D. N. MOTTERSHEAD*
Portsmouth

QUANTITATIVE ASPECTS OF PERIGLACIAL SLOPE DEPOSITS IN SOUTHWEST ENGLAND

INTRODUCTION

The aim of the present paper is to provide a quantitative description of the solifluction deposits of southwest England. These materials have been the subject of interest since W. BORLASE (1758) described one such deposit at Porthnanven, Cornwall (G. R. SW 355309) as *a load of rubbish* (p. 76). Subsequently more penetrating and detailed observations have been made by many authors, who have conferred a great variety of terms on the deposits concerned.

Similar deposits were described as *diluvium* in the early nineteenth century by A. SEDGEWICK (1825) and H. S. BOASE (1832). In 1839 H. T. de la BECHE introduced the word *head* into the literature to describe such materials, whilst in 1851 R. A. C. GODWEN-AUSTEN employed the term *subaerial beds*. None of these terms can be considered as applying exclusively to beds which are now generally interpreted as resulting from solifluction under periglacial conditions. In 1878 W. A. E. USSHER restricted the use of the term *head* to deposits of stony angular debris, and in 1892 J. PRESTWICH described the same material as *rubble-drift*. These remarks serve to illustrate the variety of terminology used by these early workers, and the need for some degree of clarification. On the positive side, however, these early papers do offer a large number of useful and accurate descriptions of the deposits concerned, even though many of the interpretations are no longer acceptable.

The first use of the term *solifluction* in relation to southwest England appears to be by G. ALBERS in 1930. He draws on B. HÖGBOM's descriptions of Spitsbergen, and relates the tors and clitters of Dartmoor to environmental conditions and erosional processes under a periglacial régime. More recently the periglacial origin of many features in southwest England has been generally recognised. Many workers have given updated descriptions of the periglacial deposits (M. T. TE PUNGA, 1957; R. S. WATERS, 1957, 1961, 1964, 1965; N. STEPHENS, 1961, 1966). Good as these

* Department of Geography, Portsmouth Polytechnic. Lion Terrace, Portsmouth PO1 3HE, England.

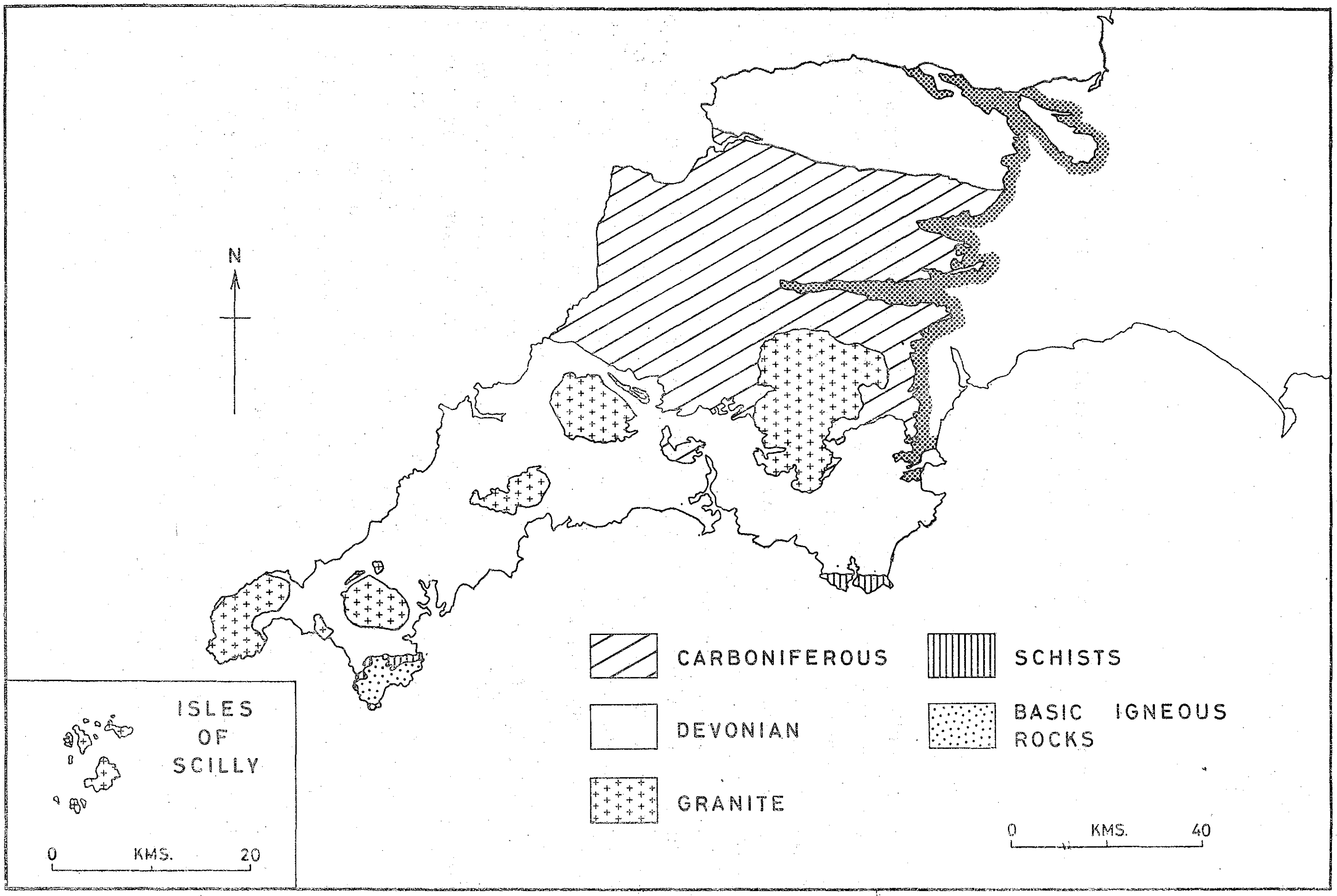

Fig. 1. Solid geology of southwest England

works are, however, solifluction deposits are rarely the central theme, and when they are the work concerned is usually restricted to a small area geographically. There is still lacking a comprehensive regionwide quantitative description of the deposits resulting from periglacial mass movement. It seemed to the author that a quantitative approach to these deposits might provide a unifying description, and perhaps enable a numerical definition of them to be made.

SAMPLE COLLECTION

The study is confined to the Palaeozoic outcrop of southwest England, comprising Cornwall, the Scilly Isles, most of Devon, and part of Somerset (Fig. 1). In this area the vast majority of superficial deposits is comprised of Palaeozoic materials. Furthermore, the superficial deposits are of a less ambiguous nature than those of the Mesozoic outcrop to the east, where they are complicated by the abundance of derived and reworked flints and cherts. The general characteristics of deposits formed by solifluction are well attested in the literature. Thus for the present purpose the following qualitative criteria were adopted as definitive field characteristics of the deposits to be studied:

(1) The material should be locally derived, upslope from its present position

(2) it should lie on or at the base of the slope down which solifluction has taken place

(3) it should consist largely of unsorted particles

(4) the particle shape of the coarse fraction should be predominantly angular

(5) there should be preferred orientation of the large particles in the downslope direction.

These guidelines enable the results of fluvial, marine and glacial action to be distinguished and excluded from the study. The effect of recent soil movement is confined to the top half metre of exposures and can be recognised by its looser texture.

