Sgurr na Ciste Duibhe, Highland

[NG 988 143]

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Introduction

Sgurr na Ciste Duibhe (1027 m) is one of the Five Sisters of Kintail in the Western Highlands. It is the clearest case of rock slope failure controlled by a basement fault. It has been advanced — with insufficient justification — as evidence for high-magnitude seismic events following the last deglaciation (Fenton, 1992). Its summit area has been lowered by about 10 m as a result of creep or slippage, and is the most striking example in Britain of this kind of paraglacial landscape modification. It also demonstrates classic rock slope failure features including ridge-top depressions and arêtes. The deformation progresses downslope into a sliding failure of unusual geometry, which probably reaches the floor of Glen Shiel; if so, this is the greatest vertical extent of rock slope failure in Britain at almost 1000 m, approaching alpine scale.

This is one of the 20 largest rock slope failures in the Highlands, and is within one of the densest clusters situated in the Glen Shiel–Affric area (Figure 2.18). While this cluster may have neotectonic associations, it is also within an area of anomalously low valley interconnectivity (Haynes, 1977a) and may point to relatively recent breaching of the main watershed by transfluent ice (Jarman, 2003b). Sgurr na Ciste Duibhe stands directly above the gorge of the River Shiel at the probable locus of the breach (Linton, 1949).

Description

The mountain ridge on the north side of Glen Shiel is continuous above 725 m OD for 13 km, one of the longest in Scotland, and matched by that on the south side. For 1 km, the ridge is dislocated by the intersection of the Glen Shiel Fault-swarm with the crest of Sgurr na Ciste Duibhe (Figure 2.23); (Figure 2.24); (Figure 2.25). The main fault passes 100 m behind the summit, where a 10 m red rock step on the north-east spur is prominent on the skyline (Point 985). The fault then crosses the ridge 300 m east of the summit, interrupting it with a 15 m crag (Point 935). Between these incidents, the fault is expressed as an arête across a small corrie head, partly smooth but partly fretted, and trapping two dry depressions (Figure 2.26). West of the red rock step, the scarp diminishes to 1 m before returning at right angles to the summit ridge. The fault trace, however, continues WNW, impounding small ribbon pools before recrossing the ridge; to the ESE the trace descends gradually into Glen Shiel. In all it is distinct for 5 km (Fenton, 1992).

The summit area is a coarse blockfield (Zone B, (Figure 2.23)), more disrupted than is usual for such periglaciated terrain; a 2 m-deep hole beside the trig point indicates tension, as does a 3 m x 3 m trench across the ridge to the west. Antiscarps up to 5 m high have developed along parallel members of the fault-swarm on both sides of the crest.

To the south-east of the summit, an area 250 m by 150 m is dislocated by a striking series of antiscarps up to 3 m high on two steep diagonals, with large tension fissures in between (Zone D, (Figure 2.27)). The uphill face of this mass presents a ragged cliff 8–14 m high to a graben-like depression, out of which decreasingly coherent debris has moved to the south-east, with a springline at its foot (Zone E2). The downhill face of this dislocated area is a crag reaching 15 m high, so close below the lowest antiscarp that in places there remains a rock parapet only 4 m wide. This crag is the top part of an approximately 60 m-high source scarp to the main sliding failure. The slide cavity (Coire Caol–Zone E1) is contained by prominent sub-parallel scarps 300 m apart, orientated NNW–SSE at 45° to the fall-line. The cavity reaches 50–80 m deep by contour extrapolation, with the scarp on its east being considerably higher than that on the west, and stepped and embayed with signs of incipient retreat above. In the head of the cavity a large monolithic failed mass remains, presenting an antiscarp up to 8 m high to its source; its surface is convex and subdued, with distinct decimetric antiscarplets and furrows. Below this, the main cavity is not fully evacuated: its floor also has antiscarplets, and a substantial stream sinks beneath it. Beyond the confines of the cavity, a very degraded debris-lobe descends at least to springs at 300 m OD, and probably to 200 m OD.

On the west side of this slide cavity, a broad midslope convexity has distinct indicators of tensional failure in its upper parts, including a 5 m-deep fissure, and some minor antiscarps (zone F). At its head at 650 m OD, the cavity scarp breaks back as an 11 m-high rockface with slickensiding on its smooth surfaces (Gordon, pers. comm.). The lowest part of this convexity forms a bluff protruding into Glen Shiel to form a local gorge with anomalous local topography; it has an absence of rock outcrops or surface wetness, but displays no positive indicators of failure. In its lee to the west, a broad embay-ment beneath the convexity has a series of debris ridges with pronounced uphill faces, reaching 3 m high, which however are not typical anti-scarps. To the west again, a steep open slope extends almost unbroken from summit to valley floor, lacking surface-water drainage and the broken crags typical of the lower glen. Several springs rise near the slope foot, but when observed with the River Shiel in spate, their flows were modest and adjacent gullies remained dry.

