Carn Dubh, Ben Gulabin, Perthshire

[NO 113 721]

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Introduction

The landslide at Carn Dubh on Ben Gulabin is a translational failure in steeply dipping meta-sediments, a type of rockslide that is fairly widespread in the Scottish Highlands. The distinctiveness of this site arises from the unusual form of debris runout, which takes the form of two thick debris-tongues bounded by steep levees. There is no published account of this site; the observations below combine unpublished research by Cullum-Kenyon (1991) and the present author.

Description

Setting

Carn Dubh is the eastern spur of Ben Gulabin (806 m), 2 km north of Spittal of Glenshee in the south-east Grampian Highlands. The eastern slope of Carn Dubh descends towards the floor of the adjacent valley (Gleann Beag) at an average gradient of *c.* 33°. The slope is underlain by Dalradian schistose graphitic pelites and quartzites of Neoproterozoic age that dip moderately eastwards. At the last (Late Devensian) glacial maximum the area was completely over-ridden by SE-moving glacier ice that covered even the highest of the nearby summits (Glas Maol, 1068 m). During the final episode of glaciation, the Loch Lomond Stadial of *c.* 12.911.5 cal. ka BP, a small valley glacier advanced south down Gleann Beag, probably terminating near the valley mouth. The former extent of this glacier coincides with a thick accumulation of till. On the west side of the valley the upper limit of till ascends northwards against the slopes of Ben Gulabin in the form of a discontinuous lateral moraine or drift limit that reaches an altitude of 490 m at the southern margin of the landslide, and is continued on the north side of the slide at an altitude of 520 m. Removal or burial of the intervening glacial drift confirms that the landslide occurred after glacier retreat. The failure scar occurs immediately upslope from the site of the former drift limit; and the debris tongues occur mainly downslope from this limit (Figure 2.57).

The failure scar

The failure scar has a roughly trapezoidal plan, but is extensively obscured by bouldery scree (Figure 2.57). Its southern margin is, however, defined by a partly vegetated cliff 10–15 m high, and a rockwall 20–30 m high crops out along the crown of the scar. The southern sidewall reveals a succession of well-jointed quartzites (Creag Leucach Quartzite Formation) in beds 1–4 m thick, interbedded with strongly foliated, weathered phyllitic semipelite and micaceous psammite beds generally less than 1 m thick. The bedding and foliation planes dip eastwards, sub-parallel with the slope at angles of 25° to 43°, forming part of a broad anticline. An exposure at the base of the southern sidewall suggests that rupture occurred (at least locally) along a 0.5 m-thick semipelite unit.

The debris lobes

Two thick tongues of debris extend downslope from the foot of the failure scar, and form the most conspicuous feature of the site (Figure 2.58) and (Figure 2.59). The two are separated just below the failure scar by a bulbous protrusion, probably underlain by bedrock, that split the mobile landslide debris into two separate flows. The top of the protrusion is covered by a wedge of angular bouldery landslide debris up to 7 m thick, formed into three transverse ridges.

The southern debris-tongue extends 320 m downslope from an altitude of 520 m to 415 m. It averages about 70 m in width and stands 3–10 m above the adjacent terrain. The gradient of the tongue declines downslope from 27° to 18°. The lobe margins are sharply defined by steep-sided boulder levees that decline in height downslope to terminate in overlapping ramp-like ridges 1–3 m high. Smaller longitudinal ridges occur inside the outer levees, suggesting that a pulse of flowing sediment occurred after the main body of the flow had stabilized.

The northern debris-tongue extends 380 m downslope from about 525 m to 420 m altitude, declining in gradient downslope from 31° to 15°. It averages about 80 m in width and 5 m in thickness, but is bounded by boulder levees up to 12 m high. Unlike its southern neighbour, it terminates abruptly downslope in a bold arcuate ridge that impounds a thick wedge or plug of debris, but lacks interior longitudinal ridges (Figure 2.58).

Between the outer levees, both tongues are crossed by arcuate transverse boulder ridges 1–3 m high. The central parts of the tongues are extensively vegetated, but numerous large angular boulders, mainly of quartzite, are scattered over the surface, and spreads of quartzite boulders mantle the higher parts of the levees. Sections in the levees occur where an estate track cuts across both debris-tongues (Figure 2.57). These reveal a predominantly clast-supported diamicton in which poorly sorted angular clasts, mainly of quartzite, are embedded in a compact, sandy matrix. Crude inverse grading is evident, with clasts increasing in both concentration and size towards the surface, forming a mantle of large (typically 0.3–2.0 m long) angular boulders. A small number of sub-angular facetted clasts, apparently derived from reworked till, are also exposed in the diamicton.

