
FIELD GUIDE TO THE PERIGLACIAL LANDFORMS OF NORTHERN ENGLAND

Edited by J. Boardman

Quaternary Research Association

Prepared to accompany the field meeting held in conjunction with the symposium: Periglacial Processes and Landforms in Britain and Ireland, held at Manchester 21-23 September 1985.

Sponsored by the International Geographical Union, Commission on the Significance of Periglacial Phenomena (Chairman H M French), and the Quaternary Research Association.

Quaternary Research Association
Cambridge, 1985

Cover illustration

Frost split block of Carboniferous sandstone on Little Dun Fell (NY 704329)

Sketch by Lance Tufnell

Quaternary Research Association

International Geographical Union Commission on the Significance
of Periglacial Phenomena

FIELD GUIDE TO THE PERIGLACIAL LANDFORMS OF
NORTHERN ENGLAND

CONTRIBUTORS

J Boardman	Department of Humanities and Countryside Research Unit, Brighton Polytechnic
R H Bryant	Geography Department, Polytechnic of North London
C R Carpenter	Geography Department, Polytechnic of North London
T Douglas	School of Geography and Environmental Studies, Newcastle Polytechnic
S Harrison	School of Geography and Environmental Studies, Newcastle Polytechnic
M P Lee	Computing Studies Unit, Leicester University
S P Oxford	Department of Geography, Birkbeck College, University of London
E J Pounder	Department of Town and Country Planning, Bristol Polytechnic
T S Ridge	Geography Department, Polytechnic of North London
P A Smithson	Department of Geography, University of Sheffield
L Tufnell	Department of Geographical Sciences, Huddersfield Polytechnic
J Warburton	INSTAAR, University of Colorado

EDITED AND COMPILED BY J Boardman

EDITOR'S NOTE

The short field excursion for which the guide is prepared will visit only three of the sites described herein. However, it was felt to be of value to attempt to collect together accounts of current and recent work in a Field Guide which could be used by others when visiting the region.

No regional introduction has been attempted because of the breadth of the topic and the extensive geographical spread of the sites. Each section in the guide is self-contained and all contributors have made reference to the existing literature on their area.

Acknowledgements

The editor would like to thank staff of the Humanities Department, Brighton Polytechnic, particularly Mrs Pam Turner (typing), Mr Stephen Frampton (cartography) and Dr H Ainsley, Head of Department for financial and logistic support.

Organisation of the field excursion to northern England has been facilitated by provision of vehicles by Birkbeck College, University of London; Polytechnic of North London and Brighton Polytechnic.

I would like to thank the IGU Periglacial Commission for a grant towards the cost of field expenses incurred in organising the excursion.

The site on Great Dun Fell which forms part of the Moor House National Nature Reserve is visited by permission of the Nature Conservancy Council and use of the access road is by permission of National Air Traffic Services.

Major J H Spedding of Mirehouse and the Forestry Commission are thanked for permission to visit Throstle Shaw and Sandbeds quarry. The Coledale site is visited by permission of the National Trust.

C Quaternary Research Association, Cambridge 1985

ISSN 0261-3611

All rights reserved. No parts of this book may be printed or reproduced or utilized in any form or by any electronic, mechanical or other means, now known or hereafter invented, including photocopying and recording, or in any information storage or retrieval system, without the permission in writing of the publishers.

Recommended reference: J Boardman 1985. Field Guide to the Periglacial Landforms of Northern England. Quaternary Research Association, Cambridge.

Printed by Barbican Press, Castle Ditch Lane, Lewes, East Sussex.

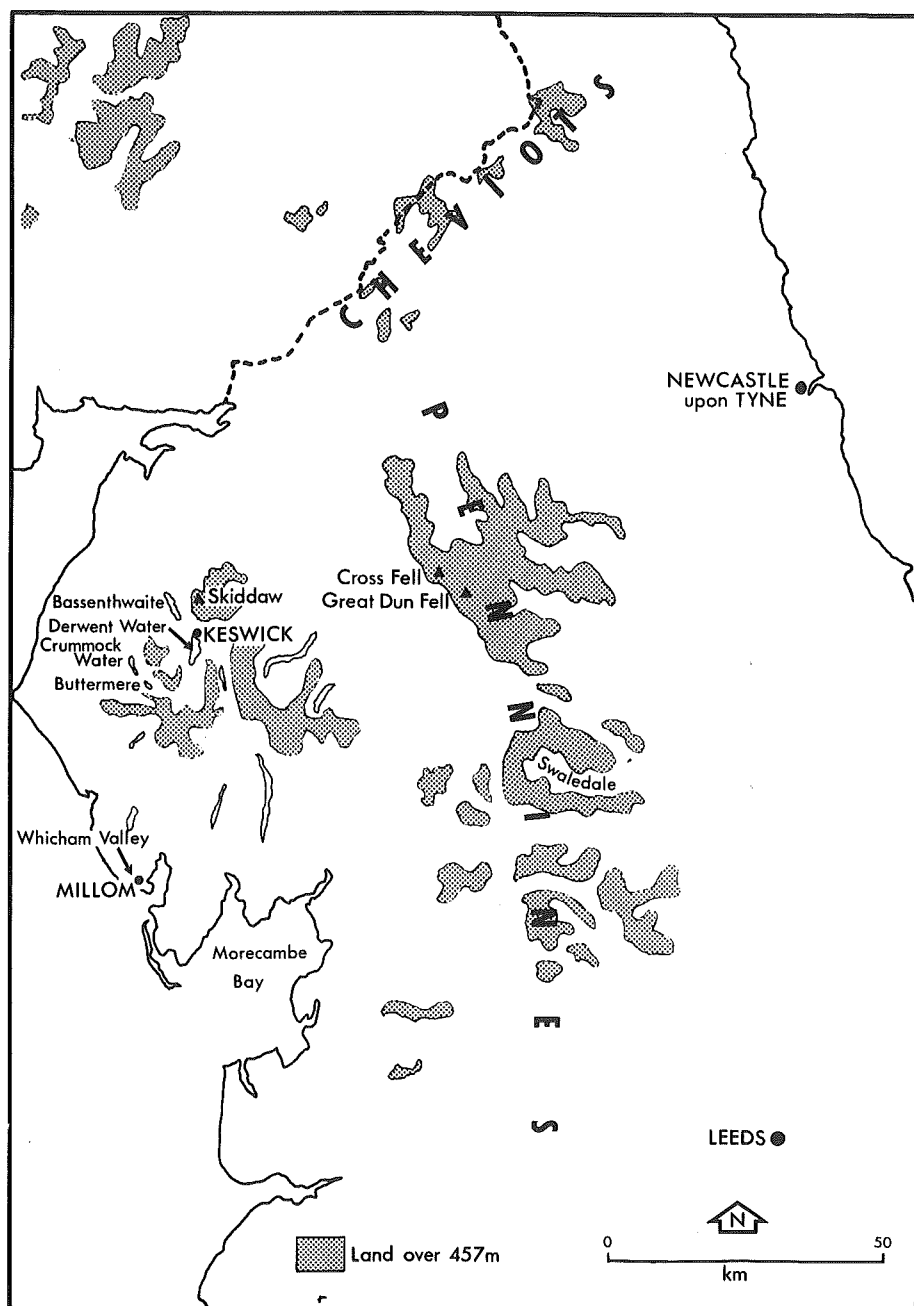


FIGURE 1 Northern England: location of areas described in the guide

CONTENTS

The present climate of the northern Pennines P A Smithson	1
Periglacial landforms in the Cross Fell - Knock Fell area of the north Pennines L Tufnell	4
Periglacial river activity in upper Swaledale, north Yorkshire E J Pounder	15
The northeastern Lake District: periglacial slope deposits J Boardman	23
Protalus ramparts, portalus rock glaciers and soliflucted till in the northwest part of the English Lake District S P Oxford	38
Pingo scars and related features in the Whicham valley, Cumbria R H Bryant, C P Carpenter and T S Ridge	47
Contemporary patterned ground (sorted stripes) in the Lake District J Warburton	54
A note on the loess around Morecambe Bay M P Lee	63
Periglacial landforms and sediments in the Cheviots T Douglas and S Harrison	68
References	76

THE PRESENT CLIMATE OF THE NORTHERN PENNINES

The climate of the northern Pennines is dominantly cool, cloudy and wet, influenced by its proximity to the sea and by its altitude. Rising steeply above the Eden Valley in Cumbria, the Cross Fell escarpment reaches about 850m before descending to a plateau level at about 500m to form the headwaters of the Tees, the Wear and the South Tyne. Unusually for upland Britain, three climatological stations have been maintained in the area in recent years; one near the crest at Great Dun Fell (847m) and two on the plateau to the east, at Moor House (556m) and Widdybank Fell (513m), 5 km and 11 km ESE of Great Dun Fell respectively. Unfortunately since 1972 only wind observations are available on a continuous basis at Great Dun Fell together with a few non-instrumental observations such as fog frequency, and Moor House closed in 1979 but a sufficiently long record is available to assess the nature of the upland climate of the northern Pennines.

Monthly mean maximum and minimum temperatures for Great Dun Fell and Moor House are shown on Table 1. The typical seasonal cycle of temperature for upland locations in temperate latitudes is seen and compared with mean values for central England (1941-1970). The most noticeable feature is the more rapid decrease of maximum temperature with height than the decrease in minimum temperature. Indeed, the differences in monthly mean minimum temperatures between Great Dun Fell and Moor House are small. On fifteen occasions out of 110 months when comparisons were possible, even the monthly mean minimum temperatures were lower at Moor House than at Great Dun Fell. Lower minimum temperatures on the plateau would be expected during periods of cold air or katabatic drainage off Cross Fell Edge so months dominated by anticyclonic circulations and clear skies should show this tendency. As some parts of most months experience anticyclonic spells the lowest minimum temperature for each month is usually at Moor House rather than on Great Dun Fell - about three-quarters of the months displaying this effect.

With even the mean maximum temperatures at Great Dun Fell below freezing point it is not surprising that air frosts are a common feature of the winter. Most days at both sites record air frost with the frequency for mid-winter being slightly higher at Great Dun Fell. For late-spring, summer and early autumn when frost will only occur during katabatic flow, Moor House has a higher air frost frequency but incidences are small, rarely being more than one night per month in mid-summer. From an environmental view point, grass minimum temperatures are often more significant than screen temperature. No observations are taken at Great Dun Fell but Moor House records ground frost for an average 181 days per year with about 23 days per month in winter and about 5 days per month in mid-summer. Temperatures can be extreme with values below -20°C in most winters and even in summer, grass minimum temperatures below -5°C can occur. Freeze-thaw cycles are a frequent occurrence. In a sample of one year (September 1978-August 1979) there were 134 days in which the air maximum was above freezing but with a ground frost by night.

Soil temperatures are recorded at Moor House at 30 cm depth only. Monthly mean values rarely drop below freezing; only February 1963 with a mean temperature of -0.2°C achieved this figure in the twenty-five years from 1956-1979. Occasional daily readings may fall below freezing but soil temperatures at 30 cm are very stable so major differences from the monthly mean do not occur. In severe winters, an extensive blanket of snow will prevent excessive cold penetrating to this depth.

Precipitation increases rapidly with height on the western side of Britain. Chuan and Lockwood (1974) obtained the regression equation of $y = 1.890x + 916.29$ where x is the mean altitude at 8 km radius in metres and y is the predicted annual precipitation in millimetres. Taking the mean altitude to be 600 m for Moor House and 850 m for Great Dun Fell, the predicted mean annual precipitation would be 2050 mm and 2522 mm respectively. Measured mean annual precipitation at Moor House for the period 1941-1970 is 2010 mm confirming the applicability of the model in this location. As no rain-gauge record is available for Great Dun Fell the predicted total must be taken as approximate but close to the actual value in view of the validity of the regression model for Moor House. Whilst mean annual precipitation is high, daily falls are not noticeably great. Daily falls above 50 mm occur most years but are restricted mainly to the period from September to April. The highest daily total for 1956-1979 was 104.6 mm in January 1977 when the monthly total was 520 mm. Precipitation is a frequent occurrence at this altitude in northern England. The average number of days per year with precipitation observed to fall is 247 with mean monthly figures above 20 for the period September to March and May having the lowest figure with 11. Because of these frequent additions to the soil moisture and the low evapotranspiration, the ground surface is often wet and in low-lying areas it rapidly becomes waterlogged.

Not all the precipitation falls as water. The decrease of temperature with height means that snowfall is frequent especially between November and April. "Snow falling" data are notoriously difficult to assess being dependent upon observer vigilance by day and by night. Figures from Moor House give a mean value of 61 days per year (1953-78) with extremes of 24 and 94. In winter with low temperatures the falling snow will remain on the ground to add to the pre-existing blanket of snow. The situation of snow covering more than half the surrounding countryside is counted as a day with snow lying and is often a better index of snow severity than days with snow or sleet observed to fall. The mean annual figure for Moor House is 67 days with a range from 35 to 110 days rather similar to the figures for snow falling. Manley (1971) examined the available snow lying records for upland areas of the UK and concluded that the mean snow-cover value for the Great Dun Fell area was about 105 days per year based on the period 1949-70. The 300m increase in altitude from Moor House enhances the total by 40 days per year. More recent data confirm this value but year to year fluctuations are considerable. The snow lying season at both sites extends from late-November to early-April with the mid-winter months occasionally having a complete snow cover throughout the month - once in December and January, four times in February and twice in March at Moor House (1935-78). At Great Dun Fell this frequency is likely to be even greater.

An adequate measure of the snow depth is difficult to determine at exposed sites like Great Dun Fell and Moor House. Strong winds will cause the snow to drift so that accumulation will depend upon the degree of shelter and the detailed form of the surface.

The climate of the area may appear cold from the temperature levels shown in Table 1. A further factor which can emphasize the sensation of coldness when working in the area is wind. Because of altitude wind speeds in the area are high. The mean annual velocity on Great Dun Fell is 20.0 knots (10.4 m s^{-1}) with gusts above 100 knots (51 m s^{-1}) sweeping the area every few years. The escarpment provides some shelter to the east so that at Moor House mean speeds are only about 75% of those on the summit.

TABLE 1	Great Dun Fell (847m) (1963-1972)		Moor House (556m) (1953-1978)		Central England (Sea-level) (1941-1970)	
	Mean Max	Mean Min	Mean Max	Mean Min	Mean Max	Mean Min
January	-0.2	-2.9	2.3	-2.4	6.0	0.4
February	-1.2	-3.8	1.8	-3.3	7.0	0.5
March	0.6	-2.6	4.0	-1.6	10.2	2.0
April	3.6	-1.0	6.9	-0.2	13.6	4.1
May	7.7	2.0	10.8	2.5	17.1	6.5
June	11.1	5.0	13.8	5.4	20.4	9.7
July	11.8	6.4	14.8	7.2	21.8	11.5
August	11.8	6.8	14.7	7.3	21.5	11.2
September	10.1	5.6	12.4	5.9	19.0	9.6
October	7.4	3.5	9.5	3.8	15.1	6.9
November	2.1	-1.2	5.1	0.2	9.7	3.4
December	0.5	-2.4	3.4	-1.7	7.6	1.5
Year	5.4	1.3	8.3	1.9	14.1	5.6

Dampness is another all-pervading feature of the climate. Cloud frequently envelopes the summits of the escarpment especially in winter. Mean annual figures for fog at 9 am (visibility less than 1 km) are 240 days per year at Great Dun Fell but only 52 at Moor House. In summer it is less frequent with only half the days per month experiencing fog at 9 am and there is a diurnal cycle with cloud base rising during the day which may lift the fog. Fog at Moor House is mainly a winter-time phenomenon during inversion conditions. When surface temperatures fall below freezing, the drifting, super-cooled fog droplets may impact onto any surface obstruction to produce rime. Rime is one of the major problems affecting instrumental performance at upland sites. It grows into the wind at a rate dependent upon wind speed and moisture content and may accumulate so rapidly that anemometers seize up and screens become choked with ice crystals unless preventive measures are taken.

The climate of the northern Pennines is harsh. Temperatures are low, moisture is abundant and sunshine duration is short. Not surprisingly the vegetative growing season is relatively brief so that disturbed surfaces are recolonized only slowly. Frost action on the bare soil can be frequent in winter especially where the strong winds minimize snow accumulation. Altogether it is a climate unfavourable for man but interesting for the differences in type and intensity of climatic and geomorphological processes which it exhibits compared with lowland England.

PERIGLACIAL LANDFORMS IN THE CROSS FELL - KNOCK FELL AREA
OF THE NORTH PENNINES

PHYSICAL SETTING

Seen from near Penrith in the Eden valley the north Pennines exhibit a distinctive skyline which rises and falls like the battlements of a castle. The profile is dominated by the massive flat-topped bulk of Cross Fell which reaches 893m and is therefore higher than anywhere else in the Pennines. Directly south are the peaks of Little Dun Fell and Great Dun Fell. They also have flat tops, though their bulk is less and their summits only attain 841m and 847m respectively. To the south again is Knock Fell, which is lower than the other three peaks (summit 794m) and which rises less markedly above its surroundings. The skyline of the Cross Fell - Knock Fell area is completed by the cols which separate these four peaks (Figure 2). Most of this region lies within the Moor House National Nature Reserve. It forms the highest parts of a large scarp and dip feature whose steeper slopes look westward over the Eden valley towards the Lake District. The streams draining these slopes are tributaries of the Eden river which flows into the Irish Sea. By contrast, streams on the gentler dip slopes flow eastwards, their waters eventually reaching the North Sea.

The solid geology of the Cross Fell - Knock Fell area consists principally of sandstones, limestones and shales from the Middle and Upper Limestone groups of the Carboniferous sequence. The area's soils are derived from these Carboniferous rocks. On the fell tops and surrounding slopes, podsoles, gleys and block fields are common. At rather lower levels (eg. on the gentle dip slopes) blanket bog is widespread, though in some places this has been heavily eroded. There are also red brown limestone soils (eg. on Green Castle and in the upper Knock Ore Gill valley) and areas of made ground (eg. in association with Dun Fell hush and the Silverband mine) (Johnson and Dunham, 1963). The Cross Fell - Knock Fell region is above the present tree line but supports a variety of flowering plants, mosses, liverworts, lichens, fungi and algae. At the highest levels sub-alpine grasslands occur, though these are rather poor in species of flowering plants. Indeed, the lichen and bryophyte flora of the adjacent block fields are probably of greater interest. More varied assemblages of flowering plants can be found on limestone soils and calcareous flushes. The widespread areas of blanket bog are mainly covered with Sphagnum, Calluna and Eriophorum. The significance of each at a particular locality depends on such factors as the intensity of sheep grazing, history of burning, altitude, and moisture content of the peat (Eddy, Welch and Rawes, 1969). Sheep are also important because they help to keep the area's vegetation short and thereby assist frost penetration of the ground. Owing to its high altitude and inland location, the Cross Fell - Knock Fell area is the coldest place in England (Manley, 1936). Average temperatures on the summit of Great Dun Fell are usually lower than those at Reykjavik in Iceland (Tufnell, 1975). Snow lie is important, being recorded on average about 100 days a year (Manley, 1942, 1971) (see also Smithson's article in this volume).

While glacial and fluvioglacial phenomena are common in the Eden valley, they are decidedly rare on the high ground of the Cross Fell - Knock Fell area. By contrast, periglacial landforms and deposits are widespread on the fell tops and include frost-shattered bedrock, scree and block fields, mass movement features such as gelifluction terraces and ploughing blocks, stone polygons and stripes, thufurs, and various nivation phenomena. Many of these features have a late Devensian age and probably formed when the area was underlain by permafrost. However, the present climate, though able to bring about only temporary freezing of the ground,

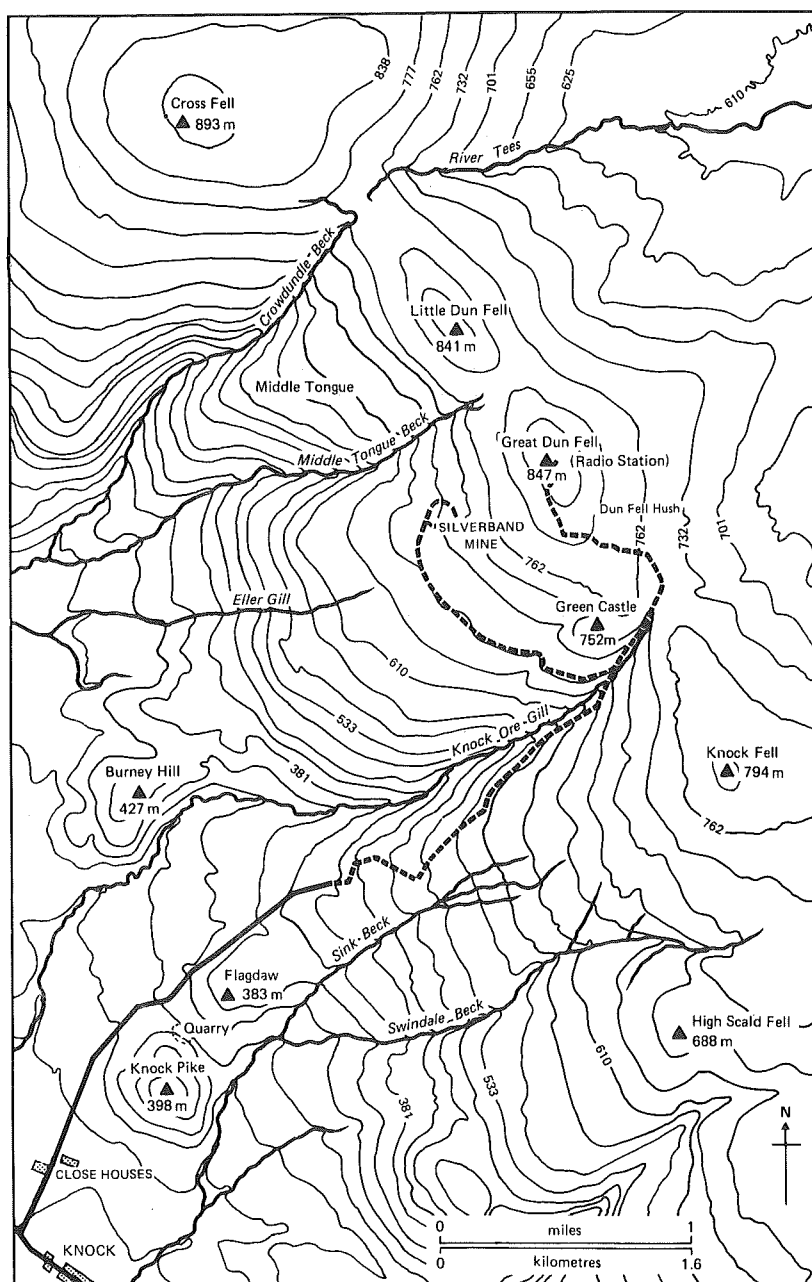


FIGURE 2 Cross Fell - Knock Fell area: location map

is nevertheless creating some periglacial landforms.

Access to the Cross Fell - Knock Fell area is best gained via a road which begins a short distance north-west of the village of Knock and passes to the north of Knock Pike on its way to the Great Dun Fell radio station. Much of this route lies within the Moor House National Nature Reserve and visitors should observe any notices they encounter. The route from Great Dun Fell to Cross Fell is over exposed fell tops and marshy cols and follows the Pennine Way. Low temperatures, swirling mist and high winds are common in this area, so appropriate precautions must be taken.

KNOCK PIKE AREA: VEGETATION COVERED HUMMOCKS

At several places in and around the Cross Fell - Knock Fell region there are 'fields' of small vegetation-covered hummocks. Good examples can be found at 680-750m in the Knock Ore Gill valley where they are typically associated with calcareous flushes (NY 716309). Examination of these hummocks showed that they possess a varied morphology and that their mean maximum dimensions are 14.7cm (height) and 37.1cm (diameter). Although it is possible to consider several origins for these features, the most likely explanation is that they are due to current frost action (Tufnell, 1975). At lower altitudes, just outside the Cross Fell - Knock Fell region, a second type of hummock 'field' occurs. Examples may be found on Knock Pike (NY 688284) and Flagdaw (NY 689288) at altitudes of around 350m. Again, hummocks are closely-packed and vegetation-covered, but they are distinctly larger than those in the Knock Ore Gill valley. Thus, 55 examples studied on Knock Pike averaged 0.13m in height and had a mean diameter of 1.56m. Similar features have been reported by Pemberton (1980) on other hills along the foot of the Pennine escarpment and in the Eden valley. Interestingly, he has ascribed these hummocks to recent frost action because of their relationships to man-made features like ridge and furrow systems. It should, however, be appreciated that they are not identical to hummocks in the upper Knock Ore Gill valley and on Great Dun Fell. Above all, there are marked differences in both size and shape. The low-level hummocks are, in fact, more akin to features which occur at Cox Tor, Boulter's Tor, Smeardon Down, Sourton Tors and other localities on the western edges of Dartmoor (Tufnell, 1978). If the Eden valley hummocks are indeed the result of frost action during historic times, similar origins and ages are presumably likely for their counterparts in Devon.

CROSS FELL TO KNOCK FELL SUMMIT AREA

Frost weathering phenomena

The most striking legacy of past frost weathering in the Cross Fell - Knock Fell area is the loose, angular debris to which various English names (stone sea, block field, block scree, scree, talus) might be applied. Such material girdles the summit plateau of Cross Fell and is also found near the top of Little Dun Fell and Knock Fell. It equally occurs at lower altitudes on the steep escarpment which overlooks the Eden valley (eg. at Middle Tongue below Little Dun Fell) (NY 693327). Particularly accessible examples mantle ground in the vicinity of the Great Dun Fell radio station - Silverband Mine road junction at around 670m (NY 714309). Immediately below the junction is a mass of loose, angular debris which has originated through frost weathering of the Six Fathom Hazle, a medium-grained light-coloured sandstone. A short distance upvalley there are outcrops of the Great Limestone, some of which form prominent cliffs. Weathering of these has led to areas downslope becoming mantled with numerous gelifractions.

Analysis of debris on slopes around the radio station - Silverband Mine road junction has included measurement of the roundness index (RI) according to the formula:

$$RI = \frac{2r}{a} \times 1000$$

where r is the radius of curvature of a fragment's sharpest angle in its principal plane, and a is the maximum dimension of a fragment's long axis. This technique produces a scale of roundness which has a minimum at 0 and a maximum at 1000 (Cailleux, 1945). Examination of 225 fragments at three sites on debris of the Six Fathom Hazle gave low roundness index values of about 44. Similarly, 525 gelifracts derived from the Great Limestone produced average values of 42.1 for the first group of 75 fragments examined rising to a maximum of only 123.2 for the seventh and last sample. Therefore, debris of both the Six Fathom Hazle and the Great Limestone clearly exhibits marked angularity. On the other hand, size was found to be a more variable characteristic. It was determined by using the maximum values of a fragment's long (a), intermediate (b) and short (c) axes (Table 2).

