Benvane (Beinn Bhàn), Stirling

[NN 533 122]

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Introduction

Benvane is a major reference site for the diversity of rock slope failure modes and features in the old hard rocks of Britain (Figure 2.33), (Figure 2.34), (Figure 2.35). It displays a lateral progression from in-situ slope deformation to translational sliding. It is located on some of the lowest relief to give rise to extensive failure in the Scottish Highlands. Its boundaries are notably distinct, and it displays one of the finest and most extensive lattice antiscarp arrays in Britain, here, unusually, exhibiting three distinct orientations. The failure extends up to 120 m behind the brow of the broad ridge over a distance of 1 km, and is a telling indicator of the effect failure can have in wholesale reduction of relief in mountainous areas. With an area of 1.25 km^2, Benvane is one of the ten largest rock slope failures in the Highlands.

Description

The rock slope failure affects the west side of the broad, gently undulating south ridge of Benvane in the Trossachs area of the Southern Highlands. It has four distinct components: spreading ridge, lattice slope deformation, translational slide, and transitional zone (Figure 2.34) and (Figure 2.35). The ridge itself has failed for over 1 km south of the 745 m south top [NN 537 129], with a discontinuous zig-zag headwall locally expressed as a 5 m rockwall and 7 m grass scarp. This is set back 120 m behind the crest of the ridge at the north end and 80 m behind at the south end. At the north end, an array of 14 decimetre-scale furrows and antiscarp steps between crest and source scarp illustrates the pervasive fracturing of the bedrock.

The northern half of the rock slope failure is a slope deformation which presents a remarkable network of antiscarps well seen on aerial photographs (Figure 2.33). They follow three alignments; contour parallel (NNW–SSE), gently diagonal (NNE–SSW), and a few more widely spaced on a steeper diagonal (WNW–ESE) which nears vertical lower down. By contrast with the Beinn Fhada antiscarp array which attains heights of 5–10 m, this array generally attains less than 1 m in height, with many elements merely being benches; the WNW–ESE set locally reaches 3 m. Some of the intersections are finely detailed, and suggest platy tilt-outs ((Figure 2.34) (inset); cf. An Sornach, Jarman 2003c). This area of virtually in-situ deformation extends down to a more pronounced (1.5 m) lowest antiscarp at 420 m OD, which steps across the slope within a broad area where springs issue. Below it, a smooth, steep slope split by a vertical dry rupture, and a subdued slump zone, may extend the failure down to 350 m OD. The northern margin of this deformation is defined by a deep gully complex that cuts off at least eight anti-scarps or benches.

The southern half of the rock slope failure has developed into a long-travel translational slide (Figure 2.36). It has a degraded grassy head-scarp 26 m high at the apex of an irregular bowl (Coire Dubh) almost biting into the crest of the ridge at 610 m OD. The slide mass has descended almost to the slope foot at 230 m OD, protruding as a broad lobe with a 20–25 m-high basal rampart. Despite its viscous appearance, there is no evidence of disintegration to blocky or slumped debris in the failed mass. It displays a staircase of four widely spaced risers 4–30 m high; each tread has occasional 1–2 m antiscarps indicating some retention of coherence. The boldest riser could match intact slope steps to the south, representing an approximately 300 m translation downslope; it is cut by two streams with gorges in apparently intact bedrock, suggesting rafting of large failed slices. One of these streams emanates from a spring, but the other sources at 500 m OD within the bowl, indicating that the rock slope failure is well-consolidated. The southern flank of the failure is well defined and displays a classic transition, with the source scarp rapidly reducing in height until the slip protrudes from the slope to form a flank rampart that reaches 20 m high.

The most striking rock slope failure features are developed in a fourth component, transitional between the slope deformation and the slide bowl (Figure 2.37). The north flank of the bowl is highly irregular but attains 20 m in depth in places. It is incidented by four prominent antiscarps. The second highest is a wafer of quasi-intact slope with a 4.5 m-high rock anti-scarp as its uphill face that extends out into the floor of Coire Dubh; its downhill face is a crag above a zone of slippage with tensional anti-scarps. Adjacent to the headscarp of CoireDubh, another wafer with a fretted crest has slipped down approximately 10 m, opening a 4 m-deep tension trench. At the neck where it still attaches to the deformed slope, it transmutes into trifurcating antiscarps 0.5–2 m high. At the head of this transitional sector, a short 10 m rock crag is the most pronounced feature of the rock slope failure. It breaks back to become an obtuse wedge source scarp to a subsided section of the spreading ridge, which is some 400 m long and extends 80 m in from the ridge crest (Figure 2.38). A series of tension trenches up to 2 m wide and deep occur above the north side of this subsided wedge, and in its floor, on the WNW–ESE orientation, with the sense of movement being southwards down-ridge as much as valley-wards (cf. Sgurr na Ciste Duibhe).

Deranged drainage is a standard indicator of rock slope failure (Holmes, 1984) and here the pattern may provide pointers to the structure and sequence. It is unusual to have substantial streams flowing over a large slide lobe and incising its risers. It is also unusual to have extensive springs above the lowest antiscarp in the slope deformation zone, with the main source on a remarkable 50 m-wide front, although more conventional springs also occur at the north end of this antiscarp. The deformation otherwise lacks any surface drainage, even dry fluvial gullies as seen on Beinn Fhada (Jarman and Ballantyne, 2002).

