PL ISSN 00697-038

J. L. McArthur*
Palmerston North

PERIGLACIAL SLOPE PLANATIONS IN THE SOUTHERN PENNINES, ENGLAND

Abstract

An examination of the morphology and regolith characteristics of valley-side benches and their bounding slopes in the upper Derwent basin demonstrates that the benches are periglacial slope planations exhibiting strong structural control. They are best developed against the dip but occur also along the strike of the alternating hard and soft rocks. During periglacial times, the congelifractate from the retreating sandstone or gritstone escarpments together with the products of corrasion of the predominantly shale planations beneath them were transported towards the valley axes and at least in some cases down-valley by solifluction. At some time during the development of the slope planations stream incision occurred, truncating the distal portions of the slope planations and converting them to benches.

INTRODUCTION

The topography of the southern Pennines is striking for the ubiquity of summit plateaus and valley-side benches. It has been customary to interpret these as indicative of still-stands of base-level (Linton, 1956; Johnson and Rice, 1961) during which predominantly humid-temperate ('normal') processes have operated to widen valleys and lower relief (Young, 1963). On the basis of such postulates, the *planation surface* whose remnants are most extensive in the present-day landscape has been named the Upland Surface and is represented mainly by the limestone plateau of Derbyshire (Linton, 1956). Valley-side benching in the headwater region of the River Derwent and *erosion surfaces* (= planation surfaces) on the western flank of the Pennines have been correlated with this feature (Linton, 1956; Johnson and Rice, 1961). Such interpretation has not found universal acceptance. Pitty (1968), for example, has shown that the limestone plateau may be a structural feature and Palmer and Radley (1961) have argued for a periglacial origin for some valley-side features.

This account and disscusion of land form in the headwater region of the River Derwent aims to demonstrate that the valley-side benches of the southern Pennines are the product of late Pleistocene cryergy operating in the presence of gently-inclined, clastic sedimentary rocks. Such a conclusion and remarks concerning the relationship between such benches and adjacent slope elements are based on an examination of the morphology and associated regolith characteristics of selected slope profiles traversing several benches.

* Massey University, Department of Geography, Palmerston North, New Zealand.

GENERAL DESCRIPTION OF THE AREA

The location of the headwater region of the River Derwent is shown in Figure 1. The lithology consists of rhythmically-deposited shale and sandstone cyclothems comprising the Kinderscout Grit Group of the Millstone Grit Series (Carboniferous). At the top of the sequence in this area is the Kinderscout Grit which is coarse-grained and poorly cemented, and in common with the sandstone is well-jointed and contains a number of shale partings. Beneath the Kinderscout Grit, and separating it from the Shale Grit, are the Grindslow Shales which reach a thickness of 100 metres. The Shale Grit consists mainly of massive sandstones with numerous inter-bedded and irregular shales.

Fig. 1. Location and surface configuration of the upper Derwent valley showing also the location of the slope profiles, the viewpoints of Pl. 1 and Pl. 2 and clast site D (ORT. D)

Much of the topography is patently related to the lithological succession. Escarpments are widely developed against the dip of the sandstones and gritstones, with benches on the intervening shales (Fig. 2; Pl. 1 and 2). Flat-topped interfluves, however, are usually underlain by the coarser-grained rocks. These and some high-level benches have been interpreted as the remnants of a former planation feature termed the Summit Surface (LINTON, 1956).

The incision of the stream system (Figs. 1 and 2; Pl. 1) is a remarkable feature which has been attributed to Tertiary uplift (LINTON, 1956; WALSH *et al.*, 1972). It is likely, however, that the rejuvenation to which it is related may be much younger than this (MCARTHUR, 1977).

VALLEY-SIDE MORPHOLOGY AND REGOLITH CHARACTERISTICS

Selected valley sides were profiled with tape and abney level and the regolith examined by excavating pits. The location of the profiles is shown in Figure 1 and the profiles themselves together with the nature of the regolith in the pits in Figure 2. All slopes are mantled with a layer of peat, commonly in the order of a metre thick on the interfluves, which often obscures the smaller blocks strewn across the benches. This organic layer is not shown on the regolith profiles. Owing to the shallowness of the slope covers, the effects of pedogenesis typically extend to the base of the regolith and, as a result, the more subtle textural characteristics reflect the imprint of podzolisation (MCARTHUR, 1973). Nevertheless, there is still a considerable amount of genetic information discernible in the regolith.

All slope profiles except Profile 1 are either against the dip or along the strike. With the exception of Profile 1, they comprise multiple slope sequences (YOUNG, 1963) in response to the alternation of argillaceous and arenaceous bedrock and to the latest stream incision. Maximum segments are developed on sandstone or gritstone or are components of the incision slopes. Thick shale beds support long concavities which invariably pass on to sandstone at their lower extremities, and the thinner shale partings in the sandstone give rise to small benches. Thin sandstone partings in predominantly shale strata are associated with small scarps.

