Llyn-y-Fan Fâch, Carmarthenshire

[SN 801 215]

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Introduction

On the scarp face of the Black Mountain, facing northwards above Llyn-y-Fan Fâch, a number of deep gullies are cut through the vegetated scree surface (Figure 4.5) and (Figure 4.6). In some cases they reach the underlying bedrock for part of their length. Debris-flow activity is episodically taking place along the gullies' axes at the present time, transporting material derived from the gully sides by wash and other processes (Statham, 1976).

The Black Mountain is part of the north-facing Old Red Sandstone (Devonian) escarpment in south Wales. The scarp face above Llyn-y-Fan Fâch consists of a headwall of alternating hard sandstones and soft silty shales. The slope is about 60 m high, and stands at an overall angle of 45°–50°. Two prominent chutes/avalanche couloirs cut the upper slope of the headwall (Ellis-Gruffydd, 1972). Against the lower part of the headwall a scree-slope has accumulated, which is now well vegetated. The scree debris includes a significant proportion of coarse to fine sand-sized material, occupying the interstices between the boulders. Statham (1976) gives an average grading curve envelope for the scree material (Figure 4.7). Transport of debris down these gullies is resulting in the accumulation of debris-flow cones below the gully mouths. The cones are broadly concave in profile but irregular in detail as they are composed of a criss-cross accumulation of old debris-flow levees (Statham, 1976).

Debris flows are rapid mass movements of poorly sorted debris with a high water content. They are often associated with rockfalls from cliffs farther upslope, and tend to occur on talus that has accumulated from such rockfalls. Typically they follow a well-defined path as a fluid-like mass, leaving small linear ridges or levees on either side of their trail as they move. Sharp (1942) observed that quite rapid rates of movement (30–40 cm s^{-1}) are necessary for levees to be built. The levees have a high percentage of boulders, which are in a matrix of fine-grained sediments, and become concentrated at the head of the flow, partly blocking progress downslope until they are pushed aside by the advancing flow. The channel between the levees may or may not be eroded by passage of the flow, but if it is not it is usually free of any deposition.

Grass surfaces have been observed free of debris and entirely undamaged between levees (Rapp, 1960), indicating that basal shear, which may not always occur, is not great in such flows. However, many trails are not grassed over, because they erode their beds, and are, effectively, self-feeding. Trails tend to be a few centimetres to a few metres in width, with levees from about 1 cm to 1 m in height. Each flow generally transports anything from a few cm^3 to a few m^3 of material only. Many flows are single events, with no tendency for future flows to be concentrated along former lines, but more often flow activity is concentrated along a line to form a gully and a low-angled debris-flow cone of accumulation at its base (Johnson and Rahn, 1970). Debris flows almost always occur as a consequence of heavy rainfall or snowmelt. Mobilization may be due to the presence of a sub-surface, concentrated seepage line beneath the debris, which causes high porewater-pressure (Prior *et al.,* 1970). In the case of debris flows initiated in gullies, mobilization is a result of steady dilution of debris by water, rather than a steady increase in sediment content of a stream (Johnson and Rahn, 1970; see Iversen and Major, 1986; Addison, 1987). Movement probably begins as a slide but subsequent motion incorporates more water into the mass when it may behave as a fluid.

The Llyn-y-Fan Fâch GCR site was selected to represent well-documented debris-flows of a kind that is potentially atypical. Debris flows are a major and widespread type of mass movement in Great Britain, many occurring as relict periglacial forms (Ballantyne and Harris, 1994).

As well as being a mass-movement GCR site, the area was independently selected for the GCR for its Quaternary features of interest (Campbell and Bowen, 1989) and its fluvial geomorphology (Higgs, 1997).

Description

The Black Mountain debris-flows themselves are quite small, the tracks being from 1 m to 1.5 m in width with levees from 0.3 m to 0.4 m high (Figure 4.8). The uniformity of size, observable in recent flows and numerous old flows, is striking. On leaving the gully mouth, recent flows enter a short section undergoing erosion across the accumulation cone, but are then entirely depositional. Most have continued to move until nearly all of their load was deposited as levees, so that very little of the original mass can be found at the end of the flow track.

