THE CAIRNGORMS

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OS Grid Reference: NJ000000

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 (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).

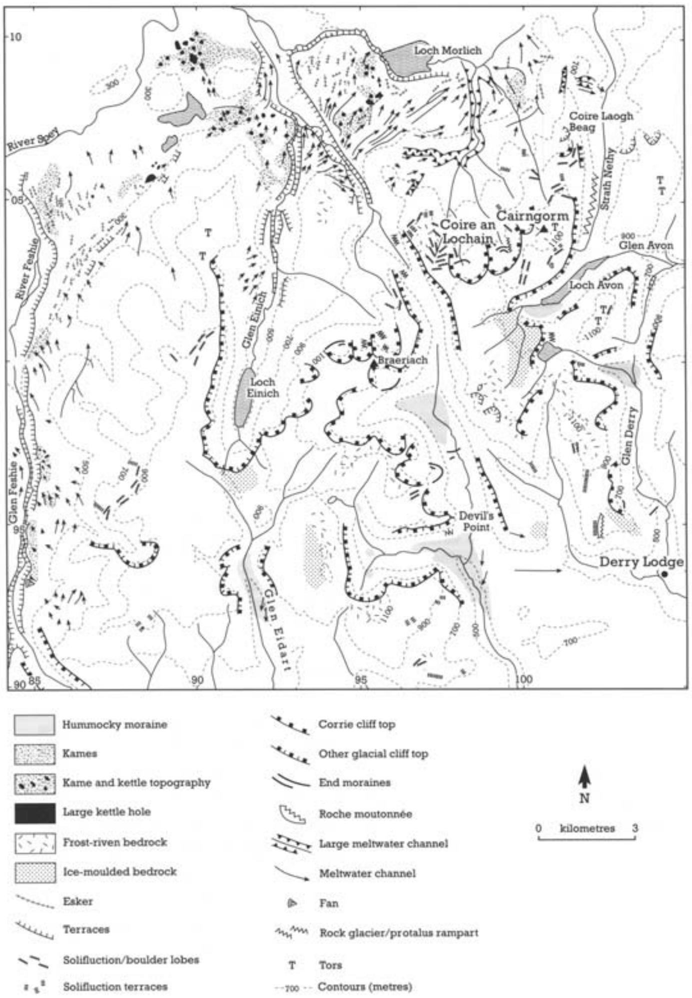

Figure 9.2: Principal geomorphological features of the Cairngorm Mountains (sources include Sugden, 1968, 1970; Young, 1974, 1975a; Sissons, 1979f; J.E. Gordon, unpublished data).

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 M¢r – 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 ofthe 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 location in relation to ice moving from the south-west.

