Glen Ample, Stirling

[NN 596 160]–[NN 610 215]

D. Jarman

Introduction

The area south of Lochearnhead, Perthshire is of exceptional significance as having the highest known density of rock slope failure in the Highlands, with seven failures affecting 16% of the 26 km^2 Glen Ample area (Figure 2.40). Core areas of other failure clusters studied do not exceed 8% (Table 2.2). It is also one of the most pronounced concentrations of significant failures along the line of a major basement fault, the Loch Tay Fault. The two principal failures, at Ben Our and Beinn Each, are essentially in-situ slope deformations with marked structural expression. Their extensive, but often delicate, ground rupture features are possible indicators of neotectonic activity: high-magnitude seismic shocks following deglaciation have been proposed but not yet confirmed in the Highlands (Stewart *et al.,* 2000). These structures provide unusually clear evidence of how deep-seated deformation can develop in some of the gentlest relief known to be affected by paraglacial rock slope failure. Ben Our is of exceptional significance for its extent and its unique platy structure.

Description

Glen Ample is a short (8 km) side-valley off of Loch Earn, with rather open slopes and less than 500 m relief to its immediate rims. It narrows at its head into a minor glacial breach of the main Forth–Tay divide south to the major breach of Loch Lubnaig (Figure 2.39). There are several lesser rock slumps and slides on its flanks, and just south of the pass is a more extensive anti-scarped zone. Directly above the pass stands the impressive Beinn Each rock slope failure. At the foot of the glen, one of the three largest rock slope failures in the Highlands occupies most of the low rounded hill of Ben Our. Being located at the junction of Glen Ample with the trough of Loch Earn, it is unusual in responding to slope stresses in directions almost 90° apart.

On the opposite side of Loch Earn, a small but striking rock slope failure has a deep, narrow wedge cavity and a slide lobe exhibiting creep in the last century. The west side of Glen Ogle has a chain of crag collapses across which a railway was engineered without re-activating them. Its rounded nose has signs of deformation, progressing to sliding slumps, complementary to Ben Our. Together with some rock slope failures on the south-west side of Loch Lubnaig, this dense cluster stands apart from the general concentration along the main Highlands watershed close to the west coast (Figure 2.13), and it occurs in some of the lowest relief in the Highlands to support rock slope failure.

Geologically, Glen Ample comprises Dalradian metasedimentary rocks (late Precambrian–early Cambrian in age). These are mainly arenites, semipelites, and pelites, with a distinctive intercalation of 'Green Beds' (which include reworked volcanic detritus) on the south-west slope of Ben Our. The rocks of Ben Our contain a higher proportion of schistose pelites and semipelites. The rocks are of greenschist to lower amphibolite metamorphic grade, typified by biotite and garnet growth. Structurally, Glen Ample lies close to the Highland Boundary Fault, where the relatively flat-lying Dalradian rocks become downfolded into a large monoformal structure called the 'Downbend', whose axis trends north-east. Thus while the beds dip gently on Ben Our, they are steeply inclined on Beinn Each. Glen Ample has formed by enhanced erosion along the line of the Loch Tay Fault, a sub-vertical NNE-trending structure. There is no recorded information on joint-sets, but there appear to be no obvious bedding or cleavage dips that can easily account for the incidence of rock slope failure in this area (J. Mendum, British Geological Survey, pers. comm.)

Ben Our (Beinn Odhar)

When seen on an aerial photograph, or in ideal snow or light conditions, the pervasive platy deformation of Ben Our is very unusual for a hill of relatively unassuming height and character (Figure 2.41). The summit area is almost flat, with tops at 730 m and 740 m OD separated by a shallow graben-like saddle. A swarm of scarp-lets runs behind the summit above the col to the south and below the broken crags on its east. To the west, these scarplets converge into a major scarp reaching 4 m in height, which runs for 600 m above the fluvial cleft of Coire Mheobhith. Since this scarp faces uphill (north) it appears to be an antiscarp, but together with the scarplet swarm girdling the summit, it is in fact the source fracture from which the whole mass of the hill has slipped slightly away (Figure 2.42).

The broad shoulder north from the summit is split by a fracture 1.2 km long, in places a mere furrow, but generally a sharp step typically 1–2 m and locally up to 5 m high. This is another source scarp to the subsidence, with slight movement along or away from it, although tension fissures and steps also occur on the brow east of it. The manner in which the west-trending and north-trending source scarps interact in the summit area is unclear.

The boldest feature of this rock slope failure is a ragged tear scarp which scythes across the whole site in two arcuate sweeps, reaching 18 m high (Figure 2.41) and (Figure 2.42). Above this feature the gentle upper slopes are split by a tension scarp and furrow, and have minor antiscarps. Below it to the north, the central part of the failure has subsided but with no open fissures or indications of significant spreading. It has fractured into a series of rectilinear plates, framed in the east by step-down scarps up to 6 m high, but in the lower ground farther west by antiscarps reaching 4 m high. The south-west end of this ragged tear scarp propagates into a series of nested slip hollows, culminating in a conspicuous promontory that has crept out into Glen Ample. This pattern of short-travel upward-propagating movement has been described at Tullich Hill (Jarman, 2003d).

All along the Glen Ample side, the glacially steepened lower slope has a dense array of anti-scarps and lineaments on several orientations, generally below 2 m in scale. Locally these become tension trenches. At the south and north ends, these features are framed by nested sub-arcuate scarps where deformation is progressing to outward movement. These source scarps reach 24 m high in the north, and locally 40 m in the south. Both these creep masses have substantial flank ramparts and toe bulges; the northern one contains the only striking rock-mass dislocation in this rock slope failure, with a 10 m head crag and rocky, antiscarped topple masses. Between these failed masses, the middle section appears substantially intact, but is crossed by steeply inclined antiscarps associated with a major fracture crossing the site. Along the steepened slope above Loch Earn, there are break-lines but only one isolated antiscarp near the foot.

The whole west and north perimeter of the site has the most extensive and abundant effusion of springs of any large rock slope failure. The springs cluster below the creep masses and major fractures, mostly on two levels. Slump bowls in superficial deposits, some very large, are actively developing and migrating upwards. There is no surface water drainage on the site, nor any sign of dried-up former watercourses save along the southern boundary, indicating the pervasiveness of fracturing.

