Chapter 7 Periglacial landforms and slope deposits of northern England

Introduction

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Periglacial climates and processes

The term 'periglacial' refers to the conditions, processes and landforms associated with cold, non-glacial environments (Harris *et al.,* 1988). The periglacial environment is diverse and includes a wide range of cold, non-glacial conditions, regardless of their proximity to a glacier either in time or space (French, 1996). Periglacial processes are dominated by frost action (frost-weathering of soils and bedrock) and by permafrost-related processes (the development of perennially frozen ground with ice segregation and the thermal contraction and thawing of such ground). Other processes include frost activity in the seasonally frozen layer, rapid mass movements (often over saturated ground) and fluvial and aeolian processes. Although there is no single periglacial climate type, periglacial processes usually dominate areas where the mean annual air temperature is less than +3°C. This commonly is subdivided further at –2°C mean annual air temperature into environments where frost action dominates (mean annual air temperature less than –2°C) and those where frost action is less dominant (between –2°C and +3°C). A combination of latitude, altitude and continentality control the location of areas affected by periglacial climates.

In Britain it is helpful to distinguish between two types of periglacial environment. First is the present-day periglacial environment, where periglacial processes are still active and periglacial landforms and sediments are currently forming. In general this is confined to mountainous and upland areas (Ballantyne, 1987). In northern England the active periglacial environment is manifested normally by small-scale periglacial processes, such as those on Cross Fell (Tufnell, 1985) and the higher summits of the Lake District (Hollingworth, 1934; Caine, 1963a, b), including Helvellyn (Warburton, 1985), Grasmoor (Caine, 1972), Skiddaw (Caine, 1972; Warburton, 1985) and High Pike (Warburton and Caine, 1999). Second is the assemblage of landforms and sediments that are no longer forming under present-day climatic conditions. These essentially are relict features that belong to periglacial climates of the past (Ballantyne, 1984).

It is important to recognize that the influence of periglacial climates on the British landscape has varied both in time and in space. Thus the limits of periglacial activity have migrated across the landscape over time during the Quaternary Period, and it is only relatively recently that the active periglacial environment has retreated into mountainous areas. On this basis, it is possible to recognize four different periglacial regions within Britain according to the intensity of landscape modification (Figure 7.1). Of these, three periglacial regions are found in northern England. First is an area occupied by glacier ice during the Loch Lomond Stadial, where periglaciation is restricted solely to high ground during Holocene times. These areas are limited in extent, and confined to isolated mountainous and upland areas of the Lake District and northern and western Pennines. Second are areas located within the limits of the Late Devensian ice sheet that were subjected to severe periglacial conditions during ice recession after *c.* 18–15 ka and again during the Loch Lomond Stadial. Much of northern England, including the Pennines, North Yorkshire, Lancashire, Northumberland and the Cheshire–Shropshire Lowlands is located within this periglacial region. These areas are currently affected to some extent by Holocene periglaciation on high ground. Third are those areas probably not glaciated since the Anglian (marine Oxygen Isotope Stage 12). These areas therefore have been subjected to successive periods of prolonged severe periglacial conditions since that time and include the North York Moors, the Peak District and parts of the southern Pennines.

Partly as a result of the temporal migration of the limits of periglacial activity, a wide range of periglacial landforms and sediments is present within northern England (Table 7.1). In upland areas, such as the Cheviots, Cross Fell and the Lake District, periglacial features form major landscape elements. Examples include the Late Devensian scree at Throstle Shaw, the periglacial alluvial fan at Sandbeds, the active scree slopes at Wasdale, and the protalus rampart at Dead Crags, Skiddaw. Elsewhere, at sites such as Chelford and Four Ashes, where periglacial activity is represented only in sedimentary successions and has little surface expression, the evidence is more subtle. The aim of this chapter is to outline the nature of periglacial climates and landforms, focusing in particular on the landforms and sediments that are encountered in northern England. Ballantyne and Harris (1994) provide an excellent general review of periglacial processes and landforms both globally and in Great Britain.

Permafrost characteristics

One of the distinguishing characteristics of the periglacial environment is the presence of permafrost. Permafrost generally is defined as ground in which the temperature remains below 0°C over at least two consecutive years (Ballantyne and Harris, 1994). Permafrost is not always present at the ground surface, where a seasonally thawed zone (the active layer) develops in the summer months, but normally is present only at depth. No true permafrost exists in Britain, although there is evidence that it has been widespread in the past (Seddon and Holyoak, 1985). The existence of features indicative of former permafrost conditions suggests mean annual temperatures of below –5°C (Rose, 1975; Sissons, 1977, 1979b). The landforms and sediments indicative of widespread former permafrost are therefore important palaeoclimatic indicators (Williams, 1975).

Periglacial landforms

Ice-wedge casts and polygons

The processes operating in permafrost terrain create a diverse range of landforms and sediments. Some of these processes, for example the seasonal expansion and contraction of the ice and sediment in the active layer, may also penetrate downwards into the permafrost beneath to create ice wedges. Relict examples of ice wedges, in the form of ice-wedge casts, are often present in Quaternary sedimentary successions. They have been described at sites such as Four Ashes and Chelford, as well as throughout the area covered by this volume (Worsley, 1966). They are often visible from the air in plan view as large networks of polygons.

Pingos, thufurs and thermokarst

Permafrost processes often involve the growth and subsequent melting of massive ground-ice masses within near-surface sediments. This process can create large near-surface ice and sediment blisters that rise above the surrounding topography as pingos. Melting of the ice core in pingos leaves a more or less circular depression surrounded by a low rampart (pingo scars). Examples in Britain include those of the Aberystwyth and mid Wales area (Watson, 1971, 1972), East Anglia (Sparks *et al.,* 1972) and in the Whicham Valley, Cumbria (Bryant *et al.,* 1985). Bryant and Carpenter (1987) provide a detailed review of these features in Britain as a whole. Much smaller ground-ice lenses can create earth hummocks or thufurs. These features are found in the northern Pennines and possibly are forming under present-day conditions. Shallow thaw lakes on permafrost surrounding pingos often create a complex association of irregular water-filled depressions and hollows known as 'thermokarst'.