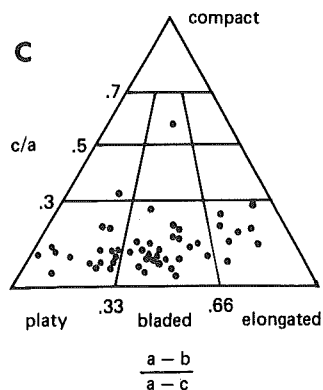
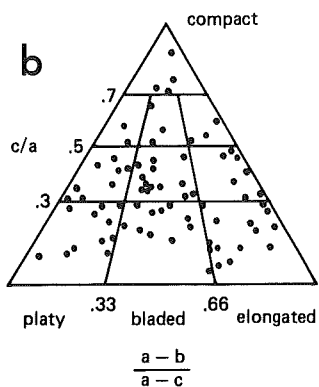
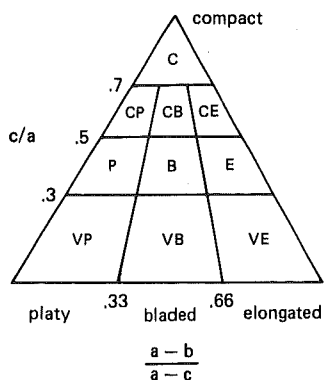
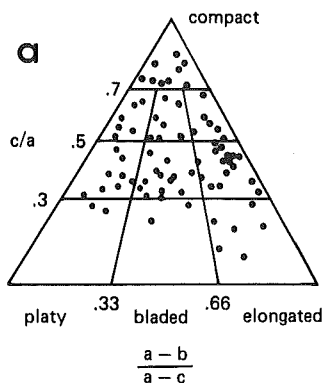
TABLE 2 Six Fathom Hazle debris

	SITE	NUMBER OF FRAGMENTS EXAMINED	AXES (cm)		
			a	b	c
Top of slope	3	75	37.0	22.8	11.1
	2	75	102.4	58.2	40.1
	1	75	64.3	44.1	29.1

Bottom of slope

These values reflect the fact that bedding of the Six Fathom Hazle is massive, except near the top of the outcrop where it becomes finer. Significantly, at two places Great Limestone fragments are in general larger than those from site 3 on the Six Fathom Hazle. Elsewhere, however, the average size of limestone fragments is less, falling to a mean of only 7.5 x 4.6 x 2.7cm at site 7. Maximum dimensions of the three principal axes of each fragment were also used to define shape. According to Sneed and Folk (1958), this can be determined by plotting on a triangular graph the values obtained by calculating $\frac{a-b}{a-c}$ (x axis) and $\frac{c}{a}$ (y axis). Use of this technique has shown that many fragments on the Six Fathom Hazle tend towards a compact shape, though very platy, very bladed and very elongated forms become more common on the upper parts of the slope (ie. at site 3) (Figure 3a, b). This is another reflection of the decrease in bedding thickness towards the top of the Six Fathom Hazle. By contrast, there is little difference in the range of fragment shapes on the Great Limestone debris. Hence, at all seven sites examined, most shapes cluster in the 'middle' categories of the form triangle (ie. those designated as compact platy, compact bladed, compact elongated, platy, bladed and elongated).

Disturbance of the Six Fathom Hazle debris is now probably small. The difficult nature of this terrain means it is usually avoided by sheep and man. In addition, the generally large fragment size and lack of a fine matrix hinders the effectiveness of slope processes. On the other hand, displacements of Great Limestone fragments have been both observed and measured. For example, it has been noted that when sheep cross these slopes they may dislodge fragments, so that on occasion it is necessary to clear them from the road below. Starting in 1965, at attempt was made to determine more precisely the amount of fragment disturbance on north-western slopes of the upper Knock Ore Gill valley (NY 716313). An area of vegetated ground measuring 4m x 2.5m was pegged out with its upper edge immediately downslope



C – Compact

CP – Compact Platy

P – Platy

VP – Very platy

CB – Compact bladed

CE – Compact elongated

B – Bladed

VB – Very bladed

VE – Very elongated

E – Elongated

FIGURE 3 Fragment shapes of three sites in the Cross Fell to Knock Fell area (a & b at NY 714309, c at NY 713321)

of a debris tongue. After one year this plot had acquired nearly 30 fragments from the debris tongue. The total gradually increased, so that by 1975 it numbered just over 180. In fact, this figure probably underestimates the amount of debris movement, because the plot had an open lower end. Netting was not installed there to prevent loss of debris, as it would have been visible to people on the road below. There is also evidence that frost weathering of the limestone cliffs continues to supply new debris, though amounts are probably small. Thus, staff in their travels to and from the Great Dun Fell radio station observed changes in the form of cliffs on the south-eastern side of the upper Knock Ore Gill valley (NY 717314) during the winter of 1968-9. When the area below these degraded cliffs was examined, limestone fragments were discovered which had very fresh looking faces.

On first encounter the debris slopes of the Six Fathom Hazle appear markedly different from those of the Great Limestone, even though the two are only a short distance apart. This is no doubt because the Great Limestone forms impressive cliffs, especially on north-western slopes of the Knock Ore Gill valley, whereas the Six Fathom Hazle does not: broad differences in fragment size and colour at the two localities also help to suggest a contrast. On the other hand, there are some decidedly similar and overlapping characteristics (eg. debris at both places is angular and has probably been derived by frost weathering). This raises the question of a suitable terminology. Above all, there is the problem of whether these features have enough in common to warrant the same name, or whether they are sufficiently dissimilar to require different names. Given the imperfect state of knowledge, it seems prudent that, until differences have been properly evaluated, all such features are assigned the one name: it is proposed that this should be '(periglacial) rock-fragment slopes'.

Even outside the areas of rock-fragment terrain there is ample evidence of the potency of frost weathering, especially that dating from the past. On Great Dun Fell, for example, platy sandstone gelifractions occur and many of these have been sorted by frost to form the borders of stone polygons and the coarse bands of stone stripes. Equally, large sandstone blocks dotted around some vegetation-covered terrain have been split right across by frost (eg. on Little Dun Fell; Figure 4). According to Tricart (1970), a severe climate and deep frost penetration are necessary to achieve such large-scale gelifraction. At a few places, frost-weathered bedrock has been observed. For example, Johnson and Dunham (1963) have remarked on a large pit dug in 1957 for the foundations of a mast at the Great Dun Fell radio station. Bedrock at the base of this pit was overlain by a thick zone of weathered Dun Fell Sandstone. A particularly accessible exposure of frost-shattered bedrock occurs in a small quarry near the Silverband Mine - radio station road junction where the upper layers of the Six Fathom Hazle are visible.

Mass movement features

At several Pennine localities there are features which have been interpreted as glacial moraines dating from the post-Allerød climatic recession (Manley, 1959). Johnson and Dunham (1963) recorded such features at 381, 579 and 695m in the Knock Ore Gill valley and at 457m in the Middle Tongue Beck valley. They also mentioned "stony drift" at 762m on Knock Fell and have tentatively assigned this to the post-Allerød recession. Later work, by officers from the Institute of Geological Sciences, did not record moraines at these localities, but showed instead that a number of escarpment valleys, both within and close to the Cross Fell - Knock Fell region, possess landslide deposits (Institute of Geological Sciences, 1972). Unfortunately, no details of these features were given except to note that they are common and to

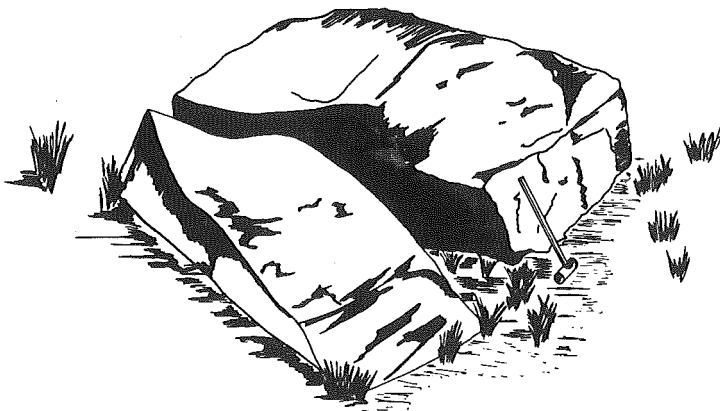


FIGURE 4 Large frost-split block of Carboniferous sandstone
on Little Dun Fell (NY 704329)

mention that bedrock in the Cross Fell area often shows signs of cambering (Burgess and Wadge, 1974). The 1982 IGS map indicates several areas in the Knock Ore Gill valley where landslides have occurred, for example at NY 712306. This feature appears to correspond to Johnson and Dunham's (1963) 579m moraine. As blocks of the sandstone rest on its surface, and accepting that it is in fact a landslide (not least because of its valley-side disposition), it would appear to represent a late Devensian periglacial slope movement.

Since glacial and fluvioglacial deposits are rare above 457m in the Cross Fell - Knock Fell region (Burgess and Wadge, 1974), it is Pleistocene gelifluction clay, often overlain by Flandrian peat, which constitutes the dominant superficial material at higher levels. The clay possesses many angular sandstone fragments of varying sizes but has few limestone gelifracsts. According to Johnson and Dunham (1963), this is because of the limestone's relative resistance to frost weathering. In some places there is clear evidence that frost has caused the upward migration of platy sandstone gelifracsts, so that they now form a 'pavement' at the ground surface or immediately below an overlying peat layer. A good example occurs near where the road to the radio station crosses the line of mining activity on the southern flanks of Great Dun Fell (NY 714317). The features here are similar to the *dallages de pierres* of French writers. More important, however, is the way gelifluction deposits and their overlying soils have been moulded into small terraces: these form significant features in the higher parts of many valleys on the western escarpment and are also present on slopes which lead to the region's flat-topped summits. Five varieties of gelifluction terrace have been identified in the Cross Fell - Knock Fell area. Two of them have risers which are convex downslope and may therefore be called garland terraces. Many in this category have an uninterrupted vegetation cover on both tread and riser and so merit the name vegetation-covered garland terraces. Numerous examples occur on the Dun Fells (eg. at site 1, Table 3). A minority of risers, however, are vegetation-free, perhaps due to the effects

TABLE 3 Characteristics of gelifluction terraces at sites in the Cross Fell - Knock Fell area. All slope angles and terrace dimensions are average values.

Site	Number studied	Terrace type	Angle riser	Angle tread	Angle along tread	Distances front - back	Cross-slope width	Height riser	General slope angle
1. Great Dun Fell (NY 713323)	50	Veg.-covered garland	37°	8°	4°	52cm	70cm	17cm	10-15°
2. upper Knock Ore Gill valley (NY 716314)	25	Veg.-covered parallel	48°	19°	4°	39cm	5.6m	31cm	30-35°
3. upper Knock Ore Gill valley (NY 717312)	50	Earth-banked parallel	65°	18°	7°	43cm	1.5m	20cm	25-30°

of wind and snow, in which case the category to which they belong may be described as earth-banked garland terraces. These have been noted on Little Dun Fell and in the upper Knock Ore Gill valley. A second, morphologically distinct group of terraces has risers which are roughly parallel to each other and approximately at right angles to the direction of steepest slope. With these it is possible to distinguish vegetation-covered, earth-banked, and vegetation-banked types. Good examples of the first occur at 730m on north-western slopes above the Knock Ore Gill near the upvalley end of the Great Limestone cliffs (site 2, Table 3). Earth-banked parallel terraces are also found in the Knock Ore Gill valley. Those examined in detail (site 3, Table 3) come to within 1.1m of the Knock Ore Gill itself and are about 100m upvalley of the Silverband Mine - radio station road junction at an altitude of 690m. Much less common are vegetation-banked parallel terraces. Admittedly, some were found near where an unnamed tributary from Great Dun Fell enters Middle Tongue Beck (NY 706326) and there are others between here and the Silverband Mine, but they are not sufficiently numerous to warrant a detailed survey.

Of the three sites where gelifluction terraces have been closely examined, the first, on Great Dun Fell, has displayed little obvious evidence of movement in recent years. At site 2, however, there are lengths of terrace which have lately advanced several centimetres downhill beyond the general position of the riser. In one such case, the terrace had a cross-slope width of 5.2m and the protruding section was 45cm across. This appeared to be a consequence of relatively rapid flowage movements. On the other hand, a nearby terrace some 5.8m wide has experienced a rather chaotic forward collapse over a length of 1.2m. Frost cracking of the soil, which is common in this area during winter, ground water (including that derived from melting snow) and sheep may all contribute to displacements of this sort. Movements at site 2 are also indicated by the unvegetated gaps which sometimes occur in terrace fronts. These can act as routeways for the transfer of loose material from one terrace level to another (cf. Hollingworth, 1934). At site 3, evidence for current slope movements is even more pronounced. Again,

there are sections of terrace which have either moved in advance of the general position of a riser or have collapsed onto the tread immediately downslope. In addition, many gaps of unvegetated ground interrupt terraces and facilitate downhill transfer of material. A further type of movement, recorded only at site 3, involves the forward displacement of a section of terrace, but does not lead to the opening of a gap immediately upslope. Instead, movement is accommodated by a steepening in the angle of the tread and a lowering in the angle of the riser which is also displaced forward. The terrace is therefore deformed, rather than disrupted. Indications of slope movements at site 3 are also provided by the many small stones which litter terrace surfaces or which protrude to varying degrees from vegetation-free risers. They would appear to be evidence of subsurface debris movement which leads to the expulsion of material through the face of the riser. These various erosional processes have contrived to give many of the terraces at site 3 a ragged and broken appearance. Hence, it is in some places difficult to know where one terrace ends and another begins. In particular here, but also at site 2, the overwhelming impression is that current slope processes are tending to destroy, rather than create gelifluction terraces.

On many slopes in the Cross Fell - Knock Fell area, at altitudes above 600m, gelifluction terraces have ploughing blocks associated with them. These blocks are usually of sandstone, but there are some composed of limestone (eg. in the upper Knock Ore Gill valley). As blocks move faster than the surrounding ground, they push up soil and vegetation in front of them and leave a depression to their rear. The micromorphology and size of these associated features is very varied (eg. the length of depressions ranges from a few centimetres to around 6m). Over the 10 years, 1965-75, the maximum shift registered by a ploughing block in any 12-month period (August to August) was just under 8cm, though most displacements were well below this value. By far the greater proportion of the annual movement takes place during the colder half of the year (Tufnell, 1972, 1976). Ploughing blocks are common on Knock Fell, Little Dun Fell and Cross Fell but are scarce on Great Dun Fell. They also occur in the upper parts of the Knock Ore Gill, Middle Tongue Beck and Crowdundle Beck valleys.

Patterned ground

Active stone polygons and stripes are more numerous and better developed in the Lake District than in the north Pennines. Indeed, the only place where they have been found in the Cross Fell - Knock Fell area is on the zone of mining debris which stretches from Dun Fell hush to the Silverband Mine (NY 714317). Furthermore, none of the examples here are well formed or particularly interesting.

By contrast, large-scale patterned ground, of a probable late Devensian age, is widespread on the tops of the Cross Fell - Knock Fell range. It consists mainly of polygons and stripes though there are also a few interesting circular forms. Large inactive polygons are well developed on the extensive summit 'flat' of Cross Fell. Examples with a smaller diameter are numerous on the tops of Little Dun Fell and Great Dun Fell though at the latter place some must have been destroyed during building of the radio station and its associated masts. Similar features have been identified on Knock Fell and in areas to the south (eg. on High Scald Fell and on Backstone Edge). Often, large stone stripes are associated with the polygons. This is especially true on slopes leading to the summit 'flats' of Cross Fell, the Dun Fells, and Knock Fell. At a few places, a circular pattern has been discovered which forms an island of fine material within the coarse debris of a low-

angle rock fragment slope. These circular areas may have a diameter of 15m (as on Knock Fell), but are usually much smaller (eg. 1 - 2m across, as at localities beside the Silverband Mine road).

Large patterned ground in the Cross Fell - Knock Fell area has developed in the sandstone debris of horizons such as the Six Fathom Hazle, the Coal Sills and the Dun Fell Sandstone. No similar patterns exist in the weathering products of the area's other important rock types, limestone and shale. The thickness of sandstone beds has clearly influenced the shape of debris in polygon borders and in the coarse bands of stripes. Thus, at some localities (eg. on Great Dun Fell and Little Dun Fell) stones are angular, very platy or very bladed, and frequently in an erected position. However, at other places (e.g. on Backstone Edge) they tend to be more compact and rounded. It would also seem that the availability of different grades of stone material has influenced the nature of polygon borders and coarse stripes. Thus, on Great Dun Fell the commonest variety of fossil stripe has alternate bands which at the surface are entirely vegetation-covered and so must be differentiated initially on a micro-topographical basis (ie. by the uparching of fine stripes above the level of the coarse bands). Trenching, however, reveals that beneath the continuous vegetation cover there is a repetitive sorted pattern whereby the troughs are of relatively stony ground and the ridges of finer material. Nevertheless, the larger fragments in the troughs have long axes measuring just a few centimetres and this, together with the presence of intervening fine material, explains why the coarse bands have become vegetation-covered. Only on the south-eastern slopes of Great Dun Fell (NY 713321), do coarse stripes occur which have a distinctly stony surface. These are around 30m long and have a mean width of 108cm: their fine counterparts are somewhat broader, averaging 130cm across. Individual fragments in the coarse bands are relatively large, having a mean long axis value of 41.5cm, and they display a markedly angular shape which concentrates in the very platy/very bladed parts of the form triangle (Figure 3c). Many of these fragments have an erected disposition. A comparable situation exists on Little Dun Fell. In other words, of the numerous stripes found on this peak most are totally vegetation-covered and have first to be distinguished by small undulations of the ground: only on west/north-west slopes are the coarse bands distinctly stony at the surface. The polygonal networks on the tops of the Dun Fells also present a relatively stoneless surface, so they too must be identified by small topographical variations. Admittedly, some largish rock fragments do project above ground level, often in an erected position, but polygon borders at these localities are far less stony than many of those on Cross Fell.

There are perhaps three main reasons for describing the vast majority of sorted patterns in the Cross Fell - Knock Fell area as 'fossil' and for attributing them to late Devensian periglaciation. First, size alone would appear to exclude the possibility that they can be due to current frost action, as this is rather weak. Secondly, in all but a few places vegetation covers the areas of coarse as well as of fine stripes. Lastly, instances are known of sorted patterns existing beneath peat. Hence, though water (including that from snow melt) still drains away via troughs of coarse material, and though frost heave and gelifluction are still active at these altitudes (many garland terraces overlie stripes), large sorted patterns in the Cross Fell - Knock Fell area cannot be ascribed to current frost action. Moreover, their generally well-preserved appearance seems to indicate that the ground on which they occur has changed little during the Flandrian.

Nivational landforms

Because snow affects all parts of the Cross Fell - Knock Fell area for some time during every year, nivational processes must be widespread. However, they achieve importance only where snow drifts repeatedly accumulate and persist. The chief geomorphological role of nivation in such places derives from the moisture released by snow drifts when melting.

Late-lying snow in the high Pennines has been commented on at least since 1671, the year when Sir Daniel Fleming noted that it could sometimes last "until midsummer" on Cross Fell (Ferguson, 1889). By often remaining until June or even July snow probably lay longer during the Little Ice Age than is usual today. Nevertheless, it is still easy to predict the landforms and places in the Cross Fell - Knock Fell area where persistent snow is likely to be found and to observe the processes associated with its melting (Tufnell, 1971).

Among the more important landforms which tend to attract late-lying snow are the benches and semi-circular hollows on the higher slopes of Great Dun Fell, Little Dun Fell and adjacent peaks. These landforms can possess drifts up to 1m thick while the ground nearby is snow-free. Equally, wind may pile several metres of snow into the heads of the Knock Ore Gill, Middle Tongue Beck and Crowdundle Beck valleys on the western escarpment. The region's shallower valleys (eg. that containing an unnamed tributary of Middle Tongue Beck which flows off Great Dun Fell) may also become at least partly filled with snow during winter (Tufnell, 1971 Figure 2). Solution hollows, which occur, for example, in the Great Limestone on Green Castle, are perhaps the best type of landform for accumulating deep snow in this area. Large examples, such as that beside the radio station road at the head of the Knock Ore Gill valley (NY716315) can not only acquire snow which is several metres thick, but may keep it longer than elsewhere because of frost hollow effects and shading. Even on a micro scale there are features (eg. ploughing block depressions) which habitually get more snow than the surrounding ground.

The influence of current nivation processes is easily observed in the Cross Fell - Knock Fell area, given the right conditions. It includes the disruption of ground by freeze-thaw and needle ice, the movement of unconsolidated material, and water erosion. A key element in all these processes is water produced by the melting of snow patches (Tufnell, 1971). Yet, many of the landforms which each year acquire relatively deep and persistent snow are fairly large, so it is hard to imagine that they are solely the result of nivation processes during recent centuries. There is, in fact, evidence that the main characteristics of these landforms have not altered much during the Flandrian. Thus, fossil gelifluction clay, overlain by peat, occurs on the floor of some solution hollows. Equally, there are places where large fossil stripes appear to have been little affected by slope retreat associated with persistent snow patches at their downslope end. This type of evidence does not preclude that snow has been important for the development of benches, valley heads and solution hollows in the Cross Fell - Knock Fell area. It merely requires that nivational influences are seen to have operated over a longish time scale, going back at least into the Devensian, when, as at present, periglacial processes were contributing to landscape evolution in the high Pennines.

LT

PERIGLACIAL FLUVIAL ACTIVITY IN UPPER SWALEDALE, NORTH YORKSHIRE

INTRODUCTION

Swaledale is one of the major eastward trending valleys of the Pennines which form the watershed of northern England (Figure 5). The River Swale and its tributaries flow across the Askrigg Block, a structural feature which forms a dissected plateau with an altitude of more than 600m in the west, falling to 550m at its eastern end. It is composed of Visean and Namurian age rocks of the Carboniferous, termed the Yoredale Series (Phillips, 1836) and subsequently known as the Yoredale facies (Ramsbotham, 1984). In Upper Swaledale, defined for this guide as the part of the valley upstream of Gunnerside (SD 950977), the bed rocks are chiefly sandstones, cherts, shales with thin seams of coal and limestones. The latter frequently outcrop as prominent scars along the valley sides (eg. Cotterby Scar SD 876016) and these are attributed to former glacial and periglacial activity in the region.

Tributary valleys in Upper Swaledale above Keld (NY 892010) dissect the extensive plateaus over which, at the time of maximum glaciation ice moved in a north easterly direction, shown by striations and indicator erratics (Dakyns et al, 1891; Raistrick, 1926). At lower levels there is considerable evidence for the pattern of deglaciation in the area (Rose, 1980). Landforms within the valley troughs are the result of active ice, ice decay with its associated meltwaters and subsequent fluvial activity. Deep-seated land slips and debris flows resulting from glacial over steepening or, in response to a reduction of rock shear strength during periglacial conditions, are a characteristic of many valley sides (Rose, 1980). Thus the area exhibits considerable evidence of former climatic conditions conducive to periglacial fluvial activity.

GLACIAL CHRONOLOGY

The glacial chronology of the region can be established from adjacent areas in conjunction with evidence within Swaledale. During the late Devensian glaciation much of the ice originated from the Lake District (Letzer, 1978), thus it is possible to relate deglaciation in Swaledale to the dates associated with that event in the Lake District i.e. before 14,623 B.P. (Pennington, 1978). Evidence for active solifluction during the Younger Dryas comes from Lunds near Sedbergh, to the west of this area (Walker, 1955).

A succession of clay and marls typical of the Devensian Late Glacial described by Rose (1980) near Keld lends support to the view that the time of significant fluvial activity was the Late Devensian and the Younger Dryas, though subsequent modification is evident.

THE PERIGLACIAL FLUVIAL ACTIVITY

The landforms resulting from periglacial fluvial activity include a series of river terraces and alluvial fans. Fans occur at the following confluences of tributary streams with the Swale, Whitsundale Beck (NY 870014), Great Ash Gill (NY 869014), Swinner Gill (NY 909005), Arn Gill (NY 908993) and Gunnerside Gill (NY 869014). Dissected remnants of fans are also described by Rose (1980) at Thwaite (SD 893973) and at Hartlakes (NY 904005).

All the fans occur where there is a marked difference in relief between the tributary and the main valley which is a consequence of glacial over-deepening of the Swale valley, but the critical factor is the change in geometry of flow after the stream leaves the confines of the trunk stream

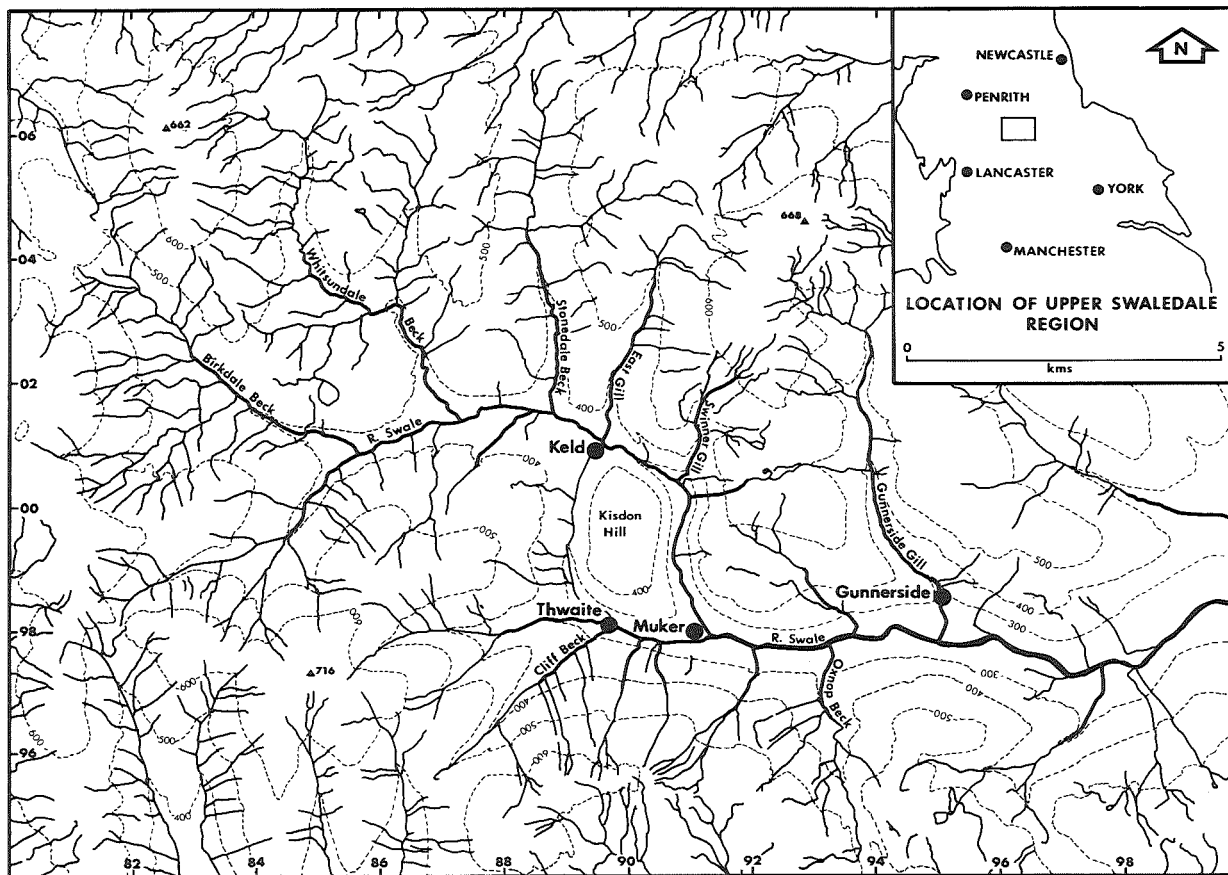


FIGURE 5 Relief and drainage of Upper Swaledale. Contours are in metres.

channel (Bull, 1977). Fans can be regarded as valley fill which has "spilled out" in the relatively unconfined space of the larger valley. The periglacial environment is conducive to fan formation as large amounts of sediment are normally available, usually in excess of the transporting capacity of the streams. This appears to have been the case in Upper Swaledale, though there is evidence of significant modification in the Holocene and small fans are currently accumulating e.g. at Gunnerside New Bridge (SD 950978). Two fans are discussed in detail in this guide.

River terraces occur along most of the Upper Swale except in the gorge at Keld (NY 895010). Two suites are discussed below, those at Whitsundale Beck (NY 870014) and those between Hartlakes (NY 907005) and Muker (SD 915989).

THE ALLUVIAL FANS

Whitsundale Beck at Hoggarth's (NY 870014)

This fan occurs where Whitsundale Beck enters the Swale where the main valley widens and steepens its gradient prior to entering the confined reach near Cotterby Scar (Figure 6). Upstream of the fan Whitsundale Beck flows in a narrow deep valley which drains a catchment area of 19.10 km².