The extent of failure is reasonably clear except on the north shoulder and east slope, where irregular terrain continues down towards Loch Earn and into Glen Vorlich. A separate, rectilinear rock slope failure sourcing at midslope close to the angle of these valleys has a long debris-lobe; its west flank scarp is an extension of a distinct furrow lineament. The total extent is at least 2.9 km^2. Holmes (1984) only identified the most conventional slope failure areas above Glen Ample, totalling 0.17 km^2.

Possible contributory geological controls include bedding and foliation surfaces dipping NNW at approximately 45° along the southern boundary and shallowing northwards to as low as 5°: in combination with suitable joints, these could facilitate the translational sliding along the west flank, and extensional creep within the core of the deformation. Massive rock 'Green Bed' units on the lower slopes and more schistose lithologies near the summit within an interlayered structure may also have assisted mass translation. A NNE-trending fault passes just east of the summit, and may also have assisted in releasing the failed mass, whereas the main back feature to the lower failed area may be faulted as it parallels the inferred trace of the Loch Tay Fault (J. Mendum, British Geological Survey, pers. comm.).

Ben Our — interpretation

Ben Our is a unique site. The extensive platy dislocation on the gentle upper slopes is unprecedented, and may be attributable to tensional spreading in two directions on a convex valley junction. Most of the deformation occurs over only 200–300 m of vertical relief, at a gradient of only about 18°: the slope foot in Glen Ample is glacially steepened to 27°, but produces only a bluff about 100 m high (Figure 2.43). Ben Our is almost an inverse of Benvane geometrically, with extensional platy deformation on gentler upper slopes, as against compressional latticing on steeper slopes below a spreading ridge, an instructive contrast for further investigation.

It is difficult to invoke localized glacial erosion as the prime factor here, by contrast with the comparably large deformation at Beinn Fhada (Jarman, 2003e). If a failure surface is interpolated from the scarplets behind the summit to the slope foot springline in the north-west corner, then at 14° this is too low for conventional translational sliding (Figure 2.43). Such a surface is unlikely to exist as a planar throughgoing discontinuity: the component blocks are more likely to have their own 'floors', whether clear-cut or transitional, staircasing down the slope as joint-sets intersect above the NNW-inclined foliation surface. This would favour tensional spreading (as along the ragged tear) and assist translational movement on the outer slopes, but its concave nature may have restrained mass creep. The interpolated 'failure plane' would simplistically give a general depth of failure in excess of 150 m, which is comparable with the maxima proposed for major rock slope failures in high relief in the North-west Highlands (Fenton, 1991). Such a depth would give a very large total failed volume of the order of 100–200 x 10^6 m^3, comparable with Beinn Fhada. The actual extent to which the rock mass has lost structural integrity remains somewhat conjectural until geophysical surveys are conducted, but may well be considerably less.

Beinn Each

Although Beinn Each is, like Ben Our, a nearly in-situ slope deformation, the mode of expression is very different (Figure 2.44). Almost all of the features are compressional (antiscarps, ramps and benches breaking upwards out of the slope), in contrast to Ben Our where the structure is extensional (downward breaks in slope), except for a band across the waist.

The most striking component at Beinn Each is a smooth dome, only about 200 m square, tilting out from the approximately 30° valley-side to an angle of approximately 40°. It is fractured by 'noughts-and-crosses' antiscarps typically 3–5 m high but reaching 9 m at one intersection, unusually high for sites south of the Great Glen. Visual impressions suggest that sinistral displacement of about 30 m may have occurred along the lower contour-parallel anti-scarp. This extrusion has been likened to 'egg-box architecture' and 'celtic knotwork' (Figure 2.45).

This intense, but localized, deformation is at the lowest corner of the rock slope failure, only 150 m above the col at the head of Glen Ample. From it a sub-horizontal lineament extends north for 800 m, the whole width of the slope failure, below the steeper part of the valley-side. It snakes in the manner of an uncoiled rope, as do the lowest antiscarps on Beinn Fhada, but is generally no more than a broad bench ((Figure 2.44), feature A). Midway, it is intersected by two pronounced lineaments trending diagonally south-west–north-east across the deformation and emerging in places as sharp, but modest, antiscarps ((Figure 2.44), features B and C). From its north end, a ramp ascends south-east and intersects B and C in a nexus of small plates emulating in miniature Benvane and An Sornach (Jarman, 2003c). The ramp becomes a structural weakness across gentler upper slopes ((Figure 2.44), feature D) towards the headscarp, and meets the bold scarp of the west shoulder of Beinn Each at the point where it has collapsed in a pile of massive blocks. Immediately beneath this bold scarp runs a final lineament ((Figure 2.44), feature E). This starts from the extruded dome, extends uphill for 600 m as a well-defined, if discontinuous, antiscarp 2–6 m high, and continues as a trace onto the skyline. In places, it is the axis of a swarm of closely spaced lesser antiscarps; it resembles similar cliff-foot locations in the Mamores (e.g. Stob Ban, [NN 147 648]. Other features run parallel to these main lineaments and help to confirm the extent of deformation as about 0.5 km^2.

There are few obvious geological controls here (J. Mendum, British Geological Survey, pers. comm.), with the bedding and cleavage in the schists dipping too steeply to the NNW for translational sliding. The strike of the structure is however roughly parallel to lineaments B and C. A fault trace extending north-east from near Beinn Each summit may continue south-west to form the prominent southern 'headwall' to the rock slope failure, with an east–west fault causing an additional 'break up weakness' within the failure. Note that E and B correspond to fault traces mapped on the eastern side of Beinn Each.

Unlike Ben Our and Benvane, it is not at all clear where the Beinn Each rock slope failure originates. The bold scarp of the west shoulder cannot be interpreted as a 70 m headscarp since there is no sign that the failed mass has subsided or bulged out into the glen to any great extent. The collapsed section of this scarp, with its incipient encroachments into the ridge, is in effect a separate failure, as is that on the southwest flank of its nose (Figure 2.44). Nor is there any evidence of a source configuration along the heavily scoured north ridge. Nevertheless, this failure does occupy a broad wedge-shaped depression of subdued relief between steeper rockier bluffs.

