Quaternary of Scotland

Edited by

J. E. Gordon
Scottish Natural Heritage,
Edinburgh, Scotland.

and

D. G. Sutherland
Edinburgh, Scotland.

GCR Editor: W. A. Wimbledon

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Chapter 9

Eastern Grampian Mountains

INTRODUCTION
D. G. Sutherland

The eastern Grampian Mountains are considered here as the highland areas to the east of the Tay–Tummel–Truim–Spey through valley (Figure 9.1). This valley separates the western mountain areas, characterized by intense glacial erosion, and the eastern mountain plateau country, where glacial erosion has produced only specific features superimposed on an easily recognizable pre-existing landscape. There are three principal mountain groups in this area, the Gaick Plateau, the Cairngorms and the south-east Grampians around Lochnagar. Each of these is characterized by high-level plateau surfaces, which are most impressively developed in the Cairngorms. These surfaces are widely acknowledged as having formed prior to glaciation (Fleet, 1938; Linton, 1949b, 1959; Sissons, 1967a; Sugden, 1968; Hall, 1983) and carry apparently relict pre-glacial features, such as tors (Linton, 1950a, 1955) and decomposed bedrock (Barrow *et al.*, 1913; Sugden, 1968; Hall and Mellor, 1988).

The presence of these apparent pre-glacial features has resulted in certain authors suggesting that parts of the Cairngorms may never have been glaciated, but such an idea was effectively refuted by Sugden (1968). However, the eastern mountains do demonstrate eloquently the selectivity of glacial erosion, for the plateaux are frequently flanked by spectacular glacial breaches, such as the Lairig Ghru and Glen Tilt, or are bitten into by corries as on Lochnagar and on the northern flanks of the Cairngorms. The form of the corries and glacially eroded rock walls has been studied by Haynes (1968), Sugden (1969) and Dale (1981), the last author demonstrating a lower frequency and amplitude of rock walls in the eastern Grampians than in the western mountain groups. The altitude of the corries and the base of rock walls is also higher in the eastern mountains than the west and this has been related to the precipitation distribution in Scotland (today and, by inference, in the past) by Linton (1959).

With the exception of the landforms of glacial erosion, which have developed during multiple periods of both local and ice-sheet glaciations, the Quaternary history of the eastern Grampians, as presently known, relates only to the Late Devensian and the Holocene. During the Late Devensian ice-sheet glaciation, the western part of the area was covered by ice emanating from the Rannoch Moor area, and erratics of Rannoch granite can be found on the flanks of the Gaick plateau (Barrow *et al.*, 1905, 1913) and into the Truim Valley (Barrow *et al.*, 1913). Ice from the west also carried schistose erratics on to the flanks of the Cairngorms to an altitude of up to *c.* 840 m OD (Hinxman and Anderson, 1915; Sugden, 1970). Within the principal mountain masses, however, external erratics occur only sporadically, and it is probable that local ice masses developed which were sufficiently powerful to exclude ice from western sources. Erratics from these local areas were carried to the north-east, east or south-east (Sutherland, 1984a).

Throughout most of the valleys of the region there are abundant glaciofluvial landforms and deposits, as in Glen More at the foot of the Cairngorms (Sugden, 1970; Young, 1974), at the mouth of Glen Feshie (Young, 1975a) and along the Dee Valley (Sugden and Clapperton, 1975) (see Muir of Dinnet, Chapter 7). These areas of ice-decay deposits are typically accompanied by sequences of meltwater channels on the adjacent slopes (Sugden, 1968; Young, 1974) and, in places, extensive outwash terraces as in Glen Feshie (Young, 1976; Robertson-Rintoul, 1986b).

The timing of ice-sheet wastage has not been established in detail, but the occurrence of a considerable number of enclosed basins that are known to contain lacustrine sediments deposited during the Lateglacial Interstadial has demonstrated that much of the area was deglaciated prior to 13,000 BP. Important among these sites are those of Loch Etteridge (Sissons and Walker, 1974) and Abernethy Forest (Vasari, 1977; Birks and Mathewes, 1978). The vegetational succession in the eastern Grampians during the Lateglacial Interstadial showed some differentiation between the valleys of the northern and central parts and those of the south-east. After an initial phase in both areas of pioneer grass- and sedge-dominated communities, in the central mountain area there developed a shrub tundra dominated by *Empetrum* with stands of birch and willow (Walker, 1975b; Birks and Mathewes, 1978). In the south-eastern valleys there was a grassland with juniper, dwarf birch and willow and, in more sheltered areas, tree birch (Walker, 1975b, 1977, 1984b; Lowe and Walker, 1977). Higher-level sites, such as Morrone, reveal a sparser, less differentiated vegetation on the upper slopes with the development of moss heaths and grasslands (Huntley, 1976, 1981).

The Lateglacial Interstadial was terminated by a

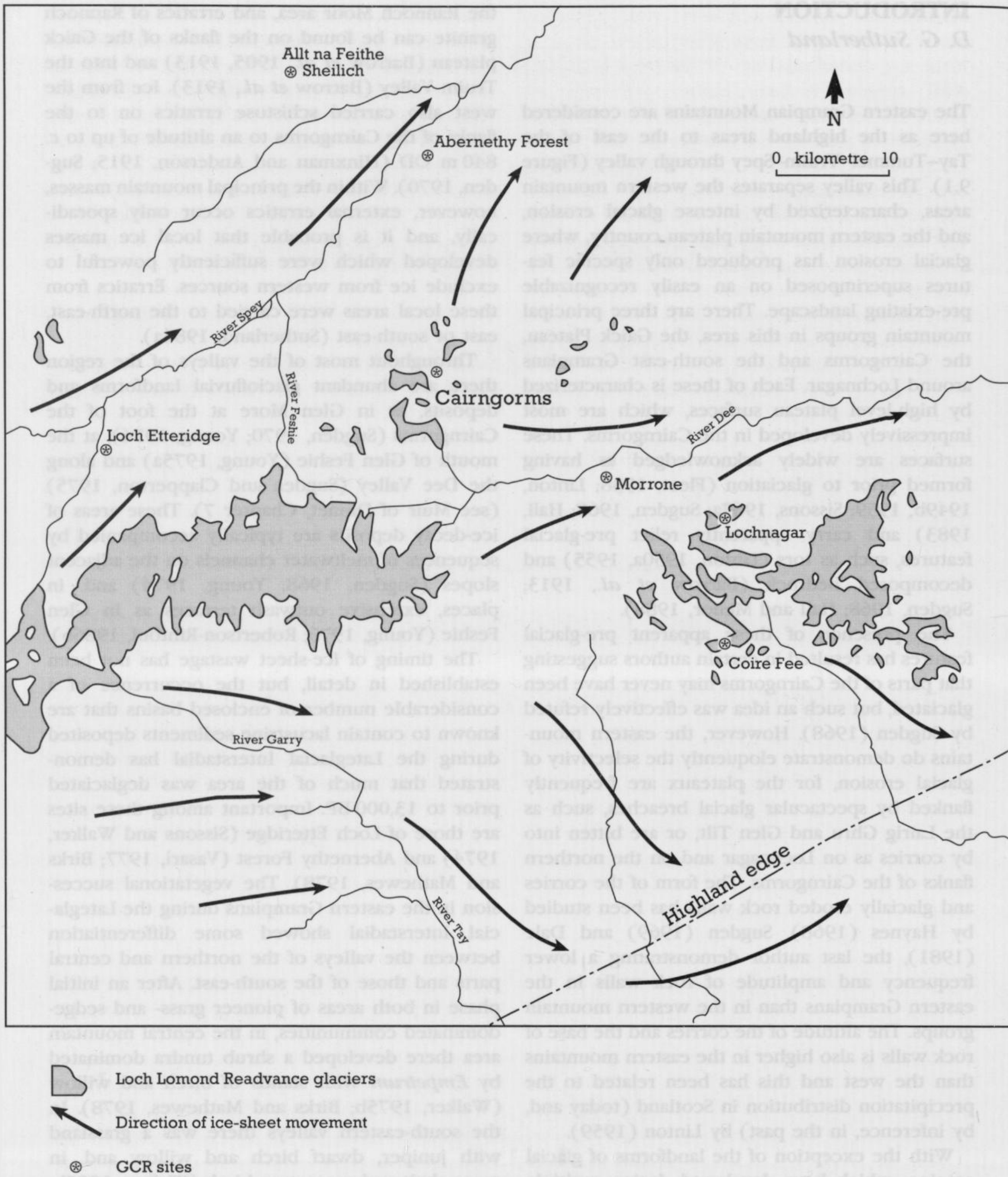


Figure 9.1 Location map of the eastern Grampian Mountains. The limits of the Loch Lomond Readvance glaciers are from Sissons (1972a, 1974b, 1979f) and Sissons and Grant (1972).

return to severe climatic conditions during the Loch Lomond Stadial. There was a recrudescence of glaciers in the high valleys and corries and the development of ice-caps on the Gaick Plateau and in the south-east Grampians between Glen Muick and Glen Clova (Figure 9.1) (Sissons, 1972a, 1974b, 1979f; Sissons and Grant, 1972). Although there has been discussion as to the exact extent of these glaciers (Sissons, 1973a; Sugden, 1973a, 1980), many of the landforms which they produced are clear, such as the end moraines in the corries of Lochnagar (Sissons and Grant, 1972; Clapperton, 1986) and the Cairngorms (Sissons, 1979f; Rapson, 1985).

It was probably during the stadial that the large-scale periglacial features that mantle many of the mountain tops received their final form. Most impressive of these features are the boulder sheets and lobes that occur on the granite of the Cairngorms and Lochnagar (King, 1972; Shaw, 1977). Additional periglacial features that formed at this time are the protalus ramparts and rock glaciers found in the Cairngorms (Sissons, 1979f; Ballantyne, 1984; Ballantyne and Kirkbride, 1986; Chattopadhyay, 1984). Enhanced fluvial activity associated with seasonal regimes was probably responsible for terrace development in areas such as Glen Feshie.

Vegetation at this time was dominated by open-habitat species and there were particularly high *Artemisia* pollen values in the sites investigated in Strathspey such as Abernethy Forest (Birks and Mathewes, 1978). These high values and their contrast with lower values in the valleys of the south-east Grampians (Walker, 1975b), have been interpreted as relating to variations in the snow-cover (Walker, 1975b; MacPherson, 1980), with Strathspey receiving very low precipitation during this period (Birks and Mathewes, 1978). Similar inferences have been made (Sissons and Sutherland, 1976; Sissons, 1980b) on the basis of variations in Loch Lomond Readvance equilibrium line altitudes throughout the region.

Following amelioration of the climate at the end of the Loch Lomond Stadial, the last glaciers melted and vegetation rapidly changed from open habitats through dwarf shrub and scrub communities (including a distinct phase of juniper dominance at around 10,000 BP or slightly later) to birch and hazel woodland in the valleys, with grass and heathland on the upper slopes by about 9,000 BP. Thereafter development of the woodlands again shows significant differences between the southern part of the region, where oak and elm dominated the forests in the valleys, and in the northern area, where pine became the principal tree species during the middle Holocene (see Allt na Feithe Sheilich, Abernethy Forest and the Cairngorms) (Birks, 1975; Birks, 1977).

One interesting aspect of vegetation development is the occurrence today of arctic–alpine species in certain of the mountains. Their presence raises the question of whether they have survived since the Lateglacial in certain favourable refuge habitats, or whether they died out in the early Holocene only to be reintroduced at a later date. The high-level pollen sites at both Coire Fee and Morrone provide direct evidence for the survival of these species throughout the Holocene.

Geomorphological activity has also continued during the Holocene, with small-scale periglacial features, such as turf-banked terraces and lobes, 'ploughing' boulders and patterned ground, forming at high altitudes (Chattopadhyay, 1986; Ballantyne, 1987a), and fluvial activity resulting in the formation of river terraces, debris cones and alluvial fans in the valley bottoms, as in Glen Feshie (Brazier, 1987; Robertson-Rintoul, 1986a, 1986b).

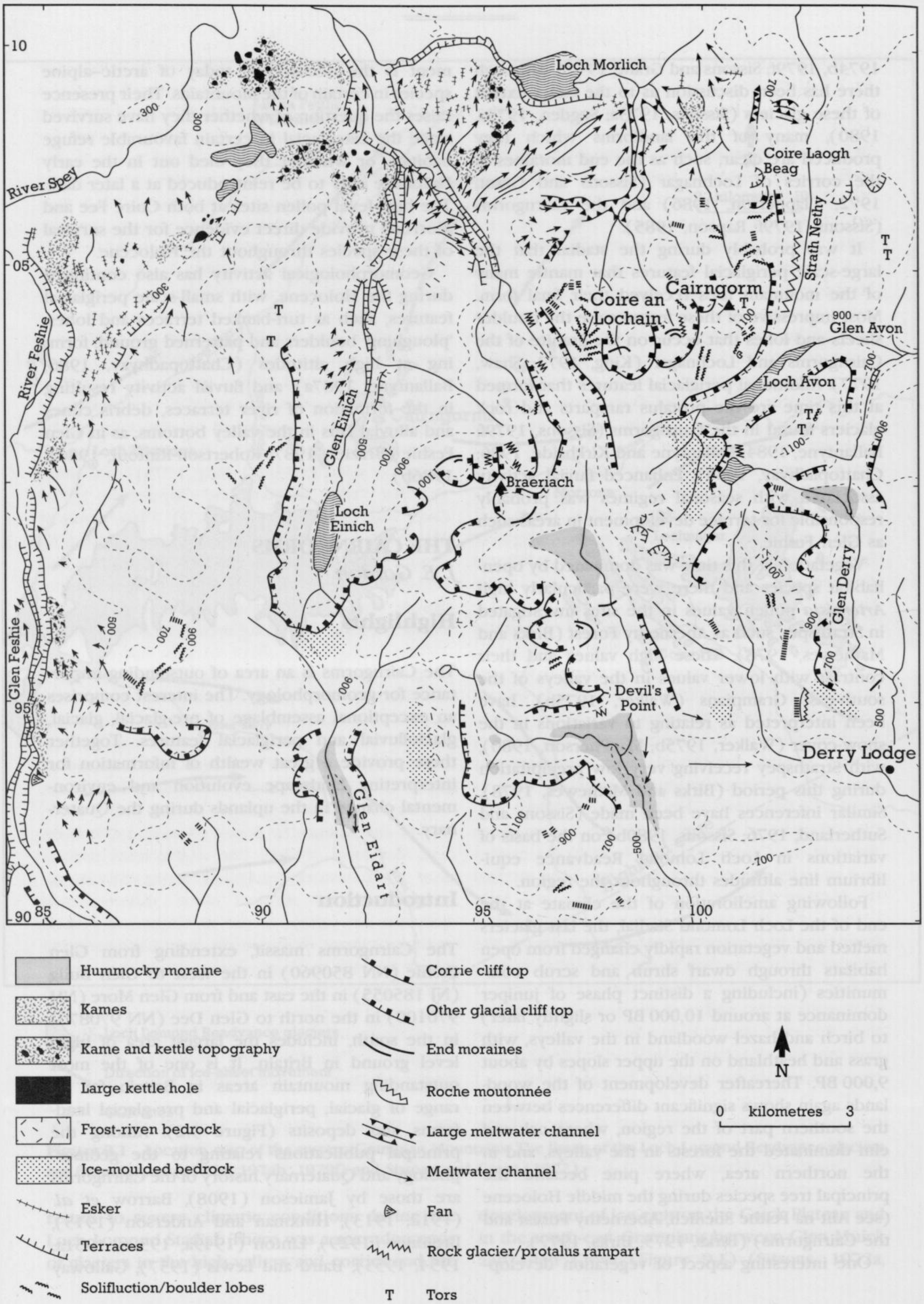
THE CAIRNGORMS
J. E. Gordon

Highlights

The Cairngorms is an area of outstanding importance for geomorphology. The interest comprises an exceptional assemblage of pre-glacial, glacial, glaciofluvial and periglacial features. Together these provide a great wealth of information for interpreting landscape evolution and environmental change in the uplands during the Quaternary.

Introduction

The Cairngorms massif, extending from Glen Feshie (NN 850960) in the west to Glen Builg (NJ 185055) in the east and from Glen More (NH 970100) in the north to Glen Dee (NN 970870) in the south, includes the largest area of high-level ground in Britain. It is one of the most outstanding mountain areas in Britain for its range of glacial, periglacial and pre-glacial landforms and deposits (Figure 9.2). Among the principal publications relating to the geomorphology and Quaternary history of the Cairngorms are those by Jamieson (1908), Barrow *et al.* (1912, 1913), Hinxman and Anderson (1915), Bremner (1929), Linton (1949a, 1950a, 1951a, 1954, 1955), Baird and Lewis (1957), Galloway



Loch Morlich
River Spey
Coire Laogh Beag
Strath Nethy
Cairngorm
Coire an Lochain
Glen Avon
Loch Avon
River Feshie
Glen Einich
Braeriach
Loch Einich
Glen Derry
Devil's Point
Glen Feshie
Derry Lodge
Glen Eidart
10
05
95
90
85
100
N
0 kilometres 3
Hummocky moraine
Kames
Kame and kettle topography
Large kettle hole
Frost-riven bedrock
Ice-moulded bedrock
Esker
Terraces
Solifluction/boulder lobes
Solifluction terraces
Corrie cliff top
Other glacial cliff top
End moraines
Roche moutonnée
Large meltwater channel
Meltwater channel
Fan
Rock glacier/protalus rampart
T Tors
700 Contours (metres)

(1958), Pears (1964, 1968), Sugden (1965, 1968, 1969, 1970, 1971, 1977, 1983), Sissons (1967a, 1979f), King (1968, 1971a, 1971b, 1972), Birks (1969, 1975), Kelletat (1970a, 1970b, 1972), Young (1974, 1975a, 1975b), Clapperton *et al.* (1975), Dubois and Ferguson (1985), Rapson (1985), McEwen and Werritty (1988) and Bennett and Glasser (1991).

Description

Geology and pre-glacial landform elements

The Cairngorms massif largely comprises a granite pluton intruded during the Caledonian orogeny, in late Silurian–early Devonian times, into Precambrian Moine metamorphic country rocks. Recent work has shown the granite to be a discordant, stock-like mass and to consist of at least two intrusions, the more extensive Main Granite which is largely even-grained, and the Porphyritic Granite which occurs on the Carn Bàn Mór–Geal-charn ridge west of Loch Einich (Harry, 1965). The most detailed accounts of the solid geology of the area appeared in the early Geological Survey Memoirs (Hinxman, 1896; Hinxman and Anderson, 1915; Barrow *et al.*, 1912, 1913).

The broad outlines of the Cairngorms massif are characterized by two major morphological elements: undulating plateau surfaces and precipitous cliffs of corries and glacial troughs (Linton, 1950a; Sugden, 1968). The former are part of a suite of surfaces rising in 'steps' inland from the coast of north-east Scotland (Fleet, 1938; Walton, 1963). Two main breaks of slope at 760 m and 910 m OD are represented on the margins of the Cairngorms, and the higher summits rise gently above a third at 1070–1220 m OD (Sugden, 1968). Similar surfaces have long been recorded throughout the Highlands and Southern Uplands, either as vast 'tablelands' or as summit accordances (see Geikie, 1901; Peach and Horne, 1930; Godard, 1965). Although the origin of the surfaces and intervening breaks of slope is a matter of debate (Sissons, 1976b), they are generally held to be of pre-glacial, probably late Tertiary age. The hypothesis that the Cairngorm summits are part of a sub-Cenomanian surface, as proposed by Linton (1951b), has been effectively refuted by George (1966).

The essentially pre-glacial aspect of the surfaces is emphasized by a number of relict features of non-glacial origin associated with them, namely tors, decomposed granite, fluvial forms and 'pseudobedding' (sheet jointing) forms in the bedrock.

The Cairngorm tors are the finest in Scotland and are best seen in the north and east of the massif, on Beinn Mheadhoin (NJ 025017), Bynack More (NJ 042063) (notably the 30 m high Barns of Bynack) and Ben Avon (NJ 132018), where a series of forms occurs across the summit plateau (Figure 9.3). On Ben Avon, fantastically sculpted potholes occur, and other weathering forms can be found on Clach Bhàn (NJ 162054) (Hinxman, 1896; Hinxman and Anderson, 1915; Alexander, 1928). First described by Hinxman (1896) and Hinxman and Anderson (1915), the Cairngorm tors were interpreted by Linton (1955) in terms of a two-stage model as residuals of deep weathering during the Tertiary, subsequently exhumed during the Quaternary by solifluction or meltwater. Sugden (1968, 1974c) concurred with this interpretation, which is apparently supported by the presence of isolated pockets of deeply weathered bedrock on the plateaux surfaces (see below). The most detailed investigation and description of the tors is that of King (1968), who found that they occurred primarily in coarser-grained granite on plateaux and gentle to moderate slopes between 710 m and 1240 m OD. He concluded that they were formed by subsurface decomposition then exhumed and modified by periglacial frost action; chemical weathering later modified the surface forms and produced undercutting of the tors. Linton (1949b, 1950b, 1950c, 1952, 1954, 1955) believed that the tors had survived because the Cairngorm plateau had escaped at least the last glaciation, a view shared by Galloway (1958). However, Sugden (1965) found evidence of ice moulding on some of the tors, and metamorphic erratics surrounding the Argyll Stone (NH 905040), a small granite tor in the western Cairngorms. It is now believed that the entire Cairngorms were ice-covered during the last glaciation (see below), and Sissons (1976b) suggested that the preservation of the large tors in the north and east of the massif resulted from their relatively sheltered

Figure 9.2 Principal geomorphological features of the Cairngorm Mountains (sources include Sugden, 1968, 1970; Young, 1974, 1975a; Sissons, 1979f; J. E. Gordon, unpublished data).

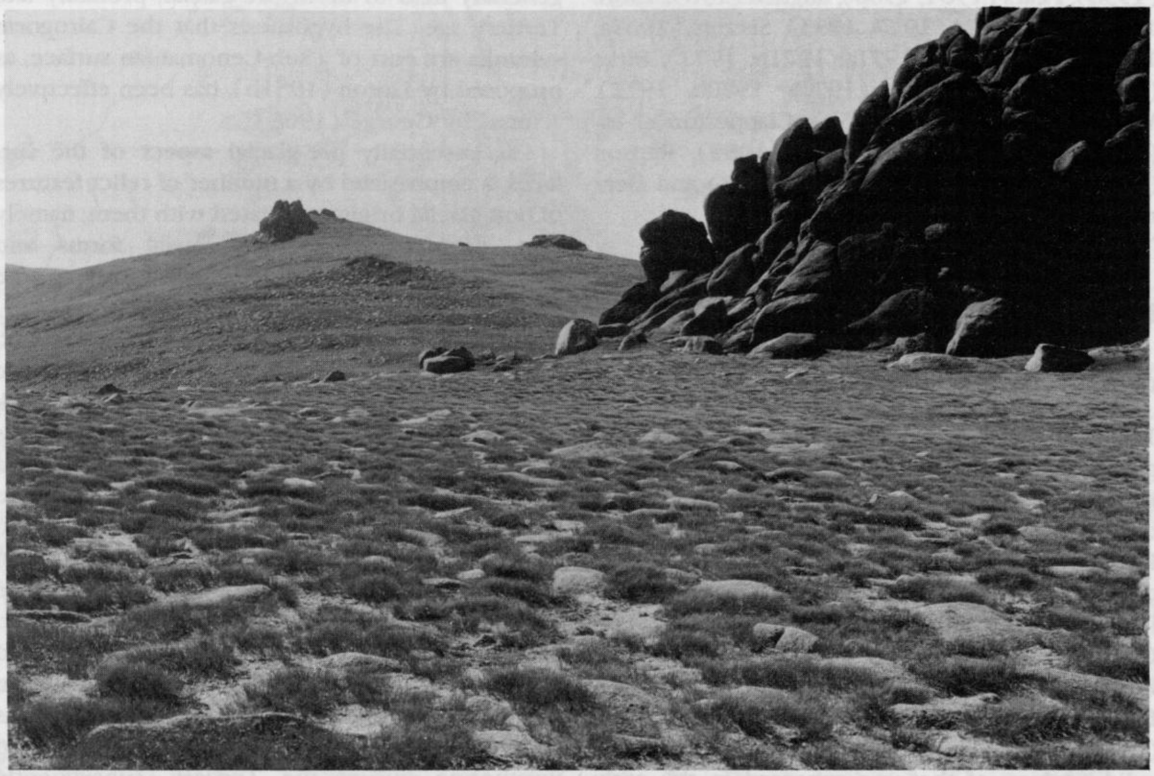


Figure 9.3 Summit plateau of Ben Avon in the Cairngorms showing well-developed tors which appear to have survived glaciation. The adjacent slopes have been affected by periglacial processes and the development of solifluction lobes. (Photo: J. E. Gordon.)

location in relation to ice moving from the southwest.