The length of the fan from apex to outer margin is 400m, the length of the margin 800m and the area 0.97 km². The mean gradient is 18.95m/km this being steeper than that of the river which bisects the fan, the latter having a gradient of 16.03 m/km. Gradients of different parts of the fan vary, the steepest being 31.06 m/km on the part which slopes down to the River Swale in the south east (Figure 6). The highest point on the fan is about 14.5m above the River Swale and about 2m above Whitsundale Beck.

The fan surface is characterised by a series of depositional lobes on the highest parts (Figure 6), vestiges of former channels and series of terraces adjacent to the rivers. A complex array of channels and former gravel bars occurs in the Swale valley immediately upstream of the confluence with Whitsundale Beck. These give an indication of the effect which the developing fan had on the depositional patterns in the main valley.

Gradients of the fan surface are controlled by the interplay of differences in elevation between the two valleys, the size of the material being transported and the discharge or power of the stream. In the case of periglacial fans palaeohydrology is difficult to reconstruct as the number of anastomosing channels is a matter of conjecture. The steep gradients here, in conjunction with the boulders of diameter greater than 50cms, indicate discharges in excess of the greatest experienced in present climatic conditions, even when taking into account the flood characteristics of this catchment (Williams, 1957).

Areas at the highest elevation above the present stream retain elements of depositional features as a series of lobes (nos. 28, 35, 40, 41 and 42, Figure 6). Observations of contemporary fan formation (Hooke, 1967) show that such forms result when water drains out of the sediment preventing further transportation. Their situation relative to palaeochannels and their down fan position indicate that these features were the last increments of material deposited on the fan surface during its period of construction in the periglacial environment. At this time large amounts of material would be available but discharges would be very variable in response to seasonal melting. At some stage a critical threshold would be passed when no discharge superseded that which formed these lobes and the rivers became entrenched in the valley fill.

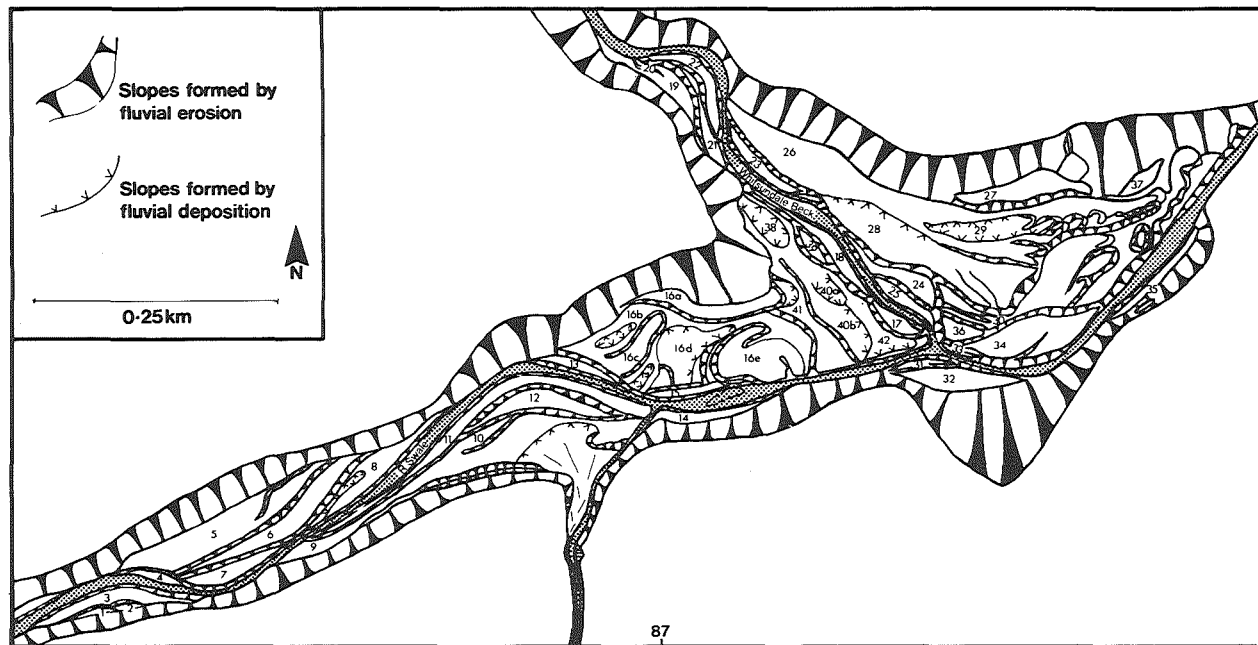


FIGURE 6 The alluvial fan at the confluence of Whitsundale Beck and the Swale

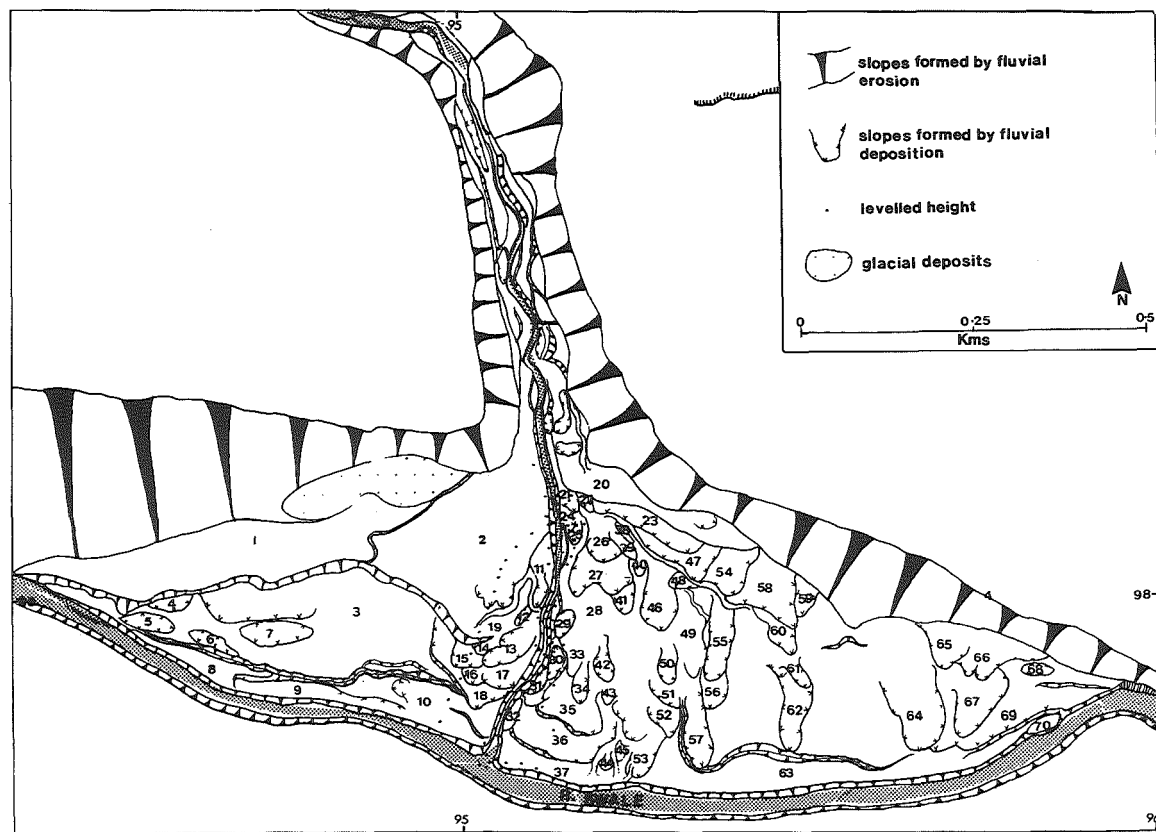


FIGURE 7 The alluvial fan at Gunnerside

Shallow pits dug in the surfaces of these lobes show considerable variation of sediment type. The highest area above the river channel on the east side (no. 19) is composed predominantly of highly weathered sandstone cobbles and pebbles, the less-resistant lithologies having been weathered away. Soil depth in these areas is only 2 or 3 centimetres. A flint found on this site has been identified as a blade failure from a small two-platformed prismatic blade core (Whymer, pers. comm.) probably of Mesolithic age. As the flint shows no sign of being rolled it is likely to be *in situ* and so indicates that the site has not been subjected to any disturbance since deposition. This affords the only tentative dating for the surface.

Not all sites have gravel deposits at the surface, the lobes on fragment 29 are variable in character, some are composed entirely of gravel whereas others have more than 50cms of sandy silty material over the coarser deposits. This presumably reflects overbank flooding. Vertical sections on fragment 38 (Figure 6) show horizontal bedding beneath zones of soil development, giving further evidence for sedimentation of finer material on these higher older surfaces. This accords with observations by Bryant (1983) as a characteristic of Arctic nival river systems which are not necessarily composed entirely of coarse material.

This site shows the transitional stage from fan formation dominated by periglacial conditions to more temperate regimes when the entrenched rivers cut into older deposits forming terraces. The trunk stream evidently abandoned the channel now represented by fragment 26 and formed a new channel located approximately along the course of the present river. The old channel is infilled with peat, preliminary examination of the pollen by Crabtree (pers. comm.) shows a succession from dominantly arboreal pollen, particularly *Alnus* at lower levels to a more open vegetation with *Calluna* presumably transported in from higher areas of the catchment.

The fan, although periglacial in origin, has the evidence of much subsequent modification and further analysis may lead to a fuller reconstruction of the palaeoenvironmental history.

The Gunnerside Alluvial Fan

This fan occurs down-stream of a narrow gorge (SD 946990) which lies at the foot of a massive landslide. The fan is developed where the Swale valley is some 200m wide allowing space for the gravels to accumulate in a fan form which has an area of 0.75km^2 (Figure 7). The area of the catchment of Gunnerside Gill is 12.62km^2 . The fan cuts into the glacial deposits on the valley side, giving an indication that its formation is subsequent to valley glaciation. Highest level river terraces in the constricted part of the valley above Gunnerside village (nos. 2 and 20 Figure 7) demonstrate the continuity of the fan with terraces before fanhead trenching occurred.

A series of levelling traverses was made to establish gradients from the apex of the fan to its margin. The mean gradient is 47.44m/km which is exceptionally steep for such a fan and is taken to reflect the coarseness of the material transported and the ruggedness of the catchment (Ryder, 1971). Boulders greater than 50cms in diameter can be seen in Gunnerside Gill.

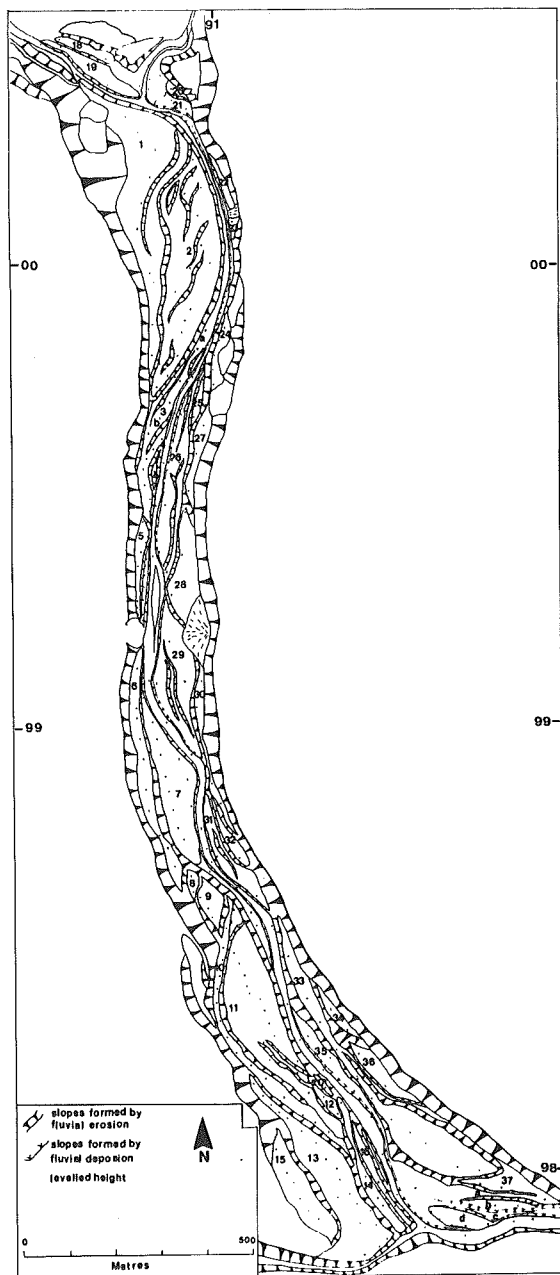


FIGURE 8 The River Swale from Hartlakes to Muker

The surface of the fan has the characteristic lobes similar to those at Whitsundale Beck fan. Preservation of these is better on the eastward, down-valley side which has been protected by increments of material which have deflected the course of the Swale, so limiting erosion, whereas upstream of the fan the main river has eroded a series of terraces at the fan margin (3-10 Figure 7).

Although the major part of the fan is deemed to have been inactive since its formation under periglacial conditions, some parts are reactivated by flash floods which are common in both the Swale and Gunnerside catchments. Boulder-size material has been seen in transport and there is evidence of this material being deposited in the small fan which is building out into the River Swale at Gunnerside Bridge (SD 949978). Williams (1957) quotes contemporary documents which record river levels 2.44m and 2.13m above the normal flow in 1892 and 1914 respectively. Upstream of the fan head the river has a steeper gradient (37.88m/km) than it has across the fan (29.44m/km). This difference is due to aggradation taking place in the river channel as sediment is brought in from upstream.

This site demonstrates that whilst former climatic conditions were more conducive to alluvial fan formation, situations exist where periglacial fans are still sites of accretion rather than dissection and removal of material.

RIVER TERRACES

In addition to terracing at the sites of alluvial fans, terraces are developed due to the dissection of large scale bedforms, alluvial plains and bedrock. The glacial history of the area brought about channel diversion (Rose, 1980) with the abandonment of the valley west of Kisdon Hill (Figure 5) and the cutting of the gorge at Keld (NY 896010). Downstream of this gorge macro bars developed (Figure 8) in response to the former high discharge and sediment yield of the periglacial river. Currently these are being dissected to form river terraces. When major floods occur e.g. the 1883 flood at Keld with a stage reading of 9.4m (Williams, 1957), the valley gravels which are on average only about 4m above the river are reactivated by scour and fill. Higher fragments along the valley (5, 6, 15, 24, 27 and 34) represent the remnants of the valley fill likely to have been deposited under periglacial conditions, but all the lower areas have been subjected to modification in the Holocene.

The terraces along the River Swale near Whitsundale Beck (Figure 6) reflect the progressive down cutting into the valley fill and some degree of local correlation is possible. Regional correlation is not possible as at each site local factors predominate. Very few sections are available in the area but close inspection of those along the riverbanks and those in pits show no evidence of cryoturbation or intraformational ice wedge casts, thus it may be tentatively concluded that periglacial activity was of short duration in the period following deglaciation and in the Younger Dryas. That such activity occurred has to be inferred from the large amount of sediment available to be worked and reworked by fluvial processes.

ACKNOWLEDGEMENTS

Thanks are extended to J. Rose for provision of the map on which Figure 8 is based and for his advice in the field, to P. Raby who dug the soil pits and to N. Cottell for help with diagrams.

EJP

THE NORTHEASTERN LAKE DISTRICT: PERIGLACIAL SLOPE DEPOSITS

INTRODUCTION

The three sites described below are in topographically similar situations: they are low altitude, mountain foot sites with long slopes rising above them. All are underlain by thinly cleaved mudstones of the Skiddaw Group (Jackson, 1978) of Ordovician age. During the Late Devensian glaciation, the northeastern Lake District was covered by an ice sheet and drumlins, composed of till, are evident around the town of Keswick and the lowlands to the north and south (Boardman, 1982). The maximum extent of the glaciation was about 18000 BP (Penny et al, 1969) and the Lake District was largely ice free by 14623±360 BP (Pennington, 1978). There is little evidence for periglacial conditions in the Lake District at the end of the Late Devensian glaciation eg. 16000-14000 BP. There is however considerable evidence for climatic conditions during the Loch Lomond Stadial (11000-10000 BP) which would favour periglacial processes. On the basis of the existence of rock glaciers, and therefore permafrost, in the Lake District, Sissons (1980) suggests a mean annual sea-level temperature no higher than 1°C and a July mean temperature of 8°C. Winter temperatures at sea level were between -15 and -25°C (Ballantyne, 1984). During this period small corrie and valley glaciers were re-established in the Lake District (Sissons, 1980). At many sites in the northeastern Lake District periglacial slope deposits can be shown to overlie Late Devensian till. It is reasonable to assume that these are the result of the deterioration of climate in the Loch Lomond Stadial (Boardman, 1978).

At the present time in the northern Lake District, frost-shattered debris are accumulating beneath steep, vegetation-free slopes. Scree occurs on Skiddaw above c500m (Figure 9). During the Flandrian, mixed-oak forest probably reached to about 640m on the Skiddaw massif but since 5000 BP clearance has gradually reduced the extent of forest, sheep grazing has prevented regeneration and the area is now dominated by open grassland (Pearsall and Pennington, 1973). Reactivation of scree slopes during colder phases of the Flandrian may have occurred (eg. Andrews, 1961) but there is no evidence for it. Low level scree sites in the Keswick area are now totally vegetated with soils developed in their upper beds. It seems unlikely that they have been active during the present interglacial.

THROSTLE SHAW (NY 237272)

This is a roadside exposure (alt. 100m) at the foot of the long, south west facing slope of Dodd (alt. 502m), the whole of which is under Forestry Commission plantation (Figure 9).

A few metres to the north of the section shown in Figure 10, bedrock Skiddaw Group mudstone rises close to the ground surface and is overlain by coarse scree including occasional glaciated boulders. Finer, disturbed stratified scree underlies the ground surface in which a brown podzolic soil is developed.

Unit A (Figure 10)

This unit is a very poorly sorted, silty sandy gravel (Tii, Table 4). The clast population is mainly angular slates but there are low numbers of edge-rounded slates, glaciated clasts and non-slate clasts. There is no bedding and little obvious sign of preferred orientation because of a scarcity of elongate clasts. However, macrofabric analysis of those that do occur suggests downslope movement of this unit (Figure 11). Stone

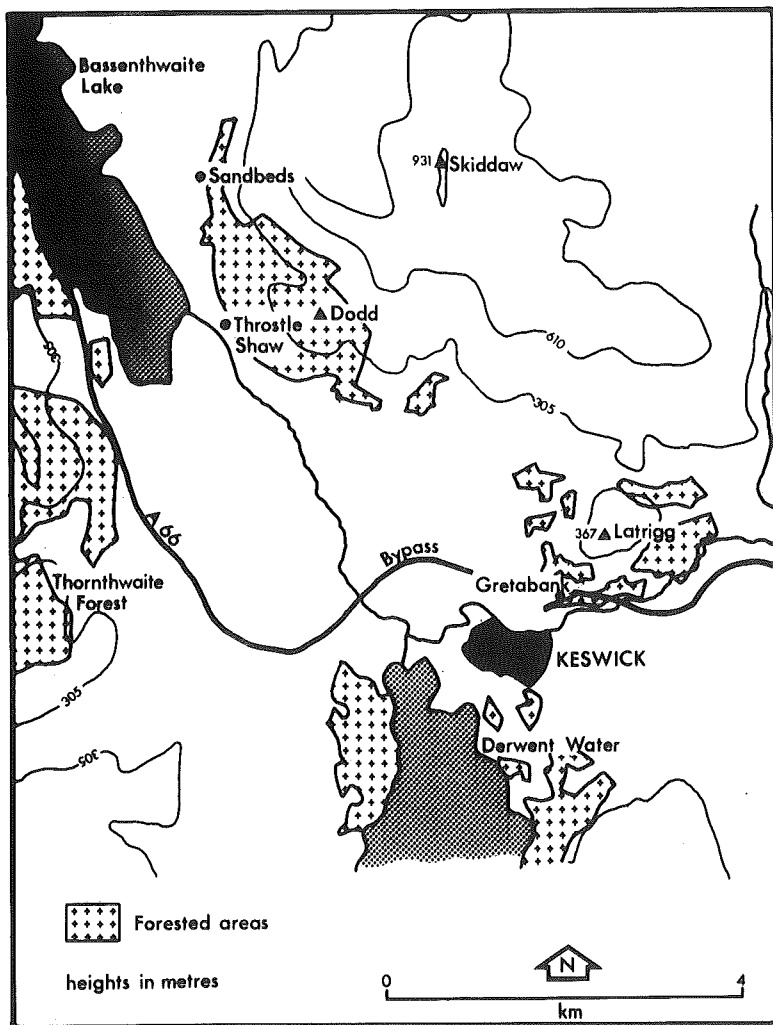


FIGURE 9 Periglacial slope deposits in the Keswick area:
location of sites

shape is variable but there is a lack of well developed blades and discs (Figure 12) and a significant difference compared to the overlying unit B (Table 4).

It is suggested that this unit is a debris flow containing frost shattered, glacial and fluvial material. Fines as well as glaciated boulders were probably derived from till on the slopes above.

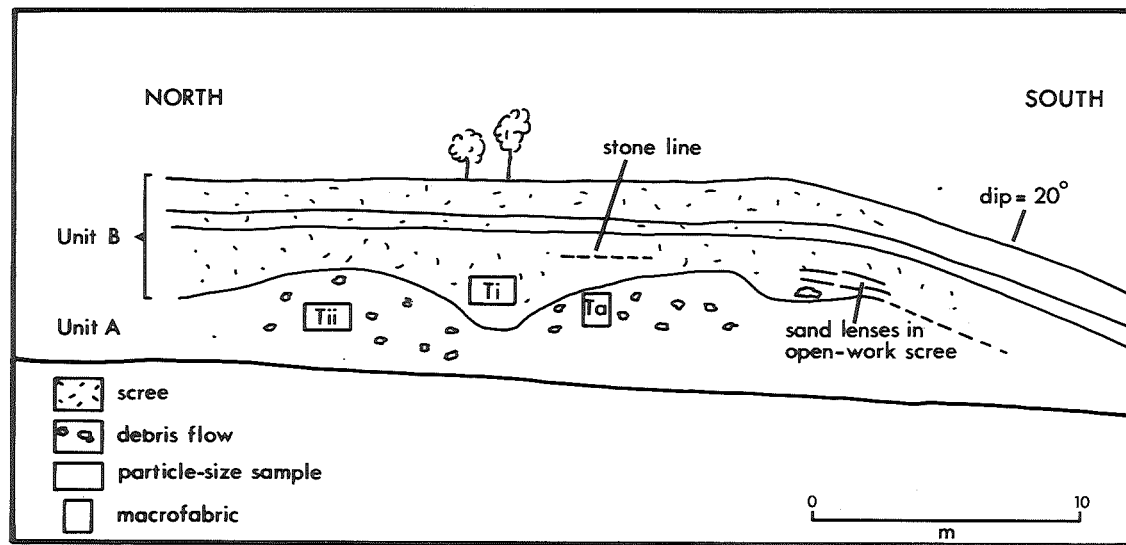


FIGURE 10 Throstle Shaw

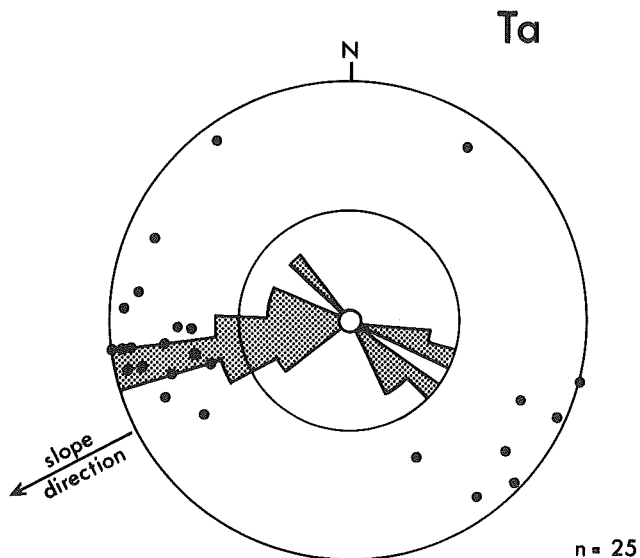


Figure 11 Macrofabric analysis of elongate clasts in the debris flow deposit at Throstle Shaw

TABLE 4 Particle size and shape characteristics of samples from Throstle Shaw and Sandbeds fan

sample	% gravel sand silt clay				% edge rounded	axis ratio 8-16mm clasts	
						$\frac{c}{a}$	$\frac{c}{b}$
Ti	89.1	6.9	1.6	2.4	4 (100)	0.160 (25)	0.300 (25)
Tii	54.1	32.8	10.3	2.8	9 (100)	0.350 (25)	0.577 (25)
Si	84.4	10.7	3.8	1.1	89 (100)		
Sii	94.5	1.9	2.8	0.8	95 (100)	0.204 (25)	0.386 (25)
Siii	76.2	23.4	0.3	0.1	89 (28)		

() = number in sample

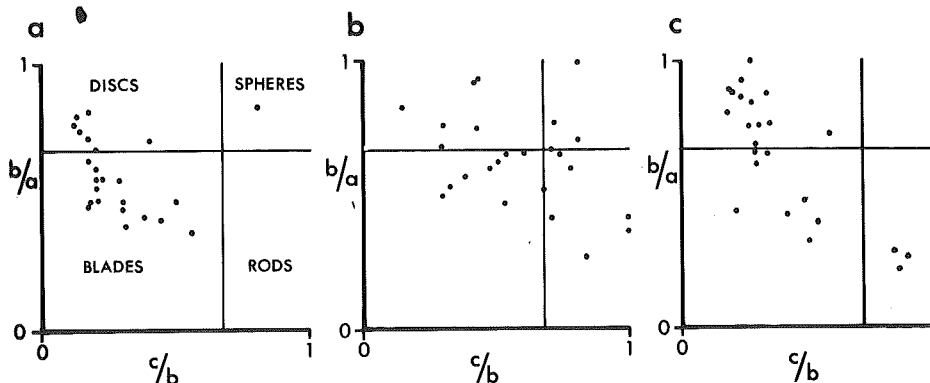


FIGURE 12 Particle shape: Zingg classification (a) Ti: stratified scree, Throstle Shaw (b) Tii: debris flow, Throstle Shaw (c) Sii: fan gravels, Sandbeds fan

At a site in Thornthwaite Forest (Figure 9) a debris flow unit was described which lies between openwork scree units (Boardman, 1977, 1981). The unit appears to be re-mobilised till with typical particle-size characteristics (31% gravel, 20% sand, 26% silt and 23% clay) and with 58% of the clasts showing signs of glacial smoothing and striation. However, a macrofabric implies downslope movement probably as a viscous debris flow across openwork scree in the manner described by Wasson (1979).

Units A and B are separated by an erosional phase, the surface of the lower unit having been channelled.

Unit B

This is a relatively well-sorted and bedded openwork gravel unit composed predominantly of angular mudstone clasts. The beds dip at about 20° to the west. Occasional edge-rounded and glaciated clasts occur in the unit. Small amounts of sand and silt are found on the upper faces of clasts, the result of washing of fines through the gravel. The unit is typical of similar deposits at many sites in the area. It is referred to as 'stratified scree' or 'grèze litées' (Boardman, 1978) on the basis of its bedded and well-sorted character. Washburn (1973) describes such deposits as being composed of 'angular, usually pebble-size rock chips and interstitial finer material'. In some areas they are rhythmically bedded with alternating fine and coarse beds (Dylik, 1960). It is suggested that the stratified scree in the northern Lake District was formed by redistribution of rockfall scree by snow meltwater perhaps over a permafrost table at or close to the surface of the scree (cf Howarth and Bones, 1972). Distance of transport was very limited since clasts are rarely edge rounded.

