Mam Tor, Derbyshire

[SK 130 836]

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Introduction

Mam Tor is the locus for one of the most conspicuous and active landslides in the inland sedimentary strata of Britain. It has long been well known as the 'shivering mountain'. The head of the Hope Valley in the Peak District (Figure 5.25) rises steeply to the little plateau top of Mam Tor (517 m), the side of which has sheared away leaving a bold rock scar 80 m high above talus and the top of the slip mass (Figure 5.26). Failure probably occurred as a single event in about 3600 BP, an unusually recent date for inland areas. It is inferred that the initial slide came to rest at a marginally unstable angle, rendering it liable to re-activation after periods of heavy rain. It is believed to have extended downslope by over 500 m at very slow and gradually reducing rates of intermittent creep, but whereas almost all similar failures in the Pennines are now inactive, Mam Tor is exceptional in being predicted to continue moving for a long time to come. This reflects the unusually weak pyritic shales that both underlie the slide and comprise a proportion of the debris.

It is unusual for an inland slide in Britain to interfere with important communication routes. Here, the original direct road between Manchester and Sheffield (A625) became so affected by repeated slippage (Figure 5.27) that it was closed in 1979, necessitating unprecedentedly lengthy detours for trunk traffic. This has prompted a series of detailed geotechnical studies including Lounsbury (1962), Brown (1966, 1977), Stevenson and Gaunt (1971), Lant (1973), Lupini (1980), Al-Dabbagh (1985), and notably Skempton *et al.* (1989), making Mam Tor probably the best understood mass movement of natural origin in inland Britain., It provides an invaluable point of reference for interpreting similar and contrasting sites. It also has the benefit of a guide for visitors interested in its geology (Cripps and Hird, 1992), while Derbyshire County Council has placed an informative board at the foot of the closed road.

Although the Mam Tor slide is of only medium extent, affecting 0.35 km^2 (Figure 5.28) and (Figure 5.29), it is of wider significance as part of a cluster of four major extant landslips which collectively have encroached into the Rushup Edge–Mam Tor–Lose Hill ridge (Figure 5.25). The summit of Mam Tor is ringed by the earthworks of a hill-fort, except for two sections where landslip scars cut into the hill from opposite sides, adding an archaeological dimension to site interpretation.

Description

As with many landslip locations in the 'Millstone Grit' areas of the Pennines, the slopes of Mam Tor are predisposed to mass movement by virtue of successions of weak strata underlying more competent rocks. Here, the top 100 m are of Mam Tor Beds in which micaceous sandstones alternate with siltstone and shale (Spears and Amin, 1981; (Figure 5.30)). Beneath them, the Edale Shales are hard mudstones with occasional bands of siltstone and ironstone. Pyrite occurs at several horizons, generally as scattered crystalline aggregations. Below some metres of weathered material, the mudstones are weakened by fissuring to about 10 m depth, probably resulting from stress-release after valley erosion, accentuated by Pleistocene permafrost action (Skempton *et al.,* 1989; cf. Rowlee Bridge GCR site report, this chapter). The strata dip NNE at about 8°.

The scar itself stands at an average angle of 45° (range 40°–51°) with a crest at 510 m above OD, and a free-face height of 80 m, entirely in Mam Tor Beds (Figure 5.29). It is an asymmetrical rectilinear wedge, but with little evidence of strong joint control. Talus extends about 30 m down from the scar foot at an average slope of 23° (range 18°–28°). The partially evacuated cavity has minor rockfalls and slumps within it. The debris mass has extended to 1000 m long at an average gradient of 12°; it is gently convex and attains 450 m wide, although the scar itself is only about 200 m wide.

Skempton *et al.* (1989) divide the landslide debris into three sectors (Figure 5.28).

(A) Upper 'slump' sector

The upper slump sector is that part of the initial slide mass that has travelled a relatively short distance, and remains largely where it first came to rest before subsequent extension of its toe. It extends from about 370 m above OD down to about 310 m above OD. Geological markers indicate that the slump mass has moved about 160 m (Figure 5.31), although the actual distance from the centre of the cavity to the lower contour is over 400 m (Figure 5.29). The slump has a very irregular surface, initially rather flat-topped then steepening where traversed by the upper leg of the former road. Borehole 8 (Figure 5.28) and (Figure 5.29) proved a slide thickness of 32 m here, with two polished and striated slip-surfaces, 10 cm apart, near the base of 2.6 m of brecciated clay. This shear zone cuts through unweathered Edale mudstone, of which at least 8 m has been removed (in addition to weathered material and superficial deposits). Landslide debris includes pieces of mudstone from the upper Edale Shales (Zone R_{1a}) in the base, and 10 m above there are blocks of micaceous sandstone from the Mam Tor Beds, back-tilted at 40°–45°. Though broken and distorted, and missing a portion of Zone Rib, the rocks are recognizably in their correct sequence, and show a displacement along the slip-surface here of about 160 m. Similar features were found in several other boreholes (Skempton *et al.,* 1989).

(B) Middle transition sector

The middle transition sector extends for about 150 m down to the lower leg of the road at about 280 m above OD. The terrain is less irregular but still quite steep, ranging between 9°–16°, and with transverse compression ridges. The debris is generally less than 20 m thick (Figure 5.32), and becomes very thin at the road. Borehole 4 proved a slide thickness of 11.8 m to a 1.8 m shear zone of brecciated clay with a thin layer of intensely sheared clay at its base on or just below the top of the weathered mudstone, which was disrupted for a further 2.2 m. This indicates that by this point no intact bedrock was incorporated in the slide.

(C) Lower 'earthflow' sector

The lower earthflow sector extends for about 420 m, down to a present lowest point of 220 m above OD. The slope varies between 6°–9°, and the deposit is generally less than 10 m thick. This part of the landslide has moved in almost pure translation by sliding on or just below the original ground surface, which is here little disturbed. The flow stands above the adjacent ground with clearly defined flanks and toe. The surface is hummocky, with transverse ridges in the upper parts, and contrasts strongly with the smooth fields alongside. The slide tongue has spread laterally, widening to 450 m compared with 250 m in the upper sector. Ponds and marshes indicate high winter groundwater levels, while there are perennial surface streams.

Near the head of this 'earthflow' Borehole 10 proved a slide thickness of 19.3 m, with a slip-surface 10 cm above the base of 1.2 m of brecciated clay. Immediately beneath this shear zone, 15 cm of peaty material contained small pieces of wood and an alder (*Alnus glutinosa*) root, above 5 cm of structureless grey clay. Together these form a fossil topsoil buried beneath the landslide.

Records of landsliding

In the historical period, records of awareness of Mam Tor's crumbling character date back to Michael Drayton's *Poly-Olbion* (1622). Charles Cotton's *The Wonders of the Peake* (1685) described seven wonders, one of which was Mam Tor:

'To the South-East is a great Precipice,

Not of firm Rock...

But a shaly Earth, that from the Crown

With a continual motion mouldring down

Spawns a less Hill, of loose mould below...'

The Wonders of the Peake was influential because all later visitors felt obliged to see the seven wonders described by Cotton. The most graphic description is probably that given by Celia Fiennes in the late 18th century (Fiennes, 1947):

'The fifth Wonder is Mamtour which is a high hill … next Castleton…on that side its all broken that it looks just in resemblance as a great Hay-Ricke thats cut down one halfe, on one side that describes it most naturall, this is all sand, and on that broken side the sand keeps trickling down allwayes … [it is] … very dangerous to ascend and none does attempt it, the sand being loose slips the foote back againe.'

However, these accounts appear to refer to the scar itself being active, and a rare and conspicuous exposure of friable, layer-cake bedrock, rather than movement of the debris lobe.

The coach road was constructed in 1810, its hairpin actually taking advantage of the landslip to gain height and surmount the 100 m headwall of the Hope trough, which is otherwise only negotiable by the narrow fluvial channel of Winnats Pass (Figure 5.25). Evidently at that time, the terrain was not seen as hazardous.

Since 1907, notes of maintenance to the road after slips have been kept. This need not imply some general re-activation after long quiescence — this date coincides with the advent of motor traffic, heavier vehicle loadings, and an expectation of a smooth, bound and better-drained surface. Until then, it is probable that cracks and minor slips would have been infilled and regraded as with any other road after a winter's attrition. (Table 5.1) (Skempton *et al.,* 1989) shows a summary of such information since 1915, when local rainfall records became available. Slips of varying magnitude have been noted on 16 occasions during 66 years, on average at four-year intervals. Movements usually arise from re-activation of the transitional and lower sectors of the landslide, revealed by tension cracks in or above the upper leg of the road, accompanied by subsidence and outward displacements. In some cases there is upheaval on the edge of the slide.

In winter 1965–66 almost the entire landslide lobe re-activated. On 10 December 1965 cracks appeared following 120 mm of rain in six days. Abrupt movements were noticed on 18, 23 and 29 December, in each case within a day of further rainy spells. By mid-January, when movement had practically ceased, the total displacement in the upper sector amounted to 0.7 m, and shear displacements of about 0.4 m were observed where the road crosses the flanks of the slide (Brown, 1966). Most of this movement would have taken place during the last 20 days of December at an average rate of around 30 mm per day. The upper road subsided by as much as 1.5 m in places and a local 'confined' slip developed over a short width below the road. Activity renewed in February, mainly in response to 100 mm of rain in 10 days towards the end of the month. The rate at that period was about 15 mm per day and diminished almost to zero by mid-March (Figure 5.33).

Movements at the lower road are less than at the upper road, an observation consistent with the existence of compression ridges; indeed, it remains open for access to Mam Farm. Forward movements of the toe are therefore smaller than those at the upper road, though on a long timescale the difference cannot be great, and clear proof of advance at the toe in recent times is provided by slide debris encroaching on Blacketlay barn (see (Figure 5.28)).

Table 5.1 Records of movement and rainfall at Mam Tor, 1915–1977. After Skempton *et al.* (1989).

