineae-*Salix-Artemisia*
 SLD-1 Gramineae-*Salix*-Compositae

LPAZ's SLD-1 to SLD-4 span the Lateglacial Interstadial, SLD-5 and SLD-6 are of Loch Lomond Stadial age, while SLD-7 and SLD-8 date from the early Flandrian.

Slochd Dubh provides a type profile for the Lateglacial in western Skye. The pollen diagram shows an early Lateglacial Interstadial open-habitat grass and sedge-dominated landscape with *Rumex*, *Artemisia*, Compositae, Filicales and *Lycopodium* (SLD-1/2). *Salix* was the principal woody plant present, although low frequencies of *Juniperus*, *Betula* and *Empetrum* are recorded. This open grassland was succeeded during the later interstadial by a mosaic of grass and heathland, with acidophilous *Erica* and *Empetrum* heaths becoming widespread, and with tree birch probably only growing in more sheltered localities (SLD-3/4). During the Loch Lomond Stadial (SLD-5/6), the heathland communities were progressively replaced by a grass-sedge tundra, in which plants characteristic of rock outcrops and unstable soils formed the dominant elements (Caryophyllaceae, Chenopodiaceae, *Artemisia*, *Rumex*, *Lycopodium*, *L. selago* and *Selaginella*). During the early Flandrian, these communities were succeeded by heathland and birch-hazel wood and scrub (SLD-7/8).

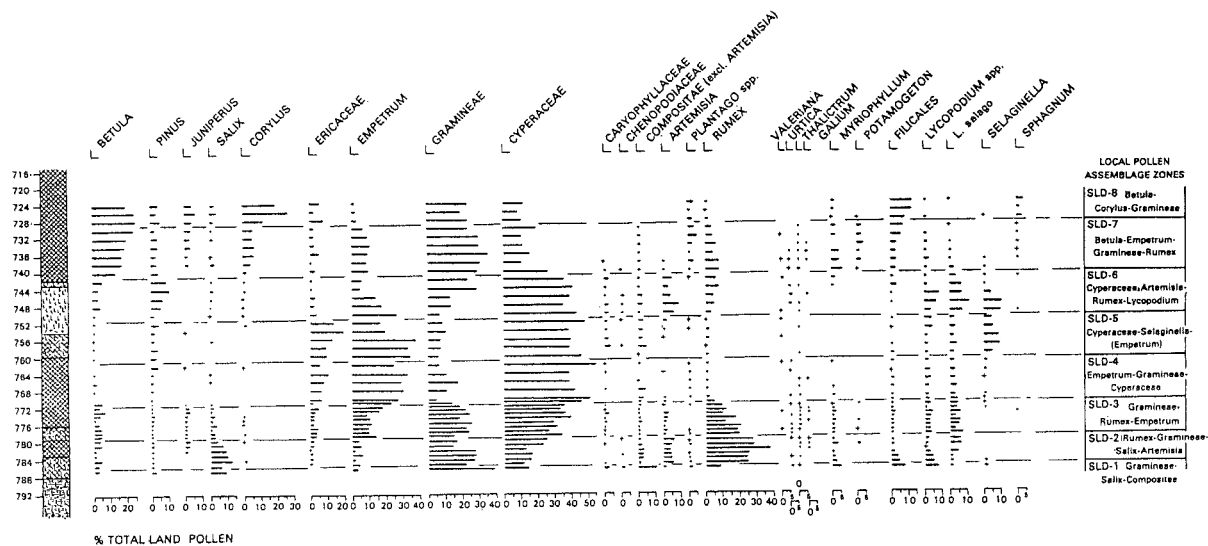


Figure 7.5: Lateglacial pollen diagram from Slochd Dubh.

Several features of the Slochd Dubh profile merit further consideration. First, although the pollen-stratigraphic record is similar in general terms to that from Loch Ashik and Loch Cill Chrìosd, there are a number of differences which are believed to reflect the effects of aspect and, in particular, exposure to onshore winds, including the very low representation of juniper in both the early-mid interstadial and early Flandrian and the lower *Betula* counts throughout the profile. In addition, the markedly higher frequencies of *Artemisia* and *Rumex*, particularly in SLD-6, may indicate more restricted snow lie on windward slopes during the Loch Lomond Stadial (see above).

Second, the very high counts for *Pinus* pollen (over 20% TLP in some levels) in paz SLD-6 is a distinctive element of the pollen record from this site. These pine grains are almost certainly of long-distance provenance, but their source is difficult to establish. Relatively high counts for pine have been recorded in Loch Lomond Stadial spectra at other sites along the maritime fringes, and particularly in the far NW of the British Isles (Watts, 1963; Telford, 1977; Lowe and Walker, 1986a). This may well reflect wind patterns during the Loch Lomond Stadial, possibly associated with a dominantly anticyclonic system over NW Europe, as has been inferred from periglacial and related evidence (Washburn, 1979).

Third, the Slochd Dubh site, in common with those farther north, displays clear evidence of a reversion episode during the Lateglacial Interstadial. This is reflected both in the lithostratigraphy, where organic sediment accumulation is interrupted by increasingly minerogenic sedimentation between 776-779 cm, and also in the pollen record where these levels are accompanied by a decline in *Juniperus* and heathland plants, and by a complementary increase in taxa such as *Artemisia*, Caryophyllaceae and *Lycopodium*.

Finally, as at Loch Ashik, the data from Slochd Dubh demonstrate the value of deteriorated pollen analysis (Figure 7.6). The reversion phase in the Interstadial, for example, is reflected in an increase in percentages of deteriorated pollen, while the very high counts for *Empetrum* in paz SLD-5 are composed almost entirely of grains that show signs of exine damage. This, in association with the progressive decline in *Empetrum* pollen frequencies throughout the Loch Lomond Stadial, suggests that the large numbers of *Empetrum* tetrads found in the early stadial sediments are not a reflection of primary deposition from heathland plants growing in the vicinity of the site, but rather that they are of secondary derivation from eroded interstadial soils from around the basin catchment.

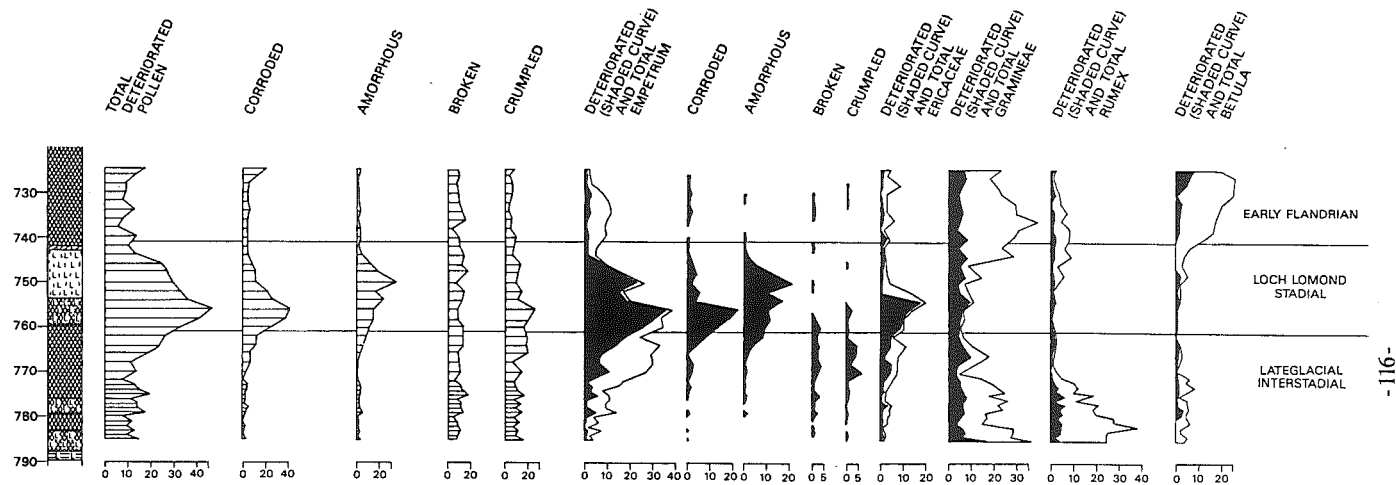


Figure 7.6: Deteriorated pollen diagram from Slochd Dubh.

7.4 Lochan Coir' a' Ghobhainn [NG 417183]

Lochan Coir' a' Ghobhainn lies c. 2.5km west of the Coir' a' Ghrundha moraine and 1.5km NE of Slochd Dubh. The lochan measures c. 250m by 120m, and is fed by a stream from the SE. An outflow drains westward. A *Molinia caerulea*-*Myrica gale* fen has developed at the southern end of the lochan. In 1968 a series of cores was taken from this locality (Birks, 1973; Birks and Williams, 1983). The stratigraphy was:

300 - 322.5 cm	Medium brown slightly fibrous detritus mud
322.5 - 326 cm	Pale whitish-grey diatomite
326 - 337 cm	Medium brown slightly fibrous detritus mud
337 - 356 cm	Grey-brown silty mud with detritus fine sand and stones
356 - 362.5 cm	Dark brown silty fine detritus mud
362.5 - 383 cm	Green-grey silty diatomaceous fine detritus mud
383 - 391+ cm	Pale grey silt and fine sand

The pollen diagram from the site (Figure 7.7) was divided into five LPAZ's:

- LCG-5 Abundant arboreal pollen: *Betula* >20%; *Corylus* >10%
- LCG-4 Herb pollen dominant: Gramineae >20%; *Juniperus* >10%; *Rumex* >4%
- LCG-3 Dwarf shrub pollen dominant: Ericaceae >30%; *Empetrum* 5-10%; *Lycopodium selago* >5%
- LCG-2 Herbaceous pollen dominant: Cyperaceae >30%; tree, shrub and dwarf shrub pollen <10%; *Lycopodium selago* >6%
- LCG-1 Abundant herb pollen: Cyperaceae >20%; *Lycopodium selago* >10%; *Oxyria digyna* >10%

Zones LCG-1 and LCG-2 are of Lateglacial Interstadial age, LCG-3 represents the Loch Lomond Stadial, while LCG-4 and LCG-5 date from the early Flandrian. Four ¹⁴C dates were obtained from the profile. The rise in *Corylus* in LCG-5 was dated at 8650 ± 150 yr BP, while the Lateglacial/early Flandrian stratigraphical boundary (LCG-3/LCG-4) yielded an age of 9420 ± 150 yr BP. Two dates from lower horizons in the profile, 9691 ± 150 yr BP from 362.5-365 cm, and 10,254 ± 220 yr BP from 380-382.5 cm, appear to be aberrant, and may reflect infiltration of humus-rich groundwater through the shallow deposits at the site.

Though there are differences in detail between the diagram from Lochan Coir' a' Ghobhainn and that from Slochd Dubh (*e.g.* the markedly lower representation of *Pinus* and *Artemisia* in stadial sediments at the former), there are similarities also. These include the dominance throughout the profiles of Gramineae and Cyperaceae pollen; the high counts for *Rumex/Oxyria* in the early interstadial biozones; the low values recorded for both *Betula* and *Juniperus* throughout the interstadial; and the very high frequencies of Ericaceae/*Empetrum* tetrads in stadial sediments, along with the occurrence in those spectra of *Lycopodium selago* and *Selaginella selaginoides*.

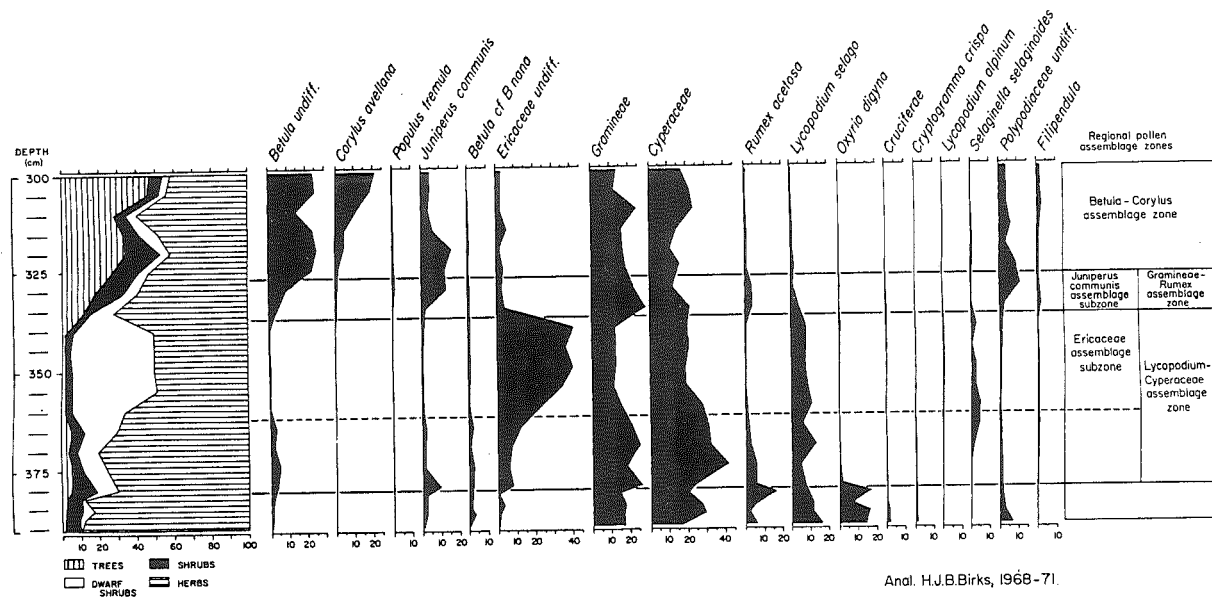


Figure 7.7: Lateglacial pollen diagram from Lochan Coir' a' Ghobhainn.

8. VEGETATIONAL HISTORY OF THE ISLE OF SKYE

II. THE FLANDRIAN

J.J. Lowe & M.J.C. Walker

Introduction

Current understanding of the Flandrian vegetational history of Skye is based largely on a number of recent pollen-stratigraphic investigations. The first Flandrian pollen diagrams were obtained from Lochs Cuithir and Fada in Trotternish (Figure 7.1), and these data were augmented by plant macrofossil studies (Vasari and Vasari, 1968). Williams (1977) subsequently presented detailed Flandrian pollen diagrams from Lochs Meodal, Ashik and Cleat (Figure 7.1). The evidence from these sites was summarised by Birks and Williams (1983) in a general review of the history of the late Quaternary vegetation of the Inner Hebrides. They also drew attention to observations of arboreal macrofossils on the islands, including some records from Skye. More recent studies by Walther (1984) and Walker *et al.* (1988) have been confined to the early Flandrian sequences of a number of sites in SE and south-central Skye (Figure 2.7).

The Last Glacial-Interglacial Transition

Pollen-stratigraphic studies have shown that there is a characteristic sequence of pollen assemblage zones common to most early Flandrian profiles for northern Britain. This consists typically of biozones characterised by successive maxima in pollen of Gramineae, *Rumex*, *Empetrum*, *Juniperus*, *Betula* and *Corylus* (Table 8.1).

Approximate ¹⁴ C timescale (¹⁴ C yr BP)	RANNOCH MOOR	MULL
8,800	<i>Betula-Corylus-Ericaceae</i>	<i>Corylus</i>
9,000	<i>Betula-Corylus</i>	<i>Betula-Corylus</i>
	<i>Betula-Juniperus</i>	<i>Betula-Juniperus</i>
9,600	<i>Juniperus-Betula</i>	<i>Juniperus</i>
10,000	<i>Empetrum</i>	<i>Empetrum-Gramineae</i>
		Gramineae-Cyperaceae- <i>Rumex</i>

Table 8.1: Early Flandrian regional pollen assemblage zones for Rannoch Moor and the Isle of Mull.

The ten sites on Skye investigated by the present authors also conform in broad outline to this sequence (Figure 8.1).

Generalised sequence of Local Pollen Assemblage Zones (Stages 1-10)	Varragill NG 473349	Sligachan 1 NG 465325	Sligachan 2 NG 477315	Sligachan 3 NG 478298	Marsco NG 483257	Luib 1 NG 567271	Luib 2 NG 568298	Luib 3 NG 567268	Clach Oscar NG 559222	Glen Arroch NG 752209
10. Betula-Corylus		•	•	•	•	•	•	•	•	•
9. Betula-Juniperus		•	•	•		•	•	•		•
8. Juniperus-Betula	•								•	
7. Juniperus-Empetrum (Betula)			•	•					•	•
6. Empetrum-Juniperus (Betula)		•					•			
5. Empetrum-Gramineae (Lycopodium)		•		•		•	•	•		•
4. Empetrum			•	•	•					
3. Empetrum-Gramineae (Betula)	•				•			•		
2. Gramineae-Rumex-Empetrum (Lycopodium)	•	•	•							•
1. Gramineae-Rumex (Lycopodium)	•									•

Figure 8.1: Generalised sequence of early Flandrian pollen zones in the Scottish Highlands and the earliest zone identified in each of the 10 sites from Skye located within the Loch Lomond Stadial ice limits.

The most complete early Flandrian pollen sequences are from Glen Arroch and Glen Varragill, where vegetational stages (from the base) dominated by *Rumex*, *Empetrum*, *Juniperus*, *Betula* and *Corylus* are recorded in the biostratigraphy of the lowermost organic sediments (Figure 8.1). Both of these sites are discussed in more detail below (sites 8.2 and 8.4). Other profiles which show a similar sequence of pollen assemblage zones in the lowermost organic sediments are Sligachan 1 and Sligachan 2 (site 8.1; Figure 8.6). Insofar as the pollen record at each site reflects the sequence of local plant colonisation, and on the not unreasonable assumption that the expansion of vegetation at the beginning of the Flandrian would have been both rapid and orderly (in terms of sequential immigration of herbaceous through to arboreal taxa), then the local pollen assemblage zones can be integrated into a scheme of regional pollen assemblage zones which are considered to be broadly synchronous for the island as a whole (Figure 8.1). If this line of reasoning is correct, then the boundaries of the regional pollen assemblage zones provide a basis for time-stratigraphic correlation across southern Skye.