Fenton (1992) includes all of these areas within the rock slope failure boundary, giving a possible maximum area of 1.9 km^2. Holmes (1984) identified only a limited area of 0.14 km^2 near the summit, as does the 1:50 000 geological map. The failure certainly extends over at least 0.95 km^2 including the in-situ summit ridge deformation, and probably over at least 1.25 km^2 (Jarman, 2003b). The volume of the main cavity is of the order of 5–10 x 10^6 m^3. Efforts to assess the overall volume of the rock slope failure would be very difficult; suffice it to say that it appears deep-seated, with Fenton (1991) estimating a depth in excess of 50 m.

The bedrock consists of Neoproterozoic age Moine psammites and subsidiary semipelites of the Morar Group; the bedding and main foliation in the rocks dips at 50°–75° to the east or southeast. It is probably co-incidental that this rock slope failure is developed in stratigraphically equivalent rocks to those underlying the Beinn Fhada failure. No detailed structural analysis has been made, but Fenton (1991) suggests fractures dipping south more steeply than the slope at about 45°. Fluid alteration has occurred along the near-vertical Glen Shiel Fault, giving rise to a weak band of oxidized and degraded rock: this is visible as an eroded trench and may have aided mass slippage.

Interpretation

This complex rock slope failure demonstrates a clear progression from in-situ deformation along the ridge west of the summit, through spreading, creep, and embryonic sliding failure in the summit area and upper slopes, to sub-cataclasmic failure of a large segment of the midslope.

The configuration of the whole complex is unusual in being orientated up to 90° away from the fall-line trend of the glen wall. This suggests, as at Beinn Fhada nearby, that joint-sets conducive to translational sliding are not well developed here. Indeed, analyses of 12 sites north-west of the Great Glen by Watters (1972) and Holmes (1984) suggest that both schistosity surface and principal joint planes are commonly inclined above 60°, by contrast with the South-west Highlands (e.g. The Cobbler).

Here four structural components can be identified. The Glen Shiel Fault is clearly the backing scarp for the whole rock slope failure; Fenton (1992) describes it as the 'headscarp', but movement is as much along it as down it. Secondly, the schistosity strikes orthogonally to the fault, and provides the return scarp and internal step-down scarps to the failed summit mass. Thirdly, the parallel members of the fault-swarm have allowed graben-type spreading and subsidence of the summit mass and short-travel sliding to the south-east. Some elements of these parallel faults appear to have been displaced south as part of a broader slope spreading. Fourthly, the main slide cavity is controlled by a north-west–south-east joint-set that may be cognate with the main joint-set identified at Beinn Fhada.

It is inferred from the 10 m height of the red rock step on the north-east spur that the summit of Sgurr na Ciste Duibhe has been lowered by 8–10 m (Figure 2.25). Although the return scarp to the north-west is only 1 m high, the step scarps within the disrupted blockfield make up the difference. Such lowering of a major summit by paraglacial rock slope failure would be unique in Scotland: close parallels occur at Carn na Con Dhu near Glen Affric [NH 07 24] and Beinn Bhreac by Loch Lomond [NN 32 00] where large sections of summit plateau have subsided. The area affected by lowering here extends 100 m north-east and north-west of the summit, and 200 m to the south-east, one of the most substantial encroachments into a mountain ridge by rock slope failure in Britain.

Equally remarkable is the failed mass south-east of the summit, which is semi-intact rather than disrupted, but is carved up by curving antiscarps on alignments discordant with the general structure (Figure 2.27). These suggest that the mass has begun to move by basal creep plus forward toppling, with both compressional antiscarps (Fenton, 1991) and tension fissures. Poised above the main rock slope failure cavity and with only limited lateral restraint, this mass may be only marginally stable. Analogous failed masses occur at Ben Lawers [NN 63 41] and Ben Vorlich by Loch Lomond [NN 29 12]. Their survival may indicate a long-term lack of significant seismic shaking, for which precariously balanced rocks are a recognized indicator.

Although the main rock slope failure cavity is unusual in its slantwise orientation, the residual mass in the neck is a common feature of such slides (e.g. Meall Cala, (Figure 2.39)), as is the low-key disturbance of the floor (e.g. Beinn an Lochain west, Argyll, [NN 215 076]. The latter feature may indicate post-slide decompressive recovery, though the underground watercourse suggests incomplete removal (compare with Beinn Each, Glen Ample). The considerable volume of the cavity is not readily accounted for by debris below, implying partial evacuation by the last glacier. Very few rock slope failures within the Loch Lomond Stadial limits have been identified as pre-dating the Loch Lomond deglaciation (cf. Beinn Fhada). Sgurr na Ciste Duibhe provides a good opportunity to test this issue, by investigating the integrity of the knolls in Zone G (which could be a glacially overridden slipped mass), and the provenance of the atypically substantial lateral-moraine type mounds to its west.

