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A SPECIFIC EXAMPLE OF THE NATURE AND RELATIONSHIP OF WEATHERED GRANITE AND HEAD ON DARTMOOR, SOUTH WEST ENGLAND

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The study analyses the solifluction material (head) on the slopes of Dartmoor, South West England. It concludes that this material was not created as a single deposit, because there is a major discontinuity near the surface.

Key words: weathered granite, Dartmoor, grain size, periglacial movement

INTRODUCTION

The granite upland of Dartmoor, South West England, was never glaciated but slopes possess abundant evidence of the action of past periglacial processes, being mantled by a variable thickness of frost-produced soil layers (head). There have been a number of general investigations into the nature of the head and its relationship with under-lying weathered granite (growan) (Gerrard 1989a, Gerrard 1989b, Green and Eden 1973, Waters 1964) but no detailed study. The roadside exposure at Dunnabridge, near Princetown in central Dartmoor, presents an opportunity to examine the detailed relationships between the two materials as well as the smaller scale variability that exists within them. But before the data are presented it is necessary to review previous ideas concerning head and growan and to develop a conceptual framework within which to assess those data.

MODELS OF SLOPE MATERIAL DEVELOPMENT

It has been suggested (Waters 1964) that the cryergic transfer of material on Dartmoor from one part of slope to another would lead to the inversion of a pre-existing weathering profile. During the first stages of periglacial activity, successive layers of weathered granite would be moved from the upper parts of slopes and deposited in reverse order on the lower slopes. This material has been called the Main Head. Continuing movement of material would lead to the exposure of the unweathered granite enabling sound blocks to be detached by frost action. These blocks would also be moved downslope by solifluction processes. This material was called the Upper Head. A third deposit, called bedded growan, was attributed to slope wash or creep, with an emphasis on wash. It is suggested that the sequence of events, outlined above, would result in a succession of the three deposits (Fig. 1).

This argument has been challenged (Green and Eden 1973). It was noted that the majority of the coarse debris seems to occur in the lower portions of head profiles and it has been argued that much of this coarse debris is derived from local basal sources and not rock outcrops. The conclusion was that the slope materials are not the result of the progressive stripping of a normal weathering profile, but have been derived from many parts of the slope. Also there is evidence that a substantial amount of basal material has been incorporated into the transported layer.

The changes brought about by periglacial processes depend not only on the type and intensity of those processes but also on the initial surface form and the nature of the pre-existing slope materials. A simple inversion of the weathering profile will have occurred only in localised positions. Also, it is more likely that the original weathering profiles were extremely complicated and that periglacial processes, such as solifluction, would have led to a mixing of the materials rather than a simple resorting.

One of the most detailed accounts of weathering profiles on the Dartmoor granite has been provided by Brunsden (1964). He recognised four zones of undisturbed weathered granite surmounted by a variable thickness of disturbed material, which he termed the migratory layer (Table 1). The debris of Zone 1 consists of a structureless mass of quartz sand and possibly some partially weathered feldspar and clay minerals. Brunsden noted that Zone 1 is rarely present owing to the intensity of periglacial processes. The few localities where it does occur have obviously suffered very little erosion. Zone 2a consists of heavily rotted, incoherent granite but which retains its granite structure. Small, rounded corestones may be present. Zone 2b is differentiated from Zone 2a in that it has been only partially weathered and still retains its coherent structure. It is difficult to crush in the hand and breaks up into joint blocks of well weathered granite. Fairly large, rounded corestones may be present. Zone 3 is composed almost entirely of angular corestones and coarse weathered debris occurs along the joints. This zone merges into comparatively fresh bedrock.