The regolith on Profile 2 bears the imprint of the rock immediately beneath as does the surface morphology. Fine earth textures (less than 2 mm) are generally coarse although at site E loam overlies shaly sandstone. The coarser upper part of the regolith at D may indicate the presence of a thin slope deposit although vertical variation in bedrock would produce the same effect.

Profile 3 traverses a scarp developed on the Kinderscout Grit, and well-weathered, joint-bounded blocks of this grit are strewn across the concave element below (Pl. 2). These are bedded in a loam matrix containing also smaller sandstone and siltstone clasts. The gravel fraction of the upper portions of pits B and C includes rounded quartz particles clearly originating from the gritstone edge. The incision slope shows clear evidence of relatively recent disturbance with a buried soil and large flagstones paralleling the slope near the surface (MCARTHUR, 1973).

The bedrock in the upper part of Profile 4 is also Kinderscout Grit and an extensive blockfield covers the concave element. Although no pits were dug on this profile,

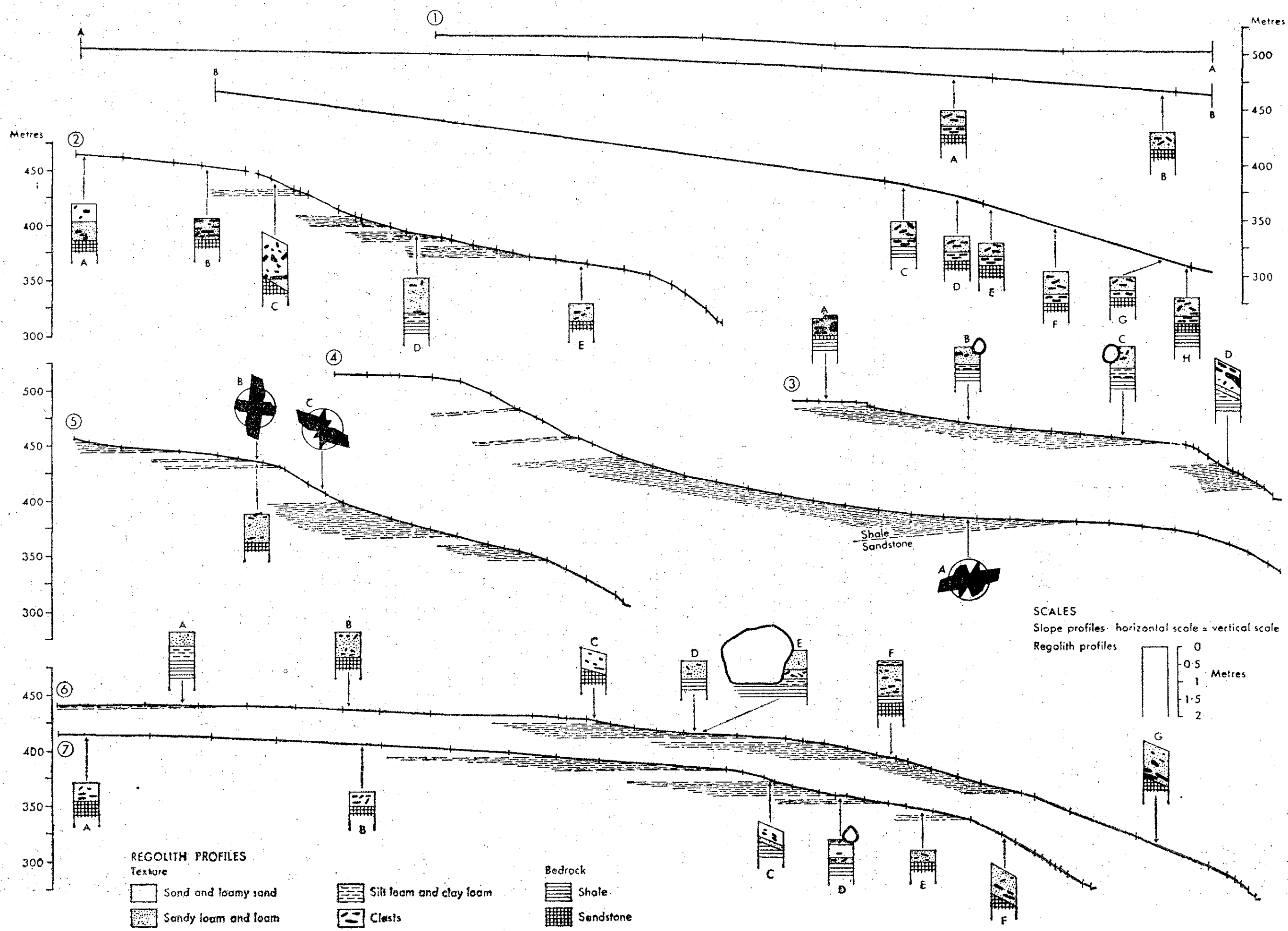
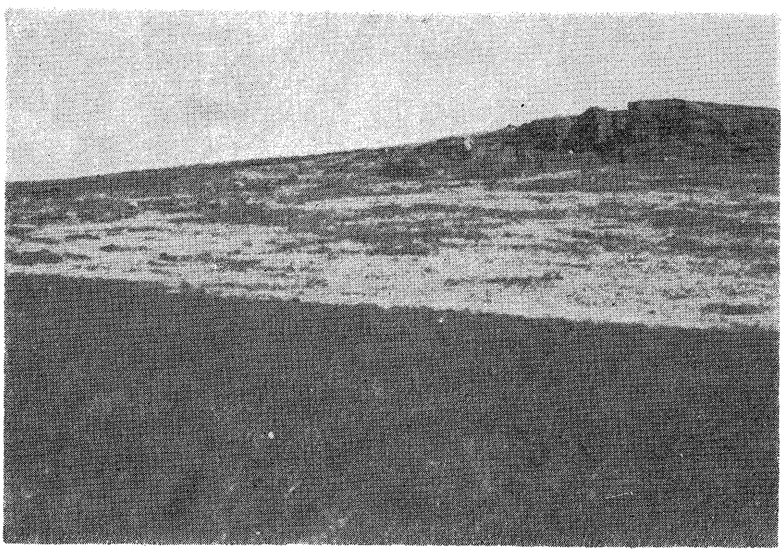