Patterned ground

Repeated freezing and thawing of the active layer in permafrost regions is responsible for a suite of small-scale landforms and sedimentary structures. The dominant process in these situations is thought to be the segregation and sorting of sediment into fines and coarser debris/ clasts, after sufficient numbers of freeze–thaw cycles (Figure 7.2). The landform–sediment assemblage produced by this process includes patterned ground (circles, polygons, irregular networks and stripes) and cryoturbation structures such as involutions. The term 'patterned ground' refers to terrain that exhibits regular or irregular patterning in the form of circles, polygons, irregular networks or stripes (Ballantyne and Harris, 1994). Landforms of this type frequently are associated with cold environments, where ground freezing and thawing is the dominant formative mechanism. As such, they are commonly regarded as indicators of former permafrost conditions (French, 1996). The surface-patterned ground features at upland sites such as Helvellyn, Grasmoor, Cross Fell and the Stiperstones fit with this overall palaeoclimatic interpretation. Following the original classification of Washburn (1956) a distinction is commonly made between sorted patterned ground and non-sorted patterned ground. Sorted patterned ground is defined by the alteration of fine and coarse debris, whereas in non-sorted patterned ground the pattern is formed by microrelief and/or vegetation cover.

Large-scale sorted patterned ground is common on higher British mountains, where essentially it is a Late Devensian relict (Ball and Goodier, 1968; King, 1971; Ballantyne, 1984), but is less common in lowland areas. Large stone-stripes have been described from lowland sites on the chalklands of East Anglia that remained outside the limits of the Late Devensian ice sheet (Williams, 1964; Watt *et al.,* 1966; Evans, 1976; Nicholson, 1976; Ballantyne and Harris, 1994) and beneath the granite tors of Dartmoor (Te Punga, 1957). Also, they have been described on the western slopes of Great Dun Fell in the northern Pennines. The slope-related transition from sorted polygons to stone stripes noted by Goudie and Piggott (1981) is consistent with observations from modern periglacial environments (Ballantyne and Harris, 1994; French, 1996).

Mass wasting and gelifluction

Periglacial processes also are active on upland and lowland areas where soil cover is developed. Here the all-encompassing term 'mass wasting' has been used to describe the downslope movement of regolith by gravity without the aid of a transport agency such as a river, glacier or wind (Washburn, 1979). Periglacial mass wasting covers both the gradual downslope movement of slope sediments as a result of repeated freezing and thawing, and the more localized sudden slope failures that occur during thawing of the active layer. The former includes frost creep and gelifluction, whereas the latter includes mudflows, debris flows and ground-ice slumps. Examples occur on Grasmoor, Skiddaw, Helvellyn and Cross Fell.

Gelifluction is the slow downslope movement of soil under conditions of seasonal freezing and thawing. This process creates numerous landforms, including solifluction sheets, lobes and terraces, as well as ploughing blocks. Solifluction operating on upland slopes during periglacial episodes previously has been invoked to explain the bulk of sediments underlying valley-floor terraces in many parts of the British Isles (e.g. Crampton and Taylor, 1967; Watson, 1970; Potts, 1971; Thomas, 1971; Harris and Wright, 1980; Douglas and Harrison, 1985).

Accumulations of periglacial slope deposits formed by mass movement are commonly known as 'head'. The term 'head' covers a wide variety of sediments, but normally these are poorly sorted mixtures of fine matrix and larger clasts. Angular clasts may dominate, although more rounded material also may be present if, for example, the head is reworked from glacial or glaciofluvial deposits. The effects of frost shattering in periglacial climates is most pronounced in upland areas, where it takes the form of mountain-top detritus, including regolith and debris-mantled slopes and plateaux, blockfields, blockslopes and tors (Ballantyne, 1994, 1999).

Nivation and cryoplanation

'Nivation' is an all-encompassing term used to describe the processes of weathering and transport that are accelerated or intensified by the presence of snow patches (Ballantyne and Harris, 1994). These processes include intensive freeze–thaw activity, enhanced chemical weathering, slopewash, transport of debris by snow creep, sediment transport across snow patches to give protalus ramparts, and accelerated solifluction through saturation of regolith downslope from melting snow (Thorn and Hall, 1980; Thorn, 1988; Ballantyne and Harris, 1994). Using modern examples in Greenland, Christiansen (1998a) concluded that the main nivation processes and landforms are backwall failure, sliding and flow, niveo-aeolian sediment transport, supra- and en-nival sediment flows, niveo-fluvial erosion, development of pronival stone pavements, accumulation of alluvial fans and basins, and pronival solifluction. Combinations of these processes are responsible for the creation of a number of erosional landforms ranging from small hollows (Nicols, 1963), through medium-size features (Nyberg, 1991; Caine, 1992; Raczkowska, 1995; Christiansen, 1996, 1998b) to nivation hollows tens of metres in size (Ballantyne, 1978; Dohrenwend, 1984; Rapp, 1984; Gullentops *et al.,* 1993).

Nivation processes operating in periglacial environments are commonly augmented by large amounts of surface runoff in subaerial fluvial streams, especially in the summer months. This type of permafrost runoff has been invoked to explain the origin of large landforms, such as the dry valleys of the Yorkshire Wolds, which were excavated by a combination of solifluction and subaerial fluvial action under periglacial conditions (Cole, 1879, 1887; Mortimer, 1885; Lewin, 1969; de Boer, 1974; Waltham *et al.,* 1997). Sediment removal and valley incision were aided by snow meltwater flowing over permafrost in the annual melt season.

Despite a long history of periglacial research in this country, however, Ballantyne and Harris (1994, p. 248) have commented that 'Relict nivation and cryoplanation landforms rank amongst the most inadequately documented of all periglacial phenomena in Great Britain'. The largest landforms attributed to nivation processes are the so-called 'nivation cirques' that have been mapped in upland Britain. Nivation cirques represent forms transitional between small-scale nivation hollows and mature glacial cirques, and these features have been identified in the Cairngorm Mountains (King, 1968), on Skye (Birks, 1973), the Cheviot Hills (Douglas and Harrison, 1985) and the Ystwyth Valley in mid Wales (Watson, 1966). Similar processes also may have operated in northern England during the Quaternary to create large nivation hollows such as the Hole of Horcum.