In some cases an exclusively periglacial or cold-climate origin has been advocated for the development of tors similar to those on the Cairngorms (Palmer and Radley, 1961; Demek, 1964; Martini, 1969; Derbyshire, 1972); in others, a polygenetic origin has been advocated (Caine, 1967; Fahey, 1981; Söderman *et al.*, 1983). Tors preserved in glaciated areas have been reported in Britain from the Cheviots (Common, 1954b; Clapperton, 1970; Clark, 1970, 1971) and Pembrokeshire (John, 1973; Battiau-Queney, 1984), and from abroad in Tasmania (Caine, 1967), northern Finland (Kaitanen, 1969; Söderman *et al.*, 1983), Norway (Dahl, 1966), Somerset Island (Dyke, 1976, 1983), Ellesmere Island (Watts, 1981, 1983) and Baffin Island (Boyer and Pheasant, 1974; Sugden and Watts, 1977). Although some authors have argued that tors and the surfaces on which they stand have either not been glaciated themselves or lay beyond the limits of the last glaciation (Boyer and Pheasant, 1974; Dyke, 1976, 1983), Sugden and Watts (1977) suggested that tors could survive glaciation where slow-moving, cold-based ice was unable to exert sufficient tractive force to overcome the resistance of the intact, massive bedrock outcrops, and they drew analogies with the process of subglacial lodgement (cf. Boulton, 1975). Sugden (1983) subsequently reviewed the evidence for a pre-glacial origin for the Cairngorm tors and advocated such a hypothesis to explain their preservation. Although Dubois and Ferguson (1985) expressed a contrary view, the balance of evidence (see below), however, appears to favour a long period of landscape evolution extending back into the Tertiary, so that the present surfaces and slopes of the Cairngorm plateaux reflect the complex interaction of pre-glacial weathering, periglacial weathering and mass movement, and limited glacial action. Models such as those of Linton and Sugden appear to be valid in addressing the main elements of this polygenetic evolution, although they are probably oversimplified in terms of their spatial and temporal resolution. Elsewhere in Scotland tors occur on the granites of Lochnagar, Mount Keen, Broad Cairn, Bennachie and Ben Rinnes; on the syenites of Ben Loyal; the gabbros of the Insch basic intrusion at Cabrach; and the conglomerates of Morven in Caithness. However, there has been no thorough investigation of their ages or processes of formation, and not all may be exhumed features.

A second pre-glacial feature of the plateau surfaces is the decomposed granite. This is best exposed in a stream section near the head of Coire Raibert (NJ 001038) but can also be seen in a gully at the top of the Glen Avon cliffs (NH 997022). King (1968) reported examples in the headwalls of Coire an t-Sneachda (NH 995032) and Coire Bhrochain (NN 955995); other sites occur in stream sections on the Mòine Mhór, above the head of Gleann Einich, and on the flanks of Beinn Bhrotain (NN 455923) (A. M. Hall, unpublished data). Preliminary mineralogical investigations have revealed the presence of kaolinite in the Coire an t-Sneachda and Coire Bhrochain exposures (King, 1968), and kaolinite, gibbsite and hematite in the Coire Raibert exposure (Hall, 1983). The granular disintegration (arenization) of the rock and the assemblage of secondary minerals are similar to examples widely reported from deeply weathered bedrock, both in the Gaick area to the south (Barrow *et al.*, 1913; Hall and Mellor, 1988) and on lower ground in north-east Scotland (see Hill of Longhaven), where such features have been generally ascribed to a long period of pre-glacial weathering (FitzPatrick, 1963; Basham, 1974; Hall, 1985, 1986; Wilson, 1985; Hall *et al.*, 1989a). From a wider study of soil profiles on Scottish mountains, Mellor and Wilson (1989) concluded that the presence of gibbsite is a feature that pre-dates the last glaciation, but its precise time of formation is uncertain; it could have formed under humid, warm-temperate to subtropical conditions during the Tertiary and/or during Pleistocene interglacials and survived under cold-based ice with limited erosional capacity. The status of gibbsite, however, as an indicator of former warm environments is uncertain, as this mineral is also believed to form at the initial stages of rock breakdown (Hall *et al.*, 1989a). Much further work is needed on the mineralogy and other characteristics of the weathering profiles in the Cairngorms before their significance can be properly assessed. In particular, more investigation is needed of the possible contribution of hydrothermal alteration to the breakdown of, and clay mineral genesis within, the granite (Hall, 1983). Additional study is also required of the possible development of clay minerals during chemical weathering beneath snow patches before a recent origin for such grusification can be ruled out (A.M. Hall, unpublished data).

The plateau surfaces of the Cairngorms are not flat but comprise smooth, rolling slopes and shallow fluvial valleys; for example Coire Raibert, Coire Domhain (NH 995023) and the valley of the Feithe Buidhe (NH 990015) on the Cairngorm–Ben Macdui plateau, and the valley of Caochan Dubh (NN 895947) on the Mòine Mhór plateau. Although such valleys probably owe part of their form to periglacial processes, they have clearly been little modified by the passage of ice and are abruptly truncated by cliffs at the plateaux margins. Such landscapes are comparable with parts of the Canadian Arctic archipelago (Sugden, 1978), although on a much smaller scale.

A fourth characteristic feature of the plateau surfaces is the 'pseudobedding' or sheet jointing present in the upper layers of the granite (Hinxman and Anderson, 1915; King, 1968; Sugden, 1968). It is particularly well seen in the tors and at the tops of many of the glacial cliffs; for example in Coire an Lochain (NH 985026) and above the Saddle (NJ 015033). Sugden (1968) noted that the spacing of the sheet joints increased with depth and that everywhere it lay parallel with the slope of the ground. He therefore concluded that since the sheet jointing conformed extensively with the detailed surface form of the plateaux, the pre-glacial surface over much of the Cairngorms was 'faithfully preserved', and he was able to complete a tentative reconstruction of its form. Sheet jointing parallel to pre-glacial surfaces has also been described from Dartmoor (Waters, 1954), New England (Jahns, 1943) and Maine (Chapman and Rioux, 1958) and is generally held to relate to stress unloading (Ollier, 1969). However, in the context of the Cairngorms, Sissons (1976b) has suggested an alternative possibility of intensive frost action under periglacial conditions.

Landforms and patterns of glacial erosion

Despite the presence of pre-glacial features it is now accepted that the entire Cairngorms massif was ice-covered during the Late Devensian glaciation, contrary to the views of Linton and Galloway outlined above. From the lack of metamorphic erratics in the central Cairngorms Bremner (1929) and Sissons (1976b) concluded that the massif was the site of an independent ice dome, albeit constrained by external ice streams on all but its north-eastern side. A similar view was put forward by Sugden (1970) for at least an early phase in the deglaciation of the mountains, although he thought that at an earlier time (not necessarily the Late Devensian), the entire massif had been overwhelmed by ice from the south-west, in order to explain the pattern of glacial troughs.

Whatever the source of the ice, successive glaciations have resulted in impressive, selective erosion of the plateaux (Linton, 1950a, 1951a; Sugden, 1968), producing the classic 'Icelandic' glacial troughs of Glen Einich and Glen Avon and their rock basins; the glacial breaches of the Lairig Ghru, Glen Feshie, Inchrory and Glen Avon–Glen Derry among others; the diffluent breach of Strath Nethy and the dramatic truncated spur at the Devil's Point (Figure 9.2). Many of these breaches are associated with abrupt changes in drainage direction and were traditionally explained in terms of pre- or post-glacial river capture (Hinxman, 1901; Gibb, 1909; Peach and Horne, 1910; Bremner, 1912, 1915, 1919, 1921, 1942, 1943b). However, Linton (1949a, 1951a, 1954) clearly demonstrated the role of watershed breaching by ice and glacial diversion of drainage. Roches moutonnées and ice-moulded bedrock are also well-displayed (see figure 3 in Sugden, 1968).

Linton (1950a, 1951a) interpreted the troughs and breaches as the product of erosion by local glaciers. Sugden (1968), however, argued strongly that they were cut by ice streams within an ice-sheet, drawing analogies with modern ice-sheets and glacierized areas, notably East Greenland. The Cairngorms massif as a whole may be described as a landscape of selective linear erosion (Sugden, 1968; Sugden and John, 1976) in which the glacial troughs and breaches contrast sharply with the little-modified plateau surfaces.

Such selectivity of erosion is widely represented in the eastern Grampians (Linton, 1963; Clayton, 1974; Haynes, 1977a), but the range of the older features, including the particularly fine development of the tors, and their close association with the glacial landforms, makes the Cairngorms by far the most outstanding illustration of this type of landscape in Britain and comparable, albeit on a much smaller scale, with examples from Baffin Island (Boyer and Pheasant, 1974; Sugden and Watts, 1977), the Torngat Mountains of Labrador (Ives, 1958, 1978); East Greenland (Bretz, 1935; Sugden, 1974a) and the Finger Lakes area of North America (Clayton, 1965). However, not all apparent examples from the Canadian Arctic may be directly analagous because of the role of tectonics there (England, 1987). The most satisfactory hypothesis to explain such landscapes relates to variations in glacier thermal regime. According to this hypothesis, relatively thin, slow moving, cold-based ice on the Cairngorm plateaux effected minimal erosion, whereas thicker and faster flowing outlet glaciers formed by ice converging on the troughs were warm based and therefore capable of more effective glacial erosion. In support, there is a body of theoretical and observational evidence, although other factors, such as topography, geology and glacier dynamics, may also interact (Sugden, 1974a, 1978; Sugden and John, 1976; Gordon, 1979; Andrews *et al.*, 1985; Gellatly *et al.*, 1988; Kaitanen, 1989).

In contrast to ice-sheet erosion, local mountain glaciers have been responsible for the formation of classic examples of corries, particularly on Braeriach, Cairn Toul, Cairn Lochan, and Beinn a'Bhuird (Westoll, 1942). The corries are notable for their regular geometric form (Sugden, 1969), which may reflect their plateau-edge location and the relatively uniform bedrock. Locally, however, structural influences can be seen in the 'schrund-line' long-profile form of Coire an Lochain (Haynes, 1968). In many cases, for example on the northern margin of the massif and in Glen Dee and Glen Lui, Sugden (1969) showed that the location, altitude and size of the corries closely relate to the form of the pre-glacial relief, in particular the pre-glacial valley heads: other corries occur on the flanks of the Glen Einich, Glen Derry and Glen Dee glacial troughs, while some form secondary basins within the larger corries; for example in Coire an t-Sneachda and Coire an Lochain. Corrie sizes are considerably greater than the volumes of debris in their respective moraines, indicating that their formation spans several periods of local glaciation. Indeed, on the basis of their size and position Sugden (1969) identified three generations of corries. Whether they can be correlated with specific glacial episodes, as he tentatively suggested, is questionable. Also open to question is the extent to which the corries may have been modified by ice-sheet glaciation (cf. Sugden, 1969; Holmund, 1991), either through direct erosion of bedrock or removal of screes and moraine debris. The location and distribution of the Cairngorm corries in a broader national context are considered by Linton (1959), Sale (1970), Sissons (1976b) and Dale (1981). On the northern flanks of the Cairngorms there is an interesting transition as the corries become increasingly shallower eastwards from Coire an Lochain to Coire Laogh Beag (NJ 013073).

Landforms and patterns of deglaciation

The deglaciation of the Cairngorms and the nature and extent of Lateglacial events have engendered considerable debate. Traditionally, the drift and meltwater channels which characterize many of the lower slopes and margins of the massif were explained in relation to a series of valley glaciers receding into the glens and corries following the last ice maximum (Hinxman, 1896; Jamieson, 1908; Barrow *et al.*, 1912, 1913; Hinxman and Anderson, 1915; Bremner, 1929; Charlesworth, 1956). Both Barrow *et al.* (1913) and Hinxman and Anderson (1915), however, acknowledged that the corrie moraines might indicate a subsequent recrudescence of glaciers. In Glen More on the northern flanks of the Cairngorms (Figure 9.4), Hinxman and Anderson (1915) identified a series of landforms (lateral moraines, terraces and meltwater channels) which they interpreted as ice-marginal retreat features of a lobe of ice derived from the south-west. According to Hinxman and Anderson this lobe of ice also advanced into the lower parts of Glen Einich and the Lairig Ghru, which were already ice-free, forming moraines there.

However, from detailed mapping and considerations of the relationships between the drift landforms and the meltwater channels, Sugden (1965, 1970) proposed an alternative model of an ice-sheet largely downwasting *in situ*, in similar fashion to the pattern of deglaciation proposed for parts of Scandinavia. He identified two main stages of landform formation, an ice-directed phase and a valley-controlled phase. To the first he attributed a series of meltwater channels and deposits which run across the northern flanks of the Cairngorms (Figure 9.4); these are discordant with the form of the underlying topography and are part of a regional meltwater drainage system mapped by Young (1974, 1975a, 1975b), extending from west of Glen Feshie north-eastwards to Abernethy Forest. In general, the altitude of the highest channels falls from west to east, reflecting a former ice-surface gradient. Many channels are cut across cols at right angles to north–south orientated spurs and several have up-and-down long profiles. The channels are similar in form, location and relationships to the superimposed englacial channels described from the south of Scotland (Price, 1960, 1963a) and the Cheviots (Clapperton, 1968, 1971a, 1971b), and are probably of similar origin. Particularly fine examples occur south-east of Creag a'Chalamain (NH 965053), south of Airgiod-meall (NH 965066) and south of Stac na h-Iolaire (NJ 015086) and on the north flank of Carn Eilrig (NH 938053) (Young, 1974). The most spectacular feature, interpreted as a glaciofluvial deposit, is the flat-topped ridge extending east from Airgiod-meall, which is over 30 m thick and supports fine sections exposed along the Allt Mór (Sugden, 1970, figure 3). Its precise origin, however, is uncertain and it may in part be an ice-marginal feature, as may some of the ridges and bouldery deposits upslope that cross the outer slopes of Coire an Lochain and Coire an t-Sneachda. A question not addressed by Sugden is whether some of the ice-directed channels and deposits might represent successive ice margin positions of the downwasting glacier in Glen More (cf. Hinxman and Anderson, 1915). In the southern Cairngorms, easterly ice-directed meltwaters have cut channels across the summit area of Carn a'Mhaim (NN 995452), in the Meirleach col (ND 000936) and at the spectacular Clais Fhearnaig (NO 070935). The Water of Caiplich gorge at the Castle (NJ 123110) is another impressive meltwater channel, reflecting glacial diversion of drainage (Linton, 1954).

In contrast to the ice-directed landforms, the valley-controlled features show progressive conformity downslope with topography and have been described in detail by Young (1974, 1975a) for Glen More and Glen Feshie. On the northern flanks of the massif, whereas the higher channels and deposits are orientated towards the east, those at lower altitudes trend more towards the north-east; for example the channels on Creag nan Gall (NJ 015103) and the suite of channels and deposits in Glenmore aligned with the Ryvoan gap (NH 001105). At lower levels still, the features have a more northerly alignment with the An Slugain gap (NH 945130) reflecting increasing topographic control as the ice progressively downwasted. Finally, widespread stagnation of the ice is indicated by kame and kettle topography to the north and east of Loch nan Eilein (NH 895075) and west of Loch Morlich (NH 965093); masses of residual ice formed the

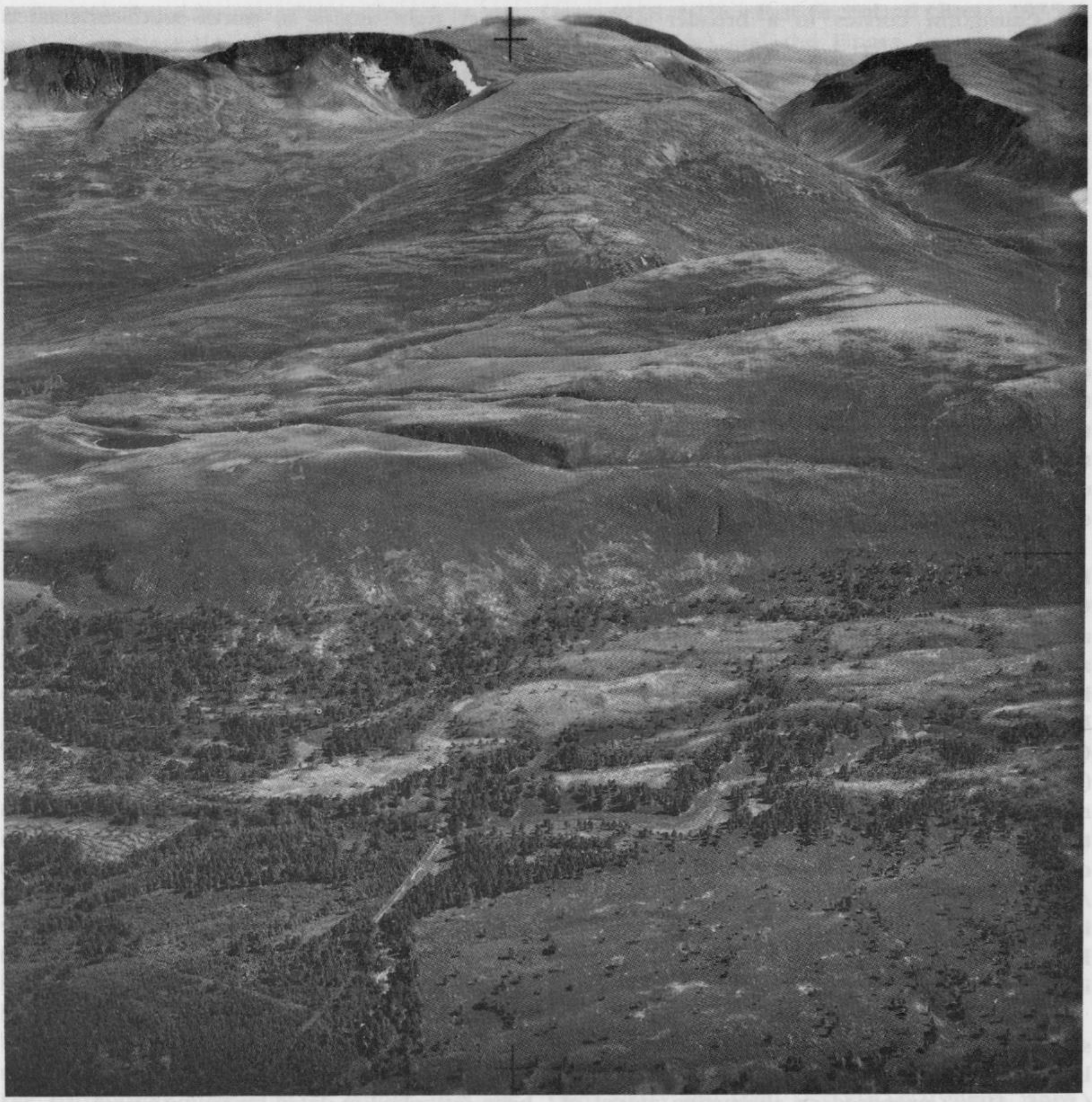


Figure 9.4 Glen More and the northern flank of the Cairngorms. The assemblage of landforms in this area includes the Cairngorm plateau and adjacent slopes extensively modified by solifluction lobes and terraces (Lurchers Gully – top centre), corries cut into the upper slopes of the massif, the striking glacial breach of the Lairig Ghru (top right), a system of ice-directed meltwater channels (including open-walled features – centre) and partly wooded glaciofluvial deposits in the valley bottom. (© British Crown copyright 1992/MOD reproduced with the permission of the Controller of Her Britannic Majesty's Stationery Office.)

large kettle holes now occupied by these lochs. During the latter stages extensive terraces were developed in western Glen More from the outlets of the Lairig Ghru and Gleann Einich towards Strathspey at Aviemore (Figure 9.2).

The overall pattern of a downwasting ice-sheet with progressive topographic control on meltwater discharge is one that is representative of Late Devensian ice-sheet decay in many parts of Scotland and northern England; for example see Sissons (1958b, 1961b), Stone (1959), Price (1963b), Clapperton (1971a, 1971b), Clapperton and Sugden (1972) and Young (1975b, 1977a, 1977b, 1978).

In the central Cairngorms, Sugden (1970) described channels and deposits that are concentrated, particularly, near the valley heads. Many of the deposits have the appearance of hummocky moraine, but have distinct linear alignments when viewed from the air (see below). Typically they have a scatter of surface boulders but largely comprise sand and gravel, a characteristic noted much earlier for those in Glen Derry by Jamieson (1860b) and Bremner (1929). Frequently channels run downslope above the ridges, but many of these clearly relate to post-glacial gullying of the valley-side drift cover, particularly by debris-flow activity. Sugden interpreted the total assemblage of landforms as valley- or topographically-controlled glaciofluvial features associated with an ice-sheet downwasting *in situ*. Moreover, he concluded that true moraines occurred only in a few of the corries and in one or two other localities. This led him to preclude a separate Loch Lomond Readvance valley glaciation in the Cairngorms as previously suggested by Sissons (1967a) for a large area of the Highlands, including the Cairngorms. In contrast, Sugden (1970) considered three possibilities for glaciation of the Cairngorms during the Loch Lomond Stadial, suggesting that it was represented by (1) a few corrie moraines; (2) a few moraines marking a stage in the wastage of the main ice-sheet, or (3) by an early stage in the deglaciation of the main Scottish ice-sheet, which persisted in the Cairngorms and Strathspey until the end of the Lateglacial, as in Scandinavia. Sugden initially (1970) favoured the third hypothesis.

In the debate that ensued, the key issues were whether complete deglaciation occurred in the Cairngorms during the Lateglacial Interstadial, and the location and extent of the Loch Lomond Readvance glaciers (Sugden, 1973a, 1973b, 1974b; Sugden and Clapperton, 1975; Sissons, 1972a, 1973a, 1973b, 1974a, 1975b; Sissons and Grant, 1972). Sissons argued for complete deglaciation in the interstadial followed by a fresh build-up of ice in the corries, parts of the plateaux and in some of the upper valleys, a pattern which he had established generally for the eastern Grampians and elsewhere in Scotland, based on evidence including the down-valley limits of fresh hummocky moraine, occasional end moraines, the distribution of solifluction lobes and pollen stratigraphy (Sissons, 1967a; Sissons *et al.*, 1973). He indicated that similar evidence occurred in the Cairngorms.

Sugden, however, argued that the evidence was inconclusive for complete deglaciation in the Cairngorms during the interstadial. He asserted that the hummocky moraine could be alternatively explained and was not a definitive characteristic of the Loch Lomond Readvance glaciers, as evidence at Loch Builg (NJ 187035) demonstrated (Clapperton *et al.*, 1975). Moreover, the formation of solifluction lobes could be diachronous and their distribution related to a wide range of local variables.

An important piece of evidence bearing on the debate came from a core from Loch Etteridge (see below). Not only did it contain a full Lateglacial pollen sequence, but the basal layers provided a radiocarbon date of about 13,150 BP, clearly indicating that Strathspey was already deglaciated early in the Lateglacial Interstadial (Sissons and Walker, 1974). In the light of this discovery, Sugden rejected his second two hypotheses in favour of the first; that the Loch Lomond Readvance in the Cairngorms was confined to a few corries.