Fig. 2. Slope and regolith profiles

Pl. 1. View west from Howden Edge (see fig. 1) across the River Derwent

The continuation of the escarpment from which the photograph was taken can be seen at the top right and the extensive slope planation beneath this extends to the clearly defined stream incision. Profile 1 traverses the dip slope on the far side of the River Derwent



Pl. 2. View east to Cartledge Edge (see fig. 1) showing the escarpment and slope planation traversed by profile 3

shallow drainage channels, probably originating from artificial drainage ditches cut through the peat, show the regolith to be sandy with sandstone clasts. These fragments are disc- or blade-shaped and appear to have a preferred A-axis orientation in a downslope direction as determined at site A (Figs. 2 and 3A). Also of interest on this profile is the distinct 'bulging' of the gritstone above thin shale partings on the escarpment.

The nature of the clast fabric was determined at two sites on Profile 5. At both sites fragments are of similar morphology to those at orientation site A on Profile 4 (Fig. 3). At B, the primary mode for the azimuth is at right angles to the slope with a secondary mode downslope, and the dip preference is only weakly expressed. At C, however, both long axis azimuth and dip are strongly related to surface slope.

Profiles 6 and 7 have many features in common, being on opposite slopes aligned approximately with the strike. Both traverse gently-sloping interfluves, have benches related to shale beds and steep slopes adjacent to the stream. Although no major escarpments are present, isolated sandstone blocks rest on the benches extending from small scarps.