Samples were collected from over seventy sites, distributed throughout the region (Fig. 2). A major objective was to achieve a good spread of samples across the variety of bedrock types present in southwest England. Sites studied included many previously alluded to in the literature, together with several more discovered by the author. The sampling scheme can best be described as deliberative, and it is hoped that a fair cross section has been achieved. At each site sampled at least one representative sample was taken, and sometimes more in cases where there was a clear variation in the deposits. In all 110 samples of head were collected and subjected to particle size analysis. The Appendix explains how the extremely coarse material was measured. Parameters of mean particle size, skewness, and sorting were derived from the granulometric data. These also are explained in the Appendix. Particle roundness, and large particle orientation were measured in the field at

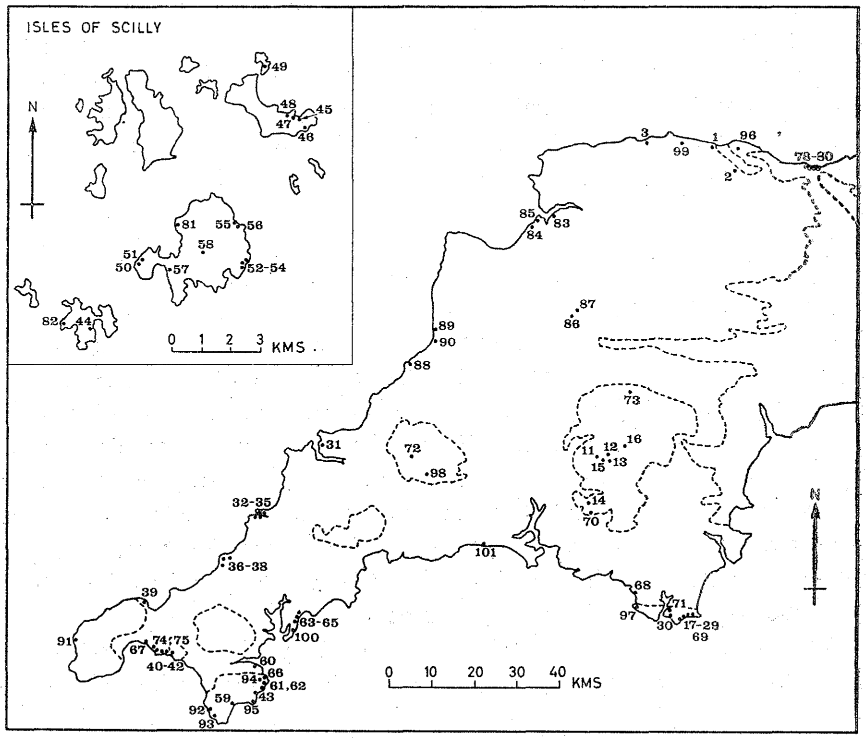

Fig. 2. Distribution of sample sites

a selection of sites. Index properties also were measured from a selection of samples.

As previously noted by many authors it is frequently possible to divide the head into two. The lower division — the Main Head — is coarser in texture, often containing large blocks of solid rock over one metre across, and comprises the bulk of the deposits. The depth of Main Head in coastal sites can be as much as 20 m. The Upper Head has been referred to as such by BARROW (1906), ARKELL (1943), WATERS (1964), STEPHENS (1966), and MITCHELL and ORME (1967). In addition COOMBE and FROST (1956) and CLAYDEN and MANLEY (1964) describe the higher than expected silt content of soils in the Lizard and Dartmoor respectively. The Upper Head is finer in texture, and rarely more than 1.5 m deep. Whilst all the sections visited show Main Head, the Upper Head is sometimes missing.

MAIN HEAD

The analysis of the sediment samples is now discussed. The sediment characteristics of the Upper Head are summarised in Table I. The frequency distribution of mean particle size for Main Head is shown in Figure 3. The mean particle size va-

Table I

Summary of sediment characteristics of Main Head

	Mean	Standard Deviation
Mean particle size	−1.10 ∅	2.02 ∅
Skewness	0.31	0.33
Sorting value	4.19	0.88
Silt %	38.4	14.4

lue is — 1.10 ∅ with an imperfect positively skewed distribution. The standard deviation of 2.02 ∅ is quite large and indicates the considerable variability of the sediments. The irregular outline of the histogram suggests that the variability is such that an even larger number of samples may be required to produce a smooth distribution.