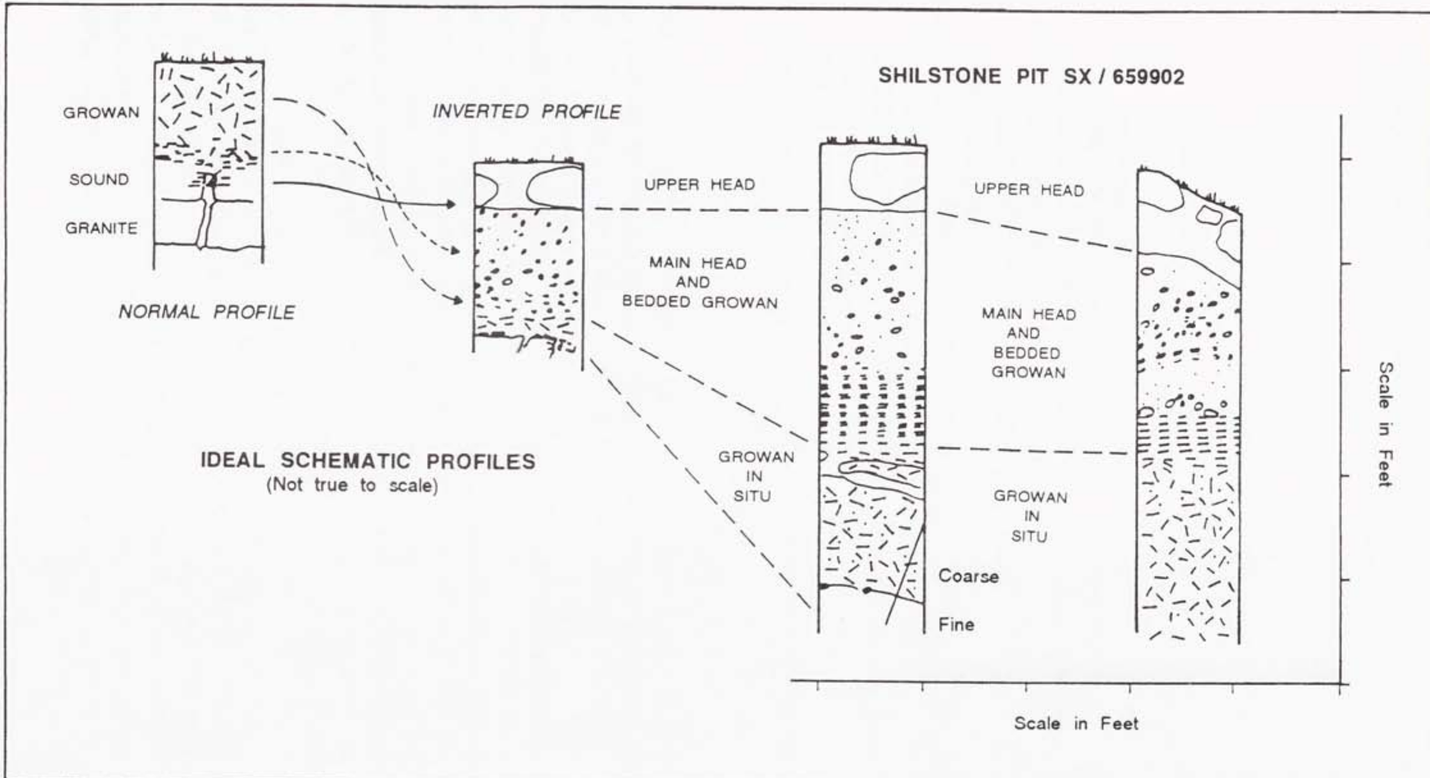

Fig. 1. The idealised profile of granite weathering and the inversion of the profile by solifluction processes (Waters 1964).

This is, of necessity, a very generalised description and exposures of growan are likely to exhibit considerable variability especially if hydrothermal alteration had occurred prior to weathering. The way in which chemical weathering has picked out areas of hydrothermal alteration, as well as areas of close jointing, creating complex weathering profiles has been noted (Dearman and Baynes 1978).

Table 1. Granite weathering zones on Dartmoor (after Brunsden(1964))

Zone	Characteristics
Migratory Layer	Disturbed, structureless layer comprising quartz sand and coarse granite fragments. Often red-brown in colour.
Zone 1	Undisturbed and structureless with a high proportion of quartz. Yellow-red-brown in colour.
Zone 2a	Well rotted and incoherent with granite structure retained. Crumbles in the hand.
Zone 2b	Well rotted but coherent and tends to break up into rotted joint-blocks. Some rounded corestones.
Zone 3	Partial decomposition along joints with corestones angilar and locked. Merges downward into solid rock.