Ballantyne and Harris (1994) have speculated that many of the larger features mapped in upland Britain that are often attributed to nivation processes, such as cryoplanation terraces and nivation cirques, are in fact immature glacial cirques. Nivation cirques 300 to 500 m in diameter and up to 200 m deep would take a prohibitively long time to form given the slow rates of nivation erosion (Thorn, 1976; Nyberg, 1991; Caine, 1992). The large, steep snow patches required to excavate such hollows would quick ly turn to glacier ice as there is a threshold length between snow patches and glaciers of 30–70 m from backwall to toe (Ballantyne and Benn, 1994). The dimensions of these relict nivation cirques are an order of magnitude larger than active nivation hollows found in the present-day Arctic. In light of the above, it appears unlikely that nivation processes alone are sufficient to account for large-scale features that occur in northern England. These large features therefore are most probably pre-Pleistocene erosion surfaces or structural benches that merely have been modified by subsequent nivation and frost-action processes. Alternatively, they may represent immature glacial cirque forms occupied during the build up and decay of the Quaternary ice sheets.

'Cryoplanation' is the formation of near-level rock-cut platforms (known as cryoplanation or altiplanation surfaces) by frost action in periglacial conditions. Cryoplanation surfaces have been reported from various sites in the UK, mainly far to the south of the Late Devensian ice limit (Guilcher, 1950; Te Punga, 1956, Waters, 1962), but also closer to this limit in the southern Pennines (McArthur, 1981) and in Shropshire (Clark, 1994a). However, a comprehensive explanation for the processes responsible for the formation of these surfaces has never been produced. Doubts remain about the location and manner of platform initiation, the production of low-angle platform surfaces and the evacuation of debris over gentle slopes as platform growth proceeds (Czudek, 1964; Demek 1964, 1968; 1969). These doubts were sufficient to lead Budel (1982) to dismiss altogether the ability of these processes to create level bedrock surfaces. Indeed, many of these well-developed, near-level, rock-cut platforms (such as those described at Burbage Brook) may actually represent glacially eroded benches related more to the underlying solid geology than to periglacial processes. This may well be the case in the small-scale terraces reported from Cross Fell.

Talus slopes and scree

Talus slopes and screes include rockfall talus, avalanche slopes, debris flows, protalus ramparts and protalus rock glaciers. Talus slopes are steep valley-side slopes formed by the accumulation of debris at the foot of a rockwall (Ballantyne and Harris, 1994) and are a common geomorphological component of upland landscapes in northern England. The term 'talus' is used to describe both the form of the slope and its constituent material. Although the term 'scree' is often used as a synonym for talus, in modern usage this term is reserved for a slope cover of predominantly coarse debris, irrespective of location. Talus slopes are not restricted to present or former periglacial environments but occur in all areas where the products of rock weathering can accumulate at the foot of a cliff or slope.

Talus slopes commonly take one of three forms:

1. talus sheets, where sediment delivery is fairly uniform across a slope;
2. talus cones, where delivery is concentrated or funnelled down a gully;
3. coalescing talus cones, formed where talus cones intersect laterally (Ballantyne and Harris, 1994).

Both active and relict talus slopes are found in Britain. Active talus slopes are commonly found in three environments in Britain: at the foot of sea cliffs, where the products of coastal erosion naturally collect (e.g. at Flamborough Head), below structural escarpments (see for example the site report for Roman Wall Escarpments) and on the lower slopes of glacial troughs and corries in upland areas (see for example the site report for Wasdale Screes). These large talus slopes are perhaps the most spectacular and therefore it is little surprise that they have attracted the majority of attention in this country (Savigear, 1952; Tinkler, 1966; Ballantyne and Eckford, 1984, Ballantyne and Kirkbride, 1987a). Relict talus slopes also are present in lowland areas, although they are often obscured by later deposits or modern soil development. Relict talus slopes are found in many areas of Britain that have been subjected to periglacial conditions, for example at Throstle Shaw in the Lake District and at Ecton in the Peak District. These periglacial conditions persisted during the Late Devensian beyond the limit of the ice maximum, and relict talus slopes are therefore important palaeoenvironmental indicators.

Loess, coversands and ventifacts

Loess (deposits of silt particles between 2 and 64 μm, transported by aeolian processes), coversands (deposits of fine-grained sand between 64 μm to 2 mm, also transported by aeolian processes) and ventifacts (stones or pebbles that have been shaped by wind-blown sand) generally are regarded as indications of cold and arid climates. Loess and coversands are widespread in southern England outside the Late Devensian ice limits and reveal a westward decrease in particle size, consistent with an easterly wind direction (Catt, 1977a, c). An easterly wind direction is also indicated by the close similarities between the mineralogy of the silt-size fraction of Late Devensian glacial deposits and loess in eastern England, suggesting that the source of the loessic material was glaciofluvial sediment in the North Sea Basin (Catt, 1987a). Analysis of coversands in the Yorkshire Wolds, where the depth of coversand reaches 7 m in places, however, suggests westerly palaeowinds (Bateman, 1998). Thermoluminescence dating indicates a Late Devensian age for the majority of these loessic deposits (Gibbard *et al.,* 1987; Parks and Rendell, 1992), although those of north Lincolnshire have been dated to the Younger Dryas (Bateman, 1998). Widespread coversands have also been described in the Vale of York by Matthews (1970).

In contrast, within the Late Devensian ice limits, aeolian deposits are restricted to isolated pockets. Catt (1987c) has described coversands at Sewerby, east Yorkshire and ascribed these to Oxygen Isotope Sub-stage 5d to 5a (Early Devensian) age. In the southern part of the Vale of York a ground surface, including ice-wedge casts, ventifacts and thermokarst features, that developed on Ipswichian river gravels, but beneath Late Devensian glaciogenic deposits, also is probably of Early Devensian age (Bisat, 1946; Gaunt, 1970b, 1976, 1981; Gaunt *et al.* 1972, 1974; Catt, 1977c). One of the most extensive sheets of coversands is the Shirdley Hill Sand Formation in south-west Lancashire, which is of Younger Dryas or Loch Lomond Stadial age (Wilson *et al.,* 1981). Lee (1979) has described loess of a presumed Late Devensian age from Thurstaston on the Wirral. Ventifacts, including faceted and sand-blasted Bunter sandstone pebbles, of a supposed pre-Late Devensian age also have been described from Trysull in the West Midlands (Morgan, AN., 1973) and in parts of Cheshire (Thompson and Worsley, 1967). These occurrences, in different positions within the stratigraphical record, suggest that there have been several different phases of aeolian activity

