Quaternary of Scotland

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Chapter 6

North-west Highlands

INTRODUCTION

D. G. Sutherland

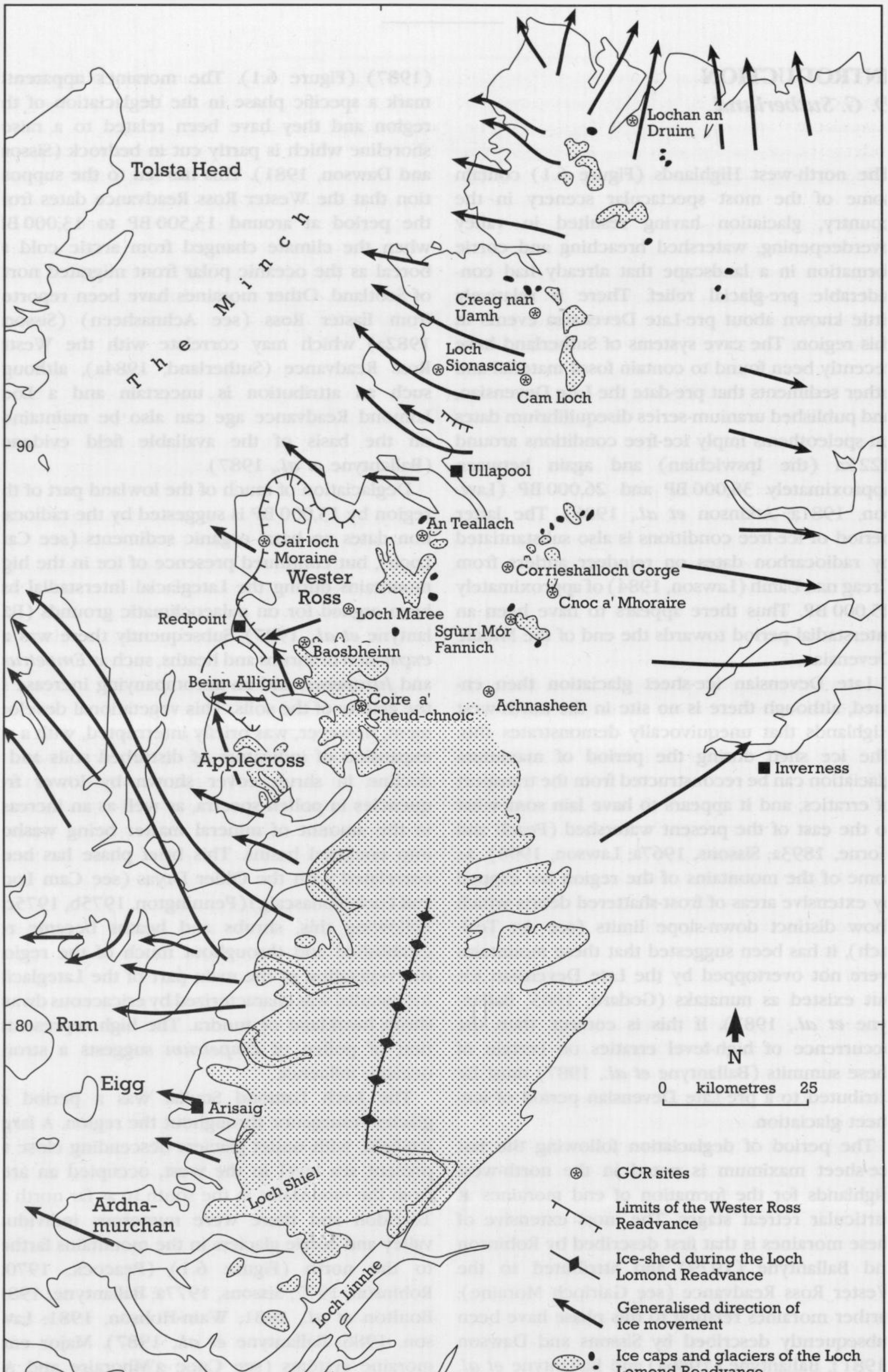
The north-west Highlands (Figure 6.1) contain some of the most spectacular scenery in the country, glaciation having resulted in valley overdeepening, watershed breaching and corrie formation in a landscape that already had considerable pre-glacial relief. There is relatively little known about pre-Late Devensian events in this region. The cave systems of Sutherland have recently been found to contain fossil material and other sediments that pre-date the Late Devensian, and published uranium-series disequilibrium dates on speleothems imply ice-free conditions around 122 ka (the Ipswichian) and again between approximately 38,000 BP and 26,000 BP (Lawson, 1981a; Atkinson *et al.*, 1986). The latter period of ice-free conditions is also substantiated by radiocarbon dates on reindeer antlers from Creag nan Uamh (Lawson, 1984) of approximately 25,000 BP. Thus there appears to have been an interstadial period towards the end of the Middle Devensian.

Late Devensian ice-sheet glaciation then ensued, although there is no site in the north-west Highlands that unequivocally demonstrates this. The ice shed during the period of maximum glaciation can be reconstructed from the transport of erratics, and it appears to have lain somewhat to the east of the present watershed (Peach and Horne, 1893a; Sissons, 1967a; Lawson, 1990). As some of the mountains of the region are capped by extensive areas of frost-shattered debris which show distinct down-slope limits (see An Teallach), it has been suggested that these mountains were not overtopped by the Late Devensian ice but existed as nunataks (Godard, 1965; Ballantyne *et al.*, 1987). If this is correct, then the occurrence of high-level erratics on certain of these summits (Ballantyne *et al.*, 1987) must be attributed to a pre-Late Devensian period of ice-sheet glaciation.

The period of deglaciation following the last ice-sheet maximum is noted in the north-west Highlands for the formation of end moraines at particular retreat stages. The most extensive of these moraines is that first described by Robinson and Ballantyne (1979) and attributed to the Wester Ross Readvance (see Gairloch Moraine); further moraines relating to this phase have been subsequently described by Sissons and Dawson (1981), Ballantyne (1986a) and Ballantyne *et al.* (1987) (Figure 6.1). The moraines apparently mark a specific phase in the deglaciation of the region and they have been related to a raised shoreline which is partly cut in bedrock (Sissons and Dawson, 1981). This has led to the supposition that the Wester Ross Readvance dates from the period at around 13,500 BP to 13,000 BP, when the climate changed from arctic cold to boreal as the oceanic polar front migrated north of Scotland. Other moraines have been reported from Easter Ross (see Achnasheen) (Sissons, 1982a) which may correlate with the Wester Ross Readvance (Sutherland, 1984a), although such an attribution is uncertain and a Loch Lomond Readvance age can also be maintained on the basis of the available field evidence (Ballantyne *et al.*, 1987).

Deglaciation of much of the lowland part of the region by 13,000 BP is suggested by the radiocarbon dates on basal organic sediments (see Cam Loch), but continued presence of ice in the high mountains during the Lateglacial Interstadial has been argued for on palaeoclimatic grounds (Ballantyne *et al.*, 1987). Subsequently there was an expansion of shrubs and heaths, such as *Empetrum* and *Juniperus*, and an accompanying increase in the acidity of the soils. This vegetational development, however, was briefly interrupted, with a re-expansion of indicators of disturbed soils and a decline in shrub cover shown by lower frequencies in pollen spectra, as well as an increase in the amount of mineral matter being washed into enclosed basins. This brief phase has been correlated with the Older Dryas (see Cam Loch and Loch Sionascaig) (Pennington, 1975b, 1975c). Following this, shrubs and heaths became re-established and throughout much of the region the vegetation of the main part of the Lateglacial Interstadial was characterized by ericaceous dwarf-shrub heathland or tundra. The high representation of pollen of *Empetrum* suggests a strong oceanic influence.

The Loch Lomond Stadial was a period of glacier resurgence throughout the region. A large ice-field, with outlet glaciers descending close to present sea level in the west, occupied an area from the mountains in the south to as far north as Torridon and there were numerous individual valley and corrie glaciers in the mountains farther to the north (Figure 6.1) (Peacock, 1970a; Robinson, 1977; Sissons, 1977a; Ballantyne, 1981; Boulton *et al.*, 1981; Wain-Hobson, 1981; Lawson, 1986; Ballantyne *et al.*, 1987). Major end-moraine systems (see Cnoc a'Mhoraire and An



Lochan an Druim
Tolsta Head
Minch
Creag nan Uamh
Loch Sionascaig
Cam Loch
90
Ullapool
An Teallach
Gairloch Moraine
Wester Ross
Corrieshalloch Gorge
Cnoc a' Mhoraire
Redpoint
Loch Maree
Sgùrr Mór Fannich
Baosbheinn
Beinn Alligin
Coire a' Cheud-chnoic
Achnasheen
Applecross
Inverness
80
Rum
N
0 kilometres 25
Eigg
Arisaig
Loch Shiel
Ardnamurchan
Loch Linnhe
20
GCR sites
Limits of the Wester Ross Readvance
Ice-shed during the Loch Lomond Readvance
Generalised direction of ice movement
Ice caps and glaciers of the Loch Lomond Readvance

Teallach) and abundant hummocky moraines (see Coire a'Cheud-chnoic) were deposited by these glaciers and are prominent elements of the modern scenery of the valleys of the north-west Highlands. Periglacial processes were particularly active in the unglaciated areas at this time, and the major periglacial landforms on the mountain summits received their final fashioning, even though the frost-weathered detritus on certain summits was derived from earlier periods of periglaciation. Two of the most spectacular landforms of the region, the Baosbheinn protalus rampart (Sissons, 1976c) and the Beinn Alligin rock glacier (Sissons, 1975a), formed at this time, with landslides being important in the formation of each (Ballantyne, 1986a).

The vegetation during this period was characteristic of open tundra, with large areas of disturbed ground. At Creag nan Uamh a cache of reindeer bones, which has been radiocarbon dated to the stadial, raises the possibility that Man was present in the area at the time, despite the severity of the climate (Lawson and Bonsall, 1986a, 1986b).

The change in climate at the end of the stadial was marked by a regular plant succession from dwarf-shrub tundra, through a juniper-dominated phase to, at around 9000 BP, the expansion of first birch and then birch–hazel woodland (see Loch Maree and Loch Sionascaig). Latterly in the southern part of the region, communities of oak and elm became established in favourable localities (Moore, 1977; Williams, 1977), but by around 8300 BP pine appeared, apparently earlier at certain sites in Wester Ross and farther north (see Loch Maree) compared with sites farther south, and even compared with neighbouring sites in the region (Loch Clair, Pennington *et al.*, 1972). In the northern part of the region there was probably only a brief phase of pine expansion in what was predominantly a birch-forest zone (see Lochan an Druim).

Reduction in the forest cover began around 5000 BP to 4000 BP, with accompanying expansion of blanket bog, possibly due to a climatic change to cooler and moister conditions. The role of Man in this process, although apparent farther south, remains to be clearly demonstrated in this region. Extensive clearance of birch forest in the last 1500 years can be more directly attributed to human activity.

Sea-level changes around the coasts have not been studied in detail. Following the phase of high sea level accompanying ice-sheet decay, there appears to have been a long period when sea level was below that of the present, and the only evidence for later higher sea levels is the sequence of beaches formed at the maximum of the Main Postglacial Transgression and subsequently. None of these shorelines has been dated, although by comparison with elsewhere in Scotland they can be presumed to have been formed during approximately the last 6000 years.

During the Holocene the mountain summits have continued to be the focus of periglacial activity, albeit at an intensity much reduced from the Loch Lomond Stadial. Small-scale patterned-ground features occur on many summits, and down-slope movement of detritus is recorded by buried organic horizons under solifluction lobes and terraces (White and Mottershead, 1972). A recent increase in such activity may be indicated by the soil horizon buried near Sgùrr Mór in the Fannich mountains in the last few hundred years (Ballantyne, 1986c). On An Teallach a notable feature is the extensive deposit of wind-blown sand with interstratified organic horizons. Following deposition of much of the sand during the early Holocene there has been a recent resurgence in sand blowing, possibly as a consequence of grazing pressure (Ballantyne and Whittington, 1987).

Figure 6.1 Location map and principal glacial features of the north-west Highlands (modified from Johnstone and Mykura, 1989).

GAIRLOCH MORAINE

C. K. Ballantyne

Highlights

This site demonstrates the best representative assemblage of landforms associated with the Gairloch Moraine, a feature formed by the Wester Ross Readvance of the Late Devensian ice-sheet.

Introduction

The Gairloch Moraine (NG 792815) extends over a distance of about 10.5 km in a north–south direction across the peninsula between Loch Gairloch and Loch Ewe. It provides important

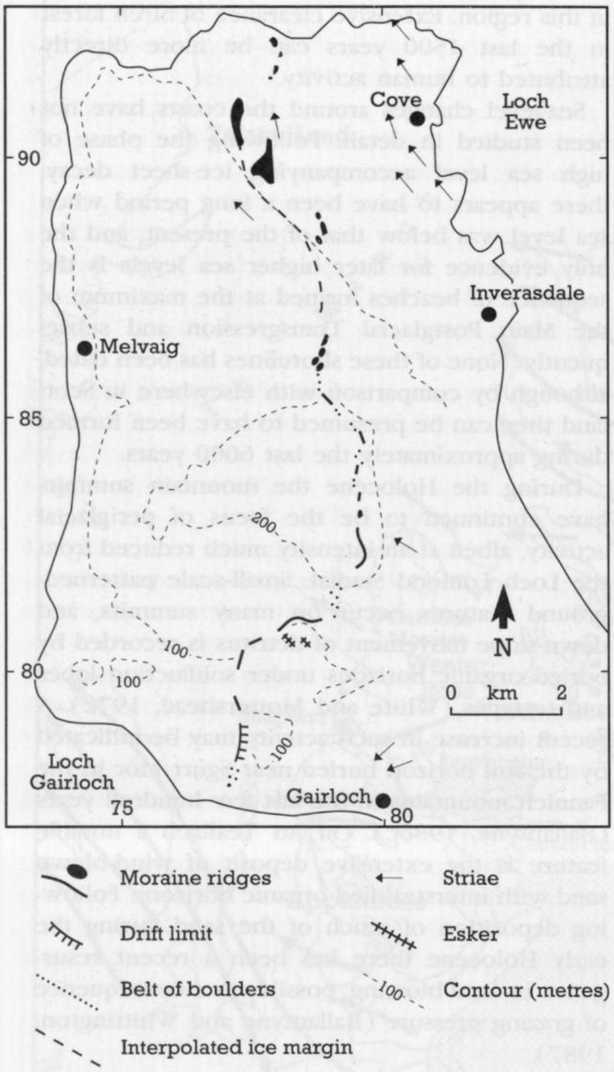


Figure 6.2 The Gairloch Moraine and associated landforms (from Robinson and Ballantyne, 1979).

geomorphological evidence demonstrating a re-advance of the Late Devensian ice-sheet in north-west Scotland, the Wester Ross Readvance, which has been identified so far over an area extending from Applecross to north of Loch Broom (Robinson and Ballantyne, 1979). The only published description of the site is by Robinson and Ballantyne (1979).

Description

The Gairloch Moraine marks the western limit of a former glacier nearly 25 km across, which occupied Loch Gairloch and Loch Ewe and the intervening low ground (Robinson and Ballantyne, 1979). The moraine (Figure 6.2) can be traced northwards from a point (NG 771780) 3 km west-north-west of Gairloch, where the former ice margin is marked by a belt of boulders and a drift limit. This is continued northwards and westwards by a discontinuous moraine ridge up to 4 m high. A pair of beaded eskers up to 10 m high terminates just east of this ridge. From NG 797821 to NG 789866, the moraine takes the form of a well-marked, though discontinous, boulder ridge 4 km long (Figure 6.3). At the foot of the Loch Maree fault-line scarp the former glacier limit is represented by broad till ridges (for example, near NG 778901), although the moraine resumes its bouldery character 1 km from the coast, at NG 780915. The total length of the former ice margin delimited by the Gairloch Moraine is about 10.5 km. The form of the moraine is very similar to that of the moraines associated with the Inland Ice near Søndre Strømfjord in West Greenland (see Ten Brink and Weidick, 1974; Ten Brink, 1975). Like these, it runs across country for long distances over low undulating topography, with loops extending down the main valleys.

Local equivalents of the Gairloch Moraine, comprising boulder ridges, moraine ridges and drift limits, have been identified on the Redpoint and Applecross peninsulas near Aultbea, on An Teallach (Robinson, 1977, 1987b; Robinson and Ballantyne, 1979; Sissons and Dawson, 1981) and on the flank of Ben Mór Coigach (Sutherland, 1984a, figure 10). Robinson (1977) and Robinson and Ballantyne (1979) record that some of the individual features were first noted by officers of the Geological Survey on their manuscript maps, although their significance was not then recognized (but see Wright, 1937). However, a whole system of ice-marginal features has now been traced out (see Sutherland, 1984a) and interpreted on geomorphological grounds as marking the maximal extent of a glacial readvance, the Wester Ross Readvance (see Figure 6.1), that interrupted the retreat of the Late Devensian ice-sheet (Robinson and Ballantyne, 1979). This event is tentatively dated to 13,500–13,000 BP (Ballantyne *et al.*, 1987), the approximate time when the oceanic polar front migrated northwards of the west coast of Scotland (Ruddiman and McIntyre, 1973). Sissons and Dawson (1981) argued on glaciological grounds that a readvance is more probable than a stillstand. A readvance is also indicated by changes in the orientation of striae on either side of the Redpoint Moraine

Figure 6.3 The Gairloch Moraine, in the valley of the River Sand north-west of Gairloch, comprises a low ridge of boulders. (Photo: J. E. Gordon.)

(Robinson and Ballantyne, 1979), but it is as yet unconfirmed by stratigraphic evidence and is of unknown magnitude. The presence of an end moraine, however, demonstrates active retreat of the last ice-sheet in this area.

Interpretation

In the past, numerous readvances of the Late Devensian ice-sheet in Scotland have been proposed (see the reviews in Sissons, 1967a, 1974c and 1976b; and also Charlesworth, 1926b, 1956; Synge, 1966, 1977b; Synge and Stephens, 1966; Smith, 1977; Synge and Smith, 1980), but the evidence for most of these has now been reinterpreted (see reviews in Sissons, 1974c, 1976b; Gray and Sutherland, 1977; Sutherland, 1984a). The evidence from Wester Ross, however, and particularly the continuity of the ice-marginal features across large tracts of country, appears to substantiate a readvance. Significantly, also, the marine limit outside the moraine represents a broadly synchronous shoreline formed at approximately the same time as the moraine (Sissons and Dawson, 1981).

Relationships between the Wester Ross Moraine and former ice limits elsewhere are uncertain (Ballantyne *et al*., 1987). For example, Smith (1977) and Synge (1977b) described a putative readvance limit at Ardersier (but see Firth, 1989b), and D. J. Balfour (unpublished data) has identified former ice limits near the mouths of a number of valleys on the north coast of Sutherland. Sissons and Dawson (1981) considered the possibility that the Wester Ross Readvance might relate to former ice limits associated with sharp drops in the marine limit at Stirling (Sissons *et al*., 1966) and Otter Ferry (Sutherland, 1981b) and to a stillstand or readvance suggested by Peacock (1970a) in Inverness-shire. However, the evidence is conflicting (Sutherland, 1984a). On the one hand, the gradient of the Main Wester Ross Shoreline associated with the moraine is similar to that of the Main Perth Shoreline which terminates inland near Stirling. In contrast, the gradual drop in the marine limit as the ice retreated from the Wester Ross Moraine appears to argue against such correlations (Sissons and Dawson, 1981). Ballantyne (1988) has also suggested that the readvance may be represented by the 'Strollamus Moraine' in southern Skye, but subsequently reinterpreted the latter as a medial moraine deposited at the convergence of two ice streams (Ballantyne and Benn, 1991).

Similarly, it is not possible to substantiate correlations with the end moraines described in Easter Ross (Sissons, 1982a; Sutherland, 1984a; Ballantyne *et al.*, 1987) for it is as yet unclear which of those moraines relate to ice-sheet deglaciation and which relates to the Loch Lomond Readvance.

The continuity and extent of the Wester Ross Moraine is of considerable importance in providing the clearest geomorphological evidence yet for a readvance of the Late Devensian ice-sheet in Scotland. This evidence is particularly well developed in the Gairloch area where the features marking the ice limit are all clearly demonstrated and seen in close geographical association – drift limits, boulder ridges and till ridges. Here too, eskers occur as part of the landform assemblage. The Gairloch Moraine site may therefore be regarded as the single most important locality demonstrating key geomorphological features of the Wester Ross Readvance. Elsewhere, other aspects of the readvance are represented at An Teallach, notably the relationship with Loch Lomond Readvance moraines.

Conclusion

This site demonstrates an end moraine and other landforms formed by a readvance (the Wester Ross Readvance) of the Late Devensian ice-sheet, about 13,500–13,000 years ago. It includes the best assemblage of landforms that mark the former limit of the ice and is therefore an important reference locality for the geomorphological expression of the event.

ACHNASHEEN

J. E. Gordon and D. G. Sutherland

Highlights

The landforms and deposits at Achnasheen are outstanding examples of glaciofluvial outwash and delta terraces formed by meltwater deposition in an ice-dammed lake during the Loch Lomond Stadial. They are also important for studies of sedimentation in a glacial lake environment.

Introduction

The Achnasheen site (NH 160575) covers an area of 4 km^2 at the western end of Strath Bran at its junction with the through valleys leading to Strath Carron and Glen Docharty. It is important for its particularly fine suite of outwash delta terraces and ice-marginal landforms, which are related to a former ice-dammed lake and associated glacier limits in Strath Bran. It is also important in demonstrating two contrasting styles of sedimentation in the ice-dammed lake. Early accounts of the site were given by Nicol (1844), Campbell (1865), Milne Home (1878), Lucy (1886), Morrison (1888), Geikie (1901) and Peach *et al.* (1913b); more recently it has been studied by Sissons (1982a), Sutherland (1987a) and Benn (1989a). The interest of the site and the formation of the terraces is also summarized by Benn (1992).