Geologically, the underlying bedrock consists of Dalradian (late Cambrian–Precambrian) arenite and semipelite of the Ardnandave Sandstone Formation, which dip at 30°–55° south-east into the slope. The rock slope failure lies just northwest of a broad, large-scale monoformal fold hinge, termed the 'Downbend', which separates rocks to the south-east that dip steeply southeast from those to the north-west that dip at shallower angles. The 1:50 000 geological map shows a minor NE-trending fault across the north part of the site. It only marks the Coire Dubh area (0.55 km^2) as a 'landslip', whereas Holmes (1984) identified 0.91 km^2 from aerial photographs, and the full extent is 1.5 km^2. It is difficult to assess the volume of the translated debris in the southern half, since the cavities are only partially evacuated, and the slide plane is unknown. At a conservative depth of 20 m as expressed in the bounding features, the order of magnitude is approximately 10×10^6 m^3. There is even less evidence for the volume affected by deformation in the northern half. A plane exposed at source scarp and slope foot would slice 50–60 m off the ridge, and at an average depth of 25–30 m the failed, but still quasi-in-situ, mass could amount to an additional 15–18 x 10^6 m^3. The total failure volume is thus very substantial in Scottish Highland and north European terms (cf. (Table 2.3)).

Benvane lies within a structurally related cluster of rock slope failures (Figure 2.39). The aerial photographs show its NNW–SSE ridge-splitting component continuing as an erosional lineament, which then controls a shallow, arrested 0.24 km^2 landslip on the east side of the ridge in Gleann Casaig. To the north of the deformation, the geological map shows similar features recurring sporadically for 2 km along the midslopes almost to the col above Glen Buckie. On the opposite side of Gleann nam Meann, the south ridge of Meall Cala is nicked by a small but striking failure which well represents the classic acute wedge form of rock slope failure. It has a 20–30 m-high source plane on the dip of the schists, and a 12 m detachment scarp crag on the south flank.

Interpretation

In the absence of any geotechnical studies of Benvane, it can only be observed that the large translational slide has developed contrary to the dip of the schists into the slope, and has a generalized surface gradient of less than 20°, implying an exceptionally low-angle failure surface near the lower limit for sliding (Figure 2.35). The slope deformation component may have failed to progress to actual sliding for the same reasons: its steepest gradients of 280–35° are well above the residual friction angle for schists, but the plane exposed at source scarp and slope foot is approximately 23° (Figure 2.35). This deformation is of a platy character, with the strong but widely spaced WNW–ESE and north–south joint-sets guiding the rupturing of the main plates, and the contour benches and scarplets relaxing the stresses. The whole slope is in compression, with no open fissures. By contrast, the broad ridge above is in tension, with numerous furrows and trenches; their comparatively innocuous state suggests long inactivity.

No dates are available for Benvane, and it is not obvious whether the two main components have evolved simultaneously, or by later sliding within the original deformation. The slide bowl and lobes are comparatively degraded, whereas the deformation features are fairly sharp and well preserved given their small scale. However, the transitional area between them has much larger and bolder features, and represents progressive encroachment of the slide into the deformed slope and ridge, with two substantial secondary slips into the bowl at midslope, and incipient encroachment into the ridge above. Indeed the trench fissures around the obtuse wedge bite suggest that the zone of actual translational failure has migrated up-ridge northwards as well as headwards.

It is not obvious why extensive and deep-seated rock slope failure should occur in such an area of relatively low relief, well removed from the main mountain cores, and from channels of intensive selective glacial erosion such as Loch Lubnaig (Linton, 1940). Yet there are 10 failure complexes affecting 2.9 km^2 of the 43 km^2 around Benvane (Figure 2.39), a density of 7% which compares with some of the highest in Scotland (Jarman, 2003a,b). The cognate rock slope failure cluster at Glen Ample 8 km to the north-east records an exceptional density of over 16%.

Benvane therefore provides an excellent locus for research into the mechanics of rock slope failure, and the reasons for its occurrence. Of the two triggers commonly invoked, elevated water pressures at deglaciation seem irrelevant to a compressional slope deformation and gently spreading ridge. Benvane and Ben Ledi appear to have been nunataks during the Loch Lomond Stadial (Holmes, 1984), but most of the site was probably ice covered, and hence the delicate deformation antiscarps and low-level slide lobe must post-date it. A high-magnitude seismic trigger is at odds with the presence of large erratic boulders on the steep sides of some antiscarp trenches, and the slide is far from cataclasmic. There is no major fault crossing the site, although a branch of the Loch Tay Fault passes down Gleann Casaig. However this cluster of rock slope failures, and the Glen Ample cluster nearby, are close to the outer limits of the Loch Lomond ice, and probably at a point where the Devensian icecap gradient was in steep transition from highland to lowland terrain. Differential glacio-isostatic recovery may have been most acute here, generating slope stresses sufficient to provoke deformation and sliding in vulnerable situations.