A further sharp contrast with Ben Our, and with most deformations including Benvane, is the drainage pattern. Rather than a springline along the slope foot, there are major effusion zones at the upper and lower ends of lineament D, several springs associated with lineaments B and C, and streams following irregular courses over the rock slope failure. This could indicate that deformation is unusually shallow or partial, or alternatively that it is of such antiquity that it is reconsolidating. Examples such as Beinn an Lochain West and Beinn an Fhidleir in the Arrochar Alps [NN 215 076], and Na Gruagaichean in the Mamores [NN 227 105]; (Figure 2.11), suggest that removal of a previous failed layer might unload the surface sufficiently to reactivate deep-seated weaknesses. The 70 m-high scarp at Beinn Each is not the source cavity for the extant slope failure, but in this analysis it could represent the thickness of a previous failed layer now removed. The source of earlier failure could have been on the present north ridge, lowering it to enable over-riding by ice. Evacuation of such a failed layer could have been partly by landslipping *en masse,* since the present overall slope angle of approximately 26° is just feasible for translational sliding; selective quarrying of a weakened slope may also have played a part.

The present col at the head of Glen Ample may have been lowered by 100–200 m from its pre-glacial position. Although relatively modest, this localized erosion could have augmented the rebound stresses, especially if it has occurred mainly in Late Devensian times.

The most intense deformation occurs along the foot of the bold scarp, and at its nose. This is where the greatest thickness of material will have been removed in earlier glacial-paraglacial cycles, and closest above the breach where the valley-side is over-steepened along the 500 m contour. The 'eggbox' extrusions (or forward topples) must be close to the point of shearing or collapse, and their survival suggests vertical slices pinned at depth by the intersecting lineaments.

Interpretation

Remarkably, these major rock slope failures have not previously been published or commented upon. Holmes (1984) identified small sites along the Glen Ample slope foot at Ben Our, but nothing at Beinn Each. The British Geological Survey has yet to publish revised mapping of this area, although officers are aware of these sites.

The ages of these rock slope failures have not been investigated. The features are generally sharp but not unusually fresh except in the lowest collapse at Ben Our, indicating an earlier Holocene date. Their relatively low elevation has encouraged vegetation, and possibly protected them from periglaciation during the Loch Lomond Stadial. It seems more probable that such large deformations are a response primarily to the Last Glacial Maximum and its deglacia-tion: the main dislocations possibly occurred during the Windermere Interstadial, with the finer details emerging after final deglaciation.

Explaining the Glen Ample cluster is problematic. The association with glacial breaching and hence rapid erosion is initially attractive, since the Beinn Each rock slope failure and the sub-cataclasmic failure opposite stand directly above the Ample–Lubnaig breach. If Loch Lubnaig is accepted as a major breach of the former Forth-Tay divide (Linton, 1957), then Glen Ample is a subsidiary and possibly later-formed breach. The pass is of modest capacity, and may only be accommodating local ice displaced from flowing out north by transfluent ice down Glen Ogle (Figure 2.40). It does not appear to have been enlarging vigorously, and indeed lies almost transverse to regional ice outflow

If glacial erosion has done no more than activate local slumping or forward toppling along the rock slope failure toes, then other causes must be sought. High-magnitude seismic shocks have been inferred from rock slope failure clustering and other indicators, especially where they coincide with major faults (Fenton, 1991), although the evidence is weak (see 'Introduction', this chapter). The Loch Tay Fault runs along Glen Ample, and is one of the main Caledonian (NE-SW-trending) faults, with 7 km of strike-slip movement and up to 1 km of vertical displacement (Treagus, 2003); however there is no recorded present seismic activity along it. Some of the antiscarps run broadly parallel to this fault, but most interesting is the lineament which extends for over 1 km from near the summit of Ben Our, linking but essentially out-with it main and north-east failures ((Figure 2.40). Any neotectonic origins for this feature, or for the rock slope failures themselves, must remain speculative at present. While Glen Ample is one of the best candidates for a rock slope failure cluster to be associated with post-glacial fault re-activation, it is nevertheless more likely to be a co-incidence of selective valley erosion along a suitable line of weakness.

This rock slope failure cluster is unusual in being located well to the east of the main watershed and former ice divide of the Highlands (Figure 2.15). Other easterly failures are associated with deep transectional breaches of the Grampian watershed (Hall and Jarman, 2004) or with vigorously enlarging trough heads such as Glen Clova. It may be that the location of this cluster in relation to the Pleistocene ice-sheets is significant. It lies close to the outer limit of the Loch Lomond Stadial (Holmes, 1984, after Sissons).

It also lies close to the Highland-Lowland boundary at Callander, where the Devensian and earlier icecaps were in transition from high mountain-based domes to icestreams, possibly with relatively steep surface gradients and reductions in average thickness. On deglaciation, the regional glacio-isostatic rebound stresses may have diminished rapidly over relatively short distances, including from west to east across Glen Ample. Generally, such differentials are resolved by gradual deformation, or remain locked in. Where local rock structure is conducive, they may conceivably provoke ground rupturing, perhaps where additional local factors such as valley erosion apply.

Both Ben Our and Beinn Each have one unusually long and relatively continuous lineament running diagonally across the terrain in a north-east orientation. These are not parallel with the Loch Tay Fault, but may be with the strike of the foliation surface or a major joint-set (no geotechnical survey has yet been conducted) and do correspond to secondary fault orientation. They are expressed as anti-scarps for much of their lengths. One hypothesis worthy of exploration is that initial ruptures occurred along these lineaments, which may roughly parallel the regional ice contours at their steepest. These ruptures would not necessarily involve high-magnitude seismic shocks, nor occur at the same time. They would trigger, or coincide with, delamination of the surface to a depth of tens of metres, along another joint or quasi-bedding plane, or along a more irregular self-creating surface. The failed layer would fracture into slices or plates depending on terrain and geology, and would be freed to resettle in such a way as to minimize residual rock-mass stresses. Here, they have not developed into translational slides, but have progressed by creep and subsidence. As a result, surface water is channelled along the main fractures to emerge in springs.