Two radiocarbon dates are available from the early Flandrian succession at Varragill: $9,590 \pm 90$ yr BP and $10,220 \pm 150$ yr BP (Figure 8.7) for the pre-*Juniperus* part of the succession. If correct, they indicate that the Varragill Glacier (Figure 2.4) may have begun to retreat before 10,200 B.P. Elsewhere, however, the lack of radiocarbon dates means that little is known about the timing of deglaciation. Yet even if more radiocarbon dates were available, it is doubtful whether a sufficiently reliable chronology could be established within the limited timespan of the early Flandrian, partly because of the inadequate resolution afforded by the radiocarbon method and partly because of the particular difficulties that arise in radiocarbon dating sediments that accumulated in newly-deglaciated areas (Lowe and Walker, 1980; Sutherland, 1980).

An alternative approach is to employ pollen stratigraphy to establish a relative timescale for deglaciation from the Loch Lomond Readvance maximum (Pennington, 1978; Lowe and Walker, 1981). This rests on the principle that where deglaciation has been time-transgressive, the onset of sediment accumulation in enclosed lake basins exposed by the retreating ice would be progressively delayed. Hence, the earliest Flandrian lake sediments should be found immediately within the ice limits, with progressively younger deposits in basins up-glacier. In terms of pollen stratigraphy, this pattern would be reflected in a complete early Flandrian pollen-stratigraphic sequence being preserved in those sites where deglaciation occurred first, whereas the earliest pollen assemblage zones would be absent from those sites where ice cover persisted for longer. Although the application of this approach is by no means straightforward (Tipping, 1988; Lowe and Walker, in preparation), data from other parts of Scotland have shown that, in certain circumstances, pollen stratigraphy can form a basis for the establishment of a relative chronology of deglaciation following the Loch Lomond Readvance maximum (Lowe and Walker, 1981; Walker and Lowe, 1985).

The ten early Flandrian sites on Skye investigated by Walker *et al.* (1988; Figure 2.7) occupy different positions relative to the Loch Lomond Stadial ice limits and also to former local ice thickness (Figure 8.2.). The sequence of pollen assemblage zones in each site is shown in Figure 8.1. The bold bars at the base of each profile indicate the stage in the regional pollen zone sequence at which sedimentation commenced and, by implication, at which deglaciation around the site was completed.

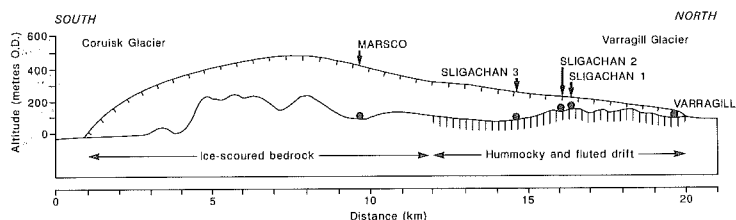


Figure 8.2: Location of Flandrian sites in the Sligachan-Varragill area and generalised profile of the Cuillin Icefield.

In Figure 8.3, the earliest pollen assemblage zones identified at each site within the area of the Cuillin Icefield are plotted against distance from the ice source as measured along former ice flow-paths. There appears to be a significant correlation, suggesting that the onset of sedimentation and hence pollen recruitment may indeed be governed by time-transgressive ice melting.

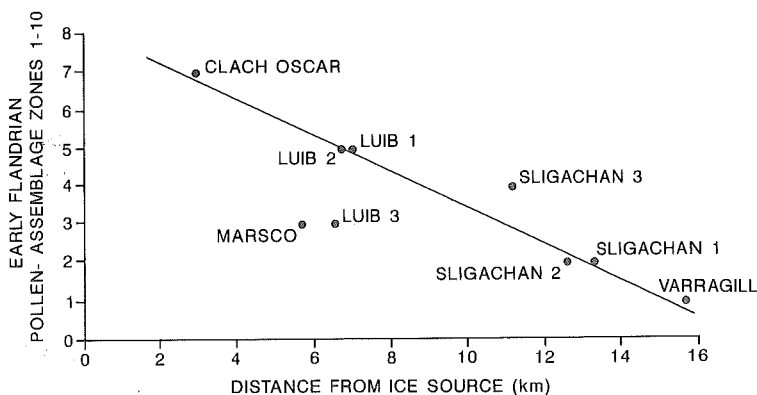


Figure 8.3: Earliest pollen zone recorded for nine sites located within the Loch Lomond Stadial ice limits plotted against distance from ice source.

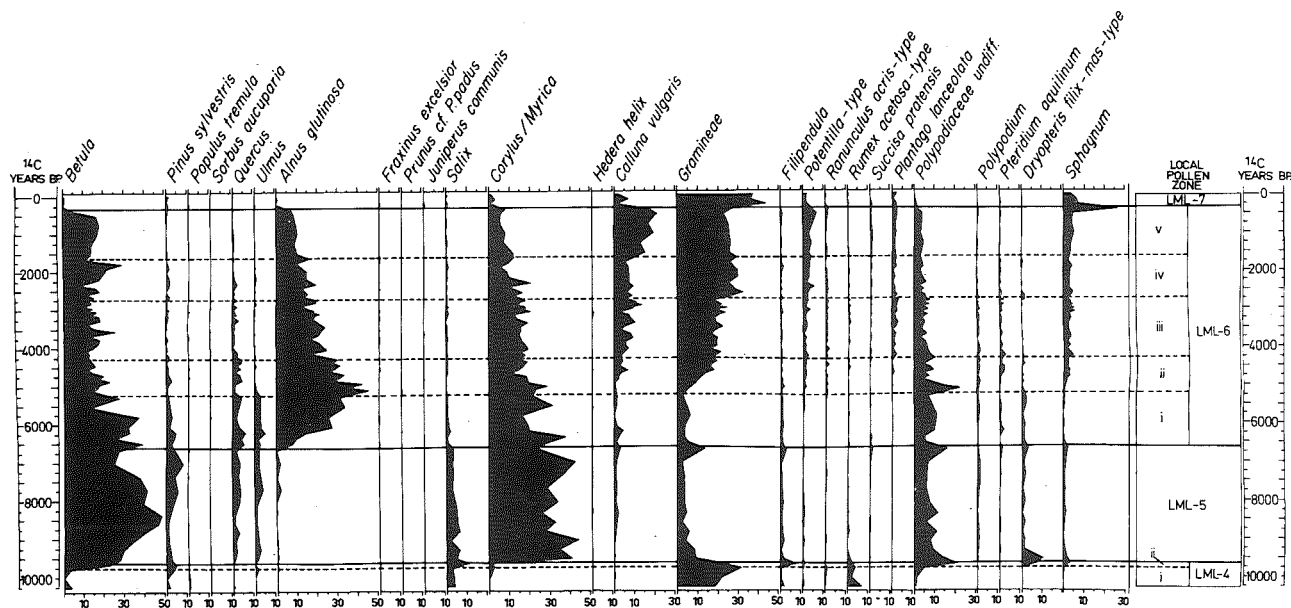
Comparisons of the pollen-stratigraphic evidence suggest that:

- (1) Frontal retreat of the ice margin occurred at the northern margin of the Cuillin Icefield in the area between the sites Varragill and Sligachan 3. This interpretation is compatible with the evidence for active retreat of Loch Lomond Readvance glaciers elsewhere in the Cuillin Hills (chapter 3).
- (2) The Ainort Glacier had retreated at least as far as the Luib area before the middle Glen Sligachan area had become deglaciated (*cf.* Luib 3 and Sligachan 3).
- (3) Ice melting in the area close to the eastern corries of the Bla Bheinn hill mass occurred later than in lower Glen Sligachan and lower Strath Mór (*cf.* Clach Oscar with Sligachan 3 and Luib 3).
- (4) Most of the main icefield had melted by the time that juniper was colonising the island, as sites closest to the ice sources show rising *Juniperus* percentages at the base. On the basis of radiocarbon dates for the early Flandrian expansion of juniper in the Inner Hebrides, this is likely to have occurred no later than 9,600 yr BP (Lowe and Walker, 1986a; Birks and Williams, 1983).

Finally, one of the profiles, Glen Arroch, provides evidence that a short climatic reversion may have occurred *during* the early Flandrian. In most Scottish sites the early Flandrian pollen successions suggest a unidirectional succession from open habitat grass and heathland communities to the establishment of birch and hazel wood and scrubland. The Glen Arroch site, however, contains an unusually detailed record of the early Flandrian, and the progression to *Empetrum* heath and *Juniperus* scrub at the site appears to have been interrupted by a short-lived reversion episode (Figure 8.10; site 8.4). Evidence for a minor reversion during the early Flandrian was also found at Gribun on Mull (Dawson *et al.*, 1987), which suggests that the oscillation recorded in the Glen Arroch profile may have had regional significance. What effect a climatic perturbation during the early Flandrian may have had on the retreating local glaciers and on other environmental parameters can only be speculated upon.

Flandrian Vegetation History

The five "full" Flandrian pollen diagrams available from Skye (Loch Cuithir, Loch Fada, Loch Ashik, Loch Meodal and Loch Cleat) show broadly similar pollen stratigraphic records, though some important differences between sites can also be demonstrated (Figure 8.4 and Table 8.2). In this section the principal features of the vegetational history of Skye are illustrated mainly by reference to the Loch Meodal pollen diagram (Figure 8.4), though comparisons will also be made with the evidence provided by the other published diagrams. Two of these - Loch Ashik (Figure 8.11) and Loch Cuithir (Figure 8.12) - are reproduced and discussed in more detail below.



Anal. W. Williams, 1973-74.

Figure 8.4: Flandrian pollen diagram from Loch Meodal; the pollen data are plotted against radiocarbon age. (From Birks & Williams, 1973, reproduced with permission of the Royal Society of Edinburgh).

¹⁴ C _{yr} BP	Loch Cleat (Northern Skye)	Loch Ashik (Kyleakin)	Loch Meodal (Sleat)
0	Landscape virtually treeless. Abundant meadows and cereal cultivation.	Landscape virtually treeless.	Landscape virtually treeless. Grassland and bog abundant.
1000	Grasslands abundant with some arable farming and tall herb meadows. Heaths local. Birch-hazel-willow scrub rare.	Abundant bogs and heaths. Birchwoods very rare with some <i>Quercus</i> and <i>Alnus</i> .	Birchwoods local with some alder and hazel. Heaths abundant, grassland and bogs frequent.
2000			Birch-hazel-alder woods. Grassland and heaths frequent. Bogs occasional.
3000	Grasslands frequent. Birch-hazel-willow scrub rare.	Birchwoods local. Heaths, grasslands and bogs common.	Birch-hazel-alder woods. <i>Quercus</i> very rare. Grasslands and heaths frequent. Bogs local.
4000	Frequent grasslands and some arable agriculture. Birch-hazel-willow scrub occasional.	Pine-birch woods. Bogs, heaths and grassland local. Birch-hazel woods. Pine local. Heaths, bogs and grassland local.	Birch-hazel-alder woods. <i>Ulmus</i> very rare. Grasslands and heath local.
5000		Birch-hazel-alder woods. <i>Quercus</i> , <i>Ulmus</i> and <i>Sorbus aucuparia</i> rare. Heaths, bogs and grassland local.	
6000	Birch-hazel scrub with <i>Alnus</i> , <i>Sorbus aucuparia</i> , <i>Prunus padus</i> and <i>Salix</i> . Grasslands and tall herbs locally frequent.		Birch-hazel-alder woods. <i>Quercus</i> , <i>Ulmus</i> , <i>Populus</i> and <i>Sorbus aucuparia</i> rare.
7000		Birch-hazel woods with some <i>Quercus</i> , <i>Alnus</i> , <i>Sorbus aucuparia</i> , <i>Salix</i> , and <i>Prunus padus</i> . Heaths, bogs and grasslands local.	Birch-hazel woods with some <i>Quercus</i> , <i>Ulmus</i> and <i>Populus</i> . <i>Salix</i> locally common. Ferns and tall herbs common.
8000	Birch-hazel scrub with <i>Sorbus aucuparia</i> , <i>Salix</i> and <i>Prunus padus</i> . Grasslands and tall herbs locally frequent.		
9000	Birch-willow scrub. Tall herbs and grasslands local.	Birch-hazel woods with tall herbs, ferns, <i>Salix</i> , <i>Sorbus aucuparia</i> and <i>Prunus padus</i> .	Birch-hazel woods with <i>Salix</i> , <i>Populus</i> , ferns and tall herbs.
10000	Juniper scrub, species-rich grasslands, tall herbs, and local birch copses.	Juniper scrub, birch copses and grassland.	

Table 8.2: Generalised comparison of inferred Flandrian vegetational history of the Isle of Skye (after Birks and Williams, 1977).

The principal features of the Loch Meodal succession are as follows (Birks and Williams, 1983). Subsequent to the invasion of Skye by *Empetrum* and *Juniperus* in the early stages of the Flandrian, birch and hazel woods with *Salix*, *Populus tremula* and *Viburnum opulus* developed at around 9,700 yr BP. Rich communities of ferns

appear to have been associated with these woods, with *Dryopteris filix-mas*, *Athyrium filix-famina*, *Pteridium aquilinum* and *Thelypteris dryopteris* seemingly most important. These co-existed with tall-herb communities which included *Filipendula ulmaria*, *Angelica sylvestris* and *Rumex acetosa*.

From about 9,000 yr BP oak and elm are recorded in the pollen diagram, though in relatively low percentages, while pine is present throughout. *Alnus glutinosa* appears to have expanded on to the island at around 6,500 yr BP. Woodland communities thrived until around 5,200 yr BP when they were replaced by grassland and heath although the vicinity of Loch Meodal remained wooded until some time after 4,200 yr BP. Indeed, although there is evidence (in the form, for example, of Iron Age duns) of a long history of occupation, particularly on the east coast, the southern parts of the island appear to have retained large areas of woodland until about 300 years ago when widespread woodland destruction occurred following the onset of cattle grazing (Birks and Williams, 1983).

This sequence of changes is also recorded at Loch Ashik, although at that site a short-lived pine expansion occurred at around 4,000 yr BP (Figure 8.11). Another major difference is that at Loch Ashik there is little evidence of human interference on the vegetation at around 5,000 yr BP.

The northern sites contrast with the southern ones, most notably in the lower amounts of tree pollen recorded throughout the Flandrian. This led Williams (1977) to conclude that *Quercus*, *Ulmus* and *Pinus* were never important colonisers of the windswept basaltic landscape of Trotternish, but that *Betula-Corylus* associations continued to dominate throughout the mid-Flandrian, with willow scrub, *Sorbus aucuparia* and *Prunus padus* locally important (Table 8.2).

The loss of woodland during the latter half of the Flandrian also appears to have occurred earlier and to have been more widespread in Trotternish. Birks and Williams (1983) point to the marked increase in Gramineae, *Potentilla*, Chenopodiaceae and Cruciferae pollen and the first appearance of possible anthropogenic indicators (e.g. cereal-type grasses, *Plantago lanceolata* and *Trifolium* pollen) from about 5,000 yr BP onwards in the northern sites (Table 8.2). This, together with marked reductions in pollen of *Betula* and *Corylus*, may indicate widespread scrub clearance and the local development of arable and pastoral agriculture. There are abundant Iron Age remains in northern Skye (duns, semi-brochs and brochs) and historical evidence indicates that the fertile soils of northern Skye were noted for cereal crop production and were often referred to as 'the granary of Skye'.

It is difficult to establish in detail the extent of the former woodland cover of Skye. Pollen-stratigraphic evidence can be misleading, as the data should be corrected for differential production between tree genera, and long-distance transport of

arboreal pollen is always likely. However, macrofossil records show that trees were firmly established on the island in the mid-Flandrian. Lewis (1906) recorded wood remains of *Betula*, *Corylus* and (rarely) *Alnus* from the base of peat exposures in central and northern Skye while fossil pine stumps, restricted to SE Skye and observable in exposures in peat near Loch Ashik, have been radiocarbon-dated to $4,420 \pm 75$ yr BP. The Isle of Skye appears to have been located in a critical ecotonal area between forest zones throughout the Flandrian, with northern and central Skye being characterised by open birch-hazel forest while southern and SE Skye lay within a region of closed oak forest. The limited development of pine in and around the Kyleakin area during the later Flandrian appears to represent a short-lived outlier of the 'Caledonian pinewoods' that dominated the landscape of the northern and central Scottish Highlands from approximately 7,500 to 4,000 yr BP (Birks, 1975; Bennett, 1984; Bridge *et al.*, 1990). The inferred north-south contrasts in the mid-Flandrian woodlands of Skye may reflect climatic differences which still exert a control over the distribution of woodland fragments on the island at the present-day (Birks, 1973).

Flandrian Pollen Sites

8.1 Sligachan 2 [NG 477315]

The area around the Sligachan Hotel is occupied by extensive spreads of moraines (chapter 3). Numerous depressions occur between the moraines, but most are less than 3m deep and contain only Flandrian blanket peats. Three basins were discovered, however, that were considerably deeper than the others, and these all proved to contain limnic sediments at the base of the infill (Sligachan 1, 2 and 3; Walker *et al.*, 1988). Pollen analysis was carried out on all three profiles (Figure 8.1) but only the data from Sligachan 2 are considered here.

The Sligachan 2 site is a small, steep-sided basin which is located c. 2km NW of the Sligachan Hotel and about 250m west of the A850 road. The sub-surface morphometry of the basin was established by making test borings along a grid pattern laid out across the bog surface (Figure 8.5) using a level mounted at the side of the basin to provide a common datum for individual test bores. This field procedure is essential if the earliest sedimentary sequence, *i.e.* that which accumulated in the deepest part of the basin, is to be located accurately. The deepest point recorded in the basin was 6.29m below the present mire surface. Coring ceased in gravel (Figure 8.6), after penetrating a basal sedimentary sequence of laminated sands, silts and clay (6.28-6.16m), diatomite 6.16-6.09m), gyttja (6.09-5.79m) and peaty-gyttja (upwards from 5.79m).