To the west of the slide cavity, the broad midslope convexity has definite indicators of failure in its upper and eastern margins, but minimal indications of downhill displacement. As a hybrid between in-situ deformation and translational sliding, it fits the model identified in this area of the Cluanie-hybrid type failure exemplified at Druim Shionnach. In a context of high-angle schistosity planes and joint-sets in steep relief, decompressive forces are envisaged as conducive to slope bulging, with formation of grabens and antiscarp arrays, but no development of a sliding surface or debris lobe. Indeed, the Sgurr na Ciste Duibhe rock slope failure could have evolved initially as a Cluanie-hybrid failure affecting much of the glen slopes, with the more disrupted upper half then slicing off diagonally by progressive creep and sub-cataclasmic sliding. Lack of surface drainage and the powerful basal springs confirm deep-seated failure.

It is unclear whether the translational slide has at some stage reached the narrow glen floor and temporarily blocked it. Major landslide dams are rare in the British mountains, although common in other ranges, the dams impounding Llyn Tal-y-llyn being a good exemplar (Hutchinson and Millar, 2001). The rock slope failure toe below the knolls is exceptionally steep without being a rock gorge, and the River Shiel immediately downstream is atypically braided through coarse angular debris. This could be a result of fluvial breaching of a small dam, without reactivating the slide lobe.

One of the most widely recognized indicators of rock slope failure in mountain ranges is the split ridge or *doppelgrat* (Radbruch-Hall *et al.,* 1976; Crosta, 1996). This occurs where the source scarp daylights behind the crest, creating an uphill-facing scarp often confused with anti-scarps. Sgurr na Ciste Duibhe exemplifies the ridge-top depression in Britain, other instances being found on Ben Challum ([NN 38 31]) and Helm Crag, Lake District [NY 325 090] and most strikingly Aonach Sgoilte (Figure 2.12). The sharpening of a crest into an arête by rock slope failure is also seen locally here, but is better-developed farther east along the ridge between Saileag and Sgurr a' Bhealaich Dheirg (Figure 2.28), and on Aonach Meadhoin.

Neotectonic activity

Fenton (1991, 1992) identified Sgurr na Ciste Duibhe as a prime example of a rock slope failure controlled by basement faulting, and triggered by neotectonic activity along it in response to post-glacial stress-release. From fault dimensions, he estimated a paleoseismic event here of magnitude 6.0–6.6 M_s, and from the incidence of rock slope failure and sediment liquefaction, magnitudes of 4.5–5.9 M_s. The implausibility of this model has been noted in the 'Introduction' to the present chapter, and the polyphase nature of the complex rock slope

failure here further militates against it. In particular, the midslope slide cavity is markedly more subdued than either the lowest side slip into it or the sharply etched antiscarps and arête above. Fenton (1992) further proposed that the ridge crest has been offset by approximately 15 m in a sinistral sense, as a result of post-glacial intra-plate shearing, and attributed the ridge-crest hollow to this movement. The model for this was the proposed 160 m lateral displacement along the Kinlochhourn Fault nearby (Ringrose, 1989), which has been refuted by Firth and Stewart (2000). Here, there is no lateral offset to the north-east spur or the adjacent corrie-head gullies: an apparent offset of this scale where the fault cuts the east ridge is attributable to sliding out of the 'graben' section of the rock slope failure (Zone E2)

However, it remains possible that this and other rock slope failures have been partly triggered by seismic shocks of local origin, as the terrain recovered from differential ice loadings of 700–1000 m between ridge and glen, and from concentrated slope-foot erosion. Kintail is currently a focus of minor seismicity, and there is a marked cluster of rock slope failures here (Jarman, 2006). The high available relief, the existence of a sizeable basement fault crossing a narrow ridge, and the evidence of slickensiding all make Sgurr na Ciste Duibhe one of the prime sites in Britain for detailed examination of paleoseismicity.