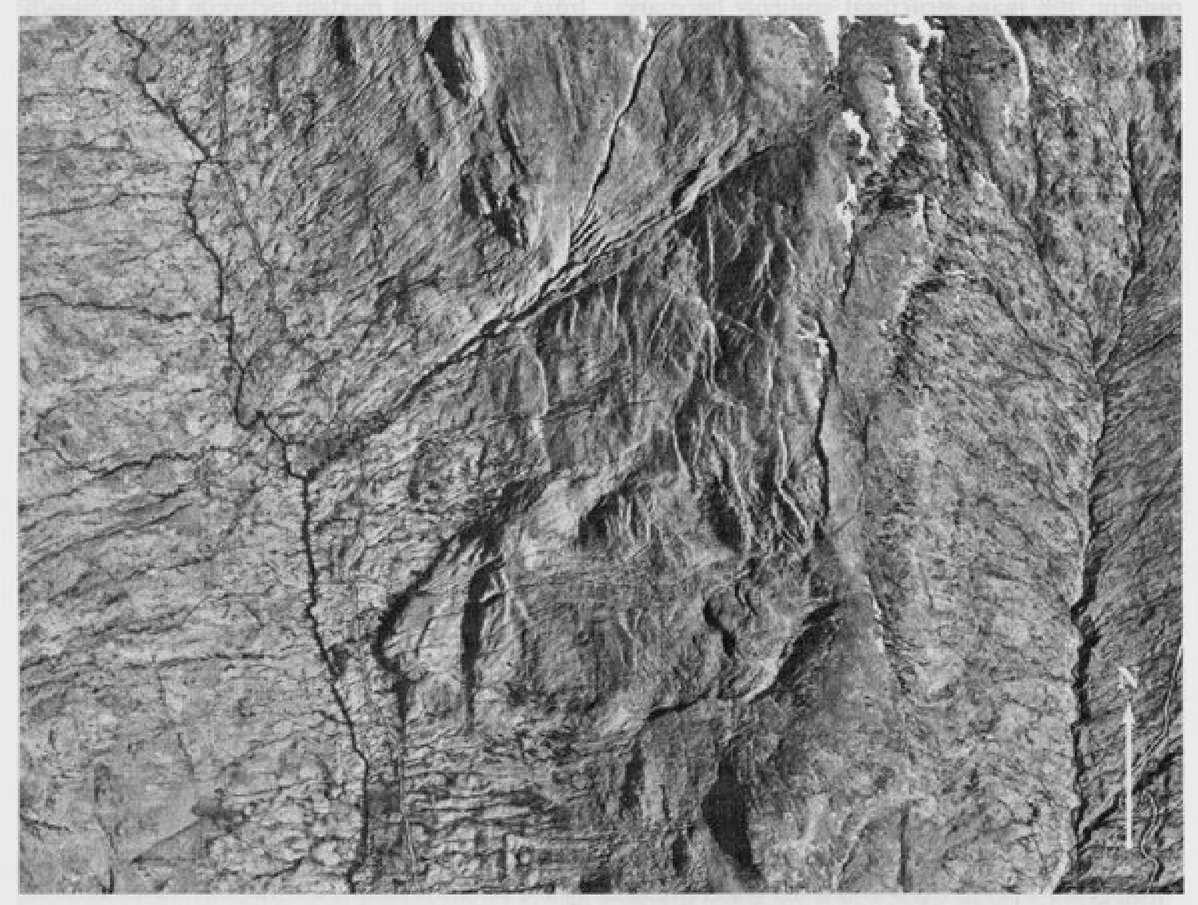
Rock slope failure is sparse or absent along the W–E-trending main valleys of pre- or early-glacial origin, such as Loch Katrine/ Venachar and Balquhidder, a pattern found throughout the Southern Highlands (Figure 2.15). The concentration of rock slope failure in N–S-orientated side-valleys may indicate an early stage in their enlargement by transfluent ice from the north. Glen Finglas and its two tributaries are a relict of the pre-glacial dendritic Forth drainage system (Linton and Moisley, 1960). Their heads show signs of glacial over-riding, and the 400 m OD col west of Benvane is an incipient glacial breach of the pre-glacial Forth–Tay divide (Linton, 1940). It is possible that glacial downcutting even in this lower-relief area has been sufficient during the Devensian glacial to destabilize the slopes of Benvane and its neighbours. Similar lattice anti-scarp arrays occur close to developing breaches in Glen Luss [NS 28 95] and near Tyndrum on Beinn Chaorach [NN 35 32].

The extant mountain-shaping effects of the Benvane rock slope failure are modest, but the scale of incipient encroachment is so great as to render the whole south ridge vulnerable to reduction and eventual 'divide elimination' (Linton, 1967).