Subsequently, Sissons published a map and detailed account of his interpretation of the Loch Lomond Readvance in the Cairngorms based on the criteria and arguments which he had applied elsewhere (Sissons, 1979f). In addition to identifying a number of important periglacial features, it differs in one major respect from that of Sugden: not only did small glaciers develop in some of the corries, but larger valley glaciers also existed at the head of Loch Avon, in Glen Eidart, in Glen Geusachan extending into the Dee Valley and in An Garbh Choire extending into the Lairig Ghru.

As yet no radiocarbon dates or pollen records are available to confirm either interpretation. However, it is clear that regardless of which interpretation one accepts, the extent of the Loch Lomond Readvance in the Cairngorms was somewhat less than in the eastern Grampians and the Gaick area to the south, as mapped by Sissons (1972a, 1974b). This pattern is thought to reflect the prevalence of snow-bearing winds from the south-east during the Loch Lomond Stadial, creating a precipitation shadow effect and a snowline rising towards the Cairngorms (Sissons and Sutherland, 1976; Sissons, 1980b).

The boulder moraines of Coire Lochan Uaine (NO 001981), Coire an Lochain (NH 945006), Coire Bhrochain (NN 960995) and Coire na Ciche (NO 103983), and the abrupt terminations of boulder spreads in Coire an Lochain (NH 981033) and Coire an t-Sneachda (NH 995034) (Figure 9.5), are particularly fine examples of Loch Lomond Readvance ice limits. Hummocky moraine associated with Sissons' Loch Lomond

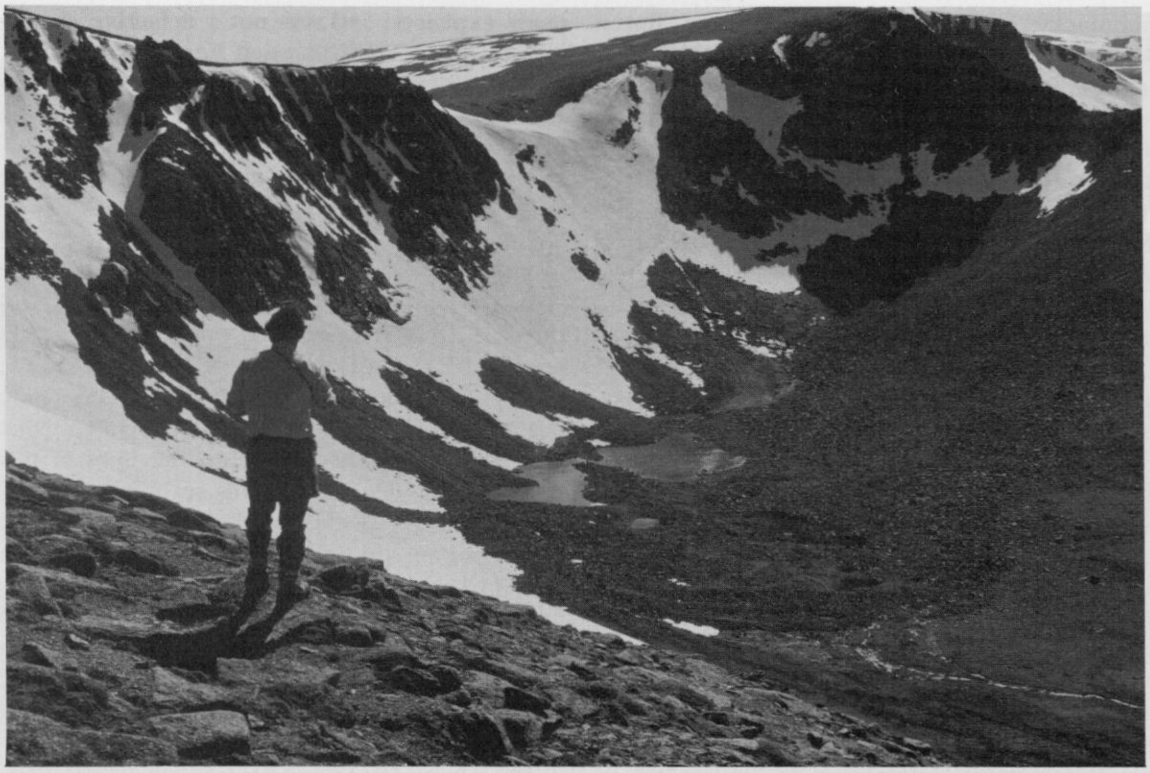


Figure 9.5 Loch Lomond Readvance boulder moraine in Coire an t-Sneachda in the Cairngorms. The outer part of the moraine comprises several clearly defined ridges of boulders. (Photo: J. E. Gordon.)

Readvance glaciers is well-displayed at the head of Loch Avon (NJ 005016), and there are clear down-valley limits to its extent in Glen Eidart (NN 918922) and Glen Dee (NN 988921). Other fine examples of hummocky moraine beyond the readvance limits occur in Glen Derry (NO 033995) and at Loch Builg (NO 190025). In several areas the hummocky moraine comprises linear alignments of ridges and mounds, for example in Glen Eidart (Figure 9.6) and Glen Geusachan. The deposits in Glen Geusachan have been mapped in detail by Bennett and Glasser (1991) and interpreted by them as a series of ice-marginal landforms, the pattern of which implies active recession of the glacier towards the head of the glen. Bennett and Glasser (1991) also speculated that the relatively large size of the inferred Loch Lomond Readvance glacier in Glen Geusachan could be explained by the survival of ice during the Lateglacial Interstadial.

Multiple end moraines or boulder ridges are a characteristic feature of a number of the corries, for example Coire an t-Sneachda, Coire an Lochain (Cairn Lochan) and Coire an Lochain (Braeriach) (Sugden and Clapperton, 1975; Sissons, 1979f). Their significance in the context of climatic change during the Loch Lomond Stadial has not been fully evaluated. However, as MacPherson (1980) has shown, there is evidence at least for a generalized pattern of a decline in precipitation in the area after the start of the stadial, which is likely to have had a significant effect on the mass balance of small corrie glaciers, followed by increased precipitation and therefore possibly by glacier expansion towards the end of the stadial. Sugden (1977) questioned whether the innermost ridges might relate to renewed glaciation during the Little Ice Age of the 16th–19th centuries (see below). However, the presence of middle and late Holocene pollen profiles on the ice-proximal (inner) sides of the moraines in Coire an Lochain (Braeriach) and Coire an Lochain Uaine (Ben Macdui) demonstrates that the sediments pre-date the Little Ice Age and that active glacier ice could not have existed there at this time (Rapson, 1985) (see also Lochnagar).

Periglacial landforms

A wide range of periglacial landforms is developed on the slopes and plateau surfaces of the

Figure 9.6 Loch Lomond Readvance 'hummocky moraine' on the east flank of Glen Eidart in the Cairngorms. The deposits have a clear upper limit on the valley side and show well-defined lineations, which may mark successive ice-front positions of an actively retreating glacier. (Photo: J. E. Gordon.)

Cairngorms. Sissons (1979f) mapped and described several large-scale features of Loch Lomond Stadial age, including rock glaciers (protalus lobes), protalus ramparts and spreads of boulders which he inferred were deposited at the downslope margins of former snow patches. The rock glaciers, which take the form of protalus lobes (for discussion of terminology and origins, see for example Wahrhaftig and Cox, 1959; Outcalt and Benedict, 1965; Lindner and Marks, 1985; Martin and Whalley, 1987; Barsch, 1988; Whalley and Martin, 1992), occur north of Loch Etchachan (NJ 007009) and in Coire Beanaidh (NH 956006 and NH 954016). The latter was described by Chattopadhyay (1984). The boulder spreads are essentially similar features (Ballantyne and Kirkbride, 1986) and bear striking comparison to the 'talus terraces' described by Liestøl (1961) in Svalbard. The largest example, some 2 km long, is in Strath Nethy (NJ 020045), and a smaller example occurs at the northern end of the Lairig Ghru (NH 962037). Protalus ramparts occur, for example, below the Devil's Point (NN 978946) and in Lairig Ghru (NH 964028). A ridge in Coire an t-Sneachda (NH 995038), described as the largest protalus rampart in the Cairngorms (Sissons, 1979f), includes a bedrock outcrop with a quartz dyke; it is considered to be either a landslide deposit or a residual rock ridge isolated by marginal meltwater channels (C. K. Ballantyne, unpublished data).

Elsewhere in Scotland fossil rock glaciers have been reported from Jura (see Beinn Shiantaidh; Dawson, 1977) and Wester Ross (see Beinn Alligin; Sissons, 1975a; Ballantyne, 1987c), and protalus ramparts notably from Wester Ross (see Baosbheinn; Sissons, 1976c; Ballantyne, 1986a) and other parts of the Highlands (Sissons, 1977a; Ballantyne and Kirkbride, 1986). The Cairngorms, however, are particularly notable for the variety of features present within the massif, ranging from simple protalus ramparts to protalus lobes.

On the summits of Ben Macdui and Derry Cairngorm extensive boulder fields or 'felsenmeer' comparable to those of other mid-latitude mountains and parts of the Arctic (cf. Dahl, 1966; Boyer and Pheasant, 1974; Nesje, 1989) have developed through frost disruption of the underlying granite bedrock (cf. Sugden, 1971; Paine, 1982). The susceptibility of the granite to weathering has been ascribed to the mechanical weakness of the rock (Hills, 1969), but may also relate to chemical weathering of the latter (Innes, 1982). In places *in situ* joint blocks can be seen below displaced blocks on the surface. On Creag an Leth-choin (NH 968033) and other locations shattered rock outcrops and a blockfield on the summit are succeeded downslope by blockslopes and bouldery solifluction lobes.

Throughout the Cairngorms, periglacial mass movement has resulted in the widespread development of sheets, terraces and lobes of frost-weathered detritus. These were first investigated by ecologists working in the area (Watt and Jones, 1948; Metcalfe, 1950) and later by Galloway (1958), who considered them to be relict features immobilized by eluviation of fines. The most abundant and impressive examples are massive sheets of large boulders that terminate in risers up to 3 m high (as at NH 960028). These become increasingly lobate in plan form as the slope steepens (as at NH 963041). Such features have been variously described as stone-banked and vegetation-covered lobes (King, 1968, 1972), solifluction lobes (Sugden, 1971), 'blockloben' (Kelletat, 1970a) and boulder lobes (Sissons, 1979f). Sugden (1971) suggested that they may have survived the passage of the last ice-sheet, or may have formed during the Little Ice Age. King (1968, 1972) distinguished between vegetation-covered and stone-banked lobes. He believed that the former developed during the early Holocene, the latter during the Little Ice Age. This interpretation, however, was constrained by King's acceptance of Sugden's (1970) reconstruction of the timing of deglaciation in the area. Sissons (1979f) noted that boulder sheets and lobes are entirely absent inside the limits that he mapped for the Loch Lomond Readvance. This strongly suggests a Lateglacial origin, or at least reactivation, of such forms. Both Galloway (1958) and King (1968) maintained that some of the stone-banked lobes at higher altitudes are currently active; for example on Carn Bàn Mór. If so, it seems probable that they were active also during the Little Ice Age climatic deterioration. However, stone-banked lobes appear to occur nowhere within the limits of Loch Lomond Readvance glaciers, which casts doubts on any significant activity during the Holocene. King (1968, 1972) concluded that both types of lobe formed by viscous flow but were influenced in the form and location of their fronts by bedrock joints. Particularly fine examples of suites of stone-banked lobes occur on Creag an Leth-choin (NH 970034), extensively on the western slopes of Carn Bàn Mór (NN 893974) and the Sròn na Lairige spur of Braeriach (NH 960028); suites of vegetation-covered lobes occur on Creag an Leth-choin (NH 979041), on the south-west slope of Sgòran Dubh Mór (NN 901999) and between Coire Bogha-cloiche and Coire an Lochain (NH 993003).

In addition to the large-scale features described above, smaller-scale solifluction lobes and sheets occur in the Cairngorms. R. M. G. O'Brien (cited in Sugden, 1971) obtained radiocarbon dates of 4880 ± 140 BP (N–622) and 2680 ± 120 BP (N–623) for organic material under such features, and Sugden (1971) thought that the most likely periods of formation of the latter were the cold phases of about 2500 BP and the 16th–18th centuries AD. Similar conclusions were reached by White and Mottershead (1972) and Mottershead (1978) concerning solifluction terraces overlying organic material dated at between 5440 ± 55 BP (SRR–723) and 3990 ± 50 BP (SRR–724) on Arkle in Sutherland. However these dates may simply reflect the time of burial of the organic material and need not indicate a relationship between solifluction and climatic deterioration (Ballantyne, 1991a). There is also evidence that some of the solifluction features in the Cairngorms are active at present (King, 1968, 1972; Kelletat, 1970b, 1972).

Other features which appear to be currently active are small, turf-banked terraces ('steps'), formed by the combined action of wind and frost-creep (King, 1968, 1971b). These frequently occur in association with deflation surfaces (see below) and in some instances have formed on the 'treads' of older boulder sheets and lobes. Recent mass movement is also indicated by 'ploughing' boulders (King, 1968; Kelletat, 1970b), and debris flows resulting from heavy rainfall have left many steep slopes scarred by gullies and debris chutes (Figure 9.7) (Baird and Lewis, 1957; Innes, 1983b; Kotarba, 1987; Ballantyne, 1991c; Luckman, 1992), notably in Glen Geusachan, at the northern end of the Lairig Ghru and in Coire an t-Sneachda. These flows are of the hillslope type (cf. Innes, 1983c), with levées of debris along the margins, and tongues of debris at the foot of the flow tracks. Debris-flow activity appears to have increased in the last 250 years, possibly as a response to land-use changes (Innes, 1983b), although in Glen Feshie natural processes

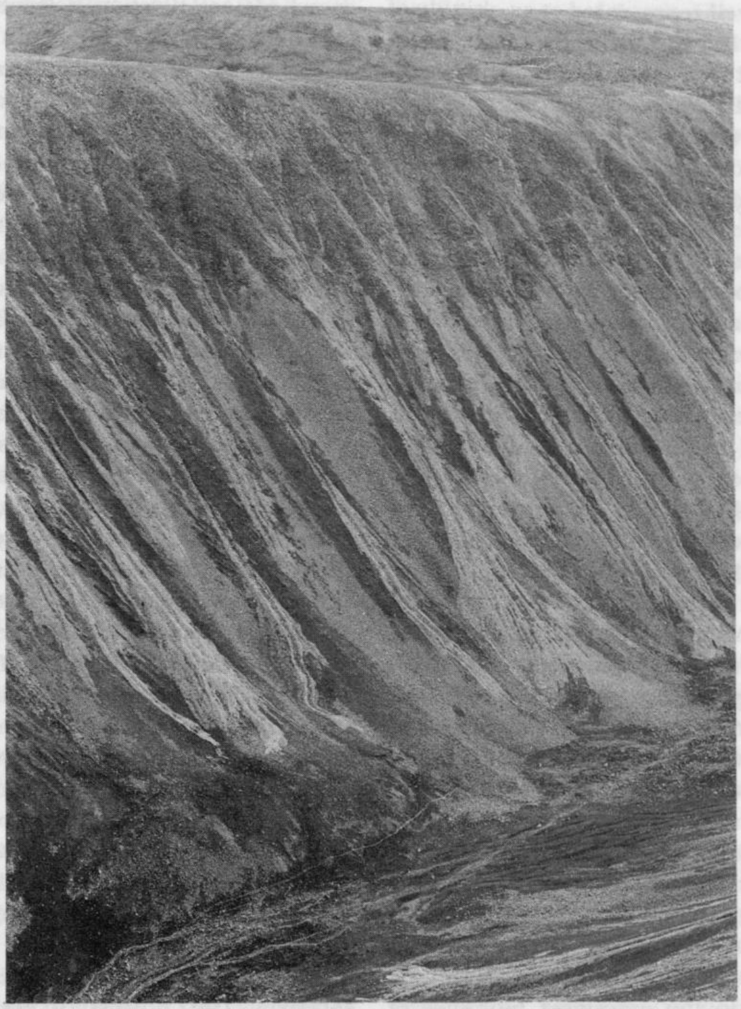


Figure 9.7 Active debris flows on the slopes above the Lairig Ghru. (Photo: J. E. Gordon.)

have been identified as the principal cause (Brazier and Ballantyne, 1989). Innes (1985) noted the importance of relatively large events in the Cairngorms compared with other areas of the Highlands (see also Kotarba, 1987). Other effects of heavy rainfall are seen in flood deposits; for example, gravel spreads in the Dee Valley (Baird and Lewis, 1957; Clapperton and Crofts, 1969) and along the Allt Mór where the ski access road has been washed away several times in recent years (Sugden and Ward, 1980; McEwen and Werritty, 1988).

Both King (1968, 1971a, 1971b) and Kelletat (1970a, 1970b, 1972) have described fine examples of patterned ground in the Cairngorms. In general, frost-sorted forms (circles and stripes) are abundant only on vegetation-free areas above 900 m OD. Some of the large, fine-grained stone circles appear to experience frost heave at present (King, 1968, 1971a). However, most of the features described by these authors are inactive, and their widths (often over 2 m) suggest that they were formed under permafrost conditions, probably during the Lateglacial, rather than the Little Ice Age, as suggested by King, although some reactivation at that later time is a possibility (C. K. Ballantyne, unpublished data). It is also possible that they are even older, since patterned-ground features are known to be preserved under cold-based ice in modern glacial environments (Whalley *et al.*, 1981). Good examples of large-scale circles occur on Carn Bàn Mór (NN 894973) and on Ben Macdui (NH 981004, NH 991012); stone stripes occur on Carn Bàn Mór, where they grade downslope into lobes, and on Geal-charn (NH 893000) and Creag Follais (NH 893043). Much smaller, active circles and stripes have been described by Kelletat

(1970a) and are well represented at an altitude of 1065 m OD near the highest point of the Lairig Ghru (NH 974023) and in Coire Raibert (NJ 005030) (C. K. Ballantyne, unpublished data). King (1968, 1971a) also described a form of wind-patterned ground which he termed denudation surfaces. These are deflation scars in the vegetation cover, typically 1 m wide and 2–4 m long; they occur extensively above an altitude of 450 m OD. According to King, they formed through a combination of needle-ice erosion and deflation. More extensive areas of deflation surface occur, for example, on Meall Gaineimh (NJ 167052) and Beinn Bhrotain (NN 955924). Pedogenesis and the influence of periglacial processes in the regolith of the Cairngorms have been considered by Romans *et al.* (1966) and Romans and Robertson (1974); in particular, the development of silt droplets in the soil profile is believed to reflect former permafrost conditions.

A further component of the periglacial landscape for which the Cairngorms are renowned is late-lying or semipermanent snowbeds (Manley, 1949, 1971; Green, 1968; King, 1968), the most famous and persistent being in An Garbh Choire (NN 942980) (Gordon, 1943). Sugden (1977) considered the intriguing question of whether such snowbeds might have expanded during the Little Ice Age to form small glaciers in a number of the corries. He argued that there was some supporting evidence, although not conclusive, from historical records, reconstructed snowlines, and lichen sizes on the innermost moraines of certain corries. However, radiocarbon dating and pollen analyses of organic sediments behind the moraines in Coire Bhrochain (Sugden, 1977) and Coire an Lochain (Braeriach) and Coire an Lochain Uaine (Rapson, 1985) have indicated that these corries have remained unglaciated during the Holocene. Nevertheless, the possibility remains open that the moraine in Garbh Choire Mór, lying well inside the Loch Lomond Readvance limit (Sissons, 1979f), formed during the Little Ice Age (Rapson, 1990).

Although the Cairngorms are almost high enough to support glacier ice at present (see Manley, 1949), Manley (1971) doubted that there had been sufficiently long unbroken sequences of cool summers (at least 20) to form glaciers in historical time, although there would have been decades during the 17th to the 19th centuries when persistent snowbeds occurred at lower levels than today.

Associated with a number of the persistent snowbeds are nivation hollows, one of the best examples being Ciste Mhearaid (NJ 012045) (see McVean, 1963b, figure 2). The location, size and site characteristics of these and a range of other mountain hollows, some perhaps better described as incipient glacial corries, are described by King (1968). Generally in the mountains of Scotland, current snow patch erosion is limited in its effects (Ballantyne, 1987a).

Snow avalanches have received increasing attention in the Cairngorms. The area, with its steep slopes and massive cornices built up by snow drifting off the plateau surfaces, is probably the most conducive in Britain for avalanche activity. Some aspects of the snow and weather conditions associated with avalanches were described by Langmuir (1970), and subsequent research has addressed the types of avalanche that occur, their frequency and magnitude, the factors governing their location and release, physical characteristics of the snowpack and a predictive model (Ward, 1980, 1981, 1984a, 1984b, 1985a; Ward *et al.*, 1985). Spectacular examples of snow avalanches occur each spring from the slabs on the headwall of Coire an Lochain (NH 984027) (see Langmuir, 1970, figures 4 and 5). The geomorpholgical effects of such avalanches are variable. Good examples of avalanche boulder tongues that are currently active occur in the Lairig Ghru, and there are excellent fossil features on the western slopes of Derry Cairngorm (Ballantyne, 1989b, 1991c; Luckman, 1992). Most of the current geomorphological activity is associated with reworking of debris flow deposits (Luckman, 1992); in most other areas the effects appear to be relatively minor (Ward, 1985b; Davison and Davison, 1987), and only on Ben Nevis in the western Highlands have features such as avalanche impact landforms been recorded (Ballantyne, 1989b).

Lateglacial and Holocene vegetation history

The Lateglacial and Holocene vegetation history of the Cairngorms area is represented in the sediments at Abernethy Forest (see below) and is summarized in part by Dubois and Ferguson (1985). Within the massif itself, biostratigraphic evidence in the form of pollen and plant macrofossil records has been described from sites at Eidart, Sgòr Mór and Carn Mór (Pears, 1964,

1968) and Loch Einich (Birks, 1969, 1975), with the particular aim of elucidating the forest history of the area. Pears also carried out a more extensive survey of macrofossils in the peat, and Dubois and Ferguson (1985) investigated climatic history using stable isotope analysis and radiocarbon dating of fossil pine stumps from the northern flanks of the massif. Further palaeoenvironmental information is available from a Holocene tufa deposit at Inchrory in Glen Avon, in the eastern Cairngorms (Preece *et al.*, 1984).

The most detailed pollen diagram compiled is that from Loch Einich. Here Birks (1969, 1975) described a lower layer of pine stumps and an upper layer of birch stumps embedded in an area of eroded, deep blanket peat. From these stumps and the pollen stratigraphy which extends over the *Betula–Corylus/Myrica*, *Pinus* and *Calluna–Plantago lanceolata* Holocene regional assemblage zones (Birks, 1970), she interpreted the following sequence. Peat from a *Juncus effusus–Sphagnum* mire community (McVean and Ratcliffe, 1962) began to accumulate in waterlogged hollows in the underlying glacial deposits. Birch then colonized the surface of the bog (as evidenced by wood remains) and coexisted with *Empetrum*, *Calluna* and *Sphagnum*. Pine initially spread on to the valley sides and subsequently on to the surface of the bog. Pine stumps dated at 5970 ± 120 BP (K–1418) are overlain by *Sphagnum* peat, indicating increased waterlogging and the demise of pine at the site, although pine trees continued to grow on the valley sides. During a drier phase birch subsequently colonized the bog surface and is represented by stumps dated at 4150 ± 100 BP (Q–883). The birch, too, was eventually overwhelmed by *Sphagnum*, and treeless conditions then prevailed until the present day. In the uppermost layers of the bog, which provide the reference site for the *Calluna–Plantago lanceolata* regional pollen assemblage zone (Birks, 1970), there is evidence of forest clearance on the valley sides near Loch Einich and recession of the treeline to near its present limit at about 400 m OD in Rothiemurchus Forest.