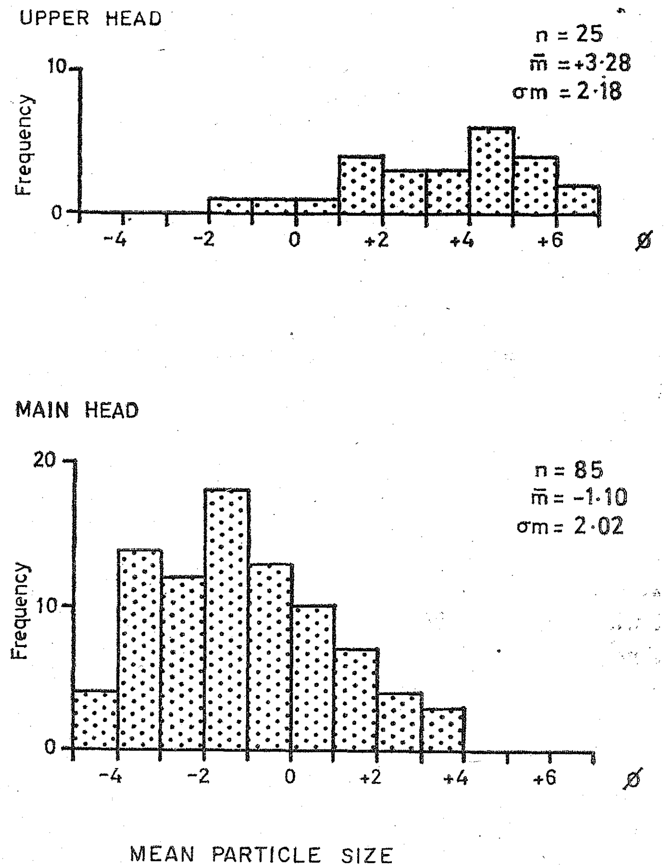

Fig. 3. Frequency distribution of mean particle size, Main and Upper Head

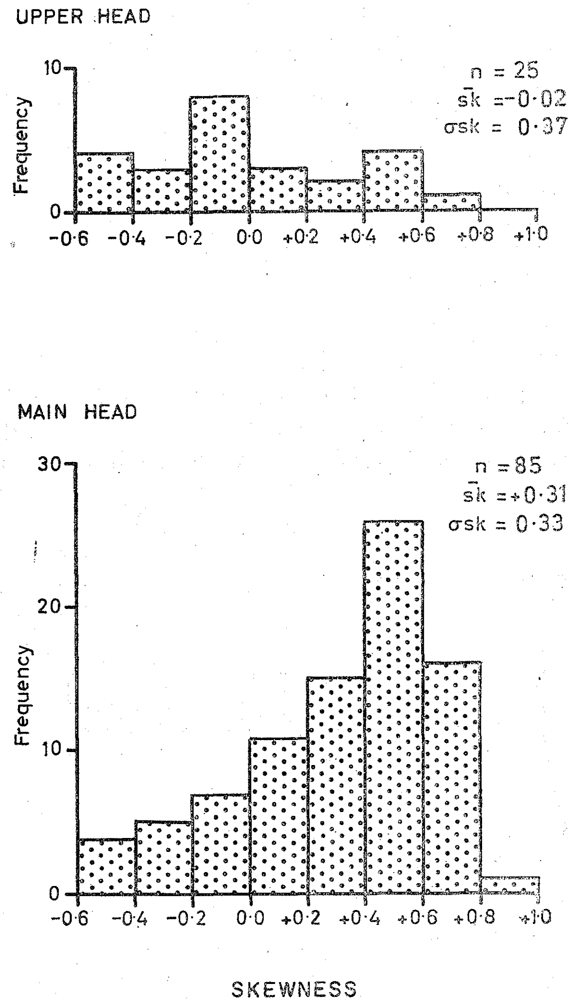

Fig. 4. Frequency distributions of skewness values, Main and Upper Head

Figure 4 shows the distribution of skewness values. The Main Head is clearly positively skewed, with a mean skewness value of +0.31. The distribution of skewness values is itself negatively skewed, and the standard deviation of 0.33 again reveals considerable variability. The dominant positive skewness of the Main Head is to be expected, since the material represents a weathering mantle which has suffered indiscriminate mass movement with little or no selection of particle size. Thus the positive skewness typical of weathered bedrock, as described by KRUMBEIN and TISDEL (1940), is dominant in deposits of Main Head. The frequency distribution of the coefficient of sorting for Main Head is shown in Figure 5. The values follow a compact normal distribution, with a mean of 4.19 and a standard deviation of

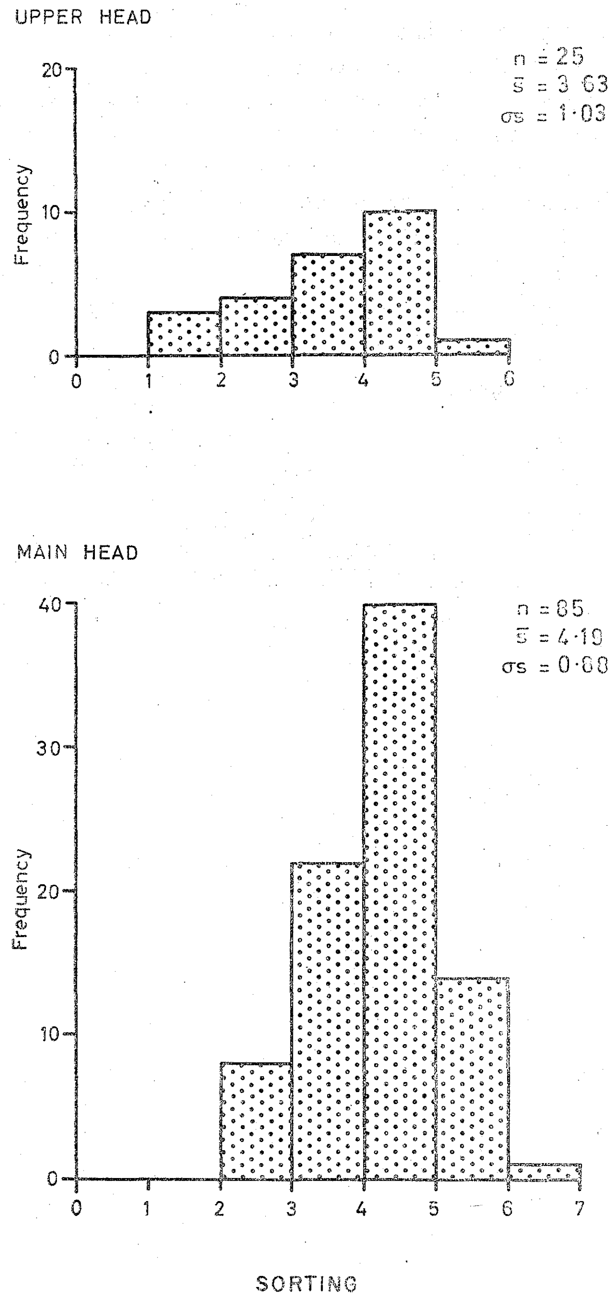

Fig. 5. Frequency distributions of sorting values, Main and Upper Head

0.88. According to FOLK and WARD's (1957) verbal scale of values for the sorting coefficient the Main Head falls entirely into the very poorly and extremely poorly sorted categories. This is consistent with the lack of selection of material during mass movement. Silt content represented as a fraction of the fines (less than 2 mm grade) was considered to be a factor with potential significance, particularly with regard to the origin of the Upper Head. This information was duly abstracted from the particle size distribution curves. The distribution of silt content is seen in Figure 6 to be approximately normal for the Main Head, with a mean value of 38.3%.

The relationships between the various sedimentary characteristics of the Main Head are next considered. Correlation tests were run comparing each pair of characteristics separately over the total population of 85 samples. The correlation ma-

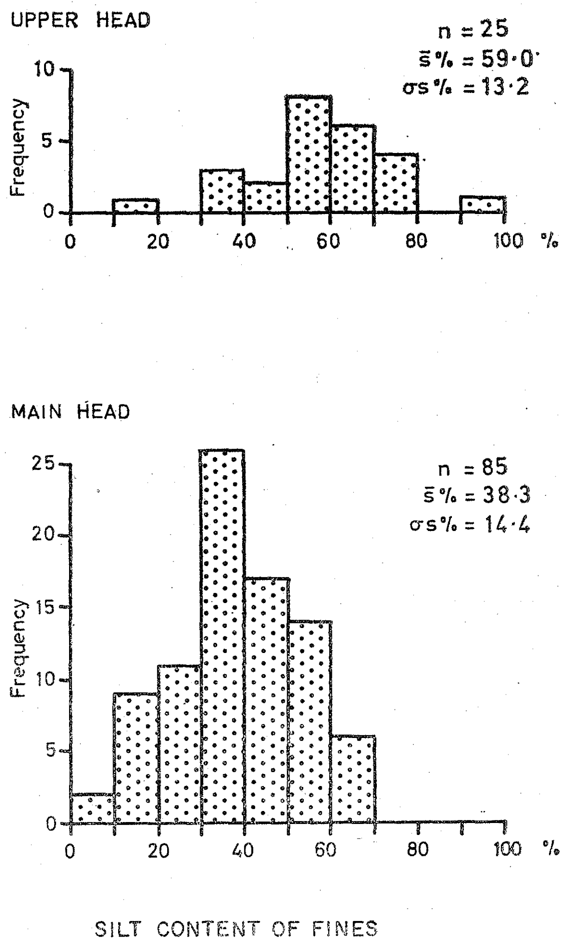

Fig. 6. Frequency distributions of silt content, Main and Upper Head

trix is shown in Table II. Skewness and sorting both show significant correlations with mean particle size, in this case the independent variable. The correlation between mean particle size and skewness shows an r value of —0.66, which is significant at the 99.9% level. This means that there is a strong tendency for coarse grained head to be positively skewed, whilst finer grained deposits are progressively more negatively skewed. This ties in well with the positive skewness of weathered bedrock.