It is this weathered material that has been altered and reworked by periglacial processes. The different zones, because of their differing characteristics, will have provided varying resistance to these processes. The thickness and distribution of the weathering profiles on slopes are crucial to the evolution of those slopes. Many studies on granite slopes in other parts of the world have shown that the nature and thickness of weathering profiles depend on slope angle and position. On gently sloping surfaces with dominant vertical rather than lateral water movement, weathering can be intense. But weathering rates are reduced on steep slopes because of reduced water residence times. Thus differential weathering rates produce systematick variations in the nature of weathering profiles. This is implied in a schematic representation of a Dartmoor slope (Brunsden 1964). The complete weathering sequence is only present on the lower slopes and the zones become thinner towards the top of the slope and some may disappear entirely (Fig. 2).

If Waters' (1964) ideas are correct there should be a sharp division between head and growan, the head should be clearly differentiated into two types with a number of large boulders in the upper layers and there should be an increase in average grain size towards the surface. If the ideas of Green and Eden (1973) are substantially correct head should be a highly variable material and there should be no clear differentiation within the head or between the head and the underlying growan. Examination of the exposure at Dunnabridge allows these ideas to be tested as well as providing an opportunity of assessing the small scale variability within the slope materials.

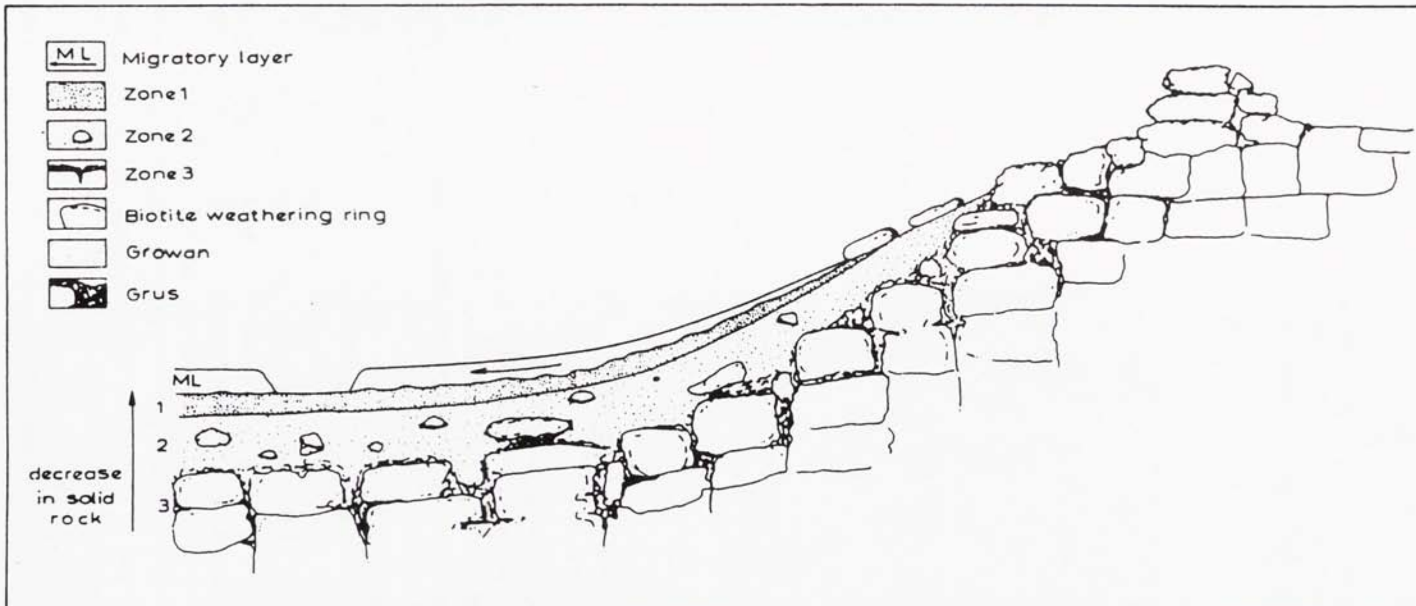

Fig. 2. Representation of a weathering profile on the Dartmoor granite (Brunsden 1964).