The evolution of tors

Tors are features that are not universally regarded as periglacial in origin. Traditionally, their origin has been explained either with reference to differential weathering in temperate, humid climates or attributed to periglacial stripping. A tor can be defined as 'a residual mass of bare rock that rises conspicuously above its surroundings, is isolated by free-faces on all sides, and owes its formation to differential weathering and mass wasting' (Ballantyne and Harris, 1994, p. 178). Tors have been described from all conventionally defined climatic regions across the world, including Antarctica (Selby, 1972), Australia (Caine, 1967), New Zealand (Wood, 1969), Canada (Sugden and Watts, 1977; Watts, 1981), Portugal (Linton, 1955) and Great Britain (Waters, 1954; King, 1958; Pullan, 1959; Eden and Green, 1971; Gerrard, 1978; Ballantyne, 1994; Glasser, 1997). In Britain, tors are found primarily in upland locations and particularly on massive, resistant rocks (Figure 7.3). They occur in both glaciated regions (e.g. the Cairngorms, the Cheviot Hills) and also in unglaciated regions (e.g. Dartmoor, Cornwall). Tors are particularly well developed on granitic lithologies, although they have been identified on a wide range of other lithologies (Table 7.2).

There currently are two main theories that can account for tor formation. The first entails a two-stage model of weathering and stripping (Linton, 1955) and the second requires only a single cycle of denudation under periglacial conditions (Palmer and Radley, 1961; Palmer and Nielson, 1962). Other theories, involving the action of present-day seepage moisture (Bunting, 1961) and 'the disintegration of resistant stratum following the rejuvenation of mature hill slopes'

(Palmer, 1956, p. 69), do not appear to have met with much favour.

The Subtropical/temperate origin

Linton's two-stage hypothesis was developed primarily from observations on the tors of Dartmoor, before it was applied to other upland areas such as the Pennines. Linton (1955, p. 472) argued that tors are the result of 'a two-stage process, the earlier stage being a period of extensive sub-surface rock rotting whose pattern is controlled by structural considerations, and the later being a period of exhumation by removal of fine-grained products of rock decay'. This model requires a long period of deep weathering of the landscape under subtropical conditions so that a weathering mantle of saprolite develops over and around the corestones beneath (Figure 7.4). Later removal of this weathering mantle during the Quaternary Period by meltwater and solifluction exposed the corestones and left them standing as residual tors. This model of tor formation therefore has important palaeoclimatic interpretations attached to it in that it requires a prolonged period of pre-Quaternary deep weathering.

(Table 7.2) The locations and lithologies of the main tors in Britain (compiled from various sources, including Goudie and Piggott (1981) and Ballantyne and Harris (1994)).

Area	Lithology	References
1. England		
Isles of Scilly	Granite	Scourse (1987)
Dartmoor (South-west England)	Granite	Linton (1955); Palmer and Neilson (1962); Eden and Green (1971); Gerrard (1974, 1978, 1988)
Exmoor (South-west England)	Sandstone	Mottershead (1967)
Weald (South-east England)	Sandstone	Robinson and Williams (1976)
Charnwood Forest (Midlands)	Granite, microdiorite and hornstone	Ford (1967)
Tabular Hills (Yorkshire)	Silicified grits	Palmer (1956)
Derbyshire	Dolomite	Ford (1963, 1969)
Derbyshire	Gritstone	Palmer and Radley (1961); Linton (1964); Cunningham (1964, 1965)
Stiperstones (Shropshire)	Quartzite	Goudie and Piggott (1981); Clark (1994a)
Cheviot Hills	Granite	Common (1954); Douglas and Harrison (1985)
2. Wales		
Central Wales	Igneous rocks, grits	Potts (1971)
Pembrokeshire	Rhyolite	Linton (1955)
Preseli Hills	Dolerite	Linton (1955)
3. Scotland		
Cairngorm Mountains	Granite	Linton (1949, 1955); King (1968); Ballantyne (1994)
North-east Scotland	Granite	Linton (1955)
Ochil Hills	Andesite	Linton (1955)
Ben Loyal (Sutherland)	Syenite	Linton (1955)
Caithness	Sandstones and grits	Linton (1955)
Trotternish, Skye	Basalt	Ballantyne (1990, 1991)

The periglacial origin

Linton's hypothesis has not met with universal acceptance and in a series of papers (Palmer and Radley, 1961; Palmer and Nielson, 1962; Palmer, 1967) it was argued that the tors of upland Britain formed during a 'single cycle' of periglacial denudation. Tor formation does not require the extensive deep weathering explicit in Linton's model. Instead it involves frost shattering of rock on the summits and edges of outcrops, together with the removal of these products by gelifluction

(Figure 7.5). Thus tors can form during periods of periglacial climate without the need for a former deep weathering mantle. Indeed, in the Pennines, tors are often part of a periglacial landform assemblage associated with the Millstone Grit. This includes the tors themselves, landslides, blockfields and gelifluction deposits. Evidence for widespread deep weathering generally is absent in this area, although Cunningham (1965, p. 431) in his evaluation of the south Pennine tors concluded that 'clearly the tors were weathered long before the surrounding blocks were exposed'. Cunningham believed that the Pennine tors were exhumed by Pleistocene glaciation, which decapitated some of the tors and totally erased others.

Assessment of the two models

The tors described in this chapter are clearly central to much of the larger debate surrounding tor formation in Britain. Palmer's original 'single cycle' hypothesis is based on his observations in the Pennines and he studied many of the tor sites described here. Sites such as Brimham Rocks and the Bridestones were also used as (Figure 7.4) (a) The two-stage model (modified from Linton, 1955). (b) The two-stage model for development of a gritstone edge (modified from Linton, 1964). Both models invoke preferential deep weathering of densely jointed bedrock and subsequent stripping of this weathering cover under periglacial conditions. Letters and numbers are used to indicate the pathways of individual blocks through the weathering process.

of tor formation evidence by Palmer and his co-workers for the single cycle model, whereas Linton cited the Cheviot Tors, Great Almscliff Crag and the tors of Burbage Brook in support of his two-stage model. Other sites, such as the Stiperstones, where tors occur in close association with periglacial features, can be used to illustrate a periglacial origin for such features. Related to this debate are sites such as Blackstone Edge, where in-situ weathered bedrock (grus) is exposed. The chief protagonists in the debate concerning the processes of tor formation in the Pennines argued over the nature of this grus and its relationship to the tors of the area.