In profile, the steeper and straighter original scree has been replaced by a long, continuously concave profile along the gully axis. This concavity declines steadily in angle from about 40° at its top to about 8° at the base, and from the lowest bedrock exposure to the foot of the profile approximates well to a circular arc with radius of curvature about 310 m (Statham, 1976; (Figure 4.9)). There is no difference in curvature between the gully and the accumulation cone and so it seems reasonable to suggest that the entire form is continuous, controlled by the debris-flow process.

Debris flows are initiated in the gullies, at locations where the slope is between 27° and 37°. The gully sides attain a maximum stable angle at 43.5° when dry. Coarse debris with negligible clay- and silt-size percentages may be considered effectively cohesionless, and following this assumption Statham (1976) takes maximum gully-side angle as 'probably a reasonable estimate' of the lower repose angle, $ø_r$', for scree origins which involve a debris slide rather than gully flow and erosion.

Debris flows are easily formed by heavy rain and snowmelt yielding gully flow, which leads to erosion and gully-side collapse. Debris slides at the head increase the solids content, and when solids become 79% of the total by weight, the behaviour changes from mass transport to mass movement. The Statham (1976) model only considers the slide (the soil mechanics), not hydraulic or rheological models.

Assuming an infinite cohesionless slide analysis (after Skempton and DeLory, 1957) and taking o_r' to be 43.5°, debris accumulating in the gully bottom due to erosion of the sides would be quite stable and would not begin to slide until the pore-pressure ratio r_u attained 0.15–0.4. For the debris to remain mobile after sliding r_u must increase steadily along the gully axis as slope angle declines. There are two mechanisms which might cause such an increase. Firstly, as suggested by Johnson and Rahn (1970), water may be added from rainfall and flow from the gully sides, which would lead to increasing water content and pore pressure as the debris moved down the gully. Secondly, accumulated material sliding from the upper part of the gully may over-ride already saturated debris in the lower part and cause undrained pore-pressures by rapid loading. Hutchinson and Bhandari (1971) have already suggested that undrained loading is important in the mobilization of coastal mudslides.

On surveying the cones illustrated in (Figure 4.10), Statham (1976) observed that six recent debris-flow trails changed without exception from erosion to deposition when the slope fell below 16°. Contrary to the observations by Rapp (1960) already described, Statham (1976) found that, in the debris flows at Llyn-y-Fan Fach, flows in the gully and steeper part of the cone increase in size by incorporation of debris at the base, whereas they decline by deposition of levees on the gentler section of the cone. Thus, movement over the lower part of the cone is not so much a reflection of very high pore-pressures but more of the inertia of the flow, as velocity declines on the lower angled section. The change from erosion to deposition implies that 16° is the transit slope for these flows: the slope over which movement takes place without erosion or deposition. If this is the case it must also mean that flow velocity is such that drainage of porewater out of the debris is precluded and pore pressures are maintained. Assuming the flow behaves as a shallow infinite slide (which is open to question), a pore-pressure ratio of about 0.65 would be necessary to keep the slide going in this material. This is in excess of hydrostatic pore-pressure, which is about 0.5 for a material of unit weight about 2.0 tonnes m^{-3}.

Statham (1976) monitored the volume of sediment derived from the sides of one gully (gully B in (Figure 4.10)) and the volume transported to the accumulation cone of all three of the gullies in (Figure 4.10). He found that the rate of lowering is much greater on the west-facing gully-sides than the east-facing sides. This has resulted in valley asymmetry in the gullies, the western slopes being both the steeper and the more unstable. Measuring the mean rate of surface lowering from the western- and eastern-facing gully-sides as 1.56 cm and 0.33 cm respectively, total yield of sediment to the gully bottom was calculated as 8.4 m^3 for the year. The volume shifted by one debris-flow from this gully was 9.8 m^3 and estimated volumes of another three flows from the three gullies (not necessarily in the observation year) were very similar, from 8.3 m^3 to 11.5 m^3. In consequence, the amount of sediment produced by surface lowering of the gully sides is roughly equal to that moved from the gully by debris-flow activity in one year. Naturally it is recognized that these quantities are only very approximate due to the methods used, and that the time-period of one year may not be sufficient to give a reliable overall picture. Nevertheless, it appears that input of sediment to the gully is balanced by output in debris flows, implying that sediment movement by other processes such as stream flow is negligible. This is supported by the fact that even in very heavy rain Statham (1976) did not observe any surface-water flow in the gullies except where bedrock was exposed in the base.