Topographical survey of the site by Cullum-Kenyon (1991) indicates that the total volume of debris contained in the debris tongues and the debris on the intervening protrusion is *c.* 0.3×10^6 m^3. Assuming an average rock density of 2550 kg m^{-3} and allowing 20% for voids, this figure implies that the mass of failed rock was *c.* 600 000 tonnes. This figure is an upper estimate, as the debris lobes contain an unknown volume of reworked till.

Interpretation

Rock slope failure

Failure at this site took the form of a translational (planar) rockslide seated on quartzite strata that dip eastwards out of the slope at angles averaging around 34°. Tilt tests carried out by Cullum-Kenyon (1991) indicate an angle of plane sliding friction of 51° ± 4° for the quartzite and 36° ± 6° for the phyllite, confirming that rupture almost certainly occurred within the latter. The closeness of the friction angle of the phyllites to the dip of the bedding and foliation planes implies that the slope was in a state of conditional stability following deglaciation. The cause of failure is unknown. Progressive rock slope weakening is likely to have been caused by opening of stress-release joints following deglacial unloading and/or shearing of rock bridges and asperities as a result of rock-mass creep. Failure may ultimately have been triggered by build-up of joint-water pressures or possibly by a seismic event; the Glen Taitneach fault crosses Carn Dubh only 300 m from the crown of the failure scar, and may have been reactivated by differential glacio-isostatic uplift.

Debris flow

The two tongues have the morphological attributes of debris flow (sediment-gravity flow) deposits, namely elongate tongue-shaped plan-forms, steep bouldery lateral levees, near-surface inverse grading and longitudinal and transverse ridges indicative of flow surges (Van Steijn *et al.*, 1988; Coussot and Meunier, 1995; Corominas *et al.,* 1996). Morphologically, they resemble the hillslope debris-flow deposits that cover the lower slopes of many Scottish mountains (Ballantyne, 2002b,c), though the latter are produced by failure and flow within unconsolidated sediments and are generally at least an order of magnitude smaller than the debris tongues below Carn Dubh. Innes (1985), for example, found that 90% of hillslope flows in the Scottish Highlands have transported less than 60 m^3 of sediment, though large flows fed by gully systems may carry over 1000 m^3 of debris (Brazier and Ballantyne, 1989).

There are two competing models of flow movement. Some channelled flows move as Bingham flows, with a rigid plug of debris being transported by laminar shear of an underlying and surrounding mixture of sediment and water (Johnson and Rodine, 1984). Movement of most Scottish hillslope flows, however, appears to be dominated by cohesionless grainflow, in which momentum is maintained by inertial collisions, with boulders attaining partial buoyancy in a mobile mass of mud (Takahashi, 1981; Blikra and Nemec, 1998). The dispersive stresses implied by the latter mechanism account for movement of the coarsest debris to the top and sides of the flow, as observed in the sections cut through the levees of Carn Dubh debris-tongues.

Irrespective of the nature of movement, the flow of coarse debris below the Carn Dubh rock-slide implies a drastic reduction in viscosity. As the lower limit of the slide plane and the upper limit of the debris tongues co-incide approximately with the upper limit of thick till, it is tempting to relate the onset of flow to undrained loading of saturated till by cascading rock that raised porewater pressures in the till until the over-burden weight was transferred to the fluid, leading to liquifaction (Hutchinson and Bhandari, 1971; Bovis and Dagg, 1992). The alternative explanation appears to be that the high initial energy of the slide was sufficient to generate inertial grainflow or fragmental flow, partially buoyant in a mixture of expelled water, crushed phyllitic semipelite and possibly entrained till.

It is instructive to compare the characteristics of the Carn Dubh rockslide and debris-tongues with those of a rockslide in Gleann na Guiserein, Knoydart ([NG 774 057]; Bennett and Langridge, 1990), where planar sliding of psammitic meta-sediments over steeply dipping slabs resulted in the formation of a debris tongue very similar to those at Carn Dubh. The Guiserein tongue is approximately 440 m long, narrows downslope from 105 m to 40 m and is bounded by steep levees up to 10 m high. The adjacent slopes are underlain by bedrock with localized thin soil cover, implying that here the debris tongue developed without deformation of underlying sediment, and thus solely as a result of fragmentation and flow of rock debris. Ballantyne (1992) inferred that the Guiserein debris-tongue formed through inertial grainflow or fragmental flow, probably aided by reduction in effective normal stresses due to the presence of mud and water. Similarly, formation of the Carn Dubh debris-lobes may also have occurred independently of till cover downslope of the failure zone.

