Coire Gabhail, Highland

[NN 166 557]

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Introduction

Of over 500 rock slope failures identified in the Scottish Highlands (Ballantyne, 1986a), relatively few involve total disintegration of the collapsed rock-mass. A double rock-avalanche site in lower Coire Gabhail, Glencoe (Figure 4.2), is of outstanding interest in several respects. First, the initial failed rock-mass completely disintegrated and accumulated as a massive talus cone resting on the valley floor. Second, a smaller talus cone partially overlaps the main cone, suggesting that a later rock-avalanche occurred after the initial failure. Third, the Coire Gabhail rock-avalanche site represents the largest failure on the Devonian volcanic rocks of the Western Highlands. Finally, the rock-avalanche debris has completely blocked the valley, forming a natural sediment trap and causing the accumulation of coarse alluvial deposits upstream (Werritty, 1997).

The larger Coire Gabhail rock-avalanche is also one of only a handful of Scottish rock slope failures to have been dated using cosmogenic isotope dating techniques.

Description

Setting

Coire Gabhail, popularly known as the 'Lost Valley', is a hanging valley on the south side of Glen Coe (Figure 4.2). The valley mouth is flanked by two truncated spurs, Geàrr Aonach (692 m) and Beinn Fhada (811 m). Gently dipping rhyolitic lavas of the Glencoe Volcanic Formation underlie the valley sides, forming steep stepped rockwalls, but the valley axis follows the line of a porphyritic dyke (Bailey and Maufe, 1960; Moore and Kokelaar, 1998). The area was completely over-ridden by westward-moving ice at the last (Late Devensian) glacial maximum (Thorp, 1987).

During the Loch Lomond Stade of *c.* 12.9–11.5 cal. ka BP, Coire Gabhail nourished a tributary valley glacier that fed the Glen Coe glacier; according to Thorp (1981), the surface of the Coire Gabhail glacier descended from 900 m at the head of the valley to about 560 m at the valley mouth. As the rock-avalanche runout debris at this site has not been modified by glacial erosion or transport, failure occurred after retreat of glacier ice at the end of the Loch Lomond Stade.

Failure scars

Two distinct failure scars are evident. Both are developed in flow-laminated rhyolites of the Upper Etive Rhyolite. The larger (south-west) scar comprises a steep 70 m-high backwall that rises above a bedrock ramp to the crest of the slope at 640–650 m (Figure 4.2). It has a maximum (across-slope) width of 150 m and is roughly trapezoidal in planform, with steep, lateral margins defined by near-vertical cliffs. At the foot of the failure scar is a large *(c.* 25 m-high) block of intact rock that has tilted outwards without toppling. A broad bedrock buttress separates the south-west failure site from the smaller failure scar to the north-east.

The latter takes the form of a broad funnel with a steep (50°–60°) basal failure plane, well-defined cuffed margins and a crown of pinnacled rock that extends to the crest of the ridge at 580–620 m. Under both failure sites and the adjacent rockwalls, stacked rhyolitic lava flows dip gently westwards, implying that failure was not seated on flow boundaries. The valley-side face is, however, seamed with vertical and near-vertical cooling and stress-release joints.

Debris accumulation

Most of the rock-avalanche debris has accumulated in two coalescing talus cones (Figure 4.2). The larger (south-west) cone extends from 470–490 m altitude downslope of the larger failure scar to the valley floor at 350–370 m and supports numerous large angular boulders exceeding 5 m in length. The southern part of the cone toe rests on the valley floor and is partly covered by alluvial gravels (Figure 4.2); (Figure 4.3); (Figure 4.4). Directly opposite this cone, numerous large (often > 5 m long) boulders have been thrown by impact on to a drift or bedrock bench on the far (south-east) side of the valley at an altitude of 385–395 m. These boulders extend up to about 30 m above the level of the adjacent valley floor and terminate at the foot of a steep, ice-moulded rockwall. Farther north-east, a jumble of huge angular boulders, many exceeding 1000 m^3 in size, completely fills the valley and abuts the opposite rockwall. Fractures in bedrock near the foot of the opposite rockwall suggest that some boulders impacted the cliff then rebounded. Some of the largest boulders have travelled over 250 m downvalley to an altitude of 300 m. Although most of the cone is mantled by coarse bouldery debris, shallow exposures suggest that fine-grained sediment occupies the interstices between clasts immediately beneath the surface boulder layer. The lower parts of the cone are extensively colonized by birch trees (Figure 4.3).