Slip	Date	Movements	Monthly rainfall (mm)
1	Jan 1915	Crack 30 m long	200
2	Dec 1918	slip, 0.3 m subsidence	240
	Jan 1919	movements continue	140
3	Dec 1919	steady movement	280
	Jan 1920	movements continue	200
4	Dec 1929	serious slip	300
	Jan 1930	movements continue	180
5	Jan 1931	slip, 60 m crack	210
	Feb 1931	movements continue	190
6	Feb 1937	considerable subsidence	220

7	Jan 1939	100 m crack, 0.25 m subsidence	210
8	Oct 1942	30 m crack, 0.1 m subsidence	160
9	Feb 1946	extensive slip	240
10	Nov 1946	new movements	230
11	Feb 1948	subsidence on 200 m length (preceded by 280 mm rain in Jan)	100
12	Dec 1949	slip (no details)	230
13	Jan 1952	large slip (preceded by 400 mm rain in November and December)	150
14	Dec 1965	serious slip, 0.7 m displacement	320
15	Feb 1966	renewed movement, 0.3 m displacement (preceded by 385 mm rain in December and January)	190
16	Feb 1977	large slip; 0.4 m subsidence (average)	230

From observations in 1918, 1939, 1965, 1966 and 1977 the average displacement of the upper road when a re-activation slip occurs is about 0.3 m, allowing for the fact that not all slips involve the full width. With a return period of four years this is equivalent to 7.5 m per century, and because the toe of the landslip will have moved by a rather smaller amount the present rate of advance is likely to be about 7 m per century.

Rainfall and groundwater

As is commonly reported in Britain and elsewhere, landslide mobilization can relate closely to groundwater availability, both seasonally and in relation to peak rainfall events. The unusually detailed records for Mam Tor exemplify this relationship. Remobilization events are most frequent in December–February, while rainfall is heaviest from October to February (Figure 5.34). Records from local rainfall stations were analysed by Skempton *et al.* (1989) in terms of the return periods of rainfall amounts over 3-day, 6-day, 10-day, and 1-month periods. Comparing these with the situation at Mam Tor in December 1965 shows that instability was almost certain to occur at this time, and in the case of the February 1966 situation (Figure 5.33) when the 10-day rainfall was around 100 mm, the analysis showed that for every ten such events about five may be expected to result in a slip. When no slip occurs, this is likely to be because winter groundwater has been lower than average.

Observations from piezometers installed at or near the shear zone for short periods in 1977 and 1978 give an indication of the seasonal response of the landslide's groundwater levels to rainfall (Figure 5.35) and (Figure 5.36). In winter months, when the soil moisture deficit is effectively zero, the greater part of the rainfall not lost as runoff penetrates to augment groundwater. Under such conditions the 'storm response' in groundwater level is more or less directly proportional to the rainfall. While the ratio may vary locally with permeability, slope angle, depth to water table and intensity of rainfall, in uniform strata the response, seasonal as well as short term, is practically the same at different depths. Thus for winter rainstorms capable of causing substantial movements, the corresponding transient groundwater rise in the lower sector is about 0.5 m. In the upper sector, permeability is higher, where broken sandstone exists in the debris, and winter groundwater is at a greater depth; the average slope is steeper, but runoff from the scarp face will contribute a throughflow component. Therefore storm response in this part of the landslide is not very different from that in the lower sector, and in any case it is unlikely, even as an upper limit, to exceed the seasonal response of 0.7 m measured in a borehole in the upper sector.

The chemistry of the groundwater at Mam Tor has been studied, with results of great significance. This is probably the classic discovery of the importance of the role of pyrite weathering reactions in lowering the residual shear-strength of the mobile horizon of a large landslide. Oxidation of pyrite (FeS_2) within the mudstones forms sulphuric acid, which liberates iron, calcium and other elements into solution. Chemical analyses have shown this process to be operating in the landslide (Near and Curtis, 1981) because water issuing from springs and seeping off the lower sector in winter is acidic with an ion concentration much in excess of that in runoff from adjacent slopes. Steward and Cripps (1983) have shown that the residual shear-strength of the pyritic Edale Shale near Castleton is sensitive to modification of both mineralogical and porewater composition. At Mam Tor, weathering solutions penetrate deeply into the landslide and may attack fresh shale below the slip-surface, thus reducing its strength. Over a period of years, this would then reduce the factor of safety to a value close to unity so that other destabilizing effects could initiate a major failure event. Of course, the effect of this leaching on the strength of the landslide materials is likely to be small in the short term; strength and other geotechnical properties determined by Skempton *et al.* (1989) are those resulting from at least 3000 years of debris-lobe activity. The importance of geochemical research here is in demonstrating that residual shear-strength is dynamic over the long term, and that there will be small seasonal variations in strength.

Geotechnical analyses

Skempton *et al.* (1989) carried out detailed geotechnical analyses to establish the index properties of the slide debris, its residual strength and stability, and the mechanics of storm-response movements, leading to a comprehensive back-analysis of the whole sequence of past and contemporary movement. Note that what follows is a much-simplified account, extracting key findings relevant to the Mam Tor failure; reference should be made to the original study and standard engineering geology texts.

The slide debris can generally be classified as clays of medium plasticity, although sand particle content and sandstone block incorporation can considerably affect its properties. The average water content is about 21% of the dry mass. It has a porosity of 36%.

The peak friction angle in intact rock, and its reduction after failure to a residual friction angle, is essential to understanding landslide activation. Here, the differences between the overlying Mam Tor Beds and the underlying Edale Shales are demonstrated to be very appreciable:

Mam Tor Beds	Peak strength	37	Residual strength	30
Edale Shales	Peak strength	30	Residual strength	14

The post-failure drop in strength therefore amounts to about 30% in sandstone and 60% in mudstone. At Mam Tor, where slip-surface testing was not feasible, estimates were obtained from the index properties. The value of 14°–15° deduced for the shear zone compares well with test results of slip-surfaces developed in compacted mudstone at other sites.

Stability analyses demonstrate that in high winter groundwater conditions, as studied in February 1978, the landslide is close to limiting equilibrium, with the factor of safety at 1.0, because it can be substantially re-activated by a transient rise in water level of 0.5 m. Moreover, because large displacements have occurred in the past, the strength along a slip-surface must be at the residual.

Skempton *et al.* (1989) considered four cases involving re-activation of different parts of the slide mass (Figure 5.37):

Case 1: Re-activation of the whole transitional and lower sectors of the landslide, below tension cracks at the upper road (between points j–e–g), and sliding on a slip-surface passing through slide debris and along the basal shear zone. The best result was obtained with residual friction angles (RFA) of 18° (in slide debris) and 14° (shear zone) when the calculated value of factor of safety (F) is 1.02.

Case 2: As a variant of case 1 the slip-surface is assumed to thrust upward through the slide debris at f–k. This simulates a 'confined' slip not extending to the toe. With the same RFAs, F = 1.00, confirming that these two modes of failure have very similar probabilities.

Case 3: In the slip of February 1977 cracks additional to those at the upper road were seen above it, as at point h. On the slip-surface h–d a higher RFA value may be taken because the slide debris here probably includes a considerable proportion of sandstone, as observed in nearby Borehole 6. A reasonable assumption is that about one-third of the debris is sandstone, with RFA of 30°, and the rest is clayey debris with RFA of 18°. The average residual angle on h–d is then 22°, and, still using an RFA of 14° in the basal shear zone, F = 0.99. Had it been assumed, as perhaps an upper limit, that half of the debris consisted of sandstone, the average RFA value on h–d would be 24° and the corresponding factor of safety would increase by 1.7% to F = 1.02 (i.e. the higher the sandstone content, the less prone to re-activation).

Case 4: Exceptionally heavy rain in December 1965 led to re-activation of practically the entire landslide up to and including the talus. The talus is granular material with little if any clay fraction, in which the RFA can be taken as 30°. The uppermost part of the failed mass (toned in (Figure 5.37)) will contain a rather high proportion of sand, derived from the overlying predominantly sandstone debris in this upper part of the upper sector. The RFA in sandy clays is very dependent on relatively small changes in plasticity index and clay fraction. The procedure in this case was therefore to determine, by back-analysis, an RFA value in the shear zone b–c. This gave a factor of safety not less than 1.0, with an RFA of 14° in the slip below point c. The result is an RFA value lying between 23°, which gives F = 1.0 exactly, and 24° which gives F = 1.02. An RFA of 24° corresponds to a clay fraction of approximately 20%. This is an acceptable result, as compared to 35% in the shear zone further down the landslide where the debris consists chiefly or entirely of degraded mudstone and clay matrix.

These four cases demonstrate that no difficulty exists in showing that the landslide as a whole, and various parts of it, are delicately balanced in a state close to limiting equilibrium with groundwater level at about the normal winter maximum.

Skempton *et al.* (1989) conclude their stability analyses by examining the effects of variations in the parameters and assumptions used, including lateral confining pressures and their interaction with internal forces. A change of RFA in the basal shear zone of 1° leads to an increase or decrease in F by 5–7%. Changes of this magnitude they describe as not admissible, indicating that 14° is the correct value for the RFA within narrow limits. Finally, a change in groundwater level of 0.5 m results in a change in factor of safety of 2–3%. Although this only affects the RFA in the basal shear zone by ± 0.4°, such a rise in groundwater level would reduce the factor of safety by 3% which is sufficient to cause substantial re-activation of a landslide previously existing in a state of limiting equilibrium.

Storm-response movements are controlled by an apparent paradox. A rise in water table will cause an increase in pore pressure in the shear zone, and therefore a decrease in shear strength. Consequently the factor of safety *(F)* falls below 1.0 and movement takes place. However, in clays of medium to high plasticity the shear strength increases with rate of displacement and with changes in the soil chemistry; movement is therefore restricted to a finite amount. The rates of movement involved are sufficiently low (about 100 mm per day) for inertial forces to be negligible. Thus although a rise in water table causes an initial drop in factor of safety, the consequent remobilization leads to an increase in strength and cessation of movement. This is why displacements are chiefly concentrated within a few days of peak rainfall events, and why they become self-limiting regardless of continued high water-table conditions (in other words, movement does not continue indefinitely, or accelerate into a mudflow).