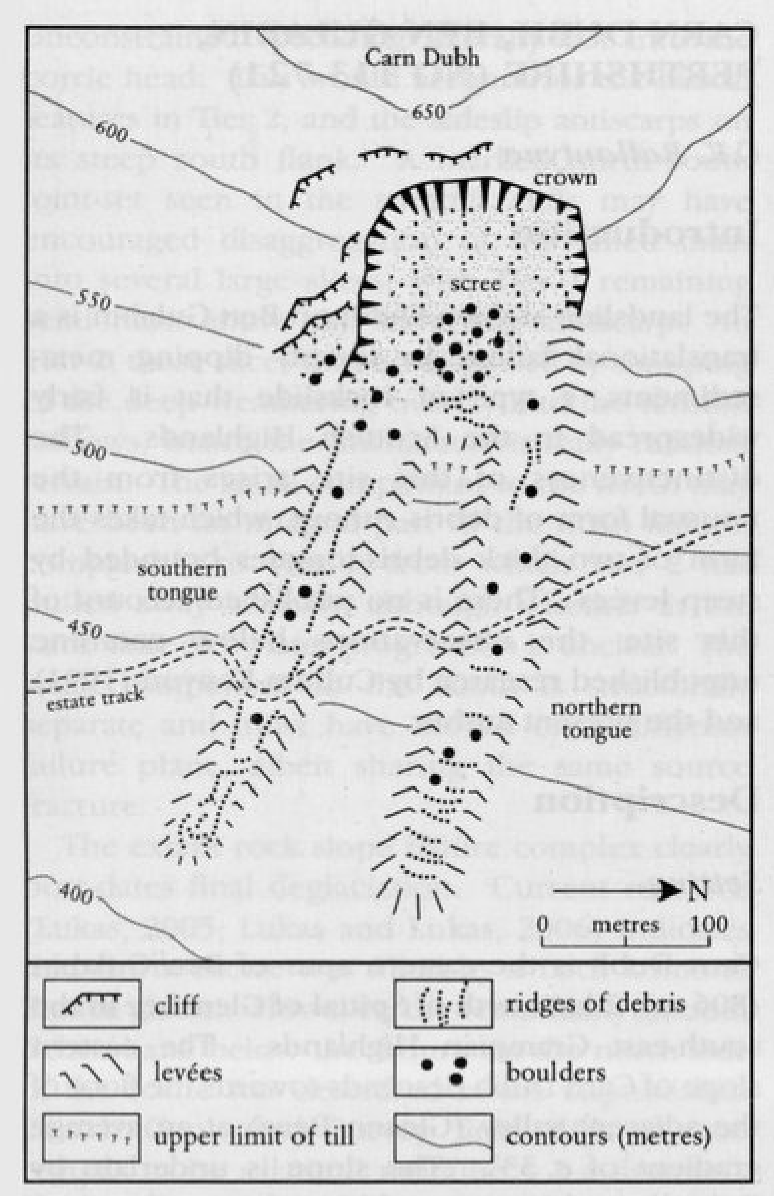
Flow of debris following rock slope failure is poorly documented in Scotland. An extreme example occurs at Beinn Alligin, where sliding of nearly 9 x 10^6 tonnes of rock along a steep (42°) failure plane resulted in movement of very coarse debris over a distance of 1.2 km along a corrie floor. Other sites occur along the Trotternish Escarpment on Skye, (Ballantyne, 1991a) and on the scarp face of the Lomond Hills in Fife (Ballantyne and Eckford, 1984) and below the basalt scarp of the Campsie Fells north of Glasgow (Evans and Hansom, 1998, 2003). None of these, however, have produced the elongate debris-tongues bounded by massive levees that characterize the Carn Dubh rockslide.