Although they were not observed, it seems likely that the flows took place on a day of heavy rain, since Prior *et al.* (1970) observed flows on days with 37 mm and 58 mm of rain in north Antrim. But although heavy rainfall was the most likely trigger mechanism, daily rainfalls of over 30 mm occurred on 16 occasions in the observation year, and on three occasions over 60 mm, with no associated debris-flow activity. Statham (1976) interpreted this as indicating that the debris-flow process is controlled by the rate of accumulation of loose sediment in the gully bottom and is not specifically a result of high-intensity rainfall. Thus, when there is sufficient material in the gully, a debris flow will occur. A storm is necessary to trigger the flow, but there is no shortage of storms of the necessary intensity and so the trigger is not an effective process control.

However, there is a substantial body of literature suggesting that availability of debris is the main control.

Interpretation

Given the occurrence of high-intensity rainfall, there seems to be very little climatic control on debris-flow activity (Statham, 1976), with a remarkable similarity of style and form of movement and of topographical situation in which flows are initiated. As the volume of the instrumented gully is 540 m^3, with removal of 8–10 m^3 per year, it cannot be more than 540–700 years old, assuming that the annual rate of removal has remained constant. Furthermore, there are no new gullies being initiated on the scarp and all the existing ones are in roughly the same state of development. It seems likely that some environmental change in the recent past was responsible for the initiation of debris-flow activity. Innes (1983) has noted similar initiation of debris flows in the recent past across the whole of upland Britain, and attributed this to environmental change, possibly deliberate fire-setting. Statham (1976) suggests that the causative environmental change at Llyn-y-Fan Fâch may have been the introduction of intensive sheep grazing in the area, resulting in damage to the vegetation surface and exposure of bare ground.

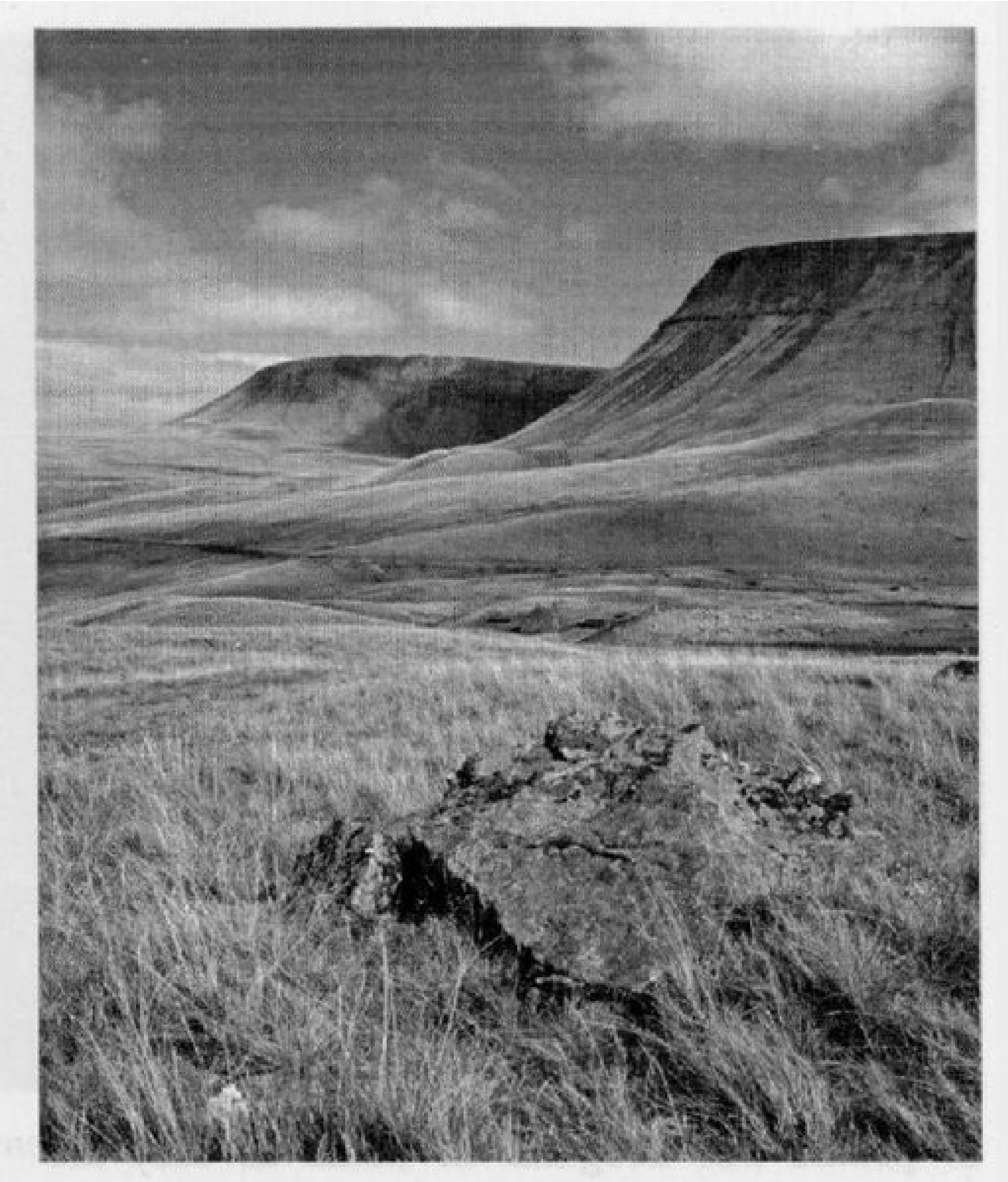
Therefore it seems that the progressive replacement of the straight scree-slopes of the Black Mountain scarp by a series of low-angled, concave debris-flow cones is a very recent change in process in the geomorphological timescale. Debris flows are initiated by heavy rainfall: this acts as a trigger, but does not control debris-flow activity. They probably require a minimum volume of material before mobilization can occur and are therefore controlled by the rate at which sediment is produced by gully-side lowering (Statham, 1976).