The total advance of the slide mass at Mam Tor by these episodic storm-response movements is currently less than 10 m in a century. This has produced a very small change in overall geometry of the slide mass, and therefore a correspondingly small change in static factor of safety under normal winter groundwater conditions. Consequently the process can be repeated many times without any considerable change in parameters. Nevertheless, on a long timescale the cumulative effect must be to bring the slide mass into a more stable configuration: F becomes marginally greater and a larger water-table rise is required to produce a given displacement. The return period for re-activation is therefore longer and the movement per century is smaller. Eventually, a state will be reached in which F is sufficiently high for the landslide to remain stable under the heaviest winter rainstorms, and this may be defined as the condition of permanent equilibrium, under present climatic and geomorphological conditions.

Interpretation

Although the nature and behaviour of the Mam Tor slide can be described in unusual detail, there still remain matters of interpretation.

Age of the landslide

Several lines of dating evidence point to a relatively young (mid-Holocene) age for the initial event. The fossil topsoil beneath the lower slide sector yields an age in pollen zone VIIb, which agrees with a radiocarbon date of 3900 BP for the fine-grained fraction. However, the *Alnus* root within it dated to 3000 +1–150 radiocarbon years BP, which is in agreement with other wood fragments sieved out of the buried topsoil. From correlations between radiocarbon and tree-ring dating (Pearson and Stuiver, 1986) the absolute age of the *Alnus* root is about 3200 ± 200 calendar years BP.

Skempton *et al.* (1989) estimated the date of inception of the landslide by reasoning as follows (Figure 5.38):

If at a time *T* in the past the toe of the lower sector was at a distance *X* from its present position, any curve relating *X* and *T* would have to satisfy these conditions:

1. At the toe, *X* = 0, *T* = 0 and d*X*/d*T* is the present rate of movement (7 m per century).
2. At the borehole containing the dated Alder root, *X* = 320 m and *T* = 3200 years.

By extrapolation to point B, where *X* = 440 m, the time T_1 to the initiation of lower sector movement can be found. For the time-displacement curve shown in (Figure 5.38), T_1 = 3600 years, and dX/dT at that time is 0.5 m per annum. The initial slip, by comparison, would have been a sudden event. Therefore T_1 is the estimated date of origin of the Mam Tor landslide. This is about 3600 ± 400 calendar years BP, which agrees with the upper limit of the radiocarbon dates described above.

However the radiocarbon dates relate to material beneath the lower slide toe, and (Figure 5.38) relates to re-activation of an initial slide which may previously have come to rest. Climatic changes to wetter conditions after 4000 BP could have contributed to re-activation, as could consolidation of the debris to elevating water tables. The possibility of an earlier initial event cannot readily be ruled out.

The archaeological evidence is also equivocal. The rampart is generally agreed to date from the Iron Age (flourished *c.* 2500 years BP), although remains of Bronze Age *(c.* 4000 years BP) dwellings have been found within it. Both the Mam Tor landslide and the Mam Nick landslide on the opposite side interrupt the rampart (Figure 5.25). Archaeological opinion is that the rampart was originally continuous, although both scars are so steep as to make construction of a rampart superfluous. Although the rampart appears to have been breached by a subsequent landslide, this could simply be the product of the later attrition which has created the large talus bank. The Mam Nick scar is however grassy, and a sample at the toe gives an age of 5900 radiocarbon years BP, suggesting that its flank scarp might have been incorporated in the defences.

Failure character and geometry

Mam Tor is described by Skempton *et al.* (1989) as a 'massive example of a slump-earthflow'. It is certainly a 'composite landslip' (WP/WLI, 1993). Following Hutchinson (1988; see Chapter 1), it can be classified as H4 (Landslides breaking down into mudslides or flows at the toe) and D3 (Compound failures — markedly non-circular, with listric or bi-planar slip-surfaces).

Although borehole evidence indicates relatively limited initial displacement, this may relate to particular back-tilted masses originating near the base of the scar cavity. It is possible that material released near the rim travelled further, over-riding the basal material to form the forward part of the initial toe. Further investigation of the rapidity of the initial movement, its degree of disintegration, and its trajectory is merited; Mam Tor has some of the topographical characteristics of Beinn Alligin (see GCR site report, Chapter 2), also in near-horizontal sandstones, if in miniature. The role of faulting in facilitating failure here might also be examined, along with proximity to the formerly mined zone of mineralization in the adjacent limestone.

The actual failure surface has been described as a 'concave-upwards curved slip-surface' evidenced by the back-tilted strata (Skempton *et al.,* 1989). (Figure 5.31) clarifies that the upper sector is a listric failure, i.e. a spoon-shaped surface that is here essentially bi-planar (scar plane and basal plane) linked by a curve. In detail, this curve may take place within a shear zone rather than as a discrete smooth concavity, given that in this sector it is in unweathered bedrock. From borehole evidence a marked convexo-concave failure surface step-down in the transition zone to the lower sector is interpolated. This could imply that the weight of the initial failure mass surcharged the weak weathered shales and triggered a secondary failure with its own listric profile. The transition 4. between the upper and the lower listric surfaces is poorly understood, but may incorporate some bedrock at the head of the lower sector. The existence of this transition, at the points selected 5. for construction of the hairpin road, may account for the tensional dislocations that ultimately closed it.

Stages in Development

Skempton *et al.* (1989) interpret the probable evolution of the landslide in four stages as inferred in (Figure 5.39)a–d:

(a) The initial event was a single large slip, rather than several relatively small slips, because:

1. About 520 m from the present toe, in the transitional zone, the slip-surface is at a very shallow depth below the original ground level. Almost all of the slide (c) debris east of this point, including the lower sector, must therefore have derived from material to the west.
2. For the same reason the initial slip or slips must have been to the west of this point, i.e. in the upper sector.
3. The volume of the initial slip or slips must equal that of the slide debris, after allowing for expansion due to softening and degradation. The bulking factor is about 20% in mudstone, 40% in clay matrix and (say) 10% in sandstone.
4. The original profile cannot have been much steeper than the steepest slopes currently existing adjacent to the landslide.
5. The basal slip-surface must pass through the points where it was observed in boreholes, and through the foot of the scarp.
6. Given the contrasting peak and residual strengths for the stronger overlying and weaker underlying strata (described above), the slip mass will undergo large and rapid displacements before reaching a position of (temporary) equilibrium.

(b) Trial-and-error solutions lead to a spreading displacement of the initial Mam Tor slip represented by point B. The slide debris is taken as having a volume 15% larger than that of the initial slip, to allow for bulking without a substantial increase in water content.

(c) As a result of degradation and softening, secondary slips occur in the lower part of the mass of the upper sector, leading to the development of a lower sector. Comparative studies (see below) indicate that the rate of advance of the lower sector would initially have been far greater, by roughly one order of magnitude, than the average figure in recent times. The advancing lower sector reached point C, 320 m back from the present position of the toe, about 3200 years ago, as demonstrated by the age of the *Alnus* root in the buried fossil soil. At that time the debris slope angle would have been about 16°. Meanwhile, the upper sector itself had been moving, partly as a result of additional weight imposed by talus eroded off the scarp face, and in response to rainfall, but partly also as a result of material lost from its front edge, due to the retrogressing secondary slips removing material at a faster rate than could be supplied by forward movement of the upper sector.

(d) These processes are still continuing today. Their resultant effect is to bring the landslide into a more stable configuration, and the rate of movement per century will therefore be decreasing. At 7 m per century the present rate of advance is substantially less than the average of 10 m per century for the past three millenia. However it is clear that a state of permanent equilibrium has not yet been reached, and the present shape of the landslide (Figure 5.39)d, with a debris slope angle of 12°, is simply the latest stage in a development that will continue for a very long time.

Comparisons

The southern Pennines contain many other large landslides in Namurian strata. These have been described by Johnson and co-workers (Johnson 1965, Franks and Johnson 1964, Johnson and Walthall 1979, Tallis and Johnson 1980; cf. the Alport Castles and Canyard Hills GCR sites). Pollen analysis and radiocarbon dating show that some of these are older than Mam Tor, and, unlike Mam Tor, apparently stable (as at Alport Castles). Skempton *et al.* (1989) made map measurements of the of the debris slope angle at four other landslips to compare with Mam Tor:

Coombes Tor	9.5°	Rough Rock cap over shales
Millstone Rocks	12.5°	Kinderscout grit over Grindslow Shale
Didsburk Intake	11°	Kinderscout grit over Grindslow Shale
Mam Nick	10°	Mam Tor Beds over Edale Shales
Mam Tor	12°	Mam Tor Beds over Edale Shales

Collating these measurements with the datings, they showed that large landslides in Namurian mudstones remain unstable if the slope exceeds about 10–11°, and that a period of the order of 8000 years is required for such landslides to attain a state of permanent equilibrium. Thus the by-road which traverses the Mam Nick landslip (Figure 5.25) does not appear to have suffered any serious disruption.

Landslipping and the shaping of the Mam Tor ridge

This conspicuous landslide is only one of a cluster which significantly shapes the ridge on the south side of Edale (Figure 5.25). Most landslips in the Peak and Pennines are on plateau rims, and their main geomorphological contribution to landscape evolution is simply one of valley widening (as is well seen at Alport Castles). Here, the south wall of Edale commences as a plateau, but from the summit of Rushup Edge eastwards for 4 km to its terminus at Lose Hill it has a well-defined crest. Only the summit of Mam Tor itself broadens out, as a residual of the former plateau ridge.