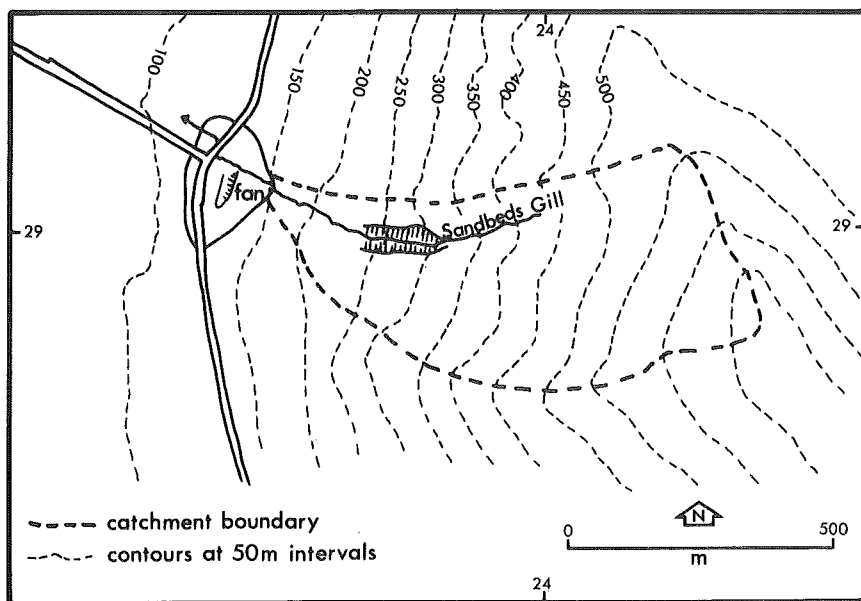


FIGURE 13 Sandbeds fan and catchment

TABLE 5 Sandbeds Fan: morphometric data

Length of slope above fan	950 m
Relief of slope above fan	530 m
Mean gradient of stream above fan	0.509 (c27°)
Area of catchment	265,000 m ²
Area of fan	25,500 m ²
Volume of fan*	153,000 m ³
Mean surface lowering in catchment	0.58 m
Rate of surface lowering in catchment**	0.58 mm yr ⁻¹

*Assumes mean depth of fan to be 6 m

** Assumes 1000 year period of formation

The fan is situated at the point where a small stream, Sandbeds Gill, debouches onto the valley bottom, till-covered ground (Figure 13). A small quarry provides excellent exposures in the fan. The morphometry of the fan and its catchment is presented in Table 5.

At the base of the quarry till is exposed (Figure 14). Macrofabric analysis gives a strong east-west preferred orientation suggesting post-depositional solifluction in an area where Late Devensian ice was moving to the north. At one site in the quarry, till appears to overlie fan gravels, implying solifluction during the early stages of fan formation.

The hillside slope above the fan is long and steep and consequently the mean gradient of Sandbeds Gill is high (Table 5). The present stream is deeply incised into the fan.

The sediments exposed in the quarry vary from fine to coarse gravels, discrete beds of sand are rare. The degree of sorting is variable and the amount of interstitial material in the gravels, principally sand, is also variable (Table 4, samples Si, Sii and Siii). A feature of many beds is the silt caps on gravel clasts. The fact that some beds lack silt caps, and underlying and overlying beds possess them, implies that the caps result from the washing in of silt during fan aggradation.

All gravel units in the fan contain high proportions of edge-rounded clasts in contrast to scree deposits in the same lithology (Table 4).

In the main face of the quarry, gravels can be seen to infill a channel of about 11m width and 7m depth (Figure 14). Units of coarse, blocky gravels are seen at the base and top of the channel. The coarse gravels contain occasional large clasts up to 0.5m in length, glaciated and non-slate clasts. They are poorly bedded and sorted. The margins of the channel are marked by a prominent iron-stained sandy gravel horizon (Table 4, sample Siii). The high angle of the northern channel margin (35°) suggests rapid channel cutting and filling before collapse could occur. Freezing of the sediments would also promote stability. At the north end of the quarry, well-bedded fine, sorted gravels are exposed: these units probably represent flood discharges from the main channel.

Directions of flow in the fan gravels are indicated by the histograms in Figure 15: Sb is in gravels from the main channel (Figure 14); Sa is from 2m below ground surface and Sc from 2.5m below ground surface. Detailed macrofabric analysis would undoubtedly reveal considerable variability in flow direction during fan aggradation.

At the southern end of the main quarry section (Figure 14), a prominent iron-stained sandy gravel horizon occurs which may represent the margin of a shallow channel. Below this unit are loose, openwork gravels. The boundary between the two units is involuted, the size of the involutions being almost 1m. These features represent disturbance within the active layer under periglacial conditions and as such imply the existence of a temporarily stable land surface on a part of the fan. The marked contrast in grain size between the two gravel units and the availability of water on the fan surface would no doubt encourage the formation of involutions (Johnson, 1975). Burial of the involuted horizon occurred due to flooding from the main channel or a change in the location of channels on the fan.

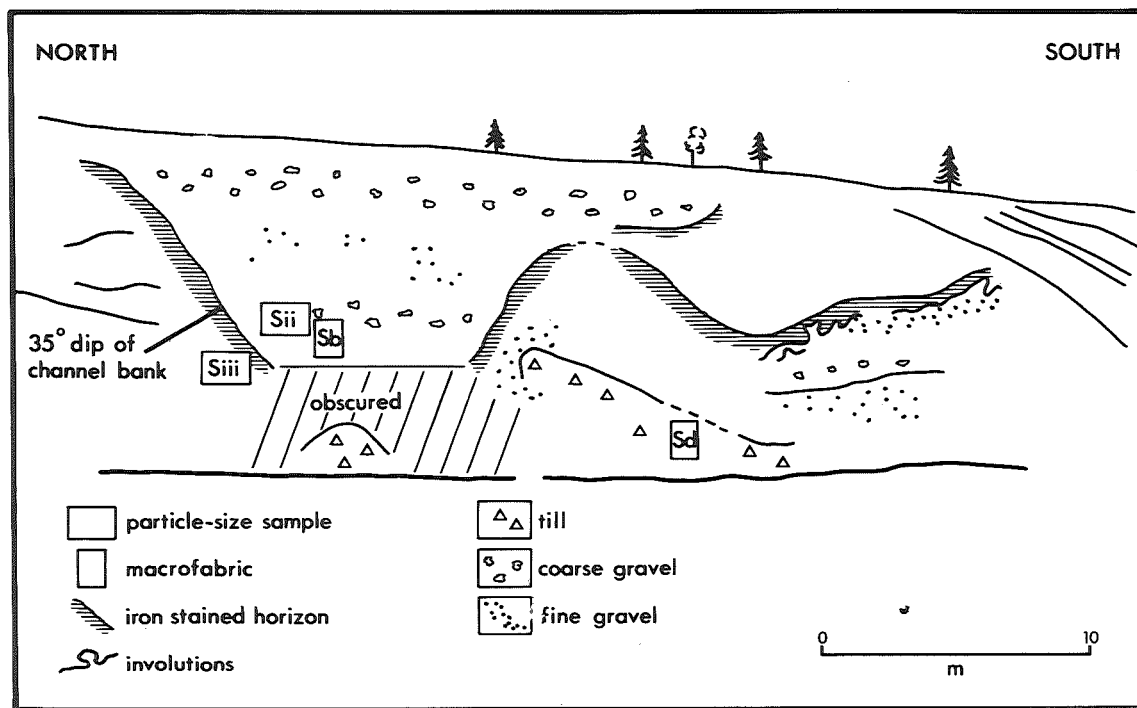


FIGURE 14 Sandbeds fan: west-facing section in quarry

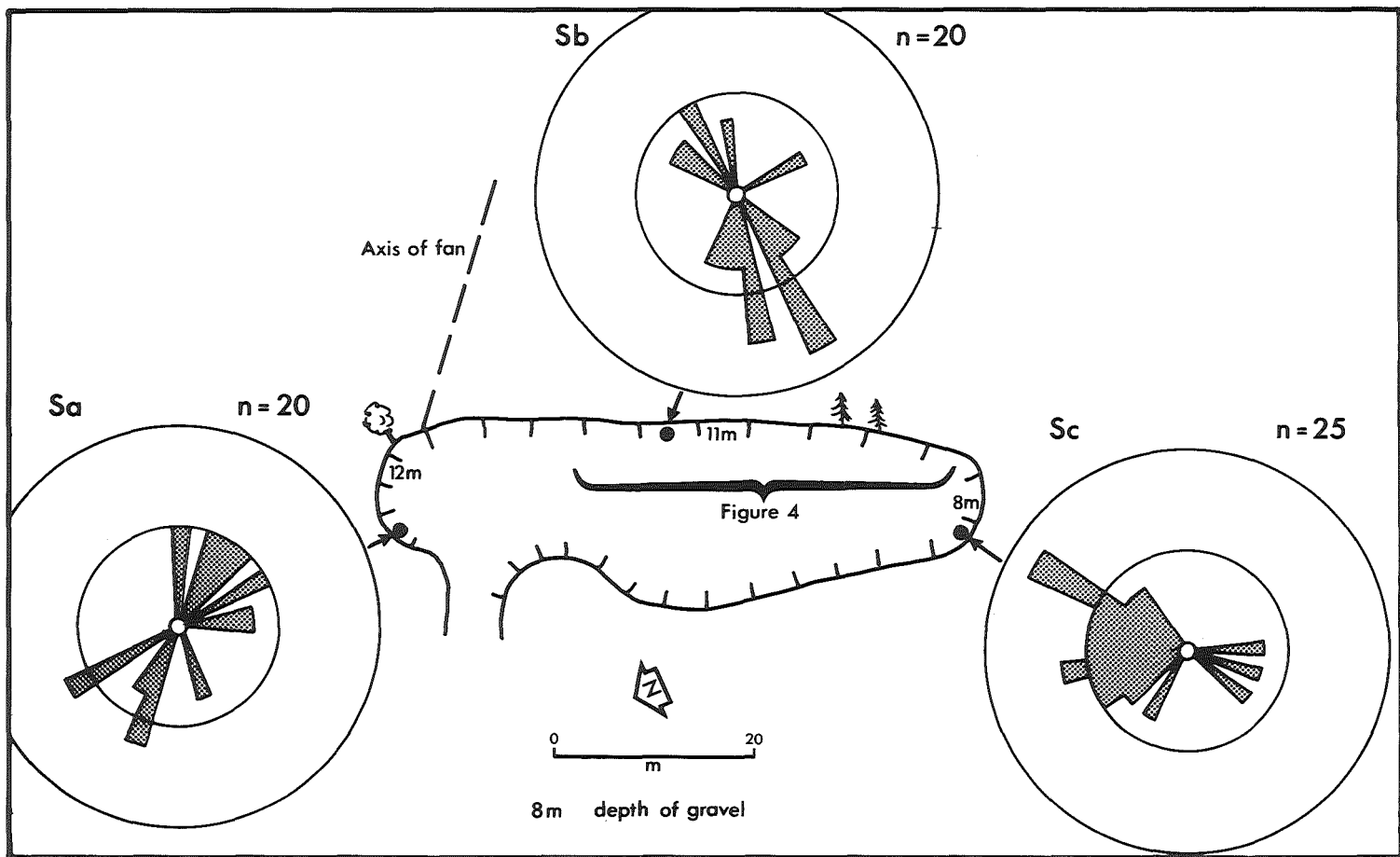


FIGURE 15 Sandbeds fan: plan of quarry. Histograms show orientation of elongate clasts in the gravels

Involutions have not previously been reported from gravels or scree sediments in the northeastern Lake District though similar forms are described in the southern Lake District (Johnson, 1975).

The character of the fan gravels suggests that they originated largely as a result of frost shattering but were subsequently transported by fluvial processes. Present day fluvial activity within the catchment is confined to the channel of Sandbeds Gill. Under periglacial conditions, drainage densities may have been high in response to seasonal snowmelt discharges. Overland flow on slopes underlain by permafrost may also have been an effective means by which weathered debris was moved to channels. Rapid rates of weathering and transport would have been favoured by an absence of vegetation.

The volume of the fan represents a mean surface lowering within the catchment of about 0.5m (Table 5). The Quaternary history of the area implies that the fan has formed since the Late Devensian glaciation. It also seems likely that it pre-dates the establishment of forest cover on these slopes at the beginning of the Flandrian.

Table 5, rather speculatively, gives a rate of ground surface lowering based on the assumption that the fan formed during the 1000 years of the Loch Lomond Stadial. The evidence for a single period of rapid aggradation is equivocal: the steep sides of the main channel imply rapid cut and fill, whereas the involuted horizon suggests that a short period of ground surface stability occurred during fan formation - a period though, when permafrost existed.

KESWICK NORTHERN BYPASS

During the construction of the Keswick Northern Bypass in 1975, temporary exposures of stratified scree, trial pits and borehole logs were examined. The road passes between the lower slopes of Latrigg (Figure 9) and an area of well-defined till drumlins around Gretabank Farm (Figure 16). Parts of the lower slopes are wooded but the upper slopes above the 244m contour are smooth, grass covered moorland interrupted by occasional outcrops of well-cleaved mudstone.

Temporary exposures in trenches at sites A, B and C (Figure 16) revealed well sorted, angular gravels predominantly composed of the local Skiddaw Group mudstone. The upper 1m of the gravel contained large quantities of interstitial sand (eg. 38%). Boreholes and trial pits provided further information on the extent and character of the stratified scree in the area of the temporary exposures (Figure 18). The main conclusions from the data are as follows.

1. Considerable depths of scree occur at sites 64a (>12m) and 67a (12.4m).
2. South of sites 63, 65 and 66, where a thin layer of scree overlies till, the slope deposits have not been detected. Altitudinally, they seem not to occur in this area, below 118m.
3. The borehole data confirm the observations at site B, as to the change in character of the scree from an upper gravel bound by a fine matrix, to a coarser, openwork or loose gravel, below.

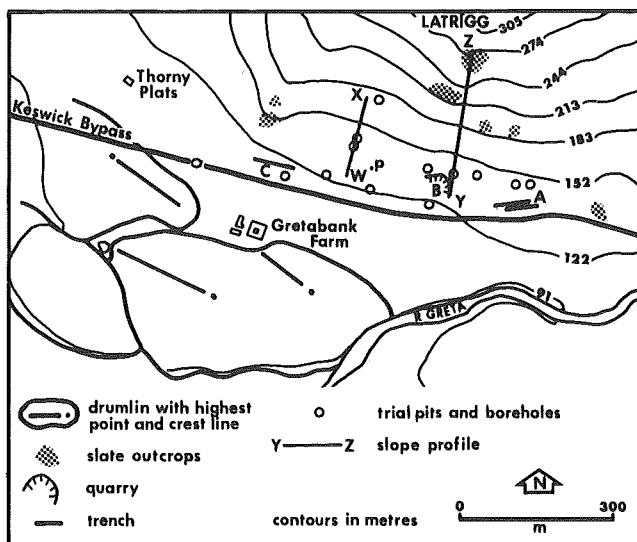


FIGURE 16 Relief and landforms on the slopes of Latrigg

Two slope profiles were surveyed and their locations are shown on Figure 16. The underlying stratigraphy is obtained from boreholes and trial pits that lie on or close to the line of profile (Figure 18). It is probable that scree on the lower part of profile W-X is partly burying a drumlin. Along most of the length of profile Y-Z it is crossing a poorly vegetated talus slope composed of slate debris that is coarser than that seen in the vegetated scree exposures along the line of the bypass. Neither the boreholes nor the exposures indicate the relationship of the surface talus deposit to the stratified scree, but it seems likely that the latter represents fines transported downslope from an unsorted rockfall accumulation at higher altitudes and in close proximity to rock outcrops. Further frost shattering would occur during transport. The upslope extent of the finer stratified scree is not known but thicknesses of 12m and 12.5 in boreholes 64a and 67a respectively, suggest that considerable depths lie upslope of these boreholes and perhaps underlie the coarse talus seen at the surface (profile Y-Z, Figure 18). In which case, the coarse talus may be regarded as a recent addition (perhaps intermittently continuing at the present time) to the vegetated surface of the stratified scree.

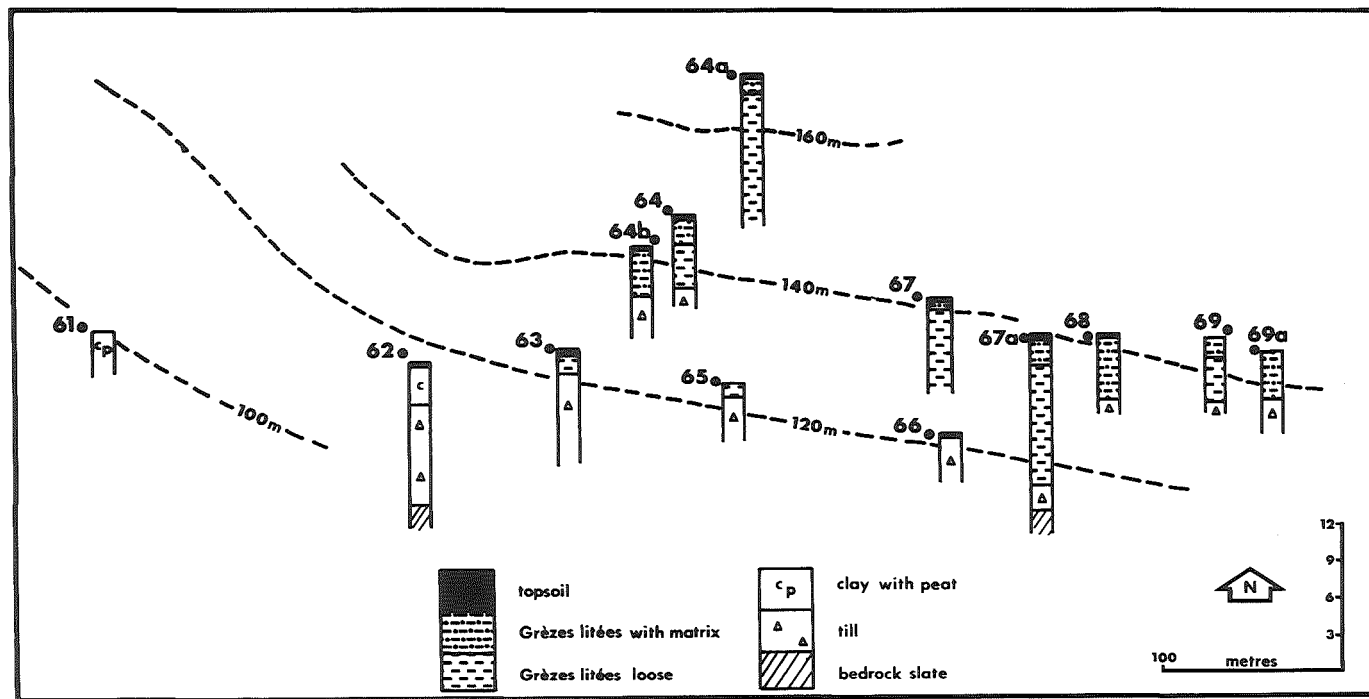


FIGURE 17 Position, altitude and stratigraphy of trial pits and boreholes on the lower slopes of Latrigg

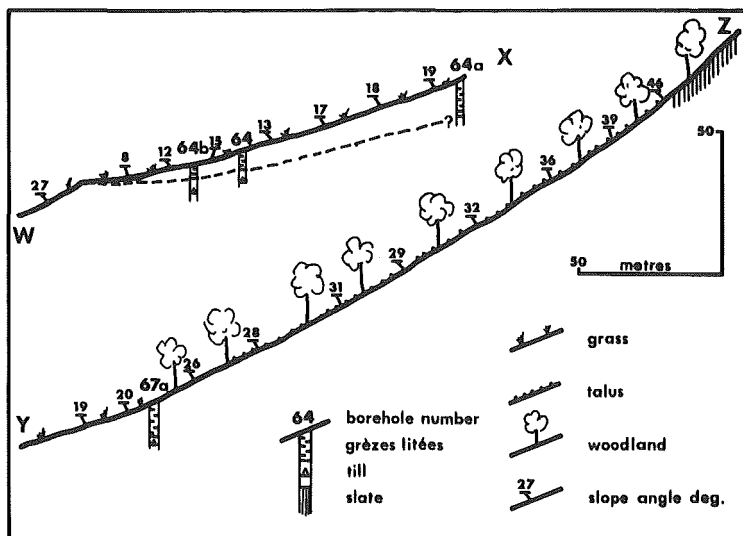


FIGURE 18 Slope profiles on Latrigg

Origin of the stratified scree

At each of the temporary exposures the deposits are seen to be bedded, both in the macro-sense of there being two major units, and in that lenses of matrix-rich slates occur within the upper unit. The borehole evidence confirms these observations. In comparison with other scree sections in the area, the Latrigg screes appear to be well-sorted. Taken together, these characteristics suggest that water has been responsible for their deposition. It is proposed that water has transported rockfall debris supplied by frost-shattering from upslope. The size and sorting of the debris is a function of material available in the source area and the power of the water.

There seems to be general agreement that water flow over coarse scree slopes will be limited and will occur effectively when one or more of three conditions is satisfied.

1. A permafrost table existing at or near the surface preventing percolation into the scree. This phenomena is referred to by Howarth and Bones (1972) and Wilkinson (1972) also records flow beneath the surface in the active layer on Arctic slopes composed of coarse, openwork material (cf. the lower unit at Latrigg). Judson (1949) suggests that frozen talus slopes would concentrate slopewash in the upper few inches.
2. Tricart (1970, p131) points out that 'on gravity screes, run-off is slight because the water sinks into the debris; it can play a part only in stratified screes which are rich in fines'. The same deduction may be made on overland flow and texture of debris from the data

provided by Dingwall (1972). He also ascribes sorting and horizonation of debris to overland flow. Unfortunately, the limited amount of data that he provides relate to a short-term project that has now terminated (P R Dingwall, pers. comm.).

3. Jahn's (1960) observations in Spitsbergen indicate that water flowing over the surface of snowpatches (supranival flow), separates silt and sand and leaves well-sorted debris (2-10mm) covering the lower parts of the patch.

Wasson's (1979) observations on stratified debris slopes in the Hindu Kush suggest that the combination of relatively low slope-angle, openwork or partially openwork fabric, and preferred orientation of clasts, is likely to be the produce of surface wash, since it is not due to rockfall, grain flow or debris flow processes. Using Wasson's work forces one to use a negative, though not unconvincing, line of reasoning - that the deposits at the foot of Latrigg do not contain evidence of certain processes and therefore are likely to be the product of surface wash.

It is therefore suggested that the lower unit at Latrigg is likely to be the product of deposition by water, either due to a permafrost table within the scree or due to supranival flow. The association of grèzes litées with water flow from snow patches is a recurring theme in the literature (Guillien, 1964), though in central Wales (Watson, 1965) and in Tasmania (Derbyshire, 1973), there appears to be no relationship between stratified slope deposits and north-facing slopes where snow patches might be expected to be large and long-lasting. The south-facing slope of Latrigg, devoid of niches or valleys, would also seem an unlikely position to favour snow patch survival, but this would not inhibit seasonal melting of snow on the slope provided sufficient was available: the dominant control on meltwater production could be climatic rather than topographic.

The great depth of scree material as revealed in the boreholes, argues for a period of climate of some severity in which frost-shattering and meltwater flow (perhaps with permafrost present), were dominant processes at what are now temperate and vegetated sites. This conclusion is valid despite the recognition that the rock type is acutely susceptible to frost-action.

The character of the stratified scree on Latrigg, particularly its sorted and bedded nature, means that application of the term 'grèzes litées', as defined by Washburn (1973), to these deposits is entirely appropriate (Boardman, 1978). The recognition of snowmelt as a probable agent of transport and deposition is in keeping with other evidence relating to the formation of grèzes litées especially from French and Polish workers.

Age of stratified scree

At this locality, the scree overlies till of Late Devensian age. A Lateglacial or Flandrian age is therefore indicated for the scree. Palaeontomological evidence suggests that deglaciation was followed by a rapid amelioration of climate climaxing in the considerable warmth of the Windermere Interstadial (Coope, 1977). It seems most likely that the Latrigg screes post-date this phase and were formed during the succeeding deterioration of climate, the Loch Lomond Stadial, equivalent approximately to Younger Dryas time.

It is of interest to note that in North Wales, Ball (1966) has calculated the time period necessary for accumulation of Lateglacial scree's using Rapp's (1960) figure for the annual average increment to the scree surface at Karkevagge, Sweden. Such an exercise is beset with difficulties involving unknown factors and known environmental contrasts. However, using the same basis for calculation, the unusually thick scree at the foot of Latrigg would have taken about 850 years to accumulate: an eminently reasonable estimate if their Loch Lomond Stadial age is accepted.

CONCLUSION

The periglacial slope deposits in this section are developed from a frost-susceptible rock type, the thinly cleaved mudstone. Nevertheless, the quantity of material accumulated at these sites represents significant landscape modification. It is argued here and elsewhere that the most likely period of formation is the Loch Lomond Stadial (11000 - 10000 BP) (Boardman, 1978, 1981). The evidence indicates that frost shattering was extensive and that overland and channel flow, the latter involving high discharges, were locally able to move weathered debris to low gradient and low altitude sites. In this manner, rockfall scree appears to have been extensively redistributed presumably by summer snowmelt discharges over a vegetation-free landscape underlaid by permafrost.

ACKNOWLEDGEMENTS

I would like to acknowledge a useful discussion on the Sandbeds fan with Dr Paul Carling; the long-standing help and encouragement of Mr J. Rose, and the ready access to borehole and trial pit records provided by Scott Wilson Kirkpatrick and Partners.

JB

PROTALUS RAMPARTS, PROTALUS ROCK GLACIERS AND SOLIFLUCTED TILL
IN THE NORTHWEST PART OF THE ENGLISH LAKE DISTRICT

The northwestern part of the Lake District comprises that region to the north and west of Derwent Water. Over the years a variety of periglacial features have been described from that region including protalus ramparts, rock glaciers, (Sissons, 1976), gelifluction forms (Hollingworth, 1934), stone streams, stripes, blockfield (Hay, 1937, 1942, 1943), scree (Marr, 1916; Tufnell, 1969), stratified scree (Boardman, 1981), sorted stripes (Caine, 1963), and erected stones and ploughing blocks (Tufnell, 1969). The altitudinal range of these features is between 200m and 931m. They are developed on slates of the Skiddaw and Borrowdale Volcanic Groups and granophyres and microgranite. At the present time the mean annual temperature at Keswick (77m O.D) is 9.2°C and the summit of Dun Fell (847m) in the Pennines, is 3.4°C (Manley, 1975). Currently the mean annual precipitation at Keswick is 1475mm and over 2000mm on Skiddaw (Manley, 1973).

PROTALUS RAMPARTS

Arcuate ridges, composed of angular debris which has moved across perennial snowbeds, have been called in the Lake District, moraines (Ward, 1873), moraine-like mounds (Ward, 1875), snow-slope foot accumulations (Marr, 1916) and protalus ramparts (Sissons, 1976). In other areas they have been called nivation ridges (Behre, 1933; Lewis, 1966), miniature moraines (Manley, 1949), nival moraines (Karczewski et al, 1981), pseudo-moraines (Watson, 1966) and protalus ramparts (Sissons, 1979; Rose, 1980a; Colhoun, 1981; Gray, 1982; Vincent and Lee, 1982; Karte, 1983; Ballantyne, 1984; Rapp, 1984; Sutherland et al, 1984). The term protalus rampart is used most widely and is here preferred.

Ward recognised that the ridges he called moraines were not true moraines but accumulations which he interpreted as resulting from frost-shattered material sliding over snow lying at the base of cliffs. Both Ward and Marr, describing these ridges in the northwest Lake District agreed that they formed during cold non-glacial conditions and that they were difficult to distinguish from moraine ridges which they often closely resemble in form. Marr suggested that they would differ mainly in the characteristics of their component materials, the frost-shattered material of the protalus ramparts being more angular than the sub-angular glacial debris.