In a specific comparison with Statham's (1976) observations at Llyn-y-Fan Fâch, Ballantyne and Harris (1994) point out that Ballantyne (1981) observed at An Teallach in northern Scotland, that the transition at which deposition succeeds erosion occurs at 20°–28°, rather than the 16° observed by Statham. Similarly, while Statham observed the Black Mountain flows to come to rest on a slope of 8°, those at An Teallach stop on gradients of 11°–23°. They remark that these differences may reflect greater flow viscosity at An Teallach.

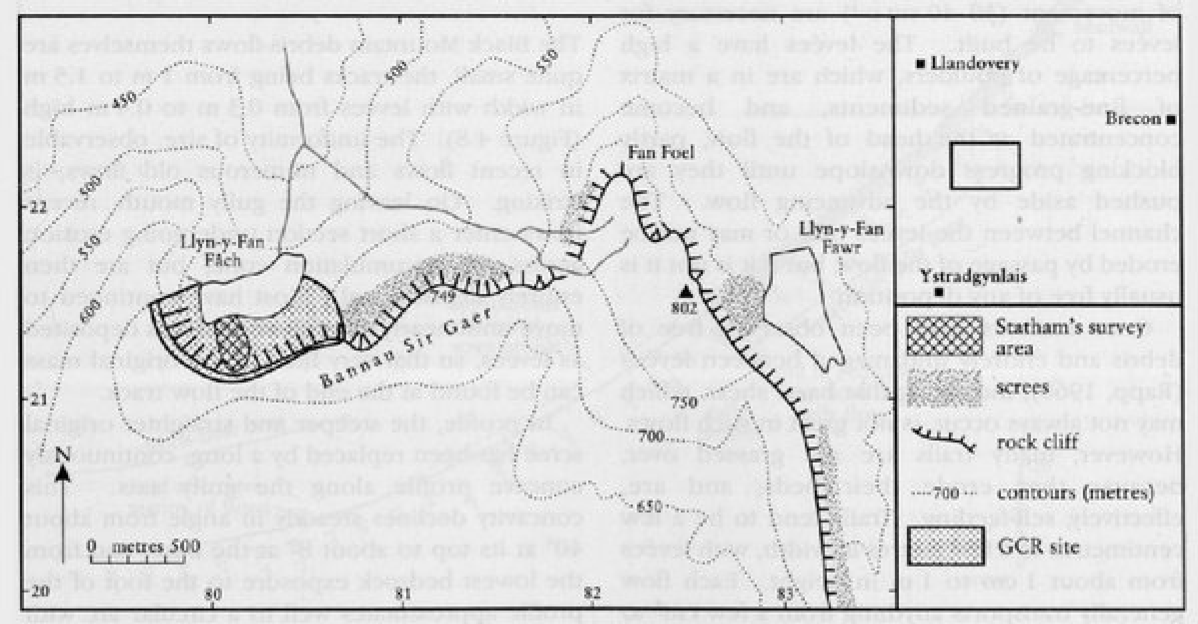
Conclusions

The Llyn-y-Fan Fâch GCR site is important in showing that the steeper and straighter scree-slope section of the Black Mountain scarp is being replaced by a series of low-angled, concave-upwards debris-flow cones. Rates of erosion in the debris-flow supply gullies suggest that this is a very recent change in process in the geomorphological timescale. Gully-side lowering produced about 8.4 m^3 of sediment from a monitored gully in one year and in the same year 9.8 m^3 of sediment was moved in a single debris-flow event. All of the sediment derived from the gullies is transported by debris flows, while other sediment transport processes, such as stream flow, are unimportant. Although debris flows are initiated by heavy rainfall, heavier storms occurr on other occasions, with no associated debris-flow activity. Since there is no shortage of large storms, they do not control debris-flow activity but merely act as a trigger. Debris flows probably require a minimum volume of material before mobilization can occur, and are therefore controlled by the availability of sediment, which in the Black Mountains is controlled in turn by the rate at which sediment is produced by gully-side lowering.