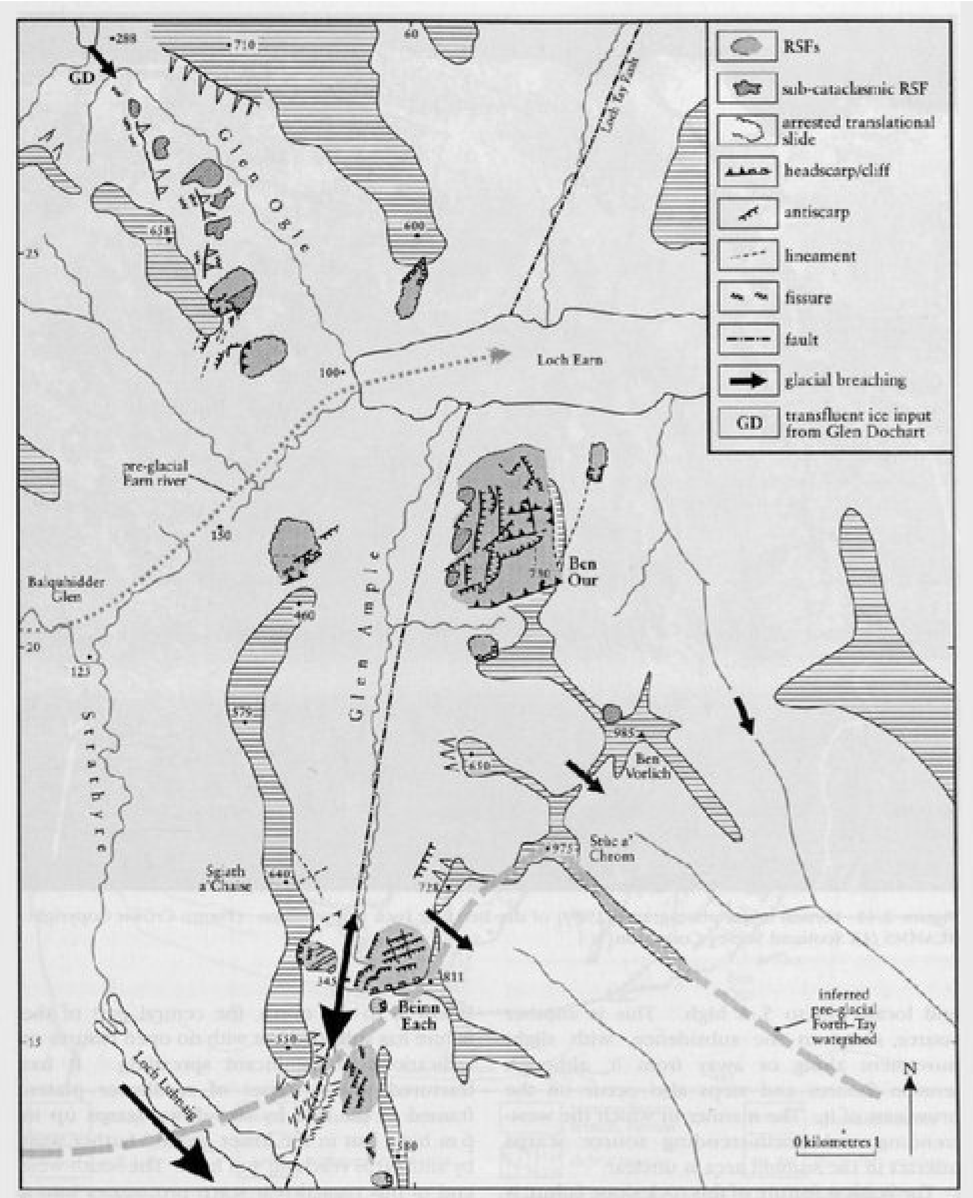
A similar interpretation has been developed for the An Sornach rock slope failure in Glen Affric (Jarman, 2003c), which was previously advanced as neotectonically triggered (Fenton, 1991). Other small clusters of significant slope failures in apparently marginal, lower-erosion locations, which might be accounted for by regional glacio-isostatic rebound gradients, include Loch Striven and Glen Shira (see Jarman, 2003a), Strathfarrar (see Jarman and Reid, 2003), and west Knoydart.

The landshaping effects of these rock slope failures are relatively subtle. Despite its low profile, Ben Our is still the bulkiest of the promontories encircling the head of Loch Earn. Removal of all of the failed material would lower the whole hill by possibly as much as a hundred metres; alternatively, removal of the material below the ragged tear would widen the glen and accentuate the promontory for an interim period, as on the Sgiath a' Chaise ridge opposite. The Beinn Each rock slope failure is similarly tending to isolate the resistant summit core, which may originally have been an extended shoulder of Stuc a' Chroin rather than a separate peak; it is also helping to enlarge the Ample–Lubnaig breach.

Conclusions

Glen Ample is of considerable interest for its anomalously high density of rock slope failure, in a relatively isolated and low-relief location. Ben Our is one of the three largest rock slope failures in the Highlands, and its extensive platy deformation is unique in Britain. It is unusual and instructive in being located on a valley junction corner, exposing the hill to slope stresses in several directions. Beinn Each has a remarkably bold and intricate antiscarp array, on intersecting alignments, in marked contrast with the parallel array on Beinn Fhada and the filigree lattice on Benvane. Both Ben Our and Beinn Each clearly exhibit slope deformation with only limited progression into downslope separation. Their extraordinary expression, extent, and enigmatic origins have attracted international attention. This is a locality where it is worth investigating whether neotectonic seismic movements have acted as a trigger for rock slope failure, but even then they may be no more than ancillary. Other hypotheses such as differential (glacio-)isostatic rebound stresses are necessarily more speculative, but the sites are ripe for detailed geotechnical examination. The cluster offers great scope for exploring the fundamental causes and spatial distribution of rock slope failure in glaciated ancient mountain areas.