Description

The terraces extend eastwards from Loch a'Chroisg and north-eastwards from Loch Gowan to the vicinity of Achnasheen (Figure 6.4). The most prominent features occur to the east of the Abhainn a'Chomair and between the Abhainn a'Chomair and the Abhainn Loch Chroisg (see figure 79 in Geikie, 1901; and plate 8 in Peach *et al.*, 1913b). In both areas the terraces comprise very conspicuous high-level surfaces and varying numbers of lower fragments down to the present river floodplains (Figures 6.4 and 6.5). At their maximum height the terraces are up to 25–30 m above the floodplains. Sissons (1982a) mapped and levelled the terraces in detail, showing the terrace north-east of Loch Gowan to descend from 191 m to 175 m OD over a distance of about 850 m (gradient of 19 m km^{-1}) and the terrace east of Loch a'Chroisg to fall from 185 m to 176 m OD in about 500 m (gradient of 18 m km^{-1}). Kettle holes occur on the proximal parts of the highest terraces, and the western and southern margins of those terraces near Loch a'Chroisg and Loch Gowan, respectively, are demarcated by sharply defined ice-contact slopes. Irregular drift mounds occur on the valley sides above the ice-contact features and Sissons (1982a)

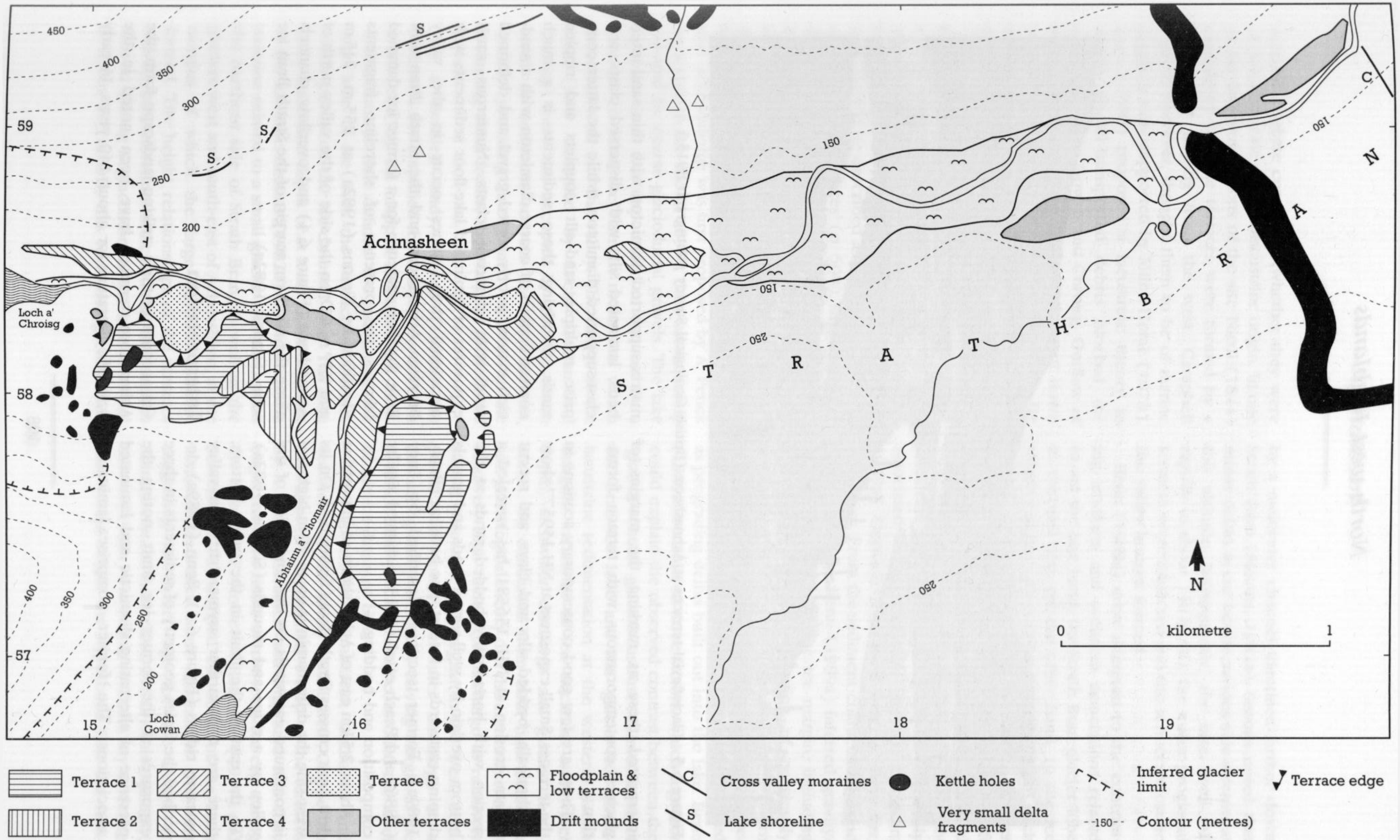


Figure 6.4 Geomorphology of the Achnasheen area (from Sissons, 1982a).

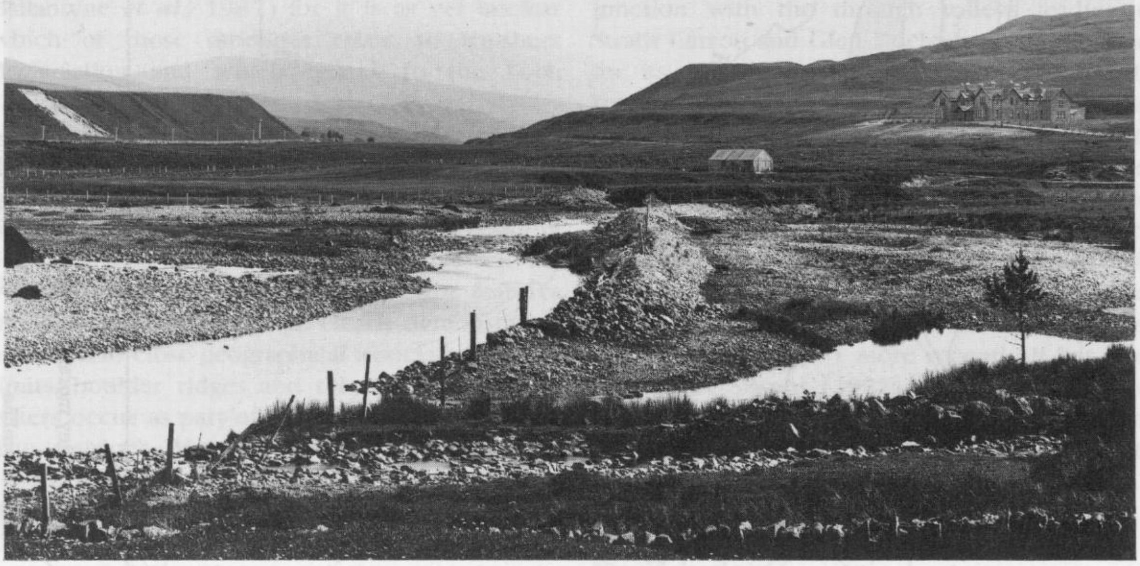


Figure 6.5 Glaciofluvial terraces at Achnasheen. (British Geological Survey photograph B915.)

interpreted these as marking the margins of glaciers contemporaneous with terrace formation.

There are few good contemporary sections in the terraces. Small exposures at NH 159577 show rhythmically bedded silts and clays, and recent stream erosion at NH 156581 has revealed a section with horizontally bedded sands at the bottom overlain by well-sorted sands and gravels dipping eastwards in foreset-type bedding (Benn, 1989a). Former sections described by Lucy (1886) and Peach *et al.* (1913b) showed similar composition and bedding.

About 2.5 km east of Achnasheen an impressive drift limit crosses Strath Bran (Figure 6.4). On its west side the drift margin is up to 20 m high and is continued eastwards on the south side of the valley by a ridge and mounds (Sissons, 1982a). To the east of the limit in the valley bottom, there are two further asymmetric cross-valley moraine ridges (Figure 6.4). Benn (1989a) described the facies geometry of sediments in three exposures at the former ice limit, noting the presence of alternating diamictic and laminated associations. The former comprise laminated, matrix-supported diamicton with thin sand interbeds, laminated silts with dispersed clasts, and clast-supported diamicton, while the latter comprise multiple sand–silt couplets and rippled sands. Overlying these sediments is a much coarser deposit of coarse diamicton with a sand-rich matrix, poorly sorted gravel and deformed sand with abundant clasts. Numerous small exposures of laminated lake-floor sediments with occasional drop stones occur in the valley between Achnasheen and the Strath Bran drift limit. Further evidence for a former ice-dammed lake is the presence of shoreline fragments identified by Sissons (1982a) at 255 m, 245 m and 237 m OD on the side of the valley north of Achnasheen (Figure 6.4) and overflow channels along the southern margin of the Strath Bran ice lobe (Sissons, 1982a).

Interpretation

On account of their striking landscape form, the Achnasheen terraces have been noted in the scientific literature for about 140 years. In early accounts, debate centred on whether they were of fluvial, marine or glaciolacustrine origin. In one of the first descriptions of the site Nicol (1844) considered that the terraces were formed by a great river flowing from the west. Campbell (1865), however, thought them to be of marine origin, a view supported by Milne Home (1878). Lucy (1886) proposed a lacustrine theory in which glacier-transported debris blocked the outlets of Lochs Gowan and Chroisg. Outflow of water from these dammed lakes then cut down into the barriers and levelled the terraces. He envisaged three separate episodes of damming and overspill to cut the three main terraces.

Morrison (1888) explained the terraces as the beaches of a former lake in Strath Bran, formed at a time when vast quantities of meltwater were released on to low ground by melting glaciers. Geikie (1901, p. 294) developed this interpretation of what he described as a 'remarkable group of ancient lake terraces' (p. 508), suggesting that they were formed in a lake ponded in Strath Bran by the build up of snow and ice to the east. Peach *et al.* (1913b) concluded that the finer-grained deposits in the lower part of the sequence were laid down as a lake delta (an explanation which they acknowledge was first proposed by A. Penck on a visit to the site in 1895), then subsequently covered by coarse glaciofluvial gravels. The lake in Strath Bran was impounded to the east by a lobe of ice from the Fannich mountains which extended west into the valley. The valleys to the west (now occupied by Lochs Gowan and Chroisg) were also occupied by glaciers, which acted as sediment sources for the terraces, initially providing fine-grained material at the advancing delta fronts, then coarser glaciofluvial gravels.

In a detailed study, Sissons (1982a) has confirmed and amplified the conclusions of Peach *et al.* (1913b). He mapped moraines and meltwater features that defined the margin of the large lobe of ice from the Fannich mountains, which produced the ice-dammed lake. The lake had a maximum depth of at least 125 m adjacent to the ice lobe. Sissons (1982a) also identified a moraine related to a small glacier that descended the northern side of Strath Bran, as well as the glaciers west and south-east of Achnasheen, at the margins of which the large outwash terraces formed. The height relationships of the terraces and the lake shorelines indicated that the terraces formed during deglaciation as the lake level fell to about 175 m OD, this level being controlled by a meltwater channel identified farther down Strath Bran (Sissons, 1982a). Sissons noted that minor deltas occur beside various side streams at this altitude. Subsequently, the lake level fell rapidly to about 140 m OD, the major proglacial terraces were dissected and the terraces close to the valley bottom formed.

Benn (1989a) drew attention to the contrasting landform and sediment associations related to, on the one hand, the Strath Bran glacier lobe in the east and, on the other hand, to the ice tongues in the valleys of Loch a'Chroisg and Loch Gowan to the west. The Strath Bran glacier produced a large, asymmetric drift ridge and drift limit, with cross-valley moraines on its proximal side. The latter have been interpreted as sublacustrine in origin (Sissons, 1982a), possibly associated with a floating ice ramp (Benn, 1989a). Outwash terraces and deltas, however, are absent. From the sediment characteristics and facies variations, Benn (1989a) inferred gravity-flow sedimentation at the ice margin, including deformation and remobilization of previously deposited materials. In contrast, the western glacier margins are marked by the large ice-contact terraces described above, which formed as prograding deltas built out into the lake. Benn (1989a) considered three factors, which together could explain the observed contrast between the 'glacier-contact' glaciolacustrine sedimentation of the Bran ice lobe and the 'glacier-fed' glaciolacustrine sedimentation at the western glacier margins: variations in ice thickness and water depth, meltwater discharge and glacier fluctuations. He concluded from both field evidence and glaciological theory that the contrast reflected relatively high meltwater discharge at relatively stable, grounded ice margins in the west, compared with lower meltwater discharge at a fluctuating and periodically calving margin of the Bran ice lobe which directly controlled the level of the ice-dammed lake.

The age of the Achnasheen landforms and sediments is not firmly established. Clapperton (1977, p. 31) reproduced a map of the terraces by A. M. D. Gemmell and suggested that they might mark the limits of 'the local ice cap during the Late-glacial'. However, Robinson (1977) and Sissons (1977a) mapped the limits of the Loch Lomond Readvance some distance to the west suggesting an earlier age for the events at Achnasheen (cf. Sutherland, 1984a). Subsequently, Sissons (1982a) was unable to locate any evidence that would refute the hypothesis that the Achnasheen ice limits and terraces were related to the Loch Lomond Readvance. Similarly, Ballantyne *et al.* (1987) concluded that there was no evidence to discount a Loch Lomond Stadial age for the deposits; of particular relevance was the apparent absence of Lateglacial Interstadial deposits within the ice limits.

The Achnasheen terraces are the best known example of a suite of outwash delta terraces in Scotland. They are one of the classic landform localities in the country (cf. Benn, 1992) and are important from both educational and scientific viewpoints in demonstrating terrace morphology and sedimentology. Achnasheen is also notable for a wider assemblage of glacial and glaciolacustrine landforms and sediments represented in a relatively compact area. These include end moraines, drift limits, cross-valley moraines, lake shorelines, ice-contact slopes and kettle holes. Recent work has further highlighted the value of the area for studies of glaciolacustrine sedimentation; two quite distinctive styles are represented and these provide a valuable opportunity to demonstrate and evaluate their relationships to reconstructed glacier, meltwater and lake-level controls. Achnasheen is therefore a key locality for glacial lake landforms and sediments.

The interests of Achnasheen complement those at several other sites in Scotland. The most comparable glacial lake outwash deltas are in Glen Spean (see Glen Roy and the Parallel Roads of Lochaber), but the terrace forms there are less clearly displayed than at Achnasheen, and the sediments have not been studied in detail; the origin of the terraces in Glen Roy (e.g. at Glen Turrett) is currently a matter of debate (see below). Detailed sedimentological studies and comparisons between the features at Achnasheen, in Lochaber and at Gartness (see below) would contribute towards a better understanding of glacial lake sedimentary environments in Scotland. In some cases individual landforms are equally or better developed elsewhere (for example, lake shorelines at Glen Roy, cross-valley moraines at Coire Dho), but Achnasheen is outstanding first, for the quality of its delta terraces; second, for a clear demonstration of some of the controls on glaciolacustrine sedimentation; and third, for the range of landforms and deposits developed in a relatively compact area. In their glacial lake associations, the Achnasheen landforms also differ genetically from the subaerial or marine-related terrace systems, for example, at Moss of Achnacree, Glen Feshie, Corran Ferry, Port a'Chuillin, Gruinard Bay, Glen Einich and Kilmartin Valley.

Conclusion

Achnasheen is a classic locality for a series of impressive outwash and delta terraces formed by glacial meltwater rivers that flowed into a lake dammed by glaciers in Strath Bran and adjacent valleys, probably during the Loch Lomond Stadial (about 11,000–10,000 years ago). The deposits are also significant for sedimentological studies, in particular for reconstructing the patterns and processes of sedimentation in glacial lakes and the factors that control them.

AN TEALLACH

C. K. Ballantyne

Highlights

An Teallach is a site of great importance for its assemblage of glacial and periglacial landforms. The interest includes a suite of moraines formed during different episodes of Late Devensian glaciation and outstanding examples of periglacial features, most notably deflation surfaces and mountain-top sand deposits.

Introduction

An Teallach (NH 038860) is located on the south side of Little Loch Broom, about 11 km south of Ullapool. It is one of the most spectacular mountains in north-west Scotland, rising to 1062 m OD, and supports many outstanding examples of glacial and periglacial features within a relatively small area (about 35 km^2). The landforms developed on and around An Teallach are typical of those of the Torridonian sandstone mountains, and several types are among the finest examples known (Ballantyne, 1984, 1987a, 1987b). The principal publications on the site are those of Peach *et al.* (1913a), Godard (1965), Sissons (1977a), Robinson and Ballantyne (1979), Ballantyne (1981, 1984, 1985, 1986b, 1987a, 1987b), Ballantyne and Eckford (1984), Ballantyne and Whittington (1987) and Benn (1989b).

Description

Abundant striae and chattermarks on both Torridonian sandstone and Cambrian Quartzite indicate that, during the Late Devensian ice-sheet glaciation, ice moving from the east and south-east was deflected around the flanks of An Teallach. The upper slopes and plateau areas of the mountain are mantled by a thick cover of frost-weathered detritus, which contrasts with the ice-moulded surfaces of the lower slopes, and as the transition from one type of surface to the other (at around 700 m OD) is apparently too abrupt to be explained by a climatic difference, it may be that the upper part of the mountain was not glaciated at the time of the last ice-sheet maximum (Reed, 1988). However, erratics are found at altitudes of up to 900 m OD (Peach *et al.*, 1913a), including a remarkable high-level train of Cambrian Quartzite erratics on the northern plateau. Such erratics indicate glaciation from the east-south-east, and may relate to an earlier period of more extensive ice-sheet glaciation (Ballantyne, 1987b).

A sequence of three end or lateral moraines is found in the broad valley west of the massif (Figure 6.6: a,b,c); this provides evidence that the retreat of the last ice-sheet was interrupted by local stillstands or readvances. These have been tentatively correlated with the Wester Ross Readvance by Robinson and Ballantyne (1979). A massive drift ridge over 1 km long at the north-east end of the valley (Figure 6.6: d) has been interpreted as a medial moraine deposited when ice in this valley parted from that occupying Little Loch Broom to the north.

During the Loch Lomond Readvance six separate corrie glaciers existed on An Teallach (Figure 6.6) (Sissons, 1977a; Ballantyne, 1987b), their limits being marked by striking end moraines, rising by as much as 30 m above the adjacent bare Torridonian bedrock in one example (at NH 092846) and, in the case of the former Coire Toll an Lochain glacier (Figures 6.6: 6, and 6.7), by a superb drift limit. On the north-west side of the mountain, below Mac is Màthair, one glacier (Figure 6.6: 2) formed a sequence of five nested boulder moraines, the outermost truncating a moraine associated with the Wester Ross Readvance (Robinson and Ballantyne, 1979; Ballantyne, 1987b). Controls on moraine asymmetry and debris transport in two of the eastern corries are discussed by Benn (1989b): moraine asymmetry strongly correlates with the distribution of source cliffs which principally reflects climatic controls.

Periglacial landforms are particularly well-developed on An Teallach (Figure 6.8). The frost-weathered detritus of plateau and summit areas underlain by Torridonian sandstone rarely exceeds 1 m in depth and consists of slabs embedded in a coarse sandy matrix. The slabs were produced by frost wedging along pseudobedding planes during the Late Devensian, the sand by the granular disintegration of rock surfaces. The latter process continues today. In contrast, on summit outcrops of Cambrian Quartzite, openwork blockfields and blockslopes are composed of more angular detritus, since quartzite is generally less susceptible to granular disintegration. In places (for example, NG 085845) Cambrian Quartzite blockslope material has moved downslope under the action of frost creep, completely covering the underlying Torridonian sandstone strata. The periglacial features of the upper slopes and plateaux of the massif may be subdivided into relict and active. The stability of the relict features under present conditions is illustrated by the strong contrast in the roundness of exposed and buried clasts, the former being rounded and the latter angular. There are relatively few relict periglacial landforms, though boulder lobes averaging 10 m in width occur in the southern part of the massif (for example, NG 059852), shallow, though well-developed solifluction lobes occur downslope, and dubious examples of sorted circles are found on the northern plateau (Ballantyne, 1981). An example of a Loch Lomond Stadial protalus rampart exists at the foot of a relict talus slope in the north-western part of the massif at NH 054875 (Ballantyne and Kirkbride, 1986).

