Ben Hee, Highland

[NC 430 343]

D. Jarman and S. Lukas

Introduction

Ben Hee provides one of the best examples in Britain of Holocene rock slope failure activity within a corrie, and is one of the largest such cases. It also clearly represents the arrested translational slide mode of failure which predominates in the Scottish mountains. The failure complex has several components of rock slope failure arrested at different stages of development, which suggest progression of activity both downslope and laterally along the corrie headwall. Unusually extensive deposits in the corrie floor below may represent material reworked from failure in a previous interglacial period. The concept of rock slope failure as a major factor in glacial/paraglacial erosion over repeated cycles is in its infancy (Evans, 1997; Ballantyne, 2002a; Jarman, 2002), and Ben Hee offers a testbed for research into its scale and mode of operation.

The rock slope failure has encroached substantially into the headwall of the corrie, and further activity will lead to breaching into the adjacent corrie and dissection of the mountain block. Viewed in conjunction with neighbouring slope failures, Ben Hee affords an excellent illustration of the role of large-scale mass movement in initiating, enlarging, and then eliminating corrie-type landforms.

Description

Ben Hee (873 m) is a large mountain in northern Scotland separated from the Reay Forest massif by a glacial breach, and standing above the glacially modelled Caithness–Sutherland intermediate surface (Figure 2.51). An Gorm-choire is a large corrie that has operated, latterly at least, as a true glacial 'cirque', its sub-parallel sides reflecting structural controls rather than evolution as a glacial trough head. The corrie is approximately 1 km wide and 2 km long, and faces ESE. Its south flank is a 200 m-high crag, its north flank is a gullied and embayed scree-slope, and below its low headwall (2–15 m high) is a large landslip complex (Figure 2.52). This has three components laterally, unified by a continuous source trench that splits the smooth, broad ridge between the two summits. At the south corner, a small shallow wedge has dropped in several slices by 6 m, and encroaches into the broad ridge by 30 m; below it, a small disintegrated debris-mass clings to the headwall. At the north end, a similar small segment lowers the skyline by virtue of daylighting behind the crest, leaving a 5 m-deep hollow. The flanking rock buttress is crazed with tension fractures, and coarse, unstable, rockfall deposits below may have formed relatively recently.

In between, the main failed mass itself has three distinct tiers (1, 2 and 3 on (Figure 2.52)) below an obtuse wedge source. This fracture begins at the upper (south) end as narrow 1–2 m-deep trenches, becoming a low angle (20–25°) headscarp which attains 15 m in height at its north end in the col. In the obtuse angle, Tier 1 is a semi-intact slice of summit ridge 200 m long by 50 m wide, which has dropped by 2–4 m; its outer parts have broken away and slipped a little further, forming minor antiscarps. Periglacial blockfields cover its surface and are identical to those found on the summit ridge.

Below this uppermost sector of recognizable provenance, the one major antiscarp of the rock slope failure crosses the full width of the main slip, typically less than 2 m high, but locally attaining 4 m. Its crest is about 15 m lower than the semi-intact surface above. This antiscarp defines the start of Tier 2, which is much the largest, and is a disaggregated mass extending out into the corrie for about 400 m. Its gently sloping upper surface also retains the decimetre-scale blockfield characteristic of the summit ridge, but appears to have a randomized topography (Figure 2.53). However the network of shallow tension hollows and minor (< 2 m) antiscarps is organized along two main axes, down and across corrie. Tier 2 terminates in a steep rampart to the lower corrie, about 50 m high (Figure 2.54), with few signs of rock slope failure apart from minor blockfalls. However its long south flank of even greater height has extensive side-slipping with some antiscarp development. By contrast, its north flank starts as a modest linear dry gully separating the main failed mass from the north component; the dry gully then plunges into the northern bay of the corrie.

Below this rampart, Tier 3 is a terrace of different, grassier character bearing weak signs of rock slope failure with hollows, antiscarplets, and an area of tensional dissection. Its northern part has a series of bold lateral ridges up to 10 m wide and 5 m high, but these are probably tension gashes possibly exploited by fluvial erosion (Figure 2.54). Its southern part extends markedly further out into the corrie floor than the main failed mass above. The toe of this tier rises 30–40 m above the corrie floor, and is sub-arcuate.