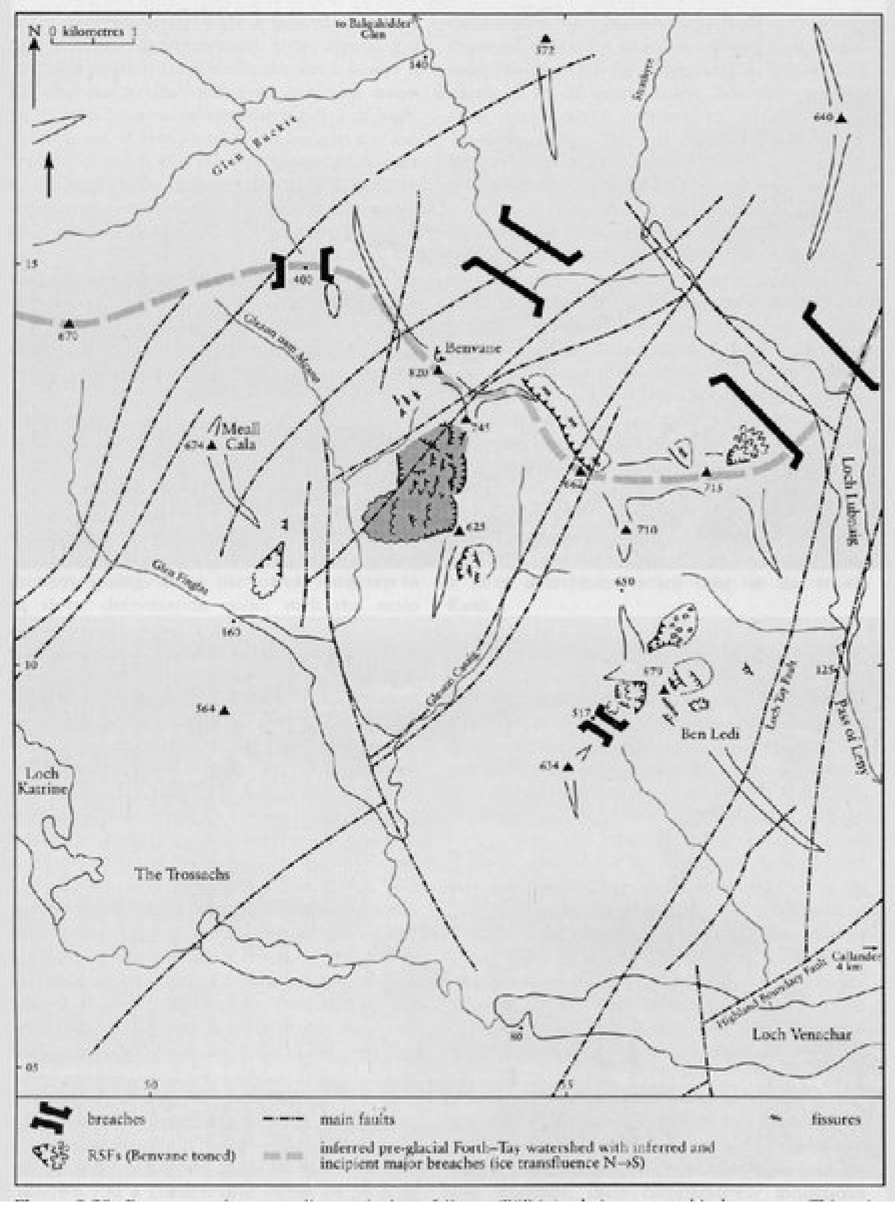
References



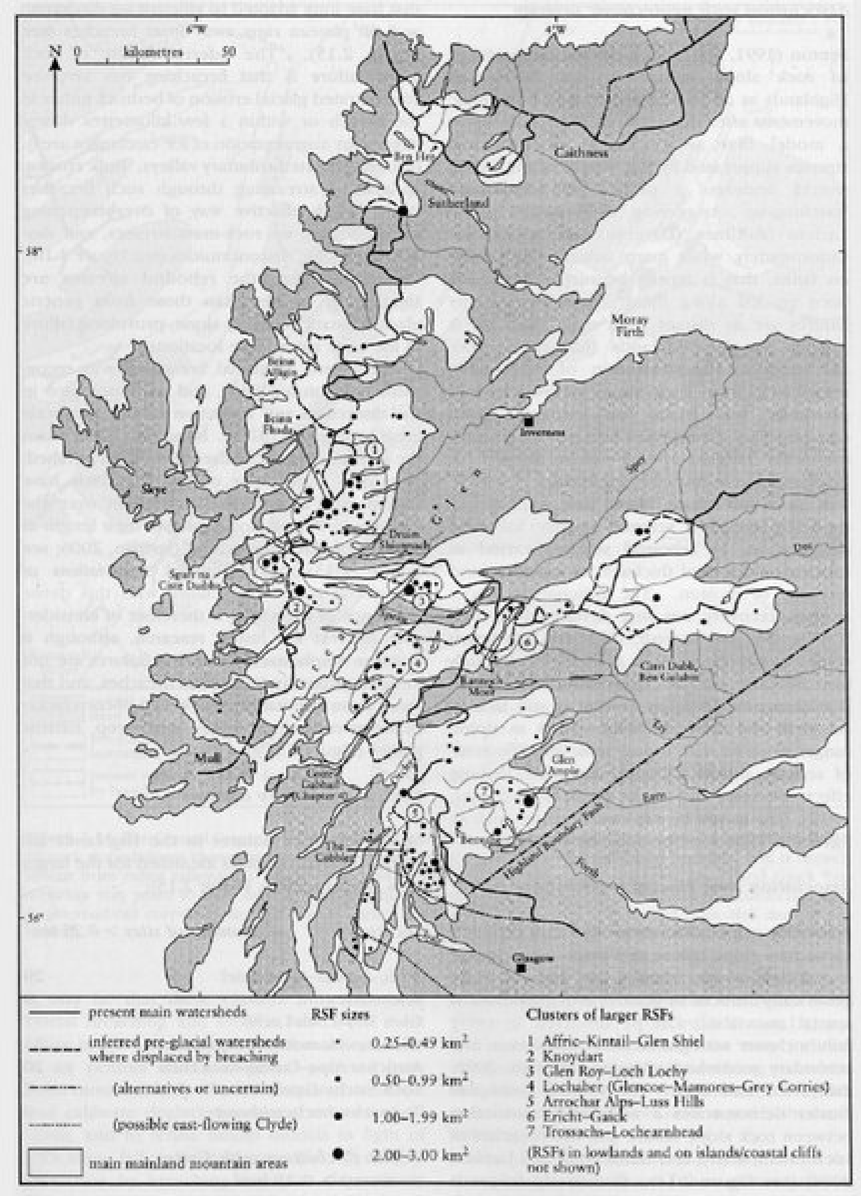
(Figure 2.40) The Glen Ample rock slope failure (RSF) cluster in relation to the Loch Tay Fault and immature glacial breaches.

	Southern Highlands				S. Affric/Kintail/Glen Shiel
	1W	1E	2	Total	7N/8S
Number of RSFs	119	40	13	172	54
< 0.25 km^2	86	33	8	127	33
0.25–0.99 km^2	31	6	4	41	17
1.00–3.00 km^2	2	1	1	4	4
Extent of RSF (km^2)	27.9	7.0	5.2	40.1	18.6
average size (km^2)	0.23	0.17	0.40		0.35
% of densest core area affected by RSF	7.7	7.2	16.7		6.0
extent of core area (km^2)	112	40	26		41
RSF character (number of)					
arrested translational slides	48	20	11	79	25
sub-cataclasmic failures	35	21	6	62	6
slope deformations	6	10	5	21	23
incipient failures	28	10	5	43	5
not ascertained	26	8	1	35	–
Landshaping contribution					
glen and trough widening	89	17	9	115	38
corrie enlargement	13	13	1	27	11
corrie initiation	11	2	1	14	–
spur truncation	39	11	6	56	9
crest sharpening, arêtes and horns	39	16	7	62	19
ridge reduction	8	5	0	13	23
potential watershed breaching/ dissection	3	2	2	7	6
elimination of mountain blocks	12	4	1	17	2
Association with evolving glacial breaches					
at a 'recent' or enlarging breach	20	5	5	30	27
near a breach (< 2 km downflow)	24	15	4	43	
in a side trough rejuvenated by a breach below					11