Table II

Correlation matrix of Main Head sediment characteristics

	Mean	Sk.	So.
Mean	+1.00 (*)	−0.66 (*)	+0.30 (+)
Sk.		+1.00 (*)	−0.13 (n.s.)
So.			+1.00 (*)

Significance levels indicated as follows:
* 99.9%
+ 99.% n.s. <95%

It is suggested that the coarsest head tends to be that which has suffered least movement, hence it tends to retain the skewness characteristics of the undisturbed regolith. As shown elsewhere (MOTTERSHEAD, 1971) the head suffers a reduction in grain size during transport. The finer grained head then begins to take on the characteristic of transported sediment (*vide* KRUMBEIN and TISDEL). A positive correlation is indicated between mean particle size and sorting coefficient. This correlation is significant (99%), but weak (r = +0.28). This means that the finer the mean grain size, then the more poorly sorted the head tends to be. This is interpreted as meaning that finer heads tend to have a wider spread of grain size. The correlation is only low, however, and probably does not merit undue attention.

Particle shape was assessed for 35 samples, as described in the Appendix. The frequency distribution of roundness values is displayed in Figure 7. Each sample value is derived from the mean roundness value of 50 stones at each site. This shows a distribution slightly positively skewed: i.e. skewed to greater roundness. It is suggested that this reflects a slight bias in sampling. Five samples are included from sites at which it is probable that the head deposits are derived from previously water lain deposits (either fluvial or marine), and they hence include material more rounded than a head derived from *in situ* bedrock. The logarithmic scale on which roundness is based also contributes to the skewness. The mean roundness value is 0.225, which falls well within M. C. POWERS' (1953) angular category. The dominance of the angular class is shown by the fact that it is the modal class in all but ten of the thirty

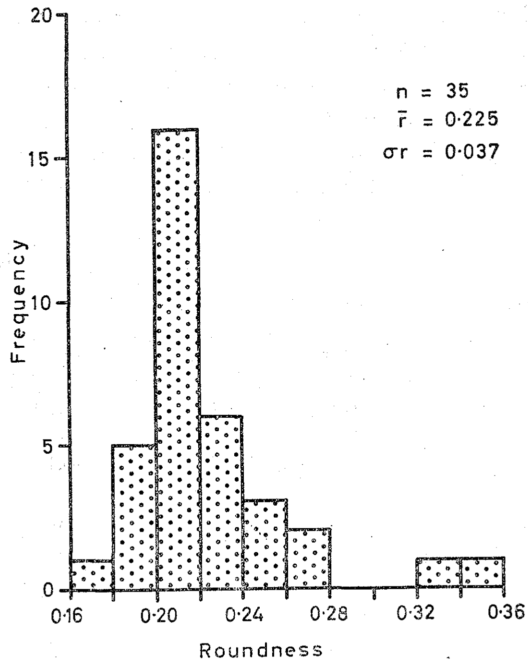

Fig. 7. Frequency distribution of roundness values, Main Head

five samples. The standard deviation of roundness is 0.037, a figure which spans less than half of the class interval of the angular class. This further emphasises the angular nature of the head. Thus the subjective observations of other writers from BORLASE onwards concerning the angularity of the head are borne out by the quantitative analysis applied here.

Preferred orientation was calculated for 52 samples of Main Head. The distribution of orientation strength values is shown in Figure 8, having a mean value of 52.35%. This represents a fairly high degree of preferred orientation, when compared to that shown by other types of deposit (G. S. P. THOMAS, 1967). This marked orientation confirms those found by previous workers (E. and S. WATSON, 1967; R. P. KIRBY, 1967) for head deposits. The negative skewness shown by the distribution of orientation strength value suggests that there is an optimum value to which it develops. It may be that orientation develops and strengthens during solifluction up to a maximum value. Thus the long tail on the negative side of the mean may represent deposits in which the strength was not fully developed before the material reached the point at which the measurements were taken. Figure 9 shows the relationship between mean direction of orientation of each sample, and the azimuth of the slope down which it has moved. This is based on a sample of 36 measurements. In several cases the solifluction slope is obscured by more recent deposits, such as dune sand. Where the sample represents head which has moved