The Mam Tor slide is the only one on the southern aspect of this ridge. On the north side, three major extant slips occur, although the terrain suggests that earlier events have embayed the ridge, the failed material having been evacuated by subsequent valley glaciers:

1. Mam Nick (0.60 km^2): this landslide has twice the extent of the Mam Tor event, and narrows the crest of Rushup Edge to a half-arête for 500 m (Figure 5.40). The source configuration is an obtuse wedge. In its south-east corner, it breaks through the ridge to create the 'Nick' followed by the minor road over to Edale. Here it has lowered the ridge by about 40 m, and truncates the west flank of Mam Tor, including its hillfort rampart (Figure 5.41). The main headscarp is of steep grass approximately 25 m high, with a clutch of short-travel sharp-crested slip masses having bold anti-scarps 3–5 m high. Beneath these, the apron of the main failed mass is crossed by the road, below which an amorphous 'earth-flow' extends at a lesser gradient for 500 m down to an 8–15 m-high toe bank above Greenhill Farm (Figure 5.40). This two-tier configuration is very similar to Mam Tor.
2. Cold Side (0.25 km^2): the grassy source scars are exposed just below the crest north-east of Mam Tor (cf. Alport Castles). They are up to 32 m in height, in a double-wedge obtuse splay. The main slip mass has a striking antiscarp 8 m high impounding a pond, while the toe is a steep rampart 10–15 m high.
3. Back Tor (0.50 km^2): this dramatic landslide bites right through the ridge west of Lose Hill for 200 m, lowering it by up to approximately 50 m (Figure 5.42). The main failed mass has slumped almost to the floor of Edale, possibly deflecting the river slightly. A more recent increment on the east side yields impenetrable antiscarped terrain colonized by Backtor Wood, below a 60 m sandstone crag comparable in scale with that on Mam Tor.

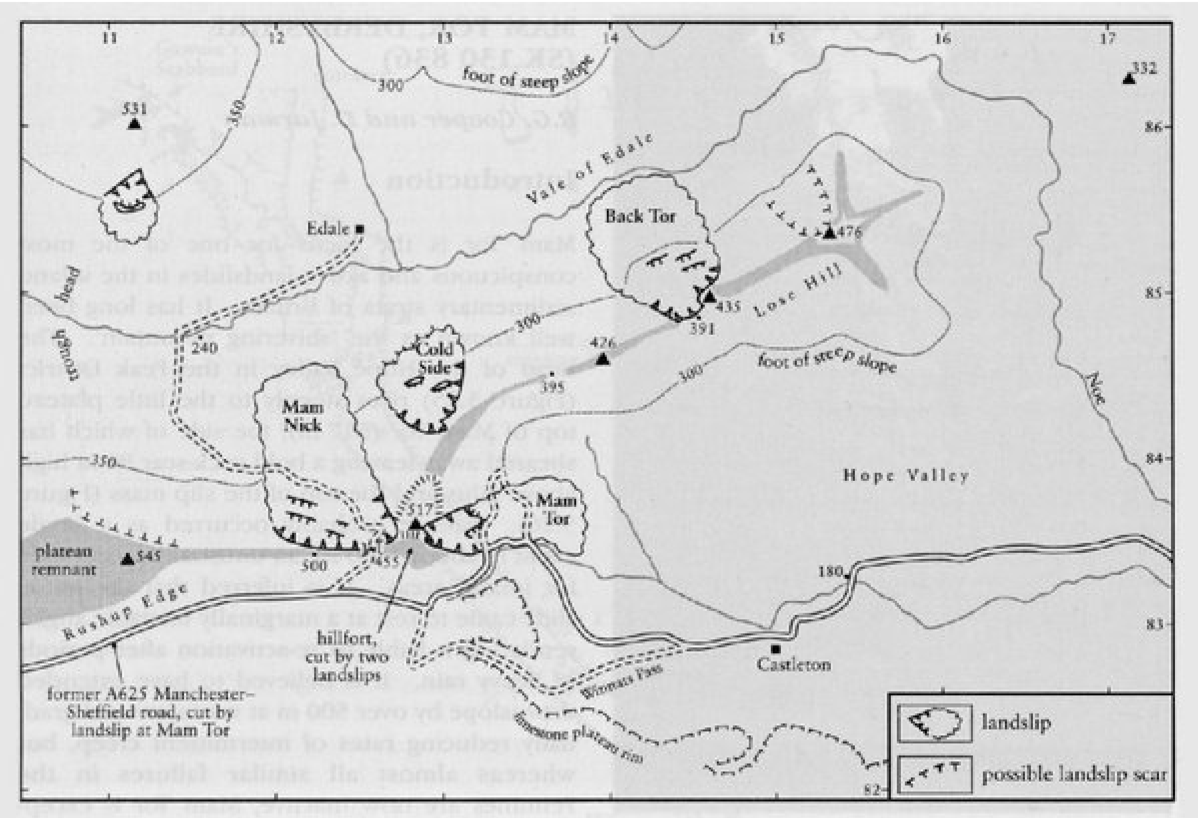
Whereas these three slips are metastable, and the Mam Tor slide is evolving towards that condition, future re-activation in response to fluvial or glacial valley incision will tend to see these and other slope failures coalesce, first eliminating Mam Tor as a separate hill, and then reducing the whole ridge to a rump.

Conclusions

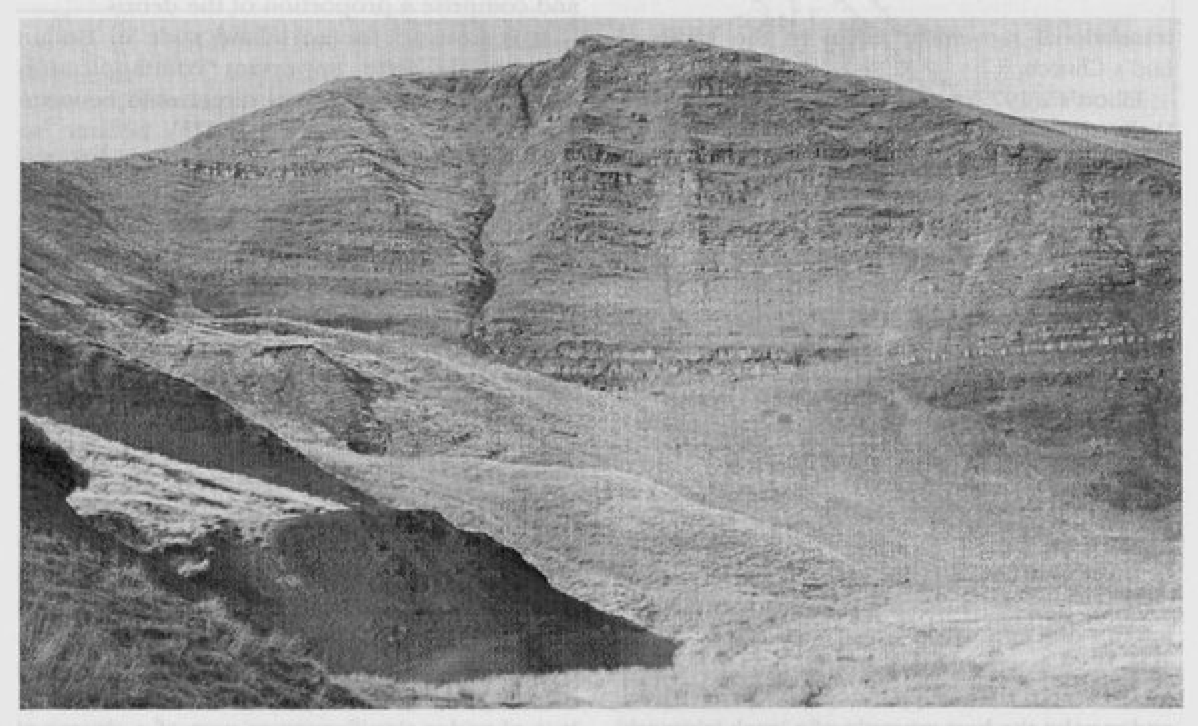
The landslide at Mam Tor is not unusually large or articulated, by comparison with (for example) the Alport Castles GCR site. In many ways, it represents the typical Pennine slump-flow where competent rocks overlie weaker strata that are less permeable and prone to deformation. However, Mam Tor is important for the high degree of knowledge of its recent evolution, including quantitative assessment of the relationships between movements, groundwater levels, storm response, and properties of the clay/mudstone (notably its geochemistry) of which the slide is largely composed. This is because it was crossed by a trunk road that eventually had to be closed because of continuing and irremediable slippage — the only such case affecting a major transport artery in inland Britain.

Mam Tor is unusual in still being an active landslide, with spasmodic advances associated with peak rainfall and raised water-table conditions. The current recession rate is 7 m per century, which, while gradually diminishing, has no foreseeable end-date. The nexus of factors that sustain instability are finely balanced, and this site is of great comparative importance. Mam Tor is also a conspicuous and readily accessible site, with a bold scar, and the 'shivering mountain' has long been known as a 'Wonder of the Peak'. It is of considerable interest to archaeologists, since this and the Mam Nick slide interrupt an Iron Age hillfort rampart. It is also important in studies of landscape evolution, since this and several even larger sites have made substantial inroads into the ridge separating Edale from the Hope Valley. It is thought to be a relatively young feature, with an inferred mid-Holocene date of initial failure at around 3600 BP, although an older date remains possible.