Conclusions

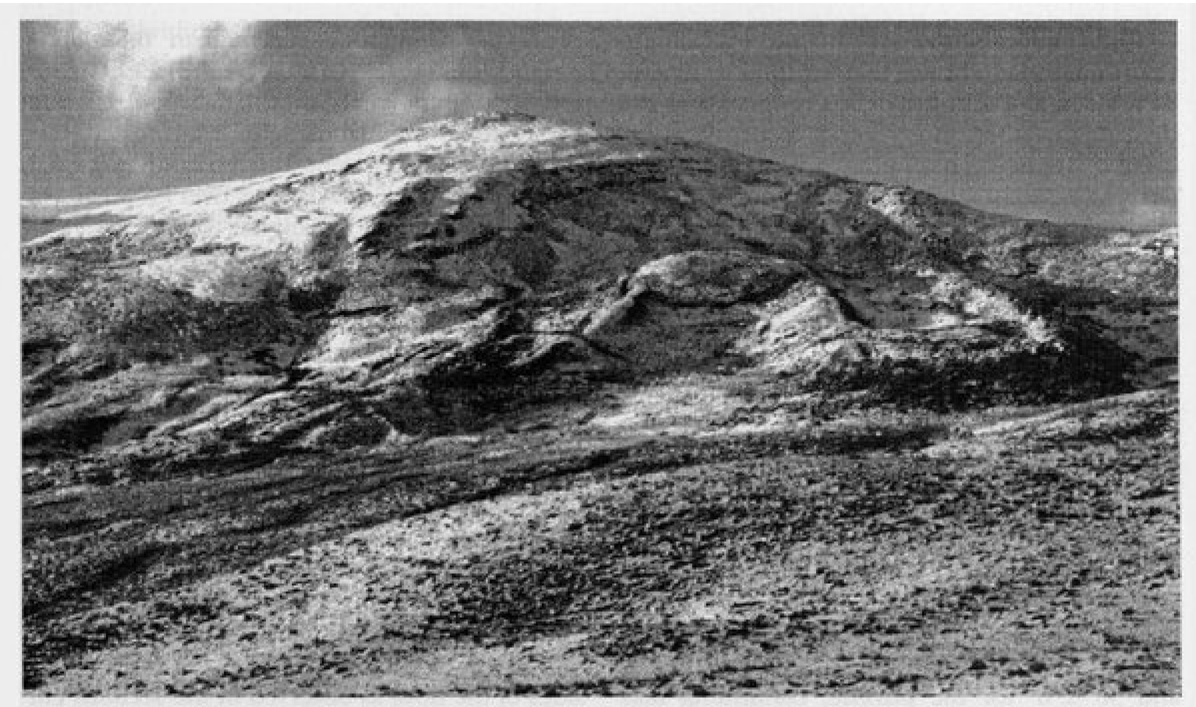
Sometime after the final deglaciation of Gleann Beag some 11 500–12 000 years ago, up to 600 000 tonnes of rock below Carn Dubh failed by sliding of interbedded quartzites and semipelites along bedding planes that dip towards the valley at angles of around 34°. Rupture occurred in the phyllites, which were probably weakened by post-glacial stress-release, though the failure trigger may have been high water-pressure or a seismic shock generated by reactivation of the nearby Gleann Taitneach fault.

The Carn Dubh landslide on Ben Gulabin represents an outstanding example of a rock slope failure where runout involved viscous flow, producing thick elongate debris-tongues that extended downslope from the foot of the failure scar. This phenomenon is very rare on the metamorphic rocks that underlie most of the Scottish Highlands; only two other examples are documented. Fragmentation and flow of mobile rockslide debris around a central protrusion resulted in the deposition of two thick debris-tongues, 320 m and 380 m long, flanked by massive bouldery levees up to 12 m high. These thick debris-tongues resemble those produced by hillslope debris-flows, but are an order of magnitude larger. Movement of the boulders in the debris tongues probably took the form of inertial grainflow sustained by the momentum of colliding boulders, with coarse debris partially buoyant in mobile mud. The degree to which movement was aided by loading and liquifaction of underlying glacial deposits is uncertain, though comparison with a similar site in Knoydart suggests that formation of massive debris-lobes such as those below the Carn Dubh rockslide was not dependent on deformation of underlying sediments. The internal composition of the massive flow-tongues suggests that flow generated by the momentum of the initial rockslide involved a mixture of expelled water, crushed phyllites, quartzite boulders and a subsidiary component of entrained till. Debris flow at this site was probably aided by focusing of runout debris around the central protrusion and runout on to initially steep gradients.

References



(Figure 2.57) Map of the Carn Dubh rockslide scar and debris tongues, Ben Gulabin.



(Figure 2.58) The Carn Dubh rockslide scar and debris tongues on Ben Gulabin. The southern debris tongue (left) peters out in low ridges and levees of vegetation-covered debris, whereas the northern tongue terminates in a bold bluff 5 m high. The inner levees of both lobes terminate upslope at the conspicuous bulbous protrusion that diverted flow of rockslide debris into two tongues. (Photo: C.K. Ballantyne.)

(Figure 2.59) The Carn Dubh rockslide, Ben Gulabin, from above. (Photo: D. Jarman.)