The basal mineral sediments proved to be non-polleniferous, and the diatomite deposits were so low in pollen content that counts of only 100 land pollen were possible (elsewhere in the stratigraphy, a pollen sum of 300 land pollen was achieved). These assemblages (lpaz Sn2-a) are dominated by herbaceous taxa, notably

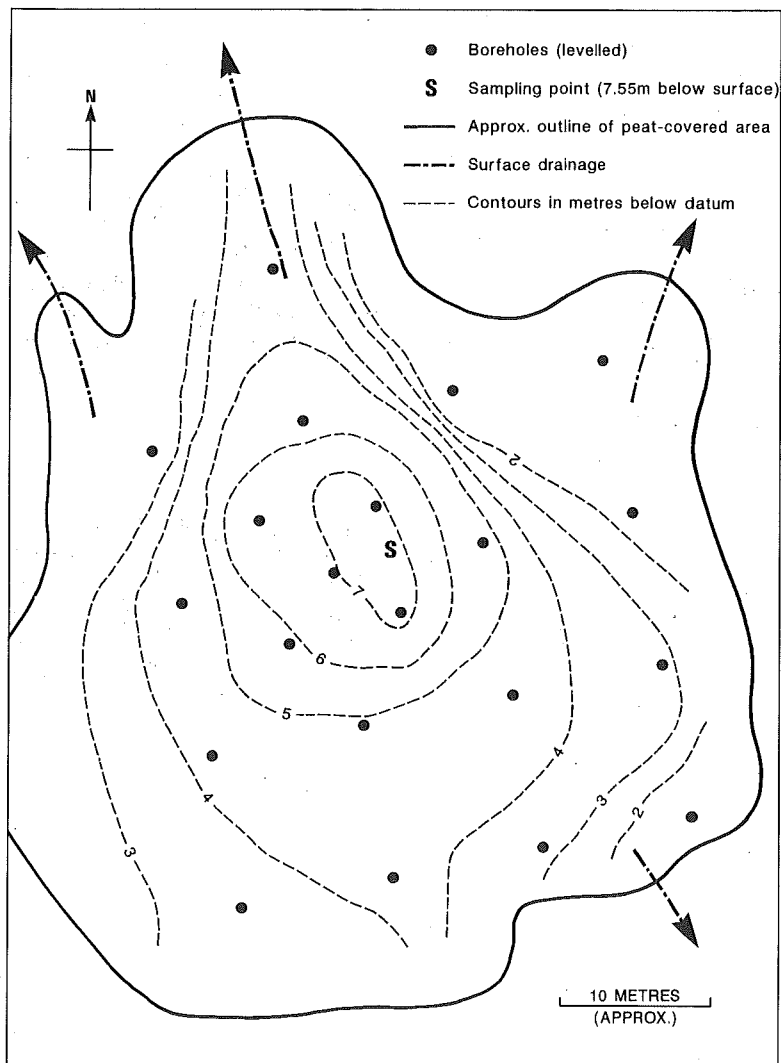


Figure 8.5: Generalised basin contours for the Sligachan 2 pollen site, measured with reference to an arbitrary ground datum.

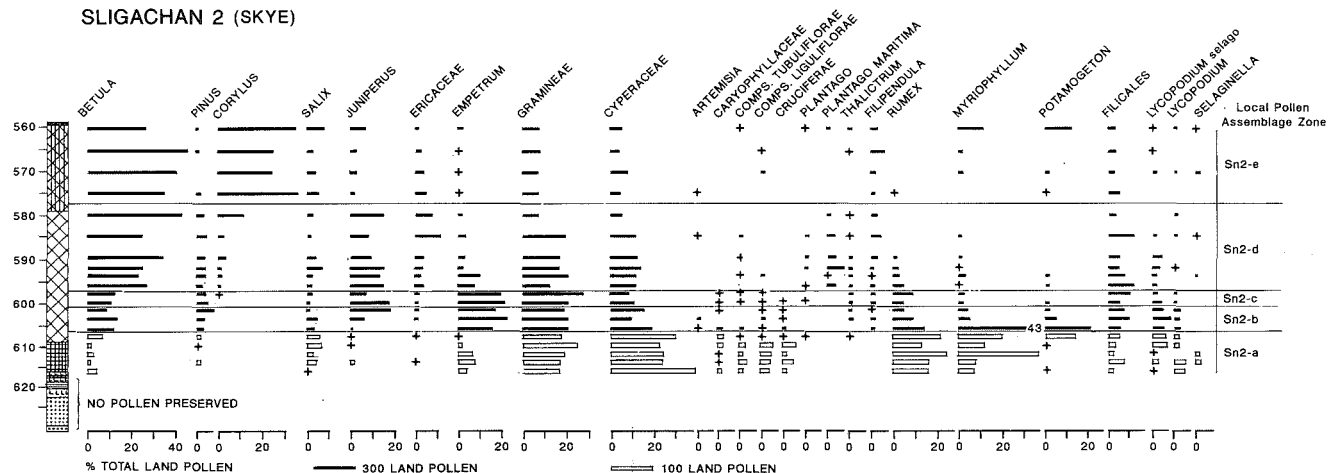


Figure 8.6: Summary early Flandrian pollen diagram (selected taxa), Sligachan 2.

Gramineae, Cyperaceae and *Rumex*. Above this an early Flandrian vegetational succession is recorded from the expansion of *Empetrum* heathland communities (Sn2-b) to the establishment of birch-hazel woodland (Sn2-e; Figure 8.6).

The Sligachan 2 site is an important element in the reconstruction of time-transgressive deglacial retreat for the Varragill-Sligachan area discussed above. The occurrence of a clearly-defined herbaceous pollen assemblage zone at the base of the profile indicates that the site became ice-free prior to the early Flandrian expansion of *Empetrum* heath and juniper scrub, the former event having been dated elsewhere on Skye at c. 10,200 yr BP (Walker *et al.*, 1988). The basal Flandrian sediments predate the earliest deposits in several other early Flandrian sites on the island (Figure 8.1) which implies that Sligachan 2 became ice-free before glacier ice wasted from those localities.

8.2 Varragill [NG 473349]

This site occupies a critical position approximately 1km up-valley from the limit of the Loch Lomond Readvance in Glen Varragill (chapter 2; Figure 2.4). Approximately 0.5km north of the confluence of the Varragill River with the Allt-Airigh meall-Beathaig is a broad, flat, peat-covered valley floor. Sections exposed in the blanket peats throughout this part of the valley show both terrestrial and limnic deposits, and pollen analysis of the limnic sediments revealed early Flandrian spectra dominated by Gramineae, Cyperaceae, herbaceous taxa and *Empetrum* (Walther, 1984). The fact that these organic sediments had accumulated in a lake so close to the mapped Loch Lomond Stadial ice limits makes the site a key element in the regional stratigraphy.

The best-developed series of exposures through the peats and underlying limnic sediments occur along the side of a small stream flowing east-west from the A850 towards the river. These typically reveal 0.5-1.0m of dark brown, fibrous blanket peat unconformably overlying lighter-coloured, fine-detrital peaty gyttja. These are underlain by a clay gyttja which is occasionally exposed around stream level.

Figures 8.7 and 8.8 summarise the litho- and biostratigraphical evidence from this site (Walker *et al.*, 1988). Figure 8.7 presents data from three monoliths and a piston core, the monoliths being obtained from exposures approximately 20m apart along the stream bank (measured with respect to a common altitude datum) while a piston core was obtained from the sediments directly below monolith 3.

The lowermost sediments in the core showed an upwards-fining sequence from coarse sands (impenetrable), through medium to fine sands and non-laminated silty clays (2.50 to 2.05m). These sediments were found to be non-polleniferous. They are succeeded by clay-rich, faintly organic muds, which give way to light brown gyttja/organic mud rich in fine macrofossil stems but also retaining a high clay

content (2.05 to 1.25m: the upper part of the core and monolith 3). This part of the sequence contains very high counts for *Empetrum* and *Myriophyllum* pollen, with *Rumex* and *Lycopodium* well represented in the spectra. It is clearly an early Flandrian record, with generally rising *Empetrum* values at the base. Two radiocarbon dates were obtained from blocks of material cut from monolith 3; the rising *Empetrum* values of 1paz Vg1-a (Figure 8.8) date to $10,220 \pm 150$ yr BP, and the start of the peak *Empetrum* values of 1paz Vg1-b to $9,590 \pm 90$ yr BP.

Monolith 2 was obtained from a higher part of the basin. It consists of gyttja/organic mud with a lower clay content but also including plant stem remains. The pollen record shows a *Juniperus-Betula* zone, in which *Empetrum*, *Rumex* and *Lycopodium* are present in low frequencies. Again, the sediments are clearly early Flandrian in age. This profile also has very high *Equisetum* percentages and a dramatic drop in percentages of *Myriophyllum*.

Monolith 1, obtained from the surface coarse-detrital peat, yielded contrasting pollen assemblages dominated by *Pinus* and Ericaceae, with low frequencies of *Corylus*. Filicales spores are also important, but many of the taxa recorded consistently in monoliths 2 and 3 are absent from these upper peats. The age of these sediments is not known, although they presumably date from the mid-late Flandrian. Indeed, if the high counts of *Pinus* equate with the *Pinus* phase in the Loch Ashik profile (site 8.5) they may have accumulated late in the fifth millennium BP, although an absolute age from the deposits is clearly required to substantiate this inferred correlation.

In an attempt to integrate these records from the separate peat monoliths into a recognisable pollen-stratigraphic sequence a series of piston cores was taken from a point nearer to the present floodplain. The sediment record at Varragill 2 (Figure 8.8) differs significantly from that of Varragill 1 in two main respects: first, the basal minerogenic sequence is poorly represented, and secondly, the sediments are much finer, with little evidence of the abundant plant macroremains recorded in the peat monoliths. At the base of the Varragill 2 profile, a thin clay-gyttja horizon (2.61-2.58m, Figure 8.8) overlies impenetrable coarse sandy gravels. This is succeeded by gyttja (2.58-2.10m), coarser gyttja with occasional plant fragments (2.10 to 1.79m), gyttja/fine-detrital peat (1.79-1.71m), fine-detrital peat (1.71-1.09m) and coarse peat (1.09m to surface).

Within this sequence a number of the biostratigraphic elements recorded in Varragill 1 can be recognised, and provide a basis for correlation. Common to both sequences are the succession from *Myriophyllum*-rich basal deposits (1paz Vg2-a and Vg2-b) to an *Equisetum*-rich zone (1paz c), along with the very high Cyperaceae totals recorded throughout the basal deposits. The land pollen record from Varragill 2 shows an early Flandrian sequence from relatively high *Empetrum* percentages at the base (1paz Vg2-a), through *Juniperus* (1paz Vg2-b), *Juniperus-Betula* (Vg2-c),

VARRAGILL I (SKYE)

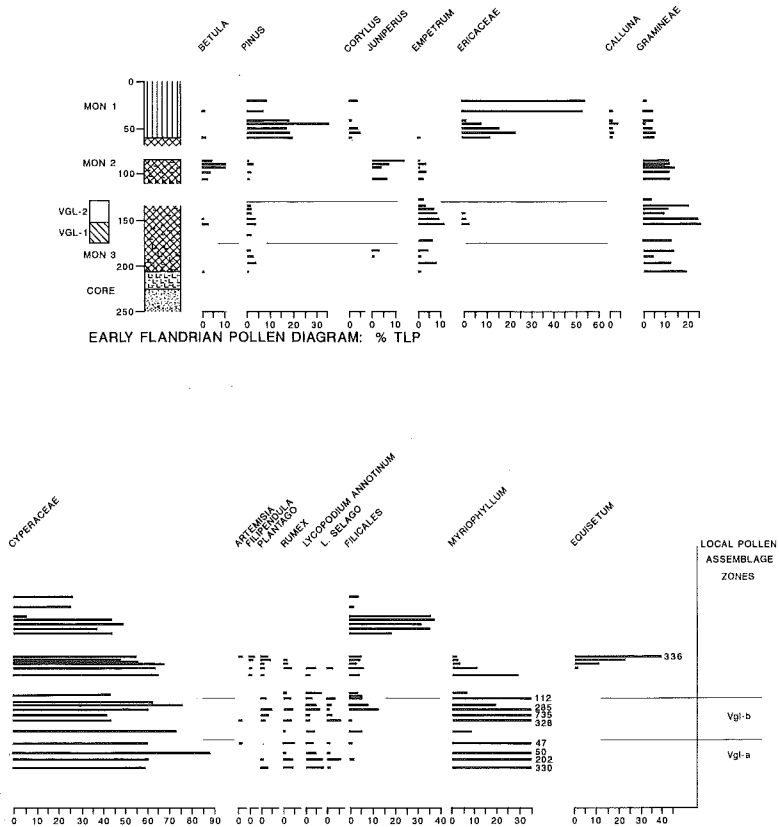


Figure 8.7: Summary early Flandrian pollen diagram (selected taxa), Varragill I.

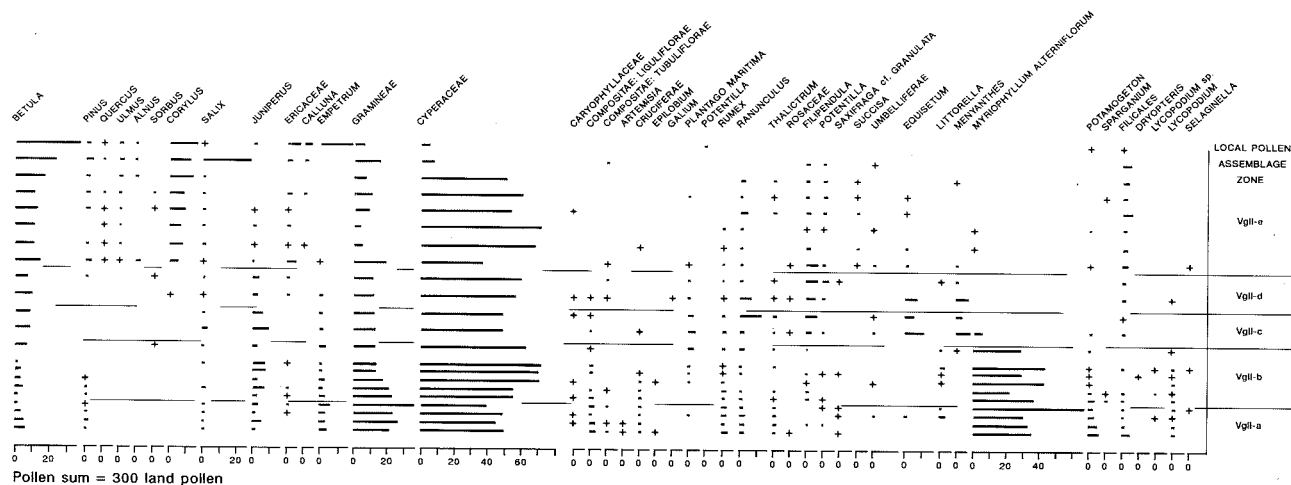


Figure 8.8: Summary early Flandrian pollen diagram (selected taxa), Varragill 2.

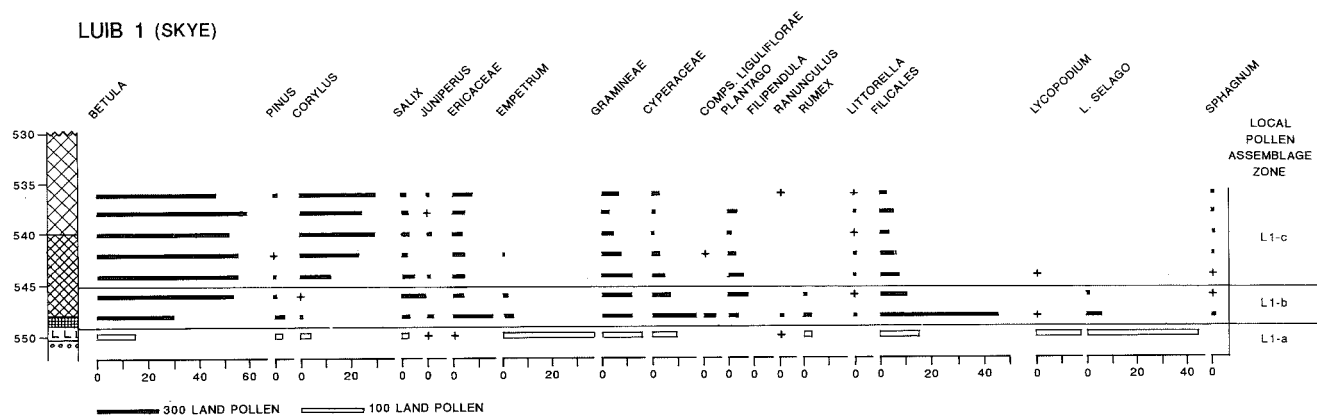


Figure 8.9: Summary early Flandrian pollen diagram (selected taxa), Luib 1.

Betula (Vg2-d) and *Betula-Corylus* (1paz Vg2-e) zones. The spectra recorded at the top of this profile, showing high *Empetrum* and *Salix* percentages together with high levels of *Corylus*, have no equivalent in the Varragill 1 record.

The importance of the Varragill site lies in the chronological control it provides for the wastage of Loch Lomond Stadial ice. The site is located only a short distance up-valley from the inferred terminus of the Varragill Glacier (Figure 2.4) and is bounded on the northern side by a low moraine ridge. The lithostratigraphic and pollen-stratigraphic record from the site indicates that, following ice wastage, meltwaters from the decaying Sligachan-Varragill glacier were dammed behind the moraine ridge to form an extensive lake. The abrupt lithostratigraphic change from gyttja with high *Juniperus* values to terrestrial peat characterised by abundant *Pinus* and *Ericaceae* pollen (the gap between monolith 1 and 2 in Figure 8.7) is thought to reflect a depositional hiatus following breaching of the moraine barrier (and subsequent lake drainage) and the later onset of blanket peat accumulation on the river floodplain. A clear relationship is therefore apparent at this site between the timing of deglaciation (early ice retreat), subsequent ice wastage and pollen stratigraphy.