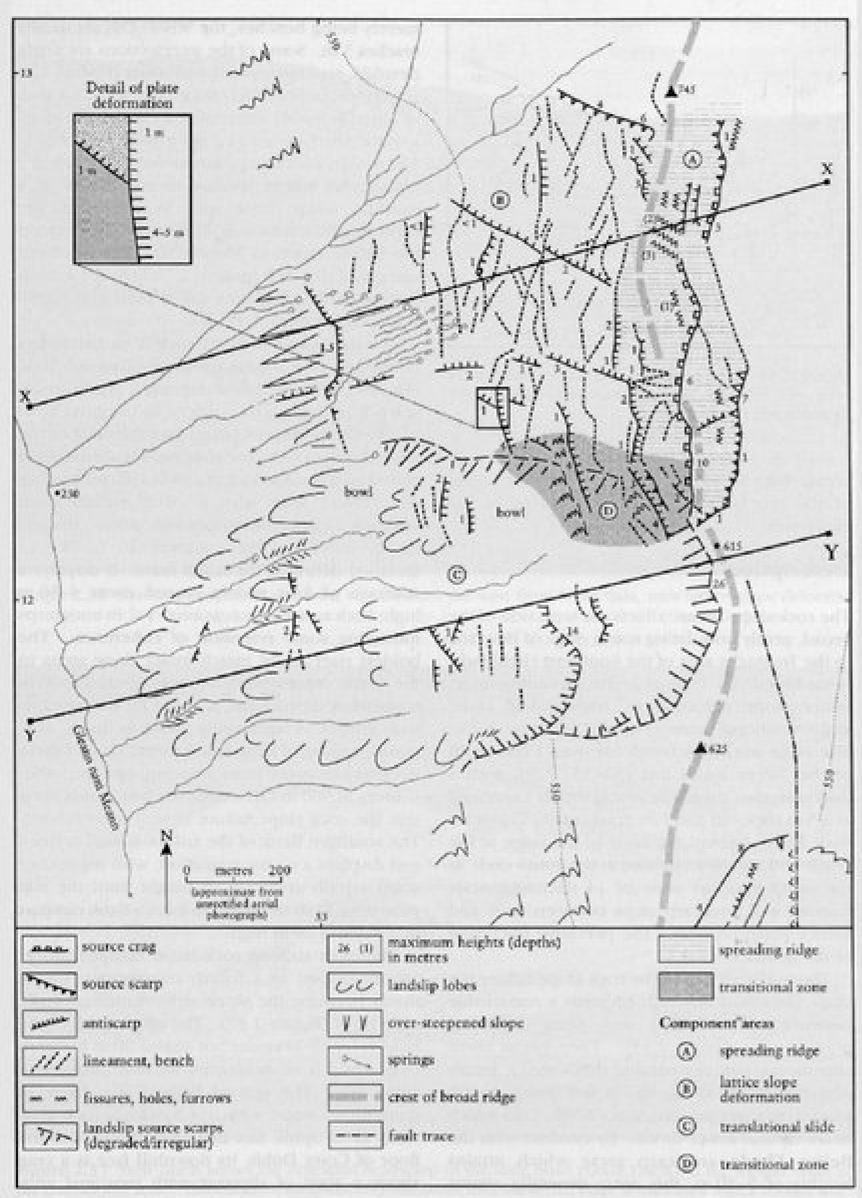
Conclusions

The Benvane rock slope failure complex is an outstanding example of quasi in-situ slope deformation, with one of the finest and most extensive lattice antiscarp arrays in Britain. It displays lateral progression to a deep but degraded, long-travelled but coherent translational slide. The interface between these two zones is made conspicuous by rock slope failure features of much fresher character. Deformation encroaches into the broad summit ridge scale, and demonstrates the past and potential contribution of failure to large-scale erosion. Benvane also affords instructive comparison with the Glen Ample failure cluster as a platy deformation on steeper valley slopes, as compared to more gently sloping upland. It provides an excellent basis for research into the mechanisms, triggers, and underlying causes of rock slope failure in mountain areas of relatively lower relief.