The corrie floor is a long, rather narrow trench, with exposed scoured bedrock in its middle reach. Here several 'pods' of fractured but coherent rock have probably been glacially entrained from a rockstep just above. This scoured area at 500 m OD hangs well above Loch a' Ghorm-choire at 330 m, which is outwith the corrie proper. The north side of outer Gorm-choire is occupied by a remarkably smooth bank of sediment consisting of a massive, matrix-supported diamicton that is over-consolidated, shows numerous fissures and contains predominantly sub-angular clasts. It is cut by an 18 m-deep gully. The top surface of this sediment accumulation is traversed by four distinct smooth ridges 0.5–1.0 m high, 1–2 m wide, and up to 600 m long. They emanate from the toe of the rock slope failure, converge, are cut by the gully, and fade out eastwards. A few large glacially transported boulders lie on the sediment bank. The gully contains a small stream emanating from lochans ponded up by this bank in a broad side bay of Gorm-choire.

To the north of Gorm-choire, a broad shoulder of Ben Hee throws out three spurs, which, with their intervening bays, are abruptly truncated on the east by steep cliffs. The north-most spur spawns a medial moraine indicating Devensian ice movement northwards along the east flank of Ben Hee, convergent with ice coming through the breach of Bealach nam Meirleach. Along the truncated east side, the cliffs are deeply fissured, with local toppling failures (Figure 2.51). Coire na Saidhe Duibhe has a remarkable midslope in-dipping open cleft approximately 250 m long and up to 10 m wide and 15 m deep. This heads a zone of fissuring and grabening with some toppling debris. The south flank of the bay is a 20 m crag heading an apparent rock slope failure cavity, with incipient fissuring. Above the great cleft, the slope is stable until a degraded short-travel debris-mass encroaches from a possible 40 m source scarp, which continues down the north-east ridge as a weak lineament defining a further large slope failure increment. This failure zone doubtless provided the large erratic on the spur above the medial moraine.

The breach north-west of Ben Hee (Bealach nam Meirleach) has a striking rock slope failure complex on its opposite flank. Torn vegetation and fresh debris indicate that creep and rockfall are still unusually active. Open fissures above the main rockslide suggest incipient encroachment into the residual summit plateau of Meall a' Chleirich (Figure 2.51).

Geologically, Ben Hee consists of Moine psammites with occasional pelitic schist bands (Johnstone and Mykura, 1989). The dip is rather regular, at 5°–15° to the east/ENE at An Gorm-choire, and a little steeper and to the south-east at the north end. Several prominent joint-sets are seen in the cliffs, and one incliqed at about 25° may control the general slope to the ESE of the Ben Hee plateau.

The smoothness of the summit ridge, with shattered bedrock, 5–10 m deep, mantling most of it, suggests that it has not been vigorously glaciated (i.e. covered by active ice), and may even be a remnant of the pre-glacial land surface (cf. Hall, 1991). A periglacial trim-zone between 680 m and 750 m OD indicates the upper limit of the Late Devensian ice-sheet (Ballantyne *et al.,* 1998b). However, cold-based ice may have extended to higher levels, and also warm-based ice may have extended higher in earlier glaciations (Lukas, 2005).

Holmes (1984) records the main rock slope failure from aerial photographs as covering 0.36 km^2 (actually 0.40 km^2), the east cliff slope failure as 0.04 km^2, and the north-east corrie bay as having three slope failures totalling 0.14 km^2 (actually 0.09 km^2 for the upper and 0.17 km^2 for the lower failure). He gives the Meall a' Chleirich rock slope failure as 0.15 km^2 whereas it is part of a complex extending for over a kilometre and affecting approximately 0.5 km^2.

Interpretation

The main Ben Hee rock slope failure was first described by officers of the British Geological Survey (unpublished field slips, 1913–1926) as 'possibly not truly *in situ* but a whole crag slipped'. They noted 'scree has slipped away from the corrie edge in parallel ridges (leaving) a gully behind it'. Godard (1965) misinterpreted these features as moraines, his Photo 17 showing the neat narrow ridge where the headscarp intersects the north corrie as a '*bourrelet morainique laissé par un petit glacier perché, tardiglaciaire'* (cf. (Figure 2.55)). Haynes (1977b) corrected this, and mapped the compound landslip with its two flank elements.