8.3 Luib 1 [NG 567 271]

An extensive area of moraine ridges occurs to the south of Luib on the southern shore of Loch Ainort (Figure 3.8). Within this area, and immediately to the south of Loch nam Madadh Uisge, three enclosed basins, each containing early Flandrian lake sediments in the lower sections of the profiles, were located in close proximity (Luib 1, 2 and 3; Walker *et al.*, 1988). Pollen-stratigraphic data have been obtained from all three profiles (Figure 8.1) but only the Luib 1 site is considered here.

Luib 1 is a small, almost circular basin within an area of prominent drift mounds immediately SW of the southern shore of Loch nam Madagh Uisge. The deepest core obtained (5.50m) revealed a thin layer of clay (5.49-5.50m) overlying a gravel base (Figure 8.9). Above the clay is a thin layer of diatomite (5.48-5.49m) which is succeeded by gyttja. Pollen spectra from the clay horizon are dominated by *Empetrum* (1paz L1-a), with *Lycopodium selago* also an important component. The overlying organic sediments are characterised by woody plant pollen with biozones dominated by *Betula* -*Ericaceae*-*Salix* (zone L1-b) and *Betula-Corylus* (zone L1-c). These pollen zones reflect the transition from *Empetrum* heath to the establishment of a birch-hazel woodland. In the context of the pattern of ice wastage, the pollen spectra in the basal levels of the Luib 1 profile imply that glacier ice remained in this valley after the Sligachan glacier had vacated the Varragill and Sligachan 2 sites (sites 8.1 and 8.2).

8.4 Glen Arroch, Kyleakin Hills [NG 753208]

Thick and extensive spreads of glacial drift ridges occur in Kylerhea Glen, Glen Arroch and Coire nan Cuilín within the Kyleakin Hills of SE Skye (Figure 2.6), and a Loch Lomond Stadial age has been suggested for these deposits (chapter 2). Only one major infilled basin has been located in the moraines, on the col between Glen Arroch and Kylerhea Glen, immediately to the west of the highest point on the road (Walker *et al.*, 1988). The deepest part of the basin is 7.53m below the ground surface and cores recovered from this point revealed laminated fine sands, silts and clays at the base (7.53-7.40m; Figure 8.10), all of which proved to be non-polleniferous. These minerogenic deposits are overlain successively by clay-gyttja and gyttja (up to 7.15m). The lowermost organic sediments contain high frequencies of *Rumex* pollen (Ipaz GAR-a). Following a sharp reduction in *Rumex*, increasing Gramineae percentages and low values of *Empetrum* and *Rumex* are recorded (GAR-b). These assemblages are succeeded by zones dominated successively by *Empetrum* (GAR-c), *Juniperus* (GAR-d), *Betula* (GAR-e) and *Betula-Corylus* (GAR-f).

This site is important because it preserves a high resolution record of the early Flandrian. It shows a sequence of zones dominated successively by *Rumex*, *Empetrum*, *Juniperus*, *Betula* and *Corylus* (Figure 8-10). The succession spans a vertical interval of some 50cm, and provides a type section for the early Flandrian pollen stratigraphy of the Isle of Skye. A distinctive feature of the pollen record is a short-lived reversion episode recorded in biozone GAR-b. That biozone is characterised by reductions in *Empetrum*, *Juniperus* and *Betula* (following an initial rise in the curves for all three taxa), and their replacement in the pollen spectra by *Rumex* and *Lycopodium*. A minor climatic down-turn may be recorded in these data. Similar fluctuations in the pollen curves for *Empetrum* and *Juniperus* in the lowermost pollen assemblage zones at Varragill (Figure 8.7) may also reflect this climatic perturbation. Similar oscillations in the representation of these two taxa are apparent in the Gribun profile of the Island of Mull (Walker and Lowe, 1987). All three sites contain an unusually detailed record of the pollen stratigraphy of the early Flandrian, which is the key to recognising such brief climatic events.

8.5 Loch Ashik [NG 691232]

The location and Lateglacial pollen stratigraphic record of this site were discussed in chapter 7. The Flandrian pollen stratigraphy (Figure 8.11) was first described by Williams (1977) who recognised the following local pollen assemblage zones:

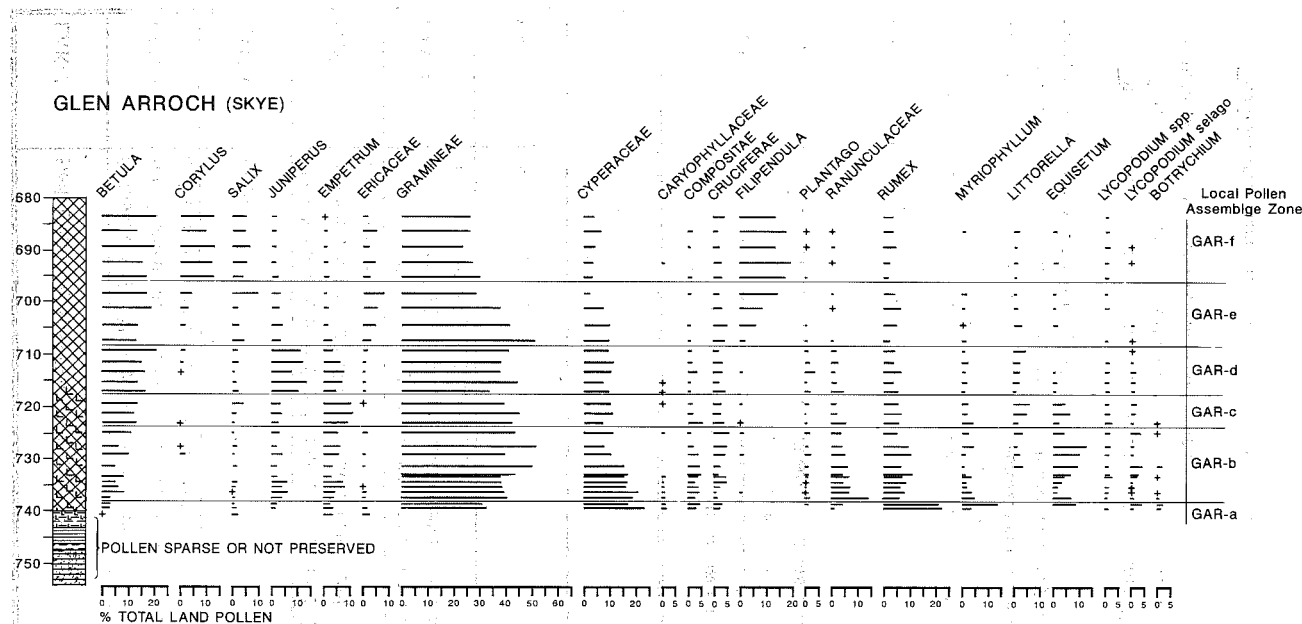


Figure 8.10: Summary early Flandrian pollen diagram (selected taxa), Glen Arroch.

LAK-7	Herb-dominated zone (<i>Potentilla</i> -Gramineae).
LAK-6	<i>Calluna-Corylus/Myrica</i> -Gramineae with <i>Betula</i> and <i>Alnus</i> : the zone is subdivided into two sub-zones on the basis of higher <i>Betula</i> and <i>Alnus</i> percentages in the lower part.
LAK-5	<i>Pinus</i> .
LAK-4	<i>Alnus-Betula-Quercus-Corylus</i> : the zone is sub-divided into two sub-zones on the basis of lower arboreal and shrub pollen values in the upper part.
LAK-3	<i>Betula-Corylus-Ulmus-Quercus</i> : the zone is sub-divided into two sub-zones on the basis of the virtual absence of <i>Ulmus</i> and <i>Quercus</i> pollen in the lower part.
LAK-2	<i>Juniperus</i> -Gramineae.
LAK-1	<i>Rumex</i> -Gramineae.

A distinctive feature of the pollen stratigraphy is the lack of evidence for any significant anthropogenic influence on vegetation at around 5,000 yr BP and also for the short but emphatic pine phase recorded in zone LAK-5. These aspects of vegetational history are in marked contrast with developments at other sites on Skye (Table 8.2).

8.6 Loch Cuithir [NG 474 597]

This site lies in Coire Cuithir on the eastern side of the main watershed of Trotternish at an altitude of 165m and close to steeply-rising mountains. It is a small loch approximately 200m long and 70m across. On the northern side is a wet, mesotrophic mire with a surface characterised by *Juncus acutiflorus* - *Acrocladium cuspidatum* association (Ratcliffe, 1964).

The cores from which the pollen diagram was obtained (Figure 8.12) were taken from the mire on the northern shore of the loch. The site contains rich diatomites which have been excavated commercially.

The lithostratigraphic record (Vasari and Vasari, 1968) is as follows:

ERRATUM: This diagram should replace that on page 139.

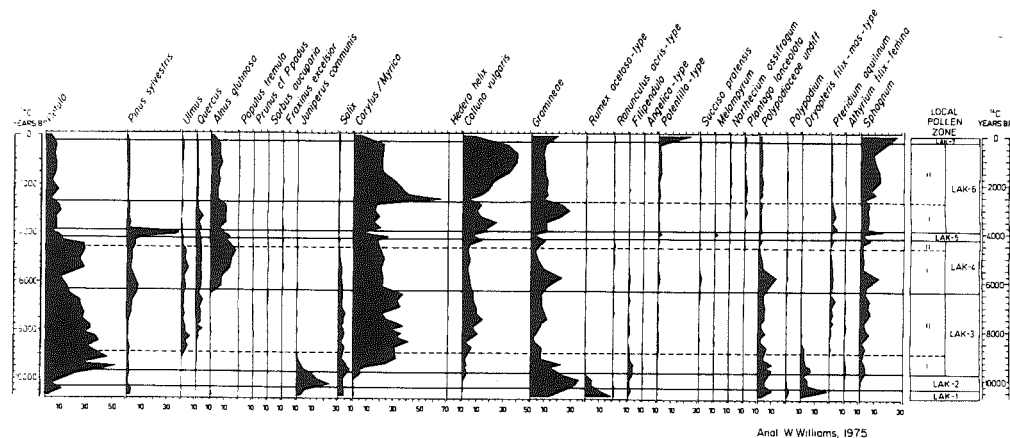


Figure 8.11: Flandrian pollen diagram from Loch Ashik: pollen curves plotted against radiocarbon age.
(From Birks and Williams, 1983).

LOCH ASHIK, ISLE OF SKYE

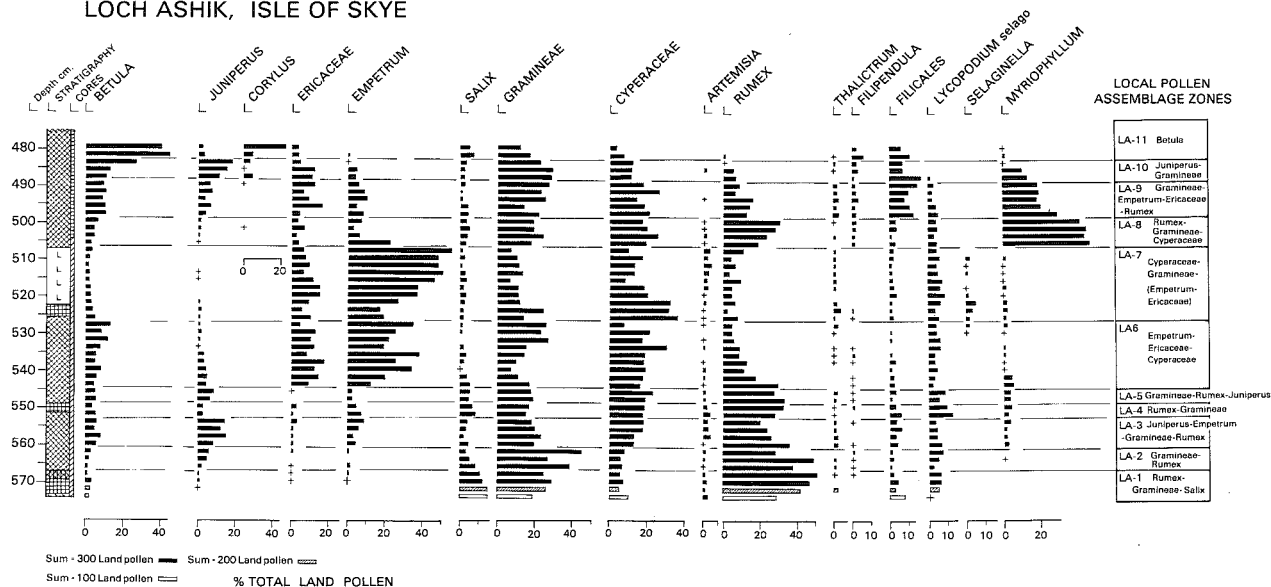


Figure 8.11: Flandrian pollen diagram from Loch Ashik; pollen curves plotted against radiocarbon age.
(From Birks and Williams, 1977).

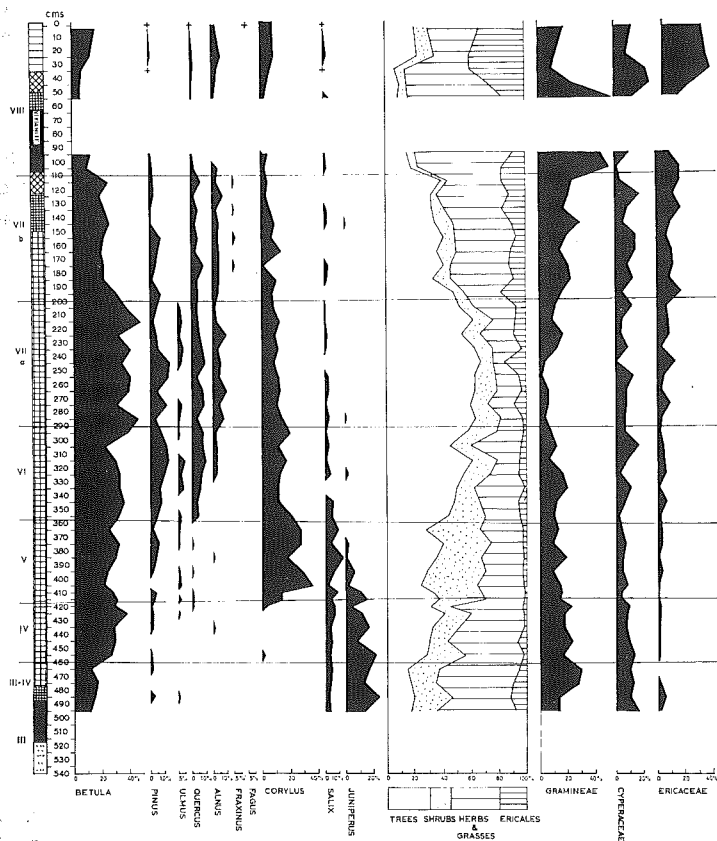


Figure 8.12: Flandrian pollen diagram (tree and shrub taxa only), Loch Cuithir (from Vasari and Vasari, 1968).

35 - 10 cm	sedge peat, humication grade 8.
50 - 35 cm	gyttja.
62 - 50 cm	clay-gyttja.
92 - 62 cm	vivianite.
110 - 92 cm	clay.
125 - 110 cm	gyttja.
150 - 125 cm	gyttja with a strong admixture of clay.
475 - 150 cm	diatom gyttja.
480 - 475 cm	clay-gyttja.
525 - 480 cm	clay.
550 - 525 cm	sand.

The pollen-stratigraphic sequence obtained from this core (Fig. 8.12) was described by Vasari and Vasari (1968) in terms of the 'standard' Godwin pollen zonation scheme, which was the practice of the time:

Zone VIII the onset of the 'Sub-Atlantic', marked by significant reductions of arboreal pollen, especially of birch and oak.

Zone VIIb declining arboreal pollen percentages with a marked *Ulmus* decline.

Zone VIIa *Alnus* zone and maximum 'expanse of forests' in the vicinity of Loch Cuithir.

Zone VI rise in *Quercus* together with *Betula* and *Pinus* and reduced values for *Corylus* and *Salix*.

Zone V *Betula* dominant with rising *Corylus* curve.

Zone IV increased values for *Betula* coinciding with reduced values for shrubs and NAP.

Zone III relatively high *Juniperus* and *Ericaceae* pollen percentages.
(or III/IV transition)

Organic sediment from the base of the core provided a radiocarbon date of $10,060 \pm 270$ yr BP and a pollen assemblage characteristic of the Lateglacial/early Flandrian transition (Vasari, 1977). The absence of Lateglacial Interstadial sediments from the core supports Ballantyne's (1990) view that Coire Cuithir was occupied by ice during the Loch Lomond Stadial.

The Loch Cuithir pollen record was the first complete Flandrian diagram to be published from Skye and is in many ways similar to other published Flandrian records from the island. Distinctive features of the Loch Cuithir sequence, however, are (a) the very thick (>3m) diatom-gyttja deposits that have accumulated through most of the Flandrian; (b) the very restricted and apparently recent accumulation of peat at the site (only the top 30cm of the record is of peat); (c) the coincidence of clay and vivianite deposition with the Zone VIIb/VIII transition; and (d) the relatively low arboreal pollen percentages recorded throughout the sequence (note that the curves shown in Figure 8.12 are based on an AP pollen sum).

9. EXCURSIONS

Introduction

The excursions outlined below were planned for the Quaternary Research Association field meeting on Skye in May 1991. All assume the use of a motor vehicle, although some also involve extensive walking. The paragraph numbers correspond to stop numbers on the accompanying route maps; the site numbers refer to the detailed descriptions of individual sites given in chapters 2-8. All excursions are of full day or half day duration.