According to Washburn (1979), it is generally agreed that protalus ramparts form at the foot of perennial snowbanks and are composed of rockfall debris. There is less agreement on the characteristics of their component materials. Washburn considers that they lack fines and that the rock particles are non-orientated. However, neither of these points is supported by all observers of protalus ramparts. The possible presence of fines is referred to by Derbyshire and Gregory (1979), Kotarba and Stromquist (1984) and Sekine (1973). They point out the importance of supranival wash in transporting fines across the snowbed and onto the accumulating ridge. The preferred orientation of rock particles in protalus ramparts has been identified by Watson (1966), Sissons (1976) and Karczewski et al (1981). Karczewski found blocks arranged predominantly transverse to the morphological axis of the ridge, with some blocks parallel to the axis of the ridge. Burnley (pers. comm., 1985) found strong preferred fabrics both transverse and parallel to the axis of the ridge on a protalus rampart in Norway depending upon the position within the ridge.

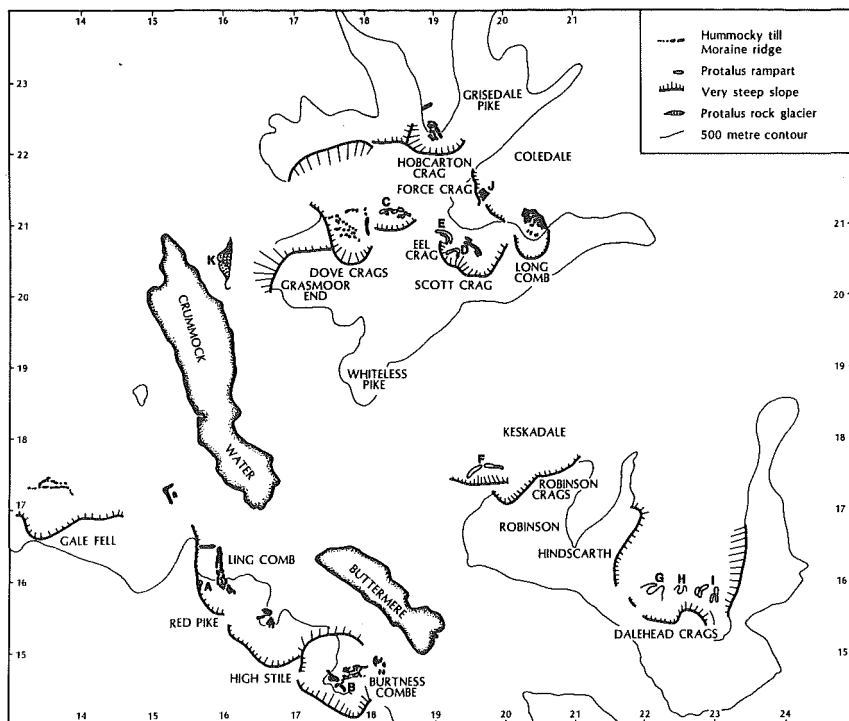


FIGURE 19 Location of some Loch Lomond Stadial moraine, hummocky till and protalus features in a part of the northwest Lake District

Ten protalus ramparts have been identified and mapped in the northwest Lake District. Their characteristics are listed in Table 6 and their distribution is shown on Figure 19. At the lowest point on their crest ridge they vary in altitude from 300 to 600m O.D. They all have aspects in the northeastern quarter (Table 6). They vary greatly in length between 60 and 550m and in height, between 1 and 10m. Material properties vary: some are matrix supported whilst others are not. Some contain rounded particles but most are dominated by angular material (Table 7). Two occur inside moraine ridges that have been attributed to Loch Lomond Stadial age (Sissons, 1980); both are therefore associated with talus which has formed since the ice of the Loch Lomond Stadial decayed.

At the head of Keskadale, NY 197176 (Table 7), there is a protalus rampart which has formed below and close to the large free face of Robinson Crags. It is an arcuate ridge which has a fresh appearance, similar to that described by Colhoun (1981), with sharp breaks of slope at its base and slope angles in excess of 25°. It is breached at its centre where a small stream,

TABLE 6 SOME PROTALUS FEATURES IN THE NORTHWESTERN LAKE DISTRICT

Location	Grid Reference (NY)	Altitude (m)	Aspect (deg)	Length (m)	Maximum height (m)
A Ling Comb	157159	600	087	60	1
B Burtness Combe	177145	450	025	180	2
C Dove Crags	185212	550	000	350	4
D Crag Hill	192206	650	025	180	3
E Eel Grags	193208	650	030	250	3
F Keskadale	197176	300	005	550	10
G Dale Head	221158	500	035	240	3
H Dale Head	225158	500	005	200	5
I Dale Head	229158	500	005	300	3
J Force Crag	198214	300	050	-	10
K Grasmoor	162205	200	275	250	5
End					

High Hole Beck, now flows and where good exposures enabled clast shape and fabric studies to be carried out. The limbs of the ridge run from 270m O.D. up the hill side to 350m O.D. where they merge imperceptibly with the hill-side. They are between 2 and 10m high and 15 to 20m wide.

In Coledale there are at least 3 protalus ramparts (Figure 19 and Table 6). Rampart J, below Force Crag is massive, Ramparts D and E are considerably smaller, apparently because they lack extensive free faces. The Force Crag rampart has been dissected by quarrying and by Pudding Beck. At a point on the section on the distal side of the ridge the rampart is over 10m high. It is composed primarily of angular clasts of Skiddaw Slate (Table 7). Few boulders are present in the section, though they are scattered across the surface of the protalus rampart. These surface boulders may have fallen since its formation as frost action is producing small quantities of rock debris. Three dimensional macrofabrics taken from the section show a statistically significant preferred orientation transverse to the axial ridge of the rampart (Figure 20).

Three dimensional macrofabrics from the Keskadale protalus rampart are similar to those seen in the protalus rampart below Force Crag in Coledale and in a protalus rampart studied in Norway (Burnley, pers. comm., 1985), being both parallel and transverse to the ridge axis. Clast shape data show that there is a far wider variety of shapes than seen in the Force Crag and Norwegian rampart, with more than 25% of the clasts being sub-rounded or rounded in Keskadale, there being no rounded clasts in the Force Crag rampart and less than 15% sub-rounded clasts. A far greater proportion of fines is present in the Keskadale rampart than in the Force Crag rampart. Sissons (1980), maps the Keskadale ridge as a Loch Lomond Stadial moraine but goes on to suggest that on the basis of site, altitude and location it may be a protalus rampart. Field evidence supports the hypothesis that this ridge

TABLE 7 LOCATIONS AND CHARACTERISTICS OF SOME PROTALUS RAMPARTS

Feature	Location	Grid ref (NY)	Lithology	%	Powers						Zingg				Mean Roundness
					VA	A	SA	SR	R	WR	S	D	R	B	
Protalus Rampart	Dale Head	222158	BVS SS	100 0	4	24	42	30	0	0	10	50	12	28	0.3082
Protalus Rampart	Dale Head	220158	BVS SS	100 0	4	60	22	14	0	0	12	40	10	28	0.2566
Protalus Rampart	Dale Head	226159	BVS SS	62 38	10	60	12	18	0	0	2	36	26	36	0.2479
Protalus Rampart	Dale Head	225158	BVS	100	0	44	38	18	0	0	12	38	26	24	0.2820
Protalus Rampart	Dale Head	228159	BVS	100	0	32	40	26	2	0	6	50	18	26	0.3083
Protalus Rampart	Dale Head	227158	BVS	100	14	24	42	16	4	0	12	44	10	34	0.2877
Protalus Rampart	Dale Head	229157	BVS	100	0	12	40	46	2	0	24	42	20	14	0.3503
Protalus Rampart	Dale Head	230158	BVS	100	0	20	38	40	2	0	14	42	20	14	0.3359
Protalus Rampart	Keskadale	197176	SKIDDAW SLATE	100	14	17	26	20	6	0	0	26	12	62	0.2537
Protalus Rampart	Keskadale	197176	SKIDDAW SLATE	100	0	18	34	40	8	0	0	38	6	56	0.3554
Protalus Rampart	Force Crag	198214	SKIDDAW SLATE	100	0	22	66	12	0	0	4	42	12	44	0.2946

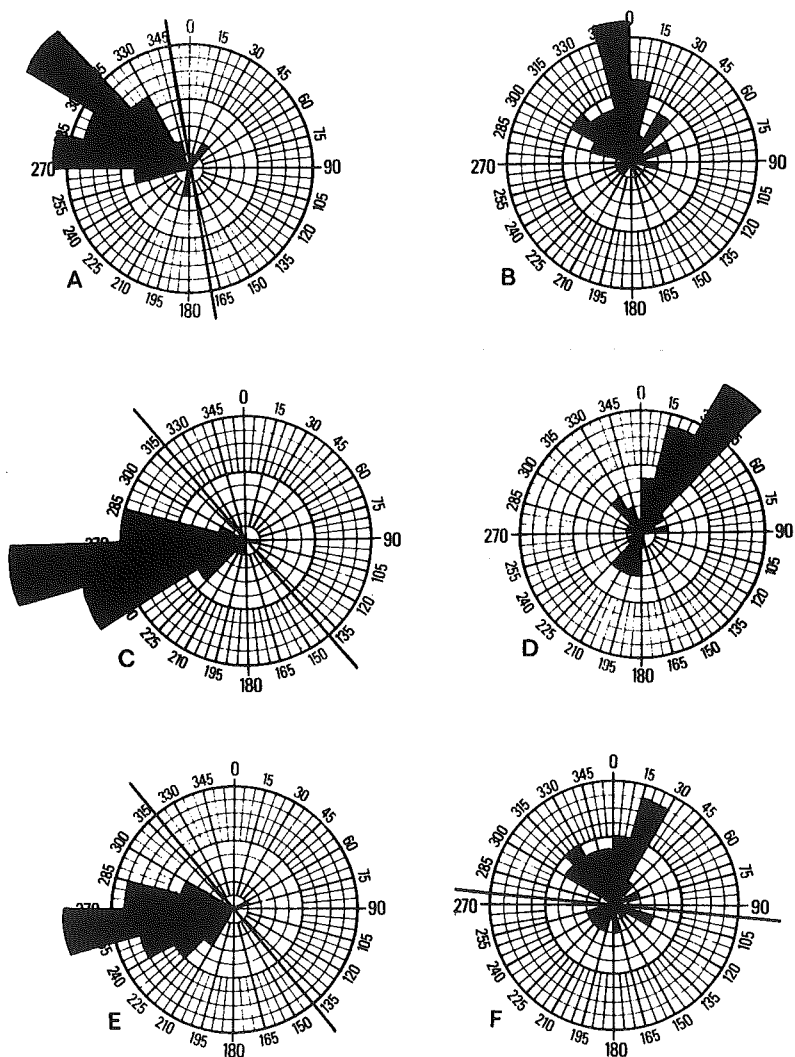


FIGURE 20 Three dimensional macrofabric results from protalus ramparts and till in a part of the northwest Lake District. The orientation of ridge crests is also shown. A, B and C Force Crag (protalus rampart); D and E Coledale (till); F Keskadale (protalus rampart).

is a portalus rampart. The ridge's closeness to the free face indicates that the depth of snow behind the ridge, especially towards the higher ends, is unlikely to have been sufficiently great to enable glacier ice to develop. The relatively high proportion of sub-rounded and rounded clasts can be attributed to the reworking and incorporation of till and to clasts supplied by meltwater coming off the extensive plateau above Robinson Crags. Schmidt hammer, (type L), measurements taken on bed rock inside and outside of the ridge and on large boulders in the ridge (Table 7), show a strong correlation between readings on the bed rock inside the ridge and the boulders on the ridge surface, and a difference between these two locations and that beyond the ridge.

PROTALUS ROCK GLACIER

Below Grasmoor End at NY 162205 (Figure 19), is an extensive accumulation of talus which at its base has a series of gently arcuate bulges to the west, away from the free face (K, Figure 19, Tables 6 and 8). These bulges are flat topped and not separated from the talus by any form of depression. They are not as fresh or clearly defined as the protalus ramparts already described. Their surfaces are strewn with angular boulders which have schmidt hammer readings considerably lower than those of boulders on the talus behind (Table 8). Although this feature is located at a low altitude and has a western aspect there is a protalus rampart below Herdus (NY 1116) which has a similiar altitude and aspect (Sissons, 1980; Ballantyne and Kirkbride, in press). Field evidence supports the hypothesis that they are a rock glacier form, here described as a protalus rock glacier. Protalus rock glaciers, often called talus foot rock glaciers (Johnson, 1978), or talus glaciers (Smith, 1973; Corte, 1976), are related to protalus ramparts and form at the foot of extensive talus slopes (White, 1976). This type of rock glacier forms part of a continuum: talus/protalus rampart/talus foot rock glacier (Blagborough and Breed, 1967; Barsh, 1977; Johnson, 1978, 1983; Swett et al, 1980).

The process envisaged for the formation of protalus rock glaciers is as follows. Where a perennial snowbank exists, at the foot of a steep and extensive rock face, frost-shattered material falls, slides or bounces across the snow surface to accumulate at its foot, forming a protalus rampart. This accumulation is dependant upon a change in slope angle at which descending material rests. Supranival wash resulting from meltwater and summer rainfall (Sekine, 1973) transports fines which accumulate between the larger particles. Meltwater infiltrates the accumulating talus and emerges at its base as springs. Some of this water is frozen as interstitial ice, the more so as the increasing thickness of talus acts as an insulating blanket. Ice lenses, resulting from buried snowbanks, may also be incorporated within the talus mass. With time the entire mass moves downslope as an active rock glacier, movement ceasing when gentler slopes are reached. The cessation of movement leads to the development of another protalus rampart before conditions allow a second protalus rock glacier to move downslope (Eugene, 1974). That some rock glaciers form as part of a continuum at the base of talus slopes as the result of the movement of protalus rampart accumulations makes the name protalus rock glacier for such forms appropriate.

SOLIFLUCTED TILL

Soliflucted till sheets have been described in the northern Lake District (Hollingworth, 1934; Boardman, 1981). In Coledale there is evidence of

TABLE 8 LOCATION AND CHARACTERISTICS OF SCHMIDT HAMMER SITES

Feature	Location	Grid Ref (NY)	Lithology	Altitude (m)	Aspect (deg)	Total Readings	Schmidt \bar{X}
Protalus Rock Glacier	Grasmoor End	162205	Skiddaw Slate	200	275	150	26.7
Talus	Grasmoor End	163205	Skiddaw Slate	200	275	90	38.6
Bedrock	Keskadale	198174	Skiddaw Slate	300	180	120	27.4
Protalus Rampart	Keskadale	197176	Skiddaw Slate	300	005	90	27.5
Bedrock	Keskadale	197179	Skiddaw Slate	300	000	120	16.3
Protalus Rampart	Burtness Combe	177145	Borrowdale Volcanic Series	450	025	150	29.9
Talus	Burtness Combe	177144	Borrowdale Volcanic Series	470	025	150	40.8
Moraine Ridge	Burtness Combe	180148	Borrowdale Volcanic Series	350	070	150	26.7
Moraine Ridge	Burtness Combe	182149	Borrowdale Volcanic Series	300	090	150	24.9
Protalus Rampart	Ling Comb	157159	Granophyre	600	087	150	41.6
Moraine Ridge	Ling Comb	157164	Granophyre	400	000	150	38.3

modification of the original till sheet which appears to have been deposited by ice flowing from the southwest towards the northeast down the valley with a three dimensional macrofabric aligned parallel to the direction of flow, as indicated by striations and erratics. For instance a section at NY 219227 (Figure 20), shows that four metres below the ground surface elongate clasts show a strong preferred orientation parallel to the inferred original ice flow direction. Whereas in the same section but less than 1 metre below the ground surface elongate clasts show a strong preferred orientation parallel to the valley-side slope and independent of the inferred ice flow direction. This modification of till fabric by periglacial processes is supported by Rapp (1960), Ball and Goodier (1970) and Potts (1971).

DATING OF PROTALUS RAMPARTS, PROTALUS ROCK GLACIER AND SOLIFLUCTED TILL

The modification of the till could have occurred during the latter stages of the Main Devensian glaciation after the ice had melted from the area but whilst conditions were still suitable for gelifluction. Similar conditions existed in the area during the Loch Lomond Stadial when in the absence of vegetation and during the existence of permafrost (Sissons, 1980), gelifluction would have been active on all but the most gentle gradients.

With only two exceptions the protalus features are found outside the Loch Lomond Stadial ice limits (Sissons, 1980), and are therefore assumed to have formed during the Stadial. They are found at locations where snowbeds rather than glaciers are likely to have developed because of local site conditions, or low altitude. The protalus ramparts, like the Loch Lomond Stadial moraine ridges, have a fresh appearance. The general lack of periglacial features inside of the Loch Lomond Stadial glacial limits except for 2 protalus ramparts and, in places, extensive talus spreads and cones, shows that there has been at least one period, since the decay of the Loch Lomond Stadial glaciers, cold enough for active frost shattering and, in favoured locations for the existence of perennial snowbeds. This could have been at the end of the Loch Lomond Stadial after the decay of the glaciers in these locations but before the intensely cold conditions had ended. Manley (1951) describes two protalus ramparts (miniature moraines) on Ben Nevis, one still forming in 1951, he also mentions snowdrifts on Helvellyn, in the Lake District surviving well into July in the early years of the nineteenth century. Perennial snowbeds need to be accompanied by a period of intense cold with frequent crossing of the freezing threshold to supply frost-shattered debris in order for protalus features to develop. Sugden (1971) suggested that during the Little Ice Age snow existed on Scottish mountains throughout the year. Alternatively the moraines could have been dated incorrectly, being earlier than Loch Lomond Stadial age, and the protalus ramparts were formed during the Loch Lomond Stadial.

The hypothesis that the two protalus ramparts A and B formed at the end of the Loch Lomond Stadial is supported by a series of Schmidt hammer readings (Table 8). The mean values ($n=150$) for the Loch Lomond Stadial moraine ridge sites in Burtness Combe of 24.9, 25.8 and 26.7 can be interpreted as indications that the moraine ridge was formed before the protalus rampart which has a mean value ($n=150$) of 29.9, and also before the talus inside the protalus rampart, which has a mean value ($n=150$) of 40.8. This relationship is also found in Ling Comb where the Loch Lomond Stadial moraine ridge has a mean value ($n=150$) of 38.3 whereas the protalus rampart has a mean value ($n=150$) of 41.6. The variations in means between Burtness Combe and Ling Comb are the result of variations in bedrock. Borrowdale Volcanic Series in Burtness Combe and Granophyre in Ling Comb.

CONCLUSION

In the North West Lake District periglacial processes have been active over sufficiently long periods at the necessary intensity to modify the landscape and produce a range of landforms, including protalus ramparts, protalus rock glaciers and talus forms and to modify the existing till sheet. The majority of these features are now fossil and were formed at the end of the Main Devensian glacial period, during the Loch Lomond Stadial or possibly during a cold period in the Holocene.

SPO

PINGO SCARS AND RELATED FEATURES IN THE WHICHAM VALLEY, CUMBRIA

During the course of investigations into the history and extent of Glacial Lake Whicham (Ridge, 1980) a series of enclosed depressions were tentatively identified as pingo scars. Subsequent detailed work on these features based on multiple augured transects and pollen analysis has confirmed this suggestion, and in addition, other relict features of possible periglacial origin have been identified. All the features cited below can be found in the vicinity of the A595, which runs along the north-western side of the valley (Figure 21) and the surrounding lanes. The lane below Lowscapes Bank (SD 156829) provides a good view of the landforms of the valley floor.

WHICHAM VALLEY SEDIMENTS

Much of the central part of the Whicham Valley is floored by a red lacustrine clay-silt deposited in the glacial lake. This is thought to have been extant during the retreat period of the main Devensian ice sheet (c15-14,000 B.P.) which gives a maximum limiting date to the periglacial features. The lacustrine deposit, typically 7% sand, 54% silt and 39% clay, is at least 4m thick in the Beckside (SD 152847) and Gateside (SD 146839) areas. In stream sections along Whitecombe Beck it can be seen to be overlain by an alluvial fan of apparently mid to late Flandrian age (Figure 22). Underlying the clay and outcropping on the south-eastern side of the valley are tills and sands and gravels of glacial origin. An extensive hummocky glaciofluvial complex lies transversely across the south-western entrance to the valley near Whicham Hall (SD 142828).

SURFACE FEATURES

The lacustrine clay-silt deposit slopes at c3° north-west to south-east towards the centre of the valley (Figure 22). It is dissected by several dendritic dry gully systems, described and mapped elsewhere (Ridge, 1980). Most of the gullies appear by eye to be symmetrical in cross section, although of two gullies surveyed in detail, one has steeper left banks and the other steeper right banks. Given the homogeneous nature of the substrate, this asymmetry may be indicative of a periglacial environment. The gully systems are thought to have been initiated following the rapid drainage of Glacial Lake Whicham from a level of 45m O.D. In the same area, the valley floor is also marked by a number of enclosed hollows, at least three of which, Grass Guards, Great Thwaite and Toppingmoss have discernable surrounding ramparts. Some of the hollows appear to be directly connected to the dry gully network, but others are not visibly part of it at the present day (Figure 22).

GRASS GUARDS PINGO SCAR (SD 158844)

This is an almost circular hollow of a c50m diameter, measured between opposite rampart crests (Figure 23). The immediately surrounding terrain slopes to the south-east. The ramparts are least pronounced on the upslope side but stand 4.5m above the valley of a small active stream on the downslope side. The enclosed hollow is 4.0m deep from the rampart crests to the base of the organic infill. Trenches dug across the ramparts to depths of c2m revealed a largely structureless lacustrine clay; there was no clear sign of a former landsurface or mass movement structures. A notable feature of