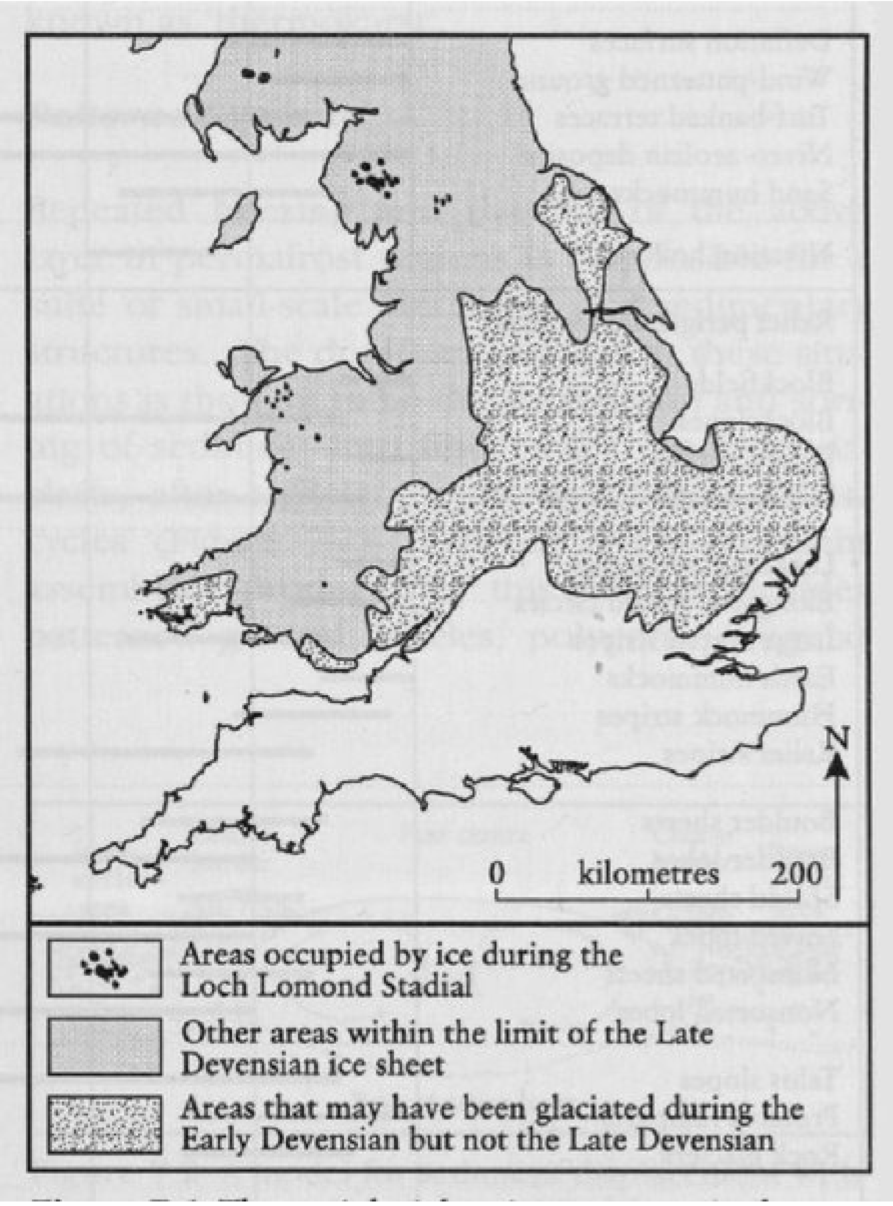
The Pennine tors are of course only a small part of a much larger body of evidence relating to tor formation. Tor sites in other parts of England, Scotland and Wales that have contributed to this debate were also selected for the Geological Conservation Review. Examples of such sites elsewhere in England are Merrivale, Dartmoor and the Scilly Isles in the south-west of England (Campbell *et al.,* 1998). In Scotland there are tor sites on Lochnagar and in the Cairngorm Mountains (Gordon and Sutherland, 1993). Tors occur in Wales at Preseli and Trefgarn in South Wales (Campbell and Bowen, 1989), together with Y Glyderau and Y Carneddau in North Wales (Campbell and Bowen, 1989). Each of these sites represents a different aspect of tor formation in order to encompass all the important factors such as tor location (summit versus scarp-edge), lithology (igneous versus sedimentary) and the extent of weathering and the nature of glaciation (non-glaciated versus glaciated).

Although tors may be polygenetic in origin, it is possible to make some generalizations about their formation. It may be significant that Linton's ideas were based on observations on Dartmoor, where the tors tend to be of the summit type and where deep weathering is common, whereas many of Palmer's ideas stemmed from research in the Pennines where scarp-edge tors are more common. Thus the two-stage model better fits the granite summit tors of areas such as Dartmoor, the Cairngorms and the Cheviots, whilst the single cycle model better explains the gritstone scarp-edge tors of the Pennines (Ballantyne and Harris, 1994). As a result, when first Palmer and Nielson (1962) and subsequently Linton (1964) tried to fit their own models to the other's geographically distinct field areas, flaws began to appear in both models. Ballantyne and Harris (1994, p. 180), in summarizing this debate over tor formation, make the pertinent observation that because 'the Pennine tors tend to differ in all ... respects from those of Dartmoor, it may appear that the search for a single unifying model of tor evolution is fruitless'. Their conclusion is that the evidence in each area should be evaluated independently and that the available evidence points to a polygenetic origin for tors in upland Britain.