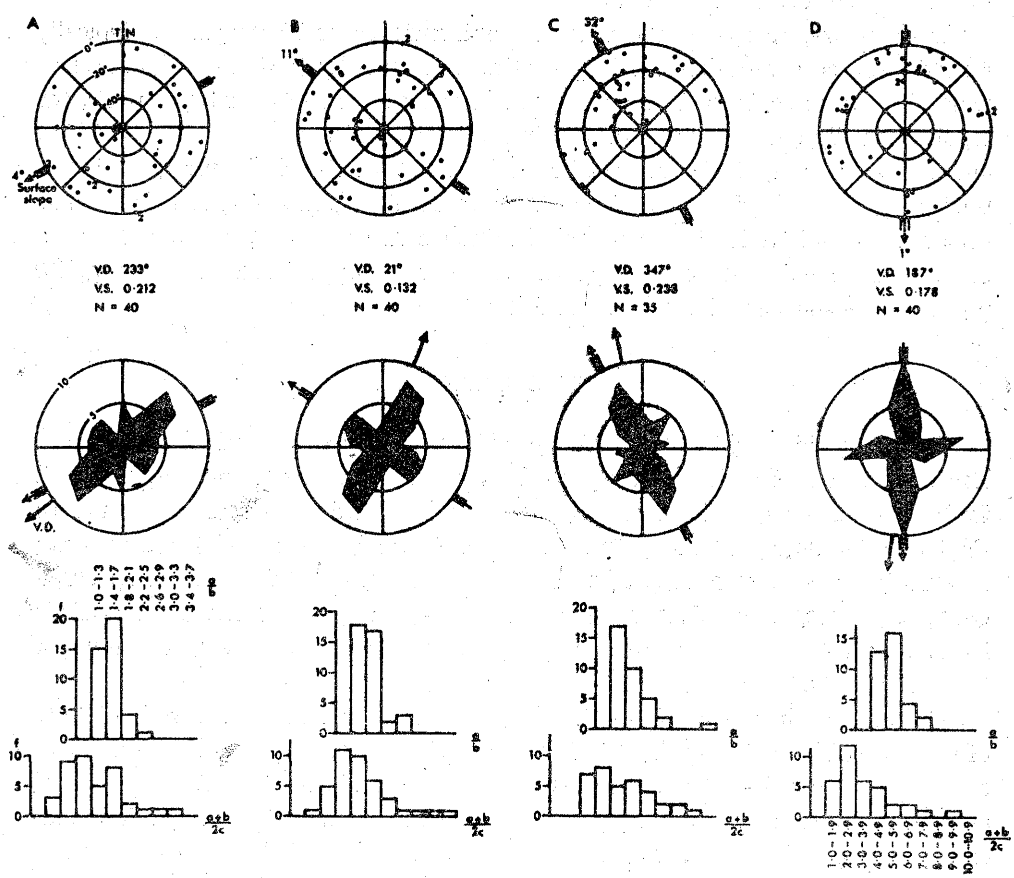


Fig. 3. Clast orientation and morphology

Sites A, B and C are located on fig. 2, site D on fig. 1; VD — vector direction; VS — vector strength; N — number in sample

At site E on Profile 6 an uncharacteristically-large sandstone block rests in the weathered basement shale and is clearly no longer undergoing transportation. Its middle portion is surrounded by a loam containing sandstone and quartz fragments in the gravel and coarse sand fractions, passing downwards to a gravelly compact zone with many small, angular sandstone clasts.

At sites A, B and C on Profile 6 regolith characteristics reflect strongly the bedrock beneath suggesting that the slope covers are here sedentary. At F, however, the regolith is complex, exhibiting a soil developed in sandy materials overlying shale and buried by a silty deposit (McArthur, 1973).

Profile 1, representing the longest dip slope, is taken from Young (1963, Profile D6). Its main morphological features are a maximum segment of 18 degrees, forming the incision slope, separated from a long upper segment of low inclination by a gentle convexity. The regolith and bedrock information provided by Young indicates that bedrock at the sampling points is everywhere sandstone except near the top of the incision slope and that the regolith comprises an upper zone of 'mainly soil with sandstone fragments' separated from the bedrock in all but one instance by a zone of 'mainly sandstone fragments'.

In summary, therefore, the regolith on interfluves and escarpments typically reflects bedrock composition and appears to be essentially *in situ*. On the benches, which pass from shale in their upper parts onto sandstone in their lower parts, the regolith usually comprises a finer matrix enclosing sandstone pebbles and cobbles, and boulders are typically bedded into this amalgam. Regolith over shale below thick sequences of gritstone such as occur on Profile 4, however, is coarser. The orientation of clasts in the slope covers of the benches and escarpments have an orientation related to the downslope direction and the upper parts of some regolith profiles show signs of relatively recent disturbance.

DISCUSSION

The valley-side benches and their covers have much in common with *cryoplanation terraces* described from many parts of the world (Reger and Péwé, 1976). In Britain, such or similar features have been identified and studied in southern England by Guilcher (1950), Te Punga (1956) and Waters (1962) and in north east Yorkshire by Gregory (1966). They are termed *altiplanation terraces* by Guilcher, Te Punga and Waters and *nivation benches* by Gregory. Characteristic features are broadly concave bedrock treads bearing only a thin cover, and an upper bounding scarp.

The benches in the southern Pennines are in general much wider than those of north east Yorkshire studied by Gregory (1966) and the altiplanation terraces of southern England described by Te Punga (1956) and Waters (1962), by factors of approximately 10 and 5 respectively. This difference may reflect the fact that the southern Pennine benches have for the most part been cut across shale, albeit constrained by the rate at which the gritstone or sandstone escarpment has retreated, whereas those in north east Yorkshire have been fashioned from homogeneously resistant rock.

On Dartmoor the benches are tiered and related to structural contrasts rather than to lithology (WATERS, 1962). In this respect, the southern Pennine planations have some affinity with *glacis d'erosion* (BIROT and DRESCH, 1966). The development of cryoplanation terraces in the context of variously resistant rocks has been described by DEMEK (1968) from Yakutia although he believes (1969) that most such terraces are independent of geologic structure.

GREGORY (1966) reports that most benches in north east Yorkshire face north east or north west and cites this preferred aspect in support of a cryonival origin. The aspects of the slope planations in the upper Derwent valley show no such preference; indeed, the largest faces south west. Here, clearly, the major control is structure rather than climate and because the dip of the rocks is generally to the north east, slopes with this aspect are often notable for their lack of well-developed benching (e.g. Profile 1).

Several authors have drawn attention to the morphological and genetic similarities between *periglacial slope planations*, including cryoplanation terraces, and valley-side planation features of differing origin. In particular, comparisons have been made with *pediments* formed in semi-arid environments (e.g. DYLIK, 1957; JUNGERIUS, 1967). Such is the likeness that CZUDEK and DEMEK (1970, 1973) use the term *cryopediment* for the cold-climate slope planation.