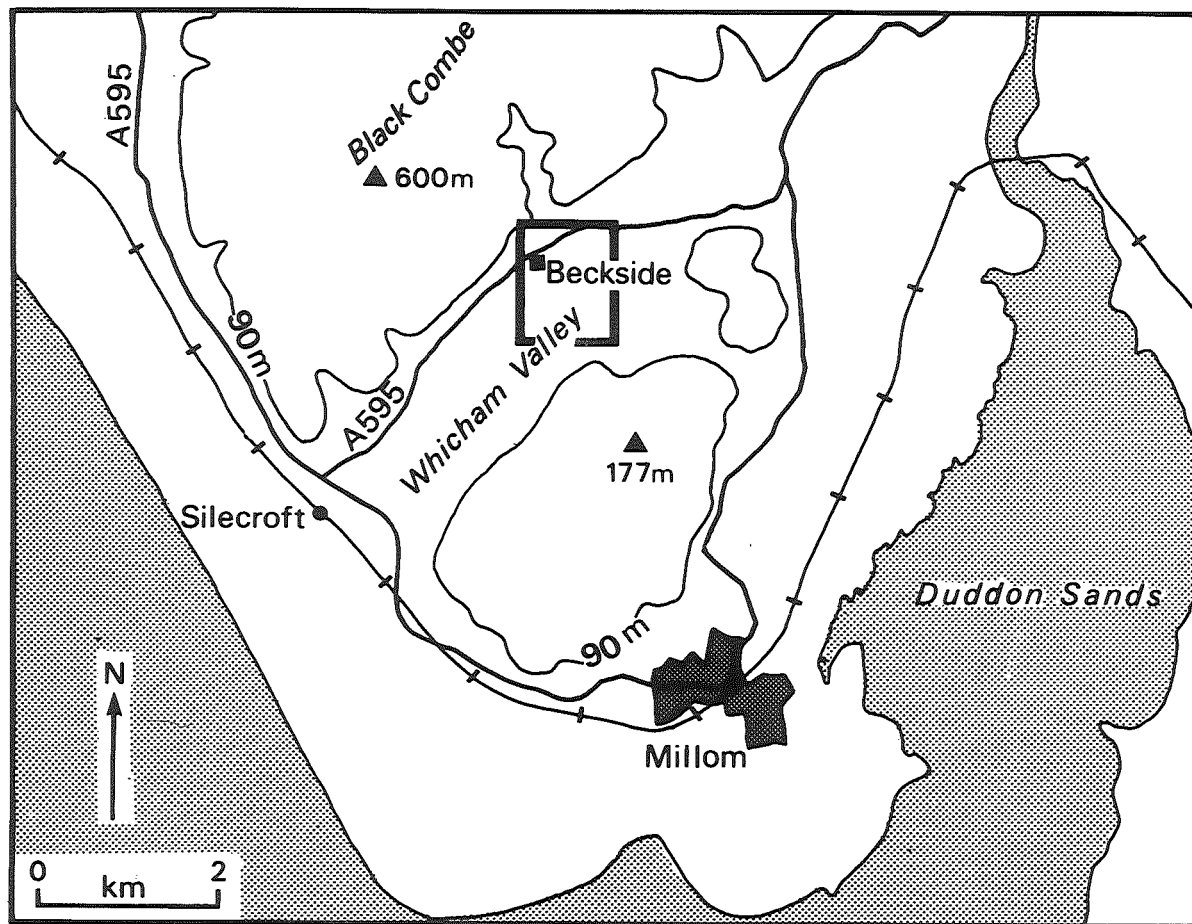


FIGURE 21 Location of the Whicham valley in south-west Cumbria

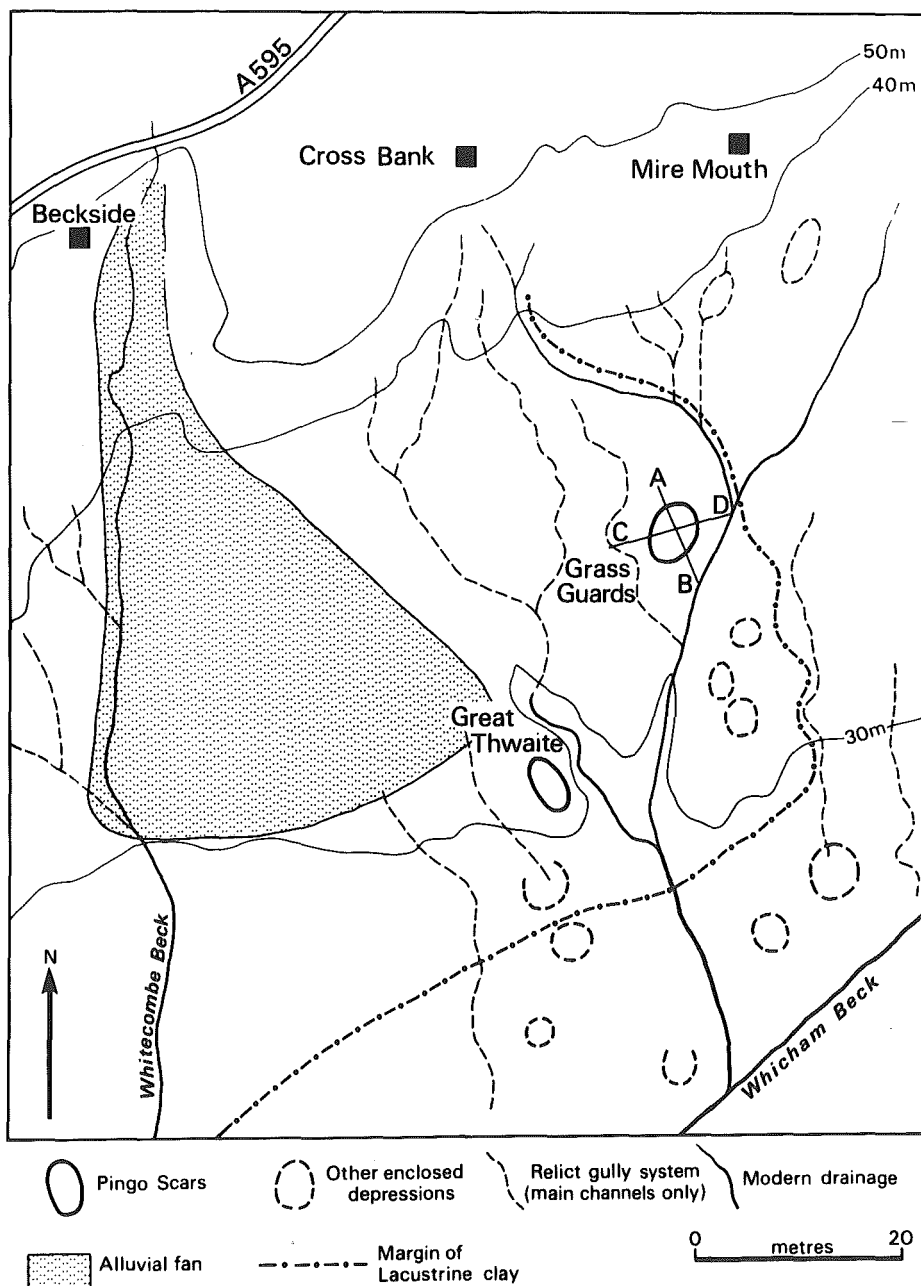


FIGURE 22 Geomorphological features near Beckside, Whicham valley

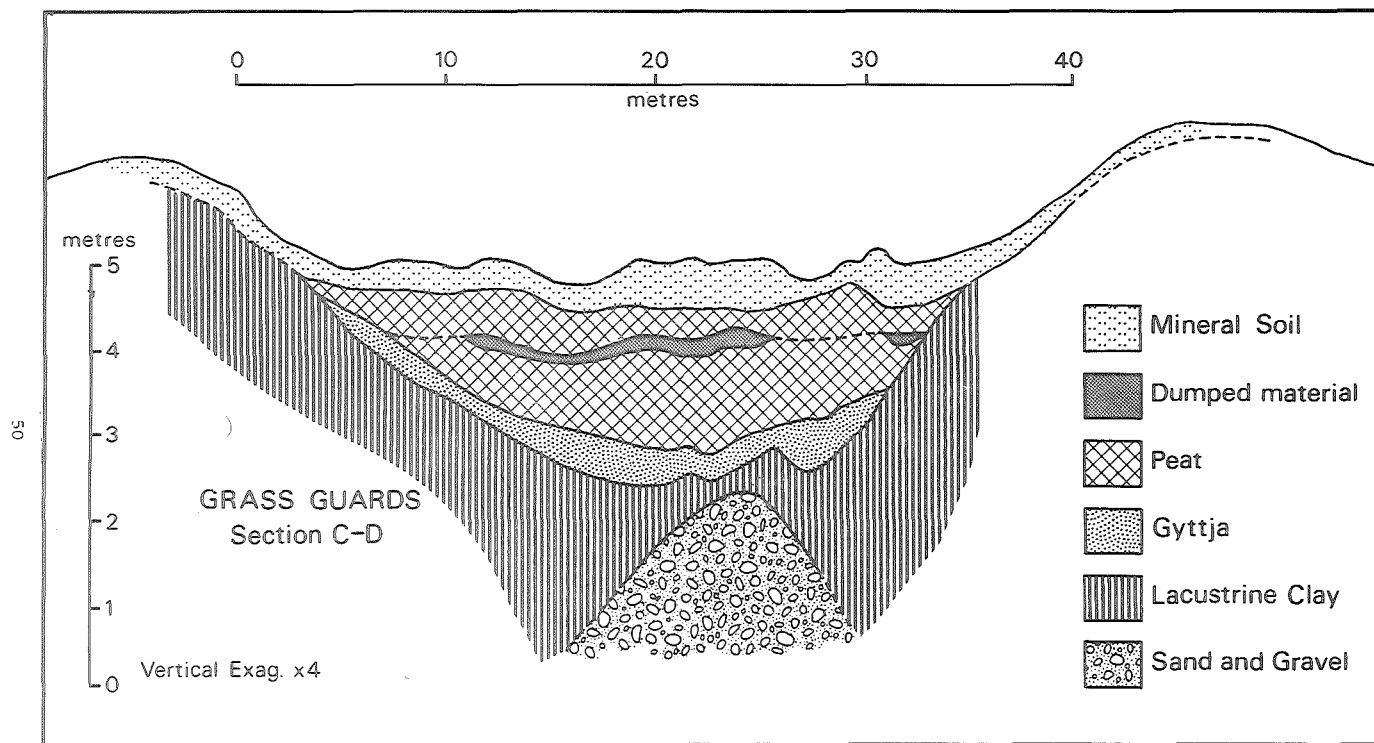


FIGURE 23 Generalised cross section through Grass Guards pingo scar,
Beckside, Whicham valley.

the lithostratigraphic cross-sections is the way that sands underlying the clay appear to form a dome under the hollow. The apex of the dome is located under the deepest part of the hollow which is slightly off-centre. There are several possibilities for the formation of this structure; in summary it may

- (a) pre-date the pingo, and be a diapiric structure formed in lake-saturated materials at the sand/clay interface;
- (b) relate to cryostatic deformation of the sediments during the active phase of pingo growth;
- (c) have been formed during the disappearance of the active ice core as a response to the unloading of the overburden.

The hollow is infilled by basal gyttja, peat and dumped material (Figure 23). Pollen analyses (Figure 24) of the lowermost organic layers indicate the presence of vegetation communities of open aspect, typical of the end of the late glacial and the opening of the Flandrian.

OTHER NEARBY SCARS AND HOLLOWES

Another postulated pingo scar similar to that just described exists in an adjacent field, Great Thwaite (SD 156841). Here the feature is more elongate in a downslope direction, measuring c47 x 80m between rampart crests. The depth of the hollow is 3.6m; the organic infill is thin and has not been analysed. Likewise, the pingo scar at Toppingmoss (SD 150833) has not yet been fully investigated, but does not seem to contain significant organic material. Enclosed or nearly enclosed hollows are to be found in other parts of the valley; many of them are enigmatic and may or may not have a periglacial origin. However, nearly all of them are situated close to the edge of the lacustrine clay tract. At SD 147833, just west of Toppingmoss plantation, are a series of shallow hollows with mutually interfering ramparts, somewhat reminiscent of the features bordering the English Fens at Foulden.

ORIGIN AND DATE

The Whicham valley pingo scars are regarded as being most likely of the hydrostatic (open-system) type in the sense of Mackay (1979) fed from an elevated source (Black Combe) via through-going taliks in an area of discontinuous permafrost. In this respect, the location of the pingos in relation to the lacustrine clay is perhaps significant. Ground water moving at depth under considerable hydrostatic pressure towards the centre of the Whicham Valley would have been inhibited from reaching the surface by the impermeable clay, except where the clay was either locally thin enough to allow the overburden pressure to be overcome, as at Grass Guards, or absent as at the Toppingmoss pingo scar. Alternatively, the drainage of the glacial lake could have resulted in the encroachment of permafrost onto the lake floor, creating hydraulic (closed system) pingos within one or more closed taliks. Given the indications of the age and distribution of the features, this latter idea is thought to be less likely, on the evidence available so far.

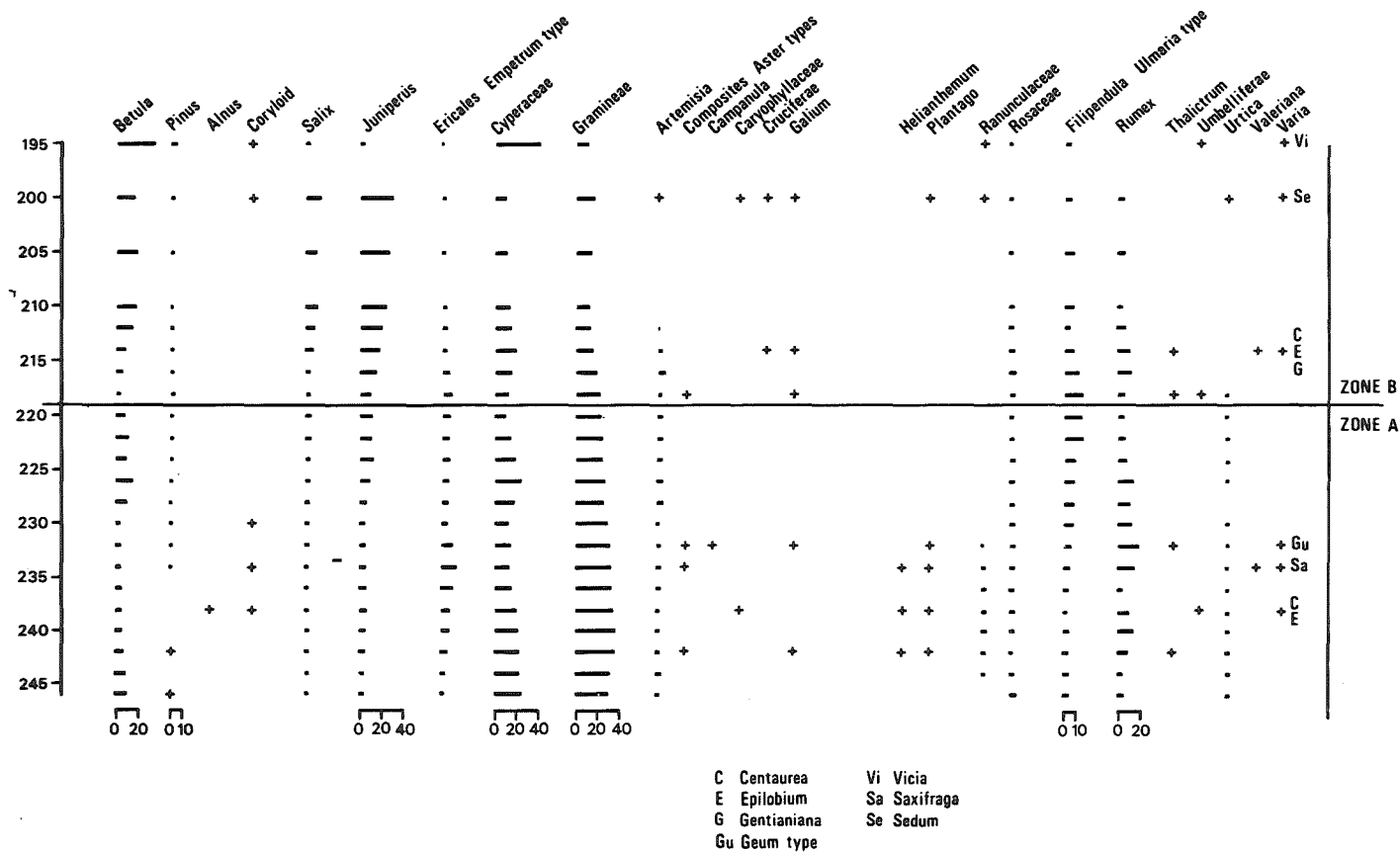


FIGURE 24 Pollen diagram from lowermost layers of Grass Guards organic infill. Percentages based on total pollen sum, excluding aquatics and spores (not shown).

The date of formation of the pingo scars is bracketed by the drainage of Glacial Lake Whicham and the beginning of the Flandrian. If one accepts the implications of the conventional climato-stratigraphy of this period (e.g. Lowe and Walker, 1984) then the formation of such permafrost features seems to relate to the Younger Dryas stadial (11,000 - 10,300 BP) unless there was a significant permafrost around at the time of the draining of the lake. No evidence of Late glacial interstadial deposits has been found so far in any of the hollows.

ACKNOWLEDGEMENTS

The authors thank the people of Whicham Valley for their help and permission to undertake field work. In particular, Mr Morris-Eyton of Beckside and Mr. Capstick of Whicham Hall, from whom permission must be sought before visiting the sites mentioned above.

RHB, CFC, TST.

CONTEMPORARY PATTERNED GROUND (SORTED STRIPES) IN THE LAKE DISTRICT

Contemporary patterned ground has been reported from the Lake District for over 50 years (Hollingworth, 1934; Hay, 1936; Caine, 1962, 1963, 1972; Warburton, 1982). Similar features have also been observed in Scotland, North Wales and the Pennines. The following description summarizes previous work and provides additional data regarding morphology and sediments of several sorted stripe fields.

Sorted patterns, in the Lake District, consist of small-scale sorted stripes, crudely developed polygonal nets and isolated sorted circles all occurring on the high fells. Stripes are more common than polygons and circles which are limited to ridge crests and lower gradients associated with the frontal lobes of sorted stripe fields (Figure 25). In both of these locations patterns are weakly developed and rarely occur in groups of more than three or four. Circle and polygon diameters are generally less than 50 cm and usually in the range of 18-43 cm (Warburton, 1982). Because sorted circles and polygons are rare only sorted stripes will be considered in further detail. Circles and polygons should still be considered as valuable 'indicators' of local contemporary frost action.

The contemporaneous origin of sorted stripes has been demonstrated on the basis of: stratigraphic relationships between the unbroken turf cover, patterned and unpatterned soils (Figure 25); formation of stripes on mining waste deposited in the last 300-400 years; and measurements of stone movement (Caine, 1963). In addition to these observations two 'test plots', on Skiddaw and Helvellyn (Figure 26), were set up in 1984 to monitor the reformation of patterned ground after homogenization, by digging to a depth below which apparent sorting extends. Surface clast movement is being monitored annually by photography.

Climatic conditions on the high fells are characterised by high rainfall amounts, in excess of 100 cm, and mean winter air temperatures of about -3 to 4°C. This constitutes a weak frost climate with several diurnal and larger freeze-thaw events each winter. Based on data from the 1961-62 winter, Caine (1963) estimates that periods of intense freezing (3-4 days) have greatest significance in terms of mechanical sorting, and tend to occur 3-6 times in any given year. These events can be related to periods of segregated ground ice development and intense needle ice growth. Cumulative winter freezing depths may be as great as 30 cm.

Multiple processes are involved in the formation of Lake District stripes. A combination of frost action and mass movements at and just below the surface have been noted. The relative importance of these processes varies both seasonally and from year to year depending on local environmental controls (temporal factors) and 'fixed' site factors (spatial factors) such as lithology which are known to vary considerably over short distances. In addition, the processes of wind action, coarse stripe drainage (rill action) and sheep trampling have also been reported as important in pattern development.

GENERAL SITE CHARACTERISTICS

The distribution of sorted stripe sites, in the Lake District, is controlled by altitudinal, lithological and related topographic influences (Caine, 1972). Areas of striping have the following general characteristics (Figure 25):

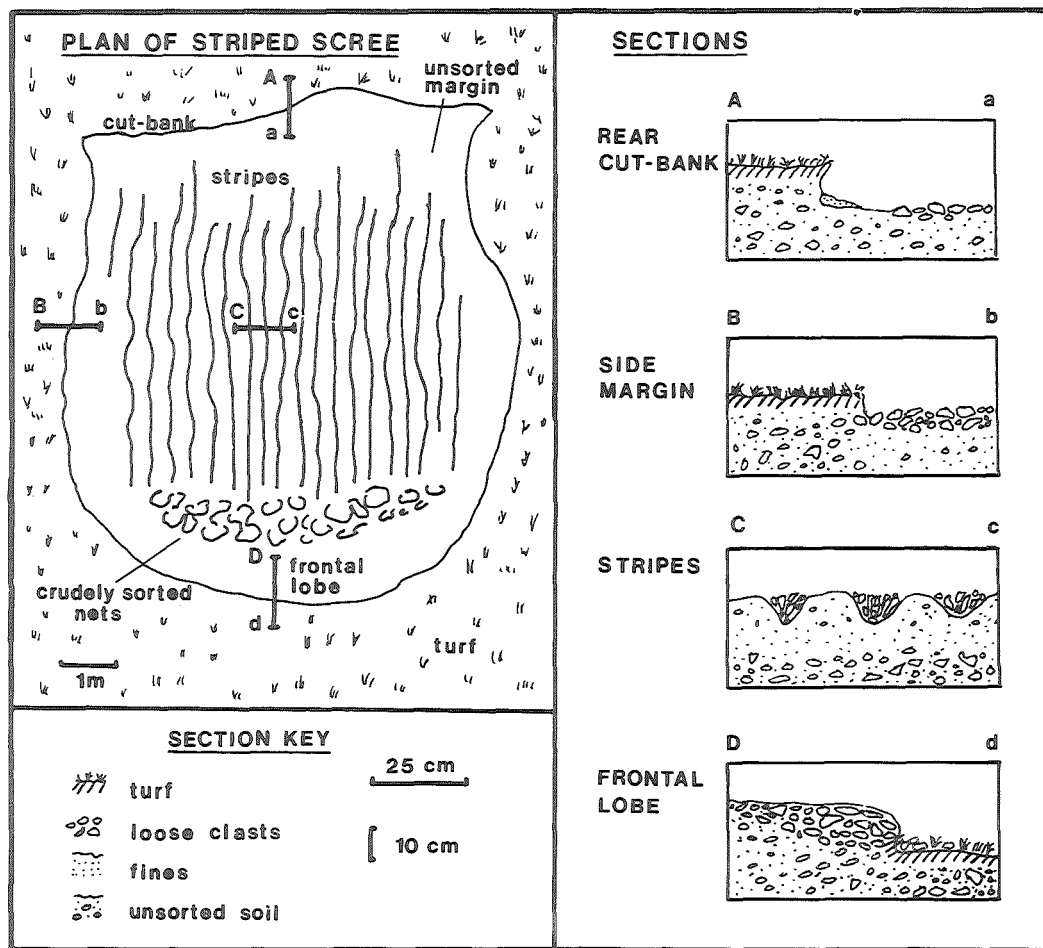


FIGURE 25 Morphology of a sorted stripe field

- (1) Stripe fields tend to be unvegetated scree slopes surrounded by turf ('Scree' is used in this context to describe the occurrence, on a slope, of an accumulation of loose stones and fines overlying bedrock).
- (2) A zone of ill-defined sorting occurs at the margin of the sorted stripe field; this is most noticeable at the head of the slope.
- (3) The lower limit of the sorted stripe field has a lobate form which appears to be advancing (Figure 25, section D-d).
- (4) The upper limit of the sorted stripe field has a cut bank form possibly maintained by wind action and erosion by sheep (Figure 25, section B-b).
- (5) Well-developed striping is confined to the central area of the scree (Figure 25, section C-c). Stripes are initiated at some point downslope from the cut bank and die out at a position just behind the frontal lobe, at which point crudely developed sorted nets may be evident. This development is thought to be associated with locally reduced slope gradient.
- (6) Striping does not normally extend beyond the area of scree (Figure 25), although turf remnants are sometimes observed along fine stripe crests (Helvellyn site 5, G.R. NY 337161).

On a smaller scale a characteristic sorted stripe profile is evident:

- (1) Sorted horizon:
 - (a) Coarse stripe gutter; many clasts being oriented vertically and some oriented downslope.
 - (b) Fine stripe ridge; few clasts some of which are oriented vertically.
- (2) Basal layer of relatively undeformed and unsorted material.
- (3) Bedrock, usually at a depth of approximately 60-100 cm.

The division between sorted and unsorted sediments is best determined by a change in clast orientation. It can also be approximated by the depth of the coarse borders or a grey discolouration of the upper mantle. Table 9 summarizes observations regarding the dimensions and material properties of Lake District sorted stripes. This emphasizes the small size of the features and the considerable variability in their dimensions and material properties.

SITE DESCRIPTIONS

Sites of sorted stripes in the Northern Lake District can be divided (on the basis of underlying lithology) into two main groups: Borrowdale Volcanics (Helvellyn sites) and Skiddaw slates (Skiddaw and Grasmoor sites). Further division into lithologic sub-sets is also possible i.e. the Kirkstile Slates of the Skiddaw group (Grasmoor sites only). All the sites described here fall within the 'frost zone' as defined by Fitzpartick (1956), although this has been shown to vary with rock type. Caine (1972) suggests a lower altitudinal limit, for sorted patterned ground, of 630 m (2080 feet) for the Borrowdale Volcanics and 675 m (2230 feet) for the Skiddaw Slates.

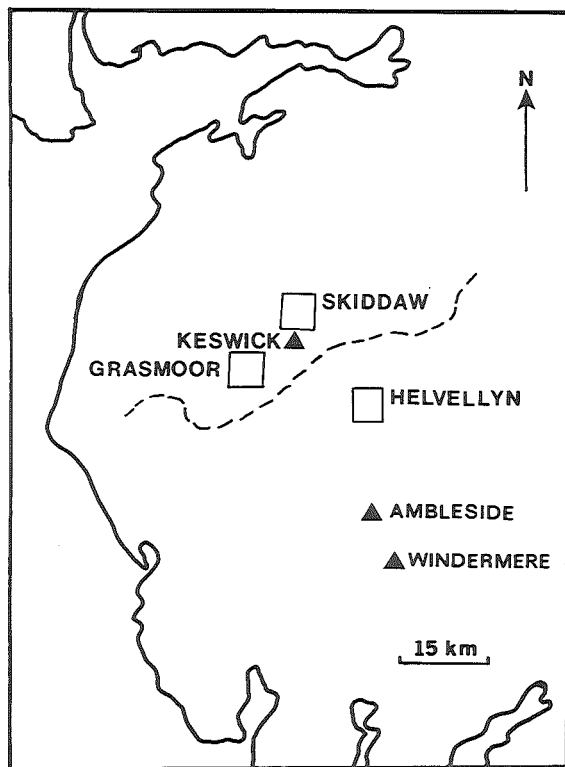


FIGURE 26a Location of study areas and the boundary (dashed line between Borrowdale Volcanics to the southeast and Skiddaw Slates to the northwest

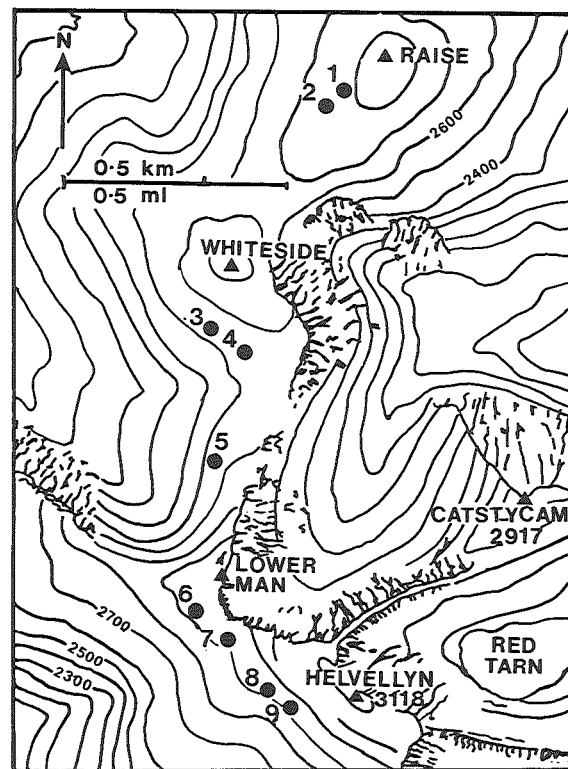


FIGURE 26b Location of sites on Helvellyn

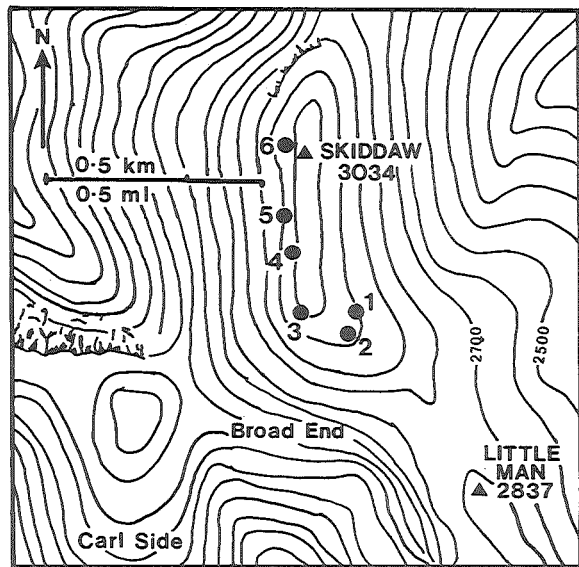


FIGURE 26c Location of sites on Skiddaw

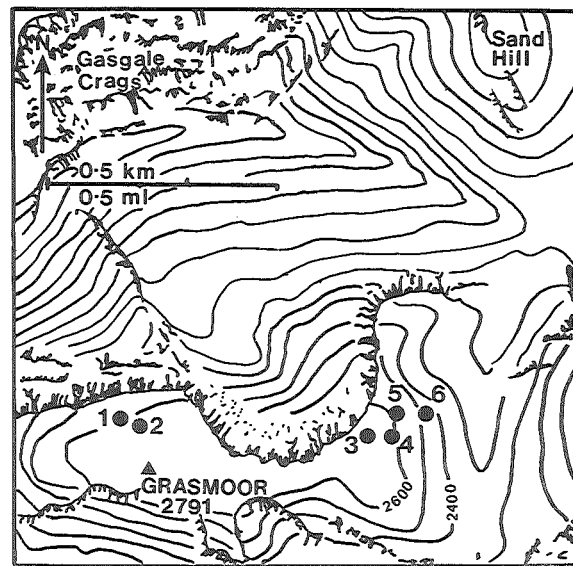


FIGURE 26d Location of sites on Grasmoor

HELVELLYN

SKIDDAW

GRASMOOR

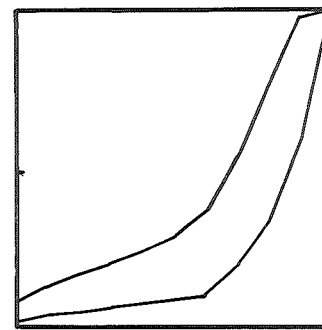
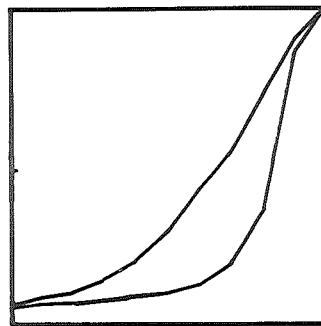
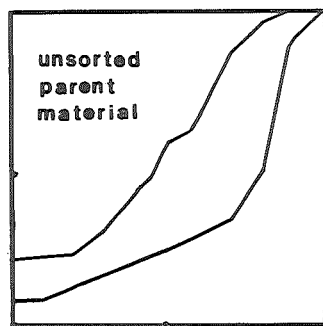
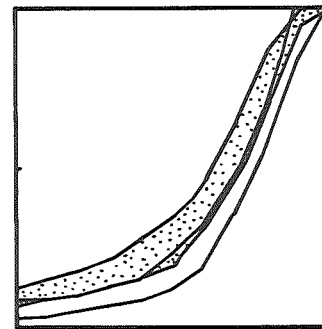
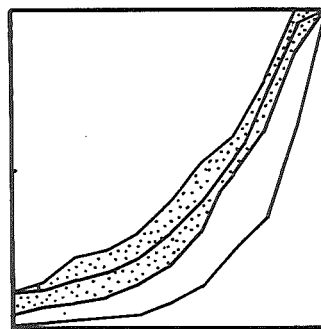
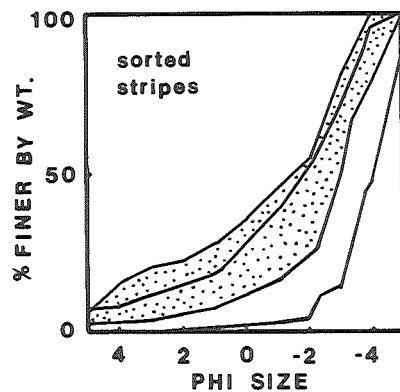


FIGURE 27 Sorted stripe grain-size distributions. Fine stripe shown by stippled shading.