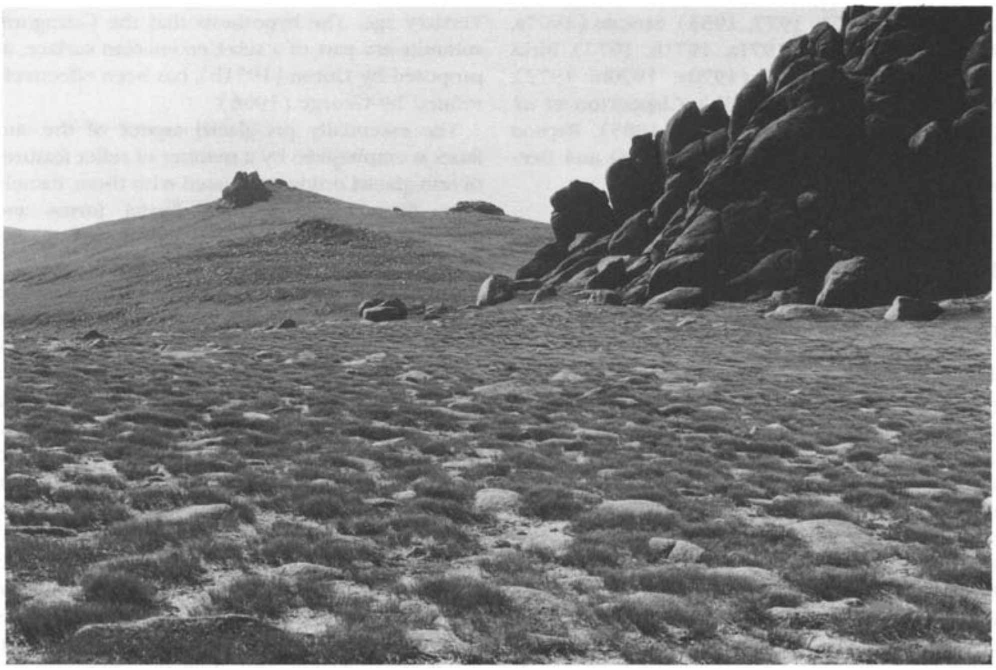

Figure 9.3: Summit plateau of Ben Avon in the Cairngorms showing well-developed tors which appear to have survived glaciation. The adjacent slopes have been affected by periglacial processes and the development of solifluction lobes. (Photo: J. E. Gordon.)

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 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 Mh¢r, 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 Mh¢r 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 steams 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 (Figure9.2). 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 "schrundline' 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 ofthe 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.