Glacial breaching

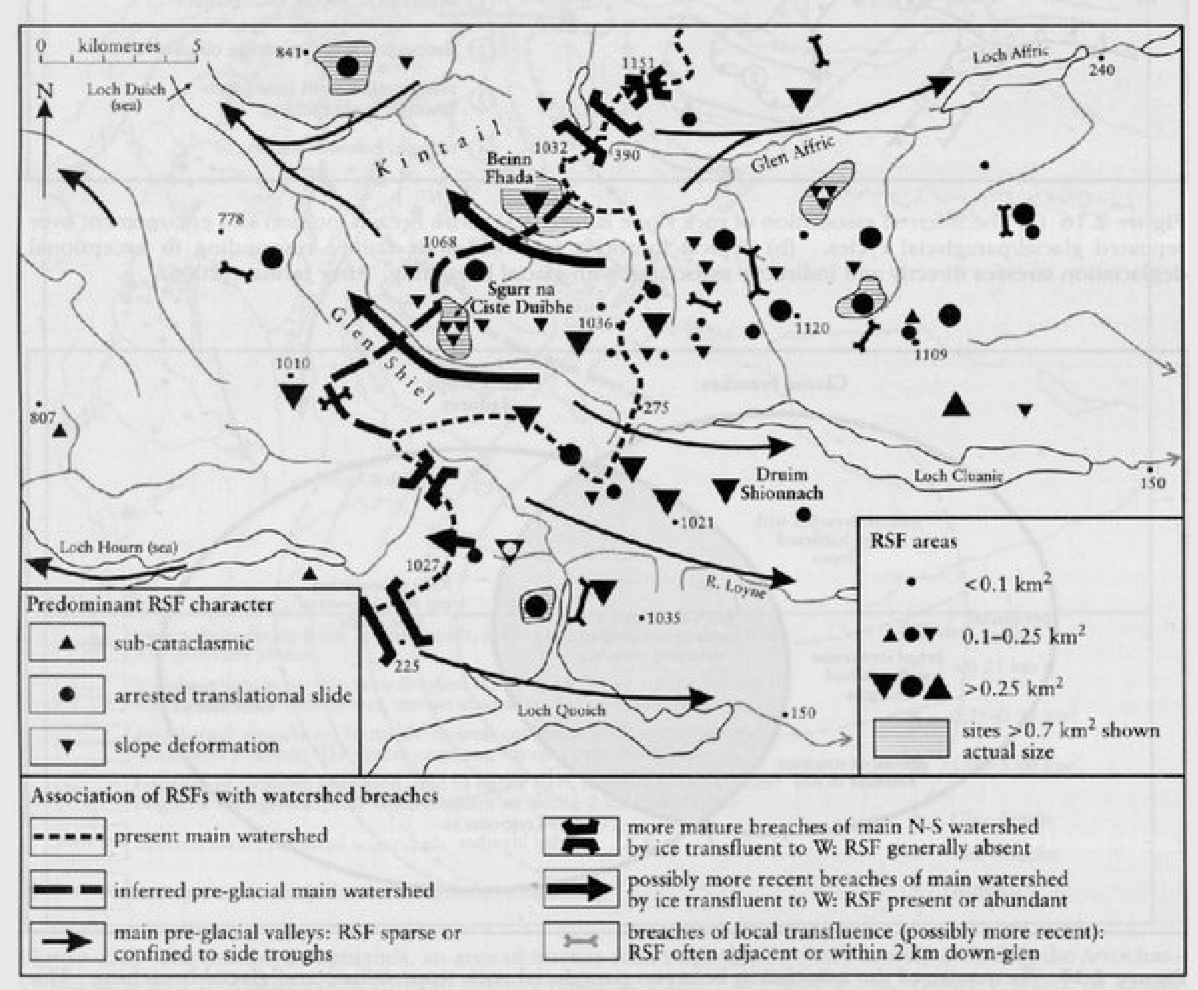
Since the precise trigger mechanisms for the rock slope failure may prove difficult to determine, it is more fruitful to consider why this major failure complex has occurred here, within a dense cluster of such failures. Glen Shiel is a short west-flowing valley typical of the Western Highlands where the main watershed lies close to the coast, with a major glacial breach at its head (270 m OD) through to Glen Cluanie (Figure 2.18) and (Figure 2.28). Sgurr na Ciste Duibhe stands above the foot of its steep descent at the point where it becomes a glacial trough only 50 m above OD. However, Linton (1949) places the pre-glacial watershed at this point, implying that possibly 500–750 m of erosion has occurred here over the Quaternary Period, by a combination of vigorous trough-head excavation by the west-flowing valley glacier, and glacial breaching at times when the iceshed lay to the east of the watershed. Haynes (1977a) observes anomalously low valley interconnectivity in Kintail, and the breaches of the main watershed are at their highest elevations here. Haynes attributes this to a subtle combination of resistant geology, a high mountain axis aligned north-east–south-west, and an ice dome centred on the range deflecting other icestreams around it. In this context, the Glen Shiel breach may be relatively young, and bulk erosion may have been concentrated at the foot of Sgurr na Ciste Duibhe. This will have provoked rock slope failure partly by exposing potential failure planes, but primarily by generating rock mass stresses sufficient to propagate deep fracturing and compensatory outward movement.

In identifying a strong association between possible recent breaches and the incidence of rock slope failure in this area, in contrast to an absence of rock slope failure along mature glen sides, Jarman (2003b) suggests that this may indicate a shift or intensification of ice dispersal patterns in Devensian times. In this analysis, Sgurr na Ciste Duibhe is the most significant rock slope failure in this area.