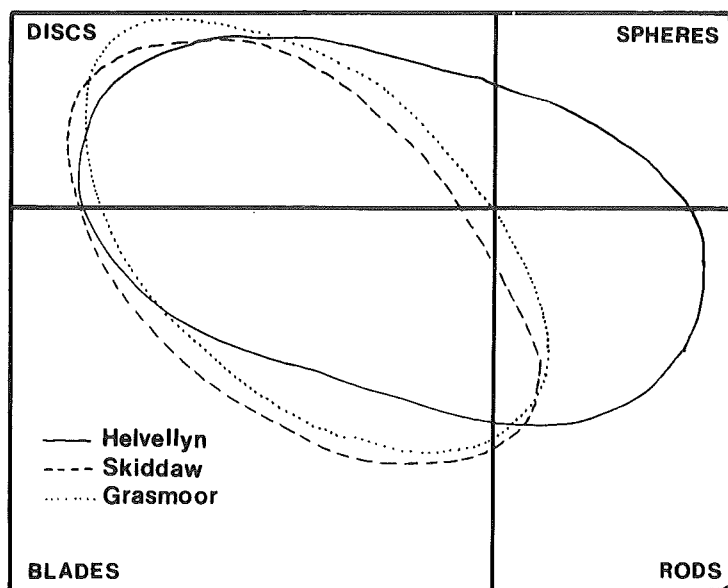


FIGURE 28 Zingg classification of coarse stripe clasts.

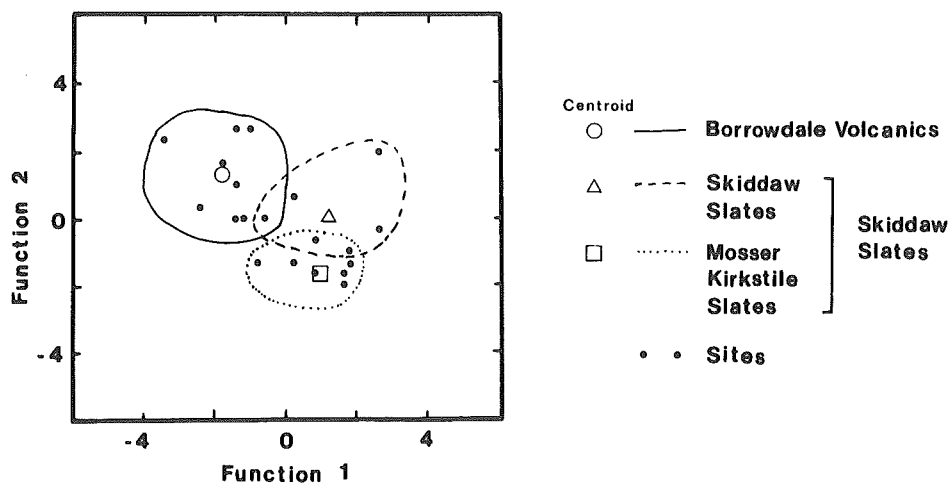


FIGURE 29 Distribution of group outlines and centroids for three groups plotted against the first two discriminant functions.

TABLE 9 MATERIAL PROPERTIES AND DIMENSIONS OF LAKE DISTRICT SORTED STRIPES

STUDY	AREA/ROCK TYPE	MATERIALS	STRIPE DIMENSIONS		
			FINE STRIPE	COARSE STRIPE	OTHER
Hollingworth (1934)	Blencathra/ Skiddaw Slates	Coarse stripe clasts 5-15 cm. Fine Stripe clasts up to 4 cm.	23-28cm wide	15-23 cm wide	13-38 cm coarse to coarse
Hay (1936)	Helvellyn/ Borrowdale Volcanics	Coarse stripe clasts up to 45 cm			33-70 cm, may be up to 100 cm
Caine (1963)	Grasmoor/Mosser Kirstile Slates (Skiddaw Slates)	Coarse stripe clasts 7-15 cm, may be up to 20 cm. Fine stripe clasts less than 2 cm.			15-20 cm coarse to coarse
Caine (1972)	Lake District/ Borrowdale Volcanics Skiddaw Slates		8-45 cm wide	5-10 cm wide	
Warburton (1982)	Helvellyn/ Borrowdale Volcanics	Coarse stripe clasts 6-13 cm. Fine stripe 3-7% less than 0.063 mm		6-13 cm deep	26.5-52 cm fine to fine
	Skiddaw/ Skiddaw Slates	Coarse stripe clasts 72-98 cm. Fine stripe 2.5-6% less than 0.063 mm		3-13 cm deep	19-34 cm fine to fine
	Grasmoor/ Mosser Kirkstile Slates Skiddaw Slates	Coarse stripe clasts 58-82 cm. Fine Stripe 4.5-7 % less than 0.063 mm		3-6 cm deep	18-27 cm fine to fine

NOTE: Original dimensions given in the Hollingworth (1934) and Hay (1936) papers have been converted from inches to centimetres.

Figure 26 shows the location of several sites in the previously defined groups. These sites serve as good examples of the range of sorted forms within any of the specific areas but are by no means comprehensive. Published data is available for sites on Skiddaw and Carrock Fell (Hollingworth, 1934), Helvellyn (Hay, 1936) and Grasmoor (Caine, 1963).

Helvellyn (Figure 26b)

All sites are underlain by Borrowdale Volcanic sequences of lavas and tuffs. Considerable local variation in lithology is apparent. Nine sites are shown; the best examples are sites 4 (338165) and 5 (337161), although all sites should be visited to see the range in features. Pattern sizes range in width (fine stripe to fine stripe) from 26.5-52 cm and depth of sorting from 6-13 cm. Variation within and between individual sorted stripe fields is evident. Silt and clay content within the fine stripes is only 3-7 percent by weight. Grain-size distribution curves (Figure 27) show a clear distinction between coarse and fine stripes although there is some overlap and a wide distribution in unsorted 'parent' materials. Clast size may be greater than 13 cm but large blocks are generally unsorted. Clast shape is variable (Figure 28), however there is a greater frequency of rounded clasts in comparison to the Skiddaw-Grasmoor samples. For the sites shown in Figure 26b slope angles vary between 9-20° and slope aspect is generally westerly (190-320°) although this is not thought to be an important factor in patterned ground development (Caine, 1972)

Skiddaw - Grasmoor (Figures 26c and 26d)

The principal lithology in this area is represented by the Skiddaw Slate group, although a lithologic sub-set, is distinguished for the Grasmoor sites. Sorted stripe fields in these areas tend to be more extensive than on the Borrowdale Volcanics and occur in a series of stepped benches separated by lobe fronts or bands of turf. The best examples are sites 1 (263286) for the Skiddaw sites and sites 1 (173205) and 2 (263285) on Grasmoor. Slope angles are comparable to the Helvellyn sites and slope aspect shows some local within group similarities (Figures 26c and 26d). This is thought to indicate a structural-topographic control on site development. Pattern width, on the Skiddaw sites, ranges from 19-34 cm and depth of sorting 3-23 cm. Grasmoor sites tend to have smaller dimensions: width 18-27 cm and depth 3-6 cm. These values contrast with the Helvellyn stripes which tend to be larger in terms of both width and depth. Silt and clay contents at the sites are comparable to the Helvellyn sites (Table 9). Figure 27 shows that the Skiddaw and Grasmoor sites have less variability in their grain-size composition and show greater segregation between fine and coarse stripes when compared to the Helvellyn distributions. Clast size also tends to be smaller on Skiddaw and Grasmoor and clast forms are more platy (Figure 28).

Since many of the differences between site groupings seem explicable in terms of lithological controls it may be hypothesized that lithology is an important factor in the production of frost-susceptible material and subsequent patterned ground development. This hypothesis has been tested by combining 5 variables (width, depth, percent silt and clay, clast roundness and clast flatness) in a multiple stepwise discriminant analysis. Results, shown in Figure 29 indicate that 3 sites were wrongly grouped. If the Skiddaw and Grasmoor sites are pooled, as the Skiddaw Slates, only one site is misclassified. This suggests that lithology may be used, as an *a priori* classification for Lake District patterned ground sites.

JW

A NOTE ON THE LOESS AROUND MORECAMBE BAY

The area around Morecambe Bay in North-West England provides an interesting example of the interaction of material, process and landform in the periglacial environment, since it is here that loess is found intimately related to nivation hollows. Loess, a silt deposit of eolian origin, has been increasingly recognised as a significant component in British soils and over the last decade or so its distribution has been described in many parts of the country (Catt, 1977).

In the northwest, it has been investigated in the area around Morecambe Bay (Vincent & Lee, 1981) where it is found in association with snow patch hollows (Vincent & Lee, 1982).

THE MORECAMBE BAY AREA

This area is characterised by a series of tilted horsts of Carboniferous limestone separated by graben of Triassic sandstones and Silurian siltstones. This gives rise to a topography of fault-scarps and rift valleys. The limestone displays some of the distinctive features of karstification modified by glaciation, in particular the development of limestone pavements. Loessic deposits can be found to a greater or lesser extent on all the limestone outcrops shown in Figure 30. On Hutton Roof (SD 555780), Farleton Fell (SD 542804) and Scout Scar (SD 487920) loess is generally thin (c 0.25 m) and patchy, although it is thicker in depressions (c 1 m). Accumulations occur on the southern end of Whitbarrow where above White Scar (SD 455850) the loess attains a maximum depth of 1.5 m in a broad south-facing amphitheatre. It reaches at least 0.75 m in thickness on the summit of Humphrey Head (SD 391738) and around 0.5 m in the Urswick area. Although the deposits are not easily mapped, their presence is indicated by the distribution of *Calluna Vulgaris* and *Pteridium aquilinum* which one would not normally expect to see growing on Carboniferous limestone.

THE LOESS OF HUTTON ROOF

Deep pockets of loess occur in many sites on Hutton Roof in the south-east of the area. These sites are generally enclosed or elongated structural depressions in the limestone. One such location (SD 555787) was examined in detail by a transect of borings (Figure 31). In the centre of the depression a pit revealed 0.70 m of buff (7.5 YR 5/6 dry) stoneless silt loam overlying a grey sandy boulder clay with abundant limestone and siltstone fragments. Five samples of the silt and two of the clay were subjected to laboratory analysis: calcium carbonate, pH, particle-size distribution. X-ray diffraction and scanning electron microscopy showed that the silt was loess and that the clay was till (Vincent & Lee, 1981. p.283).

THE SNOW PATCH HOLLOWES OF FARLETON FELL

On the northern scarp of Farleton Fell ten large hollows with distinctive topography, deposits and vegetation were found and mapped with the aid of air photographs (Figure 32). In winter the hollows hold late-lying snow delimited by distinctive loessic lips marked out by *Nardus Stricta*. They were surveyed with a pantometer and the resulting profiles (Figure 33) show the cross-sections of the hollows together with their vegetational communities and maximum depth of loess encountered. The hollows, which

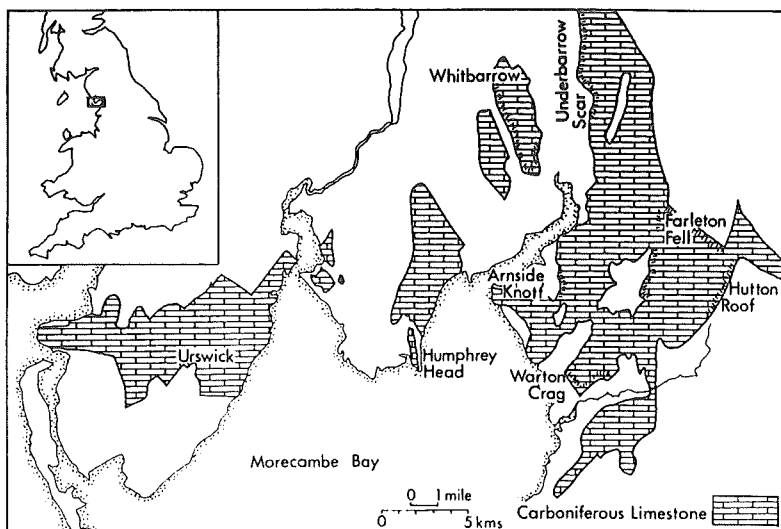


FIGURE 30 The distribution of Carboniferous Limestone around Morecambe Bay on which loess has been found.

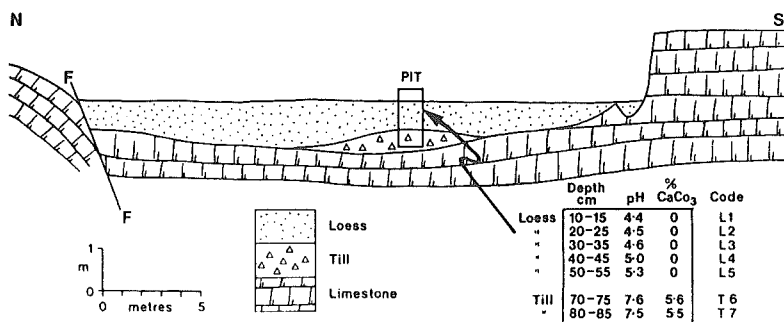


FIGURE 31 Diagrammatic section across the structural trench, Hutton Roof (SD 555787)

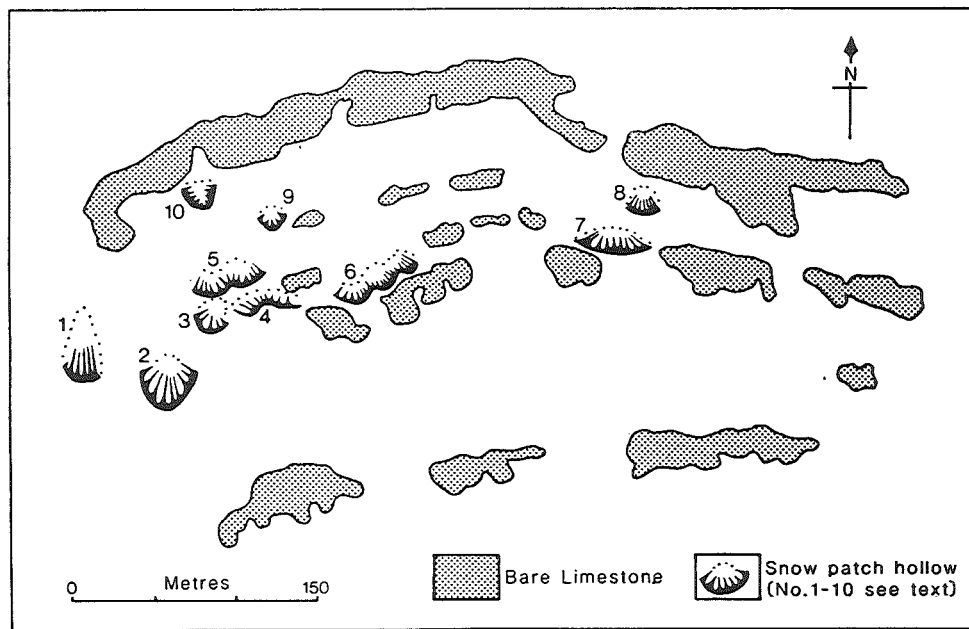


FIGURE 32 A part of the northern scarp of Farleton Fell showing ten snow patch hollows with loessic lips (dotted)

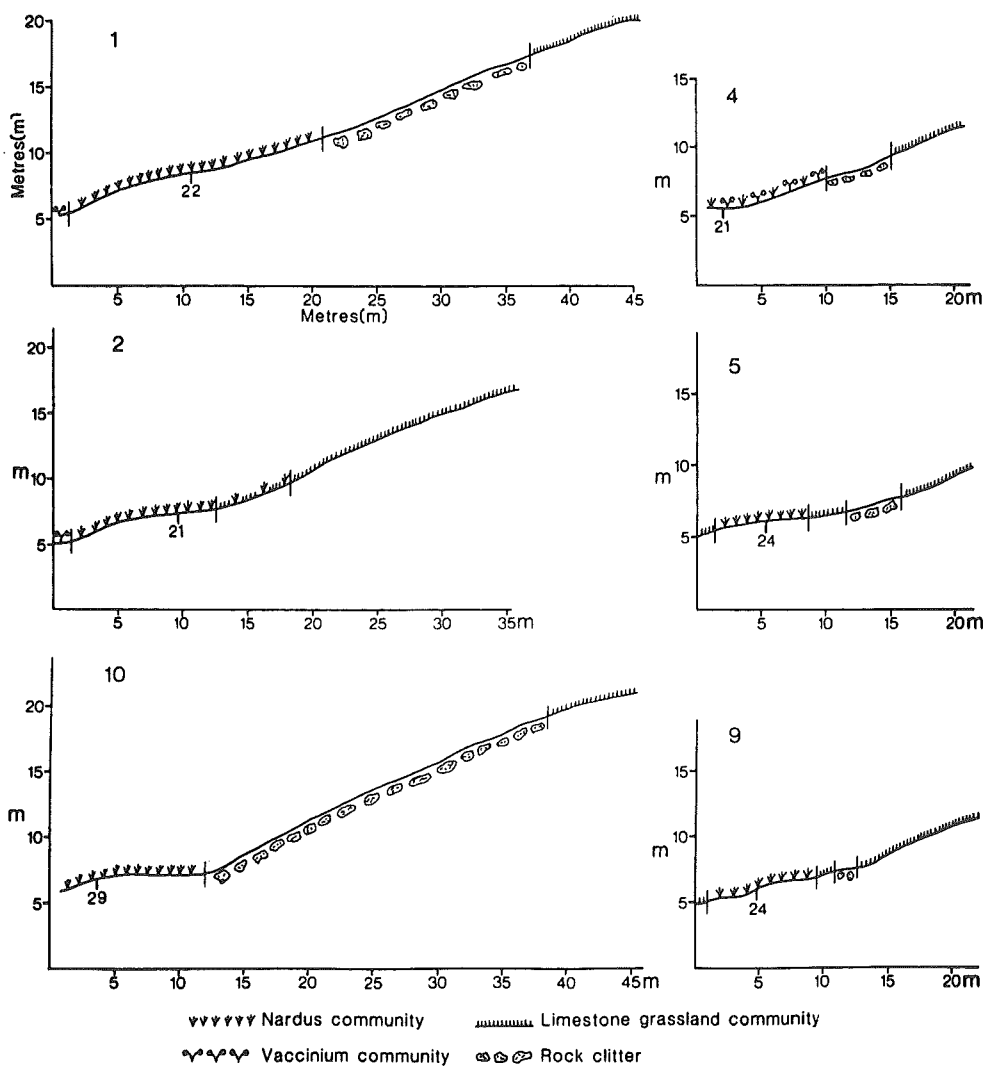


FIGURE 33 Six slope profiles across the Farleton Fell snow-patch hollows with vegetation shown diagrammatically and maximum loess depths in cm indicated on each profile

all face north, have clitter-laden backwalls whose angles vary very little around 27° in spite of the fact that the bedrock dips to the south. At the base of the limestone clitters, the slopes become more gentle and in two cases actually reverse direction on the proximal flanks of the loessic lips. The largest hollow was approximately 35 m in plan length from the top of the clitter to the crest of the lip (Vincent & Lee, 1982, p. 339).

AGE AND IMPLICATIONS

Although no direct evidence of dating is available, it seems likely that the loess is of Late Devensian age given the proximity of the area to one of the centres of glacial erosion and the relative freshness of the local limestone pavements. The relationship of loess to the hollows has implications for karst morphogenesis in general (Vincent & Lee, 1981, p. 292) and cemented screes in particular (Vincent & Lee, 1982, p. 341).

The loess around Morecambe Bay can be interpreted as the deflation product of subaerially exposed glacial sediments. These would have formed extensive outwash plains in the bay during the last deglaciation. Silt erosion, transportation and deposition by wind would then take place in a periglacial environment. It is not clear, however, if the distribution of loess is confined to the limestone areas because of preferential deposition, or lower rates of subsequent erosion, or both. The former is supported by the relationship of the loess to snow patches since wind-borne silts are effectively grounded only on moist surfaces, whilst the latter may result from the low rates of run-off and high rates of infiltration on the limestone. Once the loess has been preferentially deposited, nivation processes will have concentrated it down slope to form the distinctive apron.

MPL

PERIGLACIAL LANDFORMS AND SEDIMENTS IN THE CHEVIOTS

The Cheviot Hills straddle the England-Scotland border and present an undulating hilly terrain more akin to the Scottish Southern Uplands than the North Pennines or the Lake District. The Cheviot uplands were outside the limits of the Loch Lomond Stadial glaciation, with the possible exception of the Bizzie cirque, yet the impact of the Stadial on the landscape is considered to be significant. Clark (1970) noted some of the periglacial features in Northumberland and recognized stone-banked terraces at Auchope Cairn on the edge of the Cheviot, but in the authors' view, it is the solifluction sheets which are found in most of the upland valleys of the Cheviots as benches on the lower hillslopes which are the most noteworthy morphological expression of former periglacial activity. (We advocate the term 'solifluction sheet' rather than 'solifluction terrace', the latter having been used to describe a wide variety of forms). These solifluction sheets are similar in scale to those recognised elsewhere in upland Britain e.g. in mid-Wales (Watson, 1970; Potts, 1971) and the Isle of Man (Thomas, 1976). In the Cheviots, these features have been mapped as glacial boulder clay by the Geological Survey although they contain significant thicknesses of head and soliflucted till. Such slope forms and associated deposits can be seen as characteristic of upland valleys where landforms of the valley glacier landform-sediment association have been subject to solifluction. Thus the lack of constructional landforms in the Cheviots may be testimony to the efficiency of solifluction on frost-susceptible materials.

The sites described below all illustrate these solifluction sheets to some degree as well as associated landforms. Figure 34 shows their location within the Cheviot uplands.

LINHOPE AND STANDROP: PERIGLACIAL SEDIMENTS AND TORS

These sites lie on the southern flank of Hedgehope Hill which is situated in the centre of the Cheviot granite intrusion (Figure 34). Hill peat masks much of the upper slopes and drift the lower ones. Bedrock is rarely exposed except in the great Standrop and Little Standrop tors and along some stream beds. Several instances of deep weathering of the granite have been recorded from the area (Clapperton, 1967). The waterfall, Linhope Spout, has formed where the Linhope Burn cascades over a resistant felsite dyke. Some 100m above Linhope Spout, on the north side of the Burn, is one of the best sections in the periglacial deposits in the area with up to 9m of drift exposed (NT 958172). Many of the details of this section were recorded by Douglas and Harrison (1984).

The section lies at 300m OD and represents the downslope thickening of bedded periglacial sediments. The full section is slightly arcuate and affords near strike sections at the upstream end and near dip sections downstream. Figure 35c shows the dip section and the way in which the bedding parallels the 8° hillslope. At stream level, unit A is a massive, stiff till, matrix-supported and with a significantly higher proportion of silt and clay (29% of 2mm fraction) than the overlying soliflucted material. Some large clasts within the till exhibit a typical subglacial 'flatiron' shape and have striated facets (Boulton, 1978). The upper surface of unit A is planar and characterised by a zone of seepage from the more permeable beds above. These beds can be divided into units B-E according to their structure. All are very sandy, although unit D contains large sub-rounded boulders of granite up to 70cm in diameter and unit E is rather more stony

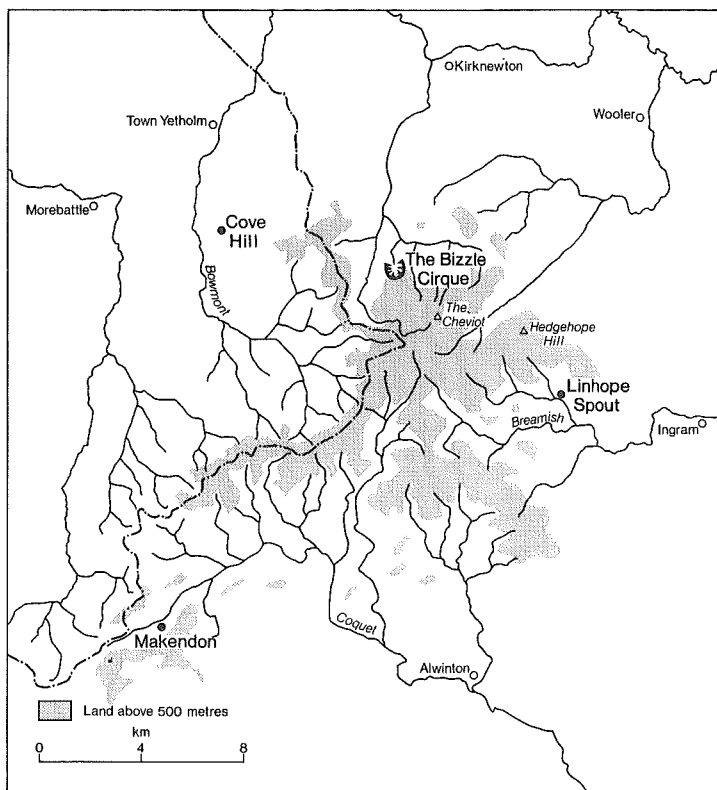


FIGURE 34 Location map of Cheviot sites

and is strongly cemented. All these units are interpreted as being the product of solifluction, but some of the banding in the better sorted layers may be the result of slopewash under snowmelt conditions. The 6m of solifluctate which overlies the till is probably derived from more than one source. Very little of the material is angular and it seems unlikely that much was derived from gelifraction of in situ bedrock. The occurrence of a few striated pebbles strongly suggests that a proportion of the solifluctate is derived from the re-working of till, whereas much of the material has the appearance of growan and can be seen as the product of solifluction acting on the weathered mantle. It is noteworthy that this element is not present in solifluction derived from other bedrock lithologies in the area. A veneer of sandy solifluctate often over 1m thick blankets many of the lower slopes on the Cheviot granite and undoubtedly contributes to the smooth morphology.

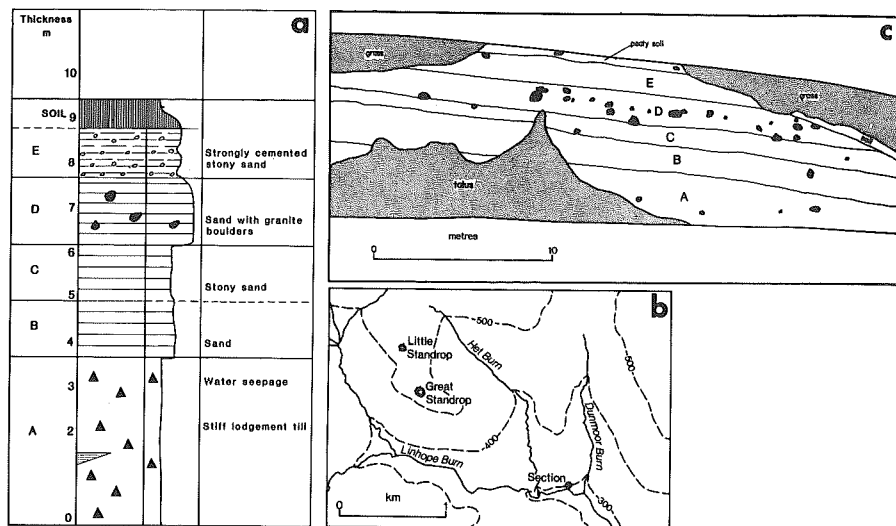


FIGURE 35 Linhope and Standrop: a, Log of Linhope section; b, Location map; c, Linhope Burn section.

Although not immediately upslope from the Linhope section, the tors of Great and Little Standrop can be related to downslope mantles of periglacially derived debris. Both tors occur at an altitude of 540m on Standrop Rigg, a ridge running south from Hedgehope Hill. Clapperton (1967) recognised at least 11 well-defined tors in the Cheviot massif developed on both granite and andesite. The Standrop tors are entirely of granite. No clitter can be readily observed in their vicinity, but the smoothed slopes below them appear to be underlain by a veneer of solifluctate similar to that described in the Linhope section. The large granite boulders in that section can be interpreted as corestones. The apparent absence of surface debris led Clapperton (1967) to consider that the tors probably survived glaciation, although this now seems unlikely given the volume of solifluctate occurring above the till at Linhope Spout which would have been swept off the higher slopes during the periglacial phase which followed the disappearance of Late Devensian ice.

MAKENDON: SOLIFLUCTION SHEET AND SECTION

This site is located 800m downstream from the farm at Makendon in the upper reaches of the Coquet River on a northwest facing slope at 330m OD (Figure 34). The section cuts into the base of the drift surface at right angles to the river. The bedrock exposed at the bottom of the section consists of Silurian shales and greywackes. The drift surface lies at an average angle of 14° and is 90m wide (Figure 36). Fluvial incision has created the 'terrace' form and the valley cross profile is markedly asymmetric. A maximum thickness of 8m of sediments is exposed.