Among the active periglacial features are probably the finest assemblage of high-level aeolian and niveo-aeolian features in Great Britain. Deflation of the extensive plateau surfaces with their sandy regolith has its counterpart in the accumulation of sand-sheets on flanking slopes (Godard, 1965; Ballantyne and Whittington, 1987). The deposits are up to 4 m in thickness at the crest of lee slopes, although they rarely exceed 1.5 m elsewhere. A formerly more widespread sand cover is indicated by the occurrence of isolated sand 'islands' on high-level cols. Interbedded with the sands are organic horizons, and analysis of these for pollen content together with radiocarbon dating has indicated that the deposits began to accumulate in the early Holocene (Ballantyne and Whittington, 1987), but that

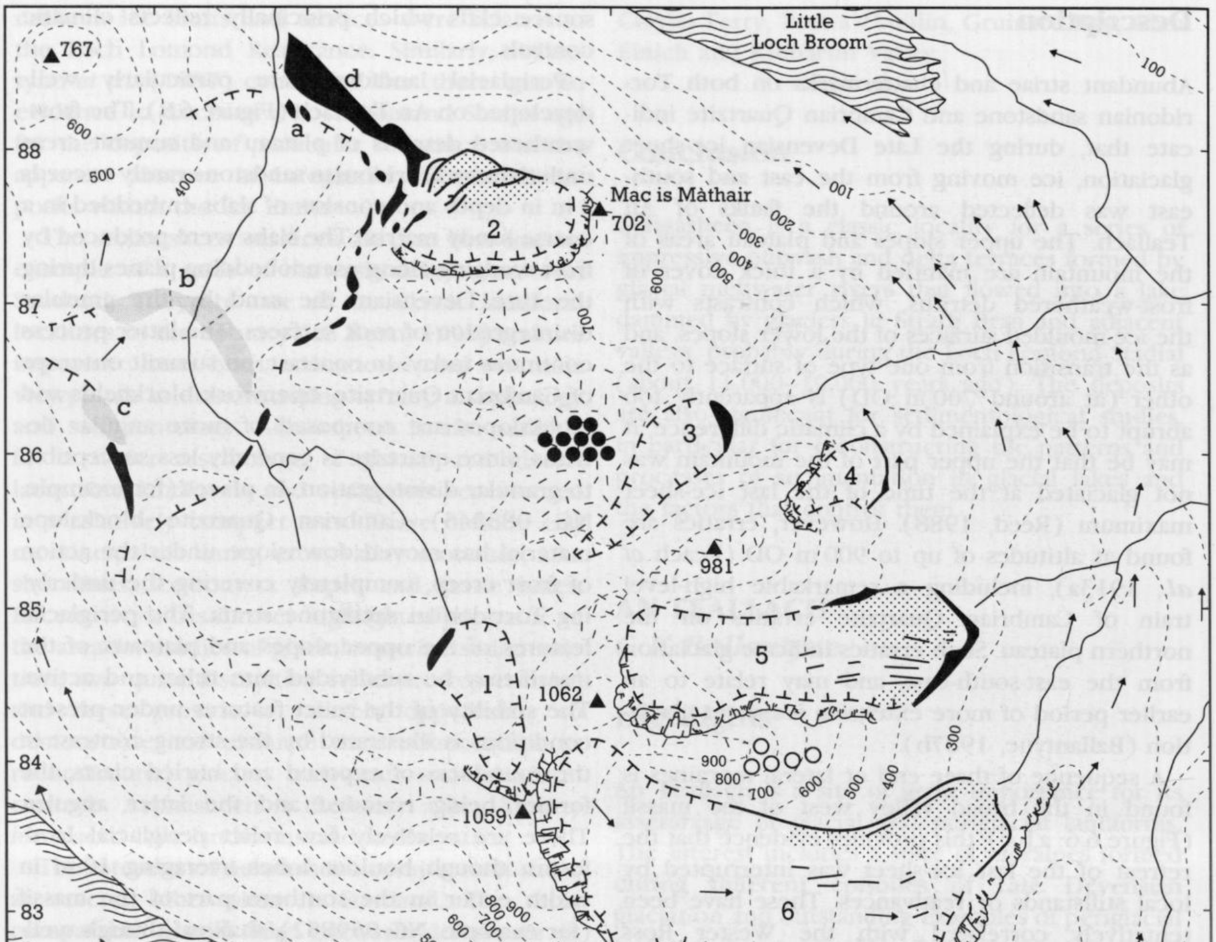


Figure 6.6 The An Teallach area, showing principal glacial features and the limits of former glaciers (from Ballantyne, 1987b).

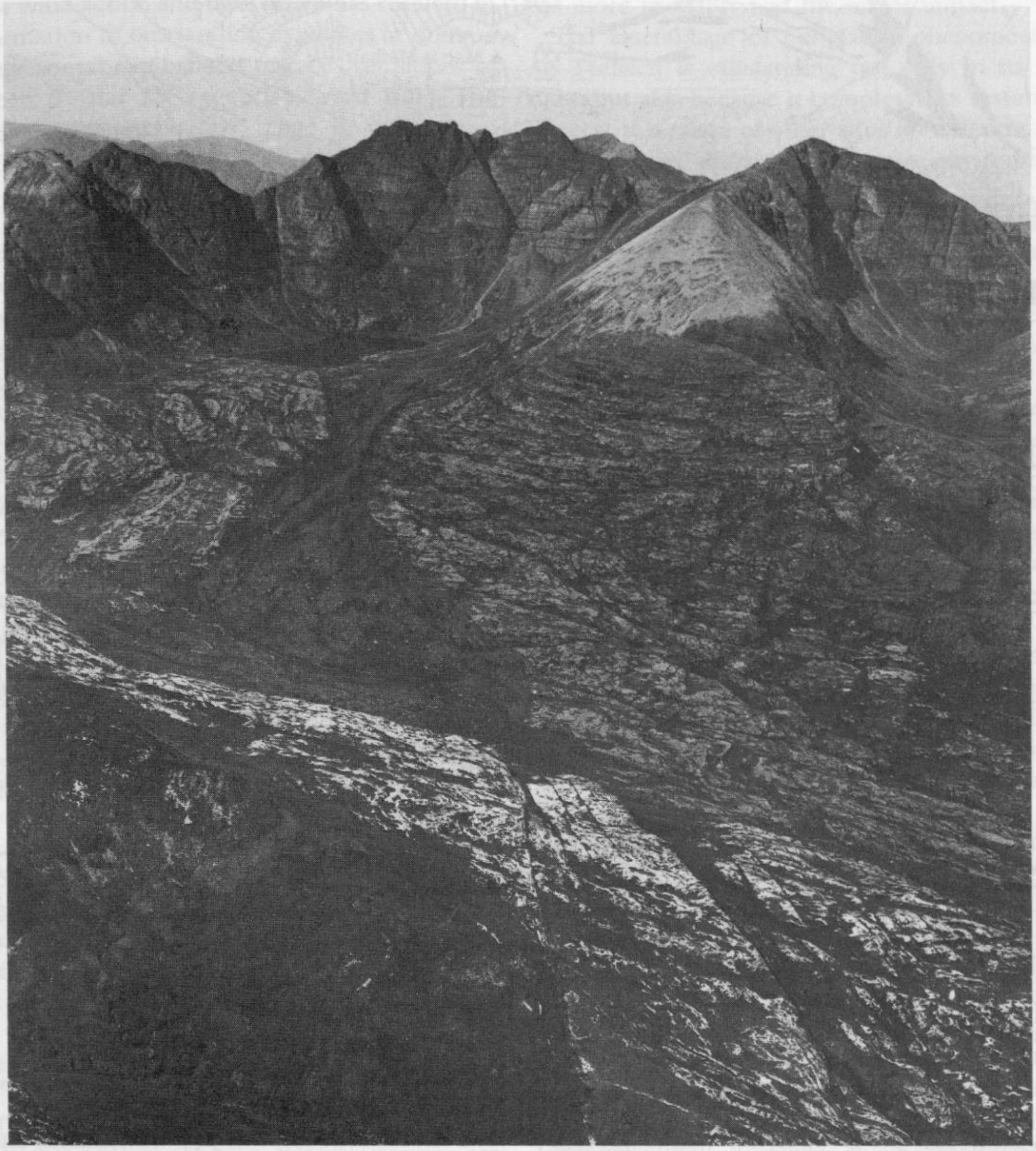


Figure 6.7 The east flank of An Teallach. A clear lateral moraine and drift limit (centre) mark the extent of the Loch Lomond Readvance glacier that occupied the corrie of Toll an Lochain. The ice-scoured Torridonian sandstone of the lower slopes contrasts with the frost-shattered slopes of the mountain ridge and the quartzite blockslopes on Glas Mheall Liath. (British Geological Survey photograph D2102.)

deposition virtually ceased in the late Holocene following establishment of a vegetation cover on the plateau areas upwind. Recent disruption of the vegetation has resulted in renewed accumulation of wind-blown sand on lee slopes.

Modification to the sand deposits has occurred by both selective eluviation by nival meltwater and scarp erosion, the former process producing large sand hummocks like thúfur (earth hummocks) (Ballantyne, 1986b), and the latter producing small nivation hollows. However, Ballantyne (1985) found that the effects of nivation were confined to localized erosion and transport of the unconsolidated niveo-aeolian sands. Despite some contrary evidence from northern England (Tufnell, 1971; Vincent and Lee, 1982), the present geomorphological role of nivation in the British uplands appears to be limited or at least localized (Ballantyne, 1985, 1987a).

Frost creep is active on unvegetated debris slopes on the Torridonian sandstone, producing an average downslope movement of surface

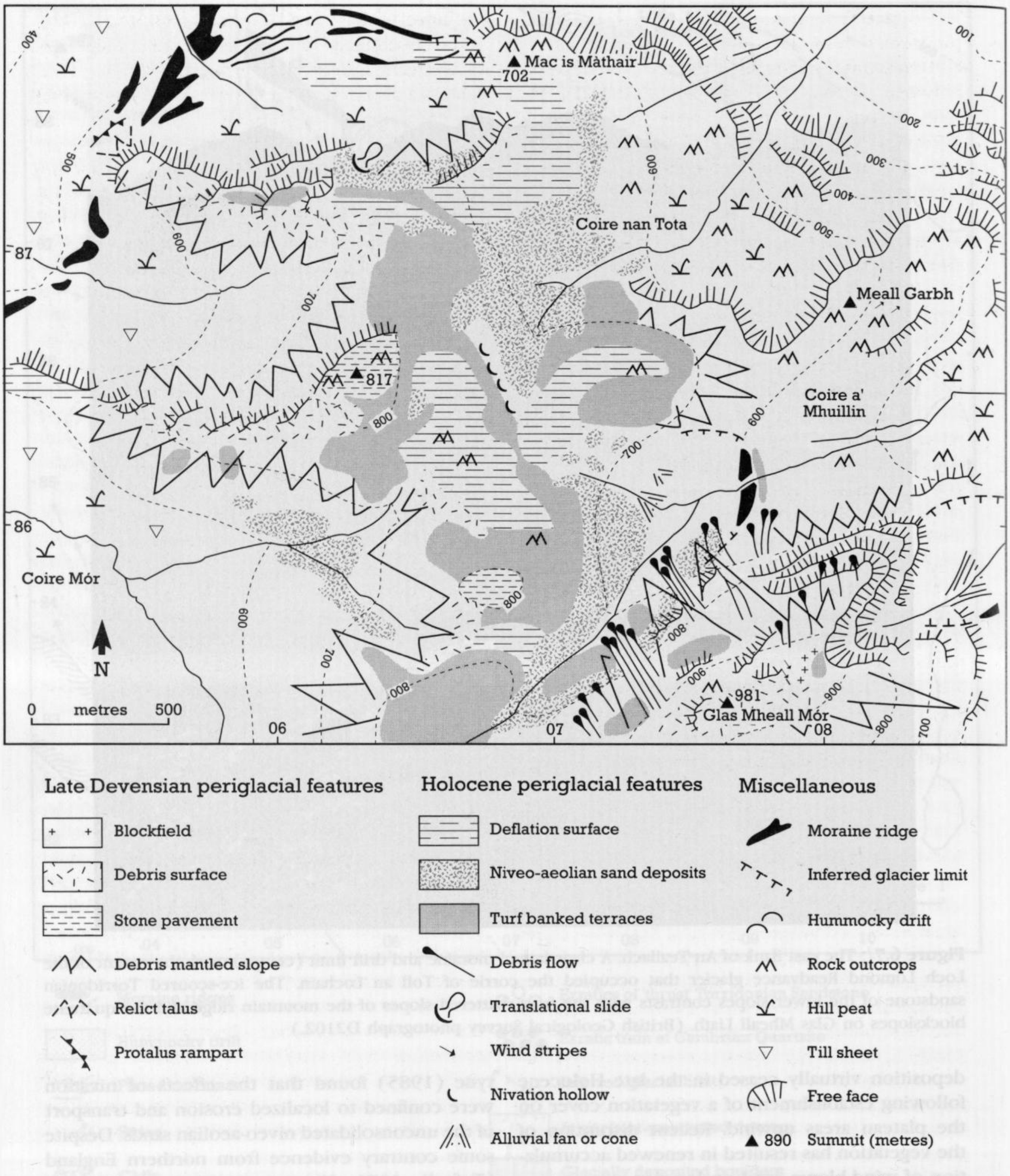


Figure 6.8 Periglacial landforms and deposits on the northern plateau of An Teallach (from Ballantyne, 1984).

stones around 0.01 m a^{-1} on the 30° slopes of Glas Mheall Mór (NG 076854). Such rates are, however, insufficient to account for the distance travelled downslope by Cambrian Quartzite clasts from summit outcrops, implying that rates of creep have been greater in the past. A combination of wind action and frost creep has resulted in the formation of outstanding examples of oblique and horizontal turf-banked terraces on slopes of between 5° and 25° (see also Ward Hill). The sparsely vegetated 'treads' range in width from 0.5 m to over 5 m downslope and from 2 m to over 100 m in length, size being closely correlated with the size of clasts in the 'riser'. On north- and south-facing slopes such terraces dip westwards, into the direction of the dominant winds; on steep slopes such as the south slope of Glas Mheall Mór, this has produced a series of remarkable oblique terraces.

Within the corries the most active processes today are rockfall and debris flow. Stonefalls from the glacially steepened cliffs of the eastern corries are fairly frequent, and a rockfall during the winter of 1976–77 on to a well-developed active talus cone (NG 845075) displaced boulders over 100 kg in mass. Talus slopes produced by rockfall during the Holocene (that is those within the limits of the Loch Lomond Readvance) show less mature profiles than the relict talus slopes formed during the Lateglacial (Ballantyne and Eckford, 1984) although rockfall activity is, after solute transport, the process responsible for the highest rate of erosion on the mountain today (Ballantyne, 1987b). Innes (1983b) has shown that there has been an increase in debris flow activity in recent centuries, which he has attributed to the effects of overgrazing or possibly burning of vegetation to improve the quality of rough pasture.

Interpretation

An Teallach is a site of great importance for Quaternary geomorphology. It not only supports a remarkable range of high-level periglacial phenomena developed on Torridonian sandstone, but has also been the focus of the most detailed investigation of upland periglaciation in Great Britain (Ballantyne, 1981). Furthermore, individual types of periglacial feature are exceptionally well developed, particularly in the case of aeolian and niveo-aeolian features and oblique terraces. The scientific work that has been carried out on An Teallach has also demonstrated the fragility of the mountain summit environment and how it has been disturbed in recent years. Such disturbance may have been due partly to climatic change (the Little Ice Age), but Man's activities, particularly the introduction of sheep and consequent degradation in the vegetation, has more probably had the major impact.

The assemblage of periglacial phenomena on An Teallach is outstanding not only in its own right, but also because it complements features of interest at a range of other sites on different rock types and in different mountain environments (see Ronas Hill, Ward Hill, Ben Wyvis, the Cairngorms, Sgùrr Mór, and the Western Hills of Rum), which together represent most major facets of the periglacial geomorphology of upland Scotland. An Teallach demonstrates better than any other mountain the range of landforms developed on a sandstone substrate.

An Teallach is of significant scientific interest in a second respect. It is exceptional in demonstrating, in a small area, evidence relating to several glacial phases. This includes high-level erratics that reflect the former passage of an ice-sheet over much of the mountain, periglacial trimlines that may represent the upper level of the last (Late Devensian) ice-sheet, and moraines of both the Wester Ross Readvance and the Loch Lomond Readvance. It provides key evidence showing Wester Ross Readvance moraines truncated by Loch Lomond Readvance moraines, thereby establishing their stratigraphic relationship (see also Ballantyne, 1986a). In at least two cases, the Loch Lomond Readvance moraines and drift limits are outstanding examples of their type.

Conclusion

An Teallach is outstanding for its assemblage of glacial and periglacial landforms. The former include an exceptional range of features, including deposits and moraines associated with the Late Devensian ice-sheet at its maximum, the Wester Ross Readvance and the Loch Lomond Readvance. The latter include both fossil and active forms, most notably a series of features formed by wind erosion, which is probably the finest of its kind in Britain. An Teallach is a key reference site for periglacial landforms developed on Torridonian sandstone mountains and is the most intensively studied site in upland Britain.

BAOSBHEINN

D. G. Sutherland

Highlights

Baosbheinn is important for a protalus rampart of

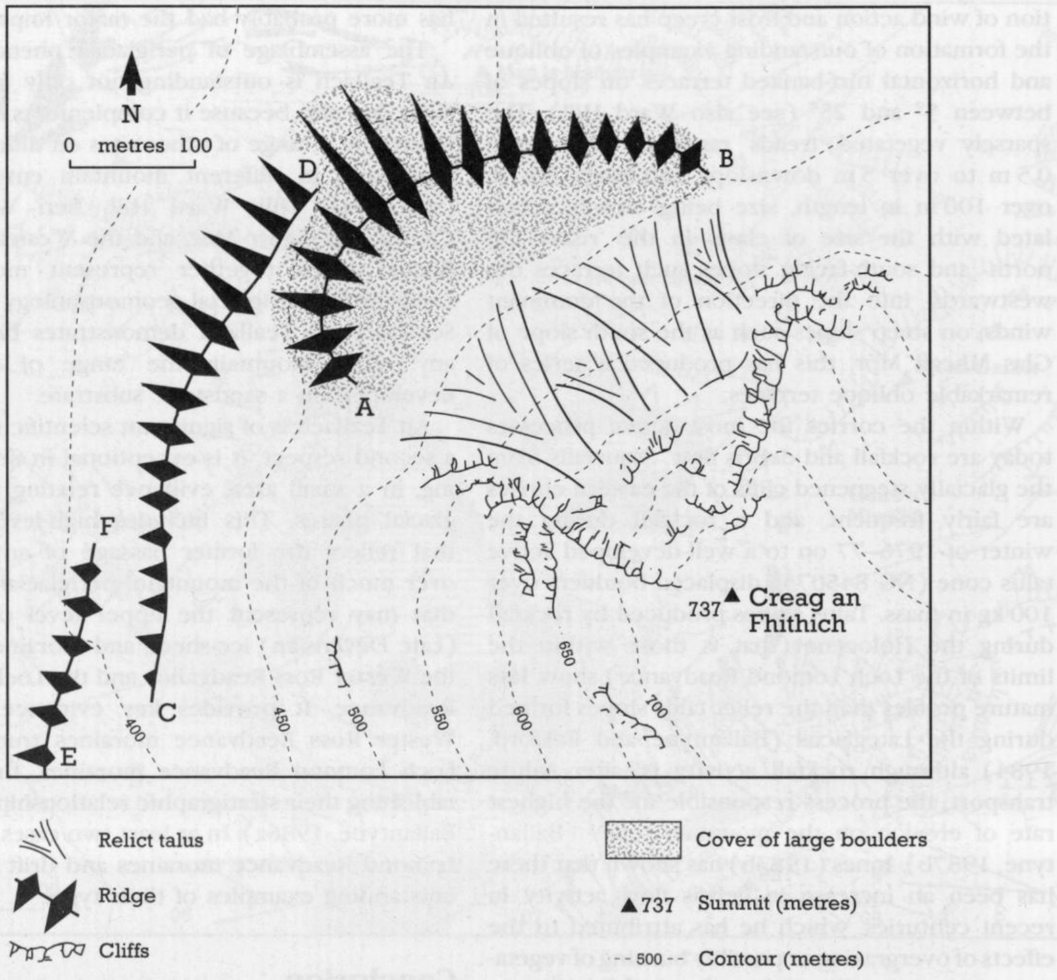


Figure 6.9 The Baosbheinn protalus rampart and associated landforms, showing the upper boulder ridge (AB) and lower ridges (CD and EF) (from Ballantyne, 1986a).

exceptional size, in part formed by large rock-slides. It is important in demonstrating slope-process activity during the Loch Lomond Stadial.

Introduction

Baosbheinn (NG 855676) is the site of the largest and most impressive protalus rampart in Great Britain (Sissons, 1976c). The rampart is located on the north-west end of the Baosbheinn ridge at an altitude of approximately 450 m OD beneath the cliffs of Creag an Fhithich. Its morphology and characteristics were originally described by Sissons (1976c) and further details were provided by Ballantyne (1986a). A number of protalus ramparts have been described in recent years (see Ballantyne and Kirkbride, 1986), but none of them rivals the Baosbheinn rampart in size. This has led Ballantyne (1986a, 1987d) to suggest that both landsliding and deformation by internal ice may have been involved in the production of this remarkable geomorphological feature.

Description

The protalus rampart consists of two distinct ridges (Figures 6.9 and 6.10): a massive, open-work, upper ridge (AB) composed of Torridonian sandstone boulders and a lower, vegetated ridge (CD) with few boulders. The arcuate upper ridge is separated from the base of the mountain by a depression approximately 70 m wide and up to

Figure 6.10 Protalus rampart on the north-west flank of Baosbheinn. The view also shows the rock avalanche scar, the two lower Wester Ross Readvance moraine ridges and a Loch Lomond Readvance moraine intersecting the latter at the base of the mountain. (Cambridge University Collection: copyright reserved.)

6 m deep, and contains two minor, enclosed hollows. This ridge is over 450 m long and its distal slope is, at maximum, 55 m high. The second, lower ridge was examined in detail by Ballantyne (1986a), who demonstrated that it is composed of a diamicton which, on sedimentological grounds (clast size, angularity, roundness, form, hardness and granulometry), is similar to the material comprising certain parts of the Wester Ross Moraine, but quite different to the upper boulder ridge. A third ridge (EF) is also present (Figure 6.9).

Interpretation

Sissons (1976c) interpreted both the main ridges (AB and CD) as part of a protalus rampart complex, the lower ridge forming during an early part of the Loch Lomond Stadial and the upper ridge subsequent to it, after a change in climate as the stadial progressed. Ballantyne (1986a), although agreeing with Sissons as to the age of the upper ridge, argued convincingly that both the lower ridge and ridge EF are lateral moraines formed during the Wester Ross Readvance at some time prior to 13,000 BP. No climatic inferences can therefore be based on the contrast in the nature of the two ridges.

Interpretation of the upper ridge as a 'conventional' protalus rampart formed by individual rockfall events was also questioned by Ballantyne (1986a). He pointed out that not only is the rampart particularly large by British and even world standards (see Washburn, 1979; Ballantyne and Kirkbride, 1986), but its formation also implies rock-wall retreat of the overlooking cliffs of an order of magnitude greater than could be inferred from other similar landforms formed during the Loch Lomond Stadial (Ballantyne and Kirkbride, 1987). He also observed that the cliffs upslope take the form of a major rockslide scar, and suggested that the rampart formed in response to one or more rockslides from the backing cliffs across a former snowbed. The occurrence of small enclosed depressions also suggested to Ballantyne the presence of buried snow, firn or ice at the time of formation of the rampart and this, in turn, raised the possibility that there had been some forward movement of the debris due to deformation of buried ice. The feature may, therefore, be regarded as a protalus or valley-wall rock glacier and has affinities with similar features on Beinn Shiantaidh on Jura (Dawson, 1977) and Coire Beanaidh in the Cairngorms (Sissons, 1979f; Chattopadhyay, 1984). Many protalus rock glaciers in the Scottish Highlands occur at sites of rock-slope failures (Ballantyne, 1987d; Maclean, 1991).