The smaller (north-west) cone consists of smaller boulders, is largely unvegetated, and presents a much fresher appearance. Unvegetated debris-flow tracks indicate recent reworking of debris. The south-west margin of this cone overlaps the larger cone, implying that this cone represents later (and possibly fairly recent) failure of the rockwall upslope.

The dimensions of the larger cone and associated runout debris were calculated from 1:5000 map data. The total planimetric area of debris cover is *c.* 23 000 m^2. Taking the average gradient of the cone surface (*c.* 33°) into account, this is equivalent to a real surface area of *c.* 27 400 m^2. The average depth of the runout accumulation, calculated by interpolating rockhead contours across the area occupied by runout debris and subtracting a grid of inferred rockhead altitudes from the debris surface altitude, is *c.* 11 m, with a maximum depth near the centre of debris accumulation of *c.* 30 m. Multiplying average depth by planimetric area yields a volume of approximately 300 000 m^3 of debris. Assuming that 20–30% of this volume represents voids, the implied volume of failed rock is 210 000–240 000 m^3, equivalent to a mass of 0.57–0.65 x 10^6 tonnes of rock for an assumed average density of 2.7 tonnes m^{-3}. The volume of the smaller cone could not be calculated, but appears to be about an order of magnitude smaller.

Interpretation

Mode of failure

The configuration of the failure scars suggests that at both failure sites thick slabs of rock failed along steep (50°–65°) basal shear planes bounded laterally by near-vertical rockwalls that represent the sites of stress-relief joints; open, near-vertical joints extend almost the full depth of the failure sites within adjacent intact rock-walls. Failure probably involved both sliding and toppling, leading to disintegration of the rock masses as they cascaded downslope. Travel of huge boulders across the valley floor and up to 250 m down the valley axis indicates that the earlier failure was characterized by extremely high energy; the large talus cone probably represents settlement of rock debris at the angle of residual shear in the final stages of movement. Only a very small component of the later failure reached the valley floor, however, with most debris accumulating in the smaller cone.

The immediate causes of the failures are unknown, but it is notable that the toes of both failure zones experienced debuttressing by retreat of glacial ice at the end of the Loch Lomond Stade, and the open near-vertical joints exposed in adjacent rockwalls imply rock-mass weakening as a result of joint extension due to deglacial stress-release. A zone of NE-trending vertical fractures followed by the Etive dyke swarm may have determined the loci of joint formation at the crown of both failures. The possible role of post-glacial seismic activity in triggering failure is difficult to assess. The larger failure scar lies roughly 1.4 km distant from two major NE-trending faults, the Ossian Fault to the north-west and Queen's Cairn Fault to the south-east, both of which originated during complex synvolcanic cauldron subsidence (Moore and Kokelaar, 1998). Neotectonic displacements due to differential glacio-isostatic adjustment along these or intervening fractures may have triggered failure, though there appears to be no evidence for post-volcanic dislocation.

Age of failure

The surface exposure age of a rock sample from the crest of a very large boulder deposited by the larger and earlier rock-avalanche has been subject to surface exposure dating by ^{36}Cl cosmogenic radionuclide assay. The provisional age obtained for this sample is 1.8 ± 0.33 ka BP, implying that failure occurred at least 9000 years

after final deglaciation. The smaller and younger failure must have occurred after this date, and possibly within the last few centuries, consistent with its much fresher appearance. In common with landslide samples dated to *c.* 6.5 cal. ka BP for The Storr landslide (Ballantyne *et al.,* 1998b; see Trotternish Escarpment GCR site report, Chapter 6) and *c.* 4.0 cal. ka BP for the Beinn Alligin rock-avalanche (Ballantyne and Stone, 2004; see Beinn Alligin GCR site report, Chapter 2), this age determination implies that slope failure due to deglacial unloading and consequent stress-release has persisted well into Holocene times, and potentially may result in future failures from glacially steepened rock slopes in the Scottish Highlands.