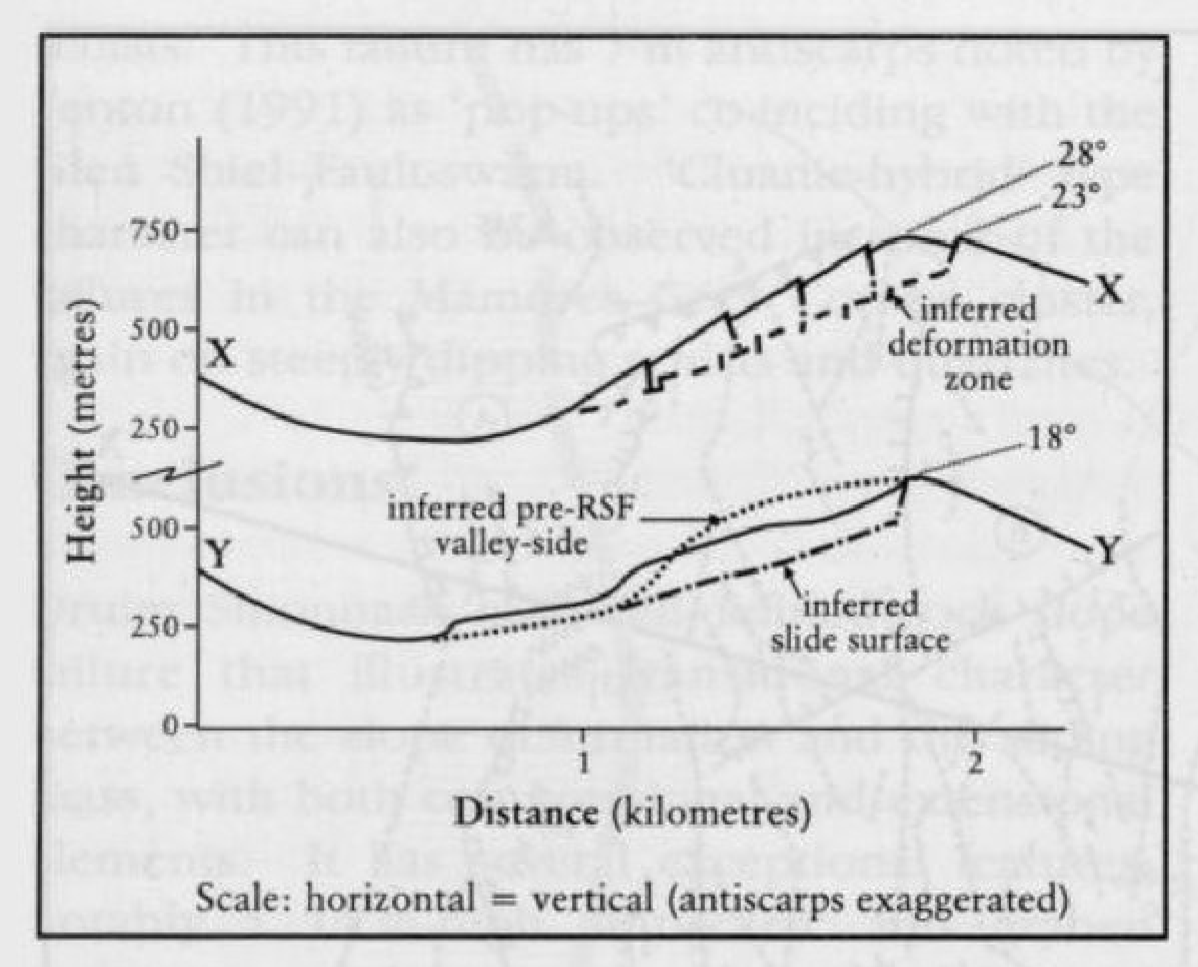
References



(Figure 2.33) Vertical aerial photograph (1989) of Benvane, with sun from the east accentuating the array of anti-scarps, scarplets and benches. (Photo: Crown Copyright: RCAHMS (All Scotland Survey Collection).)

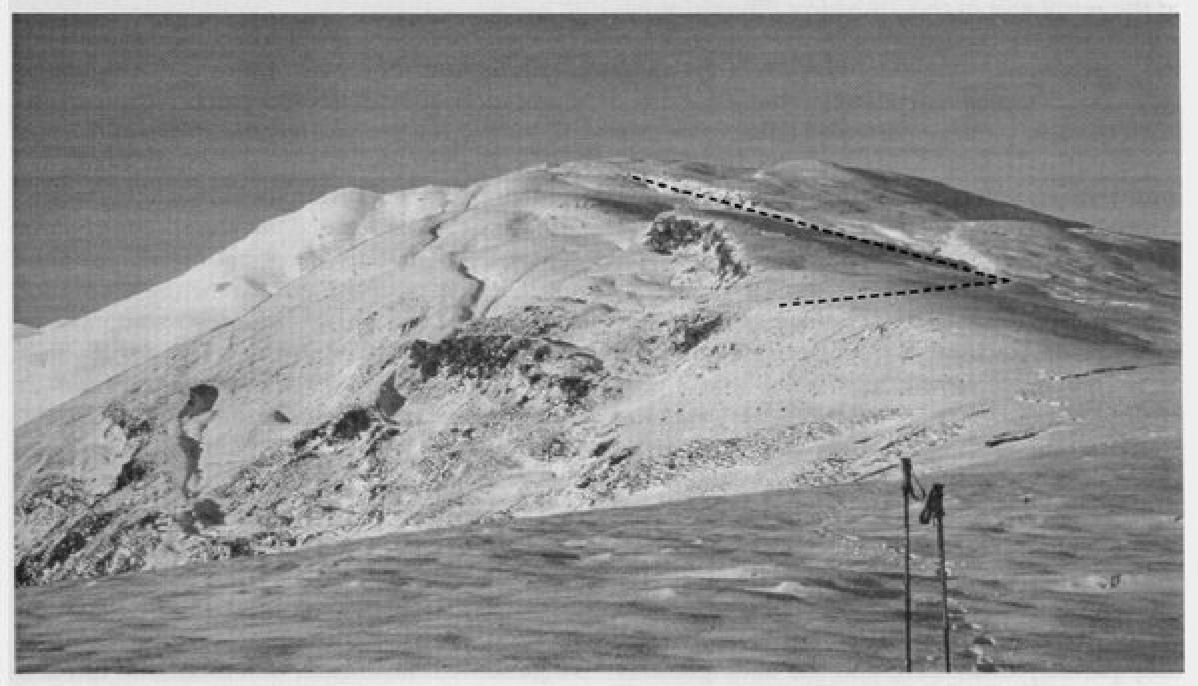


(Figure 2.34) Geomorphological interpretation of the Benvane rock slope failure complex. Based on unrectified aerial photograph with field verification.