In recent years protalus ramparts have been described from a number of localities in Scotland (Sissons, 1977a, 1979f; Rose, 1980d; Sutherland *et al.*, 1982, 1984; Ballantyne and Kirkbride, 1986), as well as more widely in the United Kingdom (Sissons, 1980a; Colhoun, 1981; Gray, 1982a; Gray and Coxon, 1991). Of the known protalus ramparts, however, none is as spectacularly developed as that at Baosbheinn. The countrywide distribution of protalus ramparts, all of which are thought to have formed during the Loch Lomond Stadial, shows a pattern of decline in altitude from the eastern Grampian Highlands to the western Highlands and Islands (Ballantyne, 1984; Ballantyne and Kirkbride, 1986) that is remarkably similar to the variation in equilibrium line altitudes for Loch Lomond Readvance glaciers (Sissons, 1980b). This similarity is considered to be of significance in palaeoclimatic terms, according with a pronounced eastwards and northwards decline in precipitation in Scotland during the Loch Lomond Stadial (Ballantyne and Kirkbride, 1986). The Baosbheinn rampart is thus part of a wider sequence of landforms of significance in the understanding of the environment of the Loch Lomond Stadial.

Conclusion

Baosbheinn demonstrates an exceptional example of a protalus rampart, a ridge formed at the base of a snowbank through the accumulation of rock debris which fell from cliffs above. Its large size appears to reflect the incorporation of material from a lateral moraine and the supply of debris from large rockslides. Baosbheinn is important in illustrating the nature of slope processes, between about 11,000 and 10,000 years ago, during the Loch Lomond Stadial. It forms part of a network of related sites, the distribution of which shows the interplay of debris supply and climatic factors during this intensely cold phase.

BEINN ALLIGIN

J. E. Gordon

Highlights

The principal interest at Beinn Alligin is a large rockslide which occurred on to the surface of a glacier during the Loch Lomond Stadial. It is the largest and clearest such feature in Britain and illustrates the geomorphological effects of high-magnitude slope failure in a glacial environment.

Introduction

Beinn Alligin (NG 870600) is located on the north side of Loch Torridon in a highly dissected landscape of glacial erosion and narrow mountain ridges. On its north-west and south-east sides the mountain is indented by corries, which acted as ice source areas for Loch Lomond Readvance glaciers (Sissons, 1977a). The most impressive corries are those of Toll a'Mhadaidh Mór and Toll a'Mhadaidh Beag, which together with Coire Mhic Nòbuil demonstrate a fine range of glacial and mass-movement landforms, including most notably an extensive area of glacially transported rock slope failure (rockslide or rock avalanche) debris that has been interpreted as constituting the largest fossil rock glacier in Scotland. Its characteristics and origin are described in detail by Sissons (1975a) and discussed by Sissons (1976d, 1977d), Whalley (1976a) and Ballantyne (1987c). In addition, lateral, medial and hummocky moraines are well represented.

Description

The rock slope failure debris in Toll a'Mhadaidh Mór (Figures 6.11 and 6.12) comprises a massive accumulation of Torridonian sandstone blocks, some exceeding 5 m in length, that form a debris tongue 1.2 km long, up to 15 m high and tapering in width from 400 m at the head to 200 m near the toe. At the surface, the debris mass displays both longitudinal and transverse ridges and depressions. The lowermost 300–400 m of the debris tongue is much less thick than the rest (Figure 6.12). The source of the debris is marked by a large scar and cleft high on the corrie headwall below the summit of Sgùrr Mhór. In part, the scar is structurally defined by two intersecting faults.

Beinn Alligin is also notable for fine examples of double lateral moraines and a medial moraine of Loch Lomond Stadial age (Figures 6.11 and 6.12). The lateral moraines are well-developed on both sides of Coire Mhic Nòbuil and mark the limit of a Loch Lomond Readvance glacier which extended just offshore into Loch Torridon (Sissons, 1977a). In places double ridges are present. Sections in the western lateral moraine along the Diabaig road reveal boulders and cobbles in a sandy-gritty matrix; upslope from here the lateral moraine comprises boulder ridges. The medial moraine in Coire Mhic Nòbuil is clearly seen as a line of boulders running south-west from the northern limb of the Beinn Alligin ridge. On its western side a zone of hummocky moraine and fluted moraine completes the landform assemblage.

Interpretation

Beinn Alligin provides a particularly striking illustration of a major rock slope failure apparently associated with glacier ice, although there are varying interpretations of the resulting deposits.

Sissons (1975a) considered that the debris accumulation in Toll a'Mhadaidh Mór was not simply a landslide deposit, since several aspects of its morphology are quite unlike those of other rockslides in the Highlands, notably its sharply defined lateral margins and long travel distance. Certain of its morphological characteristics, however, are similar to those of rock glaciers elsewhere: plan shape, transverse ridges and closed depressions. Sissons considered that the feature represented reactivation of a small decaying glacier in the corrie by a rockslide during the Loch Lomond Stadial.

As an alternative explanation, Whalley (1976a) put forward the hypothesis that the feature was simply a rockslide deposit, with only a morphological resemblance to a rock glacier from which any ice had melted (cf. Whalley and Martin, 1992). He argued that its characteristics are typical of many large features of this kind and could relate to either flotation on a cushion of air (Shreve, 1968a, 1968b) or the development of particular flow properties that aid momentum transfer (Hsü, 1975; Eisbacher, 1979; Cruden and Hungr, 1986). In reply, Sissons (1976d) contended that topographic conditions at Beinn Alligin did not favour airborne flow and that the form of the debris tongue differed in certain respects from rockslides that apparently moved in this way. In particular, it lacks the highly distinctive lateral and distal rims and surface fluting typical of many large-scale rock avalanches or flowslide deposits (Shreve, 1966, 1968a, 1968b; Marangunić and Bull, 1968; Reid, 1969; Hsü, 1975; Gordon *et al.*, 1978).

Ballantyne (1987c) accepted that the Beinn Alligin deposit is a glacially transported rockslide or rock avalanche, but noted that it lacked the steep front and high terminal ridges typical of rock glaciers and that the debris thinned downslope. He therefore suggested that the glacier may have been larger than envisaged by Sissons (1975a) and that a rock glacier in the normal sense may not have formed (i.e. through the deformation of an ice core or interstitial ice within the debris). Accordingly, the Beinn Alligin feature may resemble several modern instances of rockslides or rock avalanches on to glaciers (Marangunić and Bull, 1964; Reid, 1969; Gordon *et al.*, 1978).

Glacially transported rock slope failure deposits have been reported elsewhere in Scotland, for example on Eigg (Peacock, 1975d) and in Gorm Coire, Ben Hee (Haynes, 1977b). None of these, however, rivals the Beinn Alligin feature in terms of size, or clarity of the relationship between source and transported debris. Holmes (1984) has established that the great majority of rock slope failures in the Highlands occur within a short distance of the former limits of Loch Lomond Readvance glaciers, and he suggested that excess pore water pressures developing in oversteepened slopes during deglaciation may have contributed significantly to subseqent slope failure (cf. Whalley, 1974; Whalley *et al.*, 1983).

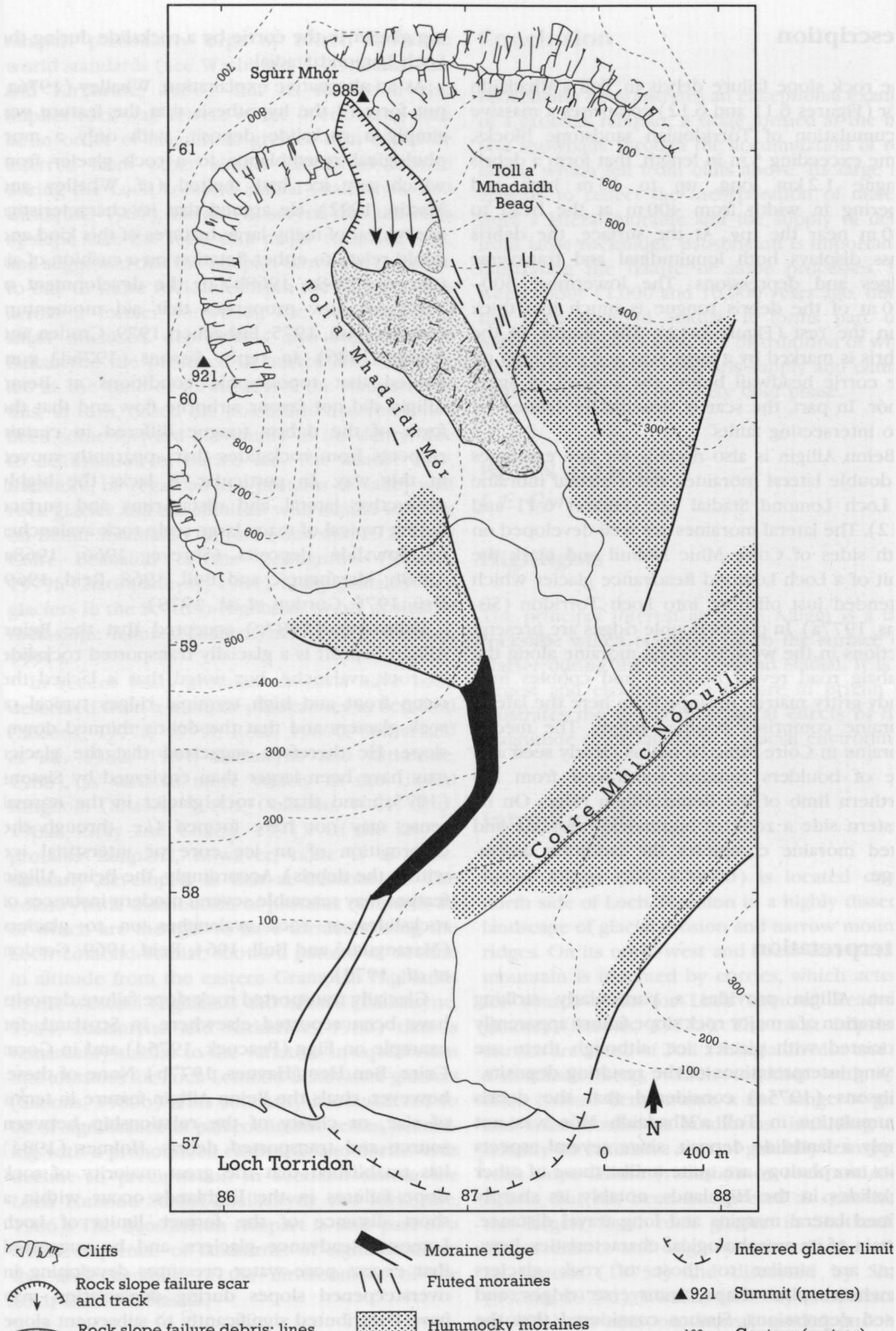

Sgùrr Mhór
985
Toll a Mhadaidh Beag
Toll a Mhadaidh Mór
921
Coire Mhic Nobuil
Loch Torridon
61
60
59
58
57
86
87
88
0
400 m
N
Cliffs
Rock slope failure scar and track
Rock slope failure debris; lines indicate surface ridges
Moraine ridge
Fluted moraines
Hummocky moraines
Inferred glacier limit
921 Summit (metres)
100 Contour (metres)

Figure 6.12 Beinn Alligin, a Torridonian sandstone mountain in Wester Ross, rises above an ice-scoured surface of Lewisian gneiss to the west. A lateral moraine (centre left) marks the limit of a Loch Lomond Readvance glacier and is succeeded on the lower slopes by hummocky moraine; fluted drift can also be seen in the centre and to the right of the photograph. A large rock avalanche scar is prominent below the summit of Sgùrr Mhór. The resulting deposit on the corrie floor includes a low tongue of boulders extending beyond the main part of the deposit. (Cambridge University Collection: copyright reserved.)

Elsewhere in Scotland, fossil rock glaciers have been described from Beinn Shiantaidh on Jura (Dawson, 1977) and the Cairngorms (Sissons, 1979f; Ballantyne, 1984; Chattopadhyay, 1984). They are all smaller features, however, and differ in their morphology and inferred mode of formation, as they take the form of protalus lobes (see Wahrhaftig and Cox, 1959; Liestøl, 1961; Outcalt and Benedict, 1965; White, 1976; Lindner and Marks, 1985; Martin and Whalley, 1987; Whalley and Martin, 1992) that have apparently developed as a result of deformation of ice within rockfall talus accumulations. The only other features in Britain that may be of similar origin to that at Beinn Alligin are at Moelwyn Mawr in North Wales (Campbell and Bowen, 1989) and Beinn an Lochain in Argyll (Holmes, 1984; Maclean, 1991).

Figure 6.11 Geomorphology of Toll a'Mhadaidh, Beinn Alligin, showing rockslide debris and principal glacial landforms (from Sissons, 1977d).

Although good examples of the different types of Loch Lomond Readvance moraine represented at Beinn Alligin occur both individually and in various combinations at other sites in the Highlands, the Beinn Alligin landforms provide a particularly fine assemblage which enhances the overall geomorphological value of the site. Further, the medial moraine in Coire Mhic Nòbuil was described by Sissons (1977a) as the 'best individual example' in the area of the northern Highlands that he had mapped.

Conclusion

Beinn Alligin is noted for a large rockslide transported by a glacier. Although it has been interpreted as a fossil rock glacier, the largest such feature in Scotland, several lines of evidence suggest that it comprises a rockslide from the corrie headwall, which accumulated on the surface of a glacier during the intensely cold phase known as the Loch Lomond Stadial (about 11,000–10,000 years ago). The site is important in illustrating the geomorphological impact of high-magnitude slope processes during the stadial, and it also shows the problems of interpreting the origins of fossil landforms from morphological evidence alone. The wider landform assemblage also includes good examples of different types of moraines.

CNOC A'MHORAIRE

J. E. Gordon

Highlights

Cnoc a'Mhoraire is a representative example of a large end-moraine ridge formed during the Loch Lomond Stadial. Its importance is enhanced by the availability of indirect dating evidence from nearby deposits at Loch Droma.

Introduction

Cnoc a'Mhoraire (NH 284755) is a large end moraine located at the mouth of the Allt Lair valley where the latter enters the Dirrie More, one of the major glacial breaches cut through the watershed of the north-west Highlands (Linton, 1951a; Dury, 1953). It is important as one of the largest and most accessible end moraines associated with Loch Lomond Readvance glaciers in northern Scotland and has been described by Geikie (1901), Peach *et al.* (1913a), Kirk and Godwin (1963), Kirk *et al.* (1966), Sissons (1977a), Smith (1977), and Synge and Smith (1980). It is also significant through its proximity to the Lateglacial pollen site at Loch Droma (Kirk and Godwin, 1963).

Description

The end moraine is an impressive landform up to 25 m high, 200 m wide and 800 m long. It dams Loch a'Gharbhrain and was formed by a Loch Lomond Readvance valley glacier fed from sources in the Beinn Dearg massif to the north (Sissons, 1977a). The lateral limits of this glacier are demarcated along both sides of Loch a'Gharbhrain by lateral moraines, hummocky moraines and a notably fine drift limit (Sissons, 1977a).

Interpretation

In an early reference, Geikie (1901) mentioned the striking moraines of the Dirrie More, referring in particular to the terminal feature at the southern end of Loch a'Gharbhrain. Later, Peach *et al.* (1913a) also made special reference to the moraine, noting its great height and conspicuous rampart when viewed from the Garve–Ullapool road. They related its formation to their valley glacier stage following ice-sheet glaciation and an episode when glaciers were confluent. Surprisingly, Charlesworth (1956) did not specifically refer to the Cnoc a'Mhoraire moraine in his extensive exposition of glacial retreat stages in the Highlands. However, he placed the limit of his Stage M glaciation, later related by Donner (1957) to Pollen Zone III (Loch Lomond Stadial) of the Lateglacial, well to the east, in the vicinity of Contin.

The Cnoc a'Mhoraire moraine assumed considerable significance following the discovery of Lateglacial organic deposits nearby at Loch Droma (Kirk and Godwin, 1963). These deposits contained Lateglacial Interstadial pollen and provided a radiocarbon date of 12,810 ± 155 BP (Q–457). Together with the sedimentary record of the site, this evidence had profound implications for the deglaciation chronology of the area. It apparently demonstrated that no active ice had passed down the Dirrie More after about 12,800 BP and that deglaciation of the area had taken place much earlier than previously suspected. The features to the east mapped by Charlesworth as Stage M were therefore older than the Loch Lomond Stadial.

Although comparison of the pollen stratigraphy with other radiocarbon-dated sites in northern Scotland (for example, Cam Loch) suggests that the Loch Droma date may be as much as 1000 years too old (Sutherland, 1987c), the main conclusion of Kirk and Godwin (1963) remains valid. Of additional note is that, at Loch Droma, laminated sediments were deposited throughout the Lateglacial, suggesting that glaciers were present in the surrounding mountains during this time. A coarsening upwards sequence in the sediments deposited in the basin during the Loch Lomond Stadial would accord with ice readvance closer to the Loch Droma site (Sutherland, 1987c).

The evidence for local glaciation following decay of the ice-sheet is confined to the tributary glens of the Dirrie More, notably at Loch a'Gharbhrain and the northern side of the Fannich mountains (Kirk and Godwin, 1963; Kirk *et al.*, 1966). Kirk and Godwin (1963) and Kirk *et al.* (1966) termed this readvance 'the Gharbhrain stage', and the latter authors inferred it to be the local equivalent of the Zone III (Loch Lomond) Readvance. This has subsequently been supported by Sissons (1977a) following his systematic mapping of Loch Lomond Stadial glaciers in the northern Highlands and by Ballantyne *et al.* (1987) and Reed (1988). Smith (1977) and Synge and Smith (1980), however, have retained the local name of the Gharbhrain stage.

The Cnoc a'Mhoraire moraine is distinguished from the many others produced during the Loch Lomond Readvance in the northern Highlands (Sissons, 1977a) by its great size and relative ease of accessibility. The most comparable feature is probably in Strath Oykell, but it is partly afforested. In addition, Cnoc a'Mhoraire is significant for its close association with the Loch Droma site. Historically, the latter was a critical locality demonstrating early ice-sheet deglaciation of the northern Highlands and providing a maximum date for the Loch Lomond Readvance represented by the Cnoc a'Mhoraire moraine.

Conclusion

This site comprises a large end-moraine ridge formed by a glacier during the Loch Lomond Stadial (about 11,000–10,000 years ago). It is a well-known and representative example of its type. The age of the moraine has been inferred indirectly from a sequence of Lateglacial deposits nearby at Loch Droma.

COIRE A'CHEUD-CHNOIC

J. E. Gordon and D. G. Sutherland

Highlights

This outstanding geomorphological locality is noted for its assemblage of hummocky moraines formed during the Loch Lomond Stadial. These deposits provide important evidence for the processes of glacier activity and wastage.

Introduction

Coire a'Cheud-chnoic (Valley of a Hundred Hills) (NG 955550) in Glen Torridon, is a classic geomorphological locality displaying one of the best and most accessible examples of hummocky moraine in Scotland. The moraines were first mentioned by Geikie (1863a) in a footnote (p. 157) reporting 'a vast but unrecorded accumulation of glacier mounds blocking up a glen between Loch Torridon and Loch Maree', and a plate of the valley, first published in the Geological Survey memoir (Peach *et al.*, 1913b), has been reproduced in standard texts such as Wright (1937) and Sissons (1967a). Despite the clarity of development of the moraines little research was carried out on the area until recent years when Robinson (1977) mapped their distribution and Hodgson (1982, 1987) carried out sedimentological and morphological studies to ascertain the genesis of the features.

Description

Coire a'Cheud-chnoic drains into Glen Torridon from the south-east and is underlain by Torridonian sandstone and north-east aligned belts of Cambrian Quartzite. The greater part of the valley floor is covered by hummocky moraines which reach 8 m in height. Areas of bedrock crop out, implying that there is no great thickness of till under the moraines. Although they have a chaotic appearance, mapping of the moraines by Hodgson (1982, 1987) has shown that, in the lower valley, the majority of the moraines are elongated in a roughly north–south direction (in conformity with striations on the neighbouring bedrock surfaces) (Figure 6.13). Many of the moraines are asymmetric in long profile, with the highest part at the northern end, which gives them a conical appearance when viewed from Glen Torridon (Figure 6.14).

Constituent materials of the hummocky moraine are revealed in a recent roadside quarry at NG 954567. The section shows till at the bottom, consisting of angular clasts and boulders in a sandy and gritty matrix. Its upper surface is deformed, and an overturned fold partly encloses a large lense of poorly bedded sands and gravels. Above, layers of sands and gravels form the core of the upper section of the mound. The depression adjacent to it is underlain by a semicircular lens of angular clasts in a gravel and grit matrix, and is capped by a layer of poorly sorted sands and gravels. It is not possible to assess how representative this section is of the hummocky moraine as a whole, although Hodgson (1982, 1987) showed that the moraines elsewhere are composed of till and that there is little vertical variation in either particle size or erratic content. He found that the majority of the moraine mounds were elongated in a north–south direction and that the clast fabrics had a primary orientation mode parallel to the long axis of the moraines. Although quartzite underlies all the steep ground above the valley, it represents only a small proportion of the surface boulders on the moraines, implying that supraglacially derived debris from the valley sides was not a significant source of the debris. Instead, a significant portion of the erratic content of the moraines is material that was introduced into the area during the Late Devensian ice-sheet glaciation. The mapping of Robinson (1977, 1987a) and Sissons (1977a) has demonstrated that the moraines in Coire a'Cheud-chnoic were formed during the Loch Lomond Readvance.