GENERAL NATURE OF THE EXPOSURE

The exposure, which is on a comparatively gentle slope in a mid to upper slope position, is approximately 8 m wide and 3 m high and shows a mass of apparently undisturbed growan between two sound stacks of granite (Fig. 3). Above the weathered granite and stacks is a variable thickness of head surmounted by an irregular thickness of medium brown loam.

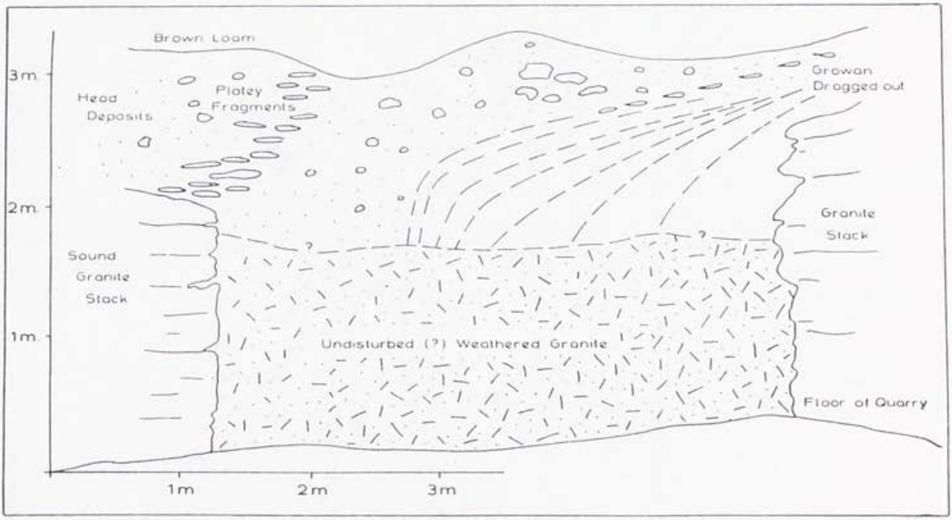

Fig. 3. Diagrammatic representation of the exposure at Dunnabridge.

The junction between the head and the growan is somewhat vague and growan seems to have been incorporated into the immediately adjacent head layers. Indeed,there is some indication that the growan has been dragged out in a downslope direction. The exposure is aligned slightly obliquely to the slope but there is a general slope and an inferred movement of material from left to right in the exposure. In addition, there is a zone of platy rock fragments within the head layer apparently emanating from one of the sound granite stacks. As indicated later, this suggested movement has an influence on grain size characteristicts. There are very few large granite blocks within the head and the few blocks that do occur are to be found either near the surface or adjacent to the sound granite stacks. The growan is reasonably structureless and appears only to have been slightly altered. Feldspar crystals are fresh and intact with only slight staining and occasional fracturing along cleavage planes. But, in spite of this, the material is incoherent and easily excavated by hand as the interparticle cohesion has been lost. The material gives every indication of having been slightly altered chemically and by physical weathering as advocated for other exposures (Dearman and Baynes 1978). The base of the weathered profile is not visible therefore it is not possible to identify the way the profile changes as the weathering front is approached. However the 2 m of growan that is visible shows very little gradation or change with depth.

The most conspicuous feature is the very abrupt lateral change from growan to sound granite stacks. There is no indication of the gradual weathering changes that are supposed to exist as solid relatively unweathered rock is approached. Visual inspection provides more justification for the ideas of Green and Eden than those of Waters.

GRAIN SIZE ANALYSIS

In order to examine the spatial variability and possible interaction between the materials twenty four samples were taken from the exposure; twelve from the head and twelve from the undisturbed growan. The sampling plan is shown in Figure 4. Analysis of the grain size

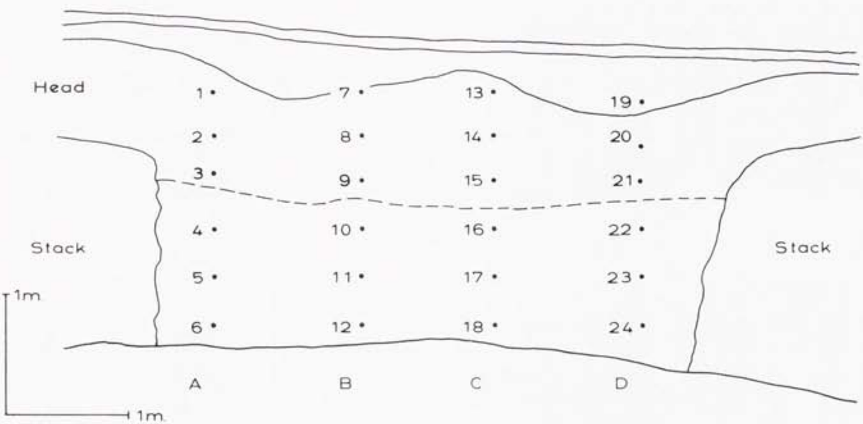

Fig. 4. Sampling scheme for head and growan.

