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COASTAL HEAD DEPOSITS BETWEEN START POINT AND HOPE COVE, DEVON

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The morphological expression of the head deposits is described, demonstrating some simple topographic relationships. The sediment characteristics are described in quantitative terms, and systematic changes shown to take place during transport. An Upper Head is shown to be present, and clearly distinguishable from the Main Head. Index properties and frost susceptibility curves enable possible processes to be considered. The head deposits still cannot be dated with any precision.

INTRODUCTION

THE presence of head deposits in this part of the South Devon coast has been noted by several authors (Steers, 1946; Masson-Phillips, 1958; Orme, 1960) and has been mapped by the Geological Survey. Masson-Phillips describes the head as background to the presence of archaeological materials, whilst Orme considers it in relation to local raised beaches.

The term "head" was introduced into geological literature in 1839, when de la Beche used it to refer to certain types of superficial material. Dines (1940) used the term to refer to a local stony deposit which is the result of slow flow of material from higher to lower ground. This kind of solifluction is held to attain great proportions under periglacial conditions, and the term "head" has come to hold connotations of a periglacial environment.

There is no evidence that an ice sheet approached this part of South Devon during any of the cold phases of the Pleistocene. Its nearest approach would appear to be in Barnstaple Bay, some 80 kilometres to the north-west, during the Saale glaciation (Stephens, 1966), at which time the Fremington Boulder Clay was deposited. Nowhere else in Devon are far travelled glacial erratics found. At this time, with the ice front only 80 kilometres distant, South Devon can be expected to have suffered a cold climate similar to those obtaining at the margins of some present-day ice sheets. Other cold periods during the Pleistocene probably gave rise to similar climatic conditions in the area, though perhaps not quite so severe, since the ice front was at no other time so far south. During each cold phase periglacial conditions will have been operative in sculpting the landscape and producing landforms, which are well preserved since the area has never been overridden by an ice sheet.

Local bedrock, on which the head is developed, consists of two main types of schist (Ussher, 1903, 1904). The quartz-mica schists are the result of metamorphism of sedimentary rocks similar in nature to the Devonian sediments to the north. The second group, the green schists, is composed largely of hornblende, epidote and chlorite. Both types of schist have been intensely folded, resulting in considerable gnarling and puckering of the schistose laminations. Quartz veins, often very contorted, penetrate both types but particularly the mica schists. The latter are distinguished by their grey colour, shiny surface and generally better state of preservation. The green schists weather readily when exposed to the atmosphere and are often in a very friable condition. The schists as a whole are part of a anticlinal structural form, with much secondary folding, which results in the two types alternating in outcrop along the coast (Fig. 1).

The head deposits are best preserved in those parts of the coast which are relatively protected from marine erosion. Where the coastline is open to large waves generated by dominant south-west winds, the relatively unresistant head is easily eroded. Thus the stretch of coast between Bolt Head (725 359) and Bolt Tail (666 396) is devoid of head except for a small exposure at the exit of the lower Sewer Valley (697 376). Similarly the extremities of Prawle Point (773 350) and Start Point (830 370) have been denuded of any head that might have been there. Those parts of the coast, however, which are protected from the south-west preserve considerable spreads of solifluction deposits. The sheltered coasts of Hope Cove (673 398), Salcombe Harbour, Rickham Common and especially Lannacombe Bay, exhibit extensive deposits of head.