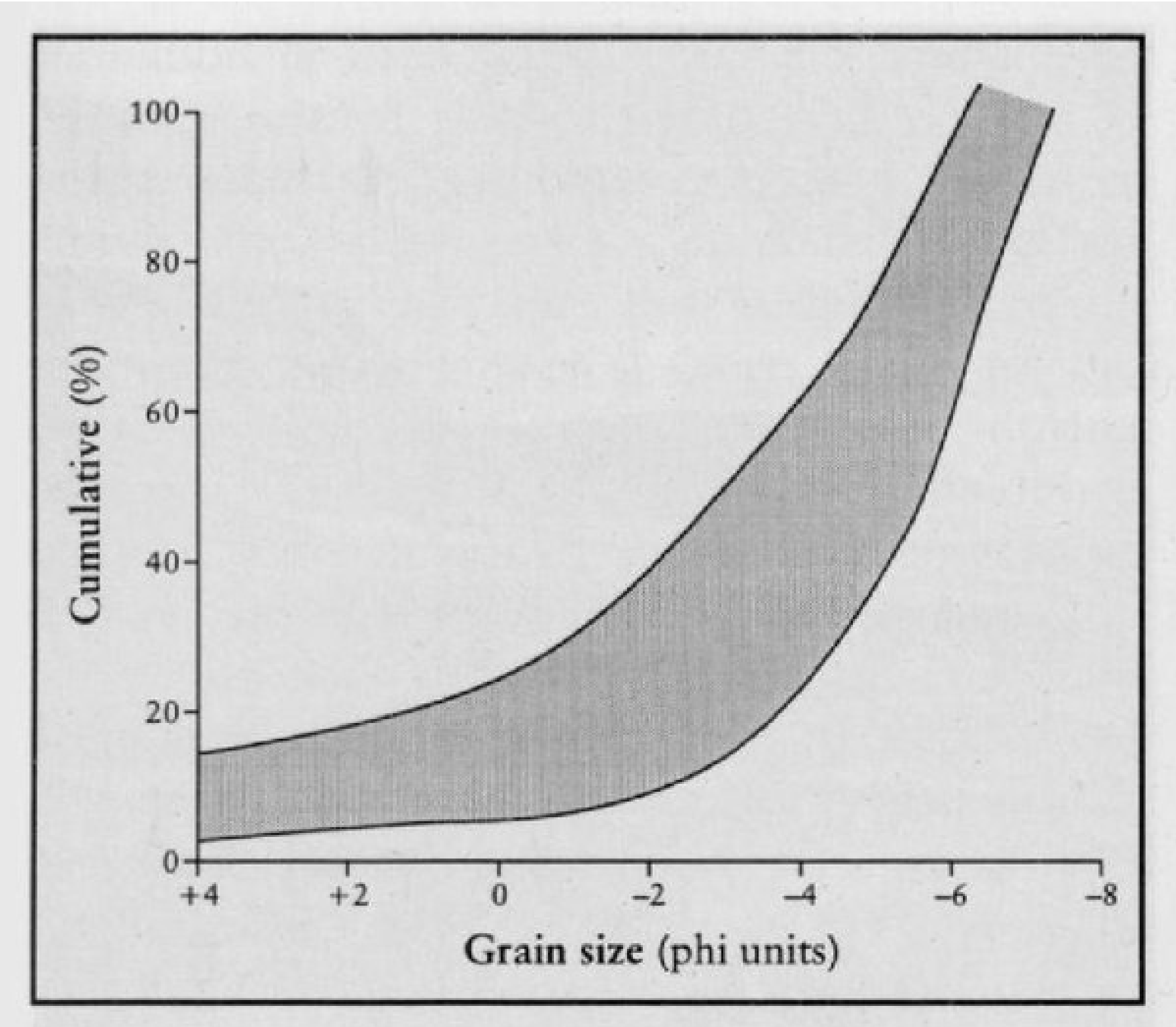
References



(Figure 4.5) General view of the Llyn-y-Fan Fach GCR site, showing the scarp face of the Black Mountain (Mynydd