parameters of the head and growan can add considerably to the descriptions and conclusions already reached. The main purpose of grain size parameters is to differentiate between materials and to aid correlation between materials and their environment. The descriptive measures most commonly used are mean particle size, median size, sorting, skewness and kurtosis. The usual method of obtaining these measures relies on the measurement of percentile intercepts from cumulative percentage weight curves obtained by sieving. Many measures based on percentiles have been proposed; the ones used in this study (Folk and Ward 1957) are shown in Table 2. Computation is helped by using a logarithmically transformed or phi scale (Krumbein 1934). Also, a probability percentage ordinate is used because values of skewness and kurtosis obtained from curves drawn on arithmetic ordinate scales are less accurate because of the uncertainty of interpolating an S-shaped curve.

Average values for the horizontal rows and vertical columns of growan and head samples are shown in Tables 3 and 4. Average values for head and growan are shown in Table 5. In interpreting the values for mean and median it must be noted that the phi scale is a negative logarithmic scale, therefore higher values indicate finer grain size. A value of -1.00 is the equivalent of 2 mm, -2.0 equals 4 mm etc. Values for mean grain size indicate that both head and growan are cuite coarse grained, with head being slightly finer especially in the

Table 2. Methods of calculating the descriptive grain size parameters based on percentiles (after Folk and Ward 1957)

Descriptive Measure	Formula
Mean	$\frac{\phi 16+\phi 50+\phi 84}{3}$
Sorting	$\frac{\phi 84-\phi 16}{4}+\frac{\phi 95-\phi 5}{6,6}$
Skewness	$\frac{\phi 84+\phi 6-2\phi 50}{2(\phi 84-\phi 16)}+\frac{\phi 95+\phi 5-2\phi 50}{2(\phi 95-\phi 5)}$
Kurtosis	$\frac{\phi 95-\phi 5}{2,44(\phi 75-\phi 25)}$

Table 3. Average values for grain size parameters grouped according to horizontal sampling levels (phi units)

	Horizontal Levels	**Mean**	**Sorting**	**Skewness**	**Kurtosis**
Head	1	-0,79	2,52	-0,30	1,05
	2	-1,73	1,76	-0,33	1,14
	3	-1,37	2,02	-0,35	1,22
Growan	4	-1,56	1,68	-0,24	1,12
	5	-1,83	1,66	-0,33	1,13
	6	-1,89	1,66	-0,30	1,15

Table 4. Average values for grain size parameters grouped according to vertical sampling columns (phi units)

	Vertical Columns	**Mean**	**Sorting**	**Skewness**	**Kurtosis**
Head	1	-1,45	1,84	-0,29	1,15
	2	-1,09	2,35	-0,26	1,13
	3	-1,45	1,67	-0,40	1,08
	4	-1,18	2,20	-0,36	1,18
Growan	1	-2,74	1,46	-0,38	1,16
	2	-1,44	1,81	-0,31	1,10
	3	-1,48	1,69	-0,19	1,11
	4	-1,36	1,70	-0,26	1,17

uppermost layer. This can be seen in overlapping grain size envelope curves (Fig. 5). Growan is noticeably coarser adjacent to thelefthand rock stack which reinforces the suggestion of downslope movement. There is also some indication of a gradual fining from the bottom of the profile upwards. Apart from the samples taken from the extreme left of

Table 5. Average values, in phi units, for the various grain size parameters

	HEAD	GROWAN
MEAN GRAIN SIZE	-1,29	-1,76
MEDIAN GRAIN SIZE	-1,68	-2,02
SORTING	2,10	1,67
SKEWNESS	-0,33	-0,29
KURTOSIS	1,13	1,13
% SILT-CLAY	4,73	1,94

the exposure there is no sharp distinction between growan and head. As would be expected the median grain size values exhibit the same pattern. Although the grain size envelope curves for head and growan overlap to a considerable extent, head possesses a greater percentage of fine material.