Excursion 1: Broadford, Strath Suardal and Loch Slapin

[Lateglacial and Flandrian pollen sites; Loch Lomond Readvance limits in the Eastern Red Hills; Main Postglacial Raised Beach at Camas Malag; recessional moraines in the Loch Slapin area]

This half-day excursion begins at Ashaig [NG 690239] and finishes on the west shore of Loch Slapin near Rubha Cruaidhlinn [NG 569193]. The route follows the A850 road west to Broadford then the A881 (Elgol) road SW to Loch Slapin (Figure 9.1).

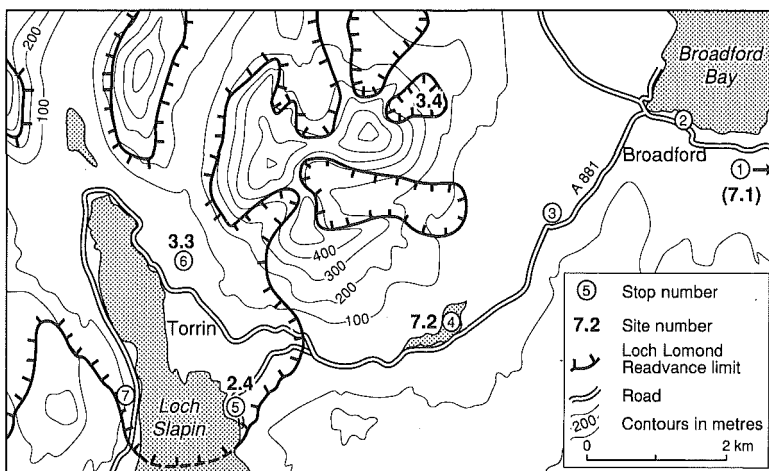


Figure 9.1: Route map for the Broadford - Strath Suardal - Loch Slapin excursion.

1. Loch Ashik [NG 691232]

Loch Ashik (site 7.1/8.5), 600m south of the road at Ashaig, is a critical Lateglacial and Flandrian pollen site. Cores from this location have provided a high-resolution pollen record of the Lateglacial and early Flandrian for eastern Skye, and demonstrate that this site lay outside the limits of Loch Lomond Stadial glaciation.

To the east of the site rise the Kyleakin Hills which supported small glaciers during the Loch Lomond Stadial (chapter 2). A Flandrian pollen site (site 8.4) is located on the obvious col on the skyline (Bealach Udal).

2. Broadford car park [NG 642236]

Broadford car park provides an excellent view of the bouldery lateral moraines of Coire Fearchair (site 3.4), on the NE side of Beinn na Caillich. These moraines represent the limit of a small glacier, 0.42km² in area, that occupied the corrie during the Loch Lomond Stadial.

3. Strath Suardal [NG 626220]

From Broadford, turn SW on to the Elgol Road (A881). A car park on the crest of a rise at NG 626220 provides a view of the Eastern Red Hills to the west and up Strath Suardal. This valley has been excavated along the line of contact between the Cambro-Ordovician rocks that crop out east of the road and the epigranite of the Eastern Red Hills. According to Harker (1901), the point of divergence of the last mainland ice sheet lay in the vicinity of this viewpoint, mainland ice from the east being diverted both northwards and southwards by ice emanating from a locally-nourished ice cap in the mountains of central Skye (chapter 2). Subsequent glaciation of this area during the Loch Lomond Stadial of c. 11-10 ka BP is represented by a massive end moraine that crosses the mouth of Coire Gorm 1km west of this viewpoint. This moraine marks the terminus of a small glacier, 1.51 km² in area, that occupied the corrie at this time. The upper slopes of the Red Hills above the level of this glacier are mantled with a cover of frost-weathered regolith that developed during the Late Devensian after the downwastage of the last ice sheet (chapter 4).

4. Loch Cill Chriosd [NG 614205]

Two kilometres farther down the road lies Loch Cill Chriosd (site 7.2). Cores recovered from this site contained organic sediments of Lateglacial Interstadial (c. 13-11 ka BP) age, and thereby demonstrate that this site was not occupied by glacier ice during the Loch Lomond Stadial.

5. Camas Malag [NG 583190]

At Kilbride [NG 593202] the excursion route leaves the A881 and forks left to the shores of Loch Slapin at Camas Malag [NG 583190; site 2.4; Figures 2.4 and 3.7], where two or three moraine ridges descend to the shore of the loch. These have been interpreted as marking the eastern limit of a large glacier (the Slapin Glacier) that descended from the valleys to the head of Loch Slapin during the Loch Lomond Stadial. The seaward end of these moraines is truncated by the Main Postglacial Raised Beach.

6. Cnoc Slapin [NG 575214]

From Camas Malag, return to the A881 and proceed westwards through Torrin. At the far end of this village, stop where the road turns west towards Loch Slapin (just beyond the cattle-grid), and climb the rocky knoll of Cnoc Slapin. Several features may be viewed from this site.

(1) The bold craggy outlines of Bla Bheinn and Garbh-bheinn to the west contrast markedly with the much gentler scree-covered domes of the Eastern Red Hills to the north and east. The much greater cover of detritus on the latter reflects the susceptibility of the Red Hills epigranite to Lateglacial frost weathering. Such detritus was subsequently transported downslope, probably by debris flow, to form the curtains of scree that fringe the Red Hills.

(2) The greater strength of the eucrite that underlies the Bla Bheinn ridge is also manifest in the steep rockwalls and deep corries that face east towards the head of Loch Slapin. During the Loch Lomond Readvance, powerful ice streams from these corries joined glaciers moving southwards from Srath Mór and Srath Beag to feed the Slapin Glacier (Figure 2.4). A drift limit marking the margin of this former glacier may be visible on the steep NE slopes of An Carnach, immediately across the loch from Cnoc Slapin. A large area of moraines deposited during the readvance occupies the low ground east of Bla Bheinn. A core extracted from a hollow in these moraines contained organic sediment dating back only to the early Flandrian (Clach Oscar, chapter 8). The contrast between the stratigraphy of this site and the Lateglacial site at Loch Cill Criosd provides strong evidence for a Loch Lomond Stadial age for the readvance of the Slapin Glacier.

(3) North of Cnoc Slapin, at the southern end of Srath Beag, may be seen an impressive suite of moraine ridges that have been interpreted as marking successive positions of an actively-retreating glacier margin (site 3.3).

(4) Immediately outside the limits of the Slapin Glacier, below the basalt scarp of An Carnach [NG 550200] are mature, relict (vegetated) talus slopes. The absence of similar slopes inside the limit of the readvance suggests that the bulk of

these taluses developed as a result of rockfall under periglacial conditions during the Lateglacial.

(5) At the head of the Loch Slapin are visible intersecting alluvial fans that have developed during the Holocene as a result of evacuation of sediment from the corrie east of Garbh-bheinn.

(6) Nearer at hand is further evidence for Holocene erosion in the form of karren (solution runnels and pockets) developed on outcrops of limestone on the summit of Cnoc Slapin.

7. Rubha Cruaidhlinn [NG 569193]

Where the road rises southwards by Rubha Cruaidhlinn, a fine view is obtained of the Eastern Red Hills to the north and, particularly in low light, of the suite of recessional moraines at the southern end of Srath Beag (site 3.3). Rubha Cruaidhlinn lies directly opposite Camas Malag, and marks the approximate southern limit of the Slapin Glacier during the Loch Lomond Readvance. Although the limit has no morphological expression on the steep western shore of the loch, a marked change in the character of the valley-side slope deposits occurs at the site. To the north, the slopes are typically masked by thick sequences of sediment-gravity flows containing numerous erratics, while to the south only thin covers of coarse, angular debris are present. This contrast reflects the presence of reworked glacial sediments within the readvance limit.

Excursion 2: Glen Brittle and the southern Cuillin Hills

[Loch Lomond Readvance limits in the corries of the Black Cuillin; the Lagan and Ghrunnda moraines; ice-moulded bedrock and periglacial trimlines; movement of the last ice sheet across southern Skye; Lateglacial pollen sites; Lateglacial and Flandrian shorelines at the head of Loch Brittle]

This full day excursion is dominated by a long walk that begins and ends in the car park at the mouth of Glen Brittle [NG 410206], but the first stop is made at the head of this glen. Features of interest *en route* to Glen Brittle include the thick deposits of drumlinoid hummocky drift that occupy the valley floor between Sligachan and upper Glen Drynoch, and the limit of the Loch Lomond Readvance in Glen Drynoch. The latter takes the form of irregular mounds of sand and gravel deposited across the valley floor at NG 435310.

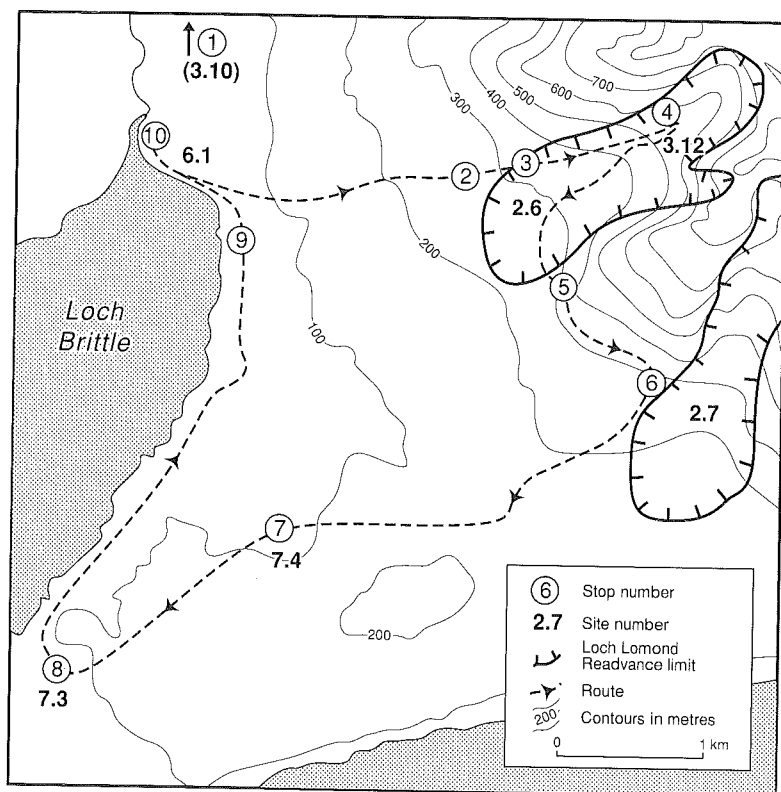


Figure 9.2: Route map for the Glen Brittle and southern Cuillin Hills excursion.

1. Upper Glen Brittle [NG 423259]

A lay-by near the head of Glen Brittle gives a striking view into the largest of the Cuillin corries, Coire na Creiche, and the mountains of the northern part of the Cuillin ridge, notably Bruach na Frithe (958m). From this viewpoint may be seen the limits of the substantial (4.5 km²) glacier that occupied Coire na Creiche during the Loch Lomond Stadial, and associated depositional landforms (site 3.10).

From here the route involves travelling directly to the car park at the head of Loch Brittle [NG 410206]. The route affords good views of Coire a'Ghreadaidh and Coire na Banachdich, both deeply incised in the Cuillin ridge to the east. Coire a'Ghreadaidh is one of the most spectacular stepped corries in Scotland, with floors

at 230m, 380m and 500m. The landforms of this corrie are described in detail in chapter 3 (site 3.11).

2. The mouth of Coire Lagan [NG 430206]

From the Glen Brittle campsite [NG 413205] follow the obvious footpath steeply eastwards towards Coire Lagan. At an altitude of c. 290m the path runs alongside a ramp of bouldery drift that Ballantyne (1989a) interpreted as representing the limit of the glacier that occupied Coire Lagan during the Loch Lomond Stadial. Benn (1990), however, found that such bouldery drift occurs over a wider area at this altitude (Figure 2.10), and inferred that it represents deposition by the last ice sheet. Benn placed the limit of the Coire Lagan glacier farther upslope at a pronounced moraine ridge that had previously been identified by Sissons (1977a) as the limit of this glacier (site 2.6).

3. The Coire Lagan lateral moraine: north [NG 433207]

The vantage point offered by the lateral moraine that represents the northern margin of the Coire Lagan glacier offers a view of the landforms that occupy the area of the former glacier snout (site 2.6). From this point the path climbs steeply to the upper corrie. Note the progressive reduction in drift cover with distance from the snout. The path to the upper corrie passes across slabs of ice-moulded and striated bedrock that terminate abruptly upslope at a periglacial trimline.

4. Upper Coire Lagan [NG 444209]

The floor of the upper corrie (site 3.12) contains beautifully preserved ice-moulded bedrock and a small rock-basin loch. The corrie is fringed by extensive talus cones and a ring of impressive rock peaks including Sgurr Alasdair (993m), the highest point in the Hebrides. The talus cones can only have developed since the disappearance of glacier ice, and represent some of the most massive Holocene talus accumulations in upland Britain. However, surface boulders are weathered and lichen-covered, which suggests that recent rockfall accumulation has been minimal. Harker (1901) suggested that these taluses represent the persistence of periglacial conditions following deglaciation, but in view of recent evidence for rapid warming at the end of the Loch Lomond Stadial it seems more likely that they are paraglacial accumulations that reflect the instability of the glacially-steepened backwall immediately after glacier decay.

5. The Coire Lagan lateral moraine: south [NG 436199]

The excursion route follows the path back to the lower corrie, veering southwards to join the footpath to Coir' a'Ghrunnda near an area of moraines, boulders and rock-knobs. The precise limit of the Loch Lomond Readvance glacier is

difficult to determine, because the glacier apparently over-rode earlier moraines in this area (site 2.6). The path to Coir' a' Ghrunnda passes many ice-worn rock outcrops, some of which support striae that reflect the westwards passage of the last ice sheet across the southern flank of the Cuillins.

6. Coir' a'Ghrunnda [NG 444193]

From a point on the footpath before it turns northwards into Coir' a'Ghrunnda a view is obtained of what was probably the first end moraine to be recognised in Scotland (Forbes, 1846) The great arcuate boulder moraine that sweeps around the mouth of this impressive corrie (site 2.7) marks the limit of a glacier 1.46 km² in area that occupied Coir' a'Ghrunnda during the Loch Lomond Stadial (Figure 2.4).

Visible to the south is the small neighbouring island of Soay. The presence of gneiss erratics on Soay implies that it was crossed by an ice stream that originated on the Scottish mainland and moved west across the Sleat Peninsula to within a few kilometres of the south coast of Skye. Farther in the distance can be seen the island of Rhum, on which erratics transported from the mainland have also been found. During the Loch Lomond Stadial, Rhum supported a number of corrie and valley glaciers, with dimensions and equilibrium line altitudes similar to those of the glaciers that occupied the Cuillin corries (Ballantyne and Wain-Hobson, 1980).

7. Loch Coir' a' Ghobhainn [NG 417183]

From Coir' a'Ghrunnda the excursion route follows trackless moorland to Loch Coir' a' Ghobhainn, a Lateglacial site investigated by Birks (1973). The detailed stratigraphy of this site is described in chapter 7 (site 7.4).

8. Slochd Dubh [NG 403170]

From Loch Coir' a' Ghobhainn head south-west for 2km over rough ground to Slochd Dubh, a narrow incised valley in which a second Lateglacial pollen site is located (site 7.3). A further 1km to the south-west is Rubh' an Dunan which contains several sites of archaeological interest, including a chambered cairn, a hill fort, and the improved tidal harbour of Loch na h-Airde.

9. East shore of Loch Brittle [NG 414201]

From Slochd Dubh the route follows the coastal path back to the head of Loch Brittle. From a point 500m south of the head of the loch a number of raised coastal landforms are visible, notably high-level (Lateglacial) shorelines, an intertidal rock platform and relict sand dunes (site 6.3). The line of boulders on the slopes above the viewpoint was deposited during ice-sheet deglaciation, and is probably a medial moraine.

10. The head of Loch Brittle [NG 409 209]

A suspension bridge crosses the River Brittle close to the abrupt bend in the road. This bridge provides access to the Lateglacial shorelines around Bualintur and is a good point from which to inspect fluvial sediments exposed in the east bank of the river (site 6.3).

Excursion 3: Gleann Torra-Mhichaig, Sligachan and Glen Varragill

[Glacigenic sediments: ice stagnation deposits, evidence for sediment-gravity flows and subglacial deformation; the Sconser moraine; Flandrian raised shorelines; Flandrian pollen sites]

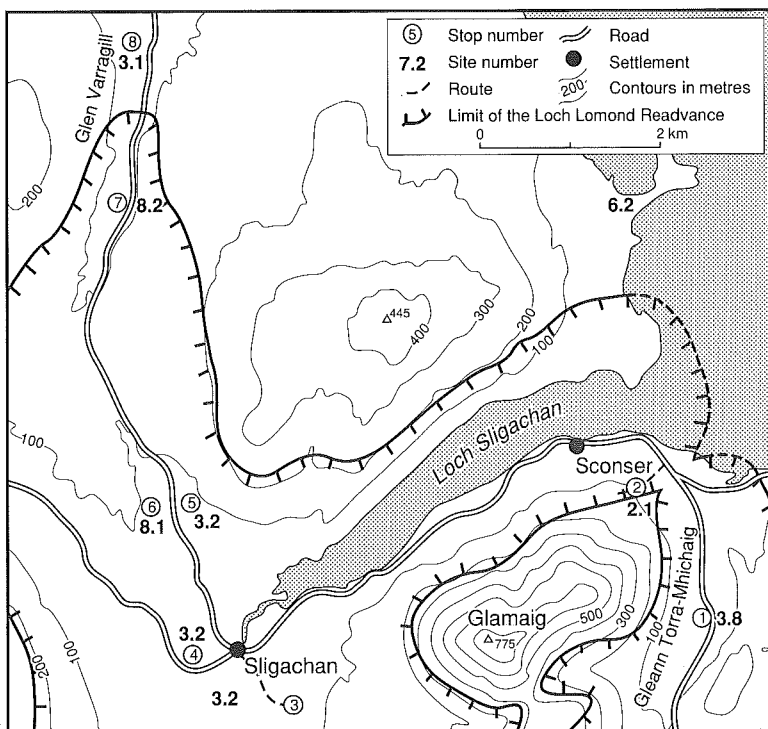


Figure 9.3: Route map for the Torra-mhichaig - Sligachan - Glen Varragill excursion

This half-day excursion begins in Gleann Torra-mhichaig, south of Sconser, and proceeds via Sligachan to Glen Varragill.