Alluvial accumulation

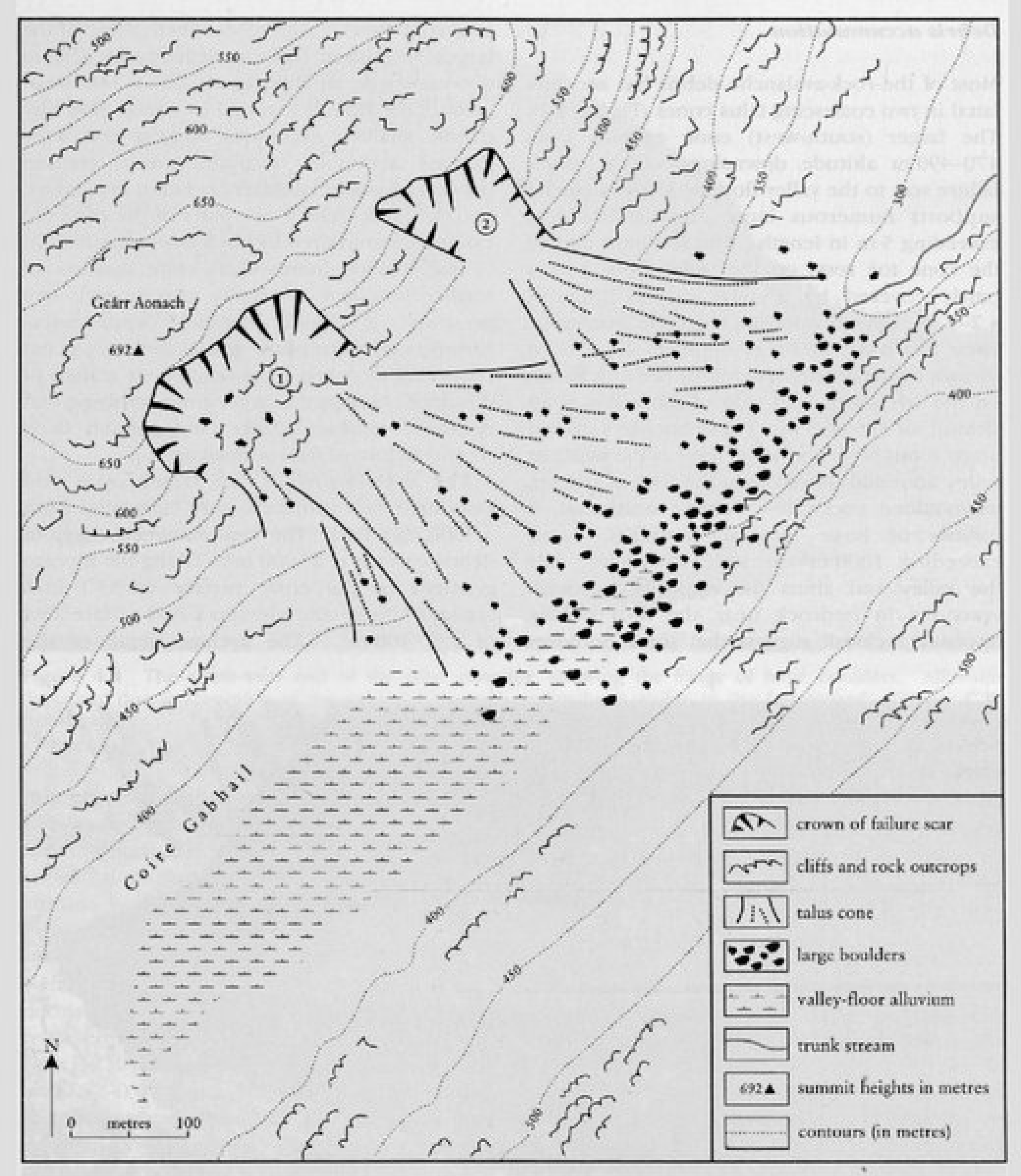
According to Werritty (1997), the alluvial accumulation at Coire Gabhail is unique in Scotland, hence it is also selected as a GCR site for the Fluvial Geomorphology of Scotland GCR 'Block' (Werritty, 1997).

Following blockage of the lower valley by the earlier rock-avalanche, evacuation of coarse bedload sediment has been impeded, allowing progressive accumulation of alluvial gravels upstream. The alluvial basin is approximately 600 m long and 150 m wide, with a concave downvalley profile that is graded to the local base level created by sealing of the valley by landslide debris. The coarseness of surface gravels declines downvalley. The channel pattern is braided, but supports surface flow only following intense or long-duration rainstorms. Under normal flow conditions the river draining the valley (the Allt Coire Gabhail) sinks into the alluval deposits some distance upvalley from the rock-avalanche runout debris, and emerges near the north-east end of the boulder dam.