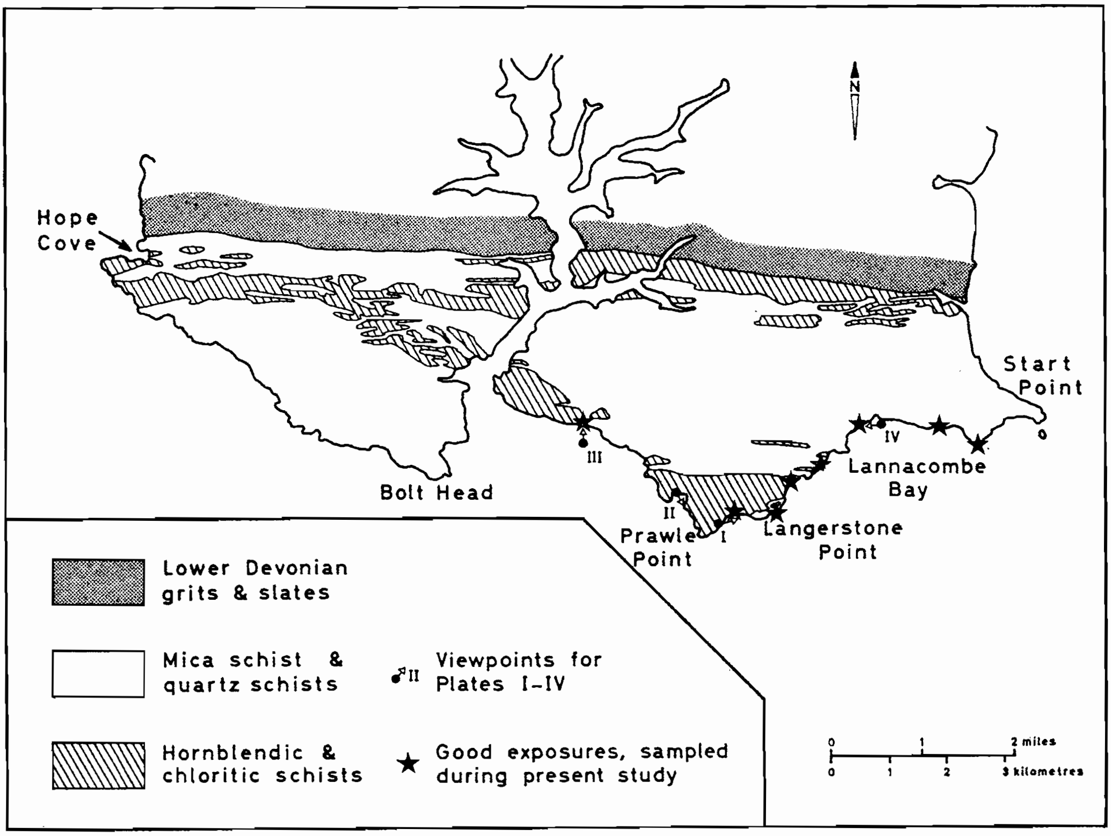

FIG. 1.
Geology.

Plate I.
View east from near Prawle Point. Three large crags overlook the apron of head which thins out seawards to Langerstone Point (right margin).

Plate II.
Signalhouse Point (771355). Craggy tors outcrop at the top of the slope, beneath them a blockfield. Cliffs cut in head are visible at bottom left.