1. Gleann Torra-mhichaig [NG 537298]

Moraines deposited during the Loch Lomond Readvance cover most of the ground below *c.* 100m in Gleann Torra-mhichaig, and can be viewed from many points on the A850. Two sediment exposures are of particular interest, both of which are described in detail in chapter 3 (site 3.8). The first is located opposite a car-park at NG 537298 and shows paraglacial deposits of local provenance interbedded with glacially-transported debris. The second section is in the west bank of a pronounced meander in the Abhainn Torra-mhichaig [NG 536303], and allows the internal structure of a large hummock to be examined. Periglacial landforms on the summit ridge of Beinn Dearg Mhór are described in chapter 4 (site 4.2).

2. The Sconser Moraine [NG 529317]

From the A850 a broad drift ridge climbs obliquely up the north side of Glamaig. This has been interpreted as the limit of the outlet glacier that occupied Loch Sligachan during the Loch Lomond Stadial (site 2.1). From the moraine, the view of the coast allows the relationship between Loch Lomond Readvance limits and raised shorelines to be appreciated. Around the mouth of Loch Sligachan, within the readvance limit, the marine limit is represented by the Main Postglacial Shoreline at *c.* 7m OD. To the north, beyond the low knoll of Torr Mór, is a raised tombolo consisting in part of high Lateglacial beach gravels (site 6.2). Lateglacial raised beaches also occur around the coast of Raasay.

3. Glen Sligachan viewpoint [NG 492292]

A good overall view of the landforms around Sligachan can be obtained from near the well-made footpath that begins at the east end of the old bridge (signposted to Coruisk). Follow the footpath for *c.* 750m then ascend the hillside for a short distance. To the south lies the glacial breach of Glen Sligachan above which rise the elegant peaks of Marsco to the east and Sgurr nan Gilleann to the west, underlain by epigranite and gabbro respectively. Nearer at hand, and occupying a large area to the west and north, is an extensive suite of moraines. The moraines are lineated approximately south-north, reflecting the ice flow direction during the Loch Lomond Readvance, and are interpreted as subglacial bedforms (site 3.2). Sediment exposures in the moraines are examined at the next two stops.

4. Sligachan roadcut [NG 481297]

Return to Sligachan, then follow the A863 (Dunvegan) road for 500m to an obvious road-cut, where lodgement tills are well exposed (site 3.2). Similar till can be examined in numerous shallow sections nearby.

5. Allt Dubh moraine section [NG 480315]

This section lies c. 100m east of the A850 in the south-west bank of a meander in the river. Lacustrine silts at this locality are overlain by lodgement till (site 3.2). The silts are sometimes obscured by an apron of debris, and some excavation may be necessary. The silts are usually nearest the surface at the left-hand end of the section.

6. Sligachan 2 Flandrian pollen site [NG 477315]

Approximately 250m to the west of the A850, directly opposite the till section, is a small steep-sided basin. A core recovered from the basin yielded only Flandrian pollen, the stratigraphy of which is described in detail in chapter 8 (site 8.1).

7. Glen Varragill Flandrian pollen site [NG 473349]

Return to the A850 and proceed northwards for c. 3km to where the Varragill River is separated from the road by a broad expanse of peat [NG 473349]. Flandrian pollen sites in this area (which lies only 1km within the Loch Lomond Readvance limit) are described in chapter 8 (site 8.2).

8. Glen Varragill till section [NG 475367]

A number of fine exposures of ice-sheet tills occur in the west bank of the Varragill River, north of the Loch Lomond Readvance limit. The finest of these is clearly visible from the A850 as a clean vertical face some 12m high (site 3.1). The section is reached by a short walk and a river crossing, which may be difficult in wet weather.

Excursion 4: The Trotternish Peninsula

[Rotational landslides and other slope failures on the Trotternish Escarpment and in Glen Uig; periglacial trimlines marking the upper limit of the last ice sheet; relict and active periglacial phenomena on The Storr; Loch Lomond Readvance limits, Flandrian pollen site and diatomite in Coire Cuithir; raised shorelines around Staffin Bay]

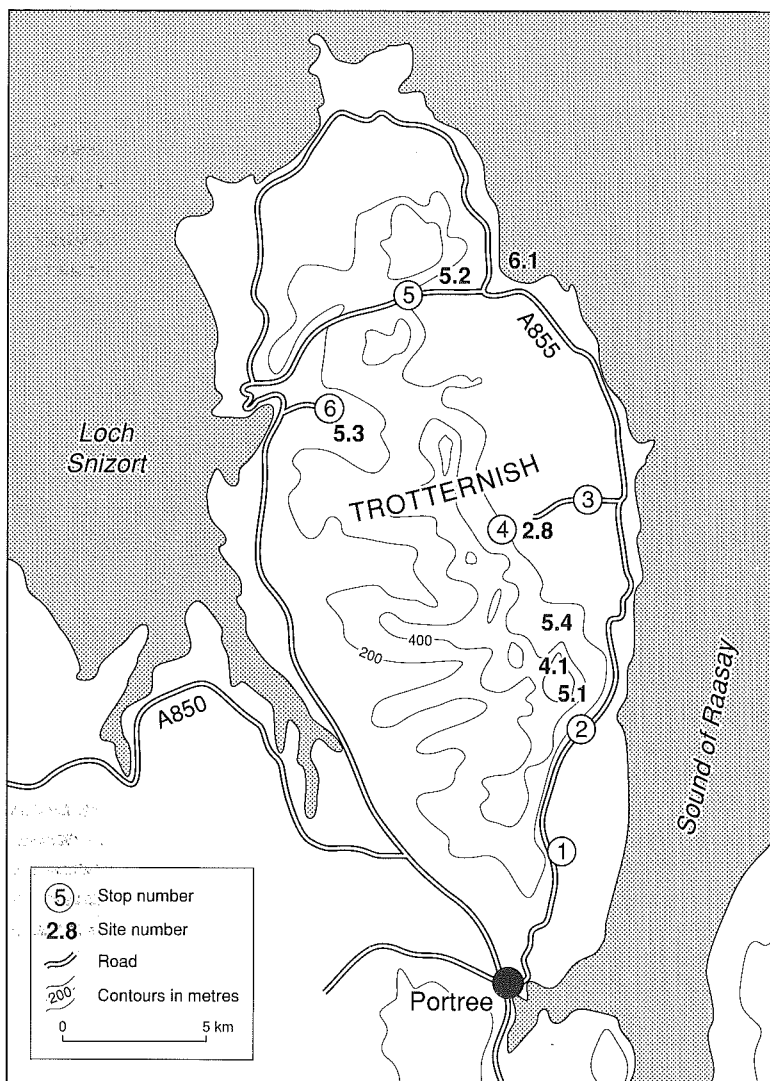


Figure 9.4: Route map for the Trotternish Peninsula excursion

This excursion begins and ends at Portree, and follows the A855 road north to Staffin; a minor road west to Uig, and the A856 road from Uig to Portree (Figure

9.4). The excursion occupies a full day if The Storr or Storr landslide are visited (stop 2); otherwise it is of half day duration.

1. Loch Fada [NG 492485]

From the roadside above the southern end of Loch Fada there is a fine view of the Trotternish Escarpment, with the Storr landslide seen in profile 5km to the north. Loch Fada and its northern extension, Loch Leathan, occupy a broad valley excavated in Jurassic sediments and partly underlain by a dolerite sill. East of the road is an outlier of westward-dipping Tertiary lavas and tuffs, whilst the bold scarp cliff to the west is developed entirely in such rocks. Bedrock outcrops have been smoothed and moulded by the northwards passage of the last ice sheet over the area. Ice moulding is evident even near the summit of Ben Dearg (552m), the southernmost mountain on Trotternish, and indicates that the last ice-sheet surface exceeded this altitude at this point (Figure 2.2). Landslide blocks at the foot of the scarp are also strongly ice-moulded, indicating that the failures they represent occurred before the passage of the last ice sheet over the area. The Storr landslide (site 5.1) consists of an outer zone of ice-moulded blocks that extend down to the road, and an inner zone of shattered rock pinnacles that represent postglacial rotational failure of the scarp through foundering of the underlying sedimentary rocks under the weight of a basalt cap c. 300m thick (Figure 5.2).

2. The Storr car park [NG 503525]

Two excursions are possible on foot from the car park at the foot of The Storr. The shorter involves following the forest walk into the pinnacled labyrinth of Coire Faoin, the area of postglacial landslipping (2 hours; 350m of ascent; site 5.1). The longer involves a south-north traverse of The Storr itself (4 hours; 600m of ascent; site 4.1) to view the landslide from above (Figure 5.1), together with evidence for an ice-sheet trimline on The Storr and the wide range of relict and active periglacial phenomena present on this mountain. The traverse of The Storr can be extended to a longer excursion of 6 hours duration by incorporating a visit to the Carn Liath landslide (site 5.4). The col south of The Storr can be gained by a steep path that follows a stream at NG 493530. The escarpment can be descended south of Loch Scamadale [NG 500546] or in the vicinity of the Carn Liath landslide.

3. Lealt [NG 503608]

North from the car park at the foot of The Storr the road crosses an area of ice-moulded landslide blocks then ascends to the crest of spectacular coastal cliffs cut in Jurassic sedimentary rocks and dolerite sills. An optional stop may be made to view these cliffs from the car park near the summit of Tobhta nan Druidhean [NG 519584]. Two kilometres north of this point, take the minor road west to Lealt. From a point 300m west of this hamlet is obtained an outstanding view of the Trotternish scarp,

dominated by the peaks of Baca Ruadh (637m), Creag a'Lain (607m) and Flasvein (596m). All of these support a cover of frost-weathered regolith, whereas intervening and neighbouring cols, such as Bealach na Leacaich (536m) and Bealach Chaiplin (516m) are occupied by ice-moulded bedrock, roches moutonnées and patches of till. This contrast suggests that the peaks remained as nunataks above the level of the last ice sheet, and implies an ice-sheet altitude of c. 530m for the central part of the escarpment. From Lealt may also be seen two of the low-level corries of Trotternish, although it seems likely that the form of these corries owes as much to rotational landslides with arcuate headwalls as to modification by glacial erosion.

4. Coire Cuithir and Loch Cuithir [NG 4759]

An unmetalled road leads west from Lealt into Coire Cuithir, one of the most impressive of the Trotternish corries (site 2.8). This corrie may be best seen from the crest of a lateral moraine at NG 471600. The corrie contains several features of interest.

(1) At the head of the corrie is a massive tabular landslide block. The absence of evidence for ice moulding suggests that failure was postglacial. Another landslide block dams Loch Cuithir on its eastern side. This is a much older degraded feature that apparently represents failure before the passage of the last ice-sheet over the area.

(2) The lateral moraine on the north side of the corrie is nearly 1km long, up to 15m high, and one of the finest on Skye. It descends southwards across the limit of landsliding and marks the northern boundary of an area of thick hummocky drift (site 2.8). This moraine has been interpreted as delimiting the margin of a small glacier, 1.67 km² in area, that occupied Coire Cuithir during the Loch Lomond Stadial.

(3) Consistent with this interpretation is analysis of a core extracted from Loch Cuithir (site 8.6). The base of this core yielded a radiocarbon age of 10,060 ± 270 yr BP and a pollen assemblage characteristic of the Lateglacial/Flandrian transition.

(4) Loch Cuithir also marks the location of extensive diatomite deposits. These occurred as a 3-6m thick horizon below 1m of peat, and were extracted commercially during the first two decades of this century. This was achieved by draining the loch through a cutting made in the landslide block at its eastern end. Unfortunately the remaining unextracted deposits of diatomite are submerged, and only the workings of this deposit remain to be seen.

5. The Quiraing car park [NG 440679]

From Coire Cuithir, the excursion route runs east to the main road, then north to Staffin. A stop may be made here to examine fine Lateglacial and Postglacial raised

shorelines (site 6.1). From Staffin continue west along the Uig road to the car park on the crest of the escarpment. The main purpose of this stop is to view the Quiraing landslide, but a much simpler landslide sequence is visible by ascending the edge of the escarpment south of the car park to an altitude of 380m [NG 441671]. From this point may be viewed a superb example of a single tabular landslide block resting against the scarp cliff [Dùn Dubh, NG 441666], the magnificent detached block of Cleat [NG 447669] and the ancient ice-moulded landslide block that dams Loch Cleat [NG 449673]. Together, these three blocks epitomise the successive rotational failures that have resulted in scarp retreat along the entire length of the Trotternish Escarpment.

The Quiraing landslide (site 5.2) is the largest in Great Britain, and like the Storr landslide consists of an inner zone of tabular landslip blocks and pinnacles, and an outer zone of ice-moulded landslide blocks. A path from the car park northwards along the crest of the escarpment gives access to the inner zone of postglacial landslipping.

6. Glen Uig [NG 4163, 4263]

A minor road leaves the A816 Uig-Portree road just north of the River Conon and gives access to Glen Uig, a natural amphitheatre floored by Jurassic sediments and ringed by basalt cliffs. Failure of the sediments under the lavas has resulted in widespread rotational sliding, especially on the southern side of the glen (site 5.3). Another road running along the south side of Glen Uig leaves the main road at NG 3966373 and gives access to the remarkable hummocky landslide topography below the cliffs of Castle Ewen [NG 414632].

Excursion 5: Loch Ainort to Strollamus

[Loch Lomond Readvance lateral moraines, recessional moraines, medial moraines and drift limits; the Strollamus ice-sheet moraine; sedimentology of recessional moraines; glaciotectonised bedrock; Flandrian pollen site at Luib; the Glas Beinn Mhór landslide; raised shorelines at Strollamus]

This half-day excursion begins at a car park overlooking Loch Ainort [NG 532283] and then follows the A850 road to the hamlet of Luib [NG 565279]. The remainder of the excursion involves exploration on foot of the ground between Luib and Strollamus [NG 594270].

1. Loch Ainort Viewpoint [NG 532283]

This viewpoint offers a panorama of much of the Loch Ainort basin. During the Loch Lomond Readvance, glaciers nourished in the corries at the head of this basin fed

a single large glacier, the Ainort Glacier (19.7 km² in area; Figure 2.4) that terminated near the mouth of the loch. Of particular interest are drift limits and recessional moraines that define the upper surface and retreat stages of the Ainort Glacier respectively (site 2.2).

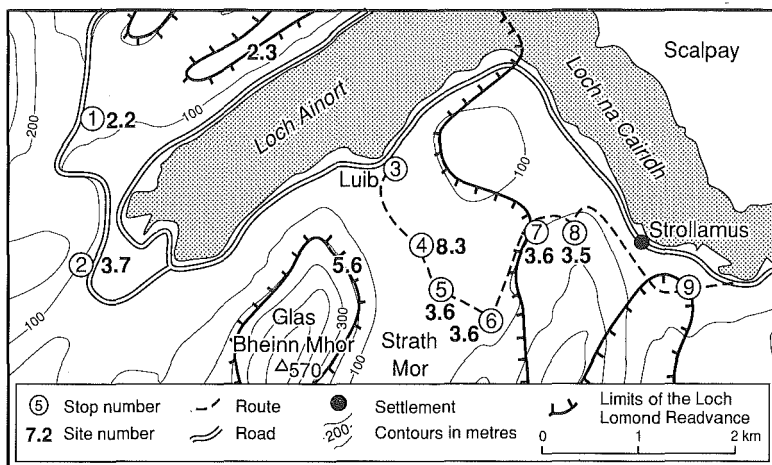


Figure 9.5: Route map for the Loch Ainort to Strollamus excursion.

2. Eas a'Bhradain [NG 534267]

Additional aspects of the Loch Ainort basin can be appreciated from the car park opposite the fine waterfall that drains Coire nam Bruadaran.

(1) The view down Loch Ainort to the Island of Scalpay is framed by the sweeping slopes of Glas Bheinn Mhór and Leathad Chrithinn. These slopes are mantled by sequences of sediment-gravity flows up to 5m thick, which consist of reworked glacial material. Exposures in such material may be examined above the road close to the car park.

(2) Recent geophysical investigations of the sea bed between the head of Loch Ainort and Scalpay have revealed the presence of numerous moraine ridges, which have been interpreted as former glacier grounding lines (site 3.7).

(3) Extensive Postglacial raised beaches occur at the head of the loch. The raised beaches and the modern tidal flats form the surface of a large delta that has built out

into the loch since deglaciation. The absence of high Lateglacial raised shorelines shows that the area was last glaciated during the Loch Lomond Stadial.

(4) On the slopes south of the waterfall is a superb medial moraine. The moraine is composed of large blocks of coarse-grained epigranite derived from Marsco at the head of the basin. The moraine and other glacial landforms in the area are described in detail in chapter 3 (site 3.7).

3. Luib [NG 565279]

The hamlet of Luib offers views of two interesting landforms. Across Loch Ainort, on the upper slopes of Leathad Chrithinn, a lateral moraine descends to the NE and marks the upper limit of the Ainort Glacier (site 2.3). To the SW is the massive Glas Bheinn Mhór landslide, which represents rock-slope failure after the withdrawal of the Srath Mór Glacier at the end of the Loch Lomond Stadial (site 5.6).

4. Luib 1 Flandrian pollen site [NG 567271]

From Luib follow the footpath on the west side of the Allt na Luibe towards Srath Mór, noting the large recessional moraine on the left (site 3.6). Approximately 700m from Luib the footpath passes through a narrow gap in a prominent moraine belt. An important Flandrian pollen site (Luib 1; Walker *et al.*, 1988) was discovered in the area of peat just north of this gap. Full details of the site are given in chapter 8 (site 8.3).