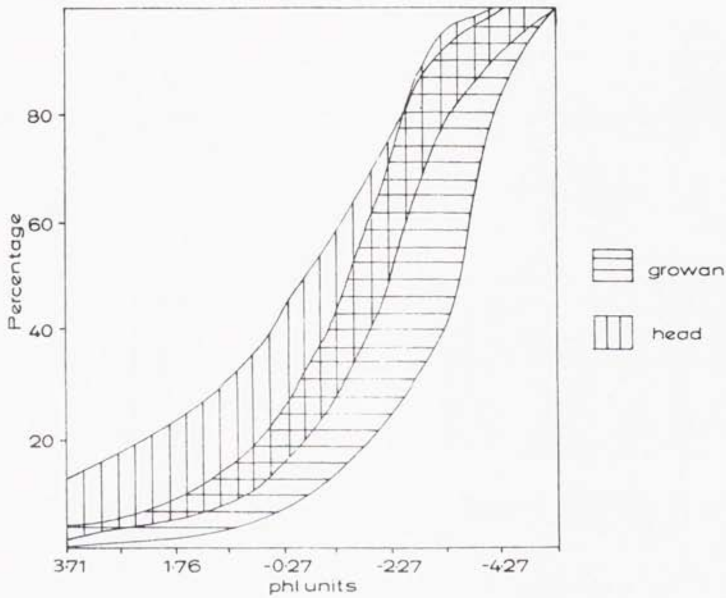

Fig. 5. Grain size distribution envelope curves for head and growan.

In general, head is less well sorted than growan and the difference is statistically significant. Sorting values also exhibit greater variability, with greater variability between sampled horizontal zones in head than between individual growan zones. In this respect growan appears to be a much more homogenous material. The surface head layer is easily