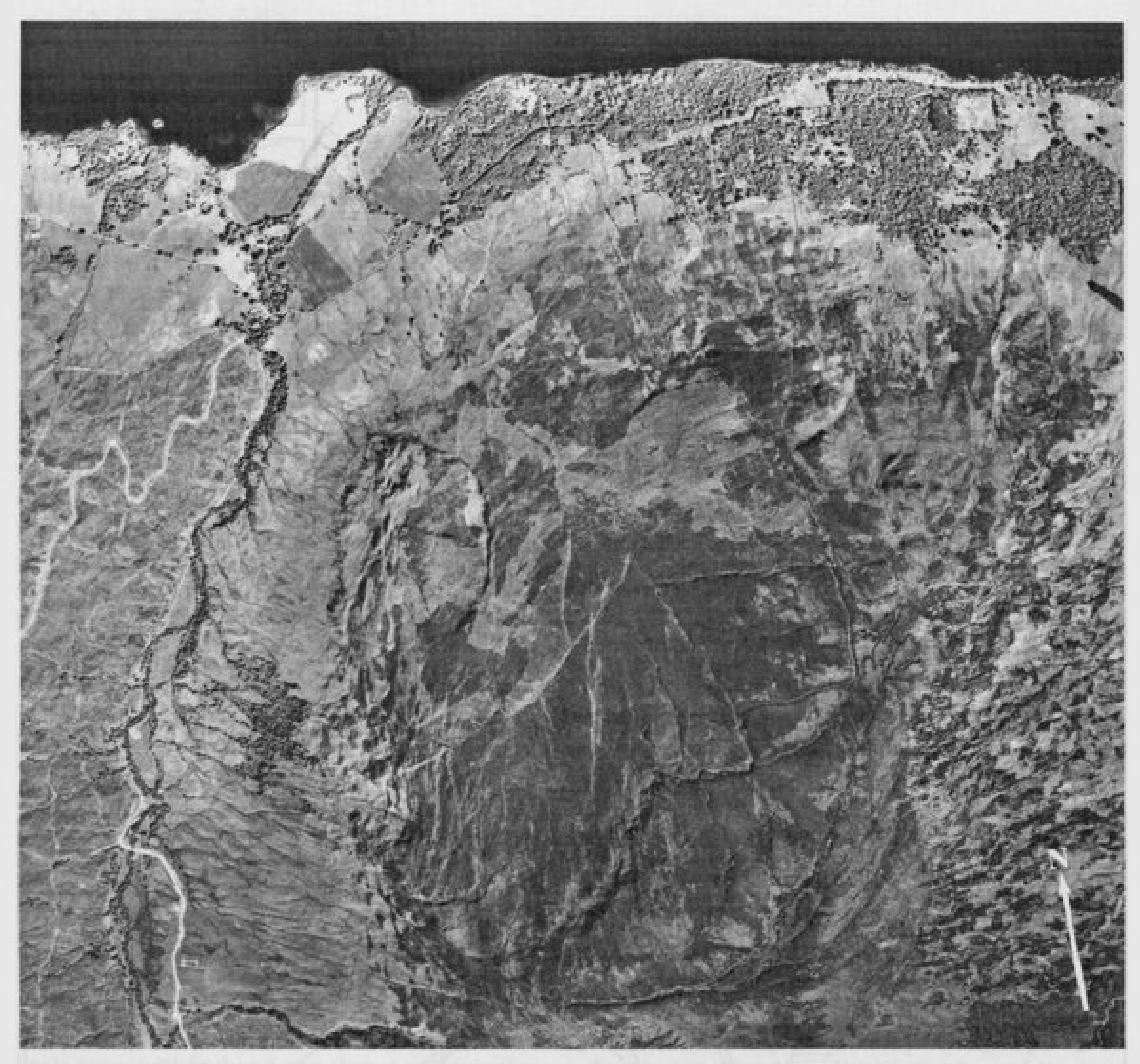
(Table 2.2) Rock slope failure (RSF) incidence, character, landshaping effect, and association with breaching in the Southern Highlands and Kintail area



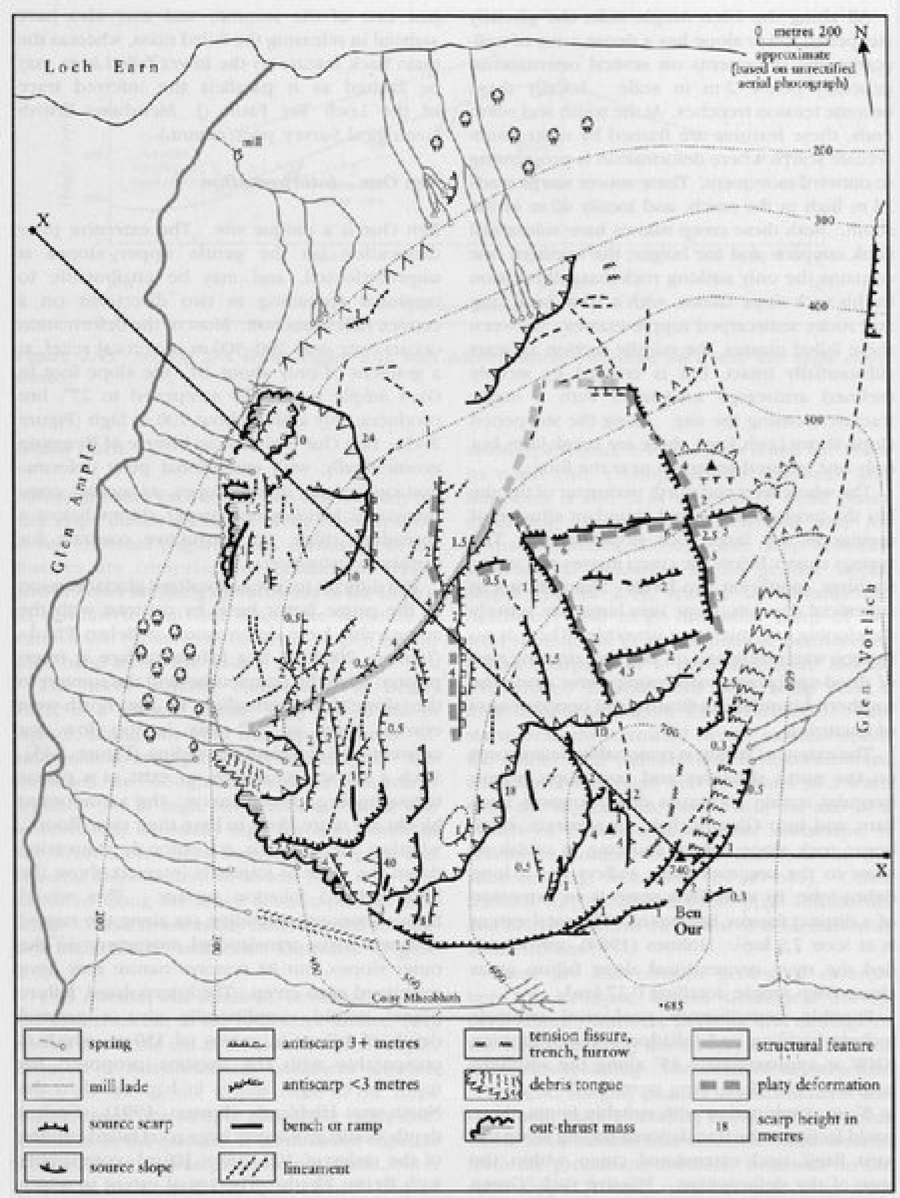
(Figure 2.39) Benvane and surrounding rock slope failures (RSFs) in their topographical context. This sub-cluster may be associated with glacial transfluence south-east across local watersheds, the breaches being at varying stages of development. Unlike the Glen Ample sub-cluster immediately to the north-east,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