There is some confusion in the literature regarding the distinction between cryopediments and cyroplanation terraces. For example, in elaborating the homologies between periglacial slope planations and semi-arid pediments, DYLIK (1957) emphasized the role of slope wash but also alluded to the similarity between such features and altiplanation terraces. FRENCH (1973) has distinguished between cryoplanation terraces and cryopediments on the basis of the presence or absence, respectively, of an upper, bounding scarp, but in 1976 invoked the position on the slope as the differentiating characteristic following CZUDEK and DEMEK's (1970) definition of cryopediment.

It seems desirable to restrict the term *cryopediment* to a slope planation fashioned primarily by slope wash in a periglacial environment. The periglacial slope planations described by ROTNICKI (1964) are thus examples of cryopediments. Like semi-arid pediments, cryopediments are usually separated from an upper marginal escarpment by a distinct break of slope (CZUDEK and DEMEK, 1973; DYLIK, 1957), and the evolution of the pediment in both cases is directly related to the retreat of the scarp.

The term *cryoplanation terrace* as defined, for example, by DEMEK (1968) is a more general term from the standpoint of process but also, strictly, requires a *lower*, bounding scarp (the terrace riser) of periglacial origin as a component. Like cryopediments, cryoplanation terraces frequently occur immediately below an escarpment which in this instance is often the riser of a contiguous cryoplanation terrace. In certain cases, therefore, a cryopediment may be the tread of a cryoplanation terrace.

The term *periglacial slope planation* is the most general term and includes cryopediments and the treads of cryoplanation terraces as well as features that are in neither of these categories. A replacement slope below a frost-riven escarpment, for example, that has been shaped by the solifluction of debris across it and that is graded to the valley axis, is neither a cryopediment nor a cryoplanation terrace. It does qualify, however, as a periglacial slope planation and in this case, as in the cases referred to above, the process of planation in distinction to the landform of planation is intrinsically linked to the congelifraction and consequent retreat of the escarpment.

In returning to a consideration of the slope planations of the southern Pennines, it thus becomes necessary to ascertain a property or properties that distinguish them as one or other of the modes of pediment or as some other type of slope planation. With reference to the latter category, the proposition that the features have resulted from rock weathering and soil creep in a humid-temperate environment, as maintained by YOUNG (1963), must be examined. Further, the relationship between the slope planations and the steep slopes below them is of importance from the standpoints of both the nature and time of bench formation.

It seems clear that the steep slopes adjacent to the stream channels are essentially the result of stream incision, which precludes the interpretation of the valley-side planations as cryoplanation terraces as these have been herein defined. Neither are the benches pediments as no evidence of slope wash was found. It remains to establish whether they are, indeed, of periglacial origin or the result of 'normal' slope processes.

The regolith-bedrock boundary shows no obvious signs of corrasion which is a characteristic that would preclude the movement of regolith by soil creep according to PENCK (1924). DYLIK (1957), however, has noted that in Poland corrasion beneath thin congeliflual deposits is insignificant on the gentler slopes of periglacial slope planations. It is possible, of course, that in the study area former corraded rock surfaces have been destroyed by the subsequent weathering of the weak shales across which they were cut.

No examples of patterned ground or other unambiguous periglacial structures have been reported from the southern Pennines and none were encountered during this investigation. A soliflual origin for the blockfields in association with the congelifraction of the escarpments has been invoked by EDWARDS and TROTTER (1954) but EL ENIN (1964) attributes the blockfields to Postglacial (non-periglacial) solifluction.

It has been noted that the orientation of clasts within the regolith appears to indicate a preferred orientation of the primary or secondary mode downslope. The bimodal distributions are probably at least partly the result of the low a/b axis ratios (Fig. 3) although they may also reflect the combination of flowage and rolling in the transportation process. It may be noted in passing that the presence of two modes at right angles to each other is common in glacial tills and it is not unusual for the larger to be normal to the direction of ice flow (HARRIS, 1972). More pertinent to the present discussion is the fact that pebbles in regolith that has suffered creep typically exhibit a random orientation whereas solifluction debris displays a marked preference for clast orientation in the direction of flow (HARRIS, 1972; MOTTERSHEAD, 1976).

In Cartledge Brook (site D, Fig. 1), for example, two head deposits of Late Glacial age rest on a truncated sandstone surface (MCARTHUR, 1970, 1971). Data for clast shape and orientation in the lower head are shown in D of Figure 3. Orientation is predominantly downstream with a secondary mode at right angles to the direction of flow. The fabric in this instance also shows imbrication.

A statistical analysis was made of the orientation data in an endeavour to confirm the presence of a characteristic fabric. The vector directions and vector strengths of the data sets given in Figure 3 were calculated using the methods described by DOORNKAMP and KING (1971). All vector strengths are rather weak and do not indicate a statistically significant departure from a uniform (random) distribution on the basis of a Tukey chi-square test (e.g. HARRISON, 1957). It would appear, therefore, that this test lacks power although clearly the secondary modes make such a test (based on a circular normal distribution) strictly inappropriate. Indeed, modes at right angles to the direction of flow are properly interpreted as enhancing the vector in the direction of flow rather than detracting from it.