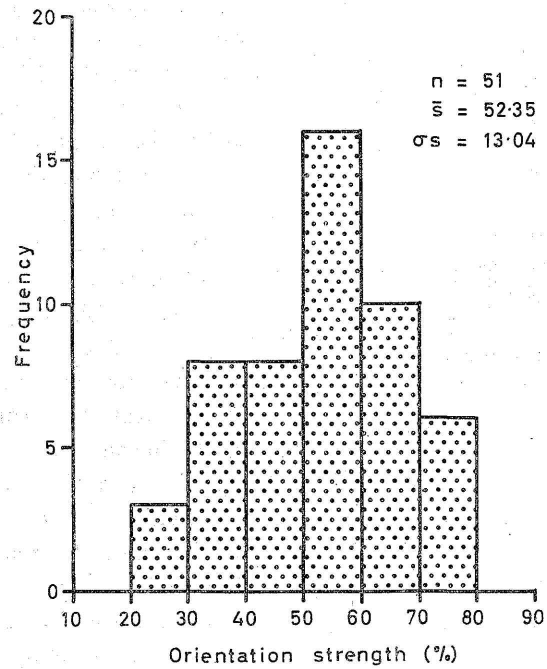

Fig. 8. Frequency distribution of orientation strength, Main Head

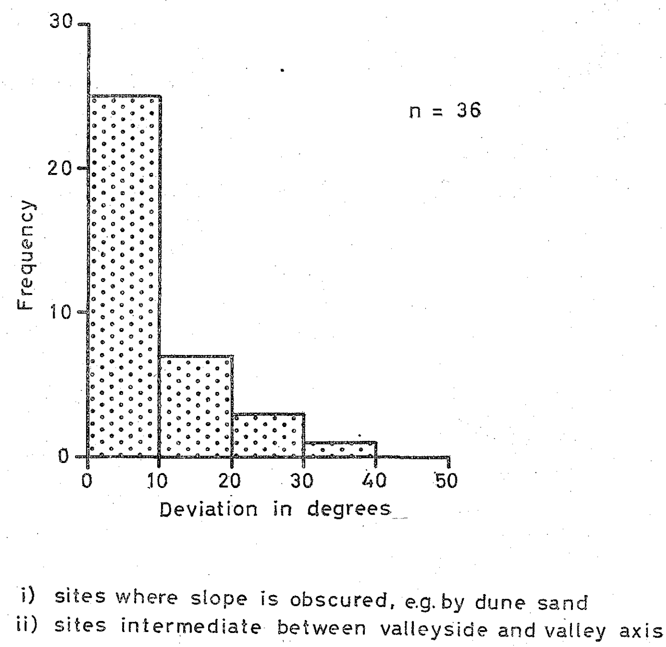

Fig. 9. Deviation of preferred orientation from azimuth of slope, Main Head

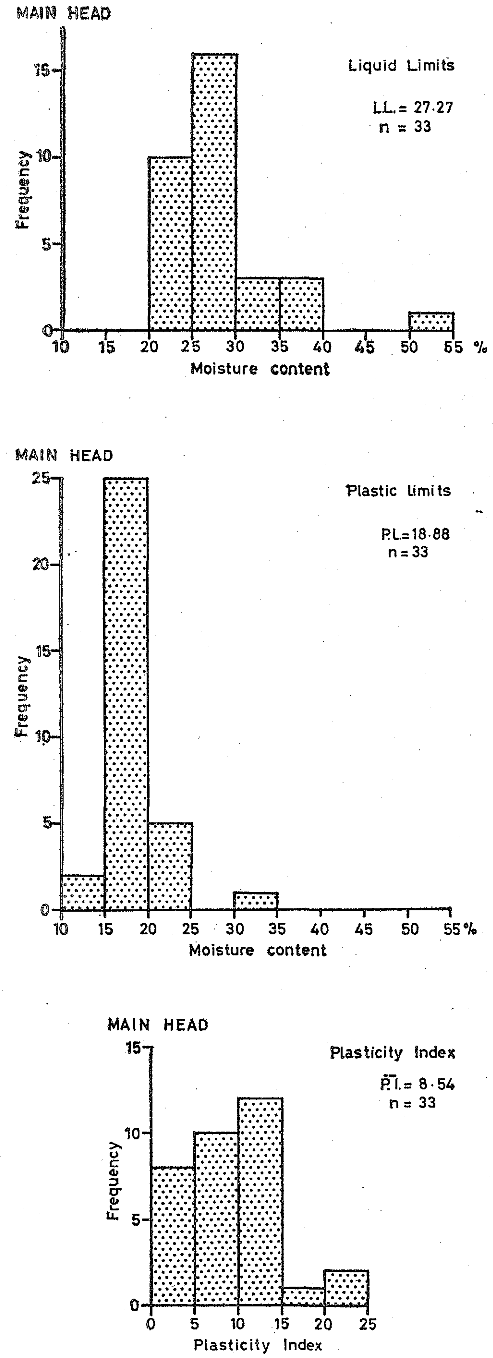

Fig. 10. Frequency distribution of index properties, Main Head

straight down a valley side, or along a valley axis, then there is no problem in determining the azimuth of the slope concerned. At the intersection between valley slope deposit and valley bottom deposit, the direction of flow is along an indeterminate line somewhere between the two. Thus samples in this situation were excluded.

Figure 9 shows a Poisson-type distribution. Twenty-five of the thirty-six samples show a deviation of their mean of less than 10° from the slope azimuth. The number of deviations exceeding 10° falls off very rapidly, with a maximum deviation of 35°. Thus the consistency of the relationship between preferred orientation of stones in Main Head, and the slope across which they have flowed is amply demonstrated.

The index properties are summarised in Figure 10. The frequency distribution of liquid limits is positively skewed, with a mean of 27.27 and the majority of values falling in the 20 to 30 range. The plastic limits show the same positively skewed pattern, but with a much more tightly restricted range. The distribution of plasticity index values is rather irregular. With a mean value of 8.54 and the vast majority of values below 15, the head is characterised by low plasticity. This is attributable to the generally low percentage (never exceeding 40) of clay in the samples. These values are entirely consistent with those reported from currently active periglacial regions, by authors who have studied contemporary solifluction processes. A. L. WASHBURN (1970) investigated liquid limit values as an essential soil property in mass movement in West Greenland, whilst C. HARRIS (1972) quotes index properties from soils involved in solifluction movement in northern Norway. The significance of the low liquid limit values in terms of process, means that only a limited amount of water is required to bring the sediment to a state of potential flowage.

As far as the Main Head is concerned, the results would suggest that there is no simple quantitative definition of the sediment. Of the granulometric characteristics, only the sorting value has a reasonably restricted range. Mean particle size and skewness both show such variability as to have limited value as diagnostic characteristics, unless one is considering a very large population of samples. The roundness, orientation, and orientation strength characteristics present a more distinctive aspect to the head deposits and it is suggested that these, taken together with the sorting value, may provide an assemblage of characters unique to bedrock--derived head deposits.

The wide variability in quantitative characteristics revealed by the above data is suggested by the appearance of the head deposits in the field. It can differ widely in nature and appearance from one locality to another, and additionally considerable variation can be seen in the depth of a single deposit. The crude stratification of head into layers of differing calibre is a widely noted feature. The variability of one characteristic, mean particle size, is shown in Table III, where pairs of samples taken from 13 sites show the degree of variation found. Figure 11 shows the range of variation of the three granulometric parameters in six contiguous samples of what is visually an apparently homogeneous deposit. One must conclude, therefore, that as far as quantitative characteristics are concerned, the most outstanding property of the Main Head deposits is their variability.

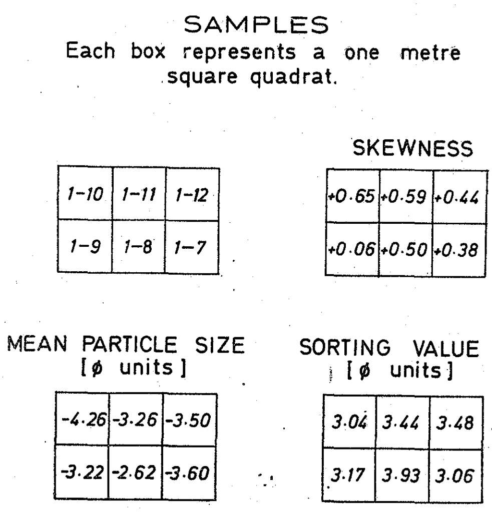

Fig. 11. Variability in sediment characteristics at one site — Porlock Weir G. R. SS 868476

UPPER HEAD

The Upper Head was observed at many sites during the present study. There are several problems, however, associated with the investigation of the Upper Head. First, since it occurs at the top of the sections, it is often inaccessible except when

Table III

Variability of mean particle size of Main Head in vertical section (ø units)

Site	Lower Sample	Upper Sample	Coarser/Finer Upwards
12	+2.26	−0.96	C
17	+0.42	+1.96	F
19	+2.22	+1.88	C
21	+0.92	−3.02	C
22	−0.56	−4.46	C
28	−3.48	+1.72	F
30	+0.48	−1.98	C
33	+1.84	−1.16	C
39	−4.24	−2.34	F
40	−1.54	−0.60	F
41	−0.06	+2.22	F
50	−1.70	−3.60	C
52	−2.34	−0.28	F

the sections themselves are less than 3 m deep. Detailed observations, even of such simple variables as depth, are possible only when the exposure can be approached. Thus although the Upper Head is often visible, the opportunities for close examination are far less frequent. Secondly, there is the problem of alteration by recent or contemporary processes. Weathering and soil formation can drastically alter the nature of the Upper Head. In the Scilly Isles, for example, the deposit is silty and consequently weathers readily. This results in a podsol leached to a depth of 0.5 m or more, and grey in colour, with a zone of Fe accumulation at the base. Loss of mass and structure accompany this weathering process. Surface erosion on slopes destroys and removes the Upper Head, thus rendering it impossible to gauge the original depth and extent. Thirdly, there is the problem of distinguishing the Upper Head from adjacent deposits. There is considerable overlap in quantitative sediment characteristics between Main and Upper Head. This overlap is apparent in field exposures also. Often it appears that there has been some mixing between the two deposits thus making it difficult to define a junction between them. At other sites the Main Head becomes finer upwards, grading into an Upper Head. At sites where contemporary deposition of slope material has taken place, the Upper Head is buried beneath this more recent material. Since both deposits are the result of mass movement on slopes a further problem of definition is posed. As a generalisation the more recent material is looser in texture and of a more dull colour, and often contains the contemporary soil. In sections adjacent to ploughland it is evident that the top 0.5 m may have been affected by agricultural activity. In seeking undisturbed fossil Upper Head deposits, then, the top 0.5 m of sections was usually discounted.