The pollen diagrams of Pears (1968) are less detailed than those of Birks and are zoned according to the Jessen–Godwin scheme, so that direct comparisons are not facilitated. However, it is clear that *Pinus* formed the dominant element in the forests, with *Betula* playing a subsidiary role. Moreover, the radiocarbon dates obtained by Pears (1970, 1975a) from Carn Mór, the former site of Jean's Hut, Sgòr Mór, Coire Laogh Mór, Meall a'Bhuachaille and Barns of Bynack and by Birks (1975) from Loch Einich demonstrate that the stumps in both the lower and upper wood layers in the peat are asynchronous. Therefore they cannot be assigned to particular climatic periods (Boreal and Subboreal) in the Blytt–Sernander scheme, as was assumed before radiocarbon dates were available (see discussion for the Allt na Feithe Sheilich site); their occurrence reflects instead local site topographical and hydrological factors (Pears, 1970, 1972). This applies also to tree stumps in peat investigated elsewhere in Scotland (Birks, 1975).

Dubois and Ferguson (1985) reported a series of 40 radiocarbon dates on pine stumps from the northern flanks of the Cairngorms. The oldest, 7350 ± 85 BP (IRPA–594), provides a minimum age for the establishment of pine in the Cairngorms. Dates obtained for the inception of blanket bog range between 5230 ± 260 BP (IRPA–361) and 6090 ± 300 BP (IRPA–362), which again may reflect the influence of local conditions (Pears, 1970, 1988). Dubois and Ferguson (1985) also investigated the stable isotope chemistry of wood cellulose extracted from the dated pine stumps. Assuming that the deuterium/hydrogen ratio of precipitation is related to local surface air temperature and to the intensity of the precipitation (see Dansgaard, 1964), and that the moisture taken up by the tree roots and utilized in the production of cellulose reflects the isotopic composition of the precipitation, then the isotopic composition of the wood potentially provides a valuable palaeoenvironmental record (but see Dubois, 1984; Siegenthaler and Eicher, 1986). On this basis Dubois and Ferguson (1985) identified four periods of increased rainfall distinguished by low deuterium/hydrogen ratios around 7300 BP, between 6200 BP and 5800 BP, between 4200 BP and 3940 BP and around 3300 BP. Pears (1988), however, cautioned against interpretation of the stable isotope results purely in terms of precipitation and argued that the low deuterium/hydrogen ratios could equally reflect locally high values of relative humidity at individual growth sites. In reply Dubois and Ferguson (1988) provided further evidence to support their case. The results of Bridge *et al.* (1990) from a detailed study of macrofossils in the Rannoch Moor area, supported by radiocarbon dating and pollen analysis, lend some support to the conclusions of Dubois and Ferguson (1985), but also emphasize both the complex relationships between climatic factors, site conditions, forest ecology, tree growth and preservation of macrofossils, and the need for further investigations.

Pears (1975b) estimated growth rates of peat in the Cairngorms for various periods covered by his radiocarbon dates between 6700 BP and the present. Values lie in the range 1.4 to 3.4 cm 100 years^{-1}. The rates are consistent for sites in the Cairngorms and also with Birk's (1975) estimate for peat growth at Loch Einich. They are also broadly similar, although slightly lower, than rates of peat growth in Deeside reported by Durno (1961). A significant conclusion reached by Pears (1975b) is that, due to the slow growth rates, even relatively minor peat erosion scars are unlikely to develop sufficient vegetation cover to heal themselves, particularly in view of the increased human pressures on the sites.

The present treeline in the Cairngorms is constrained by exposure to high winds and biotic stress (Pears, 1967) and only in one area, on Creag Fhiaclach (NH 898055), does it approach its natural level of 610–685 m OD (Pears, 1968). The maximum Holocene altitude of the treeline was 793 m OD, recorded by the highest stumps (*Betula pubescens*) found in the region in Coire Laogh Mór. These have been dated to 4040 ± 120 BP (Pears, 1975a).

Interpretation

Five key elements can be identified within the total assemblage of geomorphology and Quaternary interests in the Cairngorms:

1. The surviving elements of the pre-glacial landscape, comprising tors, weathered regolith, plateau surfaces and river valleys are exceptional for the assemblage of forms within a single area. Although individual elements, such as tors and deep weathering, are represented in other mountain areas, such as Lochnagar and the Gaick Plateau respectively, the Cairngorms are unsurpassed for the range, scale and quality of the features preserved. The Cairngorms therefore provide an invaluable insight into long-term processes of mountain landscape development in Britain. In this respect they differ significantly from western mountain areas such as the Cuillin, Lake District and North Wales, where the imprint of glaciation is dominant. Within Britain the Cairngorms provide potentially important comparisons with areas such as Dartmoor where many similar features occur, albeit in an unglaciated environment, and with parts of south-west Wales located close to the margins of the Pleistocene ice-sheets. On an international scale, the pre-glacial forms of the Cairngorms bear comparison with those that have survived glacierization in Norway and East Greenland, but the closest parallels are probably with parts of north Finland, the Canadian Arctic islands and Baffin Island.
2. The elements of glacial erosion provide an assemblage of landforms for which the Cairngorms is both nationally and internationally recognized. These include the glacial troughs, breaches, corries and large-scale diversions of drainage. Although individual examples of troughs and breaches are arguably as well developed in the northern and western Highlands, on Skye (Loch Coruisk), in the Lake District and Wales, few areas can demonstrate a range of features comparable to those of Loch Avon, Glen Einich, the Lairig Ghru and Strath Nethy. Moreover, unlike those in other areas, in the Cairngorms the features of glacial erosion are juxtaposed with pre-glacial landscape elements to form a classic landscape of selective glacial erosion. In this respect, the Cairngorms surpass other examples in the eastern Grampians (Loch Muick area and Glen Clova) and rank on an international scale along with examples from parts of East Greenland, Labrador, Norway and Baffin Island. In terms of the diversity of features, the closest comparison is with parts of eastern Baffin Island.

   Cut into the granite plateau surfaces, the corries display classic forms which are relatively simple in outline; their principal interest lies in the diversity they lend to the geomorphology of the Cairngorms.

   Glacial diversions of drainage are particularly well demonstrated in the Cairngorms area. While other examples are known from the eastern Grampians, there is probably no finer an assemblage of such forms in Britain than occurs in the Cairngorms.
3. A third element of the Cairngorms landscape is the evidence for patterns of deglaciation in a mountain area, as represented by meltwater channels, glaciofluvial deposits (eskers, kame terraces and dead-ice topography) and mo-

raines. The meltwater features are best developed on the northern flanks of the massif and are of interest both as individual landform examples and as an assemblage of landforms which demonstrates downwasting of the last ice-sheet and the accompanying changes from ice-directed to topographically-controlled meltwater flow patterns. Some of the individual landforms are notable examples of their type, although not as distinctive as, for example, the meltwater channels at Carlops or Rammer Cleugh or the deposits at Carstairs Kames, Torvean or Kildrummie Kames. However, they are distinguished by their clear spatial patterns and the evidence that they provide for evolution of the meltwater drainage system during deglaciation. In this respect, they provide an outstanding assemblage of landforms comparable only to that at Muir of Dinnet (see above).

Morainic landforms are principally associated with the Loch Lomond Readvance, although there are some notable exceptions, for example at Loch Builg. The boulder moraines in the corries and the hummocky moraines in the valleys include many fine examples of landforms that are widely represented elsewhere in the Highlands. The particular significance of the Cairngorms features is the diversity they add to the geomorphology of the massif.

4. The Cairngorms contain an outstanding range of periglacial landforms and deposits. Individual examples of many of the types present are equally well, or better represented elsewhere in the Highlands (see in particular, An Teallach, Ben Wyvis, Beinn Shiantaidh, Sgùrr Mór, Ward Hill and Ronas Hill), but it is the combination and range of features which distinguishes this element of the geomorphology of the Cairngorms. The high plateau surfaces provide the closest analogue in Britain to sub-arctic or montane fellfield landscapes, containing blockfields, deflation surfaces and large-scale patterned ground. Slopes below the plateaux support a variety of mass-movement features. These include excellent examples of relict, bouldery gelifluction lobes, protalus ramparts and rock glaciers, as well as debris flows and snow avalanche landforms of more recent origin. The Cairngorms contain the greatest number of fossil rock glaciers (protalus lobes) of any mountain range in Britain. The gelifluction lobes compare with examples on Lochnagar, Mount Keen and Creag Mheagaidh in terms of size and extent, and the debris flows are characteristic of similar features elsewhere in the Highlands, for example, in Glen Coe and Drumochter Pass. The small-scale patterned ground, wind and active frost features form part of a network of upland sites of current periglacial activity ranging from Shetland to the Southern Uplands, the Cairngorm examples representing the conditions of the more continental high summits of the eastern Highlands. Overall, the assemblage of periglacial features in the Cairngorms is of national importance.
5. In terms of Holocene vegetation history and environmental change, the Cairngorms are important in several respects. The extensive peat deposits and bogs provide a record of both regional upland environmental changes and the role of local site-specific factors such as topography and drainage, in influencing changing vegetation patterns. The pine stumps extensively preserved in the peat provide a record of Holocene treeline changes and have significant potential for elucidating palaeoenvironmental conditions through the application of stable isotope analyses.

Key areas and individual sites have been identified in the descriptive sections above. However, it is important to stress the integrity of the total landform assemblage since this is an aspect of the geomorphology that is as important as each of the individual elements. Relationships between landforms and landform types are important and clearly demonstrated, and the scale of the site is such that spatial and altitudinal patterns can be distinguished. Thus, for example, the northern flanks of the massif from Cairngorm and Braeriach down to Glen More provide a transect from plateau surfaces with tors, weathered regolith and periglacial features, through corries with boulder moraines, protalus ramparts, rock glaciers and slope mass movements, leading downslope to ice-marginal features, meltwater channels, and finally eskers, dead-ice topography, outwash and river terraces.

In summary, the Cairngorms are exceptional for the range of particular landform elements and for the diversity of the total assemblage of features. Each of the five elements identified above ranks on a national scale of importance, while some rank on an international scale. Further, when the total range of interests is combined, the Cairngorms qualify as a site of international importance for geomorphology. The Cairngorms represent a striking demonstration of landscape evolution over a long time-scale, of the impact of successive geomorphological systems on the landscape and of the spatial variation of forms and processes within individual landform systems. They provide crucial field evidence for testing models of landscape evolution, patterns of glacial erosion, meltwater drainage evolution, periglacial and slope processes and Holocene environmental changes. Above all, they demonstrate the diversity of the geomorphology of glaciated mid-latitude mountains.

Conclusion

The Cairngorms is an area of the very highest importance for Quaternary geomorphology in Britain, providing an outstanding range of features for interpreting landscape evolution and environmental change during the Quaternary. The interest comprises five principal components. First, there are the planation surfaces, tors and pockets of deeply weathered bedrock that appear to have survived the effects of glaciation, and which illustrate aspects of longer-term landscape development. Second, a striking assemblage of landforms of glacial erosion demonstrates the powerful capacity of glaciers to modify the landscape, but in a selective fashion. Third, the Cairngorms display particularly well the landforms and deposits formed as the glaciers melted, including moraines, meltwater channels and meltwater deposits. Fourth, there is a range of periglacial landforms and deposits that illustrate the effects of cold climate conditions on the soil and its movement downslope. Fifth, the peat deposits and bogs provide a detailed record of environmental changes and vegetational history during the Holocene (the last 10,000 years). Many of these features are essential components of the wider site networks for their particular interests. Some are among the best examples of their kind in Britain, and others rank on an international scale for their clarity of development and interrelationships. However, it is the total assemblage of interests, developed in a relatively compact area, that makes the Cairngorms so remarkable.

LOCHNAGAR

J. E. Gordon and C. K. Ballantyne

Highlights

Lochnagar is important for its glacial and periglacial landforms, including corrie moraines and geliflucted boulder lobes. These features formed during the Loch Lomond Stadial and provide a record of glacier dynamics and geomorphological processes active at that time.

Introduction

Lochnagar (NO 250860), a mountain massif rising to 1150 m OD and located *c.* 10 km south-east of Braemar, is important for its assemblage of glacial and periglacial landforms. It is noted for one of the best examples in Scotland of a suite of boulder lobes and terraces dating from the Loch Lomond Stadial. It also includes a fine example of a corrie and an excellent sequence of moraines formed during the Loch Lomond Readvance. The periglacial landforms have been investigated by Galloway (1958) and Shaw (1977), and the glacial landforms by Sissons and Grant (1972), Rapson (1985) and Clapperton (1986).

Description

In broad outline Lochnagar has the form of a residual granite massif rising above the plateau of the 'Grampian Main Surface' (Fleet, 1938). Landforms of glacial erosion are impressive and stand in sharp contrast to adjacent plateau surfaces and slopes that are essentially pre-glacial in their broad outlines, although modified in detail by periglacial processes. The glacial troughs of Glen Callater (NO 190835) to the south-west and Loch Muick (NO 290830) to the south-east are fine examples of selective linear erosion by ice-sheets and valley glaciers; on the northern slopes of the massif, corrie development has been predominant. These erosional landforms reflect the effects not only of Late Devensian glaciation, but also of earlier glaciation. Depositional landforms associated with both the Late Devensian ice-sheet and Loch Lomond Readvance glaciers are extensively developed and include hummocky moraines, fluted moraines and corrie-glacier moraines, together with eskers and other meltwater deposits (Sissons and Grant, 1972; Clapperton, 1986). However, it is the north-east corrie of Lochnagar and the higher southern slopes of the mountain that are of special interest for particular glacial and periglacial landforms, formed mainly during the Loch Lomond Stadial.

The north-east Corrie

The north-east corrie of Lochnagar is a striking example of a corrie with a steep headwall, an enclosed loch basin and a sequence of end- and lateral-moraine ridges (Figure 9.8). A total of nine moraine ridges is present, each less than 3 m high and comprising arcuate lines of boulders resting on a bouldery till substrate (Clapperton, 1986). The boulder moraines represent progressive recession of an active glacier into the corrie, but there are different interpretations of its former extent (Sissons and Grant, 1972; Clapperton, 1986).

The landforms and deposits in this area have a significant bearing on the interpretation of the Late Devensian history of the Cairngorms and adjacent parts of the eastern Grampian Highlands. Sissons and Grant (1972) mapped the geomorphological evidence for the last glaciers in the Lochnagar area and defined the limits of a series of corrie and valley glaciers associated with the Loch Lomond Readvance. This work and its subsequent extension in adjacent areas stimulated keen debate on the wider regional implications of the status of the Loch Lomond Readvance in the Cairngorms and vicinity (Sissons, 1972a, 1973a, 1973b, 1975b, 1979f; Sugden, 1973a, 1973b, 1980; Clapperton *et al.*, 1975; Sugden and Clapperton, 1975). In the absence of a locally established dating framework, interest centred on the extent of the Loch Lomond Readvance and indeed whether some of the small boulder moraines, including those on Lochnagar, could have formed during the Little Ice Age (Sugden, 1977). However, pollen analysis of cores taken from sites within the glacial limits defined by the corrie moraines on Lochnagar demonstrate that sedimentation has continued undisturbed from about 9700 BP (Rapson, 1985). A peat sample and pine stump located within these moraines have yielded radiocarbon dates of 7170 ± 80 BP (SRR–2272) and 6080 ± 50 BP (SRR–1808), respectively (Rapson, 1985). Together with similar evidence from the Cairngorms, these results preclude any significant Little Ice Age or earlier Holocene glacier development in the Lochnager corrie and imply that the boulder moraines are most probably of Loch Lomond Readvance age.

Using reconstructed glaciers as palaeoclimatic indicators, Sissons and Sutherland (1976) derived equilibrium line altitudes for the eastern Grampian Highlands during the Loch Lomond Stadial and inferred that precipitation and snow accumulation in this area were principally associated with winds from a southerly or south-easterly direction. Clapperton (1986), however, questioned this interpretation. His reconstruction of the glacier that formerly occupied the north-east corrie of Lochnager not only identified a slightly lower snowline, but also suggested that the dominant ice source was the south-west basin of the corrie. He therefore concluded that south-westerly winds were dominant at the time of glacier growth and that it was unnecessary to invoke unusual climatic conditions and south-easterly air flows.

Periglacial landforms

On the granite massif of Lochnagar there is a striking contrast between well-developed corries to the north and smooth slopes to the south. The latter are covered by frost-weathered debris on which have developed massive boulder lobes and terraces, considered by Galloway (1958) to be the finest in Scotland.

The boulder lobes and boulder sheets of Lochnagar are best developed on Broad Cairn around (NO 240818), Cac Carn Beag (NO 244861) and on the south-east slope of Cuidhe Cròm (NO 262848) (Figure 9.9). Galloway (1958) described those of Cuidhe Cròm in detail, and concluded that the lobes were stone-banked solifluction lobes of Lateglacial age, immobilized by eluviation of fine material, but that nearby boulder sheets and blockfields are still undergoing mass movement. Shaw (1977) carried out a very detailed study of the boulder lobes. He found that they occupy slopes of 10°–34° at altitudes of 640 m to 1110 m OD, and are most frequently developed on west-facing slopes. They range in thickness from 0.3 m to 5.9 m, in width (across slope) from 3.9 m to 33.3 m, and in length (downslope) from 2.1 m to 76.3 m. They are composed of openwork boulders with an average length of more than 0.7 m, with little interstitial finer material and a cover of peat up to 1.2 m thick over the 'treads'. Boulder terraces generally occupy gentler slopes (14°–22°) and

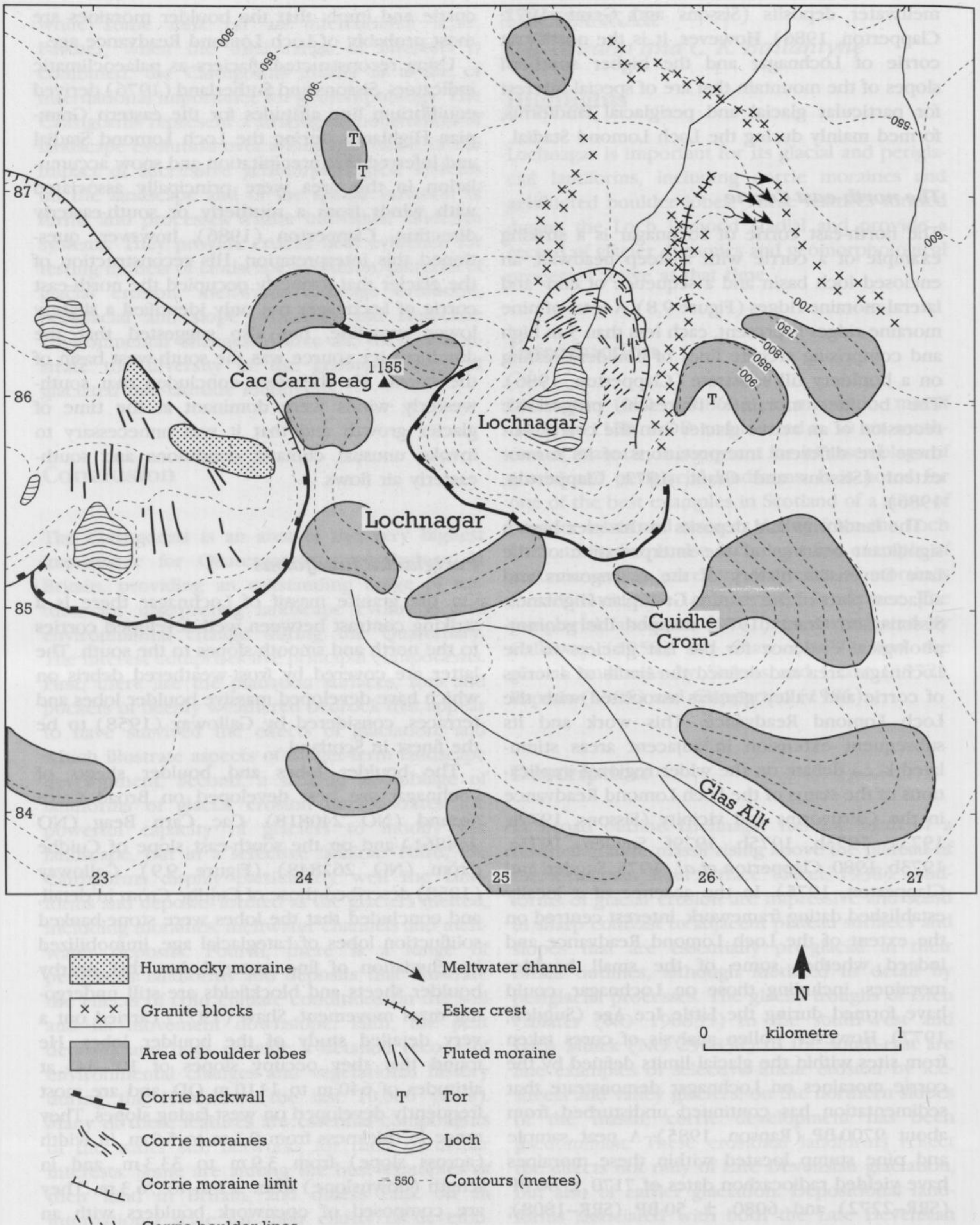


Figure 9.8 Geomorphology of the Lochnagar area (from Shaw, 1977; Clapperton, 1986).

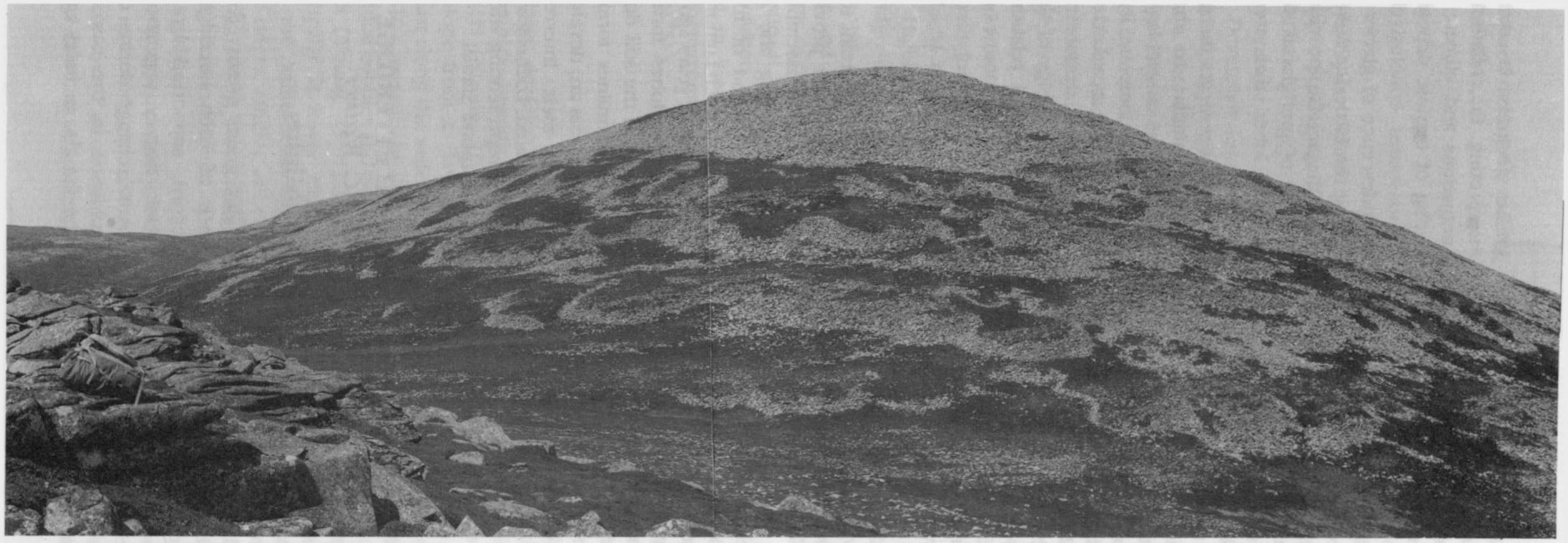


Figure 9.9 Summit blockfield, blockslopes and boulder lobes on the south-east flank of Cuidhe Cròm, Lochnagar. (Photo: J. E. Gordon.)

are similar in composition and thickness. Shaw considered all of these features to be inactive, and concluded that they had crept downslope as a result of the deformation of interstitial ice. Strong evidence of a Lateglacial age for these features has been provided by Sissons and Grant (1972), who observed that they are entirely absent from the areas that were occupied by Loch Lomond Readvance glaciers, and indeed that near Loch Buidhe (NO 252827) the boulder features are apparently truncated by a lateral moraine deposited by the Glen Muick glacier.