The strongest vector direction is notably that associated with the steepest slope and it is acknowledged that a fabric of this type in association with a steep slope would be expected from a variety of environments. In such cases, dips are downslope.

A rotational vector procedure was also used to generate mean vector data following MARK (1971) and using a rotation interval of 10 degrees. This method, unlike the former, uses all the information by virtue of incorporating dips and the full 360 degrees for azimuth specification. The results of this analysis are shown in Table I. The maximum 'mean vector' is defined with respect to a rotational plane that determines the direction of clast orientation. The perpendicular to this plane is the 'rotational vector'. R is the length or strength of the maximum mean vector, θ is the *spherical radius of confidence* and k the *estimate of precision parameter*, both of these being computed in MARK's program following ANDREWS and SHIMIZU (1966). If k is greater than or equal to 3, the sample can be assumed to be drawn from a spherical normal distribution and the probability is accordingly 5 per cent that the mean of this distribution lies more than θ degrees from the sample mean. The chi-square statistic is used to test the statistical hypothesis that the distribution from which the sample was drawn is a uniform distribution.

This procedure demonstrates a preferred orientation for all populations. For sites C and D the interval estimate for the orientation of the mean vector includes the mean given by the simpler method which reduces orientation information to 180 degrees. For sample A the orientation of the mean vector is upslope and the point estimate in fact is identical to the sample orientation computed by the other

Table I

Orientation statistics for the samples shown in Fig. 3

Sample	N	Rotational ORT	Rotational DIP	Mean Vector ORT	Mean Vector DIP	R (%)	θ	k	χ^2 (d.f.= 3)
A	40	50	0	53	−1	66.72	16.22	2.93	17.81
B	40	0	0	360	2	63.34	17.49	2.66	16.05
C	35	0	0	359	22	73.18	14.93	3.62	18.74
D	40	10	0	190	−8	67.89	15.80	3.04	18.44

All χ^2 values are significant at the 1% level method which is only arbitrarily given as downslope. The dip is above the horizontal or in a downslope direction. The orientation statistic for sample B is clearly affected by the bimodality of the sample which has reduced k to a value less than 3. Thus, although the parent distribution is not uniform, neither is it circular normal. The vector strength for A is notably of similar strength to that of the congelifluctate (D), and both of these are less than that of sample C. There is no measure of the precision of these statistics, however, and so differences could be due to sampling. The dip of the mean vector for D confirms the imbrication already noted.

On the basis of the composition and fabric of the slope deposits it seems reasonable to conclude that they are thin solifluction spreads that were capable of both corrading the shales over which they flowed and rafting quite large joint-bounded blocks away from the escarpment as they were released during periglacial times by frost-riving. The speed of scarp retreat clearly would have been the controlling factor in the rate of development of the slope planation below. The valley-side benches are thus deemed to be periglacial slope planations.

The relationship between the slope planations and the fluvial incision is difficult to determine. Because virtually all slopes are erosional there is no prospect of developing a denudation chronology on the basis of deposits. Nevertheless, some observations having some bearing on this problem are possible.

As already concluded, the products of both scarp and bench denudation were readily transported towards the valley axis by solifluction where, at least in some cases, they joined down-valley solifluction streams such as is recorded at site D. Here, the two heads, which rest on a corraded bedrock surface, probably are of Older and Younger Dryas age by analogy with dated deposits of a very similar nature in a nearby valley (SAID, 1969; MCARTHUR, 1971). This does not indicate that the planation surface associated with these deposits is of this age but rather that only the deposits associated with the most recent phase of cryergic activity remain to constitute the geomorphological record. Indeed, it seems certain that in the southern Pennines, as in southern England, the effects of successive periglacial episodes would have been cumulative (TE PUNGA, 1957). Thus, the distal portions of planation features are older than their upslope portions.

At site D the incision obviously postdates the solifluction deposits in the valley floor as it now separates some large blocks belonging to the block-field shown in Pl. 2 from their source. Cartledge Brook is but a small headwater tributary of the River Derwent, but has entrenched some 3 metres into bedrock during Postglacial time. In this instance, therefore, the terraces are Postglacial in origin in the sense that they were not terraces prior to this, and may well be *climatic terraces* (COTTON, 1958) related to the change to a fluvial regime.

It is highly unlikely that the longer incision slopes of the main valleys are of solely Postglacial origin. In fact, the over-steepened basal portions of many incision slopes probably represent the extent of Postglacial erosion so far as downcutting is concerned. It seems even more unlikely that the incision is related to Tertiary uplift. A recent analysis of the volume of material removed during the excavation of the stream incision has shown that rejuvenation may have been initiated less than 100,000 years ago (McArthur, 1977) and an earlier study by Young (1958) in a nearby catchment led to the conclusion that valleys similar to those of the incision could have been produced in a period of between 20,000 and 60,000 years. The fact that the incision slopes have suffered at most only minor retreat from the valley axes by itself suggests that they were not in existence during the formation of the larger portions of most of the planation surfaces. Nevertheless, because the Shale Grit into which the incision is cut contains few major shale beds and because it would be expected that more-recently exposed sandstone would be less susceptible to frost weathering than the higher 'edges' owing to tighter joints, it is quite possible that the incision slopes have endured the latest of the Pleistocene cold-climate episodes without marked periglacial modification. Moreover, if the incision was initiated during the Pleistocene, debris transported across the valley-side benches must have continued in transport down the incision slopes of the larger valleys at least during the later periglacial phases and hence the slopes would have had some insulation from freeze—thaw action.