No geotechnical analysis has been made of Ben Hee. The simplest interpretation of its failure geometry invokes the joint-set dipping at 20°–25° south-east, which can be seen in the summit cliffs, and which forms the main head-scarp plane. A failure plane of approximately 18° is indicated by terrain reconstruction (Figure 2.56), and would just permit arrested translational sliding within the range of residual friction angles in the psammites (Watters, 1972). The tripartite scarp of the main failed mass (including the dry gully on its northern side) suggests an obtuse armchair-source configuration, with travel down the corrie axis plus unconstrained spreading laterally out into the corrie head. This would account for the biaxial features in Tier 2, and the sideslip antiscarps on its steep south flank. A marked north–south joint-set seen in the summit cliffs may have encouraged disaggregation of the failed mass into several large slices, with Tier 1 remaining semi-intact above the traversing antiscarp. In Tier 2, these slices may be disguised by slumping of the deep weathering overlay into the tension hollows, hence the uncharacteristically random terrain. The small component to the north may have been an integral part of the main failure, comparable to Tier 1, from which Tier 2 has pulled away laterally, although whether at the same time or by later progression is unclear. The small component to the south is structurally separate and must have moved on a different failure plane, albeit sharing the same source fracture.

The extant rock slope failure complex clearly post-dates final deglaciation. Current research (Lukas, 2005; Lukas and Lukas, 2006) indicates that Gorm-choire was filled by a Loch Lomond Stadial glacier. However, the remarkably smooth debris-bank below the failure on the north side of the corrie was described in the unpublished British Geological Survey field slips as 'too regular to be a lateral moraine — ? a drumlin'. Lukas (2005) describes the feature as a stack of sub-glacial till sheets recording various ice-flow directions and possibly a succession of late Quaternary glaciations (Lukas, 2005). Haynes (1977b) noted that the quantity of drift is exceptional, and 'might well suggest that land-slipping has been progressing simultaneously with glaciation over a period, rather than merely just once'. This interpretation hints at the glacial–paraglacial rock slope failure cycling model now becoming recognized (Hall and Jarman, 2004; see Trotternish Escarpment GCR site report, Chapter 6). Similar exceptionally massive drift banks occur in corries on Maoile Lunndaidh in the Western Highlands [NH 140 450] and in Caenlochan [NO 170 765], with traces of rock slope failure in the headwalls. The officers of the British Geological Survey also noted the '3 or 4 ridges on the drift bank trailing like 'tail' from the 'crag' to the WNW', which Haynes (1977b) mapped as five ridges of 'streamlined drift' (Figure 2.54). These are probably sub-glacial flutes, as they are parallel to the palaeo-ice-flow direction indicated by the fabric analyses taken from the sub-glacial till accumulation they are placed on (Lukas, 2005). This might indicate that Gorm-choire had two ice sources, with the separating spur now destroyed by the rock slope failure that overruns them. Haynes (1977b) also observed the 'low hummocks' at the base of the slip. This anomalous lowest Tier 3 of the rock slope failure and the remarkable 'drift bank' merit closer investigation as to whether they stem from earlier episodes of rock slope failure, with differing degrees of glacial reworking.

Landscape evolution

A reasonably constrained reconstruction of the pre-rock slope failure topography is possible (Figure 2.56). With contours extrapolated from both flanks, and with negative and positive pre-and post-rock slope failure relief in balance, it indicates a compound corrie with a large projecting nose on the headwall that has collapsed. The col between the summit and the north-east top has been lowered by up to 35 m as the failure-enlarged corrie has encroached by 80–120 m into the bowl of Garbh-choire Beag on the north. The failed mass may have reached 60 m thick above the slide plane at the former crest; it has spread out to depths reaching 20–40 m at an overall surface angle of only 18°, and has a total volume of 5–10 x 10^6 m^3. This is at least an order of magnitude larger than typical rock slope failures within corries estimated by Holmes (1984) and 2–3 times the size of the Beinn Alligin intra-corrie rock-avalanche.

The idea that rock slope failure may be a contributor to corrie initiation and development has been mooted since Clough (1897). However, only 18% of rock slope failures identified by Holmes (1984) are located within corries (broadly interpreted), most of them minor. It is difficult to point to any extant failure that is clearly seeding a new corrie, which is unsurprising given that the most promising localities have been selected over many glacial cycles. Ben Hee is therefore of exceptional interest in assessing the scale and *modus operandi* of this putative process. Here, it appears likely that the pre-glacial summit plateau of Ben Hee was originally continuous between the two present tops, and that the linking ridge has been lowered and displaced to the north-west by vigorous headward extension of An Gorm-choire, aided by repeated episodes of paraglacial rock slope failure on the favourable structural dip. Further episodes will lower the col to the point where breaching by transfluent ice may become possible, eliminating the corrie and converting Ben Hee into two separate mountains.