Du), and screes and gullies. (Photo: S. Campbell.)

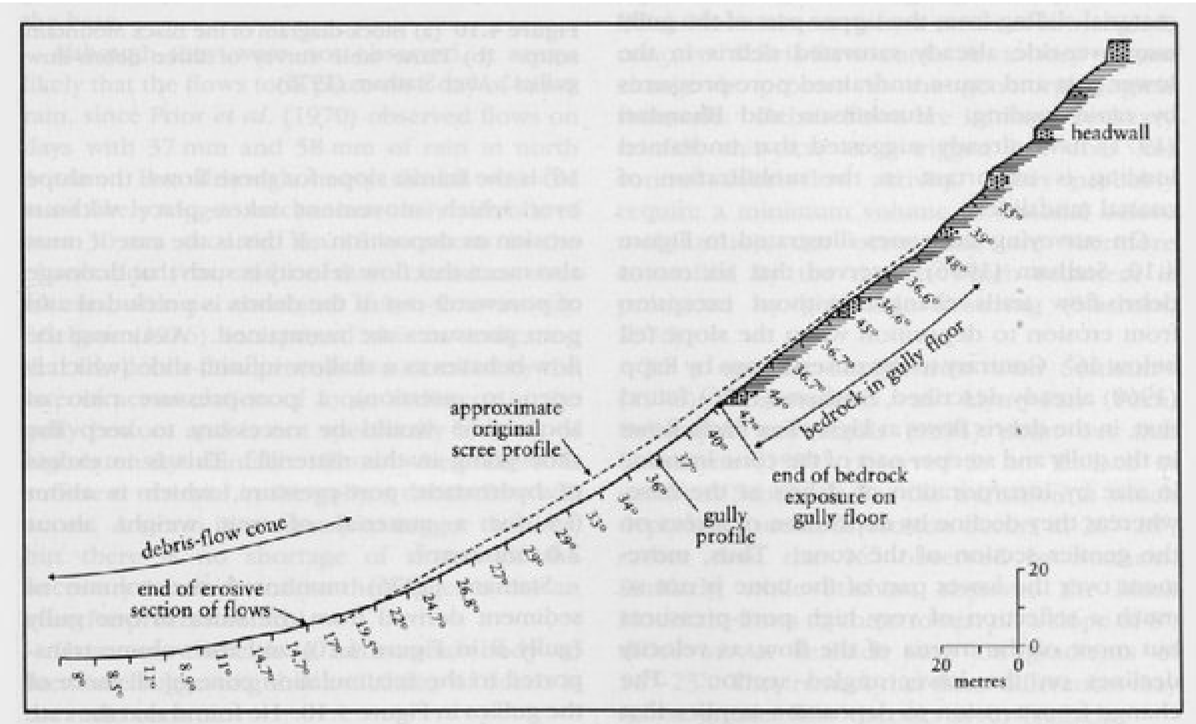


(Figure 4.6) The location of the Llyn-y-Fan Fach mass-movement site.