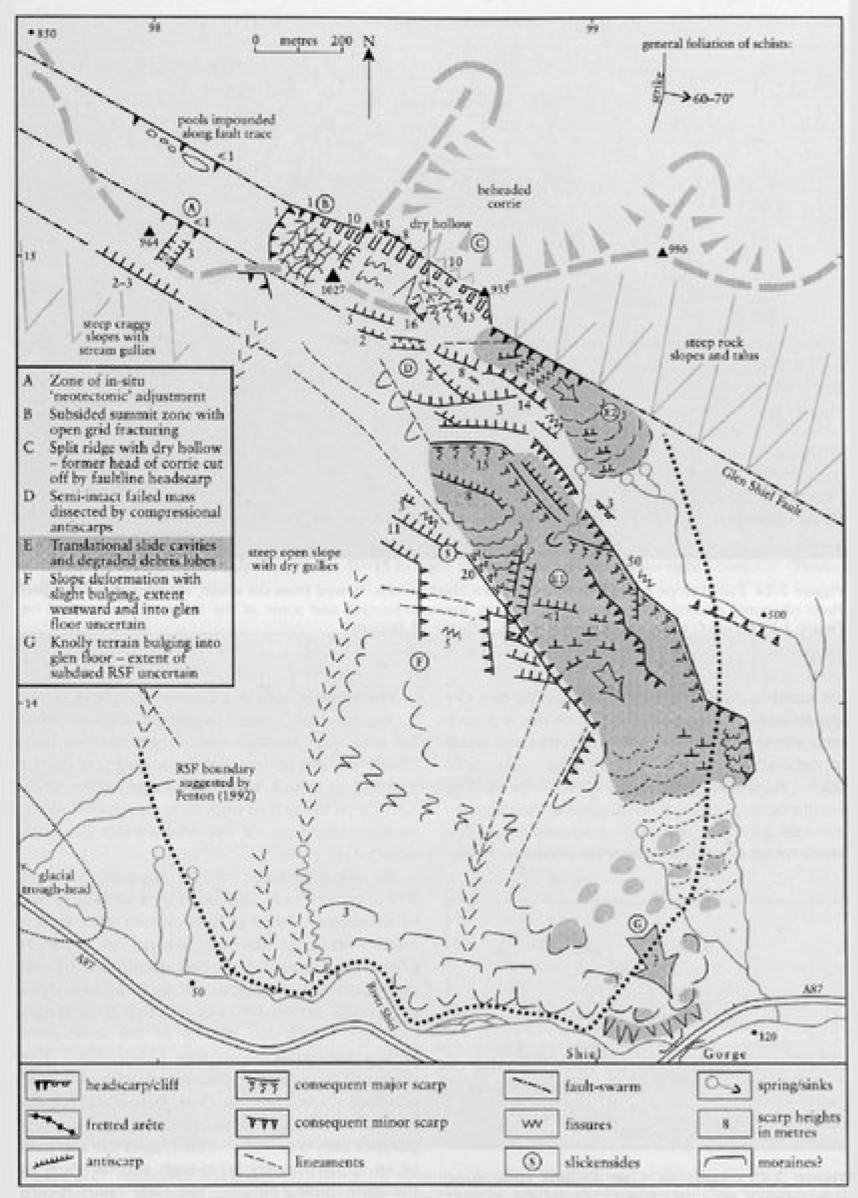
Conclusions

Sgurr na Ciste Duibhe is a key site for showing structural controls on rock slope failure, and paraglacial mountain summit shaping. The failure complex demonstrates vertical progression from in-situ deformation to long-runout sliding over almost 1000 m of valley-side. It is clearly associated with a basement fault zone, and is the best site on which to test theories of elevated seismic activity around deglaciation. The mountain top owes much of its present shape to rock slope failure, with fine examples of arêtes, ridge-top depressions, and antiscarps; its fractured and lowered summit may be unique in Britain. The failure stands above one of the most deeply excavated glacial breaches in Britain, and is the most significant member of the Kintail cluster in exploring the association between recent bulk erosion, generation of deep-seated rock-mass stresses, and their release in various modes of slope failure.