Interpretation

Hodgson (1982, 1987) concluded that, since the moraines were dominantly composed of exotic material but had been formed by glaciers that were confined to the local valley system, then the moraines were the result of a Loch Lomond Readvance glacier overriding and partially deforming pre-existing debris into a crude type of fluted moraine. He considered that such an explanation could be applied more widely to hummocky moraine in the Highlands of Scotland, although he cited only one particular study, that of Donner and West (1955) on Skye (see the Cuillin), which apparently described similar moraines. Detailed studies elsewhere in Torridon supported his contention that the fluted moraine had formed by subglacial deformation of the sediments (Hodgson, 1982, 1986).

Hummocky moraine occurs widely in the Highlands, Inner Hebrides and parts of the Southern Uplands (see, for example, Geikie, 1863a; Geikie, 1901; Bailey *et al.*, 1924; Peacock, 1967; Sissons, 1967a, 1977a; Gray and Brooks, 1972; Sissons *et al.*, 1973; Bennett, 1991), but its best development in the British Isles is in north-west Scotland (Sissons, 1976b). The Torridon area contains some particularly notable examples, especially to the north of Beinn Eighe and Liathach (Sissons, 1977a; Hodgson, 1982). The moraines of Coire a'Cheud-chnoic are especially significant, both as a representative example of these landforms in the Torridon area and as an area on which detailed research has been carried out into their mode of formation. The locality is also well-known because of its use as a text-book illustration.

Despite considerable documentation of the location of hummocky moraine and some controversy over its implications for the reconstruction of former ice margins (see the Cairngorms), there have been few detailed studies of its origin until recently. Three main explanations have been proposed (see also Loch Skene and the Cuillin). First, it may be a type of chaotic, 'dead-ice' topography formed by rapid stagnation of ice that carried an extensive cover of supraglacial debris (Sissons, 1967a; Thompson, 1972). Second, it may be produced by controlled or uncontrolled deposition by actively retreating glaciers (Eyles, 1979, 1983; Day, 1983; Horsfield, 1983; Benn, 1990, 1991; Bennett, 1990, 1991; Bennett and Glasser, 1991) (see the Cairngorms). Third, as demonstrated by Hodgson (1982, 1987) for the Coire a'Cheud-chnoic features, it may be a subglacial deposit formed by deformation of pre-existing till (see also the Cuillin; Ballantyne, 1989a, Benn, 1991). Probably all three types exist, often in a single area (as in the Cuillin and at Loch Skene), but their relative importance is generally unknown. As the focus of a detailed

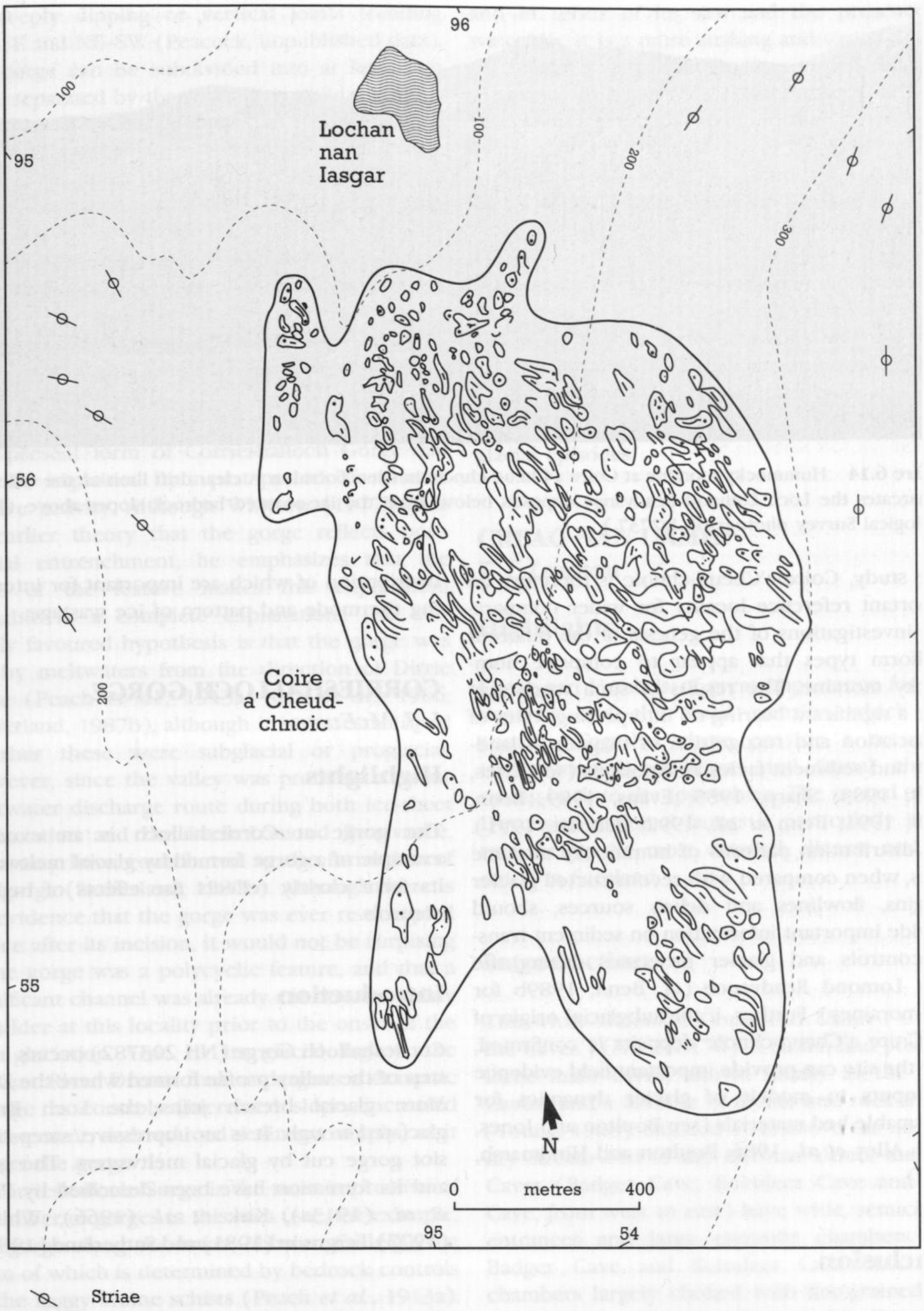


Figure 6.13 Geomorphology of Coire a'Cheud-chnoic (from Hodgson, 1987).

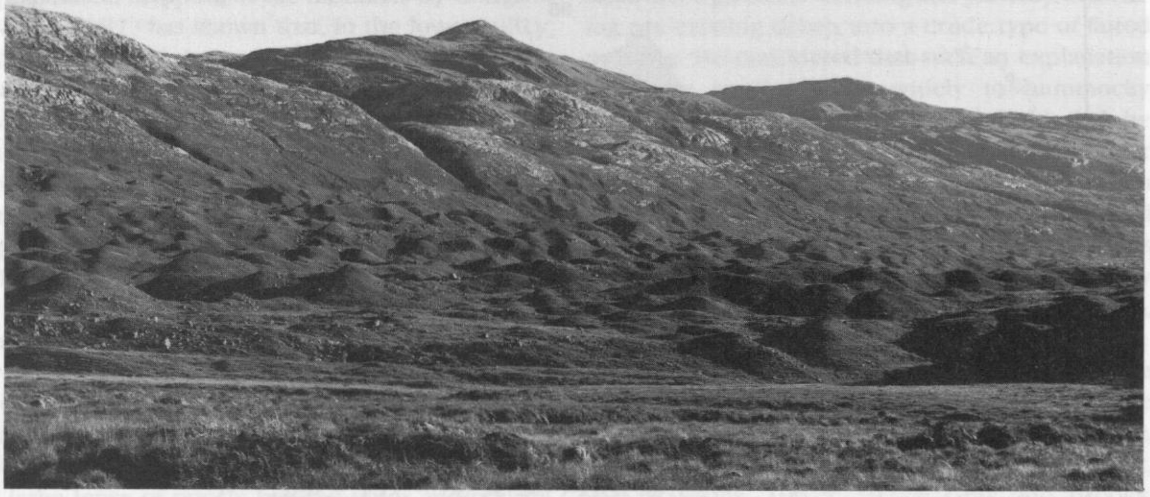


Figure 6.14 Hummocky moraine at Coire a'Cheud-chnoic in Glen Torridon. A clear drift limit on the valley side demarcates the Loch Lomond Readvance deposits below, from the ice-scoured bedrock slopes above. (British Geological Survey photograph D2737.)

case study, Coire a'Cheud-chnoic is therefore an important reference locality for wider comparative investigations of the genesis of the different landform types that appear to comprise hummocky moraine. The results of such work may have a significant bearing on interpreting styles of deglaciation and recognition of diagnostic landform and sediment facies assemblages (see Eyles, 1979, 1983; Sharp, 1985; Evans, 1989; Benn, 1990, 1991; Benn *et al.*, 1992; Bennett, 1991). The distribution patterns of hummocky moraine types, when compared with reconstructed glacier margins, flowlines and debris sources, should provide important information on sediment transfer controls and glacier processes during the Loch Lomond Readvance (cf. Benn, 1989b for end moraines). Further, if the subglacial origin of the Coire a'Cheud-chnoic deposits is confirmed, then the site can provide important field evidence for inputs to models of glacier dynamics for deformable bed materials (see Boulton and Jones, 1979; Alley *et al.*, 1986; Boulton and Hindmarsh, 1987).

Conclusion

Coire a'Cheud-chnoic is a classic geomorphological locality for an assemblage of hummocky moraines formed by a glacier during the Loch Lomond Stadial (about 11,000–10,000 years ago). It is one of the best locations in Scotland showing this type of glacial deposit, the form and distribution of which are important for interpreting the mode and pattern of ice wastage.

CORRIESHALLOCH GORGE

L. J. McEwen

Highlights

The gorge at Corrieshalloch is an excellent example of a gorge formed by glacial meltwaters; its form closely reflects the effects of bedrock controls.

Introduction

Corrieshalloch Gorge (NH 203782) occurs in the step of the valley profile formed where the Dirrie More glacial breach joins the Loch Broom glaciated trough. It is an impressive, steep-sided, slot gorge cut by glacial meltwaters. The gorge and its formation have been described by Peach *et al.* (1913a), Kirk *et al.* (1966), Whittow (1977), Ferguson (1981) and Sutherland (1987b).

Description

Corrieshalloch Gorge is exceptional in its length (*c.* 1.25 km), depth (60 m) and width (as narrow as 10 m at the lip). It is cut in undifferentiated Moine schists (psammite). Its form is determined by steeply dipping or vertical joints trending NW–SE and NE–SW (Peacock, unpublished data). The gorge can be subdivided into at least two parts, separated by the major waterfalls at Falls of Measach. In addition, there are several minor falls, for example, near Braemore junction. The modern channel is thus characterized by a stepped profile over these falls, which are interspaced with deep, boulder-filled pools. Ferguson (1981) observed that these are being progressively extended upstream by waterfall recession, at rates enhanced by the rock jointing.

Interpretation

The present form of Corrieshalloch Gorge can only be explained by a past period of extreme erosive activity. Although Whittow (1977) cites an earlier theory that the gorge reflects post-glacial entrenchment, he emphasizes that the scale of the feature makes this explanation unviable as a complete explanation. The currently favoured hypothesis is that the gorge was cut by meltwaters from the direction of Dirrie More (Peach *et al.*, 1913a; Kirk *et al.*, 1966; Sutherland, 1987b), although it is not established whether these were subglacial or proglacial. However, since the valley was probably a major meltwater discharge route during both ice-sheet deglaciation and the Loch Lomond Readvance, both may have contributed to the formation of the gorge (Sutherland, 1987b). Although there is no evidence that the gorge was ever re-occupied by ice after its incision, it would not be surpising if the gorge was a polycyclic feature, and that a significant channel was already cut into the valley shoulder at this locality prior to the onset of the last glaciation. Due to its glacial legacy, the present River Droma thus undergoes a dramatic change in controls (increased slope, increased confinement, and reduced sediment supply) as it enters the gorge.

Corrieshalloch Gorge is the most impressive of a number of gorges in this area (see, for example, the gorge along the lower Abhainn Cuileig), the form of which is determined by bedrock controls in the flaggy Moine schists (Peach *et al.*, 1913a). It is a classic landform and is recognized as the best-known example of a steep-sided slot gorge in Scotland. The gorge was cut by meltwaters during the last phases of glaciation of the area as well as, probably, during earlier glacial events. The scale of the feature is particularly impressive, and in terms of its size and the presence of waterfalls, it is a more striking and varied feature than the other gorges in the area and also the dramatic, but less well-known gorge at Black Rock of Novar in Easter Ross (Miller, 1887; Peach *et al.*, 1912).

Conclusion

Corrieshalloch Gorge is a classic example of a gorge formed by glacial meltwaters. It is notable for its length and depth and for showing, particularly well, the effects of geological controls on gorge formation. Its development probably reflects erosion by meltwaters during several glacial episodes.

CREAG NAN UAMH

T. J. Lawson

Highlights

Creag nan Uamh is of great importance for cave deposits and the fossil remains which they contain. Together these provide a record of environmental conditions and faunal changes dating back to the Ipswichian. The record of Late Devensian mammal faunas is particularly important, being the most detailed, diverse and best dated in Scotland.

Introduction

The white dolomite Creag nan Uamh ('Crag of the Caves') (NC 268170) in Sutherland possesses three main caves, known locally as the 'Bone Caves', and a number of niches and rock-shelters (Young, 1988). Situated 45 m above the normally dry stream bed of the Allt nan Uamh, the Bone Caves (Badger Cave, Reindeer Cave and Bone Cave, from west to east) have wide, semicircular entrances and large entrance chambers. Both Badger Cave and Reindeer Cave have inner chambers largely choked with fine-grained sediments; Bone Cave possibly also has one, but access is prevented by deposits in the back of the entrance chamber.

The caves at Creag nan Uamh are of considerable interest for Quaternary research because of the paucity of cave sites with datable sediments in Scotland as a whole, as well as their position so far north. They have yielded a Late Devensian and Holocene fauna that shows how the area acted as a refuge for sub-arctic species at the end of the last glaciation (Peach and Horne, 1893b, 1917; Callender *et al.*, 1927; Cree, 1927; Ritchie, 1928; Lawson, 1981b, 1983, 1984). The stratigraphy that has been reconstructed may extend back to before the Ipswichian (Lawson, 1981a), and recent research suggests that the caves are an important archaeological site (Lawson and Bonsall, 1986a, 1986b; Morrison and Bonsall, 1989).

Description

Bone Cave was first excavated by B. N. Peach and J. Horne in 1889 (Peach and Horne, 1893b, 1917). They described a six-layered stratigraphy and were of the opinion that the deposits related to the '. . . Lateglacial time, or at least to a period before the final disappearance of local glaciers in that region' (Peach and Horne, 1917, p. 327).

Badger Cave and Reindeer Cave were excavated in 1926 by J. G. Callender, J. E. Cree and J. Ritchie (Callender *et al.*, 1927; Cree, 1927; Ritchie, 1928; Lawson, 1981b). The results of work in Badger Cave were largely insignificant, but a more complicated stratigraphy in Reindeer Cave, together with rich faunal remains, prompted a reinvestigation of the deposits in Bone Cave in 1927 in order to correlate the stratigraphy of the two caves. However, this latter investigation uncovered largely undisturbed deposits with a stratigraphy somewhat different from that previously published, casting doubts on Peach and Horne's stratigraphic description (Lawson, 1981b, pp. 9 and 16).

The Creag nan Uamh caves are the truncated remains of large, high-level phreatic passages forming part of a cave system that once extended across the area now occupied by the Allt nan Uamh Valley (Lawson, 1983). Remnants of other abandoned phreatic passages occur at approximately the same altitude as the Bone Caves (330 m OD) in Allt nan Uamh Stream Cave and Uamh an Claonaite (entrances at NC 27461713 and NC 27091659, respectively), and these are possibly parts of the same former cave system. Uranium-series disequilibrium dating of a speleothem from Uamh an Claonaite gave an age of 122 ± 12 ka, indicating ice-free conditions at that time and placing the flowstone block in the Ipswichian (Lawson, 1981a). Three additional uranium-series dates of 181 +24/−18 ka, 143 +13/−16 ka and 192 +53/−39 ka, also from Uamh an Claonaite, indicate that part of the master cave system, at least, is considerably older (Lawson, 1983).

A recent survey of the caves showed that nearly all of the clastic deposits in the outer chambers were removed during the 1926 and 1927 excavations (Lawson, 1983). The only *in situ* deposits in outer Badger Cave are a series of yellow sands and silts occupying rock ledges on the western side. Much of the original silty sand in the inner chamber remains, overlain by breakdown slabs. Friable, red 'cave earth' comprising small dolomite splinters in a red or sandy-brown matrix containing numerous small faunal remains, especially amphibian bones, occupies ledges around the cave walls; in places it overlies or is indurated with flowstone.

No *in situ* deposits remain in the entrance chamber of Reindeer Cave or in the fissure or shaft connecting it to the inner chamber. The 1926 excavations uncovered a gravel, rich in erratic lithologies, deposited by a stream that had entered the cave by way of the side passage from Bone Cave and then plunged down the shaft into the inner cave. This was overlain by an angular dolomite-rich gravel containing an arctic mammal fauna, which was in turn overlain by red 'cave earth'. Deposits in the inner cave appear to have been largely untouched since the 1927 excavation. A number of different strata are present. The lowest layer visible is a silty clay containing breakdown clasts which have been intensively weathered to form areas of grey clay. A lens of dark-stained gravel, 0.08–0.15 m thick, with a sharp, irregular upper surface, separates this layer from reddish-yellow silts (0.33 m thick) containing a few fallen roof-stones. A concentration of these angular dolomite cobbles separates the latter from an overlying stratum of structureless, pale-yellow silty-sand, 0.45 m thick. This layer is devoid of breakdown material. In places where the intervening marker-horizon of breakdown fragments is absent, the reddish-yellow silts merge imperceptibly into the pale-yellow silty sand, suggesting that they are all part of a single depositional unit. The whole profile is capped by slabs of dolomite breakdown. Clarification of the sedimentary history of this inner chamber is complicated by the presence of a band of bedded deposits, coarsening upwards from laminated sand to rounded pebbles in a silty sand matrix, which cuts through the other deposits on the eastern side of the chamber. The relationship between this gravel layer and the one found in the outer chamber and shaft in 1926 in not known.

In Bone Cave few of the original deposits remain *in situ*. In the passage connecting it with Reindeer Cave a section through cyclically bedded stream gravels occurs. They are not as well sorted nor as rounded as the gravels just described in the inner Reindeer Cave. Foreset bedding on the leeward side of a rock bar indicates that they were deposited by water flowing from Bone Cave to Reindeer Cave. These gravels most probably represent those described in 1927 (Lawson, 1981b) as also forming the lower gravel stratum in the outer Reindeer Cave. The gravel is capped by a thin flowstone layer and overlies yellow-brown clayey sediments occupying pockets in the cave floor. A brown silty mud containing amphibian bones occurs in the fissure on the eastern side of the cave; it is unlike other 'cave earths' in these caves, and probably represents the uppermost layers of the clay underlying red 'cave earth' described here in 1927. A cemented breccia at the cave entrance cannot be related to the former sedimentary fill as no evidence of the adjoining layers has been preserved.

Interpretation

Figure 6.15 is an attempt to reconstruct the basic composite stratigraphy of the Creag nan Uamh caves. The relationship of the silts and sands to the 'cave earth' in the outer chamber of Badger Cave is entirely speculative; it assumes a correlation between these silts and sands and the yellow-brown silts of the inner cave, which is impossible to demonstrate in view of the disturbed nature of the latter. The silts of the inner recesses of Badger Cave also probably correlate with one or more of the fine-grained deposits in the inner Reindeer Cave; a smoke test in 1926 proved the two caves were linked (Lawson, 1981b), but no penetrable passages have yet been found.

Samples of sediment taken at the time of the 1926–7 excavations (and hitherto preserved in the Royal Museum of Scotland, Edinburgh), together with samples from the various litho-stratigraphic units still preserved in the cave have been analysed (Lawson, 1983) in order to ascertain their provenance and mode of deposition. Five radiocarbon dates have been obtained on selected faunal remains from two different layers in Reindeer Cave (Figure 6.15) (Lawson, 1984). Table 6.1 gives a composite faunal list after analysis of the material excavated in 1926–7. A synthesis of all the various evidence currently available allows the following stratigraphy to be proposed for the Creag nan Uamh caves.

The earliest deposit presently visible is the silty clay containing weathered breakdown material in the inner Reindeer Cave, which may correlate with the fine deposits occupying pockets in the floor of the outer chamber of Reindeer Cave (silts and sands) and Bone Cave (silty clay). It may represent a 'wash' deposit, carried into the cave by groundwater percolating through the rock above. The intense weathering of this layer perhaps suggests that the deposit is the oldest in the caves. At least one stream channel extended over this material. The small grain size of this deposit implies low energy conditions, and the staining of the overlying gravel (possibly manganese) is similar to that which affects cave and peaty surface streams elsewhere in the area at present, suggesting an interglacial or interstadial origin for the chemical precipitation. The sharp, irregular contact with the overlying gravel layer reflects a break in sedimentation of unknown duration and subsequent erosion of these deposits.