Shaw (1977) also made observations on present mass-movement activity in this area. Ploughing blocks are common on slopes of 9°–38°; these range from 0.39 m to 2.4 m in length, and movement is marked by furrows 0.13 m to 3.07 m long and turf banks that have been pushed downslope by as much as 0.83 m above the adjacent ground. Current rates of movement do not exceed a few millimetres per year. Shaw also documented several rockfalls from the Lochnagar corries, and described avalanche tracks 100 m and 180 m wide cutting through woods on the slopes north-west of Loch Muick. These terminate in fan-like avalanche tongues under the surface of the loch. The effects of recent snow avalanche activity in the north-east corrie of Lochnager are relatively minor and restricted to occasional perched boulders, pits in the surface of talus and scratch marks (Ward, 1985b). Similar findings have been reported by Davison and Davison (1987) for an avalanche site in Glen Shee. Elsewhere, however, the geomorphological role of such avalanches is locally more important, for instance, in parts of the Cairngorms and on Ben Nevis (Ballantyne, 1989b; Luckman, 1992).

Interpretation

Lochnagar is important both for a range of individual glacial and periglacial landforms and also for the complete assemblage of features present. The north-east corrie of Lochnagar is a particularly fine example of this landform type, with steep, enclosed rock walls, a loch basin and suite of Loch Lomond Readvance moraines. The latter have had an important bearing on the debate concerning the extent of the Loch Lomond Readvance both locally and regionally. The moraines also demonstrate clearly the progressive active retreat of the glacier back into the corrie and offer scope for correlations with similar features in the Cairngorms and for interpreting the relationships between glacier fluctuations and climate during the readvance. Dating of organic deposits inside the moraines demonstrates conclusively that there was no recrudescence of glacier ice on the corrie floor during the Little Ice Age.

Lochnagar also provides particularly fine examples of periglacial features, notably relict boulder lobes that are among the finest in Scotland.

In many respects the geomorphology of Lochnagar is similar to that of the Cairngorms. Although the assemblage of features on Lochnagar is less complete, it is developed in a much more compact area. Lochnagar therefore provides an outstanding demonstration of key features of the geomorphology of the Loch Lomond Stadial and their spatial relationships, notably boulder lobes and end moraines.

Conclusion

Lochnagar is important for glacial and periglacial geomorphology. It provides a particularly good example of an assemblage of landforms that developed during the intensely cold climatic phase at the end of the Devensian stage and known as the Loch Lomond Stadial (approximately 11,000–10,000 years ago). These include periglacial boulder lobes formed by the slow mass movement of the soil downslope and a series of bouldery moraines formed by a corrie glacier. The landforms are developed in a relatively small area and their interrelationships are clearly demonstrated. Lochnagar forms part of a network of sites representing the geomorphology of the Loch Lomond Stadial.

LOCH ETTERIDGE

M. J. C. Walker

Highlights

Pollen grains preserved in the sediments on the floor of Loch Etteridge provide an important record, supported by radiocarbon dating, of glacial history, vegetational history and environmental change during the Lateglacial and early Holocene in the eastern Grampian Highlands. The site also includes an excellent assemblage of glaciofluvial landforms formed during the melting of the Late Devensian ice-sheet.

Introduction

Loch Etteridge (NN 688929) is located in Glen Truim, a tributary of upper Strathspey. The site occurs at an altitude of 300 m OD, approximately 5 km south-west of Newtonmore. It is important in the context of the Devensian Lateglacial in northern Britain. The sediments preserved on the floor of the loch contain a record of vegetational changes in the Grampian Highlands throughout the Lateglacial and early/middle Holocene, and the radiocarbon assay from the base of the sequence provides a minimum date for the wastage of the Late Devensian ice-sheet from the surrounding area. In addition, stratigraphic data from Loch Etteridge and from the nearby site of Drumochter form the basis for the establishment of a Late Devensian glacial chronology for this part of the Scottish Highlands. The central location of Loch Etteridge in the heart of the Grampian Highlands means that the lithostratigraphic, biostratigraphic and chronostratigraphic evidence from the site are of national significance in terms of both vegetational history and glacial chronology. The radiocarbon dates from Loch Etteridge are discussed in Sissons and Walker (1974), and the palaeoenvironmental data are described in Walker (1975a).

Description

Loch Etteridge lies in a large, dead-ice hollow and is surrounded by a complex system of kames, kame terraces and eskers (Young, 1978). The kame terraces, which slope from *c.* 310–240 m OD towards the north-east along the valley of the Milton Burn (Figure 9.10), contain small kettle holes and comprise rounded cobbles and boulders in a coarse sand matrix (Young, 1978). Kames and eskers occur principally at lower altitudes and often merge into the kame terraces; the eskers are steep, narrow ridges, ranging in height from 1 to 15 m (Young, 1978). According to Young (1978) the kame terraces formed at the margins of the melting ice-sheet.

The loch, which measures approximately 500 m in length and up to 150 m in width, is infilled at the south-west end, where over 7 m of sediment have accumulated. The lowermost sediments show a typical Lateglacial lithological sequence (Sissons *et al.*, 1973) comprising, from the base, gravels, grey silt/clay, green-grey silt/clay, green-brown gyttja, and light grey silt/clay (Figure 9.11). The last named deposits represent the Loch Lomond Stadial, while the underlying sediments are of Lateglacial Interstadial age. These Lateglacial deposits are overlain by Holocene lake muds and peats. Four radiocarbon dates (SRR–301 to SRR–304) were obtained from the Loch Etteridge sediments (Figure 9.11).

The base of the organic sediments in the profile was dated at 13,151 ± 390 BP (SRR–304), the Lateglacial *Empetrum* maximum at 11,290 ± 165 BP (SRR–303), the onset of the Loch Lomond Stadial at 10,674 ± 120 BP (SRR–302) and the close of the Loch Lomond Stadial at 9405 ± 260 BP (SRR–301); the last age determination now appears to be at least 1000 years too young when compared with dates on similar horizons at other Scottish sites (Lowe and Walker, 1984).

Interpretation

Five local pollen assemblage zones were identified in the Lateglacial sediments at Loch Etteridge (Figure 9.11). The lowermost (zone LE–1) is characterized by high values for *Rumex* and *Salix* (including *Salix herbacea*), with significant percentages of Gramineae, *Saxifraga* and *Artemisia*. These pollen spectra are indicative of an open-habitat landscape with a limited shrub component. In the next three zones (LE–2, LE–3, LE–4) there are higher counts of pollen of shrubby, woody plants. The dominant element is *Empetrum*, reflecting the widespread development of *Empetrum* heath in Strathspey during the Lateglacial Interstadial (see also Birks and Mathewes, 1978). There are two maxima in the *Empetrum* curve, one at the initial rise in values for the genus and a secondary peak at the close of the interstadial. Similar double maxima for *Empetrum* have been recorded in Lateglacial Interstadial deposits at Loch Tarff near the Great Glen (Pennington *et al.*, 1972), and at Tirinie in Glen Fender to the south of the Grampian watershed (Lowe and Walker, 1977). The episodes of *Empetrum* dominance are separated by a zone (LE–3) in which there are higher values of *Juniperus* and *Betula*. The majority of the birch grains appear to be from dwarf birch, however, and it seems unlikely that the regional birch treeline reached this area of the Grampians

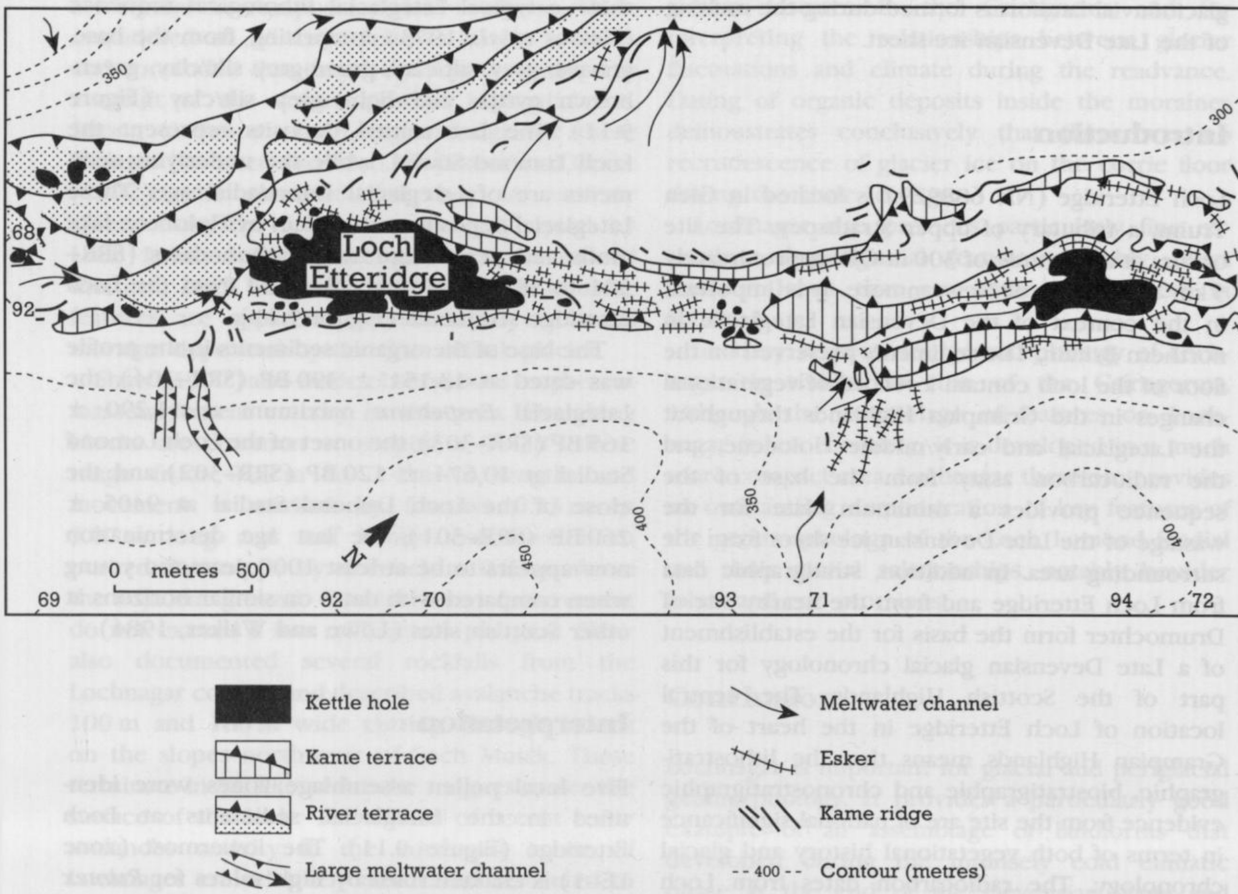


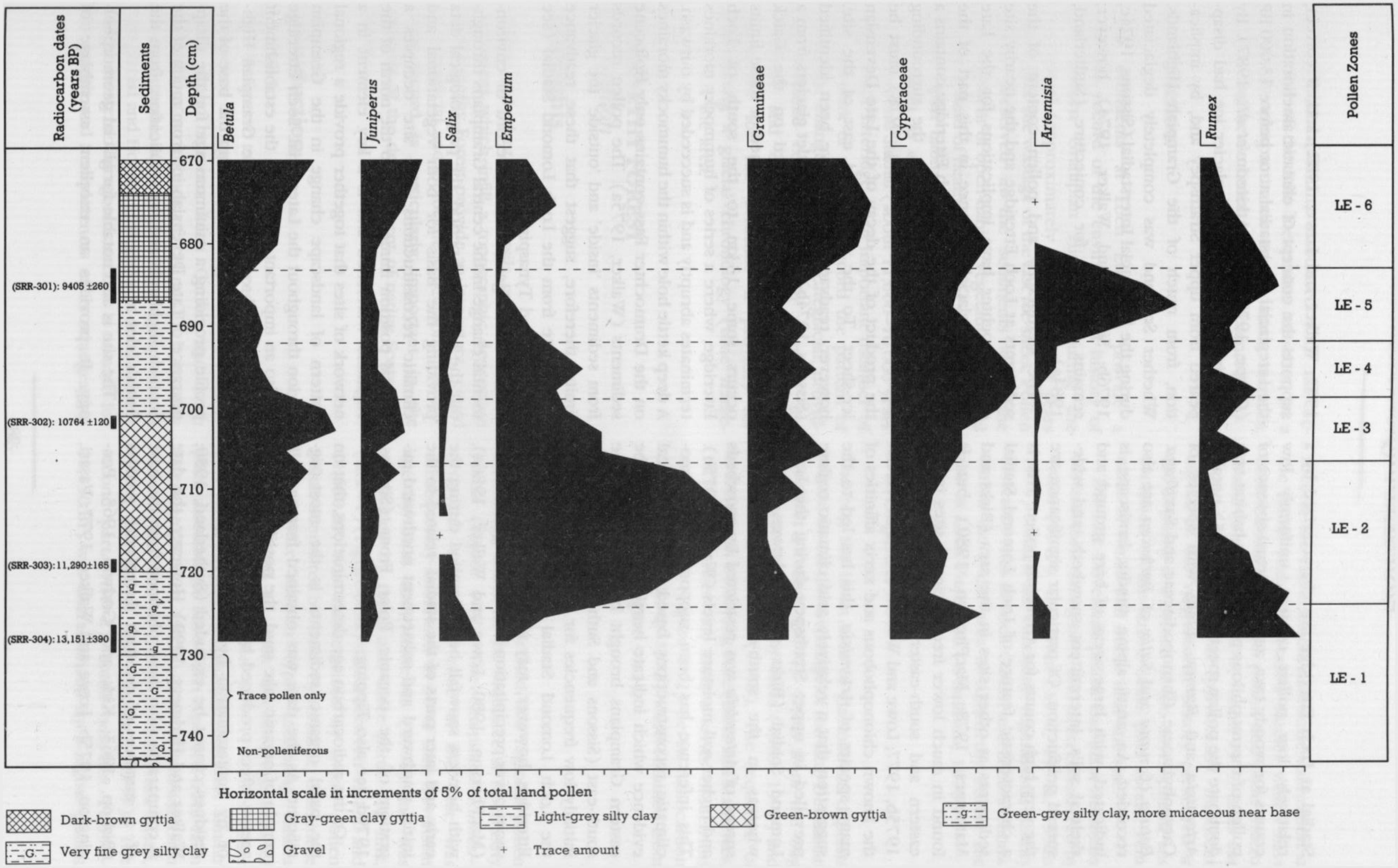
Figure 9.10 Geomorphology of the Loch Etteridge area (from Young, 1978).

during the Lateglacial (Walker, 1984b). Isolated stands of tree birch may have become established late in the interstadial, however, an inference supported by the discovery of tree birch macrofossils in late interstadial sediments at the nearby site of Abernethy Forest (Birks and Mathewes, 1978). *Salix* pollen is found at all levels representing the interstadial, reflecting the presence of shrub willows (probably such northern forms as *S. polaris*, *S. reticulata* or *S. glauca*) on the slopes around the Loch Etteridge basin. The occurrence of *Rumex* as an important element in the pollen spectra is indicative of the incomplete nature of the shrub-heath cover, and the continued presence of bare and disturbed ground throughout the Lateglacial Interstadial.

The Lateglacial Interstadial pollen records from Loch Etteridge and Abernethy Forest, which show the development of a shrub tundra dominated by *Empetrum* with *Betula nana* and *Salix*, are in marked contrast to those obtained from sites in the eastern and southern Grampian Highlands. In those areas the pollen data reflect an interstadial vegetation cover of moss heaths and poor grassland communities on the upper slopes, whereas a closed grassland with juniper, dwarf birch, willow, and stands of tree birch developed on the lower slopes and valley floors. Extensive copses of tree birch may have been found in more sheltered localities of the southern valleys (Walker, 1975b, 1977; Lowe and Walker, 1977; Lowe, 1978; Merritt *et al*., 1990).

Sediments formed during the Loch Lomond

Figure 9.11 Loch Etteridge: relative pollen diagram showing selected taxa as percentages of total land pollen. The samples for radiocarbon dating were taken from comparable lithostratigraphic horizons in an adjacent core.



Radiocarbon dates (years BP)
Sediments
Depth (cm)
Betula
Juniperus
Salix
Empetrum
Gramineae
Cyperaceae
Artemisia
Rumex
Pollen Zones
(SRR-301): 9405 ±260
(SRR-302): 10764 ±120
(SRR-303): 11,290±165
(SRR-304): 13,151±390
670
680
690
700
710
720
730
740
Trace pollen only
Non-polleniferous
LE - 6
LE - 5
LE - 4
LE - 3
LE - 2
LE - 1
Horizontal scale in increments of 5% of total land pollen
Dark-brown gyttja
Gray-green clay gyttja
Light-grey silty clay
Green-brown gyttja
Green-grey silty clay, more micaceous near base
Very fine grey silty clay
Gravel
+ Trace amount

Stadial at Loch Etteridge are characterized by a relatively low pollen content, uniformly low counts for woody taxa, and the virtual absence of pollen of thermophilous plants. Open-habitat taxa dominate the pollen spectra (zone LE–5), notably *Artemisia* and *Rumex*, along with species of Caryophyllaceae, Chenopodiaceae and *Saxifraga*. *Betula* cf. *nana* and *Salix* cf. *herbacea* are also recorded. An arctic-alpine tundra landscape is indicated, with large areas of bare ground and skeletal soils, intermittent snowbeds, and widespread gelifluction. Of particular significance are the very high counts for *Artemisia* pollen. This is a characteristic feature of Loch Lomond Stadial sediments at other sites in the area (Birks and Mathewes, 1978; MacPherson, 1980), but is found in much lower frequencies at sites in the eastern and south-eastern Grampians (Walker, 1975b, 1977; Lowe and Walker, 1977). In view of the known chionophobous and xerix affinities of many species of *Artemisia*, this has led to the suggestion that a relatively arid climatic regime prevailed in upper Strathspey during the Loch Lomond Stadial (Birks and Mathewes, 1978), whereas in the south-eastern Highlands the spread of *Artemisia* was restricted by snowbeds and higher soil moisture levels (Walker, 1975b). This inference has been supported by palaeoclimatic reconstructions based on glaciological evidence which indicate heavier snowfall in the eastern Grampians brought by winds from the south-east (Sissons and Sutherland, 1976). The initially low frequencies for *Artemisia* pollen in the Loch Lomond Stadial sediments at Loch Etteridge, however, may also reflect changes in snow cover/precipitation levels during the stadial (MacPherson, 1980; Lowe and Walker, 1986a), with heaviest snowfall being implied during the early and later parts of the stadial, related to the initial southward and subsequent northward migration of the oceanic Polar Front (Sissons, 1979d; see also Tipping, 1985).

Of the radiocarbon age determinations, that on the basal organic sediments is the most significant. As the date was obtained from a bulk sample of organic lake mud, the possibility of an ageing effect produced by the hard-water factor or by contamination by older mineral carbon residues cannot be excluded (Sutherland, 1980; Walker and Harkness, 1990). However, the date is comparable with those obtained from the base of a number of Scottish Lateglacial profiles (Bishop, 1963; Kirk and Godwin, 1963; Pennington, 1975b; Lowe and Walker, 1977; Vasari, 1977; Walker and Lowe, 1982) and, if correct, supports the concept of climatic amelioration in the Lateglacial Interstadial at or before 13,000 BP (Coope, 1975, 1977; Atkinson *et al.*, 1987). By that time, Late Devensian glacier ice had disappeared from upper Strathspey and, by implication, from much of the Grampian Highlands. Whether Scotland was completely deglaciated during the Lateglacial Interstadial (Sissons, 1974c, 1976b; Sissons and Walker, 1974), however, remains a matter for conjecture (Sutherland, 1984a).

The stratigraphy and pollen content of the sediments at Loch Etteridge and the nearby site of Drumochter have implications for the Late Devensian glacial sequence in this part of the Grampian Highlands. As Loch Etteridge contains a suite of Lateglacial sediments, the surrounding glaciofluvial landforms (Young, 1978) must be the product of the decay of the Late Devensian ice-sheet. To the south and east of the site, however, readvance limits have been identified (Sissons, 1974b) relating to outlet glaciers from a later ice-cap which developed on the Gaick Plateau. The most clearly defined of these limits occurs some 13 km to the south of Loch Etteridge, where a series of hummocky moraines terminates abruptly and is succeeded by outwash. A deep kettle hole within the hummocky moraines on the Drumochter Pass contains only Holocene sediments (Walker, 1975a). The pollen records from sediments 'inside' and 'outside' the glacier limits, therefore, suggest that these readvance limits date from the Loch Lomond Stadial (see Mollands and Tynaspirit).

Loch Etteridge contains a record of environmental change in the central Grampians throughout the Lateglacial period, the palynological data providing the basis for both vegetational and climatic reconstructions. The site occupies a critical position immediately to the north of the Highland watershed and is a key element in a network of sites that together provide a regional pattern of landscape change in the Grampian region throughout the Lateglacial. Loch Etteridge is also an important element in the establishment of a glacial chronology for the Grampian Highlands, the radiocarbon date from the base of the profile providing a minimum age for the disappearance of Late Devensian ice from much of the Scottish Highlands and, by implication, from the British Isles as a whole.

The site is also notable for glacial geomorphology. It provides an excellent assemblage of glaciofluvial landforms associated with the deglaciation of the Late Devensian ice-sheet. In a relatively compact area eskers, kame terraces, kames and kettle holes are all represented.

Conclusion

The sediments at Loch Etteridge provide a valuable record of the environmental history of the eastern Grampian Highlands during the Lateglacial (approximately 13,000–10,000 years ago), after the wastage of the last ice-sheet. Pollen grains preserved in the sediments show the development of open-habitat vegetation, followed by the spread of heath and shrubs with some tree birch. Open habitat species then became dominant again as climate deteriorated during the Loch Lomond Stadial (about 11,000–10,000 years ago). Loch Etteridge is an important member of the network of sites that record the pattern of landscape changes during the Lateglacial, providing valuable comparisons with sites in the southern and eastern Grampians. It is also significant for the evidence it provides for establishing a glacial chronology (time framework) for the area.

ABERNETHY FOREST

J. E. Gordon

Highlights

Pollen and plant macro-fossils preserved in the sediments which infill a topographic depression at Abernethy Forest provide an important record of Lateglacial and Holocene vegetational history. This record is particularly important in the context of the development of native Scots pine forest.

Introduction

The site known as Abernethy Forest (NH 967175) comprises a bog infill of a glacial channel or kettle hole between Loch Garten and Loch Mallachie at an altitude of 221 m OD. It is a key biostratigraphic site representing the sequence of Lateglacial and Holocene vegetation development in the western Cairngorms area. It is notable for the length and completeness of its stratigraphic record, the radiocarbon time-scale calibration of the latter, and the detailed studies which have been carried out on its pollen and plant macrofossils (Birks, 1969, 1970; Vasari, 1977; Birks and Mathewes, 1978). One particularly important aspect of the vegetational history preserved in the deposits is a record of the development and evolution of the native Scots pine forest, remnants of which still occur near the site.