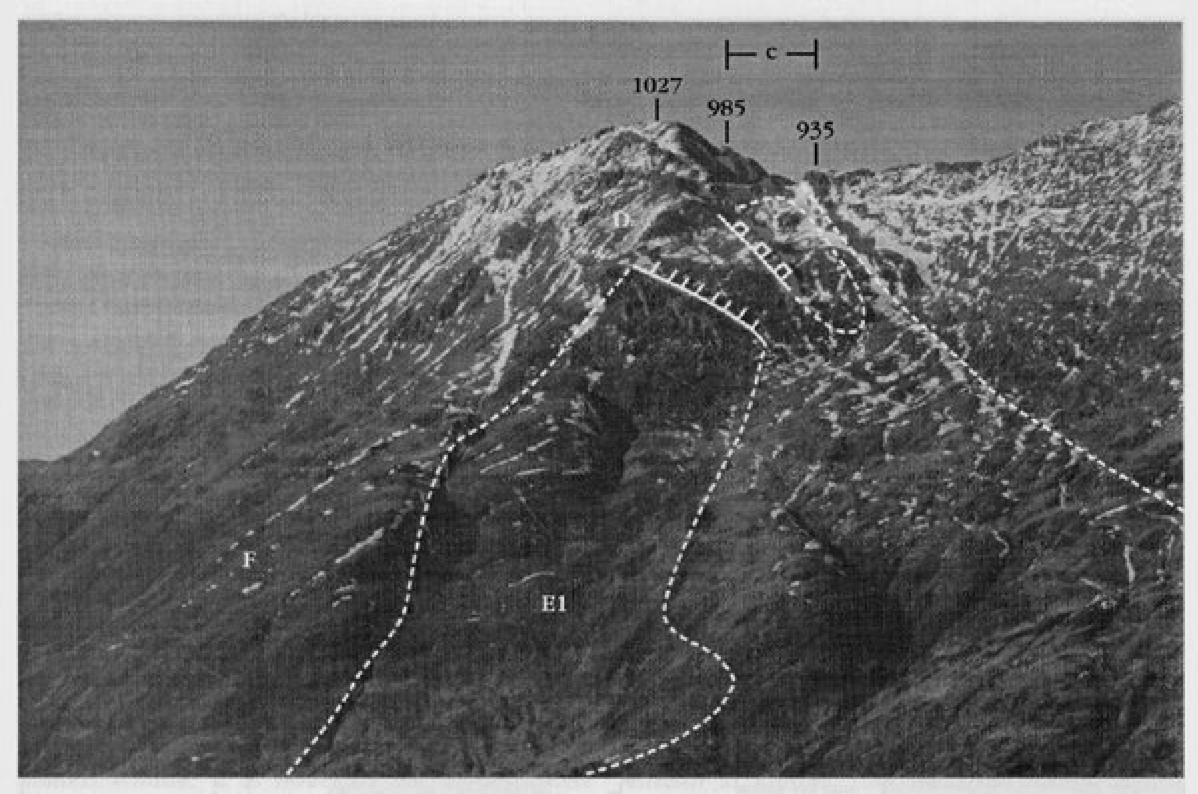
References



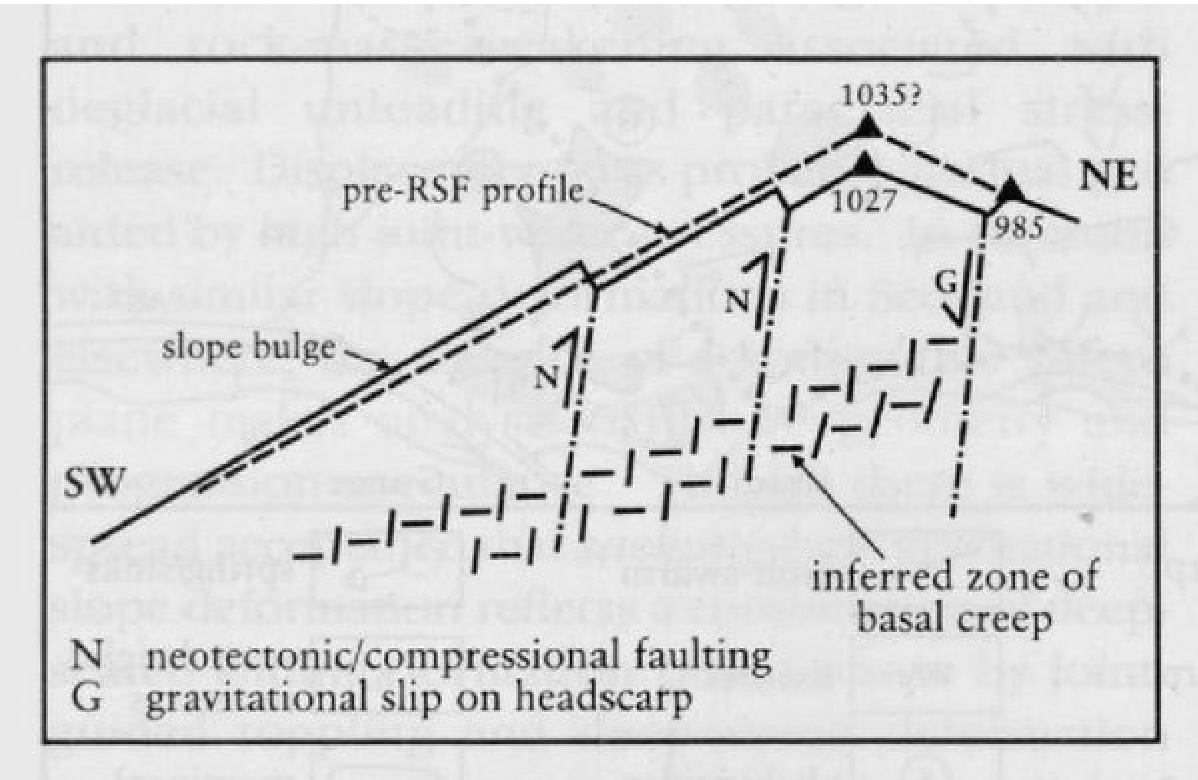
(Figure 2.18) Part of the Affric–Kintail–Glen Shiel rock slope failure cluster (cluster 1 in (Figure 2.13)). Rock slope failures tend to be located near breaches of the inferred pre-glacial watershed, and in side troughs rejuvenated by breaching. Note the locations of three GCR sites — Beinn Fhada, Druim Shionnach and Sgurr na Ciste Duibhe. Adapted from Jarman (2003b).