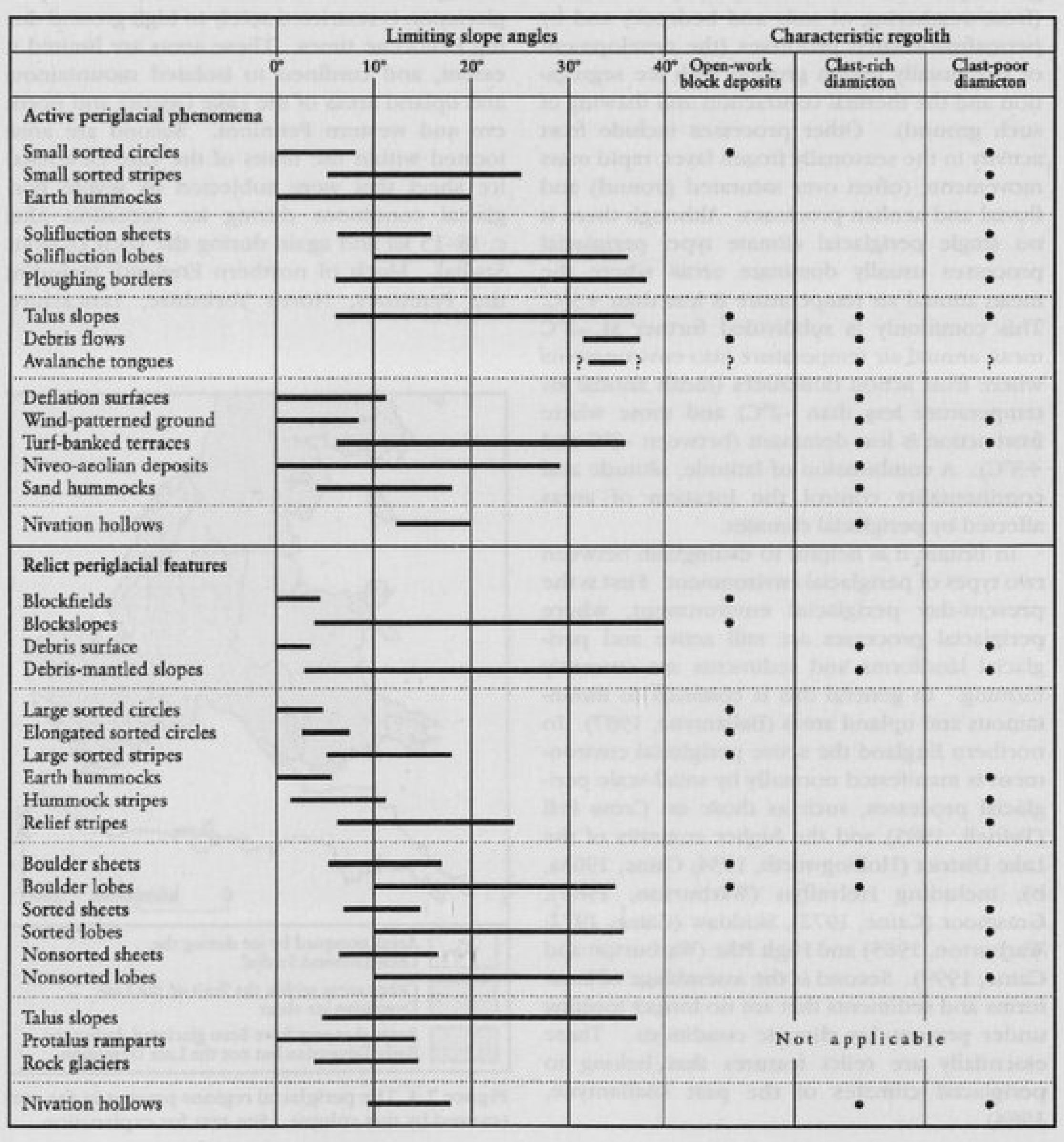
Summary

Periglacial processes are varied, but are characterized by frost action, the freezing and thawing of permafrost and/or the active layer, rapid mass movements, nivation and aeolian processes. These processes are in turn responsible for a variety of different landforms and sediments related to factors such as the intensity of freeze–thaw cycles, the availability of moisture, the type of rock or sediment being acted upon, the extent of vegetation cover, the dominant slope angle and aspect. Of the many landforms created in the periglacial environment, tors are perhaps one of the most controversial to the extent that they are not universally regarded as periglacial in origin. The intensity of periglacial modification of the British landscape has varied over time in response to climatic changes and many of the features described in this chapter therefore have important palaeoclimatic interpretations attached to them.