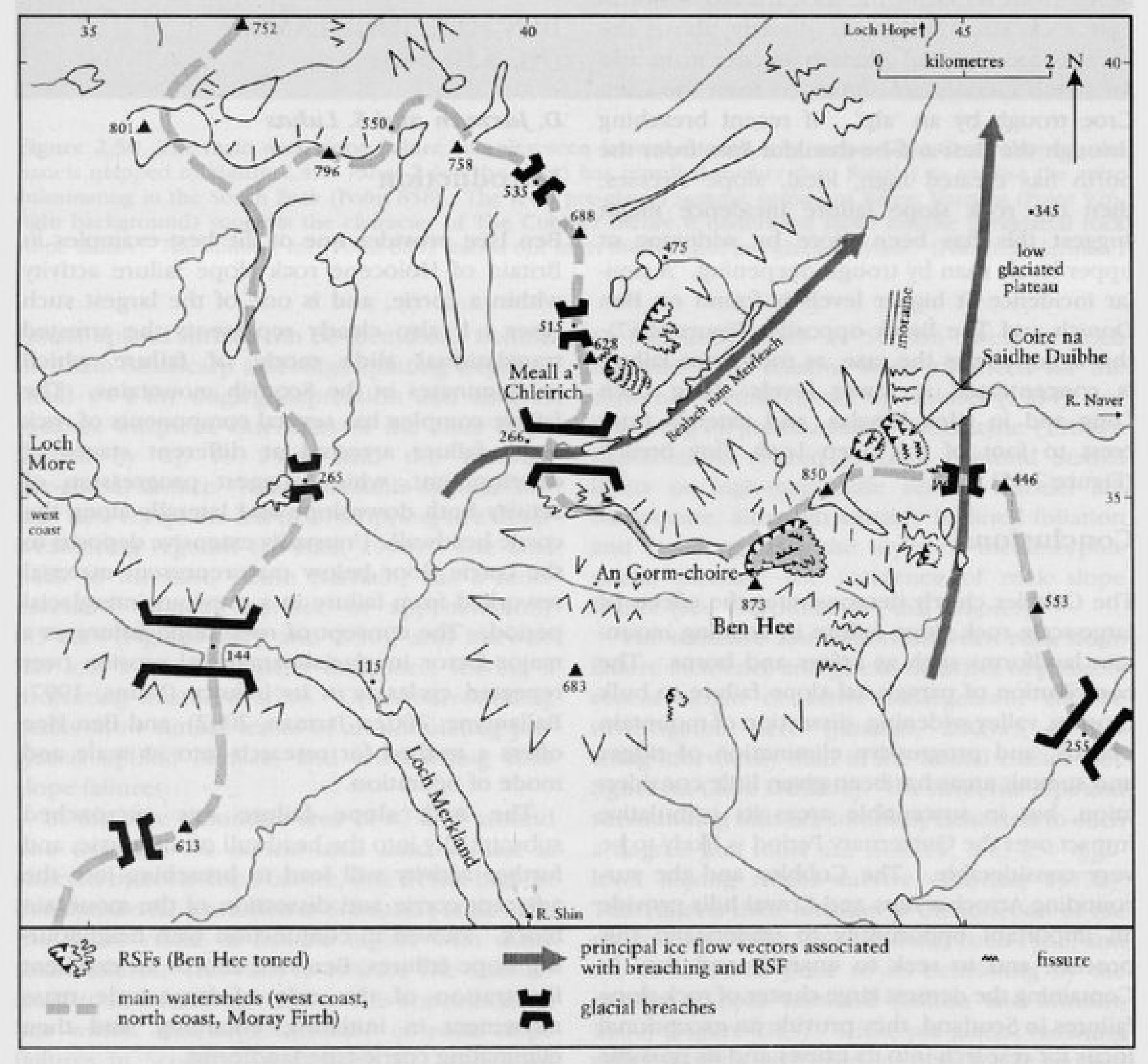
The north-east corrie bay offers an excellent comparator at an earlier stage of evolution, with the deeply fissured lower rock slope failure preparing the way for rapid headwall excavation, and the upper slope failure opening out a broader corrie bowl. The driver for this cluster of corrie-shaping rock slope failures appears to be basal over-steepening of the east flank of the Ben Hee massif by transfluent ice from the upper Loch Shin basin breaching north-east across the Reay Forest–Ben Klibreck divide (Sutherland, 1984). The pattern is repeated in the eastern corries of Ben Hope ([NC 48 49]), which contain Britain's northernmost montane rock slope failure. The relatively narrow breach of Bealach nam Meirleach on the north-west side of Ben Hee has evidently been cut or enlarged in the last main glaciation, to judge from the extensive destabilization and ensuing failure on Meall a' Chleirich.