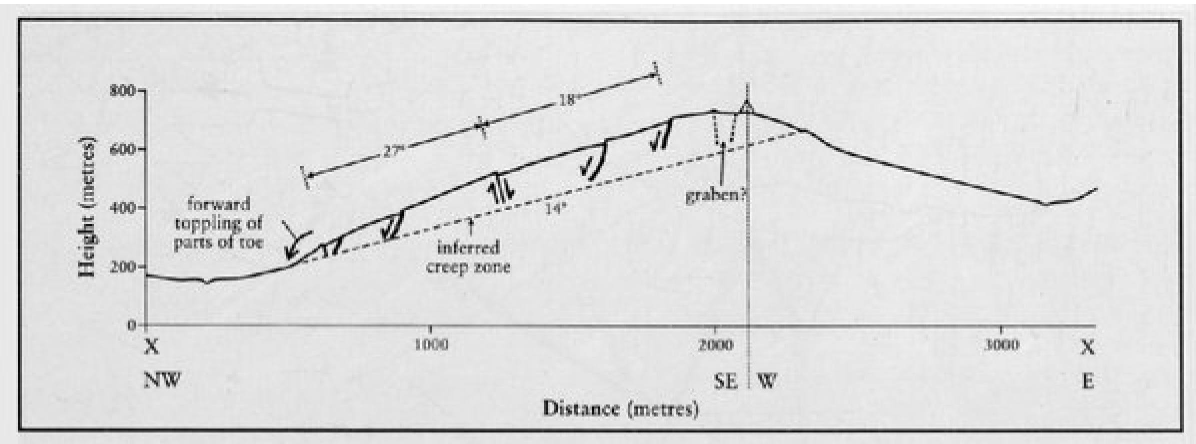
(Figure 2.13) Spatial distribution and size of 140 larger rock slope failures (RSFs) (> 0.25 km^2) in the mainland Scottish Highlands (distribution of all rock slope failures is similar). Rock slope failure is clustered on main watersheds that have been breached and displaced during Pleistocene times. It is scarce in ranges away from the watersheds, in the far north where ice cover was thinner, and in the eastern Grampians where glacial dissection is less intense. Sites reported in this chapter are shown. After Jarman (2006).



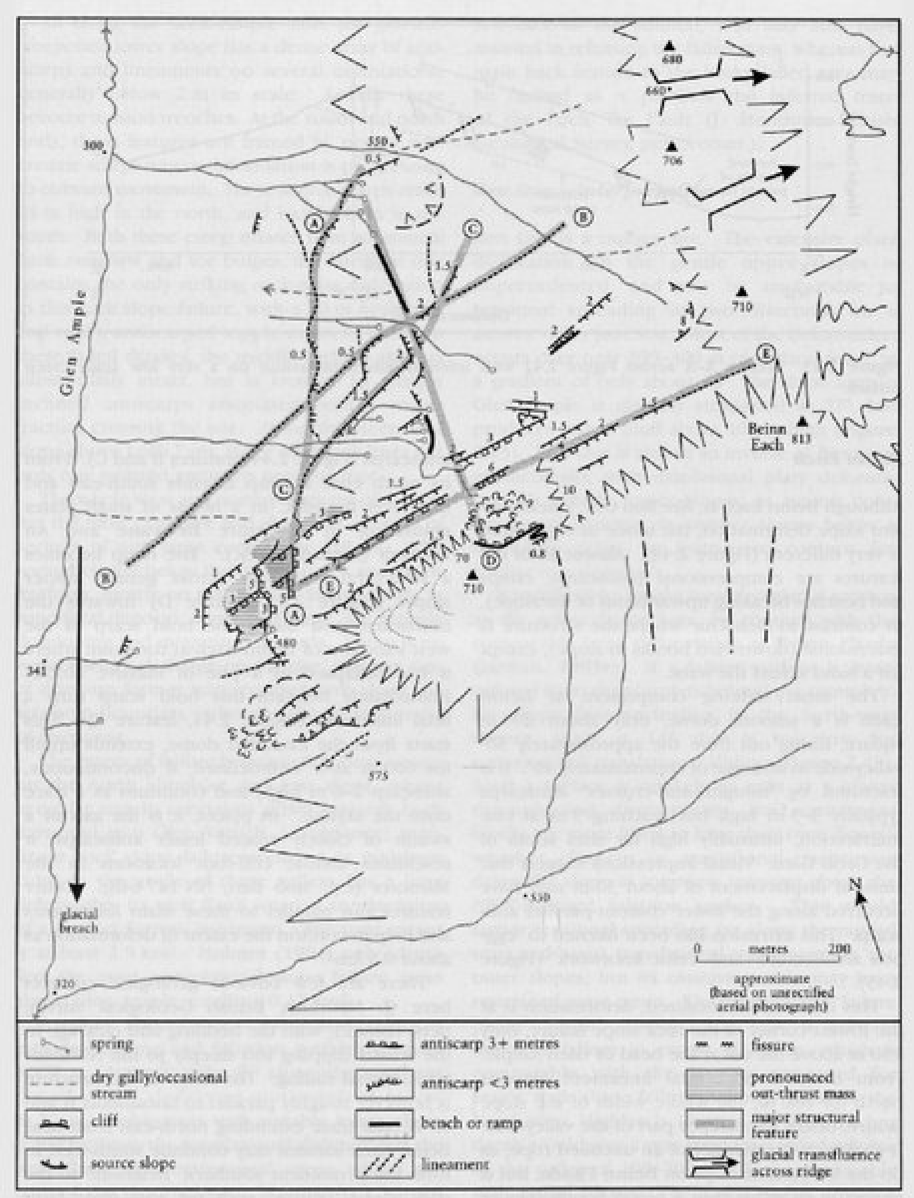
(Figure 2.41) Vertical aerial photograph (1989) of the Ben Our rock slope failure. (Photo: Crown Copyright: RCAHMS (All Scotland Survey Collection).)