The overlying reddish-yellow silt and sand containing fallen roof-stones, which gives way vertically to structureless, pale-yellow silty sand, again implies low-energy conditions. It is thought that these sediments are the finer fractions of the surficial glacial deposits washed into the caves by way of fissures in the dolomite (Lawson, 1983). Deposition to the roof of the inner Reindeer Cave and Badger Cave, that is to levels higher than the present cave entrances, requires those entrances to have been blocked and the caves to have been flooded. In the absence of material evidence of such barriers, it is presumed that the cave entrances were blocked by glacier ice. The faunal assemblage obtained from the surface of this stratum of silt and silty sand is dominantly arctic or sub-arctic in character (Table 6.1). It implies that the land surface around the caves was free of glacier ice, although the climate was still cold and the possibility of glacier ice existing elsewhere in the area cannot be excluded. Two individual reindeer antler fragments yielded radiocarbon dates of 25,360 +810/−740 BP (SRR–2103) and 24,590 +790/−720 (SRR–2104) BP, and give a minimum age for the fine-grained deposits in the inner Reindeer Cave (Lawson, 1984). These dates

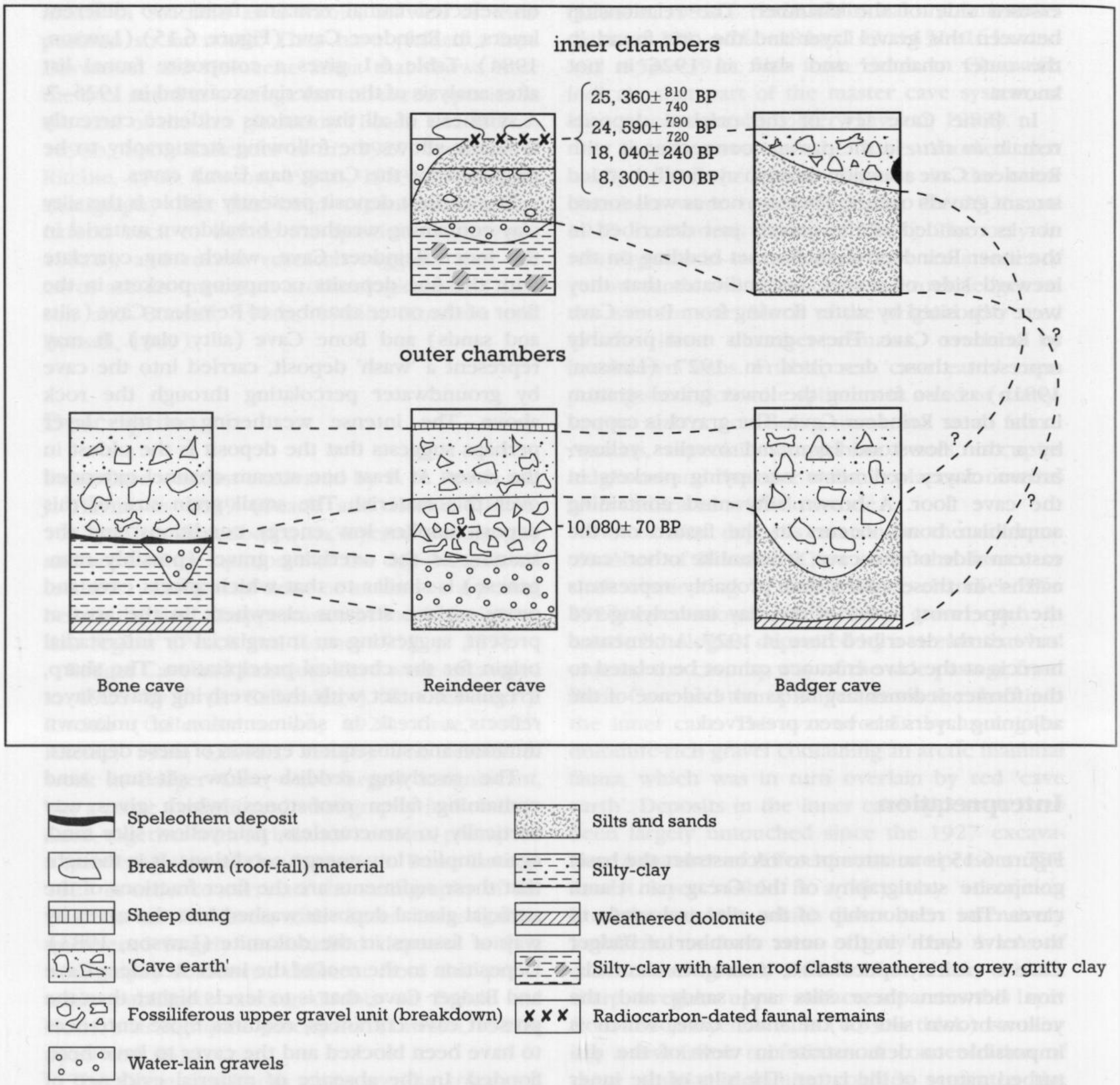


Figure 6.15 Diagrammatic reconstruction of the lithostratigraphy of the Creag nan Uamh caves, showing proposed relationships between certain of the layers (from Lawson, 1983).

correspond well with uranium-series disequilibrium dates on speleothem samples from other caves in the general area (Atkinson *et al.*, 1986), which suggests that this part of north-west Scotland experienced climatic conditions allowing groundwater recharge in a Middle Devensian interstadial approximately 38,000 to 26,000 BP, prior to the onset of full glacial conditions during the Late Devensian. A radiocarbon date of 8300 ± 190 BP (SRR–2105) on a leg bone of a juvenile reindeer from the same stratigraphic horizon shows that faunal material of a mixture of ages is present in the inner cave. This casts serious doubt on the reliability of a date of 18,040 ± 240 BP (SRR–1789) obtained from a bulked sample of antler fragments collected from this same level.

The stratigraphic relationships of the two main fluvially-deposited gravels are as yet incompletely understood. They are lithologically distinct, which

Table 6.1 Faunal assemblages from the Creag nan Uamh caves.

(a) Surface of fine-grained deposits in the inner Reindeer Cave		
Carnivora	*Ursus arctos* L.	Brown bear
	Alopex lagopus (L.)	Arctic fox
	Lynx lynx (L.)	Northern lynx
	Canis lupus L.	Wolf
Artiodactyla	*Rangifer tarandus* L.	Reindeer
Rodentia	*Dicrostonyx torquatus* (Pallas)	Arctic/collared lemming
	Microtus cf. *agrestis* L.	Field vole
	Microtus cf. *oeconomus* (Pallas)	Northern vole
	Arvicola terrestris L.	Water vole
	Apodemus sylvaticus (L.)	Wood mouse
(b) Dolomite-rich, upper gravel unit, outer Reindeer Cave		
Carnivora	*Ursus arctos* L.	Brown bear
Artiodactyla	*Rangifer tarandus* L.	Reindeer
Rodentia	*Dicrostonyx torquatus* (Pallas)	Arctic/collared lemming
	Microtus gregalis (Pallas)	Tundra vole
	Microtus sp.	Vole
(c) 'Cave earth' in Badger Cave (1), Reindeer Cave (2), Bone Cave (3)		
Insectivora	*Sorex araneus* L.	Common shrew (1)
	Sorex sp.	Shrew (2)
Primates	*Homo sapiens* L.	Man (1,2)
Carnivora	*Felis silvestris* Schreber	Wildcat (1)
	Mustela erminea L.	Stoat (3)
	Meles meles (L).	Badger (1)
	Canis lupus L.	Wolf (3)
	Vulpes vulpes (L).	Common fox (1,3)
	Ursus arctos L.	Brown bear (1,2,3)
Artiodactyla	*Sus* sp.	Pig (1)
	Cervus elaphus L.	Red deer (1,2)
	Capreolus capreolus (L.)	Roe deer (1)
	Rangifer tarandus L.	Reindeer (1,2,3)
	Ovis sp.	Sheep (1,2)
	Bos sp.	Ox (1,3)
Lagomorpha	*Oryctolagus cuniculus* (L.)	Rabbit (1,3)
	Lepus sp.	Hare (1)
Rodentia	*Arvicola terrestris* L.	Water vole (1)
	Microtus cf. agrestis L.	Field vole (1)
	Microtus oeconomus (Pallas)	Northern vole (1)
	Dicrostonyx torquatus (Pallas)	Arctic/collared lemming (2)

Continued overleaf

Table 6.1 *continued*

A variety of different unidentified bird species and fish, gastropods (including *Cepaea nemoralis* (L.) (2) and *Patella* sp. (2)) and amphibians (mainly frogs and toads) were also retrieved from this layer (c). E.T. Newton (in Peach and Horne, 1917) identified the following additional species from Bone Cave, presumably from the 'cave earth' stratum of the revised stratigraphy: weasel (*Mustela nivalis* L.), otter (*Lutra lutra* (L.)), rat vole (*Microtus ratticeps* (Keyserling and Blasius)), bank vole (*Clethrionomys glareolus* (Schreber)), ?chaffinch (*Fringilla coelebs* L.), barnacle goose (*Branta leucopsis* (Bechstein)), ?mute swan (*Cygnus olor* (Gm)), ?mallard (*Anas platyrhynchos* (L.)), teal (*Anas crecca* L.), wigeon (*Anas penelope* L.), tufted duck (*Aythya fuligula* (L.)), long-tailed duck (*Clangula hyemalis* (L.)), eider duck (*Somateria mollissima* (L.)), common scoter (*Melanitta nigra* (L.)), ptarmigan (*Lagopus mutus* (Montin)), red grouse (*Lagopus lagopus scoticus* (Latham)), golden plover (*Pluvialis apricaria* (L.)), grey plover (*Pluvialis squatarola* (L.)), little auk (*Alle alle* (L.)), puffin (*Fratercula arctica* (L.)), frog (*Rana temporaria* L.), toad (*Bufo bufo* L.), natterjack toad (*Bufo calamita* (Laurenti)), salmon or trout (*Salmo* sp.).

can be attributed to different transport paths prior to deposition. The erratic-rich gravel in the outer cave was traced by the previous excavators from the entrance of Bone Cave, through the connecting passageway to Reindeer Cave; the exposed section through this gravel in the connecting passageway attests to water flowing in that direction. Both the lack of faunal material within it and its situation in the cave are consistent with meltwater drainage from glacier ice occupying the Allt nan Uamh Valley. In contrast, the higher percentage of dolomite clasts and the greater degree of roundness of the pebbles in the gravel that cuts through the sediments on the eastern side of the inner Reindeer Cave, suggest a longer transport route through a cave system prior to deposition. Imbrication of the pebbles, the position of the gravel close to the steeply sloping cave roof and wall and the limited spread of this material over the yellow silty sand, suggest that it was deposited by a stream entering the chamber from below under hydrostatic pressure, and hence probably under phreatic conditions. These gravels are therefore also attributed to a glacial phase, and are post-dated by the faunal remains in the inner Reindeer Cave noted above.

The upper gravel unit found in the outer chamber of Reindeer Cave represents extensive frost shattering and breakdown of the cave roof and walls. Why similar layers were not found in either Badger Cave or Bone Cave is unknown. This layer yielded a faunal assemblage of distinctly 'northern' character (Table 6.1). The tundra vole (*Microtus gregalis* (Pallas)) is thought to have become extinct during the Lateglacial period (Bramwell, 1977; Stuart, 1982; A. Currant, unpublished data). A radiocarbon date of 10,080 ± 70 BP (SRR–1788) on reindeer antler fragments (Lawson, 1984), in accord with the cold-climate fauna, indicates a Loch Lomond Stadial age for the deposit. The caves lie outside the area affected by glacier ice at that time (Lawson, 1986). The faunal assemblage is peculiar in that over 830 shed reindeer antler burrs were excavated from the 0.5 m thick layer, but only two reindeer antler bones were unearthed. An analysis of the age and sex characteristics of the antler material suggests that Man may have been responsible for its introduction into the cave, which would make Reindeer Cave the oldest archaeological site yet found in Scotland (Lawson and Bonsall, 1986a, 1986b; Morrison and Bonsall, 1989).

'Cave earth' comprises the uppermost deposits in the entrance chambers of all the caves, and includes varying amounts of small breakdown flakes in a red-brown silty matrix containing abundant faunal material. These sediments are clearly of Holocene age, but they do not appear to be actively forming at present. The presence of a thin flowstone deposit low down in this layer probably reflects a temporarily moister climatic regime. The 'cave earth' contains species that are still present in Scotland today (Table 6.1). Other species no longer present (for example, brown bear, wolf, and reindeer) probably owe their extinction to Man rather than to the changing Holocene climate. The location of the Creag nan Uamh caves helps to explain the presence of other animals usually associated with more northern climes, as a region so far north is likely to have remained a refuge area for many arctic species trapped there as climate ameliorated. This may account for the presence of arctic lemming (*Dicrostonyx torquatus* (Pallas)). The presence of *Cepaea nemoralis* (L.) is interesting as this land snail is no longer found farther north than southern Skye (Kerney and Cameron, 1979, distribution map 272). The numerous frog bones in these deposits are due to the death of many of these amphibians whilst aestivating in pockets of mud.

A reassessment of the previous excavations in the caves, together with selective analysis of various *in situ* deposits, has allowed the construction of a lithostratigraphy covering a large part of the Late Quaternary. Radiocarbon dates indicate that the fine-grained sediment (silty clay, reddish-yellow silts and pale-yellow silty sand) of the inner Reindeer Cave, at least in part probably deposited beneath an ice-sheet, pre-dates a Middle Devensian interstadial; further work may show that the lowest stratum (silty clay with weathered clasts) dates from before the Ipswichian. Other stratigraphic units can be demonstrated to be of Lateglacial and Holocene age on sedimentological, geomorphological and faunal grounds. The faunal assemblages from these most recent deposits are unique in Scotland and are important in palaeobiological terms, showing how certain species with sub-arctic affinities survived into the Holocene in this remote part of northern Britain. The increasing evidence that the site is of considerable archaeological significance, being temporarily occupied by Late Upper Palaeolithic Man around 10,000 years ago, also adds to the importance of the Creag nan Uamh caves as a Quaternary site.

Conclusion

The unique assemblage of deposits and fossil animal remains preserved in the caves at Creag nan Uamh provides an important record of environmental conditions and changes in Scotland during at least the last 125,000 years. Particularly important is the detailed evidence for the range of sub-arctic mammalian species present in the area at the end of the last ice age (about 10,000 years ago).

SGÙRR MÓR

C. K. Ballantyne

Highlights

The example of solifluction terraces on Sgùrr Mór is one of the best in Scotland and one of the first to have been described.

Introduction

Sgùrr Mór (NH 204715), the highest summit (1110 m OD) in the Fannich Mountains, is important for one the best examples in Scotland of a suite of solifluction terraces. The landforms were first described by Peach *et al*. (1913a), who included a photograph showing 'plateau frost debris ... arranged in parallel lines or terraces due to soil creep aided by the movement of snow' on the ridge south-east of Sgùrr Mór. This is possibly the earliest reference to solifluction features on the mountains of Scotland. Subsequently these impressive features were used by Sissons (1967a, plate 23A) as an illustration of mass movement of frost-weathered debris. The most recent investigation of the site is that of Ballantyne (1981), later summarized in Ballantyne (1987e).

Description

Sgùrr Mór is composed of Moine pelitic schists that have weathered to produce a shallow, frost-susceptible regolith comprising slabby, angular clasts embedded in a matrix of silt and fine- to medium-grained sand ('Type 3' regolith of Ballantyne (1981, 1984)). On the south-east flank of the mountain, from 1050 m to 950 m OD, on slopes of around 13° there is an unbroken sequence of broad steps which range from 6.6 m to 12.7 m in width (downslope) and 33 m to 86 m in length (across slope). The junction between adjacent sheets is marked by a steep, vegetated 'riser', 0.5 m to 1.0 m high, interrupted in several places by the formation of small vegetation-covered solifluction lobes.

The vegetation cover of the 'treads' ranges from 0–70%, the bare areas being covered with slabs of local mica schist embedded in a deflation surface of coarse sand and granules. Excavation of one sheet revealed a typical solifluction deposit consisting of slabs up to 0.3 m across embedded in a dark-brown, structureless, sandy soil.

Interpretation

Ballantyne (1981) interpreted the features as stepped solifluction sheets (terraces) and considered that they were probably still active. Late Holocene solifluction activity on the Fannich Mountains was subsequently established by Ballantyne (1986c) at a site at 840 m altitude on the flank of Sgùrr nan Clach Geala, approximately 2 km to the west of Sgùrr Mór. Excavations at this site revealed an almost undisturbed soil horizon underlying a solifluction lobe. A series of radiocarbon dates indicated a very recent, very rapid advance of the lobe, which Ballantyne considered may have been due either to the Little Ice Age climatic deterioration in the 17th and 18th centuries AD or to vegetational disturbance due to overgrazing. Elsewhere in Scotland, Holocene solifluction has been established by radiocarbon dating of organic material from under or within solifluction lobes or sheets in the Cairngorms (Sugden, 1971) and Ben Arkle in Sutherland (Mottershead, 1978).

Frost-weathered regolith occurs widely on the mountain tops in Scotland and supports a range of solifluction deposits and landforms (see Ronas Hill, Ward Hill, An Teallach, Ben Wyvis and the Cairngorms). Sgùrr Mór is probably the most outstanding example of these landforms in Scotland, both for the clarity of the individual features and the extent of their development. The site is also of historical interest as being probably the first recorded example of solifluction features on Scottish mountains.

Conclusion

Sgùrr Mór is important for periglacial landforms developed on Moine schist. It demonstrates one of the best, and earliest described, examples of solifluction terraces in Scotland, formed by the slow downslope movement of frost-weathered debris. Some of the terraces may have been active during the last few hundred years.

CAM LOCH

H. J. B. Birks

Highlights

The sediments on the floor of Cam Loch contain a valuable record of environmental changes during the Lateglacial. This record has been studied in great detail using pollen, diatom and chemical methods, together with radiocarbon dating. Cam Loch is an important reference site for the Lateglacial in north-west Scotland.

Introduction

Cam Loch (NC 209135) is a large (2.6 km^2), irregularly shaped loch situated at 124 m OD just north of Elphin in west Sutherland. It has a large catchment (*c.* 87 km^2) with major inflowing and outflowing rivers. The sediments preserved on the floor of the loch are important for reconstructing the environmental history of the Lateglacial between about 13,000 and 10,000 BP. Evidence for rapid and marked climatic change during this interval is strongly represented in Scotland, both as landforms and as sedimentary, geochemical and biostratigraphical records. Cam Loch is one of the most intensively studied Lateglacial sites in Scotland and is of international importance because of the numerous interdisciplinary studies that have been made on its Lateglacial sediments by members of the Freshwater Biological Association (Pennington, 1975a, 1975b, 1975c, 1977a, 1977b; Pennington and Sackin, 1975; Haworth, 1976; Cranwell, 1977). It is the major reference site for the stratigraphy of the Lateglacial in north-west Scotland, and it provides critically important palaeoecological comparisons with sites elsewhere in the British Isles and in north-west Europe.

Description

The maximum water depth of Cam Loch is 37 m and the mean depth, 12 m. A sediment core has been obtained from a water depth of 10 m. The basal 0.65 m of sediment in this core comprise a succession of clay, silt and gyttja deposits (Figure 6.16) and were formed during the Lateglacial. These sediments have been intensively studied for their inorganic (Pennington and Sackin, 1975; Pennington, 1975a, 1977a) and organic geochemistry (Cranwell, 1977; Pennington, 1977a), their pollen stratigraphy (both as relative and absolute data) (Pennington, 1975a, 1975b, 1977a, 1977b; Pennington and Sackin, 1975) and their diatom stratigraphy (Haworth, 1976; Pennington, 1977a). As a result Cam Loch provides an extremely detailed environmental history for this time period. Seven radiocarbon dates (SRR–247 to SRR–253) have been obtained for consecutive sediment samples for the period 13,000–10,000 BP (Figure 6.16). The pollen record has been divided into seven local pollen assemblage zones (zones Ca–Ch) and three regional pollen assemblage subzones (subzones NWS A, B, C) described from the nearby sites of Loch Sionascaig and Loch Borralan. Correlation has been made with the Late Weichselian chronozones of

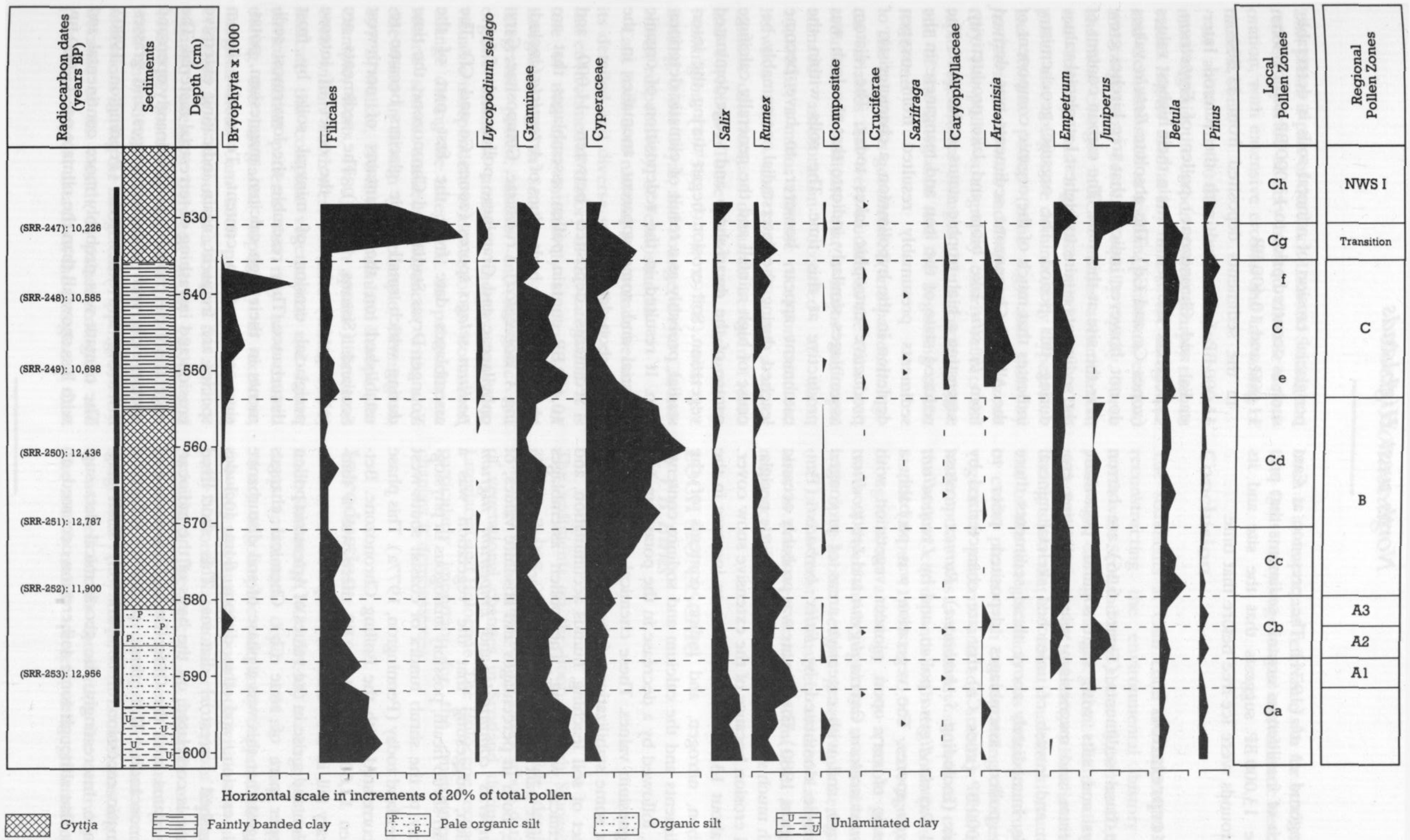


Figure 6.16 Cam Loch: relative pollen diagram, showing selected taxa as percentages of total pollen (from Pennington, 1977a).