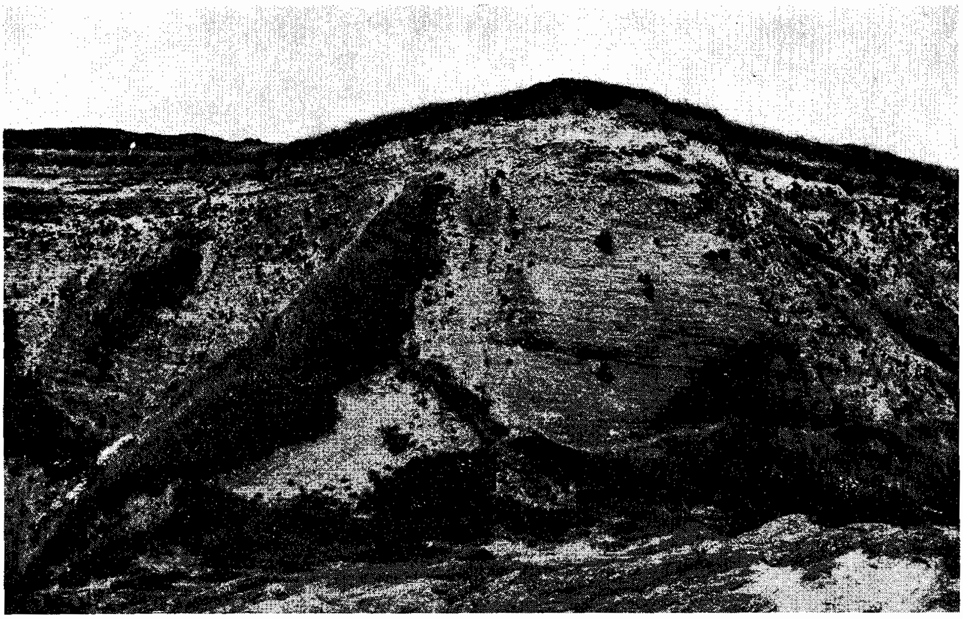

Plate III.
Section at Rickham Sands, exposing finely laminated Main head. At the top of the section dark soil overlies the pale Upper head.

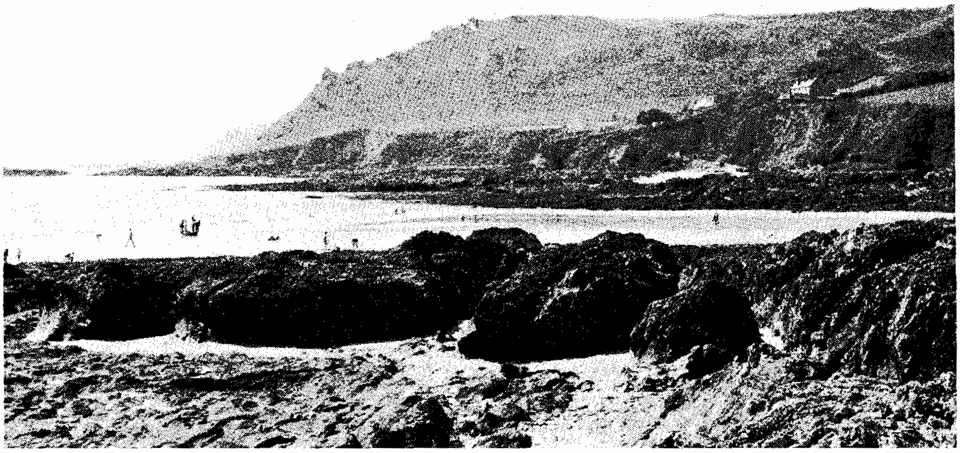

Plate IV.
View west from Lannacombe Bay. Tors overlook the apron of head deposits running along the coast. In the foreground is a raised shore platform.

MORPHOLOGY

The landforms associated with solifluction are very characteristic. The head, where preserved from marine erosion, forms a mantle of superficial material blanketing many of the slopes of the area and modifying the underlying solid rock relief. The head lies in a swathe below the steeper slopes of the solid bedrock which represent a former cliff line, and across the surface of former wave-cut benches. The slope angle of the degraded cliff line tends to be in the range 23–35°, contrasting strongly with the slopes on the head, which are generally below 10°. The profile of the solifluction slopes is gently concave, with the slope angle decreasing progressively away from the bedrock slope.

The depth of the head in section varies with distance from the bedrock slope and the shape of the underlying bedrock surface. Where the sea has cut the head back to a position close to the old cliff line, it is exposed in deep section. At Mattiscombe Sands (816 369) for instance, the head is 27–33 metres deep. At Langerstone Point (782 354) in contrast, the head extends out some 270 metres, and is reduced in depth to as little as 2 metres. Unevenness in the surface on which the head accumulated can cause rapid local variations in depth. Where the head lies over a gullied wave-cut platform, then it lies much deeper over the gullies.

Where the old cliff line is straight in plan, the head forms a bench running along its base. The width of the bench varies according to how far it has been trimmed back by marine erosion. Where the head has accumulated at the outlet of a gully in the cliffing, as below Lobeater Rock (781 356), then it forms a broad shallow fan, spreading out in this case to Langerstone Point. A third situation in which the head has accumulated is in the deep valleys which cut back into the old cliff line. Here it forms a fill in the valley floor, horizontal in cross section, and contrasting sharply with the steep valley sides. This is well seen in the valley which runs from Start down to Mattiscombe Sands.