The main quantitative characteristics of Upper Head are illustrated in the form of histograms in Figures 3 to 6 for ease of comparison with the Main Head. Table IV summarises the characteristics of the Upper Head.

The mean value of mean particle size is —3.28 ∅ which illustrates the relative fineness of the Upper Head. The standard deviation value of 2.18 ∅ is quite high despite the small sample number, and shows that in respect of this characteristic

Table IV

Summary of sediment characteristics of Upper Head (25 samples)

	Mean	Standard Deviation
Mean particle size	+3.28 ∅	2.18 ∅
Skewness	−0.02	0.37
Sorting	3.63	1.03
Silt %	58.1	13.2

the Upper Head is more variable than the Main Head. The distribution of means is negatively skewed in contrast to those of the Main Head. The fact that for this characteristic the sample values are skewed towards each other, and the overlap in values, indicate the difficulty in categorising samples in the middle of the range.

The values of skewness again show a marked contrast with those of the Main Head (Fig. 4). The Upper Head has a mean skewness value of —0.02, indicating an almost normal curve. The standard deviation of skewness values of the Upper Head (0.37) is again greater than for the Main Head (0.33), again indicating the greater variability of the former. Both distributions of skewness are themselves skewed in opposing directions, showing the same overlapping relationships as the distributions of mean values. The Upper Head shows a slightly higher degree of sorting (3.63) than the Main Head (Fig. 5), with a few samples even reaching the poorly sorted class. This slight degree of sorting may be sufficient to indicate that some process of selection has been operative during the formation of these deposits. The distribution of silt content (Fig. 6) is shown to be approximately normal, as for the Main Head. Although there is some overlap between the two heads, there is a large difference in the mean values, 59.0% for the Upper Head against 38.3% for the Main Head.

Comparison of the two histograms of each characteristic enables the difference between the two types of head to be assessed. Each pair of histograms was compared using the chi-squared test; the results are shown in Table V. The null hypothesis in each case was that there was no significant difference between the two heads. There is a clear distinction between the two types of head in respect of mean particle size and silt content. The difference in skewness is also significant. The sorting and

Table V

Chi-squared test of difference in sediment characteristics between Main and Upper Head

	Chi²	D.F.	Significance level (%)
Mean	56.98	7	99.9
Skewness	18.05	6	99
Sorting	7.60	3	< 95
Silt % fines	27.98	4	99.9

kurtosis characteristics show no clear distinction between the two sets of samples. In addition to the distinction between the two types of deposit in terms of their field characteristics, therefore, they are shown to be different also in three out of four of the laboratory-derived characteristics.

It must be remembered, however, that though there may be significant differences between the overall sets of data, these cannot readily be applied to the identification of individual samples. The degree of overlap between Main and Upper Head which occurs in each characteristic, even where there is a statistically significant difference, precludes the use of these results for that purpose. Figure 12 shows the overlap in the two heads. It is seen that in spite of the statistically highly significant difference between them the amount of overlap comprises at least half of envelope of each type of deposit.

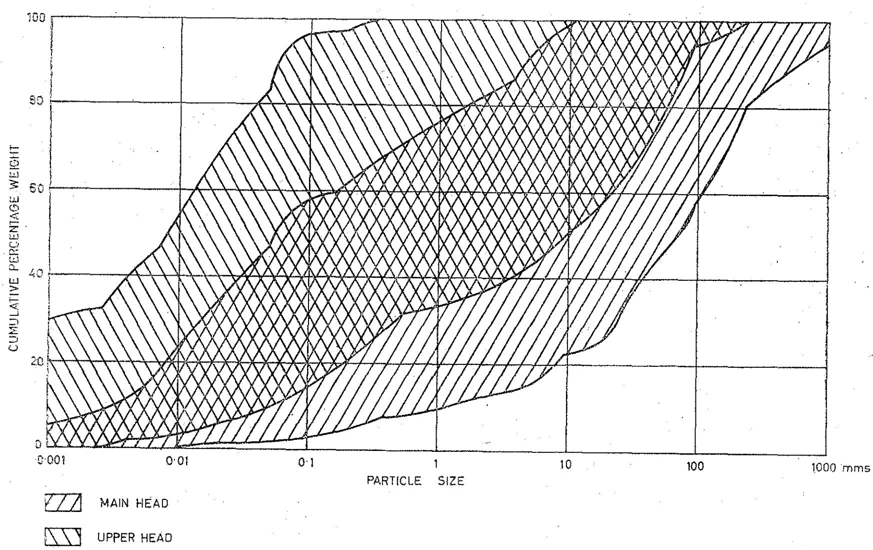

Fig. 12. Overlap between particle size distributions of Main and Upper Head

The quantitative sedimentary properties of the Upper Head have already been described. Closer study of the deposits, however, reveals a number of interesting features. Despite the low mean particle size of +3.28⌀, the Upper Head contains a significant amount of stony and boulder material. Figure 13 shows the frequency distribution of stone content of the Upper Head samples. The mean stone content

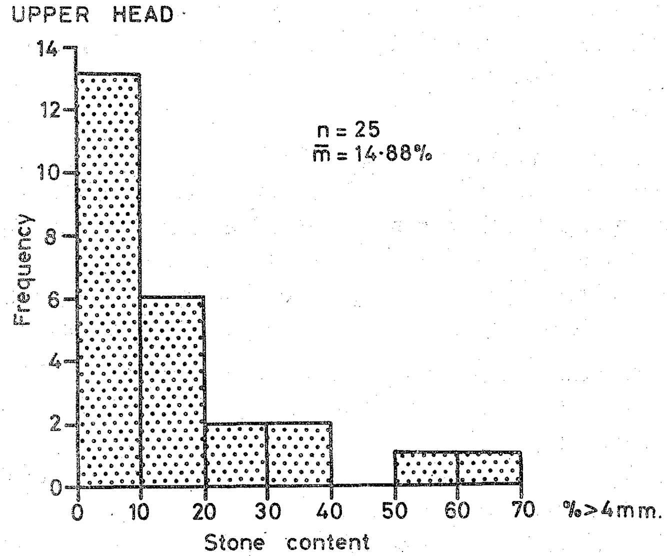

Fig. 13. Stone content of Upper Head

is 14.88% and the frequency of higher stone content falls away rapidly. In the field the stones occur usually scattered sparsely throughout the Upper Head. Sometimes they attain boulder dimensions. Associated with the coarse grained igneous rocks, the granites and gabbro, boulders up to 2 m across occur in this layer. The stones are usually angular in shape, although the boulders may have their corners rounded off.

Within the Upper Head, stones are widely scattered, and therefore orientation data are difficult to collect. Only cursory measurements were taken, which however enable two conclusions to be drawn. First, the Upper Head possesses a preferred orientation of its included stones, just as does the Main Head. Although in one of the three samples measured the orientation strength value is only 25.3%, the other two samples show values comparable to the Main Head. Secondly, the preferred orientation lies in much the same direction as that the Main Head, i.e. parallel to the slope azimuth. This is illustrated by the section at G. R. SV 895102 where the two sample points include one each from the Main and Upper Head. The difference in mean orientation is only 4.6 degrees. Thus it can be concluded from these limited observations that the Upper Head also was subjected to the pressures which induce preferred orientation. Furthermore these pressures operated in a downslope direction, suggesting that the Upper Head also is the product of downslope mass movement.