There is evidence to suggest that the waste mantle on the incision slopes, such as that at site C, is a relic of this transport (McArthur, 1970), although some authors have attributed such regolith to humid-temperate and even contemporary processess (Young, 1963; Carson and Petley, 1970). Certainly, some regolith profiles such as 3D and 6F show signs of Postglacial disturbance, exhibiting buried soils, but such morphogenesis seems to have been of a catastrophic nature, related to landuse practices during the epoch of human occupance, and usually have had only a superficial effect on the slope deposits (McArthur, 1973).

It seems necessary, therefore, to adopt the view that although some valley-side planation took place during the terrace state, planation was initiated and probably continued for some time when what are now terrace treads were graded to the valley-axis. Indeed, it may be argued that as the terraces are not entirely structurally-controlled, as indicated by the fact that their distal portions are usually cut across a resistant rock stratum, they must be related to a former, higher base level. It is this argument, of course, that forms the basis for most British denudation chronologies.

CONCLUSION

The landscape of the southern Pennines stands in marked contrast to the fine-textured ('feral') relief typical of humid-temperate ('rain-and-rivers') morphogenesis (see Cotton, 1958, 1963) by virtue of laterally-continuous valley-side slopes undissected by linear erosional processes. These comprise valley-side benches and their marginal escarpments which have been fashioned by processes of mass wasting in the context of alternating hard and soft rocks and of relatively recent uplift. The valley-side benches are in fact periglacial slope planations which have formed as the result of scarp retreat during periglacial times. The congelifractate from the retreating sandstone and gritstone escarpments, together with the products of corrasion of the predominantly shale benches which replaced them, were transported towards the valley axis and at least in some cases down-valley by solifluction. At some time during the development of the slope planations stream incision occurred, truncating the distal portions of the slope planations and converting them to benches. This necessitated the movement of material in transport across the benches down the incision slopes where some of it probably remains.

Under the present fluvial regime the solifluction sheets are essentially immobile. The stream system is expanding and in smaller tributary valleys downcutting, concomitantly eroding parts of the periglacial landscape as presumably it would have done in former inter-periglacial times (see COTTON, 1958). To date, however, periglacial processes have been ascendant in sculpturing the existing surface configuration.

References

ANDREWS, J. T. and SHIMIZU, K., 1966 — Three-dimensional vector technique for analyzing till fabrics: discussion and Fortran program, *Geogr. Bull.*, 8; p. 151—165.

BIROT, P. and DRESCH, J., 1966 — Pédiments et glacis dans l'Ouest des Etats-Unis. *Ann. de Géogr.*, 75; p. 513—552.

CARSON, M. A. and PETLEY, D. J., 1970 — The existence of threshold hillslopes in the denudation of the landscape. *Trans. Inst. Br. Geogr.*, 49; p. 71—95.

COTTON, C. A., 1958 — Geomorphology. Whitcombe and Tombs. Seventh edition.

COTTON, C. A., 1958 — Alternating Pleistocene morphogenetic systems. *Geol. Mag.*, 95; p. 125—136.

COTTON, C. A., 1963 — Development of fine-textured landscape relief in temperate pluvial climates. *N.Z. Jour. Geol. Geophys.*, 6; p. 528—533.

CRAMPTON, C. B. and TAYLOR, J. A., 1967 — Solifluction terraces in South Wales. *Biul. Peryglac.*, 16; p. 15—36.

CZUDEK, T. and DEMEK, J., 1970 — Pleistocene cryopedimentation in Czechoslovakia. *Acta Geographica Lodziensia*, 24; p. 101—108.

CZUDEK, T. and DEMEK, J., 1973 — The valley cryopediments in eastern Siberia. *Biul. Peryglac.*, 22; p. 117—130.

DEMEK, J., 1968 — Cryoplanation terraces in Yakutia. *Biul. Peryglac.*, 17; p. 91—116.

DEMEK, J., 1969 — Cryogene processes and the development of cryoplanation terraces. *Biul. Peryglac.*, 18; p. 115—125.

DOORNKAMP, J. C., and KING, C. A. M., 1971 — Numerical analysis in geomorphology. Arnold.

DYLIK, J., 1957 — Tentative comparison of planation surfaces occurring under warm and under cold semi-arid climatic conditions. *Biul. Peryglac.*, 5; p. 175—186.

EDWARDS, W., and TROTTER, F. M., 1954 — The Pennines and adjacent areas. Br. Reg. Geol., 3rd. ed., London.