Some of these morphological relationships are illustrated quantitatively in Figure 2. The different number of points on each graph is due to the difficulty of measurement in the field. It was not possible to measure all the variables at each sample point. The sample points for these data are all located between Prawle and Start Points. Graph (A) shows the relationship between depth of head and the height of the slope from which it is derived. Based on twelve sample sites it shows a strong positive correlation, with the correlation coefficient (r) equal to +0·76. This is significant at the 99 per cent level.

Figures 2B and C show changes in form of the head deposit with increasing distance away from the old cliff line. Since there is no marked break between the head terrace and the bedrock slope rising above it, the 100-foot contour is arbitrarily selected as representing the trend of the old cliff line. The values of distance from old cliff line are plotted on a logarithmic scale because the relationship may be expected to be exponential, which plots as a straight line on a semi-logarithmic graticule. Thus values of depth and slope change at a constant rate with respect to distance. Figure 2B illustrates quite clearly how the head thins away from the old cliff line. The r value of —0·76 is significant at the 99 per cent level. Figure 2C shows the decline in angle across the head terrace as it is traced away from the backing slope. The r value of —0·85 is significant at the 99·9 per cent level.

Associated with the head deposits are the outcrops of solid bedrock on the slopes overlooking the head and along ridge crests. These crags are formed of schists and