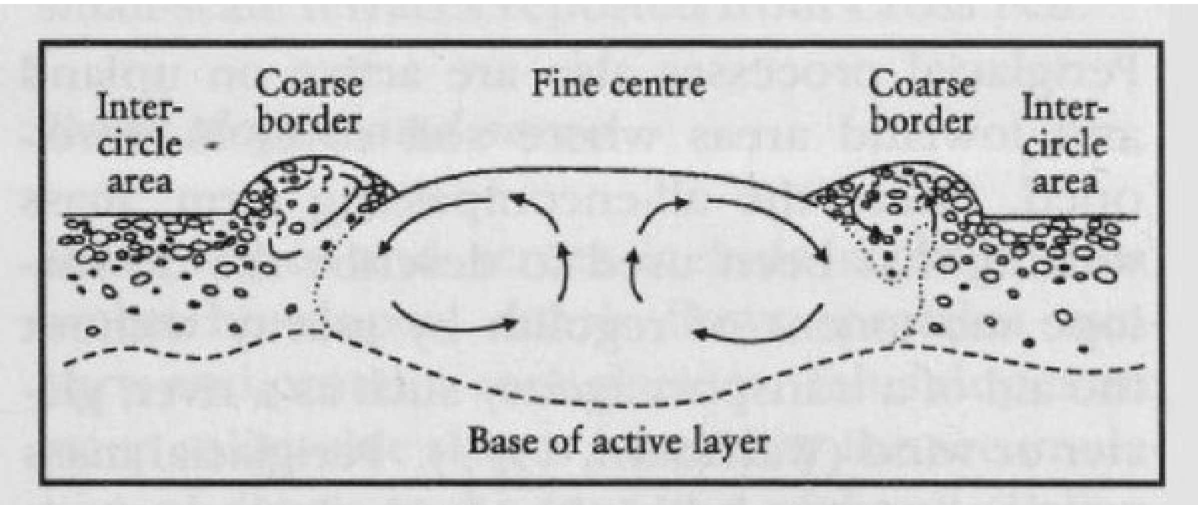
References



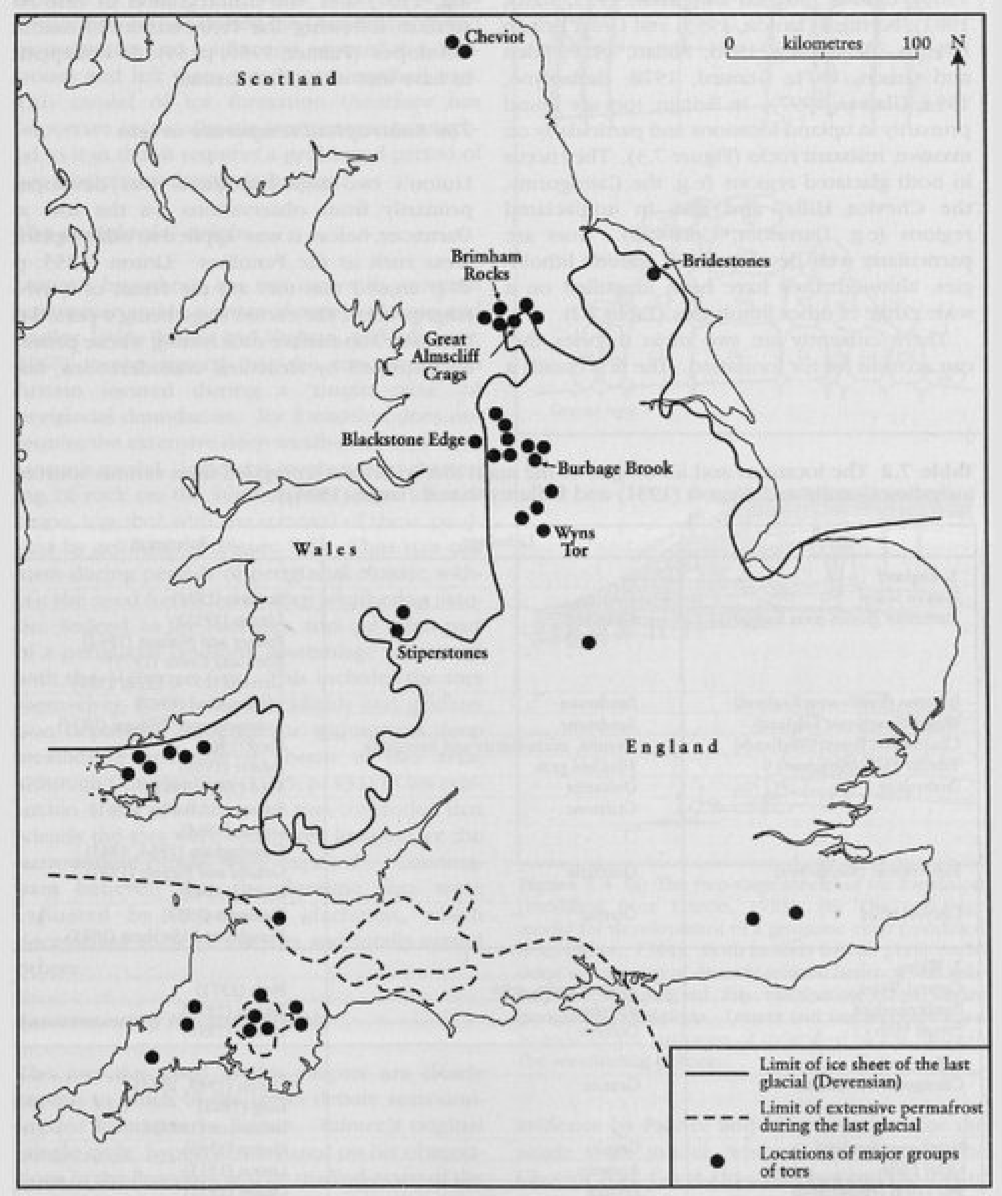
(Figure 7.1) The periglacial regions present in the area covered by this volume. See text for explanation.



(Table 7.1) Controls on the distribution of active periglacial phenomena and relict periglacial features on British mountains (modified from Ballantyne and Harris, 1994).



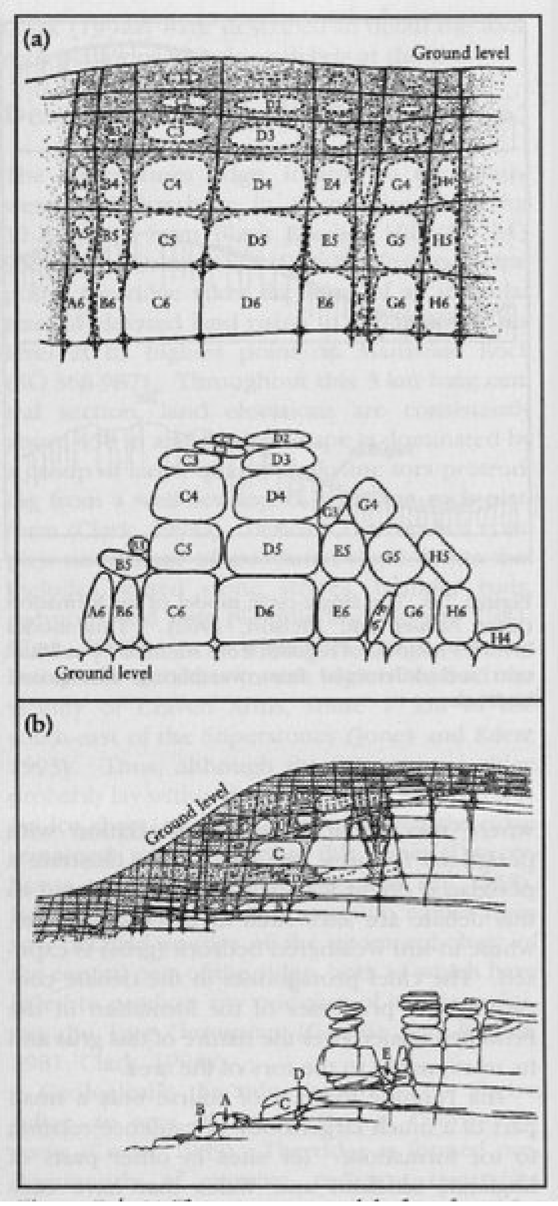
(Figure 7.2) A model for sediment displacement within periglacial sorted circles (modified from Hallet and Prestrud, 1986).