Conclusions

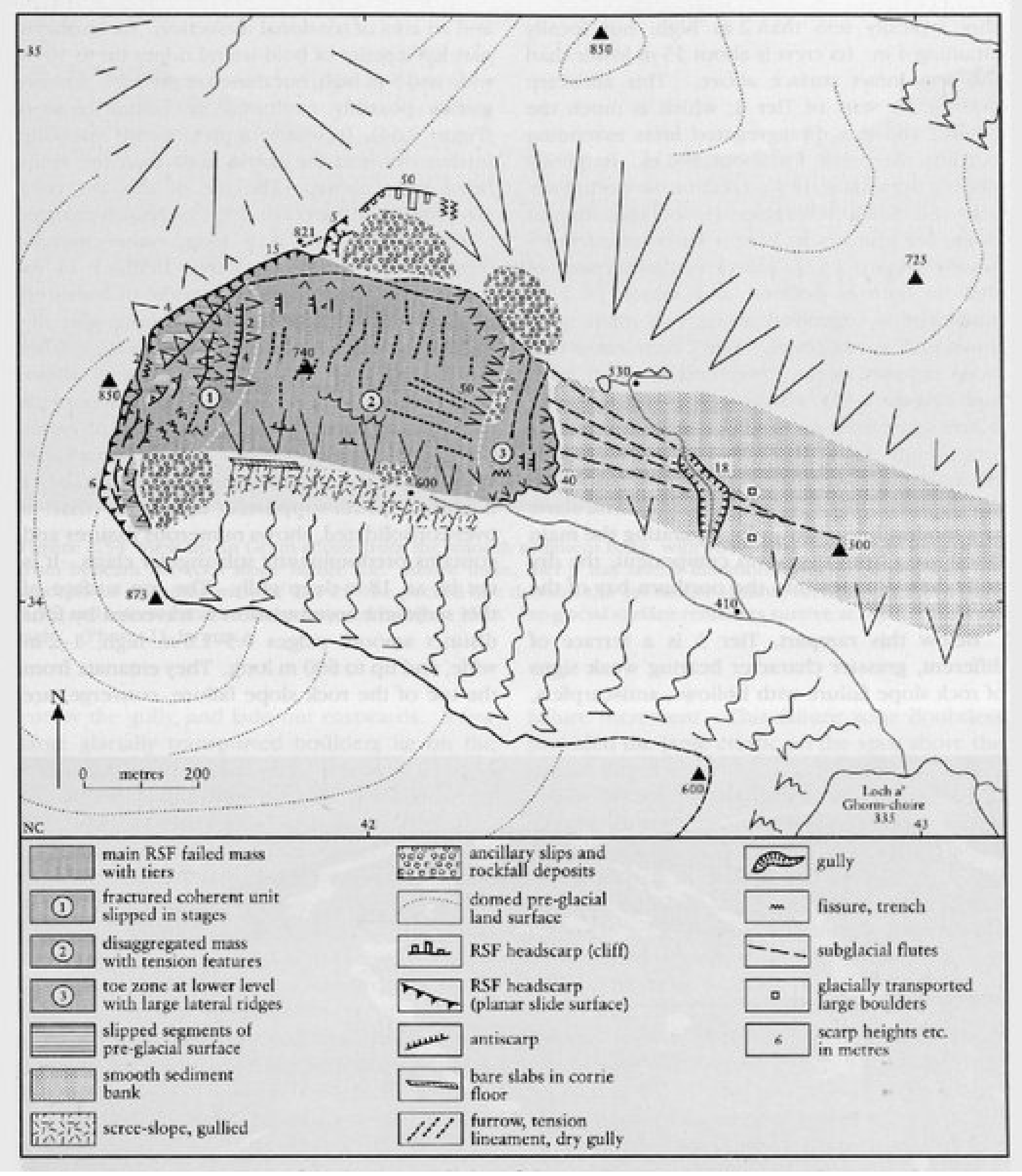
The main Ben Hee rock slope failure is one of the largest and clearest examples to be found in a corrie. It is possible to reconstruct a pre-failure topography that confirms the scale on which such paraglacial mass movements can enlarge a corrie. It is then possible to project forwards a process whereby further rock slope failure increments will eliminate the corrie headwall and pave the way for dissection of the whole mountain block by glacial breaching. The adjacent slope failures on the north-east shoulder and on Meall a' Chleirich afford instructive comparators at different stages of corrie and breach initiation and evolution, including impressive evidence of incipient failure, which appears still to be actively propagating.