References

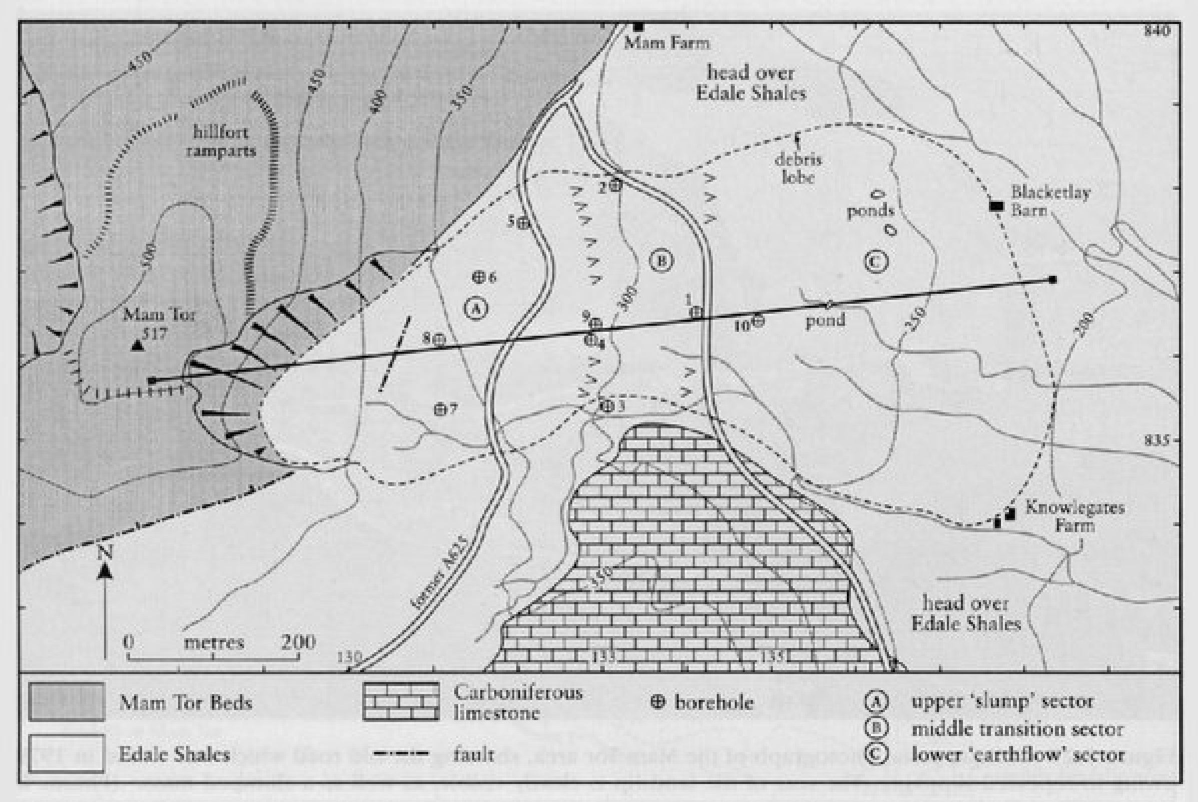


(Figure 5.25) Location of the Mam Tor landslide, showing other major landslides also encroaching into Mam Tor hillfort and Rushup–Lose Hill ridge, and the former trunk road severed by it.

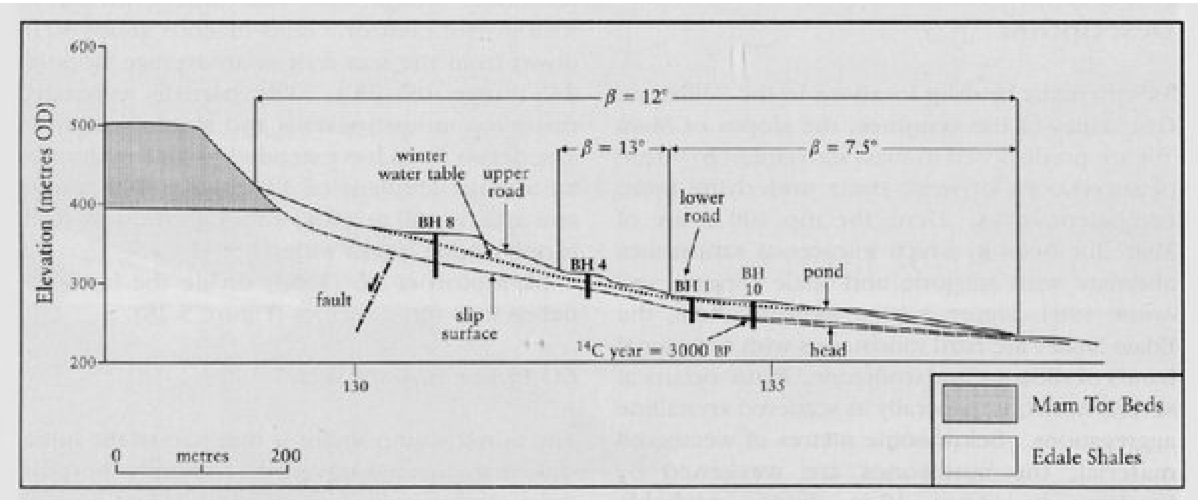


(Figure 5.26) The Mam Tor landslide scar from the top of the upper slump sector. (Photo: M. Murphy, English Nature/Natural England.)

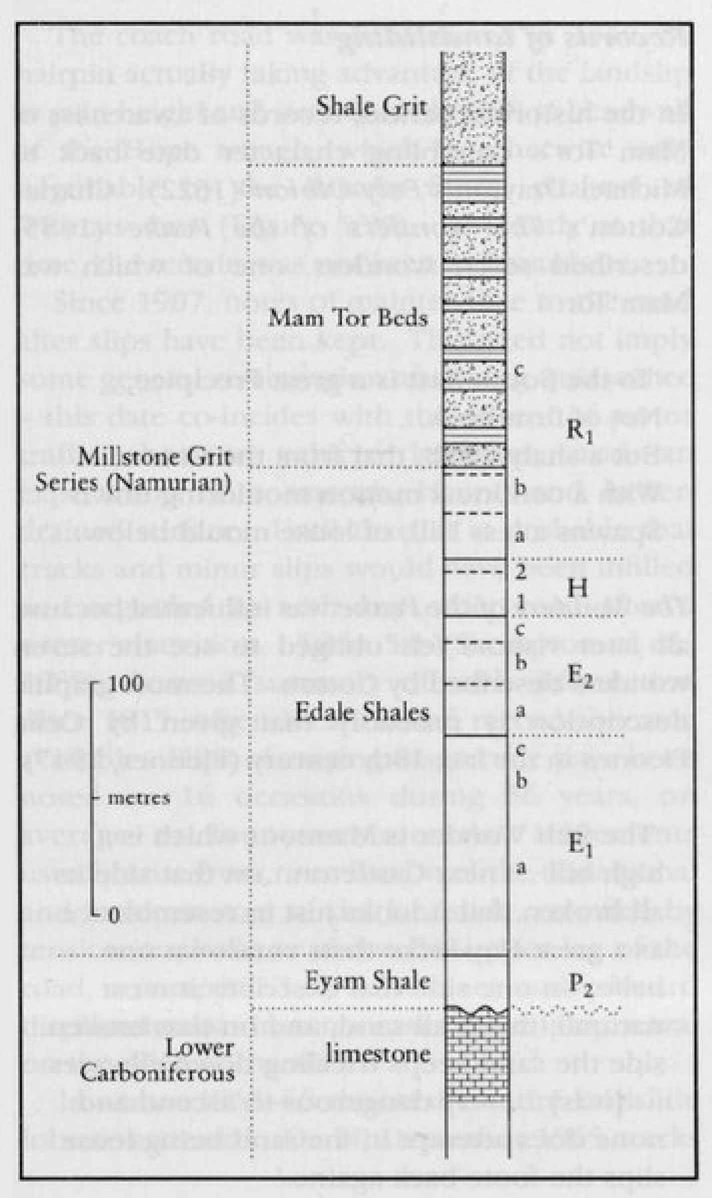
(Figure 5.27) Oblique aerial photograph of the Mam Tor area, showing the old road which was closed in 1979 owing to repeated slippage. The scar of the landslip is clearly visible, as well as a slumped mass. (Photo: © National Trust/High Peak.)



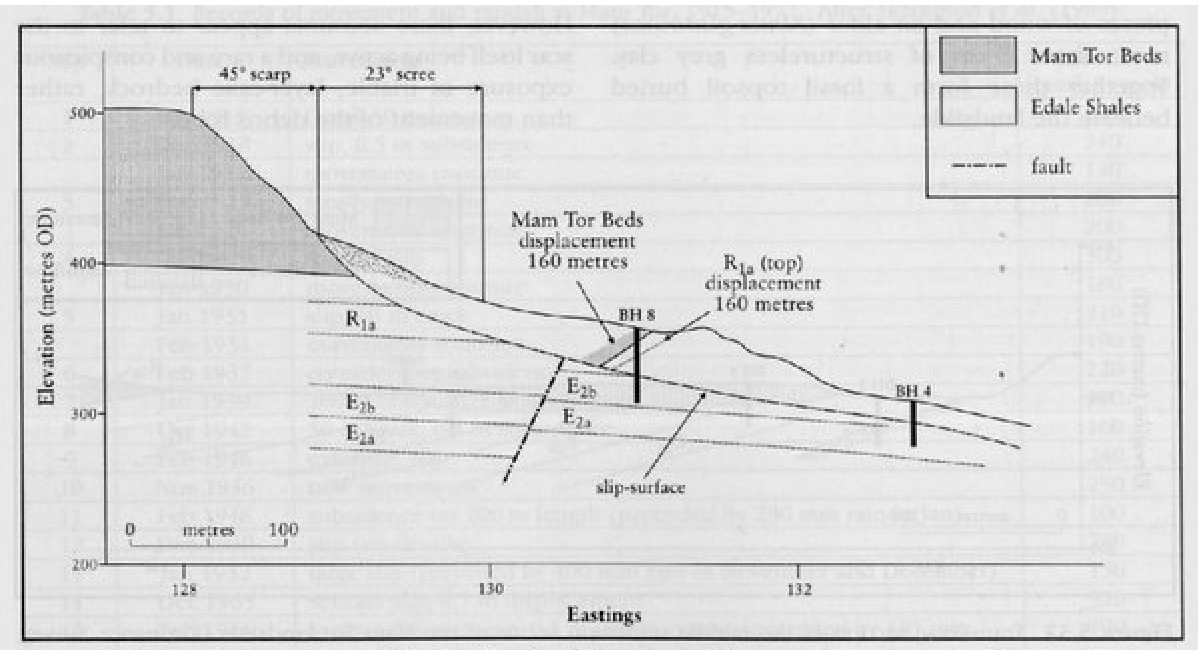
(Figure 5.28) Schematic plan of the Mam Tor landslide, showing sectors, geology, borehole locations, and the former trunk road. The line running almost west–east is the line-of-section shown in (Figure 5.29). After Skempton et al. (1989).