5. Moraine section, Srath Mór [NG 572266]

The Luib area contains several belts of large moraine ridges and mounds, marking the retreat of the Srath Mór glacier at the end of the Loch Lomond Stadial (site 3.6). A fine exposure in one of the ridges can be reached by following the undulating crest of the moraine to the south-east of the gap mentioned above. The exposure is located where the Allt an t-Sithein has cut into the north side of a prominent beaded moraine, and is clearly visible from a distance. A full description and interpretation of the section is given in chapter 3 (site 3.6).

6. Glaciotectonised bedrock, Allt an t-Sithein [NG 575264]

Evidence for subglacial plucking of well-jointed bedrock, also described in chapter 3 (site 3.6), is also exposed in the south bank of the Allt an t-Sithein, 400m to the south-east of the previous site. The exposure is located where the river cuts through a belt of moraines, just west of its confluence with a stream that drains the slopes of Glas Bheinn Bheag.

7. *Strath Mór moraine* [NG 579273]

From the bedrock section, gain the crest of the moraine belt and follow it northwards, crossing a deeply-incised stream, to reach the dirt track that leads from Luib. *En route*, note the varied form of the moraines and the abundance of large eucrite boulders derived from a rock step low on the north ridge of Beinn na Cro. Follow the track to the col between Am Meall and Glas Bheinn Bheag, where a belt of moraines marks the limit of the Strath Mór glacier (site 3.6).

8. *The Strollamus ice-sheet moraine* [NG 584272]

Four hundred metres east of the col, a ridge of erratic granite boulders descends the hillslope. This feature was initially interpreted as a lateral moraine marking the margin of a lobe of ice that occupied Loch na Cairidh to the NE, but it appears more likely that it represents a medial moraine that developed between confluent ice streams and was deposited during retreat of the last ice sheet. This site is described in detail in chapter 3 (site 3.5).

9. *Raised shorelines at Strollamus* [NG 5926]

Continue along the track towards the hamlet of Strollamus. At NG 591267 the track enters an area of moraines which is littered with granite boulders. The boulders, derived from the ice-sheet moraine, record ice movement down Strath Beag during the Loch Lomond Readvance. According to Walker *et al.* (1988) the Loch Lomond Readvance glacier extended a short distance offshore, an interpretation that was apparently supported by an associated drop in the marine limit. A clear raised beach terrace occurs at c. 23m OD below Creag Strollamus [NG 604267], while within the mapped glacier margin, '...the marine limit, represented by beach gravels deposited against moraines of the former glacier, is only c. 7m' (Walker *et al.*, 1988, p. 141). However, detailed erratic counts by Benn (1990) strongly suggest that the glacier terminated close to the point where the track crosses the Allt Strollamus. This evidence may be reconciled with the shoreline evidence in one of two ways. First, Lateglacial shorelines may be represented in the Strollamus area by a number of dissected terraces that lie between the dirt track and the A850. Sections in the terraces expose gravels which, in common with those in the 23m terrace, contain gabbro and Torridonian sandstone clasts derived from the south-east. The dissected, irregular form of the terraces may be due to incision by meltwater during the Loch Lomond Stadial or the former presence of buried ice cores within the deposits. Alternatively, the apparent drop in the marine limit may be due to the late survival of glacier ice in Strath Beag during ice-sheet deglaciation, as at Glen Brittle (site 6.3).

REFERENCES

- Addison, K.** 1981. The contribution of discontinuous rock-mass failure to glacier erosion. *Annals of Glaciology*, 2, 3-10.
- Anderson, F.W. & Dunham, K.W.** 1966. The geology of northern Skye. *Memoir of the Geological Survey of the United Kingdom*.
- Atkinson, T.C., Briffa, K.R. & Coope, G.R.** 1987. Seasonal temperatures in Britain during the last 22,000 years, reconstructed using beetle remains. *Nature*, 325, 587-592.
- Ballantyne, C.K.** 1982. Aggregate clast form characteristics of deposits near the margins of four glaciers in the Jotunheimen massif, Norway. *Norsk Geografisk Tidsskrift*, 36, 103-113.
- Ballantyne, C.K.** 1984. The Late Devensian periglaciation of upland Scotland. *Quaternary Science Reviews*, 3, 311-343.
- Ballantyne, C.K.** 1986a. Nonsorted patterned ground on mountains in the Northern Highlands of Scotland. *Biuletyn Peryglacjalny*, 30, 15-34.
- Ballantyne, C.K.** 1986b. Late Flandrian solifluction on the Fannich Mountains, Ross-shire. *Scottish Journal of Geology*, 22, 395-406.
- Ballantyne, C.K.** 1986c. Landslides and slope failures in Scotland: a review. *Scottish Geographical Magazine*, 102, 134-150.
- Ballantyne, C.K.** 1987. The present-day periglaciation of upland Britain. In: Boardman, J. (ed.) *Periglacial Processes and Landforms in Great Britain and Ireland*. Cambridge: Cambridge University Press, 113-116.
- Ballantyne, C.K.** 1988. Ice-sheet moraines in southern Skye. *Scottish Journal of Geology*, 24, 301-304.
- Ballantyne, C.K.** 1989a. The Loch Lomond Readvance on the Isle of Skye, Scotland: glacier reconstruction and palaeoclimatic implications. *Journal of Quaternary Science*, 4, 95-108.
- Ballantyne, C.K.** 1989b. Avalanche impact landforms on Ben Nevis, Scotland. *Scottish Geographical Magazine*, 105, 38-42.

- Ballantyne, C.K.** 1990. The Late Quaternary glacial history of the Trotternish Escarpment, Isle of Skye, Scotland, and its implications for ice-sheet reconstruction. *Proceedings of the Geologists' Association*, 101, 171-186.
- Ballantyne, C.K.** 1991a. Late Holocene erosion on British Mountains: climatic change or human influence? *The Holocene*, 1 (in press).
- Ballantyne, C.K.** 1991b. Holocene geomorphic activity in the Scottish Highlands. *Scottish Geographical Magazine*, 107 (in press).
- Ballantyne, C.K. & Wain-Hobson, T.** 1980. The Loch Lomond Advance on the Island of Rhum. *Scottish Journal of Geology*, 16, 1-10.
- Ballantyne, C.K. & Whittington, G.W.** 1987. Niveo-aeolian sand deposits on An Teallach, Wester Ross, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Science*, 78, 51-63.
- Bard, E., Arnold, M., Maurice, P., Duprat, J., Moyes, J. & Duplessy, J-C.** 1987. Retreat velocity of the North Atlantic polar front during the last deglaciation determined by ^{14}C accelerator mass spectrometry. *Nature*, 328, 791-794.
- Barnett, D.M. & Holdsworth, G.** 1974. Origin, morphology, and chronology of sublacustrine moraines, Generator Lake, Baffin Island, Northwest Territories, Canada. *Canadian Journal of Earth Sciences*, 11, 380-408.
- Bell, B.R. & Harris, J.W.** 1986. *An Excursion Guide to the Island of Skye*. Geological Society of Glasgow.
- Bell, J.N.L. & Tallis, J.H.** 1973. Biological flora of the British Isles: *Empetrum nigrum* L. *Journal of Ecology*, 61, 289-307.
- Benn, D.I.** 1989. Debris transport by Loch Lomond Readvance glaciers in Northern Scotland: basin form and the within-valley asymmetry of lateral moraines. *Journal of Quaternary Science*, 4, 243-254.
- Benn, D.I.** 1990. *Scottish Lateglacial Moraines: Debris Supply, Genesis and Significance*. Unpublished Ph.D. Thesis, University of St. Andrews.
- Bennett, K.D.** 1984. The post-glacial history of *Pinus sylvestris* in the British Isles. *Quaternary Science Reviews*, 3, 133-155.

- Bennett, M.R. & Boulton, G.S.** A reinterpretation of Scottish 'hummocky moraine' and its significance for the deglaciation of the Scottish Highlands during the Younger Dryas or Loch Lomond Stadial. *Transactions of the Royal Society of Edinburgh*, in press.
- Bennett, M.R. & Glasser, N.F.** 1991. The glacial landforms of Glen Geusachan, Cairngorms: a reinterpretation. *Scottish Geographical Magazine*, in press.
- Birks, H.H.** 1975. Studies in the vegetational history of Scotland. IV. Pine stumps in Scottish blanket peats. *Philosophical Transactions of the Royal Society of London*, B270, 181-226.
- Birks, H.J.B.** 1973. *The Past and Present Vegetation of the Isle of Skye: a Palaeoecological Study*. Cambridge: Cambridge University Press.
- Birks, H.J.B. & Williams, W.** 1983. Late Quaternary vegetational history of the Inner Hebrides. *Proceedings of the Royal Society of Edinburgh*, 83, 269-292.
- Broecker, W.S., Peteet, D.M. & Rind, D.** 1985. Does the ocean-atmosphere system have more than one stable mode of operation? *Nature*, 315, 21-25.
- Bonney, T.G.** 1871. On a cirque in the syenite hills of Skye. *Geological Magazine*, 8, 535-540.
- Boulton, G.S.** 1972. Modern Arctic glaciers as depositional models for former ice sheets. *Journal of the Geological Society of London*, 128, 361-393.
- Boulton, G.S.** 1978. Boulder shapes and grain-size distributions of debris as indicators of transport paths through a glacier and till genesis. *Sedimentology*, 25, 773-799.
- Boulton, G.S.** 1979. Processes of glacier erosion on different substrata. *Journal of Glaciology*, 23, 15-38.
- Boulton, G.S.** 1986. Push moraines and ice-contact fans in marine and terrestrial environments. *Sedimentology*, 33, 677-698.
- Boulton, G.S.** 1987. A theory of drumlin formation by subglacial sediment deformation. In: Menzies, J. and Rose, J. (eds.) *Drumlin Symposium*, Rotterdam: Balkema, 25-80.
- Boulton, G.S. & Eyles, N.** 1979. Sedimentation by valley glaciers; a model and genetic classification. In: Schlüchter, C. (ed.) *Moraines and Varves*, Rotterdam: Balkema, 11-23.

- Boulton, G.S. & Jones, A.S.** 1979. Stability of temperate ice caps and ice sheets resting on beds of deformable sediment. *Journal of Glaciology*, 24, 29-43.
- Bowen, D.Q., Rose, J., McCabe, A.M. & Sutherland, D.G.** 1986. Correlation of Quaternary glaciations in England, Ireland, Scotland and Wales. *Quaternary Science Reviews*, 5, 299-340.
- Bowen, D.Q. & Sykes, G.A.** 1988. Correlation of marine events and glaciations on the northeast Atlantic margin. *Philosophical Transactions of the Royal Society of London*, B 318, 619-635.
- Bridge, M.C., Haggart, B.A. & Lowe, J.J.** 1990. The history and palaeoclimatic significance of subfossil remains of *Pinus sylvestris* in blanket peats from Scotland. *Journal of Ecology*, 78, 77-99.
- Charlesworth, J.K.** 1956. The Late-glacial history of the Highlands and Islands of Scotland. *Transactions of the Royal Society of Edinburgh*, 62, 769-928.
- Chesher, J.A., Smythe, D.K. & Bishop, P.** 1983. The geology of the Minches, Inner Sound and Raasay. *Institute of Geological Sciences Reports*, 83/6, 29 pp.
- Church, M. & Ryder, J.** 1972. Paraglacial sedimentation: a consideration of fluvial processes conditioned by glaciation. *Bulletin of the Geological Society of America*, 83, 3059-3071.
- Clapperton, C.M.** 1975. The debris content of surging glaciers. *Journal of Glaciology*, 14, 395-406.
- Clapperton, C.M. & Sugden, D.E.** 1977. The Late Devensian glaciation of North-East Scotland. In: Gray, J.M. and Lowe, J.J. (eds.) *Studies in the Scottish Lateglacial Environment*, Oxford: Pergamon, 1-13.
- Clough, C.T. & Harker, A.** 1904. The geology of west-central Skye, with Soay. *Memoir of the Geological Survey of the United Kingdom*.
- Croot, D.G.** 1978. *The Depositional Landforms and Sediments Produced by two Surging Glaciers*. Unpublished PhD Thesis, University of Aberdeen.
- Cunningham, F.F.** *James David Forbes: Pioneering Scottish Glaciologist*. Edinburgh: Scottish Academic Press.
- Dansgaard, W., White, J.W.C. & Johnsen, S.J.** 1989. The abrupt termination of the Younger Dryas climate event. *Nature*, 339, 532-534.

- Davies, H.C., Dobson, M.R. & Whittington, R.J.** 1984. A revised seismic stratigraphy for Quaternary deposits on the inner continental shelf west of Scotland between 55°30'N and 57°30'N. *Boreas* 13, 49-66.
- Dawson, A.G.** 1980. The Low Rock Platform in Western Scotland. *Proceedings of the Geologists' Association*, 91, 339-344.
- Dawson, A.G.** 1982. Lateglacial sea-level changes and ice limits in Islay, Jura and Scarba, Scottish Inner Hebrides. *Scottish Journal of Geology*, 18, 253-265.
- Dawson, A.G.** 1983. Quaternary sea-level changes in western Scotland. *Quaternary Science Reviews*, 3, 345-368.
- Dawson, A.G., Lowe, J.J. & Walker, M.J.C.** 1987. The nature and age of the debris accumulation at Gribun, western Mull, Inner Hebrides. *Scottish Journal of Geology*, 23, 149-162.
- Donner, J.J. & West, R.G.** 1955. Ett Drumlinsfält på ön Skye, Skottland. *Eripainos Terrasta*, 2, 45-48.
- Duplessy, J.-C., Delibrias, G., Turon, J.L., Pujol, C. & Duprat, J.** 1981. Deglacial warming of the northeastern Atlantic Ocean: correlation with the palaeoclimatic evolution of the European continent. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 35, 121-144.
- Emeleus, C.H.** 1983. Tertiary igneous activity. In Craig, G.Y. (ed.) *Geology of Scotland*, 2nd edition. Edinburgh: Scottish Academic Press. 357-397.
- Erdtman, G.** 1924. Studies in the micropalaeontology of Postglacial deposits in Northern Scotland and the Scotch Isles, with especial reference to the history of the woodlands. *Journal of the Linnean Society* 46, 449-504.
- Erdtman, G.** 1928. Studies in the Post-Arctic history of the forests of north-western Europe. 1. Investigations in the British Isles. *Geologiska Föreningens Stockholm Förhandlingar*, 50, 123-192.
- Eyles, N.** 1979. Facies of supraglacial sedimentation on Icelandic and Alpine temperate glaciers. *Canadian Journal of Earth Sciences*, 16, 1341-1361.
- Eyles, N.** 1983. Modern Icelandic glaciers as depositional models for 'hummocky moraine' in the Scottish Highlands. In: Evenson, E.B., Schlüchter, C. and Rabassa, J. (eds.) *Tills and Related Deposits*, Rotterdam: Balkema, 47-59.

- Eyles, N. & Rogerson, R.J.** 1978. A framework for the investigation of medial moraine formation: Austerdalsbreen, Norway, and Berendon Glacier, British Columbia, Canada. *Journal of Glaciology*, 20, 99-113.
- Fraser, N.M.** 1990. *The development of rockfall talus slopes*. Unpublished B.Sc. Dissertation, University of St Andrews.
- Forbes, J.D.** 1846. Notes on the topography and geology of the Cuchullin Hills in Skye, and on the traces of ancient glaciers which they present. *Edinburgh New Philosophical Journal*, 40, 76-99.
- Geikie, A.** 1901. *The Scenery of Scotland*. 3rd edition. London: Macmillan and Company.
- Geikie, J.** 1894. *The Great Ice Age*. 3rd edition. London: Daldy, Ibister and Company.
- George, T.N.** 1966. Geomorphic evolution in Hebridean Scotland. *Scottish Journal of Geology*, 2, 1-34.
- Godard, A.** 1958. Quelques observations sur le modelé des regions volcaniques du nord-ouest de l'Écosse. *Scottish Geographical Magazine*, 74, 37-43.
- Godard, A.** 1965. *Recherches de Géomorphologie en Écosse du Nord-Ouest*. Paris: Masson.
- Godwin, H.** 1943. Coastal peat beds of the British Isles and North Sea. *Journal of Ecology*, 31, 199-247.
- Gordon, J. & Birnie, R.V.** 1986. Production and transfer of subaerially-generated rock debris and resulting landforms on South Georgia: an introductory perspective. *British Antarctic Survey Bulletin*, 72, 25-46.
- Gravenor, C.P. & Kupsch, W.O.** 1959. Ice disintegration features in western Canada. *Journal of Geology*, 12, 48-64.
- Gray, J.M.** 1978. Low-level shore platforms in the south-west Scottish Highlands: altitude, age and correlation. *Transactions of the Institute of British Geographers, New Series*, 3, 151-164.
- Gray, J.M.** 1982. The last glaciers (Loch Lomond Advance) in Snowdonia, N. Wales. *Geological Journal*, 17, 111-133.