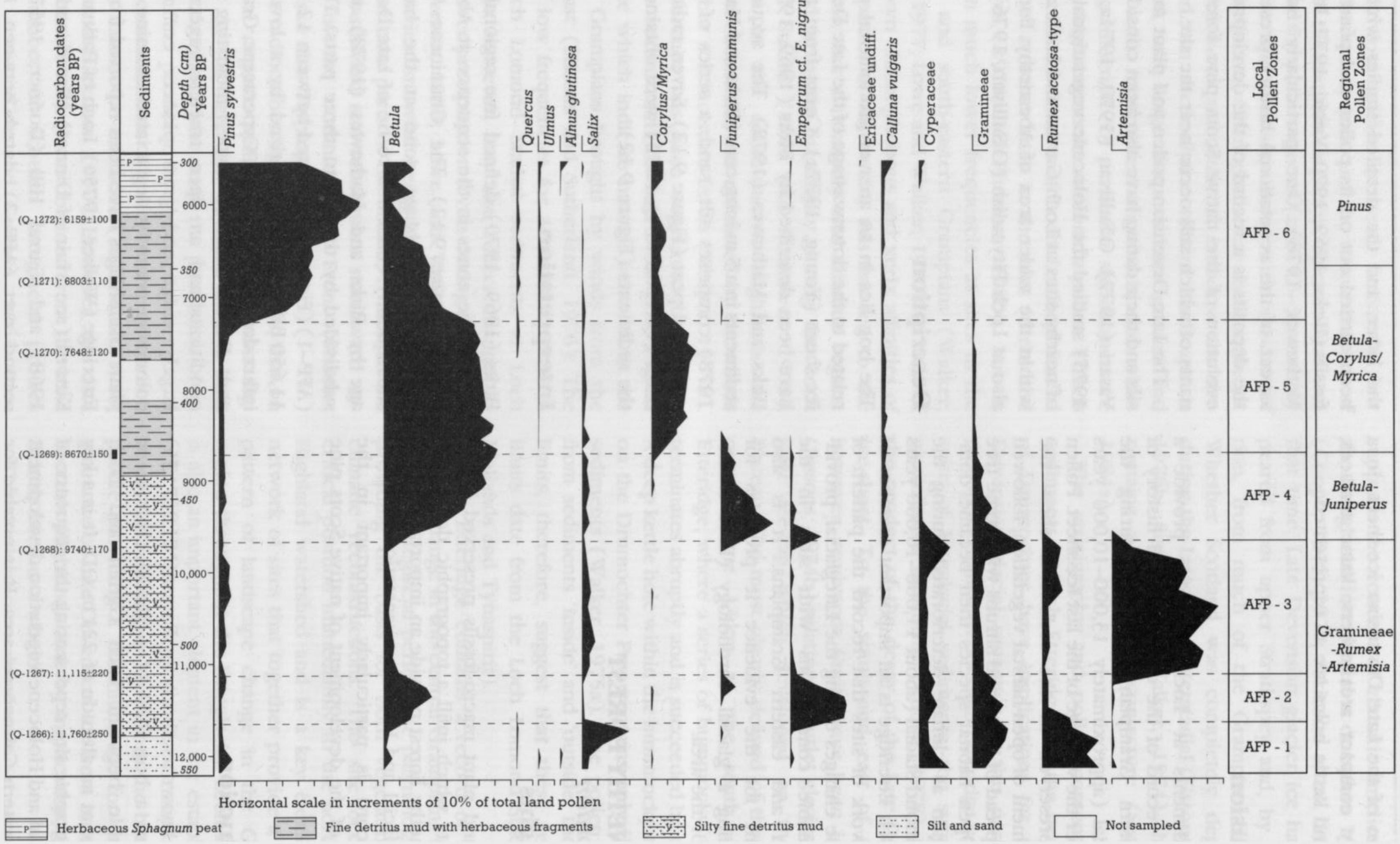
The Late Devensian pollen and plant macrofossils and their dating have also been considered by Vasari (1977). O'Sullivan (1970, 1974a, 1974b, 1975) studied the Holocene vegetational history of nearby sites at Loch Garten and Loch a'Chnuic within the wider area of Abernethy Forest and also at Loch Pityoulish (O'Sullivan, 1976).

Description

The bog lies in an area of glaciofluvial deposits related to the downwastage of the Late Devensian ice-sheet (Young, 1977a). Cores from the bog have been described by Birks (1969, 1970) and Birks and Mathewes (1978). The sequence of sediments in a 5 m long core (Birks and Mathewes, 1978) comprises silt, sand, a series of detritus muds and peat (Figure 9.12). Seven radiocarbon dates (Q–1266 to Q–1272) were obtained from the sediments (Figure 9.12).

Interpretation

Birks (1969, 1970) defined five regional pollen assemblage zones in the sequence at Abernethy Forest (Figure 9.12). The Gramineae–*Rumex–Artemisia* assemblage zone at the base was subsequently confirmed to be of Late Devensian age by Birks and Mathewes (1978) and was subdivided by them into three parts. The first, (AFP–1) (Figure 9.12) dated between 12,150 and 11,650 BP, was characterized by a low pollen influx dominated by *Salix*, Cyperaceae, Gramineae and *Rumex acetosa* type, indicating tundra conditions and an open treeless vegetation of largely sedge and grass pioneer communities colonizing recently deglaciated moraine. Similar plant assemblages have been reported from Loch Etteridge (Walker, 1975a), Loch of Park and Loch Kinord (see Muir of Dinnet) (Vasari and Vasari, 1968) and Garral Hill (Donner, 1957). The second part (AFP–2), dated between 11,650–11,150 BP, was characterized by a higher pollen



Radiocarbon dates (years BP)
Sediments
Depth (cm)
Years BP
Pinus sylvestris
Betula
Quercus
Ulmus
Alnus glutinosa
Salix
Corylus/Myrica
Juniperus communis
Empetrum cf. E. nigrum
Ericaceae undiff.
Calluna vulgaris
Cyperaceae
Gramineae
Rumex acetosa-type
Artemisia
Local Pollen Zones
Regional Pollen Zones
(Q-1272): 6159±100
(Q-1271): 6803±110
(Q-1270): 7648±120
(Q-1269): 8670±150
(Q-1268): 9740±170
(Q-1267): 11,115±220
(Q-1266): 11,760±250
300
6000
350
7000
8000
400
9000
450
10,000
500
11,000
12,000
550
AFP - 6
AFP - 5
AFP - 4
AFP - 3
AFP - 2
AFP - 1
Pinus
Betula-Corylus/Myrica
Betula-Juniperus
Gramineae-Rumex-Artemisia
Horizontal scale in increments of 10% of total land pollen
Herbaceous Sphagnum peat
Fine detritus mud with herbaceous fragments
Silty fine detritus mud
Silt and sand
Not sampled

influx representative of arctic shrub-tundra dominated by *Betula nana* and *Empetrum*. Around 11,220 BP birch trees began to colonize at the site. Similar assemblages occur at Loch Etteridge (Walker, 1975a) and Loch Kinord (Vasari and Vasari, 1968), and, with slight variations, at Loch of Park (Vasari and Vasari, 1968) and Garral Hill (Donner, 1957). The third phase (AFP–3), dated between 11,190 and 9670 BP, showed a marked vegetational 'revertance' during the Loch Lomond Stadial. The low pollen influx is typical of exposed, unstable habitats and snowbed sites. The high percentage of *Artemisia* pollen, which is characteristic of Loch Lomond Stadial pollen assemblages at sites in Strathspey (for example at Tom na Moine (MacPherson, 1980), Loch Etteridge (Walker, 1975a) and Loch a'Chnuic (O'Sullivan, 1974a)), suggests a relatively arid climatic regime, whereas in lower Deeside (Vasari and Vasari, 1968), parts of the south-east Grampians (Walker, 1975b; Lowe and Walker, 1977) and western Scotland (Pennington *et al.*, 1972; Birks, 1973) less arid conditions appear to have prevailed. Birks and Mathewes (1978) consider that this pattern reflects a precipitation shadow effect in the Cairngorm area and Strathspey (see also Sissons, 1979d, 1980b; MacPherson, 1980; Walker, 1984b). After about 9910 BP there are signs of increasing vegetational stability and climatic improvement prior to the spread of *Betula* and *Juniperus* in the early Holocene which has been dated to *c.* 9670 BP.

Birks and Mathewes (1978) noted a broadly consistent Late Devensian pollen stratigraphy between sites in Strathspey (Abernethy Forest, Loch a'Chnuic and Loch Etteridge) and Deeside (Loch Kinord). However, the radiocarbon geochronology for Loch Etteridge (Walker, 1975a) suggests that the three corresponding pollen zones at that site are 300–500 years younger. Birks and Mathewes suggested that the higher altitude of the Etteridge site (300 m OD) might explain later climatic amelioration, but this did not satisfactorily account for the apparently later onset of the Loch Lomond Stadial.

Figure 9.12 Abernethy Forest: relative pollen diagram showing selected taxa as percentages of total land pollen (from Birks and Mathewes, 1978). Regional pollen assemblage zones are from Birks (1970). Note that the data are plotted against a radiocarbon timescale.

Vasari (1977) has also investigated the Lateglacial pollen and plant macrofossils of a core from the Abernethy Forest site. He subdivided the profile into conventional Lateglacial pollen zones following principles outlined in his earlier work (Vasari and Vasari, 1968). The succession was generally in agreement with that of Birks and Mathewes (1978), although there were some differences in the relative dating of particular events. Vasari obtained the following dates for zone boundaries of the Jessen–Godwin scheme: 12,710 ± 270 BP (Hel–424) (I/II), 11,260 ± 240 BP (Hel–423) (II/III), and 10,230 ± 220 BP (Hel–422) (III/III–IV). The middle date was similar to that of the corresponding boundary in the zonation scheme of Birks and Mathewes (1978). However, Vasari's dates implied that organic sedimentation began rather earlier than suggested by Birks and Mathewes. The date obtained on the lowermost level was earlier than that for the start of the Allerød chronozone (*sensu stricto*) and the corresponding boundary in Birks and Mathewes' scheme. The basal Holocene date was also somewhat earlier than that obtained by Birks and Mathewes. Vasari's Abernethy Forest dates were also consistently older than those he obtained for corresponding zones at Loch Kinord and Loch of Park, although the youngest is broadly comparable in the latter case. He raised the possibility of a hard-water error in the Abernethy Forest dates, but based his deductions on the assumption that they were correct. He inferred that climatic amelioration began relatively early and progressed in an uninterrupted manner until the middle of the Allerød.

Vasari's (1977) date of 10,230 ± 220 BP (Hel–422) for the zone III–zone III/IV boundary at Abernethy Forest is broadly comparable to those from a variety of sites, both in eastern and western Scotland (see Gray and Lowe, 1977b, table 1). If correct, this suggests some degree of regional synchroneity.

At Abernethy Forest, in the profile examined by Birks and Mathewes (1978), the Holocene part of the sequence commences with the *Betula–Juniperus* zone, dated between 9670 and 8740 BP. This zone records the replacement of open, unstable habitats by a stable, shrub-dominated vegetation, particularly *Juniperus* (which increased to a peak and then declined) and *Betula nana* scrub. Birch forest, probably open at the start of the zone, progressively increased in density as colonization by tree *Betula* and then

Corylus took place. Similar assemblage zones are recorded at Loch a'Chnuic (O'Sullivan, 1974a), Loch Etteridge and Drumochter (Walker, 1975a), Tom na Moine (MacPherson, 1980), Loch Kinord and Loch of Park (Vasari and Vasari, 1968), Roineach Mhor and Blackness (Walker, 1975b), and possibly Morrone (Huntley, 1976).

The succeeding *Betula* and *Corylus/Myrica* assemblage zone, dated between 8740–7230 BP probably reflects dense birch–hazel forest. *Quercus* and *Ulmus* pollen are recorded continuously for the first time, but these trees were probably very local in their distribution and confined to the valleys. This zone is also represented at Allt na Feithe Sheilich and Loch Einich (Birks, 1969, 1970), Loch Garten and Loch a'Chnuic (O'Sullivan, 1974a), Tom na Moine (MacPherson, 1980), and in a large number of profiles throughout north and west Britain (Birks, 1970).

In the core examined by Birks and Mathewes (1978), the *Pinus* assemblage zone at Abernethy Forest commenced at 7230 BP and lasted until 5520 BP. From considerations of pollen influx as well as the occurrence of *Pinus* macrofossils in the sediment, Birks and Mathewes inferred that pine first arrived in the area about 7165 BP, but that it did not become established close to the site until about 6800 BP. A similar *Pinus*-dominated pollen zone has been widely recorded in the Cairngorm area, Deeside and Speyside, at Allt na Feithe Sheilich and Loch Einich (Birks, 1969, 1970, 1975), Glen Eidart, Sgòr Mór and Carn Mór (Pears, 1968), Allachy Moss (Durno, 1959), Loch Kinord (Vasari and Vasari, 1968), Loch Etteridge and Drumochter (Walker, 1975a), Tom na Moine (MacPherson, 1980), Morrone (Huntley, 1976), and Loch Garten, Loch a'Chnuic and Loch Pityoulish (O'Sullivan, 1974a, 1975, 1976). Apparent discrepancies in the rate and timing of the pine expansion in the area were discussed by O'Sullivan (1975) and explained in terms of differential sediment accumulation rates, possibly during periods of low or falling lake levels. However, Birks and Mathewes' (1978) date of 7165 BP is comparable to the age determination of 7000 BP derived by Birks (1969, 1970) from pine stumps at Loch Einich and Allt na Feithe Sheilich and with a date of 7100 BP interpolated by Birks and Mathewes from O'Sullivan's (1975) results at Loch Pityoulish. It is also comparable with the oldest date of 7350 ± 85 (IRPA–594) obtained by Dubois and Ferguson (1985) from pine stumps on the northern slopes of the Cairngorms. In addition Birks and Mathewes point out that a date of 7585 ± 335 BP (UB–852) from Loch Garten (O'Sullivan, 1974a) accords with the others if its large standard deviation is taken into account.

Following its establishment, pine came to dominate the natural forest on the more acid, well-drained soils of the Cairngorm area up to a treeline altitude of 793 m OD (Pears, 1968, 1972), and formed an important unit of one of the major distinctive forest regions of Scotland (McVean and Ratcliffe, 1962). The pollen evidence shows that thermophilous deciduous trees, such as *Ulmus* and *Quercus*, were comparatively rare in the area during the Holocene, probably due to the relatively continental climate, particularly the severe winters.

Alnus also appears to have been relatively rare in the area during the Holocene, being confined to stream-sides and fens. The *Alnus* rise at Abernethy Forest was estimated at 5520 BP (Birks and Mathewes, 1978), which is in agreement with the date of 5548 ± 50 BP (SRR–459) from Loch Pityoulish (O'Sullivan, 1975, 1976). A slightly older date of 5860 ± 100 BP (UB–851) was obtained from Loch Garten but, like the date for the *Pinus* expansion, the difference is probably not significant in palaeoecological terms (Birks and Mathewes, 1978). On Deeside, also, the pine forest appears to have been established before the alder rise, which occurred there sometime after 6700 BP (O'Sullivan, 1975).

Birks and Mathewes (1978) did not sample the sediments corresponding with the *Calluna–Plantago lanceolata* zone, which had previously been reported by Birks (1969, 1970). The zone is characterized by a reduction in woodland cover and increased non-arboreal pollen frequencies, especially *Calluna*. The decline of woodland is more marked in upland sites, for example at the Loch Einich type locality for the zone (Birks, 1969, 1970), than at Abernethy Forest where the pine forest, although it may have thinned, never entirely disappeared. The evolution of the pine forest in the Abernethy area during the late Holocene, when anthropogenic effects intruded, has been considered by Steven and Carlisle (1959) and O'Sullivan (1970, 1973a, 1973b, 1974a, 1974b, 1976, 1977).

An important point made by Birks (1970) about the vegetation succession in the area following the climatic amelioration at the beginning of the Holocene is that it can be explained in terms of biological and environmental factors without invoking further climatic change. She concluded that the order of immigration of species reflected the distance from their refuge and their rate of migration, and that their relative abundance was a function of the regional climate of the area, soil factors, and competition among species. More recently human interference has been an additional factor. Such variables also account for the distinctive forest history and patterns of the Cairngorm area when seen in an overall national perspective (Birks, 1977).

The development of the hydrosere at Abernethy Forest through lake to bog communities was traced by Birks and Mathewes (1978), mainly from the macrofossil stratigraphy. In general the aquatic plant succession is similar to that at the other sites so far investigated in Scotland, at Loch of Park, Loch Kinord and Drymen (Vasari and Vasari, 1968), although there are some local differences at Abernethy Forest, including a delay to the typical early Holocene plant expansion. Birks and Mathewes note that Abernethy Forest is additionally interesting for the record it provides of hydroseral development from open water through a relatively brief poor-fen stage to a *Sphagnum*-dominated acid mire.

Abernethy Forest is an outstanding biostratigraphic locality and is particularly important in demonstrating the Lateglacial and Holocene vegetation history of the Strathspey and Cairngorm area. It is especially significant in the context of the development and history of the native pine forest. It has also been studied in greater detail than most other sites in terms of combined pollen and plant-macrofossil analyses. Furthermore, it provides important contrasts with sites further west in Scotland. In a wider context, the Loch Lomond Stadial in Scotland is more pronounced and more intensively recorded biostratigraphically than anywhere else in north-west Europe, and Abernethy Forest contributes significantly to the detail of this record.

Conclusion

Abernethy Forest is an important reference site for studies of environmental changes during the Lateglacial and Holocene, that is approximately the last 11,000 years. The pollen and larger plant remains preserved in the sediments have been studied in considerable detail and they allow valuable comparisons with records from sites in other areas. Abernethy Forest is an integral member of the network of sites recording the vegetational history of Scotland and its major regional variations. It also contributes significantly to understanding the development of the native pine forest.

ALLT NA FEITHE SHEILICH

H. J. B. Birks

Highlights

Stream sections eroded in blanket peat by the Allt na Feithe Sheilich have provided an important pollen and plant macro-fossil record, supported by radiocarbon dating, of vegetational history during the Holocene. This record is particularly significant for understanding the development of blanket bog and pine forest.

Introduction

This site (NH 850260) is located on the Monadhliath Plateau at an altitude of about 600 m near the summit of Carn nam Bain-tighearna and comprises a large area of blanket bog that is presently being eroded by the headwaters of the Allt na Feithe Sheilich. The site contains radiocarbon-dated pine stumps and birch-wood layers buried within the peat and is of considerable importance in understanding the local and regional Holocene vegetational history of the eastern Highlands of Scotland. The peat sequence is one of the oldest blanket-peat profiles in the British Isles, as it extends almost to the Late Devensian/Holocene boundary. The site was first described by Lewis (1906) (his Spey–Findhorn watershed site) in his study of buried tree-layers in Scottish peats, and subsequently by Samuelsson (1910). The stratigraphy, palaeobotany, and palaeoecology of the sequence have since been studied in detail by Birks (1975).

Description

Lewis (1906) recorded two layers of pine stumps with birch wood below in two sections, and one layer of pine stumps with birch wood below in a third section. Samuelsson (1910) reinvestigated the site and found only one layer of pine. Birks (1975) similarly found only one layer of stumps underlain by peat rich in birch-wood remains, but overlain by peat with an upper indistinct birch-wood horizon.

Birks (1975) prepared a detailed pollen diagram from a 3.25 m deep peat profile (Figure 9.13). The profile contained large pine stumps overlying 1.3 m of humified peat with frequent fragments of birch and willow wood. The pine stumps are overlain by 1.8 m of humified *Sphagnum* peat containing an indistinct layer of birch and *Calluna* twigs at 1.5 m depth. One pine stump yielded a radiocarbon date of 6960 ± 130 BP (K–1419) and the upper birch-wood layer is dated to 4425 ± 100 BP (Q–886). The profile is divided into eight local pollen zones that are correlated with the four, radiocarbon-dated, Holocene regional pollen-assemblage zones established for the Cairngorm area by Birks (1970) (see also Birks and Mathewes, 1978) (Figure 9.13).

Interpretation

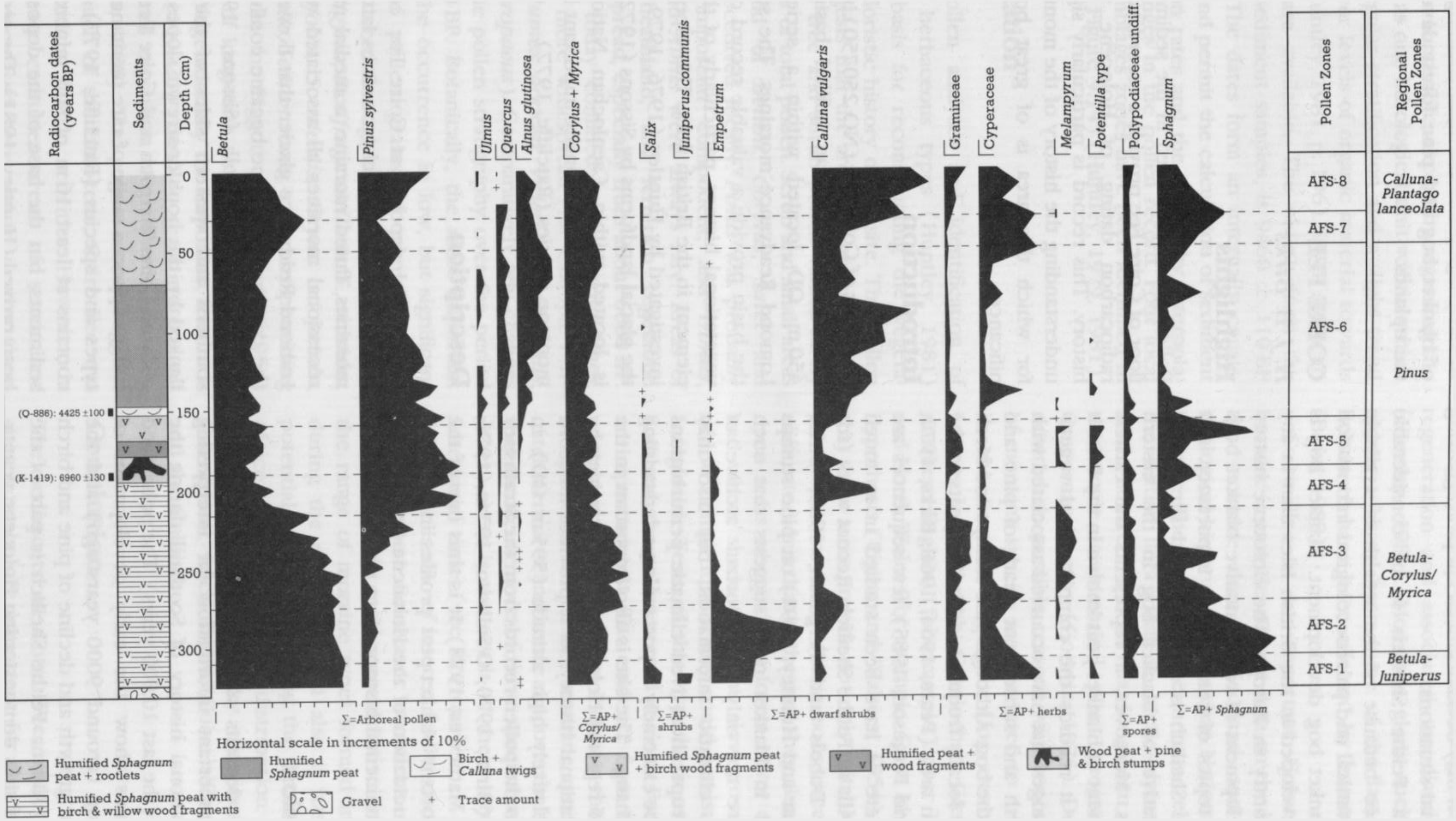
The record of regional vegetational history preserved in the Allt na Feithe Sheilich deposits suggests that before 9400 BP open birch–willow–juniper scrub with a wide variety of herbs was widespread. From 9400 BP to 7500 BP birch woodland with some hazel and willow was predominant. At about 7500 BP pine migrated into this area of Scotland (Birks, 1977) and became the co-dominant tree of the region along with birch. The pollen assemblage of the top 0.5 m of the succession reflects the regional clearance of these pine and birch woods and the extensive development of *Calluna* moor.

The local vegetational history of the site suggests that wet mesotrophic birch–willow woods with abundant *Sphagnum* and *Empetrum* and some *Calluna vulgaris* developed in poorly drained hollows on the Carn nam Bain-tighearna plateau at about 9400 BP. By 9000 BP the field-layer composition of these woods changed to an abundance of grasses, sedges, and *Melampyrum* and a variety of fen herbs. Such communities may have resembled modern 'lagg' communities of bogs in central Sweden. This type of community is extremely rare in the British Isles today, owing to Man's drainage activities or, as at Allt na Feithe Sheilich, to subsequent natural burial by the growth of blanket peat, leaving little trace of these communities except for the wood of birch and willow at and near the base of many blanket peat profiles.