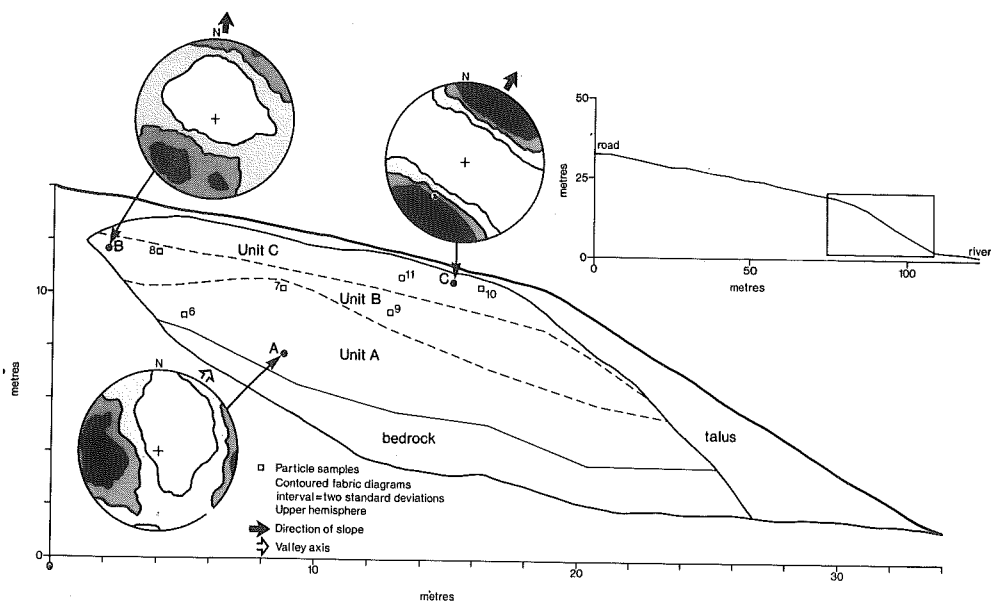


FIGURE 36 Makendon: section

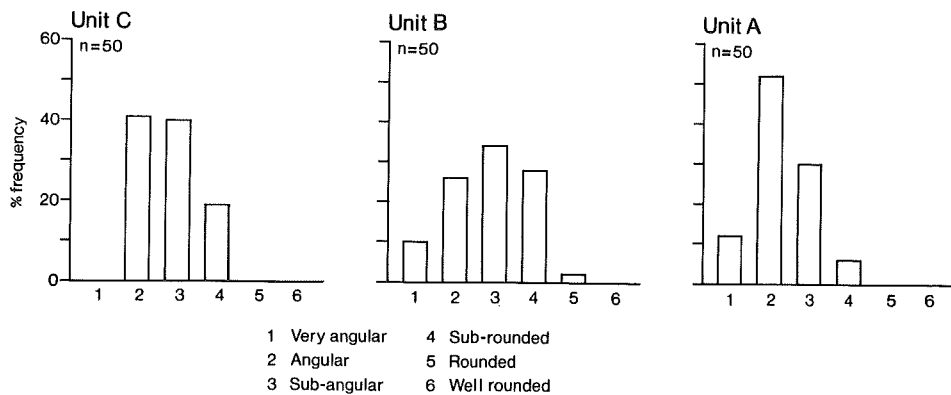


FIGURE 37 Makendon: clast roundness values

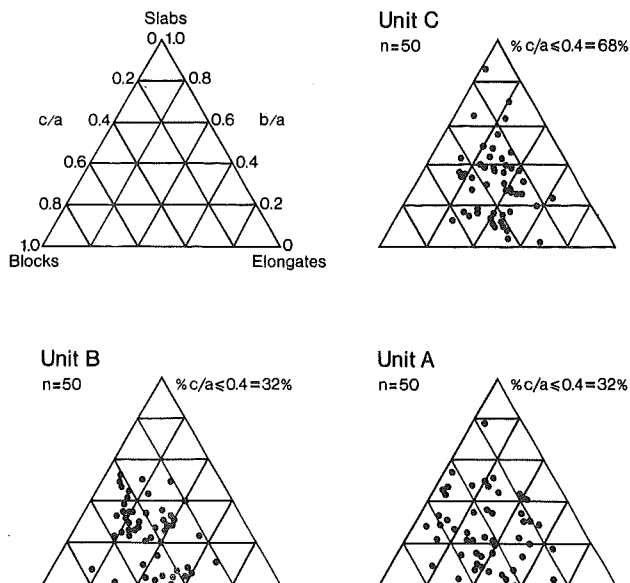


FIGURE 38 Makendon: clast shape

Three stratigraphic units parallel the drift surface (Figure 36). Bedrock outcrops at the base of the section. The upper part is heavily shattered and weathered. Unit A is up to 5m thick and consists of numerous clasts, some of which are striated, set in a silty-clay matrix. Fabrics show a moderately strong downvalley orientation (Figure 36).

Unit B, which is up to 2.5m thick, is characterised by a silty matrix and shows crude stratification. Although most clasts are sub-angular, a considerable range of roundness values exists (Figure 37). The orientation of clasts within the unit is predominantly downslope. Overlying unit B is a distinct deposit 1.5m in thickness. Unit C contains angular clasts in a tenacious silty-sand matrix. The preferred orientation of the clasts is strongly downslope. A crude stratification is evident and no striated clasts have been found.

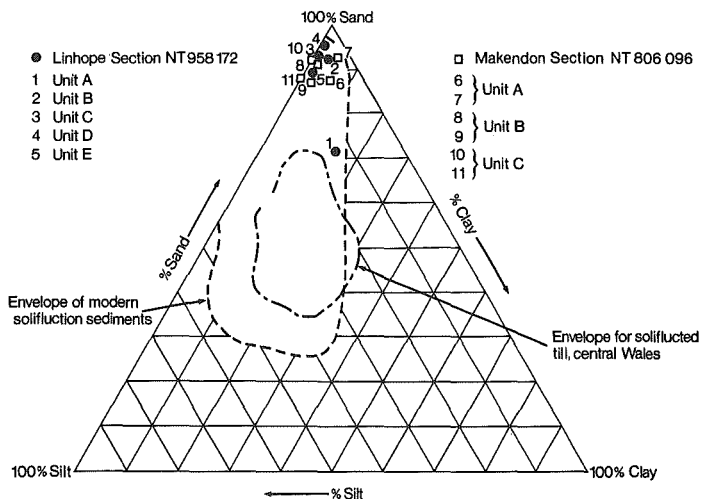


FIGURE 39 Textural properties of Cheviot sediments

Particle size, clast form and roundness characteristics of the three units are shown in Figures 37, 38 and 39.

Similarities between the clast-form characteristics of units A and B and the occurrence of striated and faceted boulders in both units suggest that they are derived from the same material. Differences are observed, however, by comparing the clast roundness data. Units A and B are shown to be significantly different with unit B showing a greater spread of values. This is interpreted as being the result of edge-rounding of clasts during movement subsequent to initial deposition. This hypothesis is borne out by the fabric diagrams. As a result unit A is interpreted as an in situ till while unit B is a till which has been subject to solifluction. Clast form characteristics for unit C which show low c/a values are typical of frost-shattered material (Ballantyne, 1982). However, evidence of edge-rounding and strong downslope fabrics for this unit suggest that these clasts have undergone gelifraction and have subsequently been soliflucted downslope.

The textural properties of the sediments are shown in figure 39. Although these lie within the envelope for modern soliflucted sediments (after Harris, 1981), they are noticeably more sandy than those reported for soliflucted tills in central Wales. At Linhope, this may be explained by the high proportion of weathered bedrock (growan) in the solifluctates. At Makendon, however, the local in situ till (unit A) is very sandy and the texture of the soliflucted till simply reflects this.

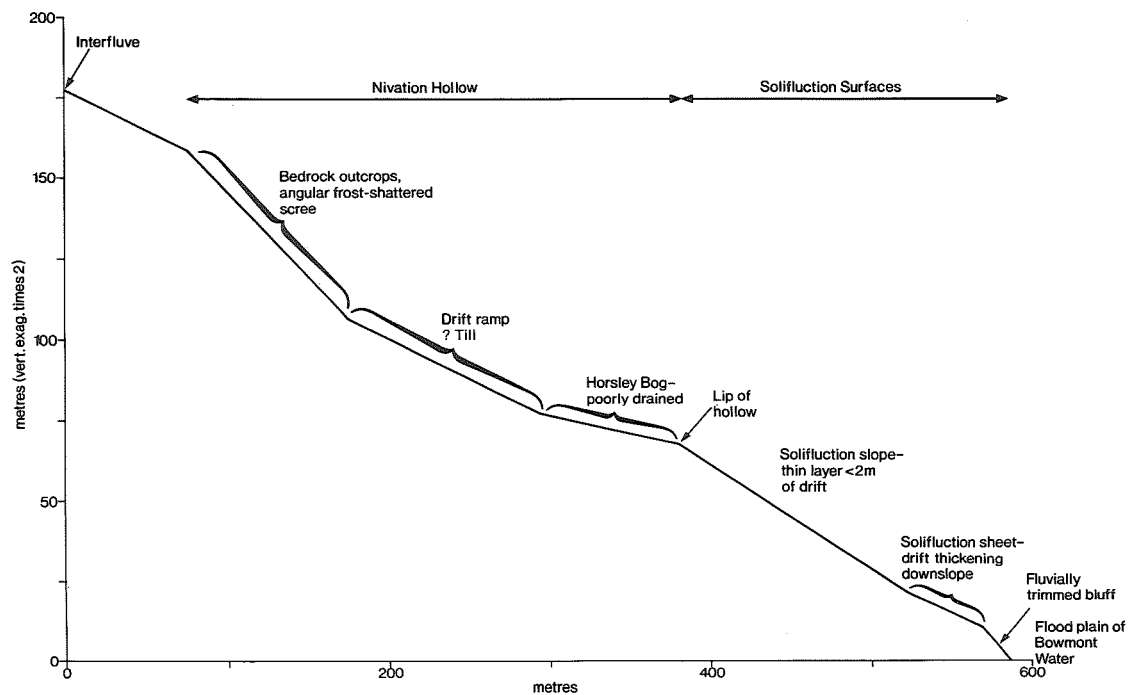


FIGURE 40 Cove Hill: surveyed profile

COVE HILL: 'NIVATION HOLLOW' AND SOLIFLUCTION SLOPE

This site is located on the west facing side of Cove Hill, 4km south of Town Yetholm in the valley of Bowmont Water, Scottish Borders (NT 817238). Figure 40 shows a slope profile surveyed through the centre of a prominent hollow. The appearance of this hollow or cove which is about 150m broad corresponds to the 'circular nivation hollow' of Lewis' (1939) classification. However, this feature is almost certainly polygenetic as is demonstrated by the distribution and range of sediments and forms within and downslope from the hollow. Figure 40 shows that the hollow contains a smooth ramp underlain by drift. This slopes at an angle of about 12° and occupies the southern flank of the hollow. Augering has indicated that it consists of till and this can be interpreted as deposition on a lee slope with respect to the trend of ice movement northwards down the Bowmont Valley. This direction has been established from the distribution of drift tails and drumlins.

The steeper back wall of the hollow which is set at an angle of about 32° , shows outcrops of bedrock and frost-shattered scree. Bounding the hollow to the west is a clearly defined lip, below which extends a smooth slope underlain by soliflucted debris. These deposits thicken downslope to produce the characteristic bench feature typical of these valleys (Douglas & Harrison, 1984).

TD, SH

REFERENCES

- Andrews, J T (1961) The development of scree slopes in the English Lake District and central Quebec - Labrador Cahiers Geogr. de Quebec 5, 219-230
- Ball, D F (1966) Late glacial scree in Wales Biul. Perygl. 15, 151-163
- Ball, D F and Goodier, R (1970) Morphology and distribution of features resulting from frost action in Snowdonia Fl. Studies 3(2), 193-218
- Ballantyne, C K (1982) Aggregate clast form characteristics of deposits near the margins of former glaciers in the Jotunheimen Massif, Norway Norsk Geogr. Tidsskrift 36(2), 103-113
- Ballantyne, C K (1984) The Late Devensian periglaciation of Upland Scotland Quat. Sci. Revs. 31, 311-343
- Ballantyne, C K and Kirkbride, M (In press) The characteristics and significance of lateglacial protalus ramparts in upland Britain
- Barsch, D (1977) Nature and importance of mass-wasting by rock glaciers in Alpine permafrost environments Earth Sur. Proc. 2, 231-245
- Behre, C H (1933) Talus behaviour above timber in the Rocky Mountains J. Geol. 41, 622-635
- Blagborough, J W and Breed, W J (1967) Protalus ramparts on the Navajo Mountains Southern Utah Am. J. Sci. 265, 762-772
- Boardman, J (1977) Stratified screes in the northern Lake District Proc. Cumbs. Geol. Soc. 3 (4), 233-237
- Boardman, J (1977a) Investigating screes: an example from Cumbria Brighton Polytechnic Geog. Soc. Mag. 2, 7-16
- Boardman, J (1978) Grèze litées near Keswick, Cumbria Biul. Perygl. 27, 23-34
- Boardman, J (1981) Quaternary geomorphology in the northeastern Lake District. Unpublished PhD thesis, University of London
- Boardman, J (1982) Glacial geomorphology of the Keswick area, northern Cumbria Proc. Cumbs. Geol. Soc. 4(2), 115-134
- Boulton, G S (1978) Boulder shapes and grain-size distributions of debris as indicators of transport paths through a glacier and till genesis Sedimentology 25, 773-799.
- Bryant, R D (1983) The utilization of Arctic river analogue studies in the interpretation of periglacial river sediments from southern Britain. In, Gregory, K J Background to Palaeohydrology, a Perspective (ed. K J Gregory) Wiley, Chichester.

- Bull, W B (1977) The alluvial fan environment Prog. Phys. Geogr. 1, 222-270
- Burgess, I C and Wadge, A J (1974) The geology of the Cross Fell area
Institute of Geological Sciences, HMSO, London
- Cailleux, A (1945) Distinction des galet marines et fluviatiles
Bull. Soc. Geol. France 5, 375-404
- Caine, T N (1962) The effect of frost action on low angled scree slopes and sorted stripes in the Lake District. Unpublished M.A. Thesis, University of Leeds
- Caine, T N (1963) The origin of sorted stripes in the Lake District, Northern England. Geogr. Annlr. 45A, 172-179
- Caine, T N (1972) The distribution of sorted patterned ground in the English Lake District. Revue de Geomorphologie dynamique 21(2), 49-56
- Catt, J A (1977) Loess and coversands. In, British Quaternary Studies, Recent Advances (F W Shotton ed.) Clarendon Press, Oxford, pp. 221-230
- Chuan, G K and Lockwood, J G (1974) An assessment of topographic controls on the distribution of rainfall in the central Pennines
Met. Mag 103, 275-287
- Clapperton, C M (1967) The deglaciation of the East Cheviot area, Northumberland. Unpublished PhD thesis, Edinburgh University
- Clark, R (1970) Periglacial landforms and landscapes in Northumberland
Proc. Cumberland Geol. Soc. 3(1) 5-20
- Colhoun, E A (1981) A protalus rampart from the Western Mourne Mountains Northern Ireland Irish Geog. 14, 85-90
- Coope, G.R. (1977) Quaternary coleoptera as aids in the interpretation of environmental history. In, British Quaternary Studies, Recent Advances (F.W. Shotton ed.) Clarendon Press, Oxford, pp. 55-68
- Corte, A E (1976) Rock Glaciers Biul. Perygl. 26, 175-197
- Dakyns, J R, Tiddeman, R H, Russell, R, Clough, C T and Strachan, A (1891) The geology of the country around Mallerstang with parts of Wensleydale, Swaledale and Arkendale Mem. geol. surv. U.K.
- Derbyshire, E (1973) Periglacial phenomena in Tasmania Biul. Perygl. 22, 131-148
- Derbyshire, E and Gregory, K J (1979) Geomorphological Processes Dawson
- Dingwall, P R (1972) Erosion by overland flow on a Alpine debris slope. In, Mountain Geomorphology (O. Slaymaker and H J MacPherson eds.) Tantalus, Vancouver
- Douglas, T D and Harrison, S (1984) Solifluction sheets - a review and case study from the Cheviot Hills Newcastle upon Tyne Polytechnic Occasional Series in Geography, No. 7

- Dvlik, J (1960) Rhythmically stratified slope waste deposits Biul. Pergl. 8. 31-41
- Eddy, A, Welch, D and Rawes M (1969) The vegetation of the Moor House National Nature Reserve in the northern Pennines, England Vegetatio 16, 239-284
- Eugene, R (1974) Geomorphology of the east flank of the Crazy Mountains Montana. Unpublished PhD Thesis, University of Montana
- Ferguson, R S (1889) Description of the County of Cumberland by Sir Daniel Fleming of Rydal, A.D. 1671 Cumb. West. Ant. Arch. Soc. Tract series 3
- Fitzpartick, E A (1956) Progress report on observations of periglacial phenomena in the British Isles. Biul. Perygl. 4, 99-115
- Gray, J M (1982) The last glaciers (Loch Lomond Advance) in Snowdonia N Wales Geol. J. 17, 111-133
- Guillien, Y (1964) Les grèze litées de Charante Rev. Geog. des Pyrenees et du Sud-Ouest 22, 154-162
- Harris, C (1981) Periglacial mass-wasting: a review of research BGRG Research Monograph 4, Geo Books
- Hay, T (1936) Stone stripes. Geogr. J. 87, 47-50
- Hay, T (1937) Physiographic notes on the Ullswater area Geogr. J. 90, 426-444
- Hay, T (1942) Physiographic notes from Lakeland Geogr. J. 100, 165-173
- Hay, T (1943) Notes on glacial erosion and stone stripes Geogr. J. 103, 13-20
- Hollingworth, S E (1934) Some solifluction phenomena in the northern Part of the Lake District Proc. Geol. Ass. 45, 167-188
- Hooke, R L (1967) Processes on arid region alluvial fans J. Geol. 75, 438-460
- Howarth, P J and Bones, J G (1972) Relationships between process and geometrical form on High Arctic debris slopes, south-west Devon Island, Canada Inst. Brit. Geogr. Spec. Pub. 4, 139-153
- Institute of Geological Sciences (1972) Geological Special Sheet (Solid & Drift) Cross Fell Inlier 1:25,000
- Jackson, D (1978) The Skiddaw Group. In, The Geology of the Lake District (F. Moseley ed.) Yorks. Geol. Soc. Occ. Pub. 3, pp 79-98
- Jahn, A (1960) Some remarks on evolution of slopes on Spitzbergen Zeit. fur Geomorph. 1, 49-58
- Johnson, G A L and Dunham, K C (1963) The geology of Moor House Mono. Nat. Cons. 2

- Johnson, P G (1978) Rock glacier types and their drainage systems Grizzly Creek Yukon Territory Can. J. Earth Sci. 15 (9), 1496-1507
- Johnson, P G (1983) Rock glaciers a case for a change in the nomenclature Geogr. Annlr. 65A, 27-34
- Johnson, R H (1975) Some late Pleistocene involutions at Dalton-in-Furness, northern England Geogr. J. 10(1), 23-34
- Judson, S (1949) Rock-fragment slopes caused by past frost-action in the Jura Mountains (Ain) France J. Geol. 57. 137-142
- Karczewski, A. Kostrzewski, A and Marks, L (1981) Morphogenesis of subslope ridges to the north of Spitzbergen Polish Polar Research 2 (1-2), 29-38
- Karte, J (1983) Periglacial phenomena and their significance as climatic and edaphic indicators Geojournal 7, 4, 329-340
- Kotarba, A and Stromquist, L (1984) Transporting sorting and deposition processes of alpine debris slope deposits in the Polish Tatra Mountains Geogr. Annlr. 66A, 258-294
- Letzer, J M (1978) The glacial geomorphology of the region bounded by Shap Fells, Stainmore and the Howgill Fells in East Cumbria. Unpublished M.Phil thesis, University of London.
- Lewis, C A (1966) The nivational landforms and the reconstructed snowline of Slaettartinour Faeroe Islands Biul. Perygl. 15, 293-302
- Lewis, W V (1939) Snow-patch erosion in Iceland. Geogr. J. 94, 163-161
- Lowe, J J & Walker, M J C (1984) Reconstructing Quaternary Environments Longman
- Mackay, J R (1979) Pingos of the Tuktoyaktak peninsula area, Northwest Territories Geog. phys. Quat. 33, 3-61
- Manley, G (1936) The climate of the Northern Pennines: the coldest part of England Q. J. Roy. Met. Soc. 62, 103-115
- Manley, G (1942) Meteorological observations on Dun Fell, a mountain station in Northern England Q. J. Roy. Met. Soc. 68, 151-165
- Manley, G (1949) The snowline in Britain Geogr. Annlr. 31, 179-193
- Manley, G (1951) The range of variation of the British climate Geogr. J. 117, 413-468
- Manley, G (1959) The late-glacial climate of north-west England. Liv. Man. Geol. J. 2(2), 188-215
- Manley, G (1971) The mountain snows of Britain Weather 26(5), 192-200
- Manley, G (1973) Climate. In, The Lake District (W H Pearsall and W Pennington eds.) Collins

- Manley, G (1975) Weather and Climate of the Lake Counties. In, The Lake District National Park HMSO
- Marr, J E (1916) The ecology of the Lake District Cambridge University Press
- Pearsall, W H and Pennington, W (1973) The Lake District Collins, London
- Pemberton, M (1980) Earth hummocks at low elevation in the Vale of Eden, Cumbria Trans. Inst. Brit. Geogr. New Series 5, 487-501
- Pennington, W (1978) Quaternary geology. In, The Geology of the Lake District (F. Moseley ed.) Yorks. Geol. Soc. Occ. Pub. 3, 207-225
- Penny, L F, Coope, G R and Catt, J A (1969) Age and insect fauna of the Dimlington Silts, east Yorkshire Nature 224, 65-67
- Phillips, J (1836) Illustrations of the Geology of Yorkshire. Part II The Mountain Limestone John Murray, London
- Potts, A S (1971) Fossil cryonival features in central Wales Geogr. Annlr. 53A, 39-51
- Raistrick, A (1926) The glaciation of Wensleydale, Swaledale and adjoining parts of the Pennines Proc. Yorks. Geol. Soc. 20, 366-410
- Ramsbotham, W H C (1974) The Namurian. In, The Geology and Mineral Resources of Yorkshire (eds. D H Rayner and J E Hemmingway) Yorks. Geol. Soc. pp 73-87
- Rapp, A (1960) Recent development of mountain slopes in Karkevagge and surroundings, northern Scandinavia Geogr. Annlr. 42, 65-200
- Rapp, A (1984) Nivation hollows and glacial cirques in Soderasen Scania Geogr. Annlr. 66A, 11-28
- Ridge, T S (1980) Glacial Lake Whicham: a former ice-dammed lake in the Whicham valley, Cumbria. Unpublished MSc thesis, Polytechnic North London and City of London Polytechnic
- Rose, J (1980) Landform development around Kisdon, Upper Swaledale, Yorkshire Proc. Yorks. Geol. Soc. 43, 201-219
- Rose, J (1980a) In, Jardine (ed) Quaternary Research Association Field Guide Glasgow Region Quaternary Research Association p.37
- Ryder, J M (1971) Some aspects of the morphometry of paraglacial alluvial fans in south central British Columbia Can. J. Earth Sci. 8, 1252-4
- Sekine, K (1973) Mechanism of the formation of a protalus rampart at the bottom of the so-called Kuranosuke glacial cirque Japanese Alps Geogr. Rev. Japan 46(4), 265-273
- Sissons, J B (1976) A remarkable protalus rampart complex in Wester Ross Scott. Geog. Mag. 92, 182-190

- Sissons, J B (1979) The Loch Lomond Stadial in the British Isles Nature 280, 199-203
- Sissons, J B (1980) The Loch Lomond Advance in the Lake District, northern England Trans. Roy. Soc. Edin. Earth Sci. 71, 13-27
- Smith, H T U (1973) Photogeological study of periglacial talus glaciers in Northwestern Canada Geogr. Annlr. 55A, 69-84
- Sneed, E D and Folk, R L (1958) Pebbles in the lower Colorado River, Texas: a study in particle morphogenesis Jour. Geol. 66, 114-150
- Sugden, D E (1971) The significance of periglacial activity on some Scottish mountains Geogr. J. 137, 388-392
- Sutherland, D G, Ballantyne, C K, and Walker J C (1984) Late quaternary glaciation and environmental change on St Kilda Scotland and their palaeoclimatic significance Boreas 13, 261-272
- Sweeting, M (1972) Karst Landforms Macmillan, London
- Swett, K, Hambrey, M J and Johnson D (1980) Rock glaciers in Northern Spitzbergen J. Geol. 88, 465-482
- Thomas, G S P (1976) The Quaternary stratigraphy of the Isle of Man Proc. Geol. Ass. 87(3), 307-323
- Tricart, J (1970) Geomorphology of Cold Environments Translated E. Watson, Macmillan
- Tufnell, L (1969) The range of periglacial phenomena in Northern England Biul. Perygl. 19, 291-232
- Tufnell, L (1971) Erosion by snow patches in the north Pennines Weather 26(11), 492-498
- Tufnell, L (1972) Ploughing blocks with special reference to north-west England Biul. Perygl. 21, 237-270
- Tufnell, L (1975) Hummocky microrelief in the Moor House area of the northern Pennines, England Biul. Perygl. 24, 353-368
- Tufnell, L (1976) Ploughing block movements on the Moor House Reserve (England), 1965-75 Biul. Perygl. 26, 311-317
- Tufnell, L (1978) Studies of periglacial phenomena on the Moor House National Nature Reserve and surrounding areas. Unpublished PhD thesis, University of Newcastle-upon-Tyne
- Vincent, P J and Lee, M P (1981) Some observations on the loess around Morecambe Bay, North-West: England. Proc. Yorks. Geo Soc. 43(3), 281-194
- Vincent, P J and Lee, M P (1982) Snow patches on Farleton Fell, South-East Cumbria Geogr. J. 148(3), 337-342

- Walker, D (1955) Late glacial deposits at Lunds Yorkshire New Phytol. 54, 343-9
- Warburton, J (1982) A study of patterned ground in the English Lake District Unpublished B.Sc. Dissertation, University college of Wales, Aberystwyth
- Ward, C (1873) The glaciation of the northern part of the Lake District Q. J. Geol. Soc. Lond. 29, 422-441
- Ward, J C (1875) The origin of some of the lake-basins of Cumberland Q. J. Soc. Lond. 30, 152-166
- Washburn, A L (1973) Periglacial Processes and Environments Edward Arnold
- Washburn, A L (1979) Geocryology. A survey of periglacial processes and environments Edward Arnold
- Wasson, R J (1979) Stratified debris slope deposits in the Hindu Kush Pakistan Zeit. Fur Geomorph. 23, 301-320
- Watson, E (1965) Grèze litées ou eboulis ordonnées tardiglaciaires dans la région d'Aberystwyth au centre de Pays de Galles Bull. Ass. Geog. Fr. 338-9, 16-25
- Watson, E (1966) Two nivation cirques near Aberystwyth Wales Biul. Perygl. 15, 79-101
- Watson, E (1970) The Cardigan Bay Area. Chapter 6 In, The glaciations of Wales and adjoining regions (ed. C A Lewis), Longman pp. 125-146
- White, S E (1976) Rock glaciers and block fields: review and new data Quat. Res. 6, 77-97
- Wilkinson, T J (1972) Downslope sequences of sediment transport and deposition on High Arctic slopes. Unpublished MSc thesis, McMaster University, Canada
- Williams, H B (1957) Flooding characteristics of the River Swale. Unpublished PhD thesis, University of Leeds.