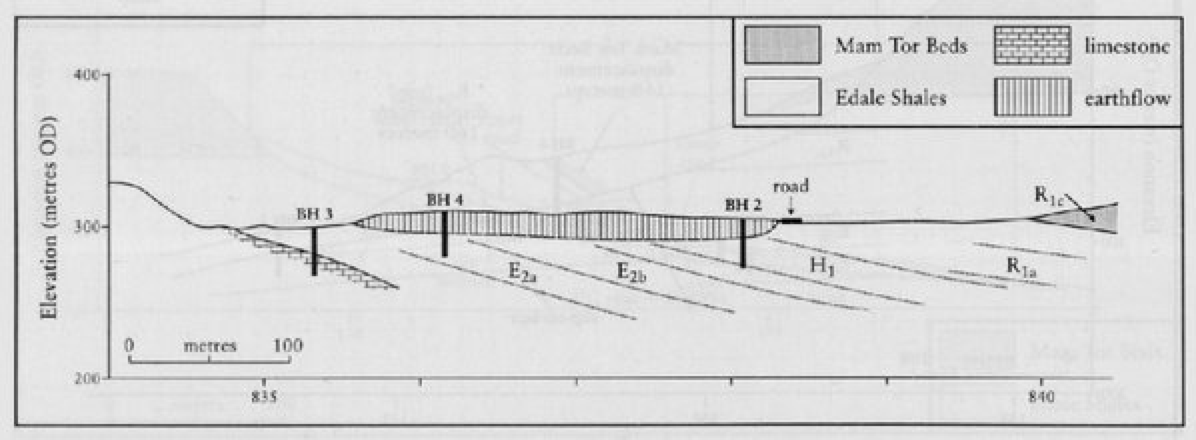
(Figure 5.29) Longitudinal section and location of boreholes through the Mam Tor landslide. After Skempton et al. (1989). The section line is shown in (Figure 5.28).



(Figure 5.30) Stratigraphical section at Mam Tor. After Skempton et al. (1989).



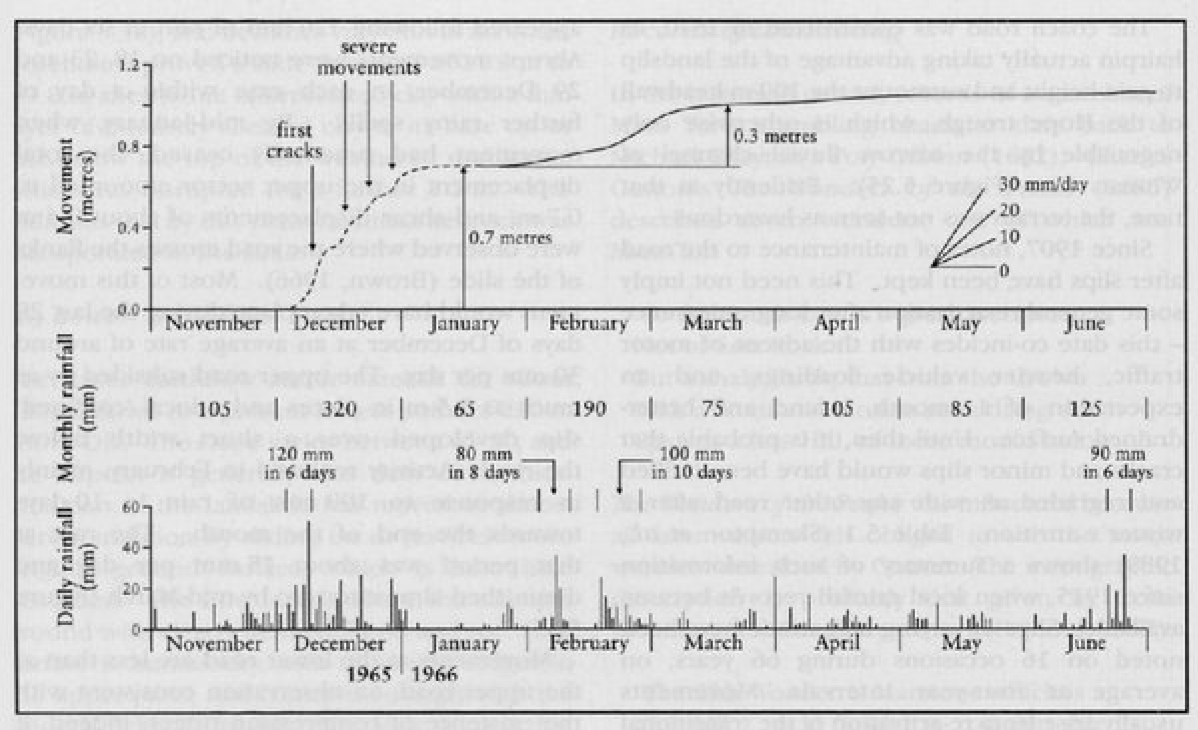
(Figure 5.31) Geological and morphological details of the scar and the upper slump sector of the Mam Tor landslide, showing the locations of boreholes 4 and 8 (BH 4 and BH 8). After Skempton et al. (1989).



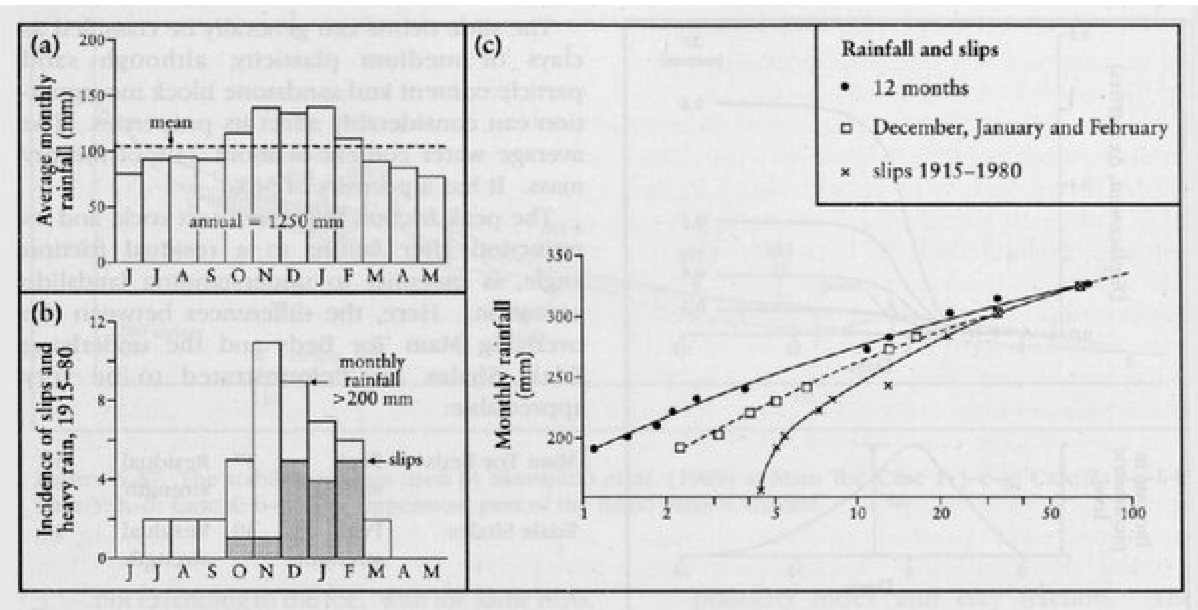
(Figure 5.32) Transverse section of the middle transition sector of the Mam Tor landslide (Ordnance Survey, gridline 133). The shaded area is the landslide; borehole (BH) positions are marked. After Skempton et al. (1989).

Slip	Date	Movements	Monthly rainfall (mm)
1	Jan 1915	Crack 30 m long	200
2	Dec 1918	slip, 0.3 m subsidence	240
	Jan 1919	movements continue	140
3	Dec 1919	steady movement	280
	Jan 1920	movements continue	200
4	Dec 1929	serious slip	300
	Jan 1930	movements continue	180
5	Jan 1931	slip, 60 m crack	210
	Feb 1931	movements continue	190
6	Feb 1937	considerable subsidence	220
7	Jan 1939	100 m crack, 0.25 m subsidence	210
8	Oct 1942	30 m crack, 0.1 m subsidence	160
9	Feb 1946	extensive slip	240
10	Nov 1946	new movements	230
11	Feb 1948	subsidence on 200 m length (preceded by 280 mm rain in Jan)	100
12	Dec 1949	slip (no details)	230
13	Jan 1952	large slip (preceded by 400 mm rain in November and December)	150
14	Dec 1965	serious slip, 0.7 m displacement	320
15	Feb 1966	renewed movement, 0.3 m displacement (preceded by 385 mm rain in December and January)	190
16	Feb 1977	large slip; 0.4 m subsidence (average)	230