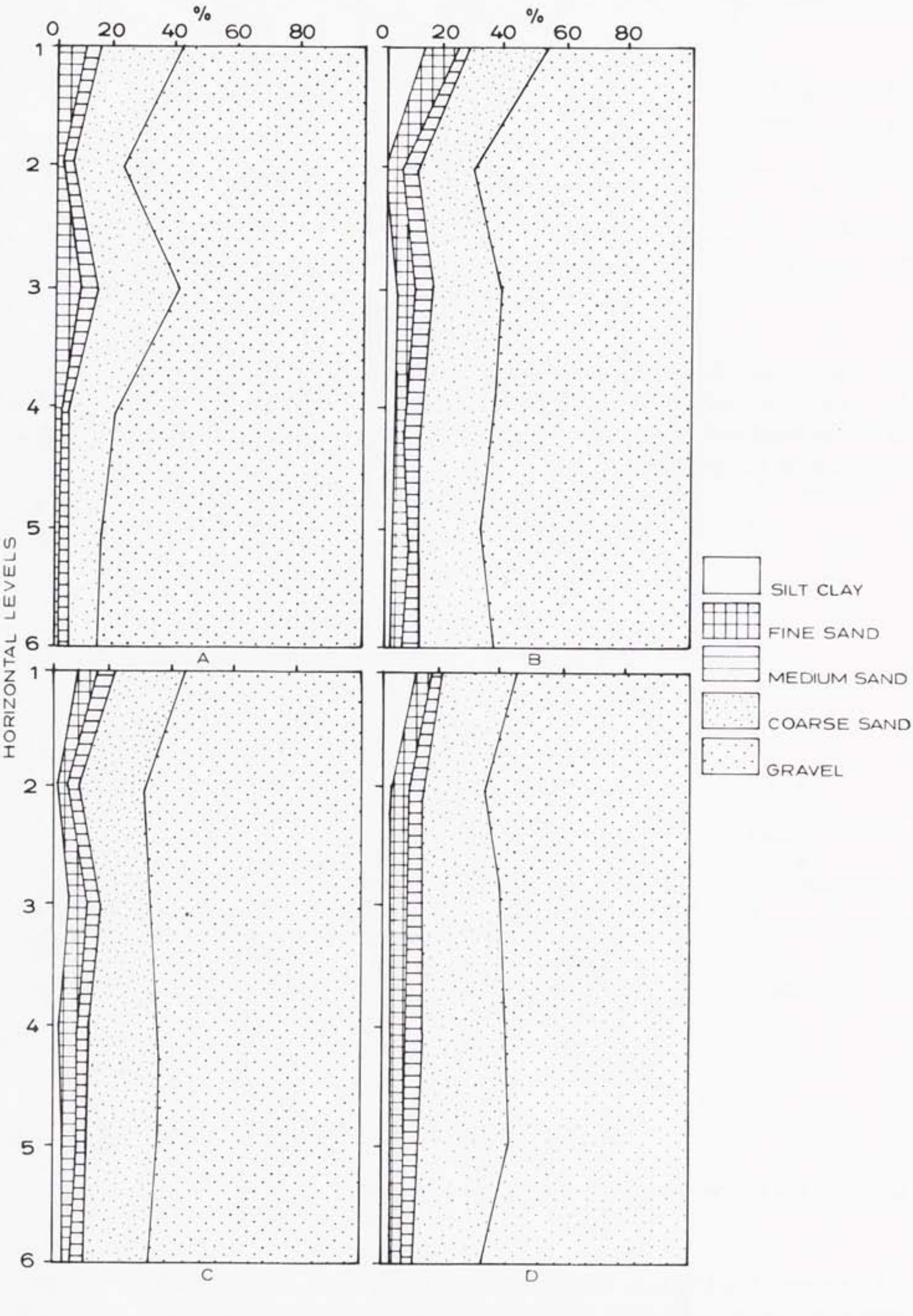

Fig. 6. Variation of size fractions with depth.

Table 6. Percentage overlap in grain size distributions between adjacent samples. Numbers in brackets refer to the sample location

									Layer Means
	(1)	70,36	(7)	75,41	(13)	89,02	(19)	78,26
	80,07		73,17		85,87		89,00	
	(2)	90,32	(8)	90,54	(14)	92,81	(20)	91,22
	85,51		83,34		92,64		92,68	
	(3)	91,18	(9)	84,27	(15)	89,16	(21)	88,20
	81,65		88,04		81,26		93,52	
	(4)	83,41	(10)	90,88	(16)	95,47	(22)	89,92
	71,80		95,09		93,63		95,39	
	(5)	56,86	(11)	94,36	(17)	93,86	(23)	81,69
	93,93		93,67		92,43		84,87	
	(6)	57,94	(12)	90,30	(18)	93,93	(24)	80,72
Column Means	82,95		86,66		89,17		91,09	

the least sorted. The marked differences in sorting values for the horizontal zones in head suggest that head was not created as a single deposit but different processes and/or different source materials have been involveed. But it does not indicate layering of materials. All samplex exhibit negative skewness which indicates the coarseness of both materials. There are few differences between layers or between the values for head and growan. Kurtosis values are also relatively similar.

Some of the uppermost head samples show a high silt plus clay content which may represent an influx of wind blown materials. This high value in the upper zones makes % silt plus clay for head samples significantly different than for growan. A relatively high silt content has been noted in many of the Dartmoor soils and in other soils in south west and southern England. Layer 2 is the coarsest and best sorted head layer and, as it is the layer immediately below the loam and soil layer, it may represent a reasonably sorted solifluction deposit, later buried by a mixture of materials, including a substantial windblown component. The silt/clay percentages emphasise the coarseness of the growan. Even the values away from the granite stack are extremely low suggesting that very little fundamental weathering has occurred, simply a breaking down of the interparticle cohesion.

The inferred junction between the head and the growan is not well marked except for the sorting and skewness values. The distinction between the two materials may be more in terms of skewness and sorting than grain size. Therefore, apart from layer 2, there is little variation of the grain size parameters with depth. This is borne out by the plots of the various grain size fractions with depth (Fig. 6). Diagrams A, B, C, and D refer to the sampling columns in Figure 4. Apart from the three very coarse growan samples and the high sorting value for one of the surface head samples, there is very little lateral variation except for a slight tendency for the growan to become finer away from the stacks of solid granite.