(Figure 2.23) Geomorphological map of the Sgurr na Ciste Duibhe rock slope failure. After Jarman (2003b).



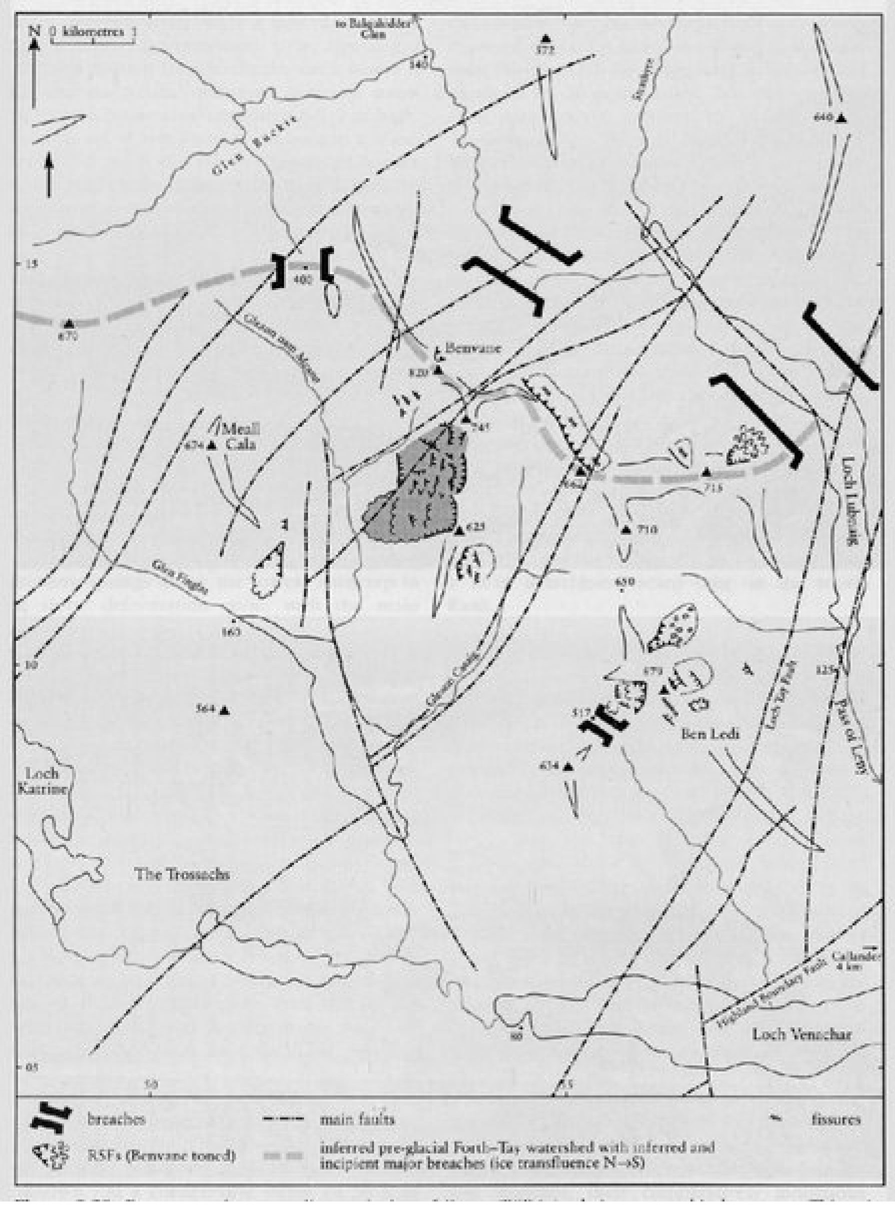
(Figure 2.24) Failed slope rising 950 m above Glen Shiel breach, viewed from the south, showing the Glen Shiel Fault (diagonal pecked line), skyline dislocation, lowered summit and some of the failure zones marked on (Figure 2.23) (Zone C is shown on (Figure 2.26)). (Photo: D. Jarman.)



(Figure 2.25) Sgurr na Ciste Duibhe rock slope failure (RSF); notional cross-section of the summit area. After Jarman (2003b).