EL ENIN, H. S. A., 1964 — An examination of the evolution of surface forms in the area drained by the Sheaf, Upper and Middle Don, with particular reference to the Quaternary era. Unpubl. Ph.D. thesis. Sheffield University Library.

FRENCH, H. M., 1973 — Cryopediments on the Chalk of Southern England. *Biul. Peryglac.*, 22; p. 149—156.

FRENCH, H. M., 1976 — The periglacial environment. Longman.

GREGORY, K. J., 1966 — Aspect and landforms in north east Yorkshire. *Biul. Peryglac.*, 15; p. 115—120.

GUILCHER, A., 1950 — Nivation, cryoplanation et solifluction quaternaires dans les collines de Bretagne Occidentale et du Nord du Devonshire. *Rev. Géomorph. Dyn.*, 1; p. 53—78.

HARRIS, S. A., 1972 — The nature and use of till fabrics. *In*: Research Methods in Pleistocene Geomorphology, 2nd Guelph Symposium on Geomorphology, 1971, Department of Geography, University of Guelph, *Geographical Publication*, 2; p. 45—65.

HARRISON, P. W., 1957 — New technique for three-dimensional fabric analysis of till and englacial debris containing particles from 3 to 40 mm in size. *Jour. Geol.*, 65; p. 98—105.

JOHNSON, R. H., and RICE, R. J., 1961 — Denudation chronology of the south-west Pennine Upland. *Proc. Geol. Ass.*, 72; p. 21—31.

JUNGERIUS, P. D., 1967 — The influence of Pleistocene climatic changes on the development of the polygenetic pediments in the Cypress Hills area, Alberta. *Geogr. Bull.*, 9; p. 218—231.

LINTON, D. L., 1956 — Geomorphology of the Sheffield region. *In*: Sheffield and its region. British Association Handbook, Sheffield.

MCARTHUR, J. L., 1970 — A geomorphological study of the upper Derwent basin, Derbyshire. Unpubl. Ph.D. thesis. Sheffield University Library.

MCARTHUR, J. L., 1971 — Periodicity in upland morphogenesis. *N.Z. Geogr. Soc. Conf. Ser.*, 6B; p. 186—191.

MCARTHUR, J. L., 1973 — Podzolisation in the headwater region of the River Derwent, Derbyshire. *E. Midld Geogr.*, p. 361—371.

MCARTHUR, J. L., 1977 — Quaternary erosion in the upper Derwent basin and its bearing on the age of surface features in the southern Pennines. *Trans. Inst. Br. Geogr.*, NS 2; p. 490—497.

MARK, D. M., 1971 — Rotational vector procedure for the analysis of till fabrics. *Bull. Geol. Soc. Am.*, 82; p. 2661—2666.

MOTTERSHEAD, D. N., 1976 — Quantitative aspects of periglacial slope deposits in Southwest England. *Biul. Peryglac.*, 25; p. 35—57.

PALMER, J. and RADLEY, J., 1961 — Gritstone tors of the English Pennines, *Z. Geomorph.*, 5; p. 37—52.

PENCK, W., 1924 — Die morphologische Analyse. Englehorn. Translated: CZECH, H. and BOSWELL, K. C., 1953 — The morphological analysis of landforms. Macmillan.

PITTY, A. F., 1968 — The scale and significance of solutional loss from the limestone tract of the southern Pennines. *Proc. Geol. Ass.*, 79; p. 153—177.

REGER, R. D., and PÉWÉ, T. L., 1976 — Cryoplanation terraces: indicators of a permafrost environment. *Quat. Res.*, 6; p. 99—109.

ROTNICKI, K., 1964 — Periglacial slope planations in the South-eastern part of the Ostrzeszów Hills. *Biul. Peryglac.*, 13; p. 235—259.

SAID, M., 1969 — The Pleistocene geomorphology of the Burbage basin. Unpubl. Ph.D. thesis. Sheffield University Library.

TE PUNGA, M. T., 1956 — Altiplanation terraces in southern England. *Biul. Peryglac.*, 4; p. 331—338.

TE PUNGA, M. T., 1957 — Periglaciation in southern England. *Tijdschr. Kon. Ned. Aardrijsk. Genoot.*, 64; p. 401—412.

WALSH, P. T., BOULTER, M. C., ITJABA, M., and URBANI, D. M., 1972 — The preservation of the Neogene Brassington Formation of the southern Pennines and its bearing on the evolution of Upland Britain. *Jour. Geol. Soc. Lon.*, 128; p. 519—559.

WATERS, R. S., 1962 — Altiplanation terraces and slope development in Vest Spitsbergen and south-west England. *Biul. Peryglac.*, 11; p. 89—101.

YOUNG, A., 1958 — A record of the rate of erosion on Millstone Grit. *Proc. Yorks. Geol. Soc.*, 31; p. 149—156.

YOUNG, A., 1963 — Some field observations of slope form and regolith and their relation to slope development. *Trans. Br. Geogr.*, 31; p. 1—29.