Mangerud *et al.* (1974). The presence at Cam Loch of fossiliferous organic sediments that predate 13,000 BP suggests that the site and its surrounds were ice-free before that time.

Interpretation

The basal sediments (Figure 6.16) are barren clays and silts with high sodium, potassium, calcium, and magnesium values, indicating erosion and inwash of unleached skeletal mineral soils. Immediately above these sediments there are pollen assemblages deposited prior to 13,000 BP (zone Ca) that are characterized by *Salix* (including *S. herbacea*), *Rumex acetosa* and *Oxyria digyna* pollen, and by *Lycopodium selago* spores. The vegetation was probably a mosaic of very open, pioneer vegetation with *Rumex acetosa*, *Oxyria digyna* and *Lycopodium selago*, and with extensive areas of prolonged snow-lie dominated by *Salix herbacea* (Pennington, 1980). The climate was probably oceanic with much snow and comparatively little periglacial erosion because of the extensive snow cover. At about 13,000 BP there was an increase in the carbon, nitrogen, and iodine contents of the sediments and the calcium and sodium contents fell, followed by a decrease in the potassium and magnesium values. These chemical changes suggest some stabilization of the landscape and the onset of soil leaching, humus accumulation, and chemical weathering. The pollen assemblages (lower part of zone Cb) are characterized by a rise, both in percentages and absolute values, of *Juniperus communis* and *Empetrum nigrum* pollen, suggesting that the vegetation was a dwarf-shrub heath, possibly analogous in physiognomy to the shrub tundra of coastal south-west Greenland today (Pennington, 1977a). This phase is correlated with the Bølling Chronozone. Between 12,000 and 11,800 BP there was a temporary fall in the values of *Juniperus communis* pollen and a rise in the values of *Artemisia* pollen (upper part of zone Cb). Chemical changes suggest that this was a phase of soil disturbance and erosion, and the diatom flora includes inwashed terrestrial diatoms. This short-lived phase is correlated, on the basis of the radiocarbon dates, with the Older Dryas Chronozone of Fennoscandia. The phase probably reflects a climatic recession of comparatively small magnitude. Interestingly, the geochemical data suggest that although some soil erosion occurred, no periglacial erosion of mineral soils is detectable, such as occurred prior to 13,000 BP and between 11,000 and 10,400 BP.

In the sediments deposited from 11,800 to 11,000 BP (correlated with the Allerød Interstadial and Chronozone) pollen of *Empetrum*, Cyperaceae and *Betula* attain their highest values (zones Cc and Cd). The absolute *Betula* values do not, however, indicate that tree birches grew near the site at this time. The carbon content of the sediments attains its highest Lateglacial values during this period. The organic geochemistry indicates that much of the organic component of the Allerød Chronozone sediments was derived from *in situ* lake biota and lake productivity, suggesting a high trophic status at this time. The reduced state of the iron and manganese in the sediments presumably resulted from oxygen depletion in the hypolimnion, a characteristic of productive eutrophic lakes today. The diatom assemblages similarly indicate that the loch was productive at this time. The soils within the catchment appear, however, to have become leached during the interstadial, presumably because of high rainfall and the generally calcifuge nature of the dwarf-shrub and sedge-dominated vegetation. Soil erosion began during the interstadial, probably as a result of climatic deterioration. It resulted in the redeposition of organic material and some apparent anomalies in the radiocarbon dates.

Sediments deposited between 11,000 and 10,400 BP contain pollen assemblages that are characterized by high values of *Artemisia* (including *A. norvegica*), Cruciferae, Compositae, Caryophyllaceae and Gramineae pollen and of *Lycopodium selago* spores (zones Ce and Cf). The assemblages date from the first part of the Younger Dryas Stadial and Chronozone, the time during which small corrie glaciers became re-established on the mountains of north-west Scotland (Sissons, 1977a). The sediments are minerogenic and reflect the onset of intense periglacial erosion of mineral soils by frost disturbance. They resemble the lowermost sediments in their high calcium, magnesium, potassium and sodium content. Terrestrial diatom species are frequent, again indicating extensive erosion and inwashing of terrestrial material. The vegetation was probably predominantly open and species-rich, with abundant sedges and grasses, *Artemisia*, and other herbs (Pennington, 1980). The climate was probably more continental and with less snowfall than the climate pre-13,000 BP.

This phase is part of the Loch Lomond Stadial and reflects a period of very marked climatic deterioration, with extensive erosion and inwashing of mineral soils.

At about 10,400 BP the sediments become more organic, the carbon content sharply rises to values higher than at any time in the Lateglacial, and elements such as sodium, potassium, calcium and magnesium decrease equally rapidly. These chemical changes indicate humus accumulation, soil stability, and high lake productivity. The pollen assemblages are dominated by Cyperaceae and *Rumex* pollen (zone Cg) and then by *Juniperus communis* and *Empetrum* pollen (zone Ch). The pollen stratigraphy clearly reflects the rapid vegetational changes that occurred at the end of the Lateglacial and the beginning of the Holocene.

The numerous geochemical and palaeontological variables that were studied in the Cam Loch sediments all indicate that a major and rapid climatic amelioration occurred at about 13,000 BP; a minor climatic recession occurred between 12,000 and 11,800 BP, and a major climatic deterioration occurred between 11,000 and 10,400 BP. These phases are correlated by Pennington (1975b, 1977a, 1977b) with the Bølling, Older Dryas, and Younger Dryas Chronozones, respectively, of Fennoscandia.

Cam Loch is of national importance because of its detailed and diverse stratigraphical record of the environmental history of the Lateglacial. It is one of the most intensively studied sites of Lateglacial age in Scotland, with detailed and integrated pollen, diatom and inorganic and organic chemical analyses, thereby providing valuable independent evidence for environmental change during the Lateglacial. Its palaeoclimate record shows marked differences with sites elsewhere in Britain (for example, Pennington, 1977b; Walker, 1984b) and mainland Europe (for example, Watts, 1980). Such spatial differences even within north-west Scotland (Birks, 1984) indicate the complex vegetational and hence environmental patterns that may have existed during the Lateglacial, especially in extreme, marginal areas. Cam Loch provides convincing evidence from various data sources for a minor climatic recession between about 12,000 and 11,800 BP. Increasing interest is now focused on such short-lived, often rather abrupt, climatic recessions during the Lateglacial (Tipping, 1991b). Because of its wealth of palaeoecological and palaeolimnological data from the Lateglacial, Cam Loch is an important reference site for studies of Late Quaternary vegetational and climatic history.

Conclusion

The sediments at Cam Loch are important for reconstructing the environmental history of north-west Scotland from about 13,000 to 10,000 years ago, during the Lateglacial. Pollen, diatom and chemical analyses, together with radiocarbon dating, show that the climatic amelioration at the end of the last glaciation was twice interrupted by colder phases, with corresponding changes in vegetation patterns and soil stability. The first interruption was a relatively short-lived event; the second corresponds with the Loch Lomond Stadial (about 11,000 to 10,000 years ago) and brought about a change from a stable ground cover of dwarf-shrub vegetation to unstable soils with open-habitat sedges, grasses and herbs. As one of the most intensively studied Lateglacial sites in north-west Scotland, Cam Loch is a key reference locality for this area.

LOCH SIONASCAIG

H. J. B. Birks

Highlights

The sediments on the floor of Loch Sionascaig and in a bog on Eilean Mór provide detailed pollen records, supported by radiocarbon dating, of vegetational changes in Scotland during the Lateglacial and Holocene. The Holocene record is particularly important for the environmental changes it demonstrates.

Introduction

Loch Sionascaig (NC 120140) is a large (6.1 km^2), deep (maximum depth 184 m, mean depth 70 m), oligotrophic (alkalinity 6 ppm CaC0, pH 6.4–6.6) and nutrient-poor loch within the Inverpolly National Nature Reserve, west of Elphin in Sutherland. The reserve is primarily moorland and blanket-bog developed over Lewisian gneiss, interspaced by numerous small lochs and wet and soligenous valley mires, with Loch Sionascaig and its wooded islands dominating the central part. The area is mainly treeless, although small areas of birch wood persist locally on steep, rocky slopes and on islands in the larger lochs. It is 'a good example of this kind of submontane moorland and wetland complex so characteristic of west Ross and west Sutherland' (Ratcliffe, 1977).

Detailed palaeoecological and palaeolimnological studies of the sediments of Loch Sionascaig (Pennington *et al.*, 1972) and of a small bog (0.42 m deep) (NC 120139) on Eilean Mór (Kerslake, 1982), its largest woodland island, provide important evidence on the Lateglacial and Holocene ecological history of this internationally biologically important and unique landscape.

Description

The shore of Loch Sionascaig is mainly bare Lewisian gneiss and sediments are absent over much of the loch floor. In the southern arm of the loch, where the bedrock is Torridonian sandstone, up to 5.5 m of sediments occur overlying glacial clays and sands. These comprise a succession of clay, silt, sand and gyttja deposits (Figure 6.17).

Pollen analyses of the Sionascaig sediments (Pennington *et al.*, 1972) show that the sequence represents a complete Lateglacial and Holocene record. This has been divided into three Lateglacial regional pollen assemblage zones (A, B, C) and six Holocene regional pollen assemblage zones (NWS I–NWS VI) (Figure 6.17). Seven radiocarbon dates (SRR–12 to SRR–15 and Y–2362 to Y–2364) (Figure 6.17) indicate a remarkably constant sediment accumulation rate for the Holocene.

Interpretation

The Lateglacial pollen stratigraphy is typical for north-west Scotland, with a pre-Lateglacial Interstadial assemblage dominated by *Rumex*, grasses and sedges, including a wide variety of other herbs characteristic of open, pioneer vegetation. During the interstadial closed-heath vegetation with *Empetrum* and *Juniperus communis*, developed on humus-rich acid soils. The overlying Loch Lomond Stadial deposits are characterized by increased values of *Artemisia* (including *A. norvegica*), Cruciferae, and Caryophyllaceae, suggesting open disturbed soils.

The boundary between the Devensian and the Holocene is marked by a series of rapid changes in the pollen record, with successive peaks of *Rumex*, *Lycopodium selago*, Gramineae, *Empetrum* and *Juniperus*, representing the characteristic vegetational succession from stadial to interglacial conditions. At about 9500 BP *Betula* woodland, with some *Corylus avellana* and abundant ferns, developed. *Pinus sylvestris* expanded at about 8000 BP, early by comparison with England and elsewhere in Scotland, with the exception of the Loch Maree area (Birks, 1972b; Birks, 1989). Open pine-dominated woodland, with abundant *Pteridium aquilinum* and some *Betula* and *Calluna vulgaris*, was the major regional vegetation from about 7500 BP to 4500 BP (Pennington, 1986). Mires were locally present in the catchment, presumably in waterlogged areas. *Alnus glutinosa* expanded locally about 6000 BP, but, as elsewhere in the north-west Highlands, it was never an important forest component (Bennett and Birks, 1990). *Ulmus* and *Quercus* were also present, but in low numbers throughout the Holocene. At about 4500 BP pine underwent a major decline here, as elsewhere in north-west Scotland (Birks, 1972b, 1975; Birks, 1977, 1989; Bennett, 1984; Gear and Huntley, 1991), probably as a result of rapid climatic change with a shift towards wetter and windier 'oceanic' conditions. Such a shift would, on the leached, acid soils of the area, inhibit the natural regeneration of pine and lead to the widespread development of blanket-bog on flat and gently sloping areas. The decline of *Pinus* pollen in the sediments at Loch Sionascaig is accompanied by rises of Cyperaceae, Gramineae and *Calluna* pollen and of *Sphagnum* spores, all suggestive of peat development and the spread of blanket-mires. *Pinus sylvestris* died out locally sometime in the last 4000 years, as it did in much of north-west Scotland (Birks, 1989). Its former widespread occurrence is strikingly evidenced by the abundant pine stumps within the blanket-peats of the Inverpolly area.

Sediment–chemical analyses provide independent evidence for soil changes within the Sionascaig catchment (Pennington *et al.*, 1972). There is a close correspondence between the pollen-record and sediment–chemical changes, suggesting important vegetation–soil relationships over the last 13,000 years (Pennington, 1986). During the Lateglacial there was progressive soil development until the later part of the interstadial with humus accumulation, nutrient leaching and chemical weathering leading to clay-mineral formation. Soils became less organic and more nutrient-rich

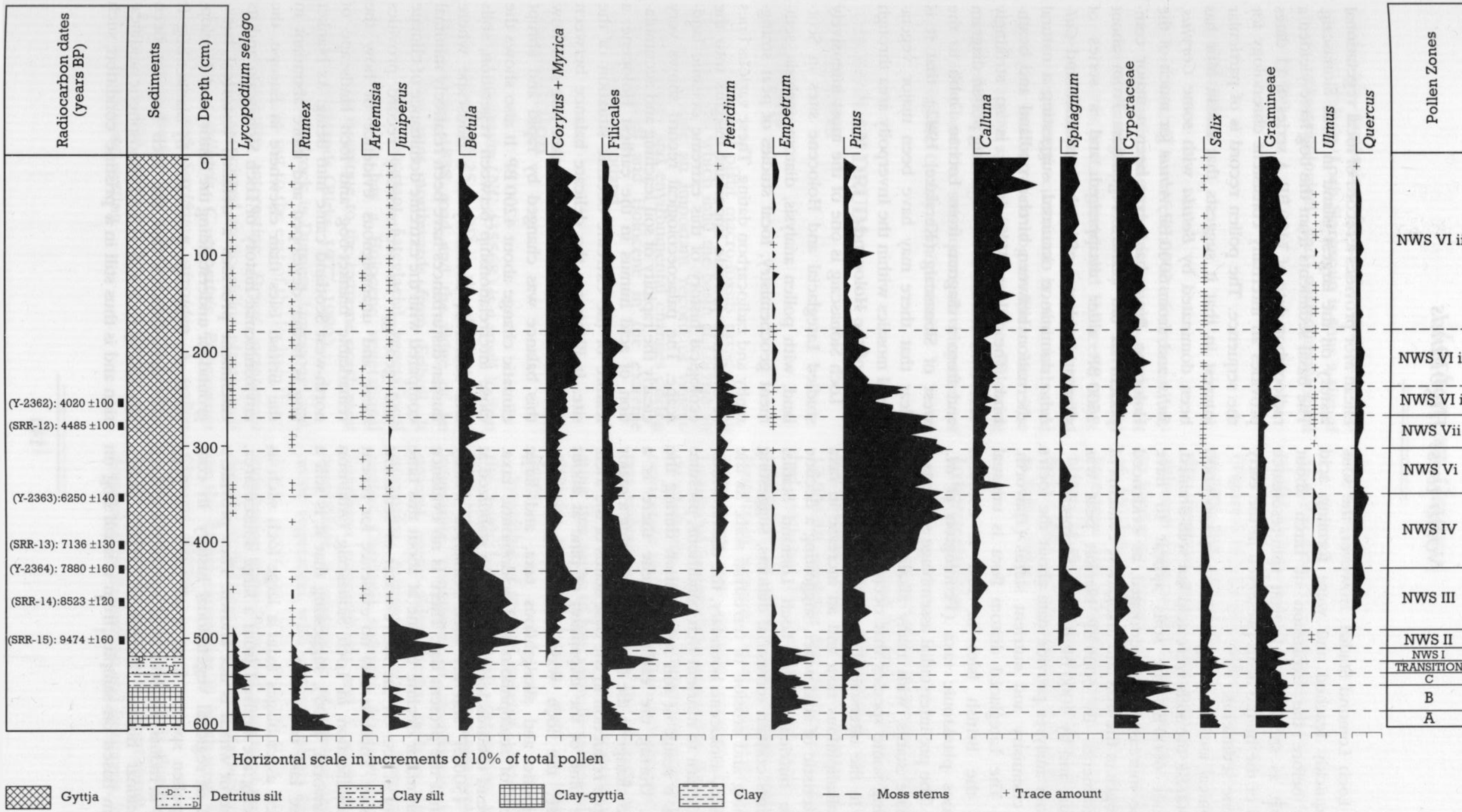


Figure 6.17 Loch Sionascaig: relative pollen diagram, showing selected taxa as percentages of total pollen (from Pennington *et al.*, 1972).

in the Loch Lomond Stadial. However, the soils were quickly leached and were forming acid humus before the expansion of birch about 9500 BP, as shown by electron spin-resonance studies of the humic acids preserved in the early Holocene sediments.

Chemical analyses suggest that between 8000 and 6000 BP the soils were acid but well-drained. At about 6000 BP the soils appear to have become increasingly waterlogged, as evidenced by changes in the iron and manganese contents of the sediments. By 5000 BP blanket peat was common, and by 4000 BP it was widespread.

Diatom analyses provide data about the loch's water chemistry and nutrient status (Haworth, 1976). The Lateglacial diatom flora is unusual within the British Isles in that it contains numerous planktonic taxa (Pennington *et al.*, 1972). The pre-interstadial assemblage suggests a high base status, with many alkaliphilous taxa, including some species that occur near glaciers today. In the interstadial there was a decline in these alkaliphilous taxa and an increase in taxa characteristic of acid water, suggesting a decline in lake nutrient status. Loch Lomond Stadial sediments contain terrestrial diatoms, suggesting inwashing and erosion of terrestrial soils. At the Devensian–Holocene boundary, the diatoms indicate a return to nutrient-rich conditions, presumably as a result of soil rejuvenation during the stadial. During the early Holocene there is a marked change in the diatoms, indicating a major and rapid reduction in the base status of the loch. By the time of the expansion of pine at about 8000 BP, the loch was acid, with very few alkalibiontic and alkaliphilous taxa, and large numbers of acidophilous and acidobiontic taxa. This trend towards loch acidification stabilized at about 4500 BP and the loch remained weakly acid until the present day. There is no evidence that the major decline of pine at about this time had any effects on the loch's water or sediment chemistry. There is also no evidence for recent lake acidification in Loch Sionascaig (Atkinson and Haworth, 1990), suggesting that it is still a 'pristine' lake ecosystem.

Pollen assemblages from a large loch such as Sionascaig are derived from a large source area, the size of which is not known. They provide a record of regional vegetational history. In contrast, pollen spectra from small lakes and bogs (<100 m radius) reflect a local, spatially restricted vegetational history. Kerslake's (1982) pollen diagram based on samples from a small bog on Eilean Mór provides a record of local vegetational history on the largest island in Loch Sionascaig. The basal sediments from the bog have yielded a radiocarbon date of 7400 BP. A series of 11 dates provides an internally consistent chronology for the sequence. The pollen record is of particular interest in that it suggests that Eilean Mór has been dominated by *Betula* with some *Corylus*, *Salix* and, from 6000 BP, *Alnus* for much of the Holocene. *Pinus* has never been a major component of the island's vegetation. From about 2500 BP alder disappeared and a series of alternating phases of birch dominance and *Calluna* dominance occurred, suggesting a natural alternation between birch woodland and heathland. The Eilean Mór profile is so strikingly different from the Loch Sionascaig pollen diagram and from a diagram from Lochan Dubh to the west of Sionascaig (Kerslake, 1982), that it is clear that there may have been major vegetational mosaics within the Inverpolly area through much of the Holocene.

Loch Sionascaig is one of the most intensively studied Lateglacial and Holocene sites in Scotland, with pollen analysis, diatom analysis, sediment geochemistry, local studies of peat stratigraphy and radiocarbon dating. These various lines of evidence provide important insights into the ecological history of this extreme oceanic landscape. The palaeoecological record shows very clearly the rapidity of soil leaching and accumulation of acid humus in the earliest Holocene, a feature of the extreme oceanic situation of the site. It illustrates the delicate balance between open pine woodland and blanket bog and how this balance was changed by rapid and abrupt climatic change about 4200 BP. It also shows the close interrelationship between vegetation, soils and sediment chemistry in a landscape where human disturbances have been relatively minimal compared with the extreme dominance of climate and geology. Its sedimentary record provides clear and unambiguous evidence of how the remarkable blanket-bog and loch landscape of north-west Scotland came into being. As blanket bog is better developed and more abundant in the British Isles than elsewhere in Europe, the environmental history of Loch Sionascaig and its catchment provides a detailed historical background for understanding the history and development of a landscape dominated by blanket-bog. It also demonstrates that the loch has not been affected by recent increased atmospheric acidification and is thus still in a 'pristine' condition; such lochs are becoming fewer in northern and western Britain. Loch Sionascaig is thus a site of great palaeoecological and palaeolimnological importance.

Conclusion

Loch Sionascaig is a reference site for reconstructing the environmental history of north-west Scotland, during approximately the last 13,000 years, that is, in Lateglacial and Holocene times. Particularly important is the intensively studied Holocene record contained in the loch bed sediments and in a peat bog on Eilean Mór. The demise of pine around 4200 years ago, following rapid climatic change to wetter and windier conditions, and the subsequent development of blanket bog are clearly demonstrated.

LOCHAN AN DRUIM

H. J. B. Birks

Highlights

The pollen and plant macro-fossils preserved in the sediments which infill the basin at Lochan an Druim provide an important record of vegetational history and environmental changes during the Lateglacial and Holocene in the extreme north-west of Scotland.