Ben Hee is a classic arrested translational slide. There is considerable scope here for detailed investigations into its geometry and mechanics, and into the sequence of rock slope failure activity probably over more than one glacial cycle. Finally, this isolated cluster of slope failures indicates that erosion both by corrie glaciers and by transfluent ice breaching has been sufficiently intense in Late Devensian times to destabilize mountain slopes even in the far north of Scotland.

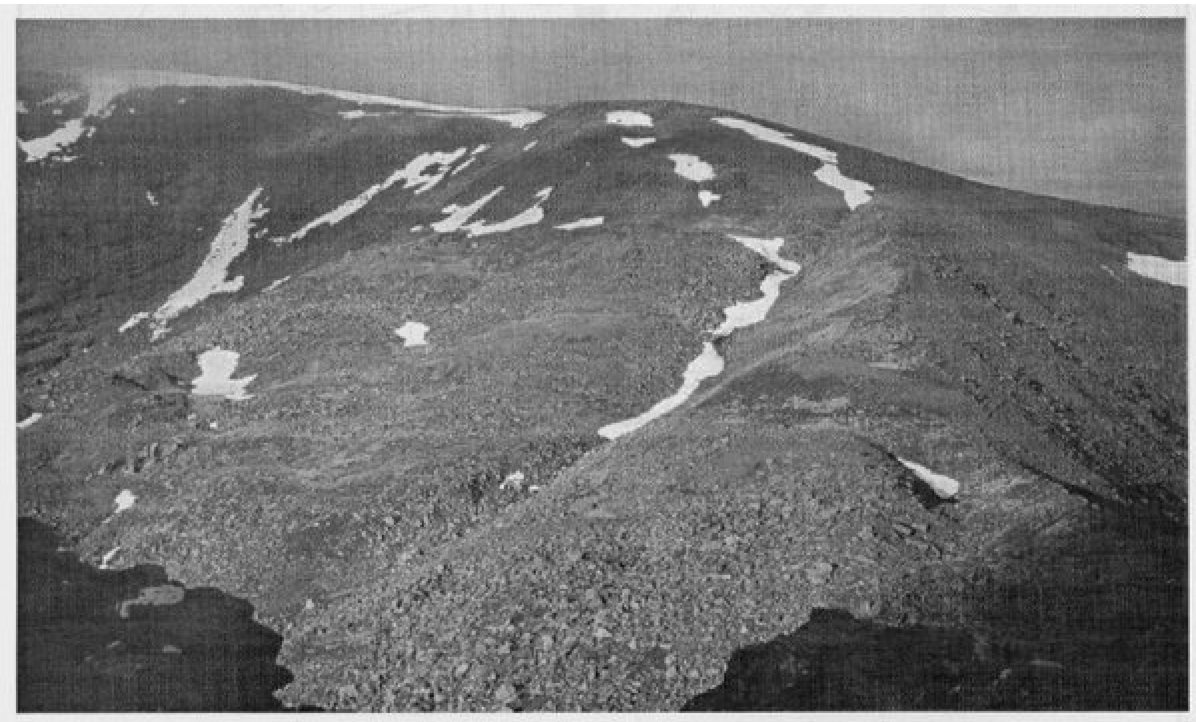
References



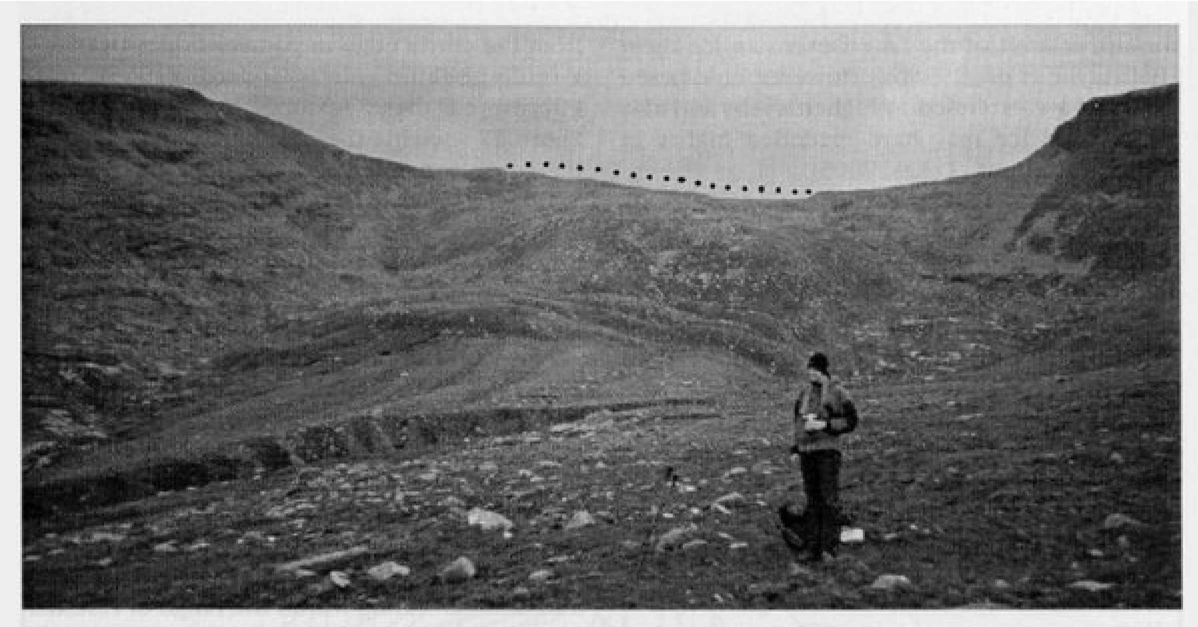
(Figure 2.51) The Ben Hee rock slope failure (RSF) cluster, with glacial breaches and related ice movements.