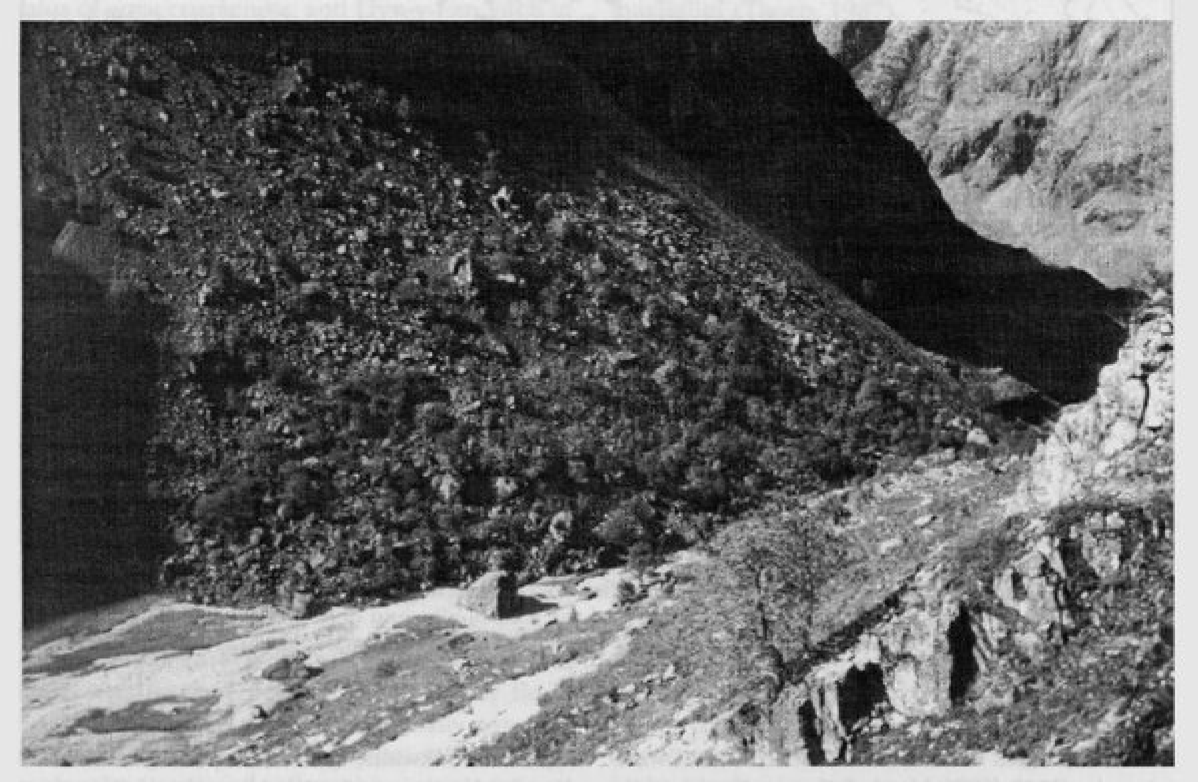
Conclusions

Roughly 1800 years ago, approximately 600 000 tonnes of rock failed near the mouth of Coire Gabhail, a steep-sided hanging valley cut in gently dipping rhyolites. The alignment of joints in the flank scarp of the failure zone suggests that failure was due to progressive joint extension and rock-mass weakening following debuttressing of the face as a result of glacier downwastage at the end of the Loch Lomond Stade, around 11500 years ago. A smaller and apparently later failure occurred about 160 m north-east of the initial failure, depositing boulders as a talus cone on the flank of the debris deposited by the earlier event. This site is important for several reasons. It represents the finest example in Scotland of rock avalanches that have come to rest as massive talus cones, with debris resting at the angle of residual shear (*c.* 33°), though the high energy of the earlier failure drove boulders at least 30 m up the opposite slope and 250 m downvalley. It is also the largest rock slope failure on the Devonian volcanic rocks of the Western Highlands. This is one of the few ancient landslides in Scotland for which dating evidence is available, and the fact that failure occurred at least 9000 years after deglaciation implies that catastrophic failures due to para-glacial (glacially conditioned) stress-release persisted into late Holocene times. Finally, the site is unique in Scotland in that the rock-avalanche runout debris completely blocked the valley mouth, allowing sub-surface drainage through the runout zone but impounding coarse alluvial gravels. The alluvial floodplain that has developed upvalley as a result is without parallel in Scotland, with river runoff sinking into the alluvium near the valley head and emerging down-valley of the landslide runoff debris, except when exceptional flood events permit surface flow.