Introduction

Lochan an Druim (NC 435568) is a small lochan at an altitude of 25 m OD in the shallow valley between the A838 road and the ridge of An Druim that runs northwards from Eriboll. It contains an important Lateglacial vegetational sequence and it has a Holocene vegetational history that is unique to the extreme north-west Scottish Highlands (Birks, 1977, 1980).

The local bedrock is Durness Limestone and, where it crops out to the east of the lochan, there are botanically interesting *Dryas octopetala* heaths, with associated arctic–alpine plants such as *Carex capillaris*, *C. rupestris*, *Polygonum viviparum* and *Saxifraga aizoides*. A pollen diagram for the site was included in Birks (1980), and Birks (1984) gives full details of the site and its environmental setting.

Description

An 8.9 m long core collected from the west side of the lochan showed a succession of silty sand, silty mud, clay and detritus mud sediments (Figure 6.18). Eleven radiocarbon dates (SRR–776 to SRR–785, SRR–866) provide a chronology for the observed pollen stratigraphy (Figure 6.18), although some or all of the dates may be subject to hard-water errors owing to the incorporation of ^{14}C-deficient carbon from the surrounding limestone and calcareous drift. The vegetational history of the site has been studied in detail by Birks (1984 and unpublished data; pollen diagram in Birks, 1980).

Interpretation

The Lateglacial part of the sequence (7.85–8.91 m) has been studied by Birks (1984) for both its pollen and spore assemblages and its plant macrofossils. The sequence begins at about 12,500 BP, implying that deglaciation of the area had occurred by that time. An open, pioneer vegetation of grasses and sedges with *Salix*, *Empetrum nigrum*, *Dryas octopetala* and *Saxifraga* spp. was initially present. During the Lateglacial Interstadial a vegetation dominated by dwarf-shrubs, such as *Empetrum nigrum*, *Dryas octopetala* and *Salix herbacea*, with some juniper was widespread. Leaves of the obligate snow-bed moss *Polytrichum sexangulare* are present, indicating that areas of late snow-lie persisted at low altitudes near the lochan, even in interstadial times.

Inwashing of mineral material occurred during the Loch Lomond Stadial, suggesting unstable soils and discontinuous vegetational cover. The vegetation contained an abundance of open ground, arctic–alpine herbs, such as *Artemisia norvegica*, *Astragalus alpinus*, *Arenaria norvegica*, *Cherleria sedoides*, *Minuartia rubella*, *Saxifraga oppositifolia* and *S. cespitosa*. This assemblage is suggestive of present-day, high-arctic vegetation, with scattered plants forming a sparse cover on open mineral soils, and with long-lasting snow beds and associated meltwater runnels. At this time small corrie glaciers reformed on the higher mountains in north-west Scotland (Sissons, 1977a).

The opening of the Holocene is clearly marked by the expansion initially of dwarf-shrub heaths, dominated by *Empetrum* and *Juniperus*, followed

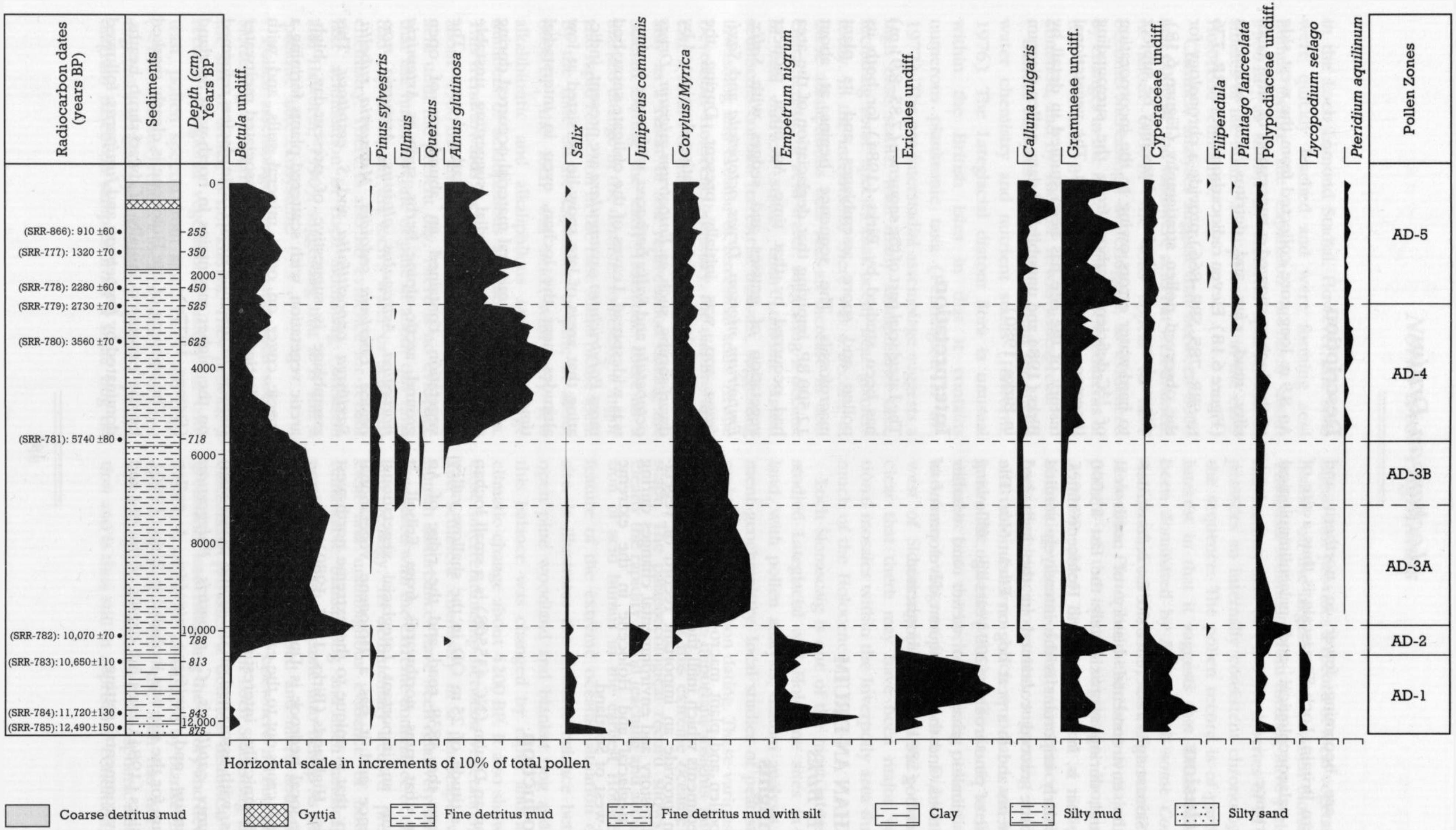


Figure 6.18 Lochan an Druim: relative pollen diagram, showing selected taxa as percentages of total pollen (from Birks, 1980). Note that the data are plotted against a radiocarbon time-scale.

by the development of open birch woods with *Populus tremula* and *Salix* spp. *Corylus avellana* expanded rapidly at about 9800 BP along with *Sorbus aucuparia*. By 9500 BP the landscape around the lochan would have been a mosaic of birch and hazel woods with aspen, rowan and willows, and with an abundance of ferns and tall herbs. Small treeless areas may have persisted where soils were shallow, and where there were natural rock outcrops.

At about 7200 BP *Ulmus* arrived in the area, but it never became an important component of the local forest vegetation. There is no evidence from the pollen stratigraphy at this site to suggest that pine or oak ever grew this far north (Birks, 1977, 1989), even though pine stumps occur locally in the Eriboll area. The natural woodland cover of this part of Scotland appears to have been primarily birch and hazel woods. At about 5800 BP *Alnus* migrated into the area (Birks, 1989; Bennett and Birks, 1990) and expanded locally in wet sites near the lochan.

Destruction of the birch and hazel woods began at about 5000 BP, resulting in the expansion of grasslands and, to a lesser extent, of heathland. There is palynological evidence for arable cultivation, presumably on the fertile limestone soils, from about 2500 BP. By this time extensive forest clearance had occurred, resulting in the virtually treeless landscape of the Loch Eriboll area today.

The site is of national importance because of its detailed and well-dated Lateglacial and Holocene pollen stratigraphy and for the co-ordinated study of pollen and plant macrofossils in the Lateglacial. These palaeoecological data provide important insights into the Lateglacial environment at low altitudes in the extreme north-west of Scotland; there is no other site that has been studied in such detail from this part of Scotland. These insights are as follows: (1) Even during the Lateglacial Interstadial, snow beds occurred at or near the site, thereby providing an interesting British parallel for the extremely open, chionophilous vegetation of south-west Norway during the Lateglacial (H.H. Birks, unpublished). (2) Major north–south and west–east floristic contrasts existed during the Lateglacial of northern Scotland and south-western Norway, as revealed by plant macrofossil studies (Birks, 1984; Birks and Mathewes, 1978; H. H. Birks, unpublished). (3) Lateglacial flora and vegetation at this far north-western site were similar to low- or mid-alpine situations today in western Norway, suggesting a considerably cooler climate than at contemporaneous sites further south in western Scotland. (4) The Holocene vegetational history from Lochan an Druim is particularly important because of the apparent lack of pine and oak. Its pollen record is thus intermediate between sites further south in western Scotland (Birks, 1980) and sites further west on Skye (Birks and Williams, 1983) and the Outer Hebrides (Bennett *et al*., 1990). Lochan an Druim thus represents a uniquely important site for the reconstruction of Quaternary vegetational history and past environments.

Conclusion

Pollen and plant remains in the sediments from Lochan an Druim provide a record of the environmental history of the far north-west of Scotland during the Lateglacial and Holocene (approximately the last 12,500 years). They show that conditions remained extreme even during the relative climatic warming in the Lateglacial Interstadial. Later, during the Holocene, birch and hazel woodland developed, but oak did not extend this far north and pine was probably only locally present. Lochan an Druim provides valuable comparisons with other areas and is important as part of the network of sites that show the wider geographical variations in the patterns of vegetation development since the end of the last ice age.

LOCH MAREE

H. J. B. Birks

Highlights

The pollen records preserved in the sediments on the floor of Loch Maree and in the bogs on its islands provide a valuable record of Holocene vegetational changes in an area of high ecological importance. In particular, they allow important insights into the development of the native pinewoods.

Introduction

Loch Maree is a long (20 km), narrow (1.6–3.7 km) and deep (in excess of 110 m) loch situated north-west of Kinlochewe in Wester Ross. The sediments preserved on the floor of the loch and in several bogs and small lochans on the islands of Eilean Subhainn and Eilean Dubh na Sroine provide important pollen records of the Holocene vegetation history of this area. The Loch Maree woods, including Coille na Glas-Leitire on the south side of Loch Maree, the islands at the north-west end of Loch Maree, and the Letterewe oakwoods on the north side of Loch Maree are internationally important (Ratcliffe, 1977) because of the abundance of *Pinus sylvestris*, a tree that today is characteristic of the eastern Highlands and is rare or absent in much of north-west Scotland. The Loch Maree pine populations are distinct in terms of their monoterpene and isoenzyme loci and 'show little genetic affinity between contemporary Scottish and continental European populations' (Kinloch *et al.*, 1986). This suggests that these pine populations may have had a history that differs from those elsewhere in Scotland. Further, the Letterewe woods are also significant as the northernmost extensive semi-natural oakwood in Scotland. The vegetation history of this ecologically unique area is thus an important and integral part of its overall conservation importance, and has been investigated through pollen analytical studies of a sediment core from Loch Maree Hotel Bay (NG 919709) by Birks (1972b).

Kerslake (1982) has also studied three pollen profiles from islands in the loch. These islands support fine stands of pine woodland, alternating with a range of mire communities and small lochans, and provide a 'natural experiment' in vegetational history, in that by being isolated and difficult to reach, they are less likely to have been influenced by grazing and by human disturbance than the mainland. The site on Eilean Dubh na Sroine (NG 909720) is a small lochan on a rocky island that supports almost continuous pine woodland today. Subhainn Lochan (NG 923721) lies within a mosaic of pine woodland and blanket mires on Eilean Suhainn; Subhainn Bog (NG 922726) represents an area of deep peat and was studied to elucidate the history of peat development on the same island as Subhainn Lochan. An interesting feature of these island sites is the occurrence of Lateglacial sediments, in contrast to their absence in Loch Maree itself. However, these Lateglacial sediments have not been studied in detail.

Description

From the site in Loch Maree Hotel Bay, Birks (1972b) recovered a 5.42 m long core from below 29 m of water. The sediments comprised 4.67 m of organic muds overlying clays and silts (Figure 6.19). Six radiocarbon dates were obtained (Figure 6.19) and these form an internally consistent series. The pollen record has been divided into five local pollen assemblage zones (Figure 6.19).

Interpretation

The radiocarbon dates indicate that organic sedimentation began at about 9500 BP. The pollen stratigraphy shows a dominance of *Juniperus communis* with some *Empetrum* and herbs, such as *Rumex acetosa*, in the early Holocene. This was replaced at about 9000 BP by *Betula* and, to a lesser extent, *Corylus*. At the 8300 BP level, small but consistent amounts of *Quercus* and *Ulmus* pollen are found suggesting the local occurrence of these trees, perhaps on the Letterewe side of the loch. The most important feature, however, is the rapid and early expansion of *Pinus sylvestris* at about 8250 BP. This is one of the earliest occurrences of pine known in Scotland (Birks, 1989). The source of this early arrival is unknown (Kinloch *et al.*, 1986; Birks, 1989). At that time pine was present in southern Ireland and parts of southern and central England. Glacial survival or long-distance seed dispersal are the most plausible hypotheses (Birks, 1989). The pollen record provides strong support for the unique history of the Loch Maree pine populations that has been inferred by Kinloch *et al.* (1986) from biochemical evidence.

After 8000 BP *Pinus sylvestris* formed extensive open woodlands with abundant *Pteridium aquilinum*, other ferns and *Calluna vulgaris*. However, the extent of these began to decline from about 6500 BP, perhaps because of climatic change or soil degradation (Birks, 1972b). At about this time *Alnus* expanded, presumably in wet areas by streams and rivers and around the loch. As elsewhere in north-west Scotland (Birks, 1977, 1988; Bennett, 1984; Gear and Huntley, 1991), *Pinus* underwent a major decline in the Loch Maree area at about 4250–4000 BP, probably because of increased oceanicity and moisture, which restricted its survival and regeneration to well-drained, steep, blocky slopes

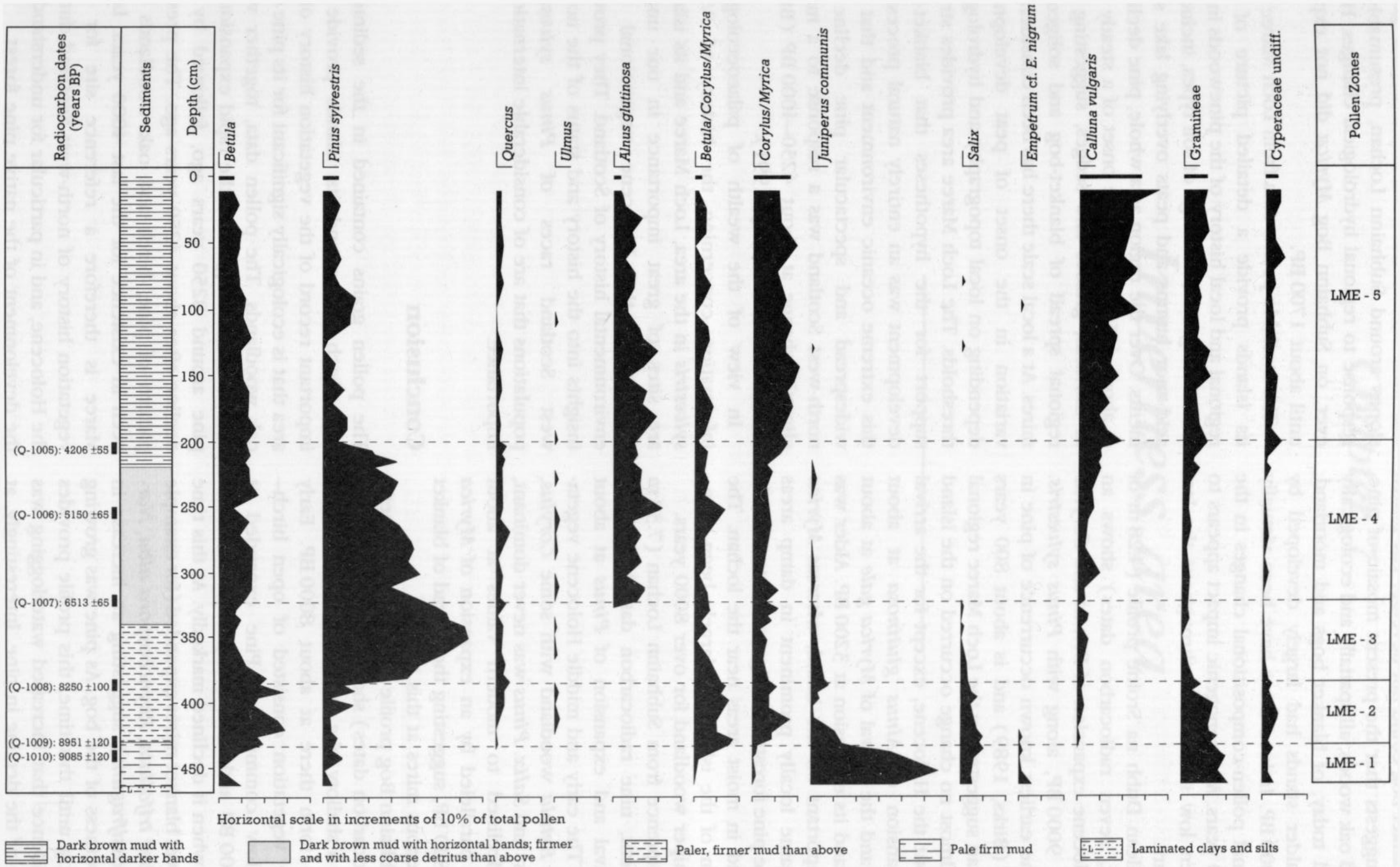


Figure 6.19 Loch Maree: relative pollen diagram, showing selected taxa as percentages of total pollen (from Birks, 1972b).

where blanket bog could not develop. The pollen record suggests that the present mosaic of pine, birch and oak woods, all spatially and ecologically separated today, of blanket bogs and moorland, and of alder stands had largely developed by about 4000 BP. Indeed there have been virtually no regional pollen-compositional changes in the last 4000 years. Anthropogenic impact appears to have been low in the area throughout the last 5000 years.

The Eilean Dubh na Sroine profile (4.28 m of sediment, seven radiocarbon dates) shows an early Holocene expansion of *Betula* and *Corylus* at about 9000 BP, along with *Pinus sylvestris*. This is the earliest known occurrence of pine in Scotland (Birks, 1989) and is about 800 years earlier than suggested by the Loch Maree regional profile. Almost no change occurred on the island throughout the Holocene, except for the arrival and expansion of *Alnus glutinosa* at about 6500 BP and the arrival of *Myrica gale* at about 3800 BP and its expansion at 3200 BP. Alder was never important on the island, whereas *Myrica gale* became locally prominent in damp areas within the pine forests, in soligeneous stream-side mires, and in moist areas near the lochan. The vegetation of the island has largely been pine–birch–juniper woodland for over 8000 years.

The sequence from Subhainn Lochan (7.38 m of sediment, nine radiocarbon dates) shows a later arrival and expansion of *Pinus* at about 7800 BP. The early and middle Holocene vegetation was *Betula* woodland with some *Corylus*, *Juniperus*, and *Salix*. *Pinus* was never dominant, and it declined to modern values at about 4000 BP, paralleled by an expansion of *Myrica gale* at 3800 BP, suggesting the spread of blanket and soligenous mires at this time.

The Subhainn Bog profile (6.25 m of sediment, nine radiocarbon dates) shows that the site was originally a shallow lake and that *Sphagnum* peat began to form there at about 8000 BP. Early Holocene vegetation consisted of open birch–hazel–willow communities. Pine expanded at about 8000 BP and was locally important until 3800 BP, when it declined markedly. At this time plants of wet blanket-mires expanded (for example *Menyanthes trifoliata*, *Rhynchospora alba*, *Narthecium ossifragum*), suggesting an increase in surface wetness of the bog. As pine was growing on the bog until this time, this profile provides direct evidence that increased waterlogging was the cause of the decline in pine. Interestingly, at this time *Myrica gale* expanded on the gentle slopes around Subhainn Lochan, presumably in response to regional hydrological changes. However, on Subhainn Bog *Myrica* did not expand until about 1700 BP.

The available pollen data from Loch Maree and its islands provide a detailed picture of the regional and local history of the pinewoods in the area. Pine grew on a range of soil types, including acid mor humus and peats overlying lake sediments. Over the region as a whole, pine declined at about 4250 BP with the onset of a steady rise in *Calluna*, grasses and sedges, suggesting the regional spread of blanket-bog and soligenous mires. At a local scale there has been considerable variation in the onset of peat development depending on local topography and hydrological thresholds. The Loch Maree area provides strong support for the hypotheses that blanket-bog development was an entirely natural process in this extreme oceanic environment and that the widespread and spectacular pine decline of north-west Scotland was a response to a major climatic change at about 4250–4000 BP (Birks, 1988; Gear and Huntley, 1991).

In view of the wealth of palaeoecological information concerning the history of *Pinus sylvestris* in the area, Loch Maree and its islands are sites of great importance in our understanding of the Holocene vegetational and environmental history of Scotland. They provide insights into the history and status of the north-west Scotland races of *Pinus sylvestris*, populations that are of considerable international importance.

Conclusion

The pollen grains contained in the sediments from Loch Maree and its islands provide an important record of the vegetation history of an area that is ecologically significant for its pine and oak woodlands. The pollen data, together with radiocarbon dating, show the rapid expansion of pine around 8250 years ago, followed by its decline after about 4250 years ago. The present pattern of pine, birch and oak woodlands has been in existence for the last 4000 years. Loch Maree is therefore a reference site for the vegetation history of north-west Scotland during the Holocene, and in particular for understanding the development of the native pine forest.