(Figure 2.42) Geomorphological interpretation of the Ben Our rock slope failure, based on the unrectified aerial photograph with field verification.



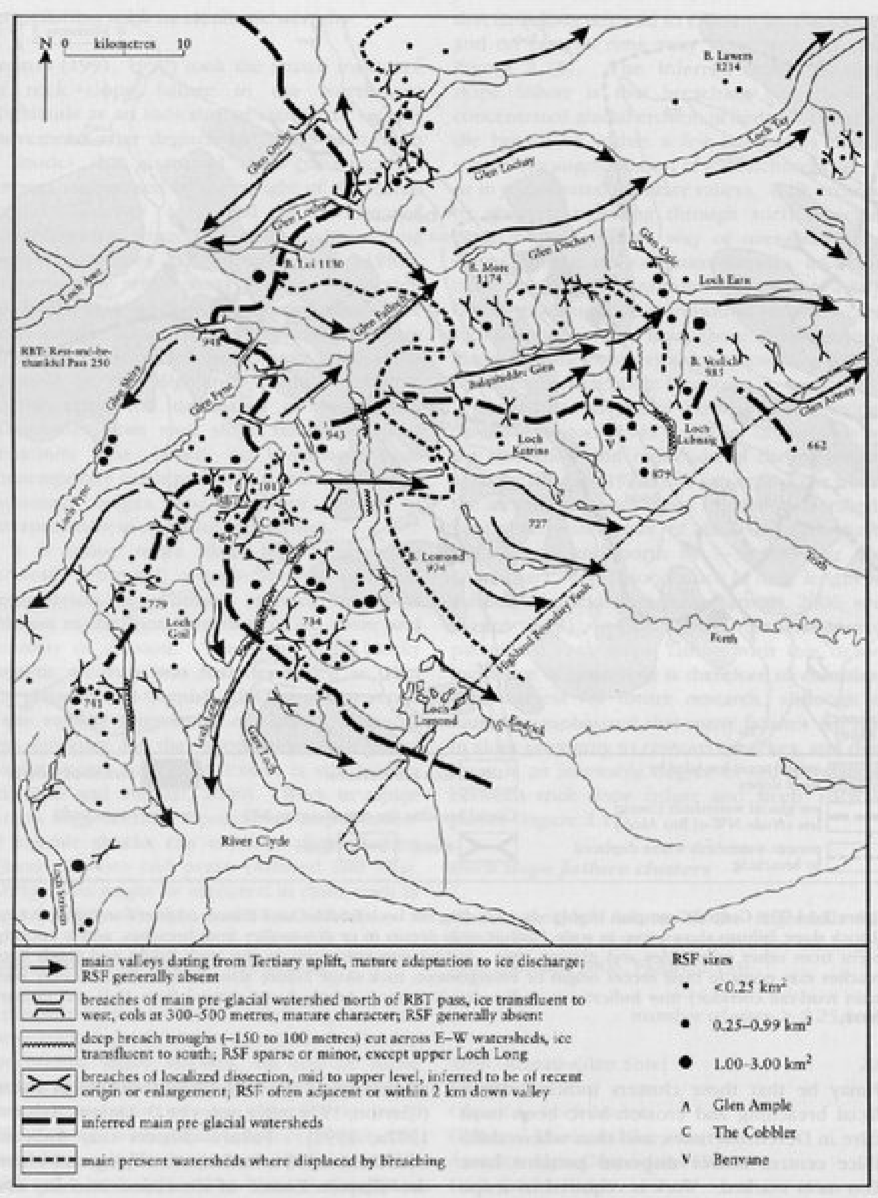
(Figure 2.43) Section X–X across (Figure 2.42) with inferred failure behaviour on a very low angle creep surface.



(Figure 2.44) Geomorphological interpretation of the Beinn Each rock slope failure. Features A, B, C, D and E are described in the text.

(Figure 2.45) Close-up of the Beinn Each rock slope failure nexus, suggesting extrusion of a component of the failed mass with fracturing along two joint-sets. (Photo: D. Jarman.)

(Figure 2.11) Na Gruagaichean rock slope failure complex, Mamores, Lochaber [NN 195 650]. The twin summits (centre and right) are divided by a 140 m-deep gash, the source of a very large wedge slide that has been substantially evacuated leaving a SW-facing bowl that is not a conic in origin or by adaptation, the floor of which is extensively ruptured with antiscarps up to 3 m high. Another large rock slope failure encroaches onto the south ridge (right), and a third slide lobe sharpens the north-west ridge (left-centre). (Photo: J. Digney.)



(Figure 2.15) The Southern Highlands, an area of intense rock slope failure (RSF) activity, including the Arrochar–Cowal–Luss and Trossachs–Lochearnhead clusters (clusters 5 and 7 in (Figure 2.13)). Failure is scarce or absent in main pre-glacial valleys and some breaches of the main watershed, despite their slopes and geology being susceptible to it. Its paucity along the deep breach trench of Loch Lomond is surprising. Note mini-clusters top-centre and top-right, where locally intense breaching occurs across main and secondary watersheds. The locations of three sites (Glen Ample, The Cobbler, Benvane) are shown. Adapted and revised from Jarman (2003a).