The granulometry of the Upper Head shows a relatively high silt content, a feature which needs explanation. Ignoring the stone and gravel content, only 6 out of 25 samples contain less than 50% silt. Furthermore, the top layer at Kennack (G. R. SW 737166) contains 81% of silt, and no stones, and is a deposit of remarkable fineness. The samples of stoneless Upper Head from the Scillies show a silt content of 70% and 66.2% respectively. Three possible explanations of this distinction will now be considered:

1. The higher silt content of the Upper Head may be due to a process of sorting during the transport and deposition of its constituent materials. Such a process would have favoured silt at the expense of other grades of sediment. This hypothesis is consistent with the higher degree of sorting shown by the Upper Head, and would favour the idea of running water being responsible in some way for the deposits of Upper Head. Exactly how this might operate is as yet not clear.

2. It is possible that the process of vertical sorting by frost action described by CORTE (1966), affected the head after deposition to produce a silt-enriched horizon beneath the surface layer.

Against this hypothesis is that in many places there is no other evidence of frost action postdating the formation of the head. Often the junction between Main and Upper Head is completely undisturbed. Secondly, there is no evidence of a silt capping of stones within the upper layers, which would indicate a downward migration of silt. And thirdly, the platy soil structure, associated with this type of horizon does not appear to be present. The evidence, therefore, seems not to favour this hypothesis.

3. The higher silt content may represent a simple addition of silt grade material. This could take place as a result of the introduction of well-sorted material such as may take place by wind action. In this way the Upper Head may contain material comparable to loess. It is interesting to note that in places where the Upper Head is stoneless, a vertical prismatic cleavage can sometimes be recognised, a feature reminiscent of pure loess.

Often the Upper Head is structureless in section. In the Scillies, in contrast, the Upper Head, consisting of granitic stones set in a sand and silt matrix, clearly demonstrates some useful structures. Flow and swirl structures are apparent, in which stringers of quartz crystals and crystal aggregates can be seen indicating a former fluid downslope motion. Granite stones are sometimes seen from which a number of crystals have been detached and are trailing away in the downslope direction. This suggests the movement of a fluid mass around the disintegrating stone. In the Scillies the Upper Head also contains erratics, sometimes striated. Clearly they could not have been emplaced in their present position directly by ice.

On the basis of the above evidence the Upper Head would appear to have a two process origin. The high silt content suggests at least an admixture of windblown loess. This has been suggested by some writers, e.g. CLAYDEN and MANLEY, and is reinforced by the occurrence of an apparently pure loess at a few sites. The presence of stones in the Upper Head indicates that some mixing has taken place, and the preferred orientation of these stones reveals a downslope movement. This is supported by the flow structures in the Scillies, which suggests that the Upper Head reached its present position by a process of solifluction. The two processes involved are therefore the addition of silt, followed by solifluction which had the effect of mixing together the silt with the stones and other material.

CONCLUSION

Quantitative sediment characteristics are reported which describe 110 samples of head. They reveal a great variability in the nature of these deposits. There is a distinction between the Main Head, often massive, and a more silty Upper Head which also has a lower content of coarse material. The granulometric characteristics of Main and Upper Head are shown to be significantly different, although there is considerable overlap between them. It is therefore not possible to identify individual samples on this basis. As far as the Main Head is concerned, its most diagnostic quantitative characteristics are shown to be sorting value, roundness, preferred orientation, and orientation strength.

ACKNOWLEDGEMENTS

This work was carried out whilst the author was in receipt of a NERC Studentship. Thanks are due to Dr. C. EMBLETON for his supervision, and to the Cartographic Unit of the Department of Geography, Portsmouth Polytechnic for assistance with the illustrations.

APPENDIX OF TECHNIQUES

APPENDIX 1: PARTICLE SIZE DISTRIBUTION

Sites sampled for particle size distribution are indicated in Figure 1. At several sites two or more samples were taken to take account of vertical variations in the head.

Problems were raised by the coarseness of the material. To cope with the large boulders a collapsible metre square quadrat frame was employed. This was erected, placed on the face of the exposure, then photographed. After processing, the film was projected in the laboratory on to a metre square screen containing a grid of one hundred sampling points. The number of points intercepting the images of material exceeding 3.8 cm was counted. Thus the proportions of coarse material were available as percentages of the whole sediment.

Any distortion of the image on the film caused by angling of the camera can be corrected by aligning the screen such that the image of the quadrat frame is congruent with the metre square of the screen. Whilst this method may be liable to some inaccuracy, as for instance if the maximum diameter of a particular stone is obscured, it nevertheless enables an estimate to be made of material which would otherwise be too coarse to cope with.

For material of size smaller than 3.8 cm a sample weighing usually between 1,000 and 1,500 gm was taken for laboratory analysis using procedures as described in the standard texts (KING, 1966: D. S. I. R., 1952).

The results were plotted initially as cumulative curves on semilogarithmic graph paper, plotting percentage weight along the arithmetic scale, and particle size along the logarithmic scale.

For the statistical analysis, the grain size data were transformed to phi (ø) units (see KING, p. 276—278). In phi units negative numbers mean increasing grain size, whilst positive numbers refer to the fine fraction. This has the advantages of normalizing the frequency distribution curves of many samples, and of producing numbers easier to deal with in computation. The various characteristics were calculated by the following formula (ø 10 indicates the ø value of the 10 per cent point on the cumulative percentage scale).

$$\text{Mean particle size} = \frac{\varnothing 10+\varnothing 30+\varnothing 50+\varnothing 70+\varnothing 90}{5}$$

$$\text{Skewness} = \frac{\varnothing 16+\varnothing 84+2\varnothing 50}{2(\varnothing 84-\varnothing 16)} + \frac{\varnothing 5+\varnothing 95-2\varnothing 50}{2(\varnothing 95-\varnothing 5)}$$

$$\text{Sorting} = \frac{\varnothing 85+\varnothing 95-\varnothing 5-\varnothing 15}{5.4}$$

The property of skewness of a sediment shows how closely it approaches a normal frequency distribution. With negative skewness there is a tail of coarse sediment; positive skewness denotes a tail in the finer direction. Skewness values fall between -1 and $+1$, with a normal distribution having a skewness value of zero.

Sorting values of sediments normally range between 0.2 and 8.0.

APPENDIX 2: PARTICLE SHAPE

The technique used was that described by M. C. POWERS, using a visual chart. Six classes of roundness are defined on a quantitative basis by the formula:

$$\text{Roundness value} = \frac{\text{average radius of curvature of corners}}{\text{radius of maximum inscribed circle}}$$

Illustrations of each class of roundness are provided by POWERS.

Using a sample size of 50, stones from the head were compared to the chart and assigned to the class to which they most closely approximated. Thus a frequency distribution was produced, from which it was possible to derive mean values.