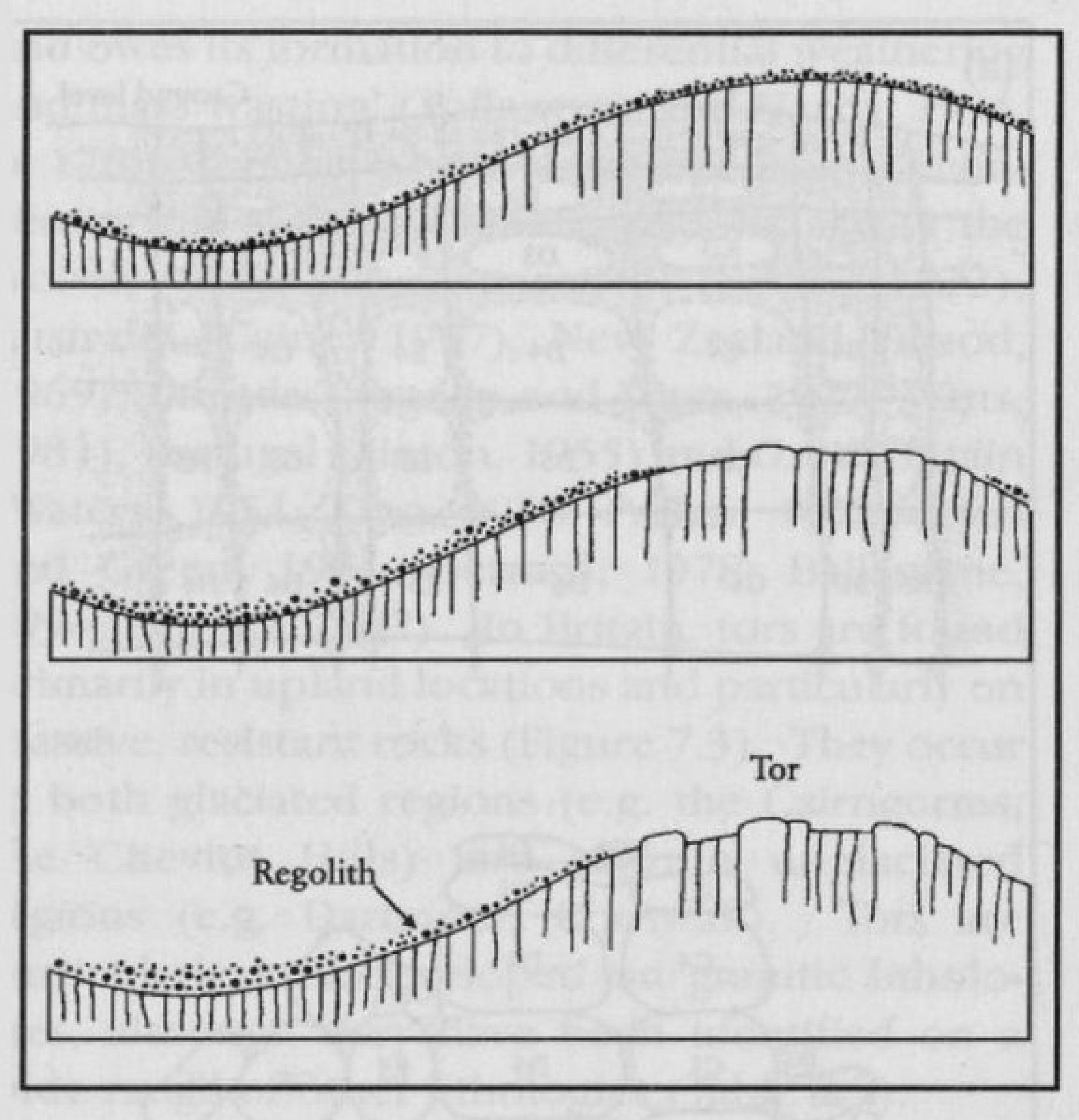
(Figure 7.3) The distribution of major areas of tors in the southern British Isles, indicating the location of sites described in this chapter.

Area	Lithology	References
1. England		
Isles of Scilly	Granite	Scourse (1987)
Dartmoor (South-west England)	Granite	Linton (1955) Palmer and Neilson (1962) Eden and Green (1971) Gerrard (1974, 1978, 1988)
Exmoor (South-west England)	Sandstone	Mottershead (1967)
Weald (South-east England)	Sandstone	Robinson and Williams (1976)
Charnwood Forest (Midlands)	Granite, microdiorite and hornstone	Ford (1967)
Tabular Hills (Yorkshire)	Silicified grits	Palmer (1956)
Derbyshire	Dolomite	Ford (1963, 1969)
	Gritstone	Palmer and Radley (1961) Linton (1964) Cunningham (1964, 1965)
Stiperstones (Shropshire)	Quartzite	Goudie and Piggott (1981) Clark (1994a)
Cheviot Hills	Granite	Common (1954) Douglas and Harrison (1985)
2. Wales		
Central Wales	Igneous rocks, grits	Potts (1971)
Pembrokeshire	Rhyolite	Linton (1955)
Preseli Hills	Dolerite	Linton (1955)
3. Scotland		
Cairngorm Mountains	Granite	Linton (1949, 1955) King (1968) Ballantyne (1994)
North-east Scotland	Granite	Linton (1955)
Ochil Hills	Andesite	Linton (1955)
Ben Loyal (Sutherland)	Syenite	Linton (1955)
Caithness	Sandstones and grits	Linton (1955)
Trotternish, Skye	Basalt	Ballantyne (1990, 1991)

(Table 7.2) The locations and lithologies of the main tors in Britain (compiled from various sources, including Goudie and Piggott (1981) and Ballantyne and Harris (1994)).



(Figure 7.4) (a) The two-stage model of tor formation (modified from Linton, 1955). (b) The two-stage model for development of a gritstone edge (modified from Linton, 1964). Both models invoke preferential deep weathering of densely jointed bedrock and subsequent stripping of this weathering cover under periglacial conditions. Letters and numbers are used to indicate the pathways of individual blocks through the weathering process.



(Figure 7.5) The single-cycle model of tor formation (after Palmer and Nielson, 1962). This model involves removal of regolith from summits by solifluction and differential frost weathering of exposed bedrock.