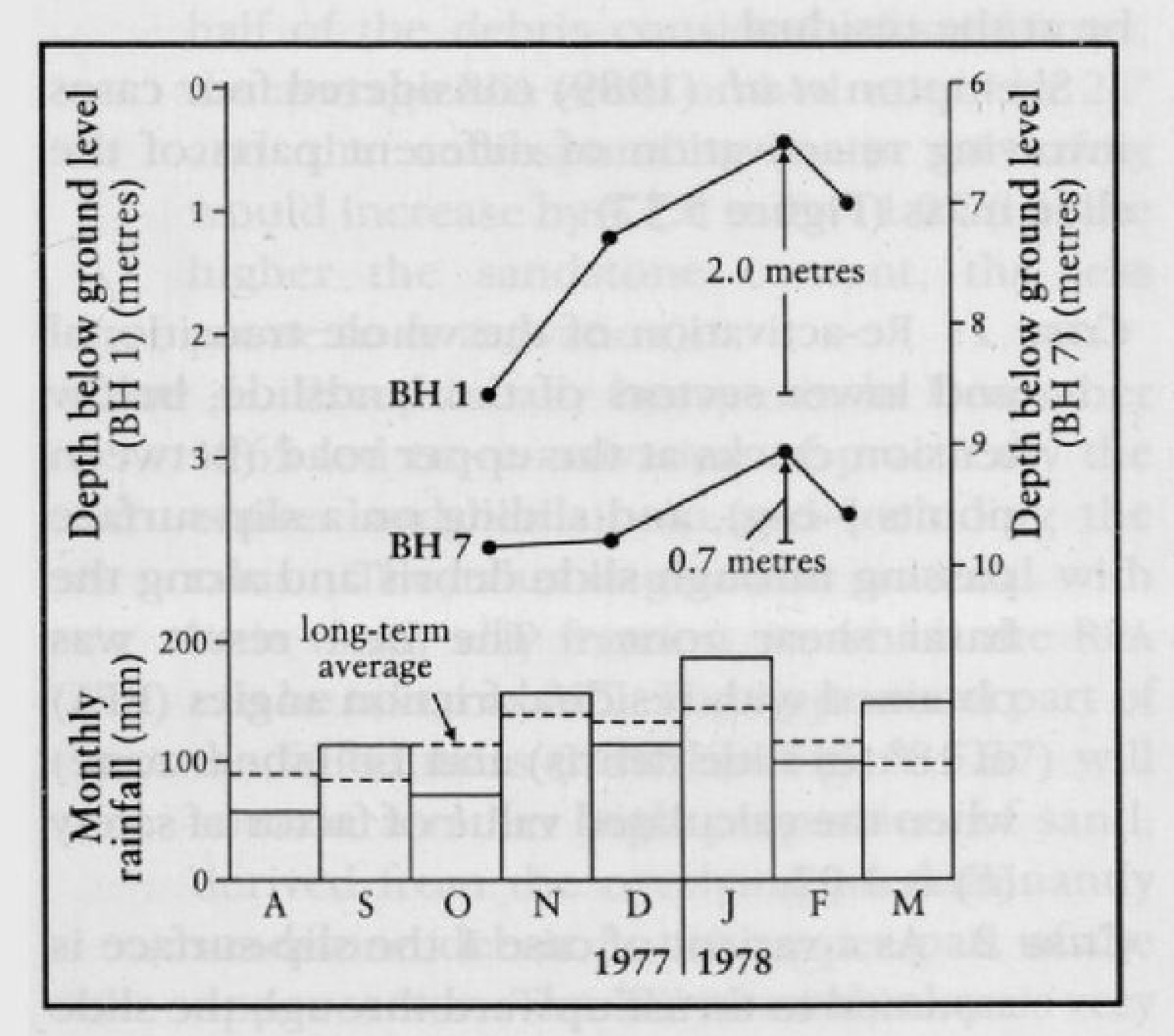
(Table 5.1) Records of movement and rainfall at Mam Tor, 1915–1977.



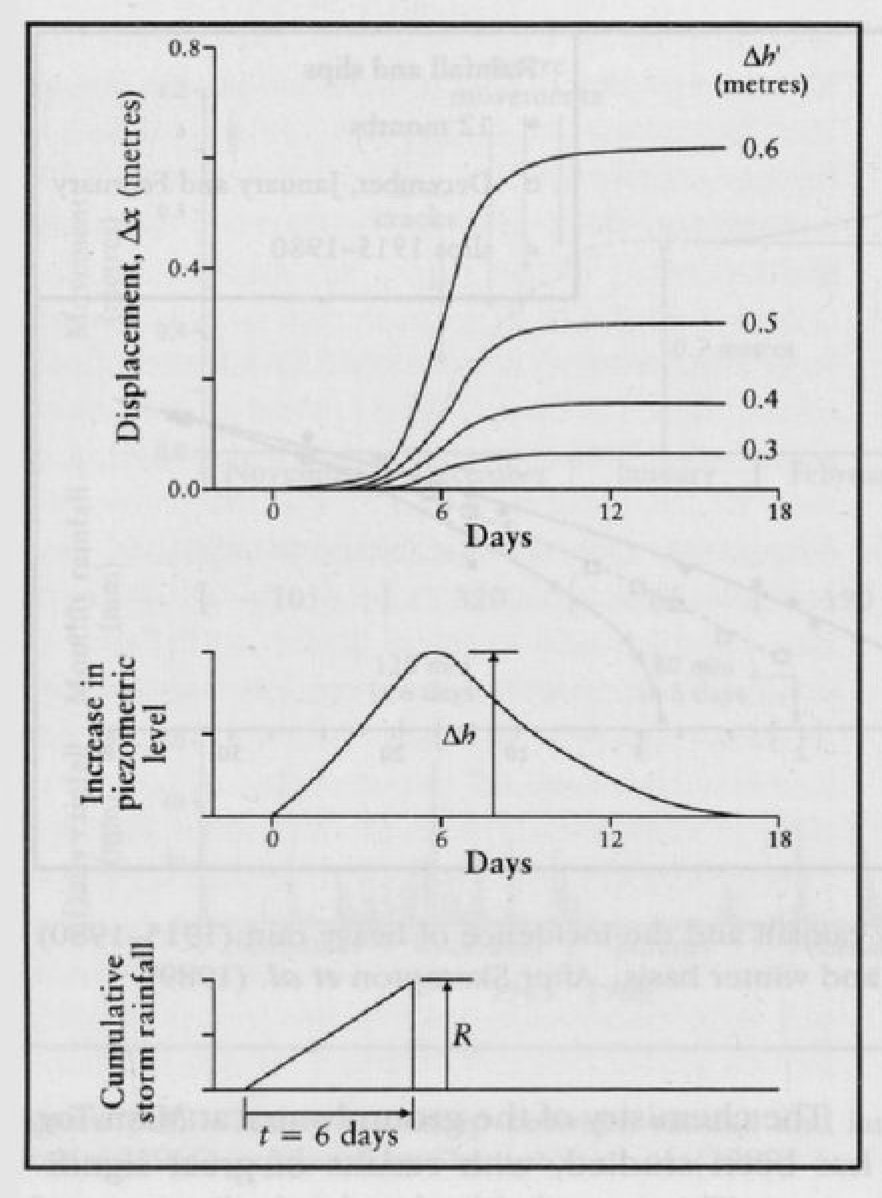
(Figure 5.33) The relationship between rainfall and landslide movements, winter 1956–1966. Recorded by Brown (1966), updated by Skempton et al. (1989).



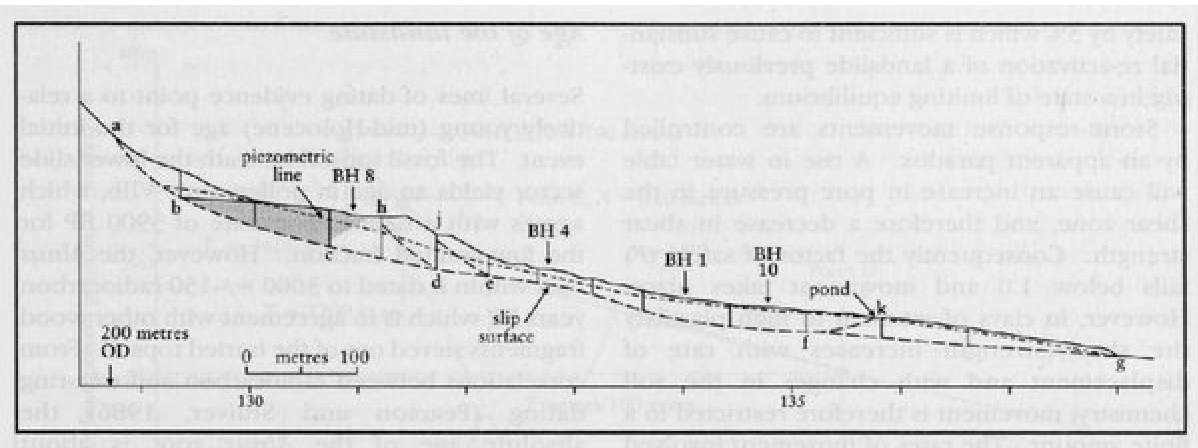
(Figure 5.34) The relationship between average monthly rainfall and the incidence of heavy rain (1915–1980) and the return periods of monthly rainfall on an annual and winter basis. After Skempton et al. (1989).