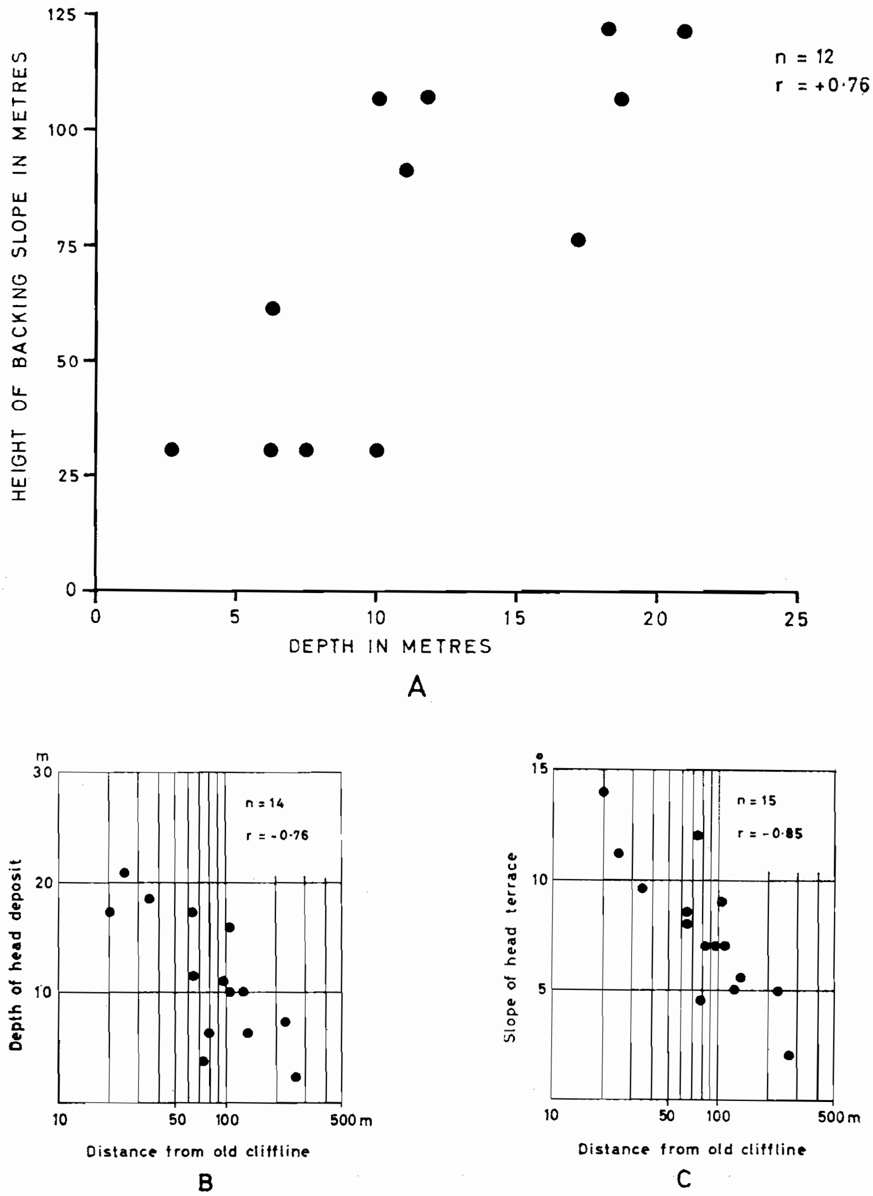

Fig. 2.
Graphs illustrating various morphological relationships of the head.

jagged in outline, their detailed form depending on the local jointing in the bedrock. Good examples, particularly prominent, exist at Gammon Head (765 356) and on the ridge running out to Start Point. Where the land has not been enclosed and cleared for agriculture, the slopes beneath these crags are littered with angular, frost-shattered blocks of schist. These often attain dimensions of a metre or more. They are well displayed on the slopes between Start Point and Peartree Point (819 366).

This association of tor, blockstream and head deposit (Fig. 3) occurs frequently in, and is characteristic of, the periglacial environment (Peltier, 1950). Waters (1964) has described analogous features on different bedrock—the granite upland of nearby Dartmoor. In detailed outline, the forms differ on account of the different type of jointing in the granite rocks, but overall the assemblage of landforms remains the same. Similar forms occur on Exmoor (Mottershead, 1967.)

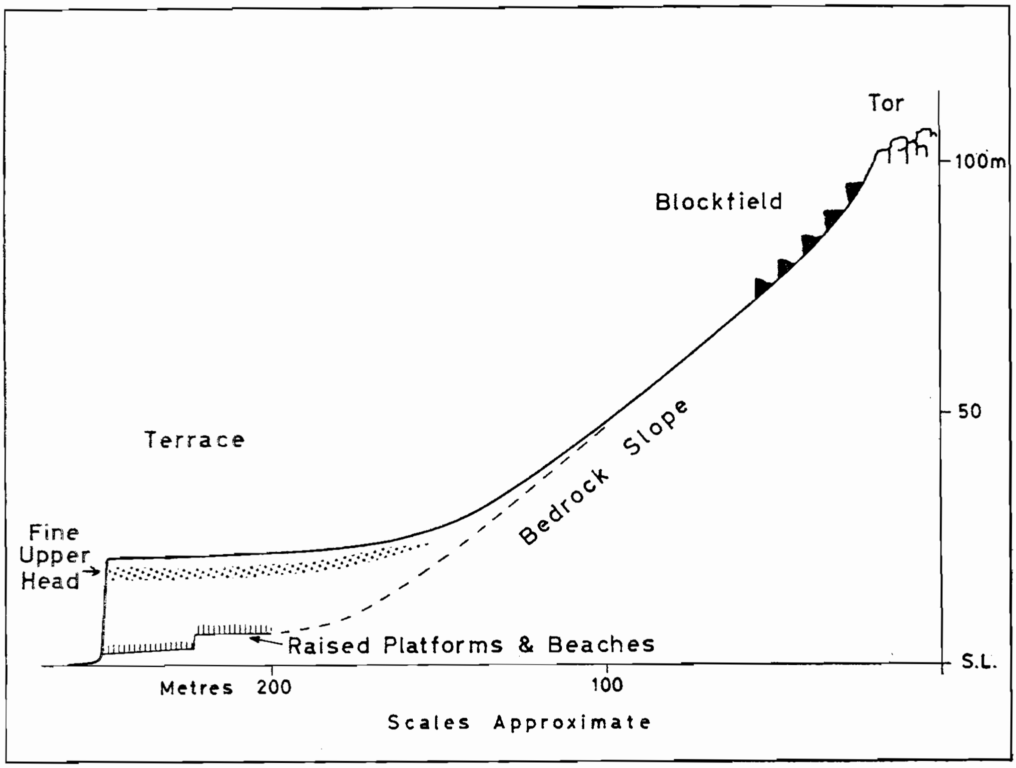

Fig. 3.
Generalized profile of the coastal cliffs.