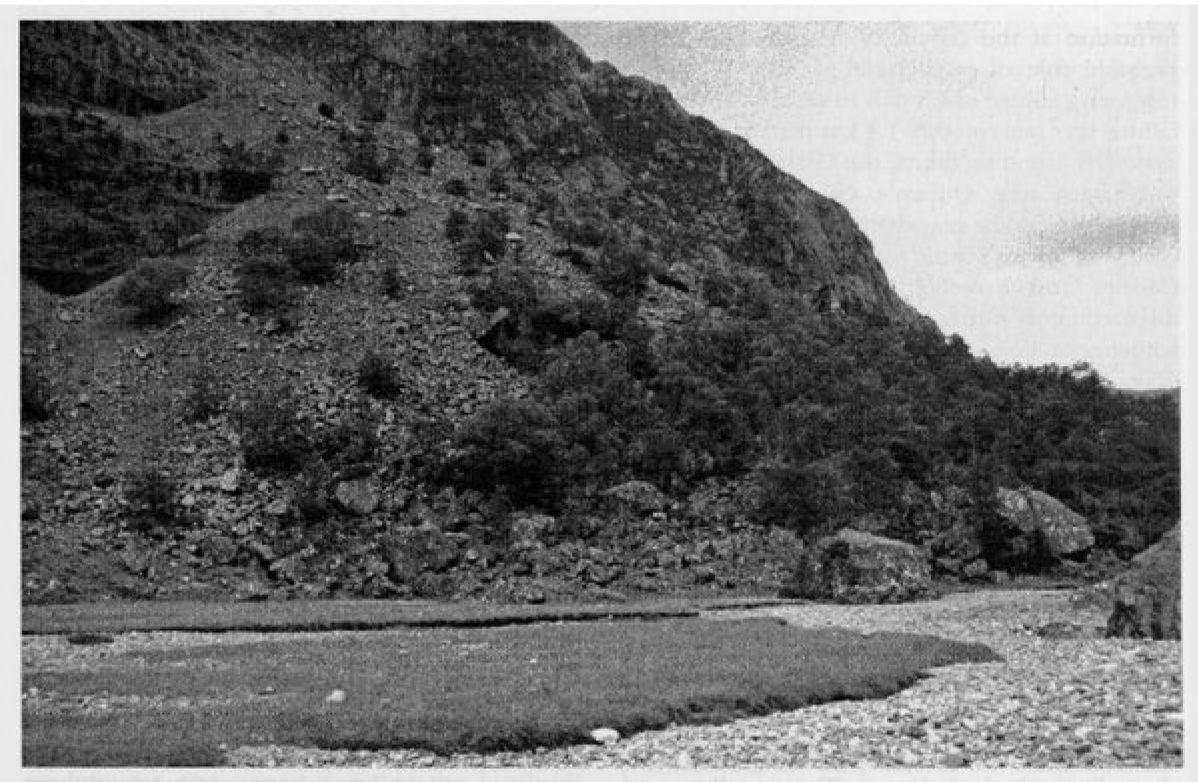
References



(Figure 4.2) Geomorphological map of the Coire Gabhail rock-avalanches, showing the failure sites, the extent of the talus complex representing landslide runout and the area of alluvium deposited in the upper valley as a result of damming of the valley by runout debris. (1) site of initial rock-avalanche; (2) site of later rock-avalanche.



(Figure 4.3) The complex talus accumulation formed by runout of the Coire Gabhail rock-avalanches, viewed from the south-west. The southern (left) edge of the larger talus cone is partly buried under alluvium. The conspicuous large boulder just beyond the toe of the cone rises about 10 m above the alluvium in which it is embedded. (Photo: C.K. Ballantyne.)



(Figure 4.4) The south-west end of the talus complex, showing the fringe of large boulders. Alluvium deposited due to damming of the valley by the rock avalanche is visible in the foreground. (Photo: C.K. Ballantyne.)