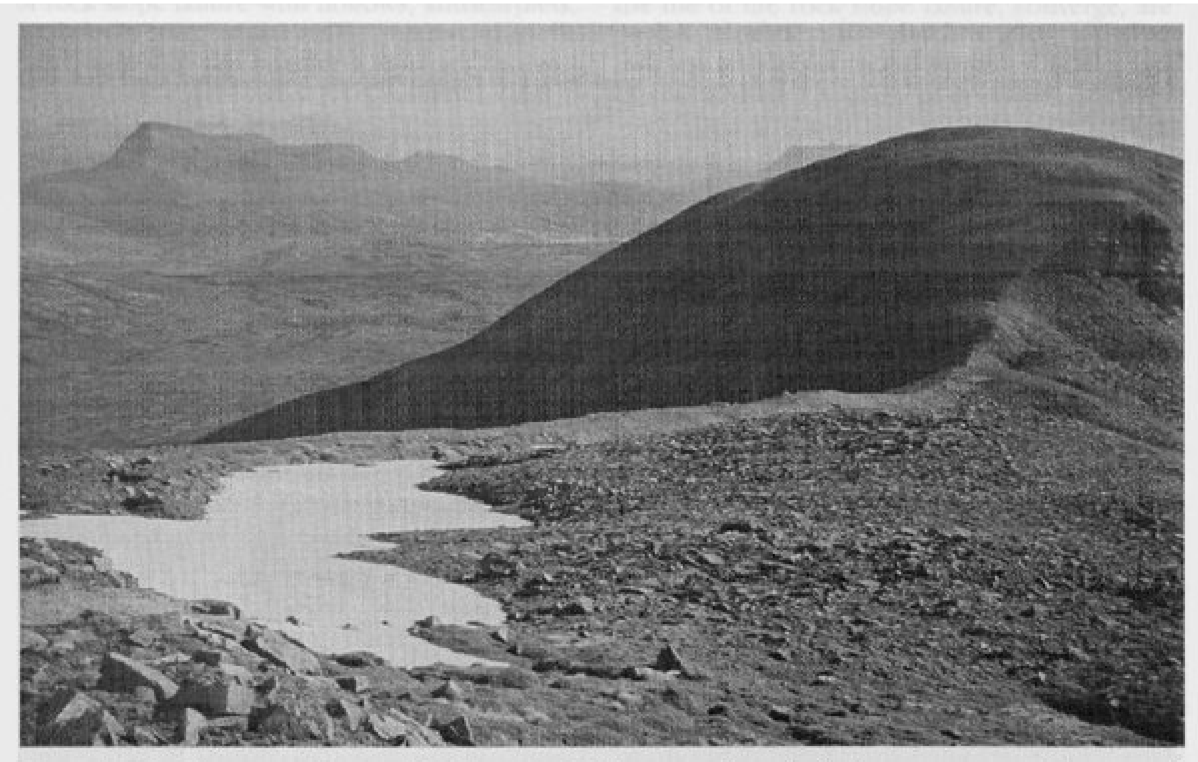
(Figure 2.52) Geomorphology of the Ben Hee rock slope failure (RSF) in An Gorm-choire. The encroachment into the undulating pre-glacial surface is considerably greater than the extent of the 'slipped segments'.