APPENDIX 3: STONE ORIENTATION

Measurements of the azimuths of long axes of stones were made, using a sample size of 50. Only stones geater than 2 cm in length were used, with an a:b axis ratio greater than 1.5:1. The long axis was defined as the axis normal to the minimum projection place of the stone, after KRUMBEIN (1939). Each stone was exposed on the working face by paring away the surrounding matrix. The long axis was determined and a brass (non-magnetic) rod was inserted parallel to it as the stone was removed. The azimuth of the rod was determined using a field compass, and the results plotted as a rose diagram. Orientation strength was calculated as a percentage using Thomas' formula, as follows

$$S\% = \left\{100 - \left[\frac{\Sigma(x-\bar{x})}{k}\right]100\right\}$$

Where x = observed values of azimuth
$\bar{x}$ = mean of observed values of azimuth
k varies according to sample size, e.g. with $n = 25$ $k = 1.125$
$n = 50$ $k = 2.250$
$n = 100$ $k = 4.500$

APPENDIX 4: INDEX PROPERTIES

These are well described in standard texts, e.g. D.S.I.R. (1952), MEANS and PARCHER (1964), YONG and WARKENTIN (1966). The index property tests utilize material passing the B.S. No. 36 Sieve (0.42 mm mesh).

The Plastic Limit is defined as the minimum water content, expressed as a percentage of the dry weight of the sample, at which a thread of soil can be rolled out to a diameter of 3 mm without crumbling. The thread is rolled out under the palm of the hand until crumbling takes place, then the water content is determined.

The Liquid Limit is determined using a standardized instrument. The saturated sediment is placed in the brass cup of the instrument and a triangular groove is cut through it with a special tool. The cup is then subjected to a number of standardized blows by dropping through a height of 1 cm so that the two halves of the sediment flow together and close the groove. The Liquid Limit is defined as the percentage water content at which twenty-five such blows are required to close the groove.

The Plasticity Index is defined as the difference in water content between the Liquid and Plastic Limits.

References

ALBERS, G., 1930 — Notes on the tors and clitters of Dartmoor. *Transactions of the Devonshire Association for Science, Literature and Art*, 62; p. 373—378.

ARKELL, W. J., 1943 — The Pleistocene rocks at Trebetherick Point, North Cornwall; their interpretation and correlation. *Proceed. Geologists Association*, 54; p. 141—170.

BARROW, G., 1906 — The geology of the Isles of Scilly. *Memoir Geol. Survey of Great Britain.*

BOASE, H. S., 1832 — Contributions towards a knowledge of the geology of Cornwall. *Transactions Royal Geol. Society of Cornwall*, IV; p. 166—475.

BORLASE, W., 1758 — Natural History of Cornwall. Oxford.

CLAYDEN, B., and MANLEY, D. J. R., 1964 — The soils of the Dartmoor granite. *In*: Dartmoor Essays, ed. I. G. Simmons; p. 117—140.

COOMBE, D. E. and FROST, L. C., 1956 — The nature and origin of the soils over the Cornish serpentine. *Jour. Ecology*, 44; p. 605—615.

CORTE, A. E., 1966 — Particle sorting by repeated freezing and thawing. *Biuletyn Peryglacjalny*, no. 15; p. 175—240.

DE LA BECHE, H. T., 1839 — Report on the geology of Cornwall, Devon and West Somerset. *Memoir Geol. Survey of Great Britain.*

D. S. I. R. Road Research Laboratory, 1952 — Soil mechanics for road engineers.

FOLK, R. L., and WARD, W. C., 1957 — Brazos River Bar: a study in the significance of grain size parameters. *Jour. Sed. Petrol.*, 27; p. 3—26.

GODWEN-AUSTEN, R. A. C., 1851 — On the superficial accumulations of the coasts of the English Channel and the changes they indicate. *Quarterly Jour. Geol. Society*, 7; p. 118—136.

HARRIS, C., 1972 — Processes of soil movement in turf-banked solifluction lobes, Okstindan, northern Norvay. *Inst. British Geographers Spec. Publ.*, No. 4; p. 155—174.

KING, C. A. M., 1966 — Techniques in geomorphology. Edward Arnold, London, 342 p.

KIRBY, R. P., 1967 — The fabric of head deposits in South Devon. *Proc. Ussher Soc.*, 1, VI; p. 288—290.

KRUMBEIN, W. C., 1939 — Preferred orientation of pebbles in sedimentary deposits. *Jour. Geology*, 47; p. 673—706.

KRUMBEIN, W. C., and TISDEL, W. F., 1940 — Size distribution of source rocks of sediments. *American Jour. Sci.*, 238; p. 296—306.

MEANS, R. E., and PARCHER, J. V., 1964 — Physical properties of Soils.

MITCHELL, G. F., and ORME, A. R., 1967 — The Pleistocene Deposits of the Isles of Scilly. *Quart. Jour. Geol. Soc. London*, 123; p. 59—92.

MOTTERSHEAD, D. N., 1971 — Coastal head deposits between Start Point and Hope Cove, Devon. *Field Studies*, 3; p. 433—453.

ORME, A. R., 1960 — The raised strandlines of South Devon. *Field Studies*, 1; p. 109—130.

POWERS, M. C., 1953 — A new roundness scale for sedimentary particles. *Jour. Sedimentary Petrology*, 23; p. 117—119.

PRESTWICH, J., 1892 — The raised beaches and „head" or rubble drift of the south of England; their relation to the valley drifts and to the glacial period; and on a late post glacial submer gence. *Quarterly Jour. Geol. Society*, 48; p. 263—343.

SEDGWICK, A., 1825 — On the origin of alluvial and diluvial formations. *Annals of Philosophy*, N. S., 9: p. 241—257; 10: p. 18—37.

STEPHENS, N., 1961 — Re-examination of some Pleistocene sections in Cornwall and Devon. Royal Geological Society Cornwall: *Abstracts of the proceedings of the Fourth Conference of Geologists and Geomorphologists working in the southwest of England.* Camborne.

STEPHENS, N., 1966 — Some Pleistocene deposits in North Devon. *Biuletyn Peryglacjalny*, 15; p. 103—114.

TE PUNGA, M. T., 1957 — Periglaciation in Southern England. *Tijdskrift Koningslink Nederlands Aardrijks Genootschaap*, 74; p. 401—412.

THOMAS, G. S. P., 1967 — Simplified technique for determining two-dimensional orientation strength of till fabric data. *Northern Universities Geog. Jour.*, 8; p. 23—27.

USSHER, W. A. E., 1878 — The chronological value of the Pleistocene deposts of Devon. *Quarterly Jour. Geol. Society*, 34; p. 449—458.

WASHBURN, A. L., 1970 — Instrumental observations of mass wasting in an Arctic climate. *Ztschr. f. Geomorphologie*, Suppbd. 9; p. 102—118.

WATERS, R. S., 1957 — Differential weathering and erosion on oldlands. *Geogr. Journal*; 123; p. 503—513.

WATERS, R. S., 1961 — Involutions and ice wedges in Devon. *Nature*, 189; p. 389—390.

WATERS, R. S., 1964 — The Pleistocene legacy to the geomorphology of Dartmoor. *In*: Dartmoor Essays, ed. I. G. Simmons; p. 73—96.

WATERS, R. S., 1965 — The geomorphological significance of Pleistocene frost action in southwest England. *In*: Essays in geography for AUSTIN MILLER, ed. J. B. WHITTOW and P. D. WOOD; p. 39—57; University of Reading.

WATSON, E. and S., 1967 — The periglacial origin of the drifts at Morfa-Bychan, near Aberystwyth. *Geol. Journal*, 5; p. 419—440.

YONG, R. N., and WARKENTIN, B. P., 1966 — Introduction to soil behavior. Macmillan.