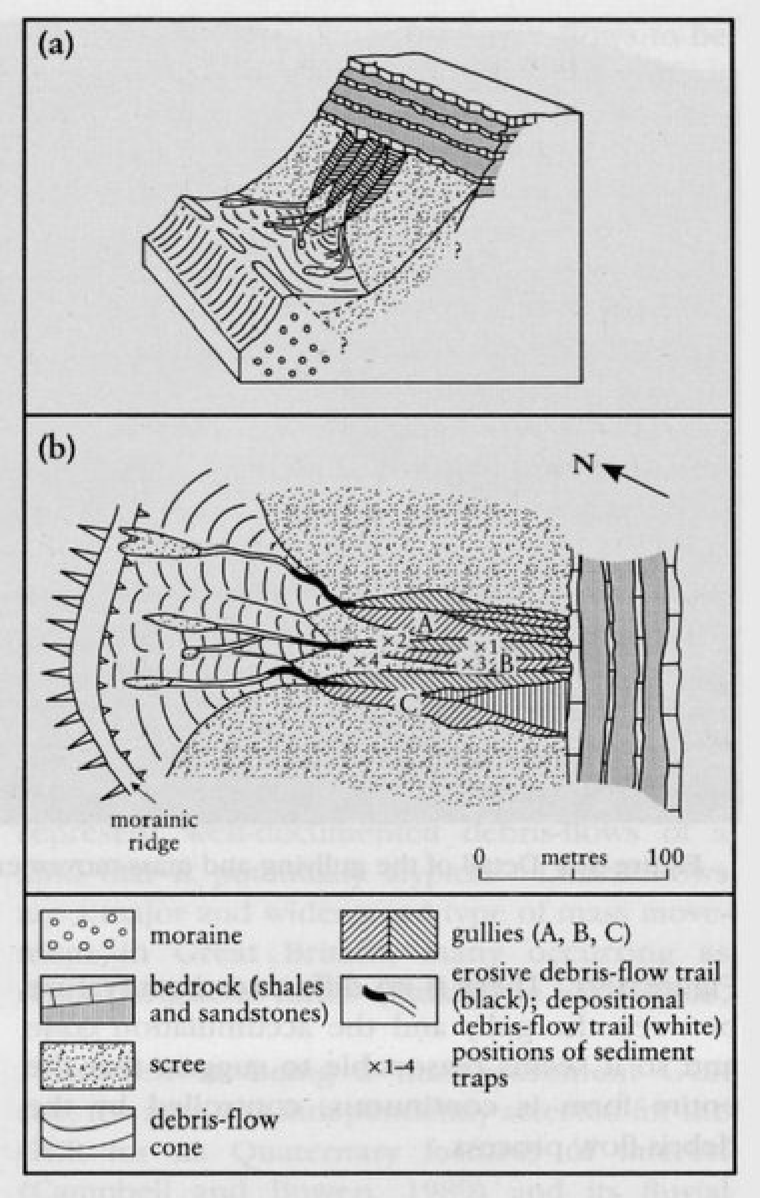


(Figure 4.7) Range of sediment grain-size distribution of scree debris at Llyn-y-Fan Fach. After Statham (1976).

(Figure 4.8) Detail of the gullying and mass-movement deposits at Llyn-y-Fan Fach. (Photo: S. Campbell.)



(Figure 4.9) Profile of a typical gullied debris-flow cone system at Llyn-y-Fan Bch. After Statham (1976).



(Figure 4.10) (a) Block-diagram of the Black Mountain scarp. (b) Plane table survey of three debris-flow gullies. After Statham (1976).