- Harker, A.** 1899. Glaciated valleys in the Cuillins, Skye. *Geological Magazine*, 46, 196-199.
- Harker, A.** 1901. Ice erosion in the Cuillin Hills, Skye. *Transactions of the Royal Society of Edinburgh*, 40, 221-252.
- Harkness, D.D.** 1981. Scottish Universities Research and Reactor Centre Radiocarbon Measurements IV. *Radiocarbon*, 23, 254-304.
- Holmes, G.** 1984. *Rock slope failure in parts of the Scottish Highlands*. Unpublished Ph.D. Thesis, University of Edinburgh.
- Humlum, O.** 1985. Genesis of an imbricate push moraine, Hofdabrekkuþkull, Iceland. *Journal of Geology*, 93, 185-195.
- Innes, J.L.** 1983a. Lichenometric dating of debris flow deposits in the Scottish Highlands. *Earth Surface Processes and Landforms*, 8, 579-588.
- Innes, J.L.** 1983b. Stratigraphic evidence of episodic talus accumulation on the Isle of Skye, Scotland. *Earth Surface Processes and Landforms*, 8, 399-403.
- Kelletat, D.** 1970. Rezente Periglazialerscheinungen im Schottischen Hochland. *Göttinger Geographische Abhandlungen*, 51, 67-140.
- King, R.B.** 1971. Vegetation destruction in the sub-alpine and alpine zones of the Cairngorm Mountains. *Scottish Geographical Magazine*, 87, 103-115.
- Krüger, J.** 1985. Formation of a push moraine at the margin of Höfdabrekkuþkull, south Iceland. *Geografiska Annaler*, 67A, 199-212.
- Lawson, D.E.** 1982. Mobilisation, movement and deposition of active subaerial sediment flows, Matanuska Glacier, Alaska. *Journal of Geology*, 90, 279-300.
- Lawson, D.E.** 1988. Glacigenic resedimentation: classification, concepts and application to mass-movement processes and deposits. In: Goldthwait, R.P. & Matsch, C.L. (eds.) *Genetic Classification of Glacigenic Deposits*. Rotterdam: Balkema, 147-171.
- Lawson, T.J.** 1986. Loch Lomond Advance glaciers in Assynt, Sutherland, and their palaeoclimatic implications. *Scottish Journal of Geology*, 22, 289-298.
- Le Coeur, C.** 1988. Late Tertiary warping and erosion in Western Scotland. *Geografiska Annaler*, 70A, 361-367.

- Le Coeur, C.** 1989. La question des altérites profondes dans la région des Hébrides internes (Écosse occidentale). *Zeitschrift für Geomorphologie Supplementband*, 72, 109-124.
- Lewis, F.J.** 1906. The plant remains in the Scottish peat mosses. II. The Scottish Highlands. *Transactions of the Royal Society of Edinburgh*, 45, 335-360.
- Lowe, J.J. & Walker, M.J.C.** 1980. Problems associated with radiocarbon dating the close of the Lateglacial period in the Rannoch Moor area, Scotland. In: Lowe, J.J., Gray, J.W. & Robinson, J.E. (eds.), *Studies in the Lateglacial of NW Europe*, Oxford: Pergamon, 123-137.
- Lowe, J.J. & Walker, M.J.C.** 1981. The early Postglacial environment of Scotland: evidence from a site near Tyndrum, Perthshire. *Boreas*, 10, 281-294.
- Lowe, J.J. & Walker, M.J.C.** 1986a. Lateglacial and early Flandrian history of the Isle of Mull, Inner Hebrides, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Science*, 77, 1-20.
- Lowe, J.J. & Walker, M.J.C.** 1986b. Flandrian environmental history of the Isle of Mull, Scotland. II. Pollen analytical data from sites in western and northern Mull. *New Phytologist*, 103, 417-436.
- McCann, S.B.** 1968. Raised shore platforms in the Western Isles of Scotland. In: Bowen, E.G., Carter, H. & Taylor, J.A. (eds.) *Geography at Aberystwyth*. London, 22-34.
- Mellor, A. & Wilson, M.J.** 1989. Origin and significance of gibbsitic montane soils in Scotland. *Arctic and Alpine Research*, 21, 417-424.
- Mottershead, D.N.** 1978. High altitude solifluction and postglacial vegetation, Arkle, Sutherland. *Transactions of the Botanical Society of Edinburgh*, 43, 17-24.
- Nye, J.F.** 1952. The mechanics of glacier flow. *Journal of Glaciology*, 2, 82-93.
- Olsson, I.U.** 1979. A warning against radiocarbon dating of samples containing little carbon. *Boreas*, 8, 203-207.
- Olsson, I.U.** 1986. Radiocarbon dating. In Berglund, B.E. (ed.) *Handbook of Holocene Palaeoecology and Palaeohydrology*. Chichester: Wiley, 273-312.

- Peach, B.N., Horne, J., Woodward, H.B., Clough, C.T., Harker, A. & Wedd, C.B.** 1910. The geology of Glenelg, Lochalsh and south-east part of Skye. *Memoir of the Geological Survey of the United Kingdom*.
- Pedersen, S.A.S.** 1988. Glacitectorite: brecciated sediments and cataclastic sedimentary rocks formed subglacially. In: Goldthwait, R.P. & Martsch, C.L. (eds.) *Genetic Classification of Glacigenic Deposits*. Rotterdam: Balkema, 89-92.
- Pennington, W.** 1975. A chronostratigraphic comparison of Late-Weichselian and Late-Devensian subdivisions, illustrated by two radiocarbon-dated profiles from western Britain. *Boreas*, 4, 157-171.
- Pennington, W.** 1978. Quaternary Geology. In: Moseley, F. (ed.), *The Geology of the Lake District*. Yorkshire Geological Society Occasional Publication, 3, 207-225.
- Ratcliffe, D.A.** 1964. Mires and bogs. In: Burnett, J.H. (ed.), *The Vegetation of Scotland*. Edinburgh: Oliver & Boyd, 426-478.
- Richards, A.** 1969. Some aspects of the evolution of the coastline of north east Skye. *Scottish Geographical Magazine*, 85, 122-131.
- Richards, A.** 1971. *The evolution of marine cliffs and related landforms in the Inner Hebrides*. Unpublished Ph.D. Thesis, University of Wales.
- Ritchie, W.** 1979. Machair development and chronology in the Uists and adjacent islands. *Proceedings of the Royal Society of Edinburgh*, 77B, 107-122.
- Robinson, M.** 1977. *Glacial Limits, Sea-level Changes and Vegetational Development in Torridon and Applecross*. Unpublished PhD Thesis, University of Edinburgh.
- Robinson, M.** 1987. Glassenock (NG 8670 4610) and Druim Dubh (NG 8845 4720). In Ballantyne, C.K. & Sutherland, D.G. (eds) *Wester Ross: Field Guide*. Cambridge: Quaternary Research Association, 154-164.
- Robinson, M. & Ballantyne, C.K.** 1979. Evidence for a glacial readvance pre-dating the Loch Lomond Advance in Wester Ross. *Scottish Journal of Geology*, 15, 271-277.
- Ruddiman, W.F. & McIntyre, A.** 1981. The North Atlantic Ocean during the last deglaciation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 35, 145-214.

- Sharp, M.J.** 1985. Sedimentation and stratigraphy at Eyjabakkajökull: an Icelandic surging glacier. *Quaternary Research*, 24, 268-284.
- Sharp, R.P.** 1988: *Living Ice: understanding glaciers and glaciation*. Cambridge: Cambridge University Press.
- Sissons, J.B.** 1967. *The Evolution of Scotland's Scenery*. Edinburgh: Oliver and Boyd.
- Sissons, J.B.** 1974a. Glacial readvances in Scotland. In: Caseldine, C.J. and Mitchell, W.A. (eds.) *Problems of the Deglaciation of Scotland*. St. Andrews, 39-48.
- Sissons, J.B.** 1974b. Late-glacial marine erosion in Scotland. *Boreas*, 3, 41-48.
- Sissons, J.B.** 1977a. The Loch Lomond Advance in Southern Skye and some palaeoclimatic implications. *Scottish Journal of Geology*, 13, 23-36.
- Sissons, J.B.** 1977b. The Loch Lomond Readvance in the Northern Highlands of Scotland. In: Gray, J.M. and Lowe, J.J. (eds.) *Studies in the Scottish Lateglacial Environment*. Oxford: Pergamon, 45-59.
- Sissons, J.B.** 1979. Palaeoclimatic inferences from former glaciers in Scotland and the Lake District. *Nature*, 278, 518-521.
- Sissons, J.B.** 1980. Palaeoclimatic inferences from former Loch Lomond Advance glaciers. In: Lowe, J.J., Gray, J.M. and Robinson, J.E., *Studies in the Lateglacial of North-West Europe*. Oxford: Pergamon Press, 31-43.
- Sissons, J.B.** 1981. The last Scottish ice sheet: facts and speculative discussion. *Boreas*, 10, 1-17.
- Sissons, J.B.** 1982. The so-called high 'interglacial' rock shoreline of western Scotland. *Transactions of the Institute of British Geographers*, 7, 205-216.
- Sissons, J.B.** 1983a. Shorelines and isostasy in Scotland. In: Smith, D.E. and Dawson, A.G. (eds.) *Shorelines and Isostasy*. London: Academic Press, 209-226.
- Sissons, J.B.** 1983b. The Quaternary geomorphology of the Inner Hebrides: a review and reassessment. *Proceedings of the Geologists' Association*, 94, 165-175.

- Sissons, J.B. & Dawson, A.G.** 1981. Former sea-levels and ice limits in part of Wester Ross, northwest Scotland. *Proceedings of the Geologists' Association*, 92, 115-124.
- Statham, I.** 1976. A scree slope rockfall model. *Earth Surface Processes and Landforms*, 1, 43-62.
- Sugden, D.E.** 1971. The significance of periglacial activity on some Scottish mountains. *Geographical Journal*, 137, 388-392.
- Sugden, D.E.** 1974. Deglaciation of the Cairngorms and its wider implications. In: Caseldine, C.J. and Mitchell, W.A. (eds.) *Problems of the Deglaciation of Scotland*. St. Andrews, 17-28.
- Sugden, D.E.** 1980. The Loch Lomond Advance in the Cairngorms. *Scottish Geographical Magazine*, 96, 18-19.
- Sutherland, D.G.** 1980. Problems of radiocarbon dating deposits from newly deglaciated terrain: examples from the Scottish Lateglacial. In: Lowe, J.J., Gray, J.M. & Robinson, J.E. (eds), *Studies in the Lateglacial of NW Europe*. Oxford: Pergamon Press, 139-150.
- Sutherland, D.G.** 1981. The high-level marine shell beds of Scotland and the build-up of the last Scottish ice-sheet. *Boreas*, 10, 247-254.
- Sutherland, D.G.** 1984a. The Quaternary deposits and landforms of Scotland and the neighbouring shelves: a review. *Quaternary Science Reviews*, 3, 157-254.
- Sutherland, D.G.** 1984b. Modern glacier characteristics as a basis for inferring former climates with particular reference to the Loch Lomond Stadial. *Quaternary Science Reviews*, 3, 291-309.
- Telford, M.B.** 1977. *Glenveagh National Park: the past and present vegetation*. Unpublished Ph.D. thesis, Trinity College, Dublin.
- Thompson, R.N.** The 'rhyolite' of Fionn Choire, Isle of Skye. *Proceedings of the Geologists' Association*, 78, 212-214.
- Thorpe, P.W.** 1981. A trimline method for defining the upper limit of Loch Lomond Readvance glaciers: examples from the Loch Leven and Glencoe areas. *Scottish Journal of Geology*, 17, 49-64.

- Tipping, R.M.** 1984. *The Late Devensian and Early Flandrian vegetational history and deglacial chronology of western Argyll*. Unpublished Ph.D. Thesis, City of London Polytechnic.
- Tipping, R.M.** 1986. A late-Devensian pollen site in Cowal, south-west Scotland. *Scottish Journal of Geology*, 22, 27-40.
- Tipping, R.M.** 1988. The recognition of glacial retreat from palynological data: a review of recent work in the British Isles. *Journal of Quaternary Science*, 3, 171-182.
- Vasari, Y.** 1977. Radiocarbon dating of Lateglacial and Early Flandrian vegetation successions in the Scottish Highlands and Isle of Skye. In: Gray, J.M. and Lowe, J.J. (eds) *Studies in the Scottish Lateglacial Environment*. Oxford: Pergamon Press, 143-162.
- Vasari, Y. & Vasari, A.** 1968. Late- and Post-glacial macrophytic vegetation in the lochs of northern Scotland. *Acta Botanica Fennica*, 80, 1-20.
- Vere, D.M. & Benn, D.I.** 1989. Structure and debris characteristics of medial moraines in Jotunheimen, Norway: implications for moraine classification. *Journal of Glaciology*, 35, 276-280.
- Walker, M.J.C.** 1984. Pollen analysis and Quaternary research in Scotland. *Quaternary Science Reviews*, 3, 369-404.
- Walker, M.J.C., Ballantyne, C.K., Lowe, J.J. & Sutherland, D.G.** 1988. A reinterpretation of the Lateglacial environmental history of the Isle of Skye, Inner Hebrides, Scotland. *Journal of Quaternary Science*, 4, 95-108.
- Walker, M.J.C. & Harkness, D.D.** 1990. Radiocarbon dating the Devensian Lateglacial in Britain: new evidence from Llanilid, South Wales. *Journal of Quaternary Science*, 5, 135-144.
- Walker, M.J.C. & Lowe, J.J.** 1982. Lateglacial and early Flandrian chronology of the Isle of Mull, Scotland. *Nature*, 296, 558-561.
- Walker, M.J.C. & Lowe, J.J.** 1985. Flandrian environmental history of the Isle of Mull, Scotland. I. Pollen stratigraphic evidence and radiocarbon dates from Glen More, south-central Mull. *New Phytologist*, 99, 587-610.
- Walker, M.J.C. & Lowe, J.J.** 1987. Flandrian environmental history of the Isle of Mull, Scotland, III. A high-resolution pollen profile from Gribun, western Mull. *New Phytologist*, 106, 333-347.

- Tipping, R.M.** 1984. *The Late Devensian and Early Flandrian vegetational history and deglacial chronology of western Argyll*. Unpublished Ph.D. Thesis, City of London Polytechnic.
- Tipping, R.M.** 1986. A late-Devensian pollen site in Cowal, south-west Scotland. *Scottish Journal of Geology*, 22, 27-40.
- Tipping, R.M.** 1988. The recognition of glacial retreat from palynological data: a review of recent work in the British Isles. *Journal of Quaternary Science*, 3, 171-182.
- Vasari, Y.** 1977. Radiocarbon dating of Lateglacial and Early Flandrian vegetation successions in the Scottish Highlands and Isle of Skye. In: Gray, J.M. and Lowe, J.J. (eds) *Studies in the Scottish Lateglacial Environment*. Oxford: Pergamon Press, 143-162.
- Vasari, Y. & Vasari, A.** 1968. Late- and Post-glacial macrophytic vegetation in the lochs of northern Scotland. *Acta Botanica Fennica*, 80, 1-20.
- Vere, D.M. & Benn, D.I.** 1989. Structure and debris characteristics of medial moraines in Jotunheimen, Norway: implications for moraine classification. *Journal of Glaciology*, 35, 276-280.
- Walker, M.J.C.** 1984. Pollen analysis and Quaternary research in Scotland. *Quaternary Science Reviews*, 3, 369-404.
- Walker, M.J.C., Ballantyne, C.K., Lowe, J.J. & Sutherland, D.G.** 1988. A reinterpretation of the Lateglacial environmental history of the Isle of Skye, Inner Hebrides, Scotland. *Journal of Quaternary Science*, 4, 95-108.
- Walker, M.J.C. & Harkness, D.D.** 1990. Radiocarbon dating the Devensian Lateglacial in Britain: new evidence from Llanilid, South Wales. *Journal of Quaternary Science*, 5, 135-144.
- Walker, M.J.C. & Lowe, J.J.** 1982. Lateglacial and early Flandrian chronology of the Isle of Mull, Scotland. *Nature*, 296, 558-561.
- Walker, M.J.C. & Lowe, J.J.** 1985. Flandrian environmental history of the Isle of Mull, Scotland. I. Pollen stratigraphic evidence and radiocarbon dates from Glen More, south-central Mull. *New Phytologist*, 99, 587-610.
- Walker, M.J.C. & Lowe, J.J.** 1987. Flandrian environmental history of the Isle of Mull, Scotland, III. A high-resolution pollen profile from Gribun, western Mull. *New Phytologist*, 106, 333-347.

- Walker, M.J.C. & Lowe, J.J.** 1990. Reconstructing the environmental history of the last glacial-interglacial transition: evidence from the Isle of Skye, Inner Hebrides, Scotland. *Quaternary Science Reviews*, 9, 15-49.
- Walther, M.** 1984. *Geomorphologische Untersuchungen zum Spätglazial und Frühholozän in den Cuillin Hills (Insel Skye, Schottland)*. Unpublished Ph.D. Thesis, Free University of Berlin.
- Washburn, A.L.** 1979. *Geocryology: a survey of periglacial processes and environments*. London: Arnold.
- Watts, W.A.** 1963. Late-glacial pollen zones in western Ireland. *Irish Geography*, 4, 367-376.
- Watts, W.A.** 1985. Quaternary vegetation cycles. In: Edwards, K.J. & Warren, W.P. (eds.) *The Quaternary History of Ireland*. London: Academic Press, 155-185.
- Williams, W.** 1977. *The Flandrian vegetational history of the Isle of Skye and Morar Peninsula*. Unpublished Ph.D. thesis, University of Cambridge.
- Whittow, J.B.** 1977. *Geology and Scenery in Scotland*. Harmondsworth: Penguin Books.
- Wright, W.B.** 1911. On a preglacial shoreline in the Western Isles of Scotland. *Geological Magazine*, 8, 97-109.

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The main meetings of the Association are the Annual Field Meeting, usually lasting 3 or 4 days, held in April, and a 1 or 2 day Discussion Meeting held at the beginning of January. Additionally, short field meetings may be held in May or September and occasionally these visit overseas locations. Short Study Courses on the techniques used in Quaternary work are also held. The publications of the Association are the *Quaternary Newsletter* issued with the Association's *Circular* in February, June and November, the *Journal of Quaternary Science* published in association with Wiley (4 issues per year), the Field Guides Series and the Technical Guides Series.

The Association is run by an executive committee elected at an annual general meeting held during the April Field Meeting. The current officers of the Association are:

President	Professor G.S. Boulton	<i>Grant Institute of Geology, University of Edinburgh, West Mains Road, Edinburgh EH9 3JW, Scotland.</i>
Vice-President	Professor W.A. Watts	<i>Provost's House, Trinity College, Dublin 2, Ireland.</i>
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All questions regarding membership are dealt with by the Secretary, the Association's publications are sold by the Assistant Secretary (Publications) and all subscription matters are dealt with by the Treasurer.

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