By 7500 BP the local vegetation changed to a drier, more acid *Calluna–Empetrum* bog with some birch, into which pine was able to establish itself, forming an open pine–birch bog with abundant dwarf shrubs. At 6900 BP the bog became wetter, leading to the death of the trees and the development of a *Sphagnum–Calluna* bog. At about 4400 BP the bog became drier again, allowing the local growth of birch, as reflected by the upper layer of birch and *Calluna* remains rich in carbonized fragments. Thereafter, *Eriophorum vaginatum* became dominant to form the characteristic ombrotrophic *Eriophorum–Calluna* blanket-bog community of plateau sites in the eastern Highlands today.

The local vegetational history of the site is of considerable importance because it records the earliest development of blanket bog in the British Isles and the establishment and subsequent demise of pine on the bog. Although Lewis (1906) assumed that buried wood layers in peats of different parts of Scotland were the same age, work by Birks (1975) clearly shows that pine stumps within an area such as the Cairngorms yield different radiocarbon ages. This asynchroneity of woodland development and the varied causes of death of the trees suggest that there were no simple, overriding, regional climatic factors controlling tree growth on peat here or in any other areas of Scotland (Bridge *et al.*, 1990). Tree establishment, growth, and death on blanket peat may have been controlled by small climatic fluctuations to which the vegetation at one site may have been sensitive at a particular time, whereas at other sites it was not, depending on local vegetational succession, aspect, altitude, hydrology and topography. Pine stumps in the Cairngorm area invariably occur at a level just after the peat became acid, but before the establishment of *Calluna–Eriophorum vaginatum* dominated ombrotrophic bog, a habitat which is unsuitable for pine regeneration today. The death of the pines seems to be due to various causes, the most common, as at Allt na Feithe Sheilich, being some increase in wetness of the peat surface. However, such an increase need not be due to any large regional climatic change because McVean (1963a) has shown that a single

Figure 9.13 Allt na Feithe Sheilich: relative pollen diagram showing selected taxa as percentages of the pollen sums indicated (from Birks, 1975).


Radiocarbon dates (years BP)
Sediments
Depth (cm)
(Q-886): 4425 ±100
(K-1419): 6960 ±130
Betula
Pinus sylvestris
Ulmus
Quercus
Alnus glutinosa
Corylus + Myrica
Salix
Juniperus communis
Empetrum
Calluna vulgaris
Gramineae
Cyperaceae
Melampyrum
Potentilla type
Polypodiaceae undiff.
Sphagnum
Pollen Zones
Regional Pollen Zones
AFS-8
AFS-7
AFS-6
AFS-5
AFS-4
AFS-3
AFS-2
AFS-1
Calluna-Plantago lanceolata
Pinus
Betula-Corylus/Myrica
Betula-Juniperus
Σ=Arboreal pollen
Σ=AP+ Corylus/Myrica
Σ=AP+ shrubs
Σ=AP+ dwarf shrubs
Σ=AP+ herbs
Σ=AP+ spores
Σ=AP+ Sphagnum
Horizontal scale in increments of 10%
Humified Sphagnum peat + rootlets
Humified Sphagnum peat
Birch + Calluna twigs
Humified Sphagnum peat + birch wood fragments
Humified peat + wood fragments
Wood peat + pine & birch stumps
Humified Sphagnum peat with birch & willow wood fragments
Gravel
Trace amount

wet season may be sufficient to kill pines growing in marginal situations.

Allt na Feithe Sheilich is of considerable importance because of the wealth of available palaeobotanical and palaeoecological information about blanket bog development. Blanket bog is better developed in the British Isles than in any other country in Europe. The Holocene history and development of representative blanket bogs are thus topics of considerable importance. Allt na Feithe Sheilich is a well-studied site that is representative of blanket bog in the eastern Highlands. Moreover, it represents the earliest development of blanket peat known in the British Isles and it records the complex local vegetational changes that have occurred associated with the growth and subsequent death of pine and birch on the bog. Although pine stumps and birch wood are locally frequent in blanket peats in the Cairngorm area (Pears, 1964, 1968; Birks, 1970; Dubois and Ferguson, 1985), few sequences are as complete or have been studied in as much detail as Allt na Feithe Sheilich. Recent work (for example, Dubois and Ferguson, 1985; Birks, 1988; Gear and Huntley, 1991) on pine stumps preserved in blanket peat, suggests that such stumps are not only an important 'archive' of Holocene climatic information, but also may reflect abrupt, short-lived climatic perturbations that may be extremely important in understanding climatic change. The site is also important in the context of regional Holocene pollen stratigraphy and vegetational history, as it provides a record from a relatively high altitude (595 m OD), in contrast to the pollen records from the Strathspey lowlands (Birks, 1970; O'Sullivan, 1974a, 1976; Birks and Mathewes, 1978). It is thus one of the most important blanket-peat profiles in Scotland for the elucidation of the Holocene vegetational and environmental history of an upland area.

Conclusion

The peat deposits at Allt na Feithe Sheilich provide important information for interpreting the vegetational history of Scotland during the Holocene (the last 10,000 years). The pollen and tree remains show the early development of blanket bog (around 9000 years ago) and the subsequent growth and decline of pine and birch woodland. Allt na Feithe Sheilich is part of the network of sites demonstrating Holocene vegetational and environmental change and is particularly significant for understanding the history of blanket bog and pine forest development in the uplands.

COIRE FEE

H. J. B. Birks

Highlights

Pollen grains preserved in the sediments on the floor of Coire Fee provide a record, supported by radiocarbon dating, of Holocene vegetational history. This record is particularly significant for understanding the history of the montane species for which this area is of great botanical significance.

Introduction

The floor of Coire Fee (NO 250750) in Glen Doll, in Angus, contains an infilled basin at about 450 m OD located within a series of Loch Lomond Readvance moraines. The sediments in the basin provide a valuable record of Holocene vegetational history, particularly of the montane element in the British flora. This aspect has been investigated by Huntley (1976, 1979, 1981) and the glacial landforms by Sissons (1972a). The site is located within Caenlochan National Nature Reserve, an internationally important location for montane species (Ratcliffe, 1977).

Description

The glacial deposits at Coire Fee comprise an assemblage of hummocky moraines, lateral boulder moraines, fluted moraine, a medial moraine and recessional moraines all associated with a Loch Lomond Readvance glacier that flowed out from the corrie and became became confluent with a glacier in Glen Doll (Sissons, 1972a). The southern and western sides of the basin are flanked by the boulder-strewn slopes below the cliffs of Coire Sharroch and Coire Fee. The cliffs today support a range of rare montane vegetation types and species (Ratcliffe, 1977). The basin contains at least 16 m of stiff minerogenic lake sediments, but the base of the deposits has not been proved (Huntley, 1981). The sediments are very complex, with interbedding and intermixture of muds, silts, and sands. 'No convenient simplification is possible, except by regarding the whole core as one lithological unit within which there is irregular stratification and a slight trend towards lower levels of organic material towards the base' (Huntley, 1981, p. 196). Seven radiocarbon dates are available. The oldest, from the lowermost sediment samples, is 9460 ± 110 BP (Q–1424). The dates form an internally consistent series and permit the calculation of sediment accumulation rates and the dating, by interpolation, of changes in the pollen record. Four local pollen assemblages zones have been identified in the profile (Figure 9.14) (Huntley, 1979, 1981).

Interpretation

Detailed pollen analyses and identification of many rare herbaceous types (Huntley, 1981) provide a basis for reconstructing the vegetational and floristic history of the site. The pollen record suggests that the area was never densely wooded, as tree and shrub pollen values rarely exceed 50% of total pollen. Scrub and small areas of woodland of *Betula*, *Corylus*, *Salix* and *Juniperus* occurred locally. *Pinus* was probably never an important component, and *Ulmus*, *Quercus* and *Alnus* were always rare. Areas of grassland, heathland, and fern-rich vegetation were widespread, especially from about 6000 BP. Tall herbs, today confined to ungrazed ledges, were once more widespread (for example *Filipendula*, *Rumex acetosa*, *Valeriana officinalis*, *Trollius europaeus*). Comparatively few changes occur in the pollen stratigraphy over the period 7000–5000 BP. Botanically, the most important feature is the occurrence in low, but significant amounts of pollen grains of many montane species scattered through much of the sequence – *Oxyria digyna*, *Saxifraga stellaris*, *S. aizoides*, *S. oppositifolia*, *S. nivalis*, *Dryas octopetala*, *Silene acaulis*, *Sedum rosea* – thereby providing clear support for Piggott and Walter's (1954) hypothesis of long-term persistence through the Holocene. Vegetationally the important feature is the recent (100–200 years) decrease in trees and the associated expansion of grasslands (Huntley, 1981; Birks, 1988). The pollen record suggests that, for much of the Holocene, Coire Fee was little affected by human activities. However, in the last two centuries areas of scrub and woodland decreased here and in nearby Caenlochan Glen, probably as a result of excessive grazing by sheep and deer causing lack of tree regeneration and associated woodland decline (Huntley, 1981). Mountain glens such as this appear to have been some of the last areas in Britain to have been affected by human impact (Birks, 1988).

Coire Fee is an important Holocene site because it provides unique data on the history of the montane flora in Scotland and on the ecological history of Caenlochan National Nature Reserve. The history of the montane element in the British flora (that is, arctic–alpine, alpine, arctic–subarctic species) has long been an important topic in historical plant geography and Quaternary botany (Godwin, 1975). Debate has centred on possible reasons why concentrations of montane species are restricted to a few areas in the Scottish Highlands (for example, Ben Lawers, Inchnadamph, Caenlochan, Glen Clova), northern England (for example Upper Teesdale), and North Wales (for example, Cwm Idwal). One hypothesis (Pigott and Walters, 1954) proposes that these areas provide not only suitable ecological conditions today (basic soils, steep slopes, cliffs, etc.), but that in the past they also provided open areas where dense forest never developed and where shade-intolerant, slow-growing herbs of low competitive ability could persist from the Lateglacial. Tests of this hypothesis are few; in Scotland, the pollen record at Coire Fee provides an important test. The evidence from the pollen contained in the sequence indicates the presence of significant numbers of montane species in the catchment area and hence supports the hypothesis that the occurrence of these species in this (and other) areas is the result of their survival from Lateglacial times (see Morrone).

The site is also of interest for its assemblage of Loch Lomond Readvance moraines. Not only does it provide good representative examples of the range of moraine types formed in Scotland during the readvance, but also it has research potential for reconstructing the detailed pattern of ice wastage from the distribution of lateral, recessional and hummocky moraines (cf. the Cairngorms, Loch Skene, Coire a'Cheud-chnoic and the Cuillin).

Conclusion

The sediments at Coire Fee, and the pollen they contain, are important for the information they provide on vegetational development during

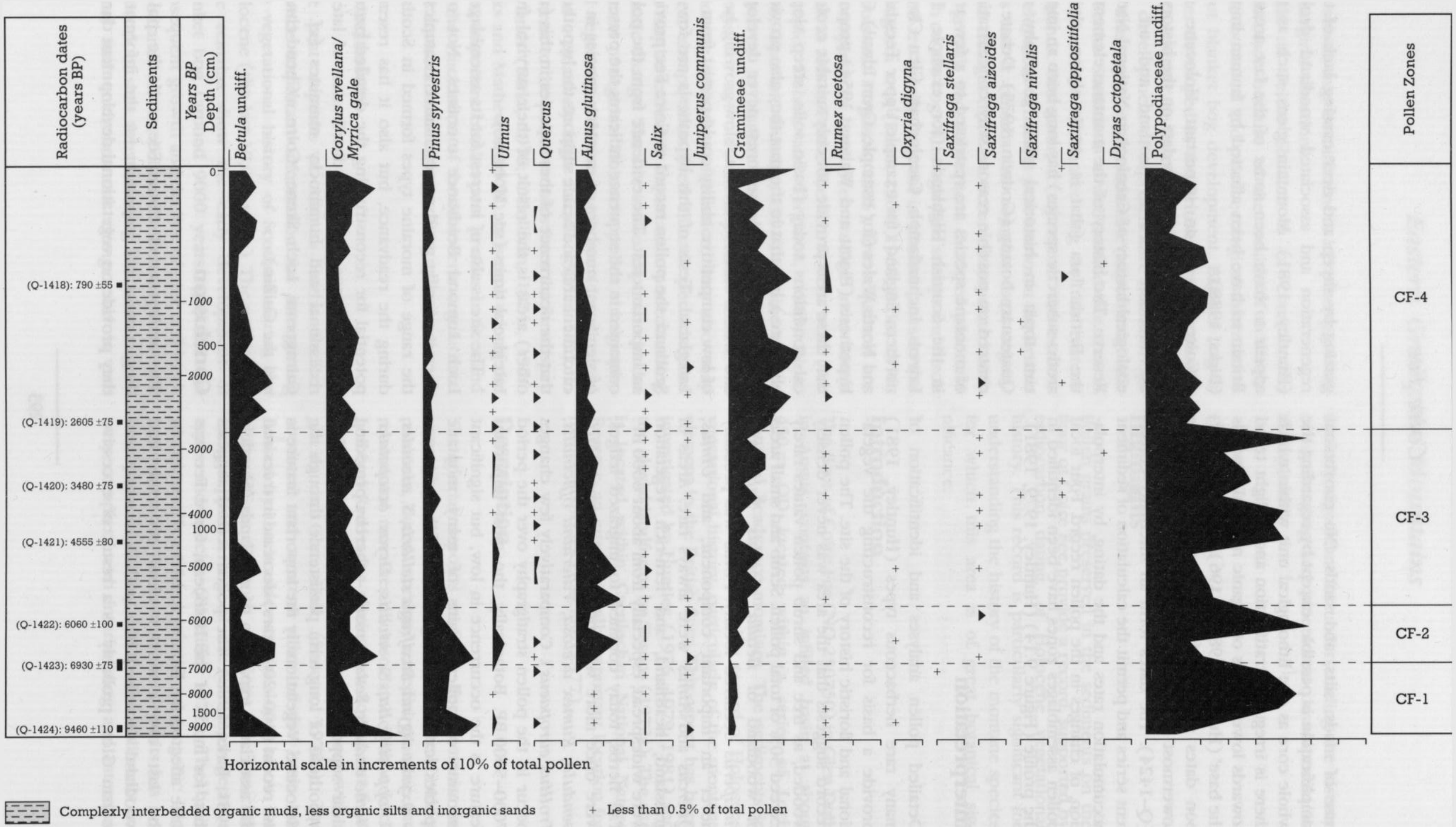


Figure 9.14 Coire Fee: relative pollen diagram showing selected taxa as a percentage of total pollen (from Huntley, 1981).

the Holocene (the last 10,000 years) and, in particular, on the history of the montane species for which the area is noted today. The pollen record supports the argument that these species have survived from preceding Lateglacial times. Coire Fee is one of the few sites in Britain where survival of these species can be demonstrated.

MORRONE
B. Huntley

Highlights

The sediments preserved in a topographic depression on the flanks of Morrone contain a wealth of palaeoecological information. Analysis of pollen and plant macrofossils, supported by radiocarbon dating, has allowed detailed reconstruction of vegetational history and environmental change during the Lateglacial and Holocene in an area of outstanding importance today for its arctic–alpine and northern–montane communities.

Introduction

The Morrone site (NO 135900) is situated at about 420 m OD on the north-facing slope of Morrone, a hill lying immediately to the south of the village of Braemar, on Deeside. The Morrone Birkwoods National Nature Reserve contains a complex of sub-alpine woodlands, scrub, flushes, mires, grasslands, tall herb and upland heath communities (Huntley, 1976; Ratcliffe, 1977; Huntley and Birks, 1979a, 1979b). The Quaternary interest at the site arises principally from the presence within the woodland area of a series of small, shallow, infilled basins which contain Lateglacial and Holocene sediments. Stratigraphic, pollen and plant macrofossil studies, and radiocarbon dating have been carried out upon a core from the deepest of these basins (Huntley, 1976 and unpublished data). These studies have revealed the history of the site since Lateglacial Interstadial times, and the plant macrofossil record for the Lateglacial period is particularly rich, allowing detailed palaeovegetation and palaeoenvironmental reconstructions to be made. The altitude of the site and its relative proximity to Loch Lomond Readvance ice limits, coupled to the known quality of the palaeoecological record that it preserves, make it unique in Scotland.

Description

The basin from which the core used in the palaeoecological studies was collected is located on a relatively gently sloping, till-covered area of the lower slopes of the hill. A small stream flows into the basin at its south-west corner, and there is also general seepage along the western side from a neighbouring basin some 350 m to the south-west. Another small stream drains from the basin on its eastern side.

Although it is primarily surrounded by heathland communities, birch woodland stands approach to within less than 300 m. The surface of the basin itself supports a soligenous mire community, and the inflow stream drains from gravel flushes and soligenous mires within the woodland area upslope of the site.

The core studied extends to a depth of 4.0 m, at which point the corer struck either bedrock or a large rock within the till. The sediments were described in detail by Huntley (1976) and comprise a sequence of organic silty mud, silts, silty muds, silts and fine sands, and gyttja (Figure 9.15).

Huntley (1976) also included a loss-in-weight upon ignition profile for the core which emphasizes the marked difference between the upper 1.5 m or so of often highly organic sediments and the predominantly minerogenic sediments of the remainder of the core.

Ten radiocarbon age determinations have been made on 0.05 m thick samples from the core (Q–1287 to Q–1291, Q–1344 and Q–2316 to Q–2319) (Figure 9.15).

The radiocarbon dates show that the lower 2.5 m or so of the core accumulated during the Lateglacial, with the first sediment accumulating in the basin about 12,600 BP. The dates Q–2319, Q–2316 and Q–1289 are indistinguishable at approximately 9800 BP, indicating a brief time of very rapid sediment accumulation during the early Holocene. In contrast, during the period between 9700 BP and 6600 BP only about 0.17 m of sediment accumulated, a very slow rate of accumulation. Although the uppermost part of the core contains a dating reversal, the results none the less indicate relatively rapid sedimentation once again during the last three to four millenia.

An absolute pollen stratigraphic study was

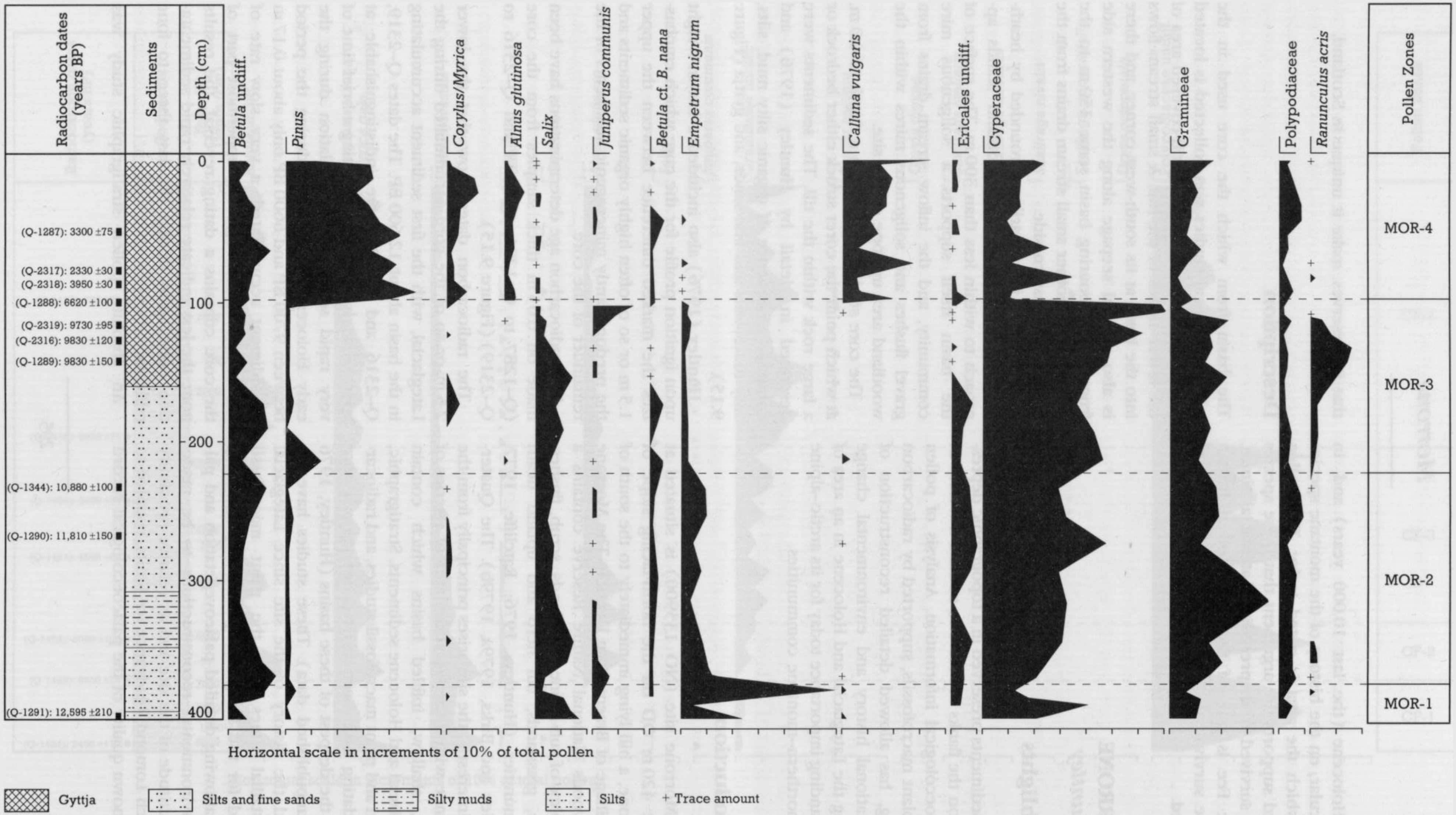


Figure 9.15 Morrone: relative pollen diagram showing selected taxa as percentages of total pollen (from Huntley, 1976).

performed on the core, and both relative pollen diagrams and diagrams of absolute pollen accumulation rates were prepared (Huntley, 1976). The relative pollen diagram (Figure 9.15) was divided into four local pollen assemblage zones (Huntley, 1976), using the results of numerical zonation techniques (Gordon and Birks, 1972) as a guide.

Interpretation

During the time represented by the first zone (MOR–1) dwarf-shrub heaths and grasslands were the predominant local vegetation types, although some scrub of *Juniperus* and *Salix* and even local stands of *Betula* were probably also present. A variety of pollen taxa together indicate the presence also of open, unstable soil areas. The evidence from the second zone (MOR–2) indicates a similar mosaic of vegetation including dwarf-shrub heaths, grasslands, scrub and occasional local stands of *Betula*, but with an increased representation of arctic–alpine and northern-montane taxa and of low-growing herbs, including taxa indicative of open soil areas. The coarse minerogenic sediments at this time, coupled to the evidence of more extensive open soil areas, combine to indicate severe environmental conditions. The environment subsequently stabilized during the third zone (MOR–3), with aquatic taxa becoming abundant in the small lake, increasingly organic sediment accumulating, and the development of extensive *Juniperus* scrub towards the end of the time represented. A vegetational mosaic continues to be present, none the less, although during this period the areas of open soil diminish. Major vegetational changes occurred at the time of the change to the fourth zone (MOR–4); *Pinus* forests became extensive on Deeside and surrounded the stands of *Betula* woodland, with their *Juniperus* understorey, at Morrone. These latter woodlands seem none the less to have persisted, perhaps favoured by the areas of better soils associated with the outcrop of calcareous rock and the base-rich tills at this site.

Although to a large extent the plant macrofossils at the site simply support the interpretation of the vegetational history based upon the pollen record, the macrofossil evidence adds an extra dimension to the palaeovegetational and palaeoenvironmental reconstruction, as well as documenting in much greater taxonomic detail the history of the flora of Morrone, especially during the Lateglacial. The identification of bryophyte macrofossils also provides information about a group of plants that leave no useful pollen and spore record, and yet are important, often dominant, components of many upland and arctic plant communities.