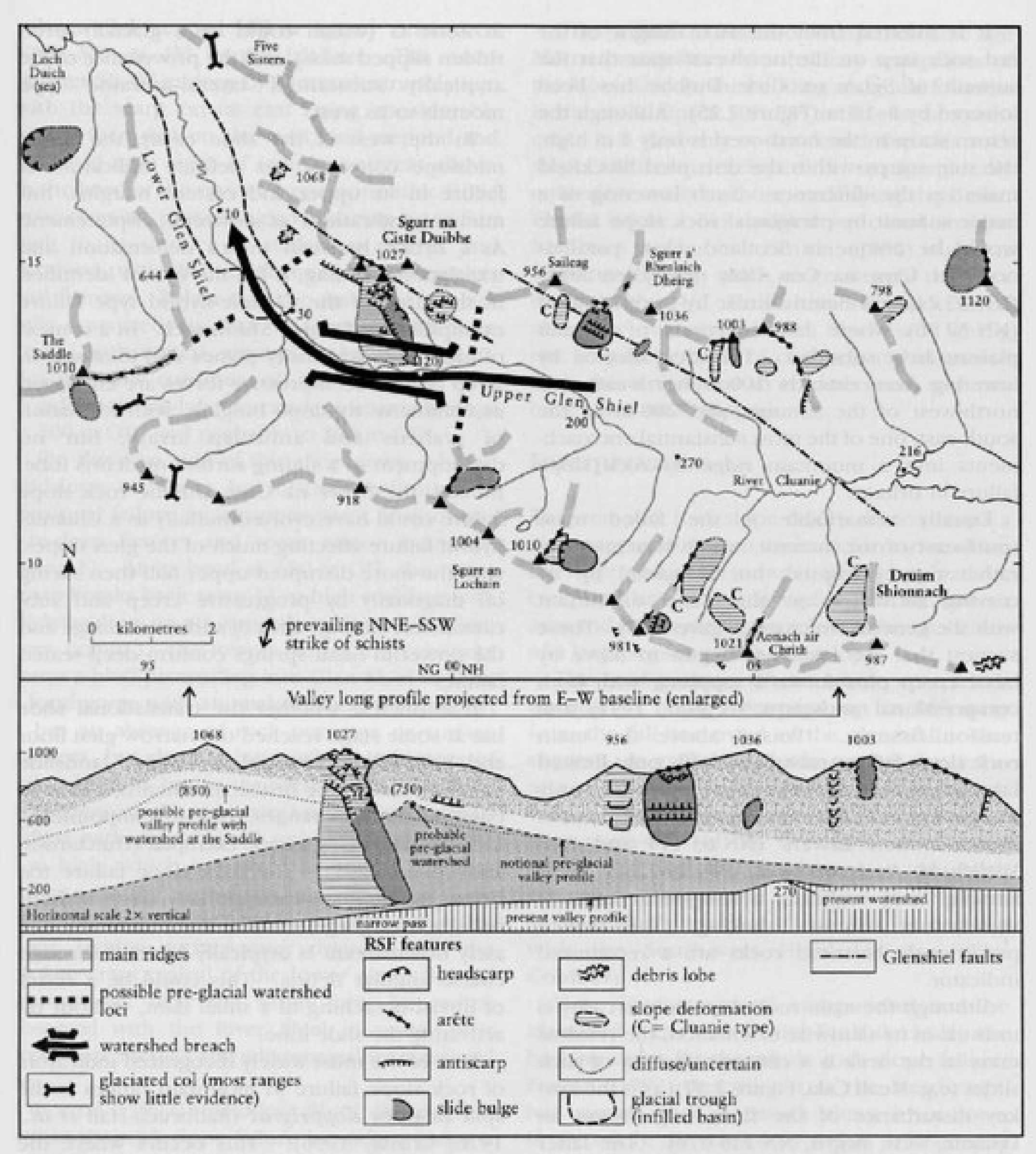
(Figure 2.26) Five Sisters summit ridge dislocated by subsidence along the Glen Shiel Fault. View looking southeastwards from Point 985. Ridge breaks are 10–15 m high; note the dry hollows, lower-right (Zone C). (Photo: D. Jarman.)

(Figure 2.27) Antiscarps and graben wall below the summit (Zone D). The bulging toe (hiding the road) creates a local gorge. The slide cavity with fissured debris-mass can be seen in the foreground. The long parapet/ antiscarp and uphill-facing crag are marked on (Figure 2.24). (Photo: D. Jarman.)



(Figure 2.39) Benvane and surrounding rock slope failures (RSFs) in their topographical context. This sub-cluster may be associated with glacial transfluence south-east across local watersheds, the breaches being at varying stages of development. Unlike the Glen Ample sub-cluster immediately to the north-east, there is no specific association with main faults.

(Figure 2.12) Aonach Sgoilte rock slope failure, Knoydart [NG 836 020]. The ridge is split over 1.5 km by a source fracture daylighting behind the crest, often 30 m downslope on the north (right). The summit mass seen here has slipped south by 10–15 m. The gentler slope below is extensively antiscarped, one being 500 m long and reaching 7.5 m in height. A wedge slip has left the shadowed notch. The rounded headscarp crest (contrasting with Sgurr na Ciste Duibhe) could indicate relatively ancient inception. (Photo: D. Jarman.)



(Figure 2.28) Map and long-section of the Glen Shiel breach with reconstructed pre-glacial watershed and associated rock slope failures on the north side of the main valley and in the trough corries of the south Cluanie ridge (e.g. Druim Shionnach). After Jarman (2003b).