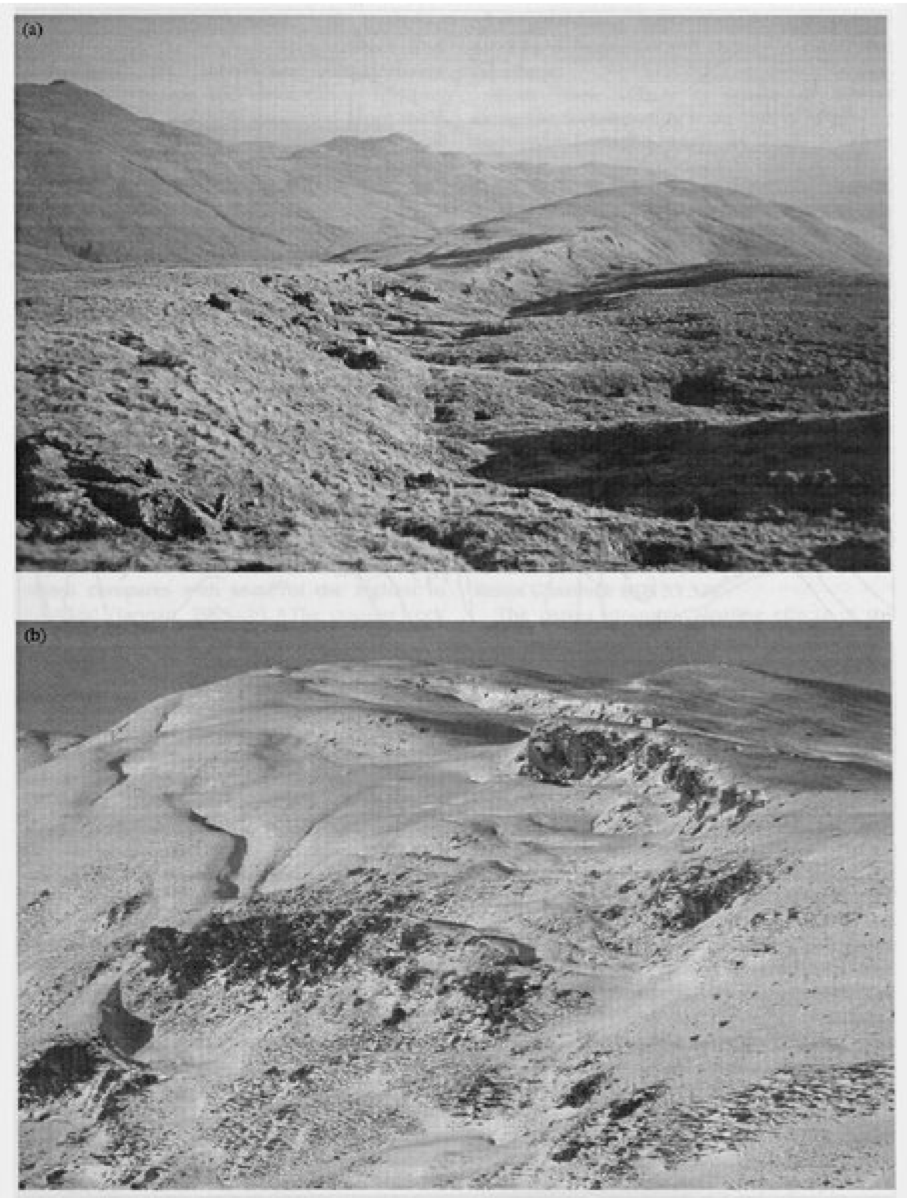


(Figure 2.35) Sections X–X through the deformation zone and Y–Y through the translational slide. For locations see (Figure 2.34).

(Figure 2.36) Benvane slide bowl and lobe, viewed from the west from Meall Cala, with lattice slope deformation upper-left; extensive springs can be seen above the lowest antiscarp centre-left. (Photo: D. Jarman.)



(Figure 2.37) View north across the degraded headscarp of the slide bowl (Coire Dubh to the fresher crags of the transitional zone. The extent of incipient encroachment into the broad ridge is indicated with a broken line. (Photo: D. Jarman.)



(Figure 2.38) (a) View south down the spreading ridge to the slide bowl. The 6 m-high source scarp to the subsidence graben is not the limit of encroachment in to the ridge, the true headscarp being just visible on the left edge. (b) A close-up view across the slide bowl of the transitional zone extending into the spreading ridge. (Photos: D. Jarman.)

RSF	Ref.	Mode	Area km^2	Vol. $\times 10^6 m^3$	Depth m	H/S m	A/S m	Slide plane	Comments
Loch Vaich, Ross-shire	2	ext def	0.5		>50?		2	J low angle	Short-travel (50 m) slip, forward toppling on 60° F
Sgurr Dhreac, Fannich	2,3	ext def	0.82	30?	?	30	5m	?	Sackung with lattice of fissures
Beinn Alligin, Torridon	1,2	cata	0.52	3.5	200 20 #1	60	–	42°	Acute faulted wedge in sub-horizontal sandstone
Glensaug, Strathcarron	2	ext def	0.7		?	<5	<2	F 15°+	Short-travel sliding slump, incipient fissuring
Sgurr na Coinbhaire, Monar	2,6	sub-cata	0.55		150		2	F 30–40°	Long-travel (150 m) slump onto lower slope
Sgurr na Feartaig, Strathcarron	2	ext def	0.9		100?	2	yes	F	Short-travel block slide
An Socach, Monar	2	comp def	1.0	–	20?	nil	sm	–	500 m long, linear A/S diffuse margins – rebound
Carn na Con Dhu, Mullardoch	2,3	slide	1.46	61?	120?	12 55?	2	not on F/J	Short-travel slide/slump, A/S <200 m long on strike of J1+J2
An Sornach, Affric	2,3,4	ext def	0.75	15?	50?	42	5	not F/J	Slip with A/S lattice > bulge > collapse. Rebound 5 m A/S
Mullach Fraoch-choire, Affric	3	sub-cata	0.2	0.75	20	10	–	J2,3 29°	Slide tongue within 1.1 km^2 slope deformation
Sgurr na Lapaich, Affric	2,5	comp def	0.3	7?	100?	10	–	–	Ridge crest failure, possibly seismic/rebound fissuring
Beinn Fhada, Kintail	2,5,4,6	comp def	3.0	112 #2	100?	none	10	–	~8 sub-horizontal A/S < 700 m long, main ones are 5–8 m high
Sgurr na Ciste Duibhe, Glenshiel	5	ext def	1.25	5–10 #3	80	15	(11) 5	not F/J	Summit lowered ~10 m > long-travel slide in deformation
Sgurr a' Bhealaich Dheirg, Glenshiel	2	comp def	0.7		100?		6	–	Bulging slide, rebound A/S < 200 m long
Coire Dhubh, Affric	5	sub-cata	0.66	7	80	30	2	?	Corrie-floor source, toe reaches river in breach glen
Druim Shionnach, Cluanie	5	comp def	0.55	–	150?	25	(15) 5	–	Top A/S is outer half of graben > Cluanie bulge
Meall Buidhe, Knoydart	6	ext def	0.5		40?	30	7?	J1,2 < 44°	Broad slump zone
Maol na Cloiche Airde, Knoydart	6	sub-cata	0.26		60	20	–	35°	Semi-intact masses > slope debris > 5° flow slide
Glen Pean, Knoydart	6	comp def	2.5	–	60?		–	J1 28–68°	A/S array on strike of F/J2, cataclasmic slide to west
GREAT GLEN									
Streap, Glenfinnan	6	Slide	0.25		25	75	(10)	J1 36°	Long-travel arrested sub-cataclasmic summit has lost top ~15 m, seismic trigger?
Beinn an Lochain W, Arrochar	6	ext def	0.84		15?	<5	<2	F 20–50°	Thin, undeveloped slide, upper toe breaks
The Cobbler SW, Arrochar	4	slide	0.62	8–10	40	28	(10) 6	not F	Four-panel, short-travel, disintegrated slip
Hell's Glen, Cowal	4,6	ext def	0.52	1.75 (+)	60	15	(15) 5	J2 40–50°	Topple block slips and collapses in broad slump
Mullach Coire a' Chuir, Cowal	6	slide	0.57	9.6?	20	50	(12) 2	F + J2	Part-collapsed sliding topple on stepped surface
Meallan Sidhein, Loch Striven	6	slide	0.75		70	40	–	F 25–32°	Slip in phyllite, effective F slip 20°, equals RFA
Tulloch Hill West and East	4	slide	1.25 in total			40	8	not F	Short-travel, multi-phase, slump complex
Benvane, Trossachs	4	def slide	1.25	25	20–30	26	3	not F	Deformation progresses laterally to slide
Ben Our (**Glen Ample**), Lochearnhead	4	def	2.90	100–200?	150?	4	4	–	Platy deformation with basal slumps