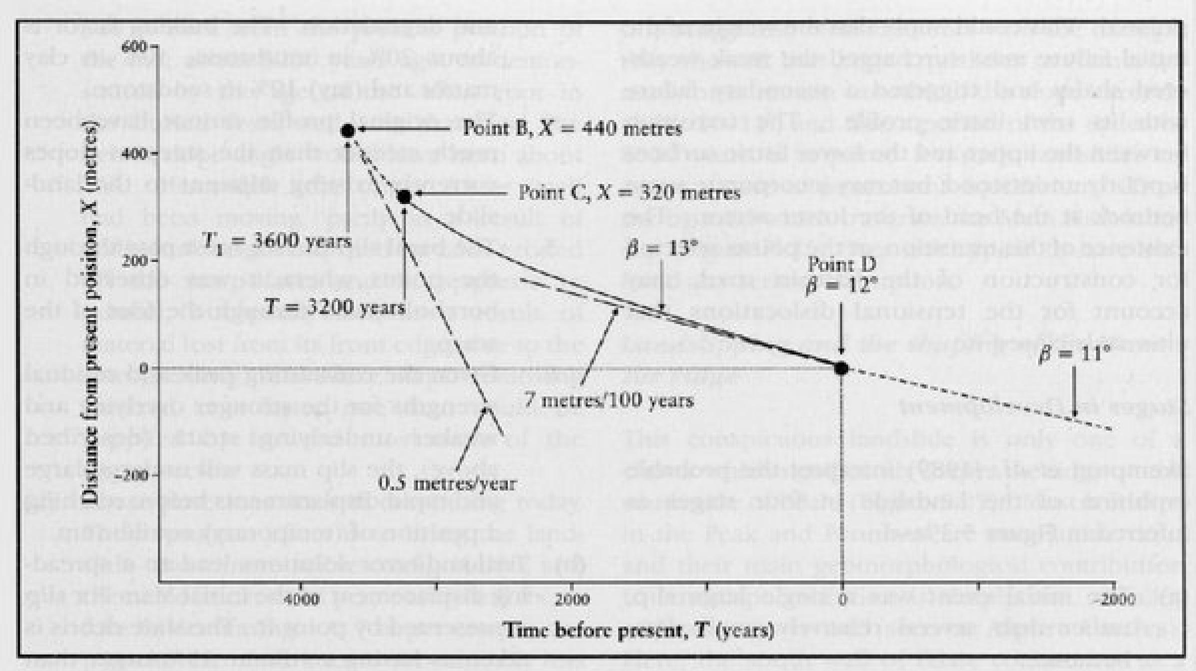
(Figure 5.35) Piezometric levels recorded at Mam Tor during 1977 and 1978. After Skempton et al. (1989).



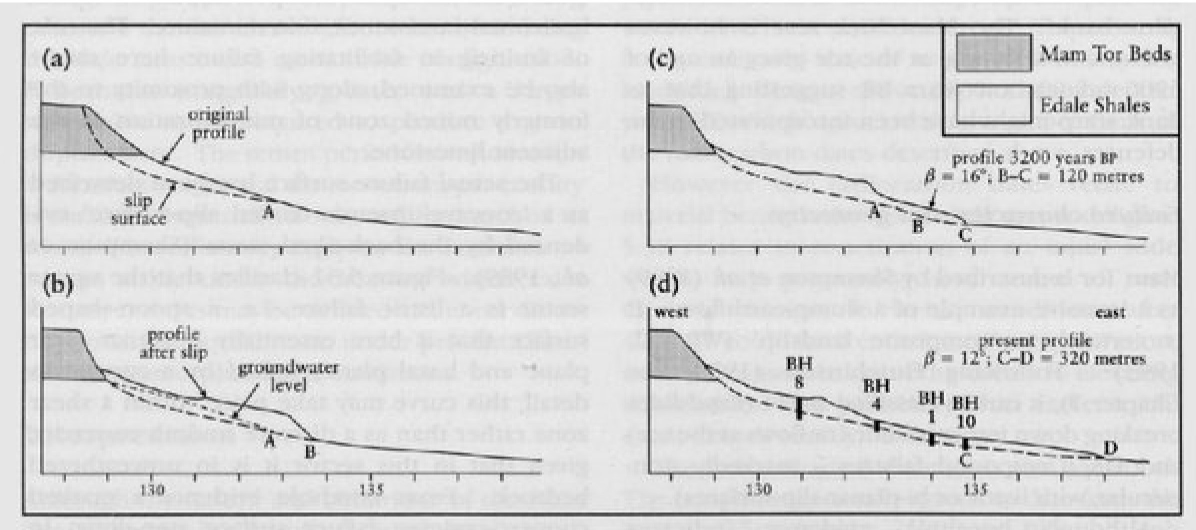
(Figure 5.36) Displacements at Mam Tor caused by winter rainstorms. Note: movement begins at a piezometric level that is lower than the level at which movement ceases. This may imply that there has been a strength gain that may be of chemical origin in which movement releases cations. After Skempton et al. (1989).



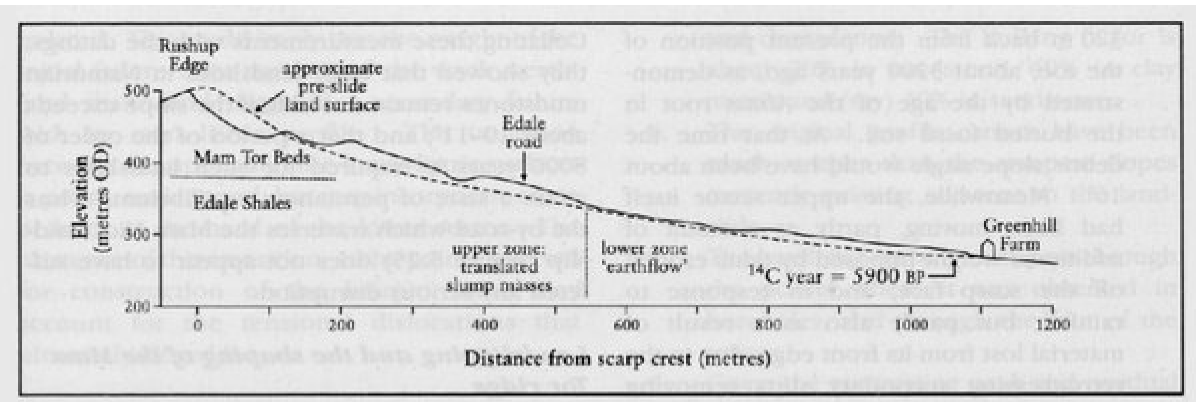
(Figure 5.37) The stability analysis used by Skempton et al. (1989) at Mam Tor. Case 1: j–e–g; Case 2: j–e–f–k; Case 3: h–d; Case 4: b–c. The uppermost part of the failed mass is shaded.



(Figure 5.38) Method of determining age of Mam Tor landslide by projecting back from current configuration and rate of movement (points B–D as (Figure 5.39)). T = 0 corresponds to 1950 AD After Skempton et al. (1989).

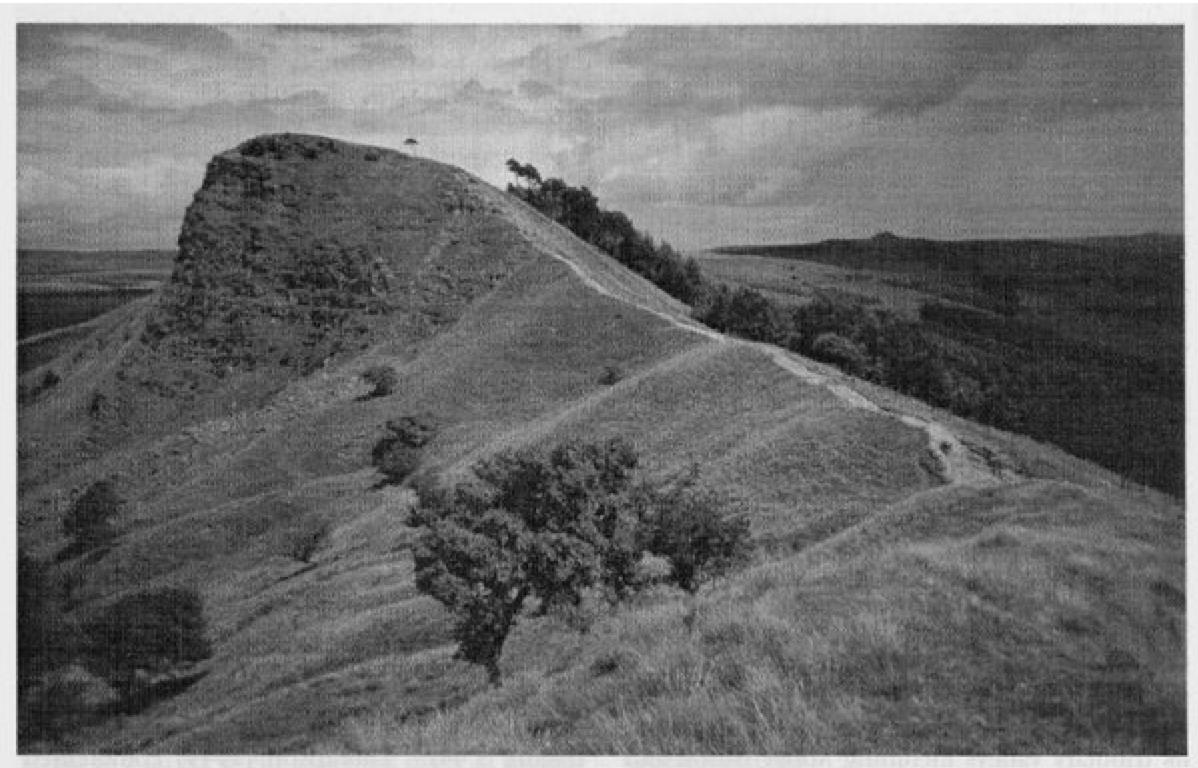


(Figure 5.39) Inferred evolution of the Mam Tor landslide (8 = slope angle at toe): (a) initial failed mass; (b) arrested slide immediately after initial landslide event; (c) early stage in progressive advance of toe; (d) present profile. After Skempton et al. (1989).



(Figure 5.40) Landslide profiles at Mam Nick, where f3 = 10°. After Skempton et al. (1989).

(Figure 5.41) Mam Nick landslide source cavity and upper slump zone, from Rushup Edge looking east. Note the far flank scar interrupting Mam Tor hillfort rampart, and the headscarp narrowing the former plateau ridge to a crest. Edale road passes through Mam Nick and descends across the slump, which has grassy slip-masses presenting uphill-facing scarps. (Photo: D. Jarman.)



(Figure 5.42) Back Tor landside from the east. The 60 m main crag is a source scar comparable to Mam Tor. The intervening ridge has been lowered by some 50 m by virtue of the slide surface here exposed behind the crest. (Photo: D. Jarman.)