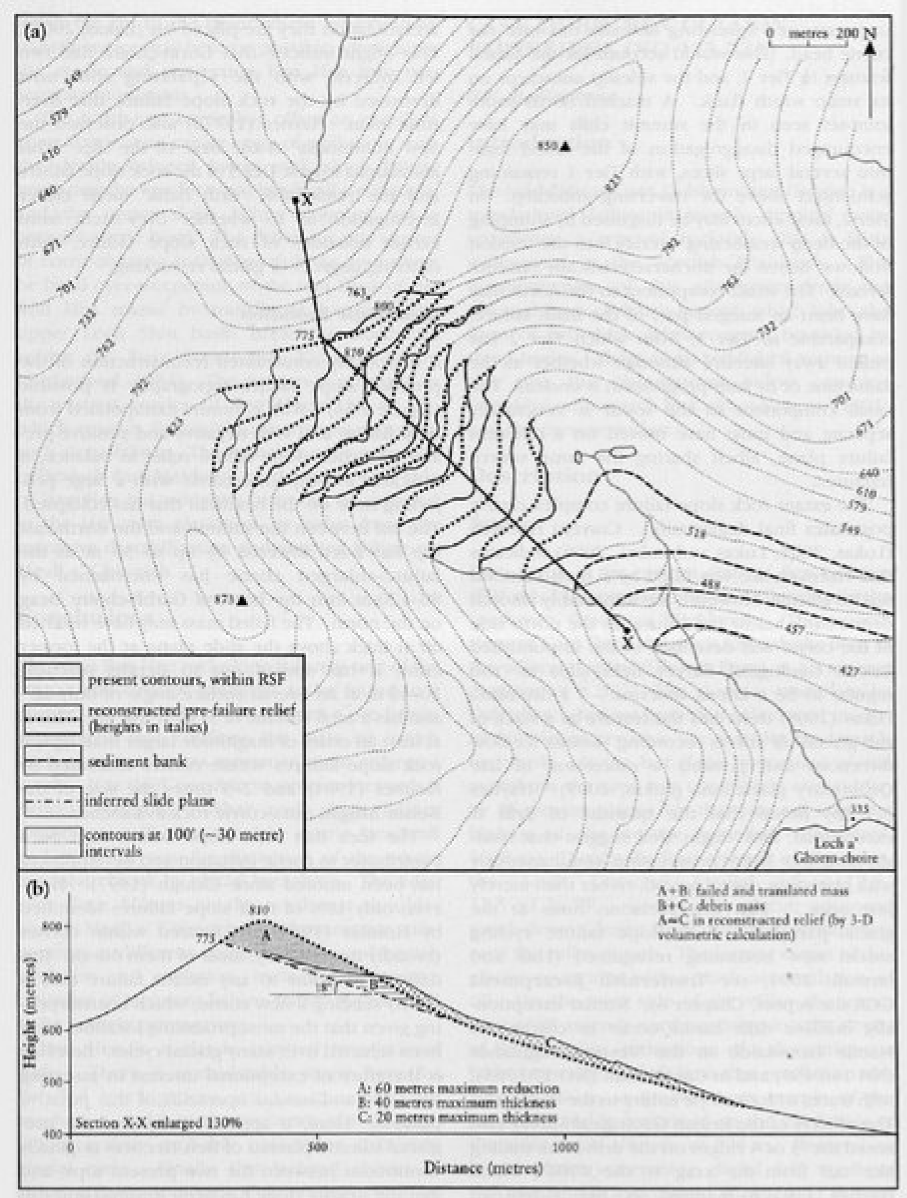
(Figure 2.53) View across Tiers 1 and 2 of the main failed mass, and both flanking increments, from the north rim to the summit of Ben Hee. The reconstructed pre-deglaciation crest follows the axis of the picture, whereas the pre-Quaternary crest probably curved more to the left between gentle domes. (Photo: D. Jarman.)



(Figure 2.54) View up An Gorm-choire from the smooth sediment bank, with sub-glacial flute ridges emanating from beneath the rock slope failure toe. Above them, Tier 3 has lateral lineations which contrast with the amorphous slumping mass of Tier 2. The pecked line denotes the pre-failure skyline, reconstructed in (Figure 2.56), and inferred to have been lowered by up to 35 m. Pre-glacial surface remnants survive at top-left and top-right. (Photo: D. Jarman.)



(Figure 2.55) The source fracture for the main failed mass and north flank component, mis-interpreted by Godard (1965) as a glacial moraine. The slipped segment retains much of its pre-glacial character. (Photo: D. Jarman.)



(Figure 2.56) The reconstructed pre-failure topography of An Gorm-choire, with the long-section of the main rock slope failure showing reduction of the summit ridge by up to 35 m and the scale of mass displacement.