Footnotes:

'**Ref.**': reference sources are (1) Ballantyne, 2003; (2) Fenton, 1991; (3) Holmes, 1984; (4) Jarman, 2003c,d,e, 2004a, and present volume; (5) Jarman, 2005b; (6) Watters, 1972.

'**Mode**': cata = cataclasmic; sub-cata = sub-cataclasmic; ext def = extensional deformation (sag, creep); comp def = compressional deformation (rebound).

'**Area**': RSF size is here taken as the gross area including source cavity, since most cases are incompletely evacuated. British Geological Survey mapping of RSF is variable and incomplete, but recent sheets only map as 'landslips' disturbed ground, thus excluding both source areas and semi-intact slope deformations. The gross area best indicates the geomorphological impact of the RSF, but clearly requires adjustment when volumetric calculations are made.

'**Vol.**' (same) and maximum '**Depth**' should be seen as broad estimates, especially sites marked '?' where the depth cannot readily be assessed.

#1 depth figures are for cavity (ref. 2) and debris tongue (ref. 1);

#2 volume (ref. 5) assumes there is a failed mass with a boundary at ~100 m, no volume can be calculated if the failure partly dissipates at depth;

#3 volume and depth are for main cavity within larger deformation.

'**H/S**' = headscarp (rear scarp, source scarp) maximum height.

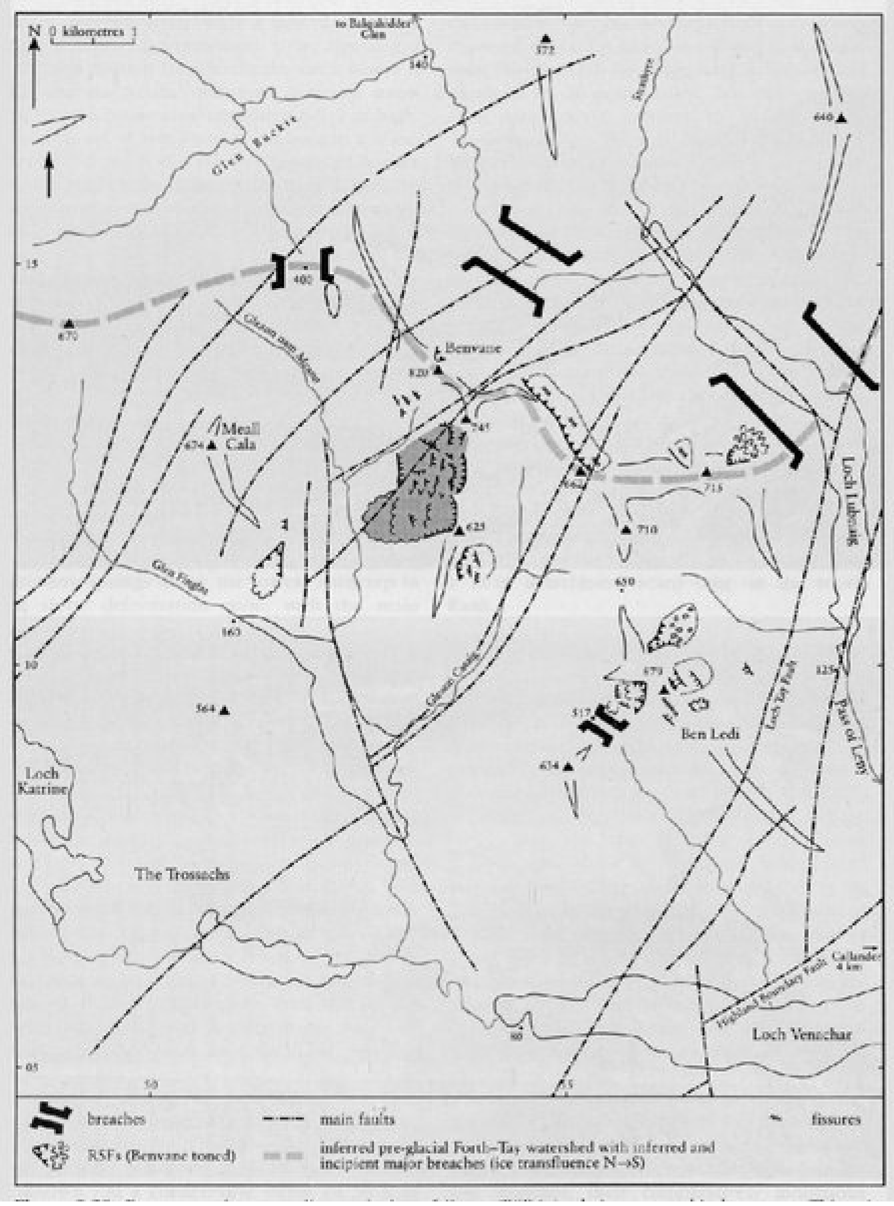
'**A/S**' = antiscarp (obsequent scarp, counterscarp, uphill-facing scarp) maximum height – figures in brackets are graben trenches or uphill faces of large slipped masses.