The macrofossil record is notable for its extreme species richness, and for the large numbers of arctic–alpine taxa represented. Most noteworthy perhaps are several taxa that are today absent from the British Isles but are found in Scandinavia (for example, *Papaver radicatum* and *Meesia tristicha*). However, the abundant remains of *Polytrichum norvegicum* throughout much of the Lateglacial indicate the presence of long-lying snow patches near to the site, an inference which could not be reached from the pollen data alone, and complete shoots of *Saxifraga oppositifolia* and rosettes of *S. cespitosa* demonstrate that both species were growing in close proximity to the site and give a clearer picture of the nature of the open-soil communities of dwarf herbs present. The wealth of ecological detail provided by the macrofossil records allows an unrivalled picture to be assembled of the Lateglacial vegetation at the site.

Together, the pollen and macrofossil records show that this site, noted today for its rich flora and the abundance of arctic–alpine and northern-montane taxa that it supports, has had a long history of such floristic wealth and biogeographic character.

This site is of regional importance because of the radiocarbon-dated pollen and macrofossil records that are available from it and which are unmatched in terms of altitude and timespan of record within the region. The wealth of data that it has furnished, and the detailed vegetational history which has been reconstructed from these data combine to give the site national importance. The modern Morrone Birkwoods are unique within the British Isles, and share their closest ecological affinities with the sub-arctic birchwoods of Scandinavia. The pollen analytical and macrofossil evidence have documented the occurrence of non-British taxa at the site throughout the Lateglacial and the Holocene. The unusual modern vegetation of the area can therefore be understood in terms of the development of the local vegetational communities during the last 12,500 years.

Conclusion

The plant fossil contents of the deposits on the lower slopes of Morrone Hill and within the Morrone Birkwoods National Nature Reserve are of great importance for studies of vegetational history. Analyses of the distribution of pollen and larger plant remains in vertical sediment profiles, together with radiocarbon dating, have provided palaeoecological data of considerable value and have allowed the history of a nationally unique area of vegetation to be elucidated in great detail. The site is exceptional for the wealth of information on vegetational and environmental changes during the Lateglacial (about 13,000–10,00 years ago) that is available from the larger plant fossil remains.

GLEN FESHIE

A. Werritty and L. J. McEwen

Highlights

The landforms and deposits at Glen Feshie include outwash and river terraces, alluvial fans, palaeochannels and debris cones. This assemblage of features provides an outstanding record of valley-floor and valley-slope development during the Lateglacial and Holocene.

Introduction

The River Feshie is a right-bank tributary of the River Spey, draining a catchment area of 240 km^2 in the western Cairngorms. It is one of the most important sites in Britain for fluvial and Holocene geomorphology. As one of the most active gravel-bed rivers in the country it has attracted considerable research interest, particularly during the 1970s and 1980s (Young, 1976; Buck, 1978; Werritty and Ferguson, 1980; Ferguson, 1981; Ferguson and Werritty, 1983; McEwen, 1986; Robertson-Rintoul, 1986a, 1986b; Brazier, 1987; Brazier and Ballantyne, 1989; Werritty and Brazier, 1991). The River Feshie and the glen it occupies are particularly important in three respects: first, for the unique opportunity they provide for the study of present-day river processes and rates of channel and landform change in a large, highly active, gravel-bed river; second, for the record of such changes in the past, which are represented in documentary, geomorphological and stratigraphic evidence; third, for the unrivalled opportunity they allow to set the present-day river dynamics into a long-term perspective of geomorphological changes during the Lateglacial and Holocene. In scientific terms, these three aspects are closely interlinked, and it is the combination of all three, as well as each individual interest, which distinguishes the site. In this report, the emphasis is placed on Lateglacial and Holocene geomorphology and palaeohydrology, whereas the historical and present-day river dynamics and landforms are to be reviewed in the *Fluvial Geomorphology* volume of the Geological Conservation Review.

Three parts of the glen are important for Lateglacial and Holocene geomorphology and palaeohydrology: (1) a 3.3 km long reach extending from Allt Garbhlach (NN 850952) to north of Achlean (NN 850986); (2) the Allt Lorgaidh fan (NN 842908 to NN 846918); and (3) an area of debris cones extending over a distance of *c.* 0.8 km below Creag na Caillich (NN 853903).

Description

Most of the drainage basin lying between 700 m and 1000 m OD is underlain by Moine schist, but to the north-east the ground rises to 1265 m OD on the Cairngorm granite batholith. The basin is dissected by a steep-sided glacial trough (Linton, 1949a) through which the River Feshie flows westwards before turning north at about 400 m OD into the wider, lower valley cut into glacial tills and outwash, these glacigenic deposits being restricted to the valley floor and lower slopes. Bedrock on the plateau (600–800 m OD) is mantled by blanket peat; at the highest levels bare, frost-shattered regolith occurs. The lower course of the river is confined locally by bedrock outcrops, and more extensively by Lateglacial and Holocene terraces, but in three reaches (upper Glen Feshie, Lagganlia and at the confluence with the River Spey) the river is free to migrate laterally and is actively reworking its floodplain.

The geomorphological impact of Late Devensian ice-sheet wastage in lower Glen Feshie has been discussed in detail by Young (1975a). During the Loch Lomond Readvance, outlet glaciers descended from the Gaick ice-cap northwards into the upper valleys of the Feshie (Sissons, 1974b) and small glaciers occurred in the Cairngorms massif to the east (Sissons, 1979f). Glaciofluvial landforms are abundant in the lower part of the catchment and local accumulations of outwash materials are remarkably thick. Young (1976) identified three stages of terrace development, but more recently five terraces levels have been described in the lower part of the valley by Robertson-Rintoul (1986b). During the Holocene in certain parts of the valley the river has trimmed the distal margins of fans and cones (Brazier, 1987). Rates of channel change, which have resulted in extensive reworking of the floodplain over the past 200 years, are remarkably high for the British uplands (Werritty and Ferguson, 1980; McEwen, 1986).

Terraces and alluvial fans

Glen Feshie is typical of valleys in upland Scotland in containing large accumulations of glaciofluvial and fluvial sediments deposited as valley fills. The particular valley fill in Glen Feshie was created towards the end of the Late Devensian as the ice-sheet in the valley downwasted *in situ* (Young, 1975a). Three groups of landforms comprise the major geomorphological features of this valley fill:

1. kame and kettle landforms and an extensive associated palaeosandur;
2. an extensive suite of terraces;
3. tributary valley alluvial fans.

All of these features are extremely well exhibited in the reach from the Allt Garbhlach to north of Achlean. The dominant landform assemblage within this reach is the Allt Garbhlach fan and dissected palaeosandur (Figure 9.16). The latter is pitted with kettleholes, between which former braided channel networks can be traced. Partially buried by fan deposits, but projecting above the level of the fan are several kames. The fan deposits have also buried the ice-contact slopes between the sandur and the kame and kettle deposits upstream. The fan was probably built during the later phases of Late Devensian ice-sheet deglaciation about 13,000 BP (Robertson-Rintoul, 1986a).

Within this area lying some metres below the level of the 13,000 BP pitted outwash terrace, there is a group of three low-level terraces. The highest of the terraces, dated by soil stratigraphic methods at 10,000 BP, is about 5 m above present river level (Robertson-Rintoul, 1986b). The middle terrace, about 3 m above the present river, has been dated to 3600 BP; the lowest terrace, about 1.5 m above the present river, has been dated to approximately 1,000 BP. All of the more extensive terrace fragments possess well developed, braided palaeochannel networks on the terrace surfaces. A fifth terrace (late 19th century) is not represented within this site.

In this reach north of the Allt Garbhlach, discharges of the prior River Feshie around 13,000 BP were about 520% higher than present discharges. This earlier river was also considerably more braided and had much higher sediment transport rates than those of the present river. The 3,600 BP terrace surface was formed by a river which had discharges 100–120% greater than those of today (Robertson-Rintoul, 1986a). Again the stream was more braided and probably had higher rates of sediment transport than the present-day river. Discharges for the 1000 BP channel were about 8–34% higher than the present-day mean annual flood (estimated at 70–80 $m^3 s^{-1}$).

The river terraces in Glen Feshie are the product of temporal changes in the balance between fluvial transport capacity and sediment supply. The patterns of runoff and sediment production have fluctuated throughout the Holocene in response to climatic change and vegetational disturbance. This has resulted in at least five phases of incision within the main valley floor since 13,000 BP, locally these phases being accompanied by aggradation.

Allt Lorgaidh fan

In the upper braided reach of the River Feshie (*c.* NN 847917 to NN 845937), where the valley floor is almost 0.7 km wide, the terrace fragments become laterally very extensive. The high dissected palaeosandur is not represented in this reach, and the terraces comprise the three low-level late Holocene surfaces discussed above. At the upstream end of the upper braided reach is the tributary valley of the Allt Lorgaidh, which terminates in a complex alluvial fan. This fan probably owes its dimensions to debris provided by meltwaters from a tongue of the Gaick ice-cap which descended into Glen Feshie during the Loch Lomond Readvance (Sissons, 1974b). The eastern side of this fan comprises three units which correlate with the three low-level Holocene terraces in the upper braided reach. On the western side of the Allt Lorgaidh stream the low angle fan has been subjected to cut-and-fill processes. Local trenching of the fan by the

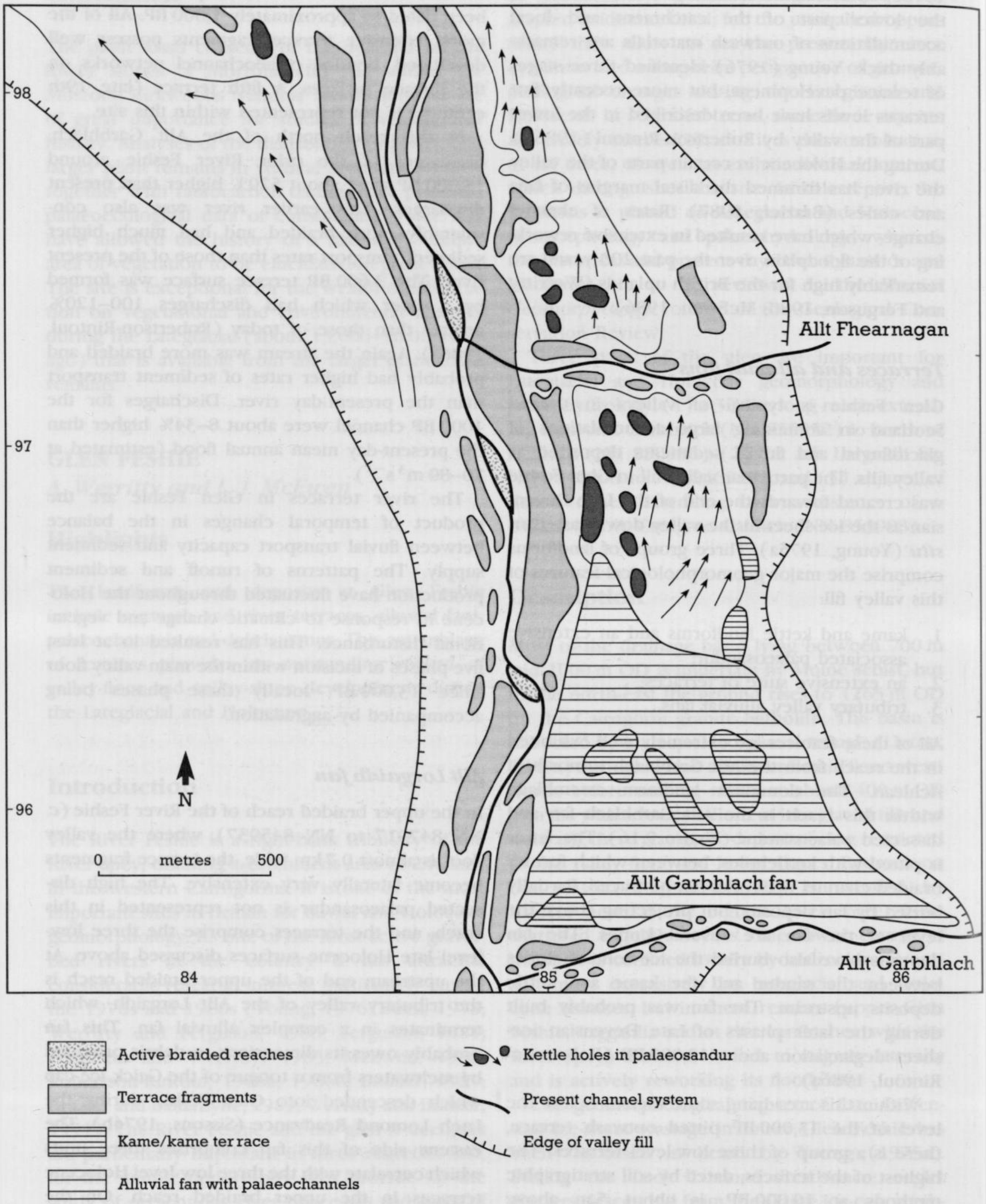


Figure 9.16 Geomorphology of the Allt Garbhlach–Allt Fhearnagan area of Glen Feshie (from Robertson-Rintoul, 1986a; Werritty and Brazier, 1991).

stream has exposed a buried podsol for which a radiocarbon date of 3620 ± 50 BP (Har–4535) has been obtained on charcoal found in the organic-rich layer. This podsol is buried beneath fluvial gravels which comprise the present upper surface of the fan, the latter forming the upper terrace surface in the tributary valley. The buried soil is traceable for some distance upstream in the Allt Lorgaidh and occurs in exposures on both banks of the tributary valley. The date of 3600 BP thus gives an approximate age for the initiation of a phase of late Holocene sediment aggradation in the tributary valley.

In the area of confluence between the River Feshie and River Spey the present alluvial fan is actively reworking a small part of a much larger fan formed during the Lateglacial. On this larger palaeofan a dendritic palaeochannel network can be identified from aerial photographs.

Glen Feshie debris cones

Three coalescing debris cones have built out from the steep gullied walls of the glacial trough in upper Glen Feshie at a mean altitude of 390 m OD. These gullies are cut into the Moine schist of Creag na Caillich from which sediment has been readily supplied into a set of coalescing cones. Basal erosion of these cones by the River Feshie has resulted in the exposure of an extensive section over 60 m long and in places up to 10 m high (Figure 9.17). The exposure consists almost entirely of coarse debris-flow deposits, with poorly sorted and dominantly angular clasts embedded in a coarse sandy matrix. The deposits extend down to the level of the river, with the exception of the northernmost cone which has buried a low river terrace. Stratification is largely absent, although when the section was freshly exposed in 1984 there were linear discontinuities that marked the boundaries between individual debris-flow units (Brazier, 1987). The flow units revealed comprise broad sheets of debris up to 1 m in thickness, which contrasts with open hillslope flows where the forms are narrower and delimited by levées (see the Cairngorms).

Radiocarbon dating of organic material (mainly woody roots) has been undertaken at four of the cones (Figure 9.17) in order to establish the timing of debris cone initiation and the subsequent periodicity in debris-flow activity at the site (Brazier and Ballantyne, 1989). The oldest age of 2090 ± 50 BP (SRR–2877) is from the base of the centre of cone 3. The other dates (320 ± 50 BP (SRR–2880) to 'modern' (SRR–2873, SRR–2874, SRR–2875 and SRR–2879) are too similar to permit any meaningful analysis of the periodicity of debris flows on the cones. It is, however, clear that the three upper debris-flow units have been deposited within the last 300 years. A minimum age for the river terrace buried by cone 1 is 270 ± 50 BP (SRR–2881).

Brazier and Ballantyne (1989) concluded that the aggradation of these debris cones in upper Glen Feshie was initiated by approximately 2000 BP. The site may then have remained stable for about 1700 years until, within the last 300 years, rapid and episodic debris-flow aggradation formed the bulk of the deposits visible in the stream-cut exposure.

It is also important to note the relationship between river undercutting and the source of the debris-flow sediments. The abundance of palaeochannels and the well-defined terraces preserved on the valley floor opposite the cones indicates that the formerly braided River Feshie has repeatedly migrated across the valley floor episodically reworking this area of the valley fill. Prior to 2000 BP the river may have eroded earlier slope deposits at the site currently occupied by the debris cones. Thus the stratigraphy of the present cones only provides evidence for debris-cone activity at this site for a maximum timespan of 2000 years (Brazier, 1987).

Debris flows and cones are a characteristic feature of the Holocene geomorphology of upland Britain (see Eas na Broige and the Cairngorms; Harvey *et al.*, 1981; Innes, 1983b, 1989; Ballantyne, 1986d; Brazier, 1987; Brazier *et al.*, 1988) and recent debris-flow events in these areas have all been triggered by heavy rainstorms (Common, 1954a; Baird and Lewis, 1957; Harvey, 1986; Carling, 1987; Jenkins *et al.*, 1988). Brazier and Ballantyne (1989) considered three possible hypotheses to explain the episodic nature of the Glen Feshie features and the marked increase in activity within the last few hundred years. First, as suggested by Innes (1983b), they may relate to changes in estate management practices and the introduction of systematic burning or overgrazing. Second, they may relate to secular climatic change and the known incidence of increased storminess during the period *c.* 2950–2250 BP and the Little Ice Age of the 16th–19th centuries. Third, they may be controlled by the dynamics of the River Feshie, debris cone formation occurring only when the river followed a course on the opposite side of its floodplain. Brazier and

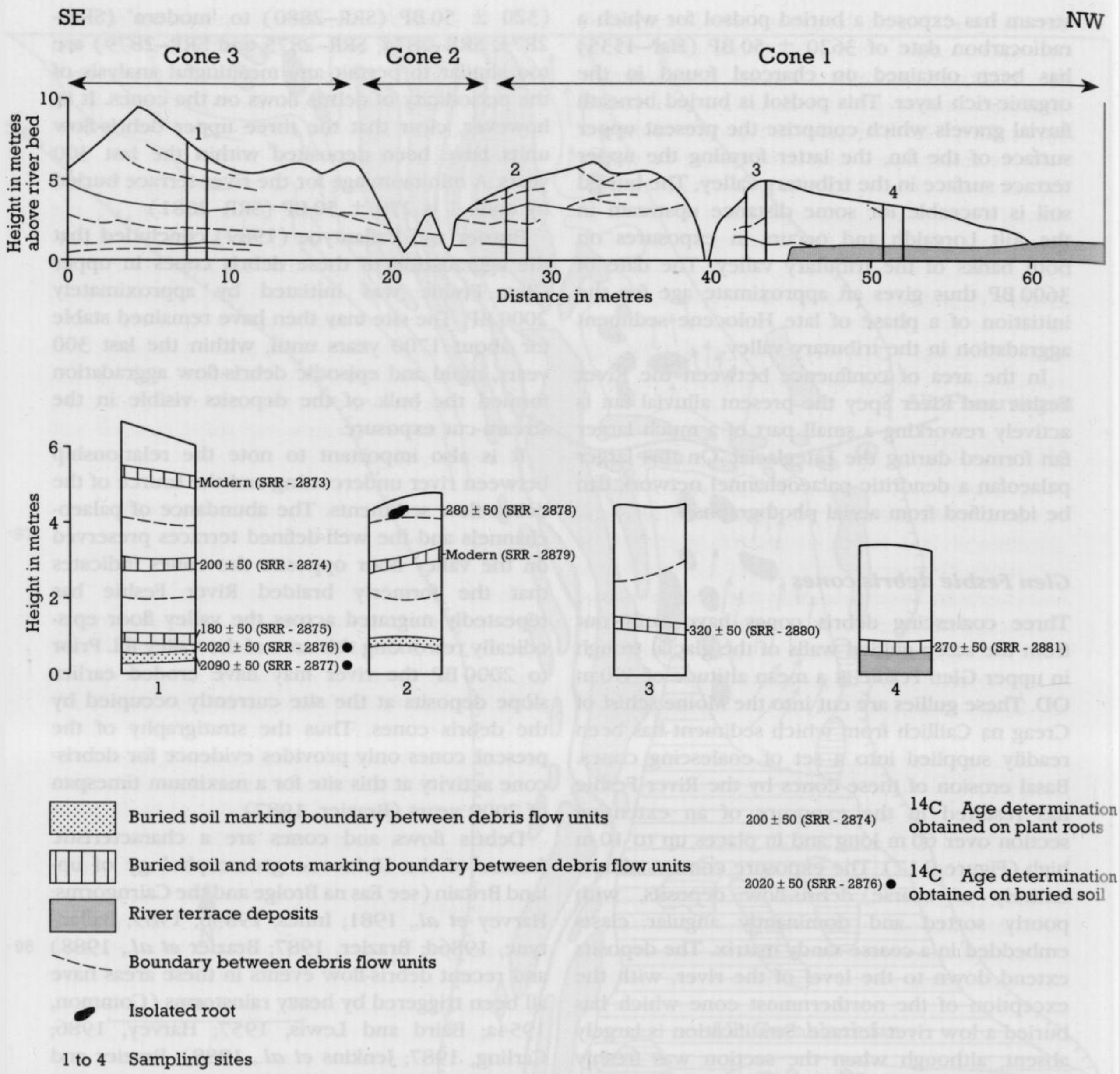


Figure 9.17 Top: surveyed section across the base of the Glen Feshie debris cones showing boundaries between individual debris-flow units. Bottom: detailed sections at sampling sites 1–4 (from Brazier and Ballantyne, 1989).

Ballantyne rejected the first hypothesis partly because the very steep and rocky nature of the source area would probably have precluded systematic forest clearance, and partly because of the absence of charcoal fragments in the sediments. Although the general coincidence in timing of debris-flow activity and known periods of climatic instability was notable, direct relationships were likely to be modulated by other variables. The major control was therefore attributed to the lateral migration of the river channel, although exceptional rainstorms were still required to trigger individual debris flows or periods of increased debris-flow activity.

In relating the Glen Feshie debris cones to natural processes, Brazier and Ballantyne (1989) also highlighted the contrast with debris cones elsewhere where anthropogenic effects had been significant in cone development (see Eas na Broige; Harvey *et al.*, 1981; Innes, 1983b; Brazier *et al.*, 1988). In terms of their more recent activity, the Glen Feshie cones also offer a further contrast with Eas na Broige, where the important control on debris cone formation is exercised by the inherited sediment supply. The geomorphological importance of debris-flow processes in upper Glen Feshie is indicated by the volume of material transported, which, when averaged over the last 300 years, represents an annual accumulation of about 50–60 m^3.

Interpretation

The geomorphological features in Glen Feshie described above are significant in a number of respects.

1. They provide a particularly good assemblage of fluvial and slope landforms and deposits, encompassing outwash and river terraces, alluvial fans, braided palaeochannels and debris cones.
2. Together these features provide one of the most detailed records of valley-floor development in Scotland during the Lateglacial and Holocene. Following deglaciation during the Late Devensian a pitted sandur surface was formed, inset within which a series of alluvial terraces developed during the Holocene. Large alluvial fans formed on the main valley floor at the confluence with tributary valleys. These formed in response to episodic release of large quantities of sediment from the steeper tributary streams. At other sites where slope processes have constructed debris cones directly on to low terraces and the adjacent floodplain, substantial debris-flow activity is reported over the last 300 years. Within the same time-scale, in response to a flashy runoff regime and a steep slope, the River Feshie has extensively reworked its valley floor in three major reaches.
3. The geomorphological and stratigraphic record provides a firm basis for setting the present-day river processes and geomorphological changes into a longer-term perspective.
4. The landforms and deposits in Glen Feshie demonstrate with remarkable clarity the complex nature of the coupling of slope and channel processes in the Scottish uplands and the highly episodic nature of fan and debris cone development.

Conclusion

Glen Feshie is outstanding for an assemblage of landforms and deposits that record the processes and patterns of valley-floor and valley-slope development during Lateglacial and Holocene times (approximately the last 13,000 years). Not only are the individual features particularly well developed, but also the total assemblage is one of the best of its kind in Scotland for the range of evidence provided and the detail of the record. This record is also fundamental to an understanding of the evolution of the present River Feshie, which is a key site for studies of active river processes.