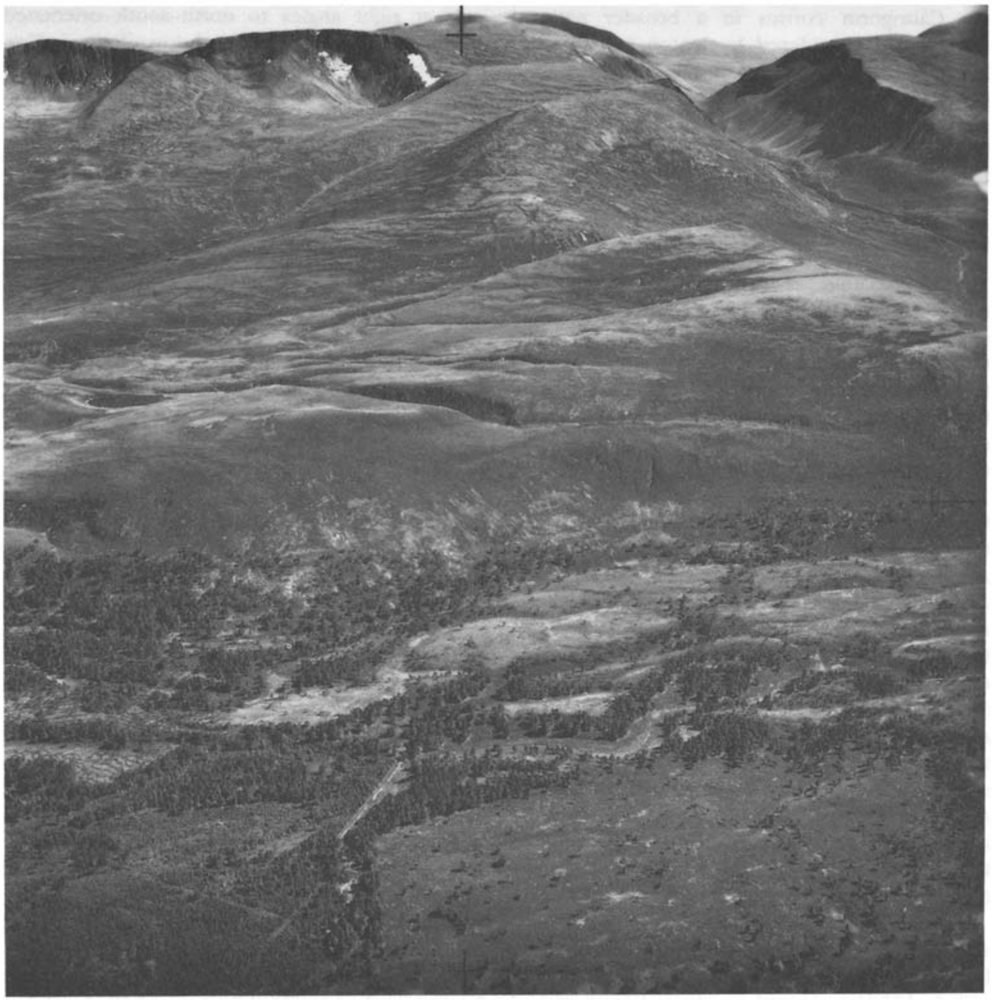

Figure 9.4: Glen More and the northern flank of the Cairngorms. The assemblage of landforms in this area includes the Cairngorm Plateau and adjacent slopes extensively modified by solifluction lobes and terraces (Lurchers Gully – top centre), corries cut into the upper slopes of the massif, the striking 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.)

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 ofthe 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 M¢r (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 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 Glenmore 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 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 Loch Lomond Stadial, 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 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.

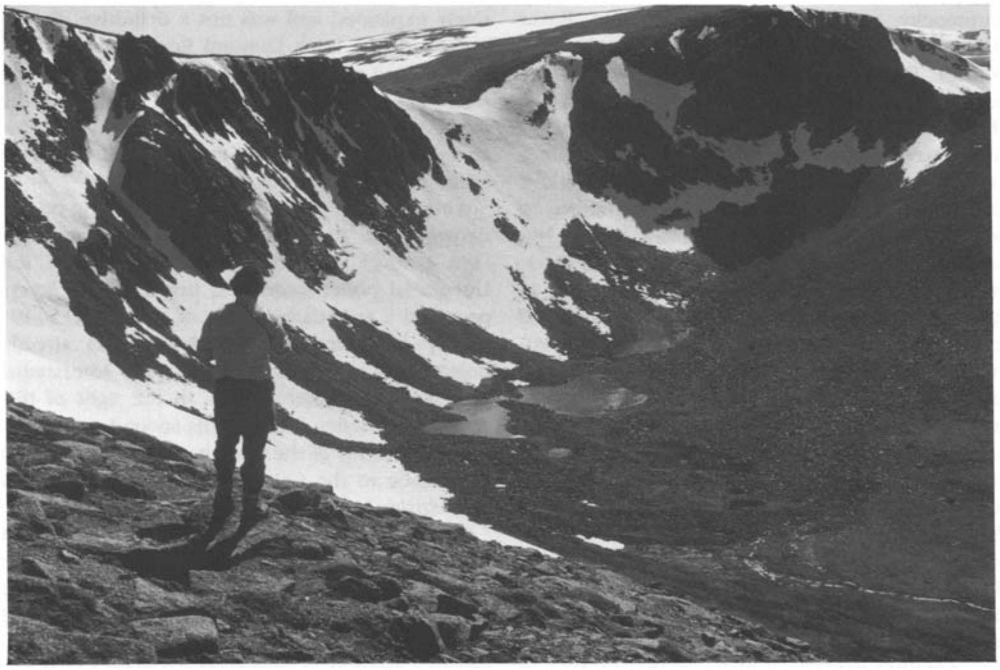

Figure 9.5: Loch Lomond Readvance boulder moraine in Coire an t-Sneachda in the Cairngorms. The outer part of the moraine comprises several clearly defined ridges of boulders. (Photo: J. E. Gordon.)

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.)

Multiple end moraines or boulder limits 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 ofthe 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 (seeBeinn 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 M¢r. 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 M¢r (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 M¢r (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 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 M¢r where the ski access road has been washed away several times in recent years (Sugden and Ward, 1980; McEwen and Werritty, 1988).

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

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 M¢r (NN 894973) and on Ben Macdui (NH 981004, NH 991012); stone stripes occur on Carn Bàn M¢r, 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 M¢r, 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 M¢r and Carn M¢r (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 M¢r, the former site of Jean's Hut, Sgòr M¢r, Coire Laogh M¢r, 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 Sub-boreal) 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 (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 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 M¢r. 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 whichthe 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 principle interest lies in the diversity they lend to the geomorphology of the Cairngorms.

Glacial diversions of drainage are particularly well demonstrated inthe 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 moraines. 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 (see below). 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 below).

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 M¢r, 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.

Conclusions

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.

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