'**Slide plane**': F = foliation or schistosity surface;

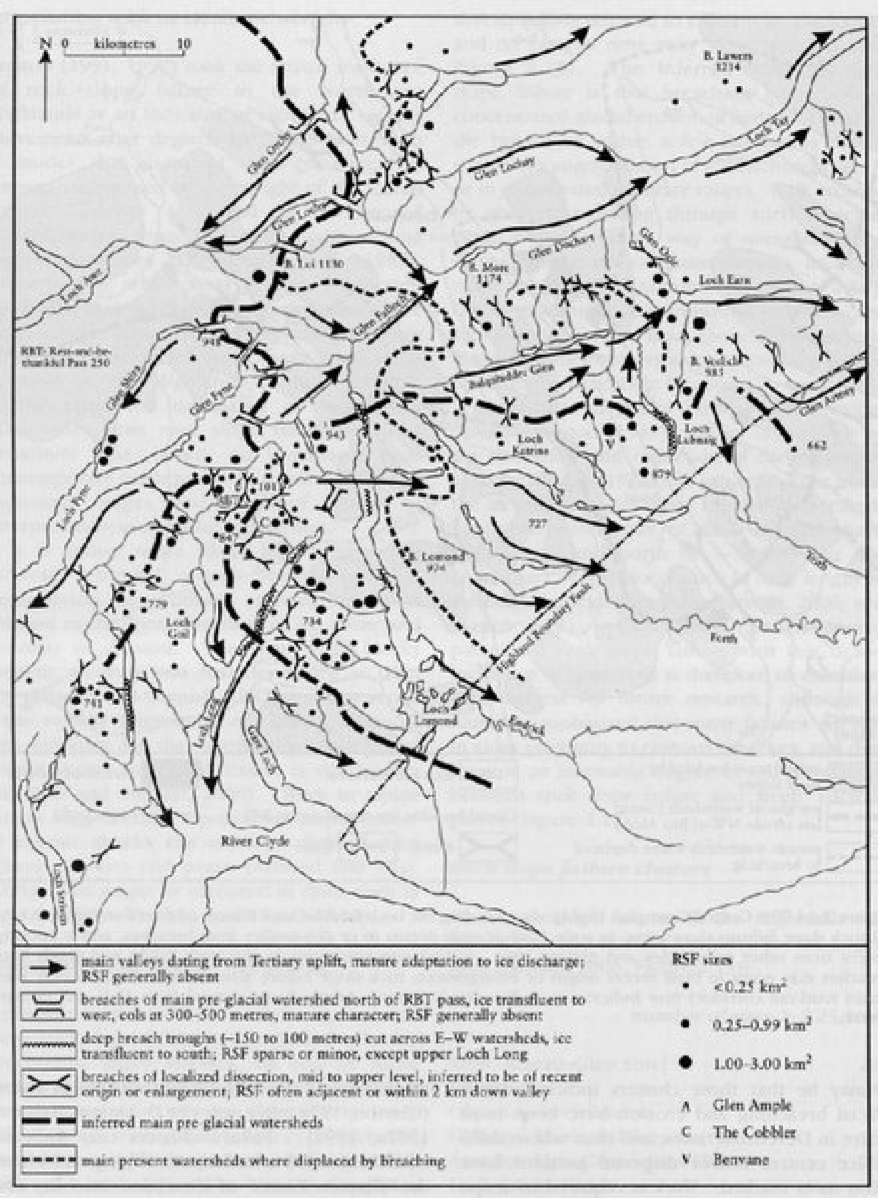
J = joint-sets (in order of significance);

RFA = residual friction angle

(Table 2.3) Large rock slope failures (RSFs) in the Scottish Highlands for which data are available.



(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 2.15) 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).