It has been suggested that the percentage overlap of two grain size distribution histograms is a means of determining the similarity of two deposits or samples (Langhor et al. 1976). The procedure is straightforward and only involves calculating the overlap between two histograms. If the overlap between samples and every other sample is calculated, a matrix can be constructed. This allows the samples with similar grain size distributions to be ascertained at a glance. The values are generally quite high, apart from the combinations involving samples 5 and 6, and, to a lesser extent, sample 4. These are the coarse grained growan samples identified earlier as being markedly different from the rest of the samples. The mean overlap value of the head samples is 85.4 % and that for the growan, omitting samples 4, 5 and 6, is 91.93 %. Thus there is slight justification for thinking that the growan is a more uniform material.

The percentage overlap between adjacent samples is shown in Table 6 together with the mean values for layers and columns. The values of adjacent growan samples are slightly higher than those for the head samples again suggesting a more uniform material. There is also some indication of a lower degree of overlap acros the supposed growan-head boundary but it must be admitted that it is not particularly marked and emphasises perhaps a gradual transition rather than a sharp boundary.

CONCLUSIONS

A number of general conclusions can be made concerning the nature of the head and growan in the exposure at Dunnabridge:

1. There is no indication that the four zones in growan described by Brunsden (1964) occur in this exposure. Growan is generally a structureless mass with feldspar crystals appearing fresh although with some fracturing along cleavage planes. But the cohesion between the individual grains been lost. This tends to suggest that considerable physical weathering has occurred on a material slightly altered chemically. There is also a very sharp transition between weathered material and solid, unweathered rock. Thus the original starting point in the model suggested by Waters (1964) has to be modified substantially. Even so, if there was a gradual inversion of the weathering profile by cryergic processes sharp divisions in the head would be expected. Such divisions are not present.

2. Grain size parameters indicate that growan is a homogeneous material. There is little variation with depth and only slight variation laterally where granite stacks are approached.

3. Head is a more variable material than growan with occasional large granite fragments in a finer matrix. There is also greater variation between samples with depth than with growan. This implies that the head was not created as a single deposit which indicates different source materials, different processes or even stillstands in slope activity. Evidence from currently active periglacial zones shows that slope processes operate in a disconti-nuous fashion being governed by freezing and thawing cycles. It can be anticipated that there were a number of major cycles of temperature change on Dartmoor during the last Glacial Period as well as a greater number of minor ones. It is also assumed that head represents the later phases of activity, there being no indication of earlier phases. The only location where two major phases of periglacial activity have been indicated is in the lower valley of the River Erme on southern Dartmoor (Golbertson and Sims 1974). The

Dunnabridge exposure occurs in an upper midslope situation; a position where the balance between erosion and deposition would have fluctuated considerably. Materials currently present represent the net effect of this balance, although there is no obvious sign of this.

4. The major discontinuity in the head layer occurs near the surface where a high silt content is encountered. This seems to represent a wind blown deposit probably indicative of drying conditions in Late Glacial or Early Post Glacial times.

5. The junction between growan and head is very indistinct both visually and in terms of grain size parameters. This indicates a gradual incorporation of growan into the head layers. Estimates of temperature values at the time of maximum extension of the Devensian ice mass indicate that Dartmoor was in a zone of discontinuous permafrost. The gradual incorporation of grown into head is what would be expected if the discontinuous permafrost periodically melted and the material started moving downslope.

6. Of the two "models" of slope material development examined earlier that of Waters (1964) is found seriously wanting. This is because the nature of the original weathering profile appears to be different from that suggested and also because the movement of material has not occurred in the systematic manner inferred in the model. The ideas of Green and Eden (Green and Eden 1973) appear to be more realistic with evidence for mixing of materials as well as the incorporation of debris into the head at various points.

The general conclusion is that both head and growan are more complicated than suspected. Also, considering the nature of discontinuous permafrost, which must have penetrated some distance into the growan as well as affecting the head, it is difficult to imagine undisturbed growan occurring anywhere on Dartmoor. Thus it may be necessary to reassess the simple dichotomy of Tertiary weathering followed by Quaternary periglacial movement of surface material. The evolution of the Dartmoor landscape has been extremely complex and the surface materials require more substantial investigation before this complexity can be unravelled.

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