Accepting Pullan's (1959) definition of a tor as "an exposure of rock *in situ*, upstanding on all sides from the surrounding slopes . . . formed by the differential weathering of a rock bed and the removal of the debris by mass movement", it is easy to understand how this landscape was fashioned. Massive solifluction selectively moved the weathered material, exposing bare rock at the surface as crags. This rock was then attacked by sub-aerial frost weathering and angular pieces of rock were shattered off to fall on the slopes below. Thus the head flowed down the slopes to collect at the base, carrying rafts of frost-riven bedrock. As the tors became progressively more exposed, they would be further attacked by frost weathering, giving rise to their present angular profiles.

SEDIMENTOLOGY

The sedimentology of the head can be studied in the numerous exposures which occur in the sea cliffs. These, however, are not always easy of access. The cliffs are often overgrown, for vegetation takes root quickly in the unconsolidated head material. The exposures are usually most fresh where there has been recent marine erosion at the base. This then creates the difficulty that the cliff cut in head is often vertical as a result, and only the bottom two metres or so are readily accessible. A further difficulty consequent upon erosion is that the cliff often suffers slumping, and it is often difficult to tell whether the head exposed at the base of the cliff is *in situ* or whether it is a slumped mass.

Size

The head material consists of the whole range of particle size from clay to boulders. It is basically a deposit of stones and boulders set in a matrix of red or red/brown sand and clay. Its poorly sorted character suggests that no sorting agent, such as running water or wind, has been active and the head is therefore the result of simple downslope mass movement.

The most striking characteristic of the head is its coarseness. Particle size analysis was carried out on eighteen samples. Of these, thirteen had a maximum particle diameter larger than —6 ϕ (65 mm.), whilst four were coarser than —8 ϕ (260 mm.),* and even coarser material exists elsewhere.

The size of the material within the head must initially be related to the breakdown of the bedrock, by chemical weathering and frost shattering. When joints are far apart, frost shattering will result in coarse blocks; where closer together, finer material will be produced. But since the bedrock from whence the head is derived is buried by the head itself, there is often no means of demonstrating this relationship in the field.

Some characteristics of the head are illustrated in Figure 4, in the form of frequency histograms. Diagram (A) shows mean particle size, with a mean value for all the samples of $-1 \cdot 28$ ϕ, and a standard deviation of $2 \cdot 21$ ϕ. The coarseness of the head deposits is demonstrated, and also the considerable variability, shown by the very broad base of the distribution. These characteristics are emphasized by diagram (B), showing percentage stone content, a stone being here defined as coarser than —2 ϕ (4 mm.). The mean value of 54 per cent, and standard deviation of 19 per cent, further underline the coarseness and variability of these deposits.

Diagram (C) shows the distribution of skewness values. The mean value of $+0 \cdot 23$ indicates a dominance of positively skewed head samples, although there is a significant tendency towards negative skewness.

Diagram (D) illustrates the near normal distribution of sorting values, with a mean value of 4·30. The well defined distribution, together with the relatively small standard deviation of 0·79, indicate that head is typified by a fairly narrow range of sorting values, in contrast to the wide variability of the characteristics described above. All the samples fall within the very poorly sorted and extremely poorly sorted categories (see King, 1966).

The effects of transport

In order to investigate the effects of distance of transport of the material, three variables were plotted against distance from the former cliff line. This distance was determined in the same way as for the morphological data, and is plotted on a logarithmic scale for the same reasons.

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* See appendix of Techniques for explanation of phi (ϕ) values.

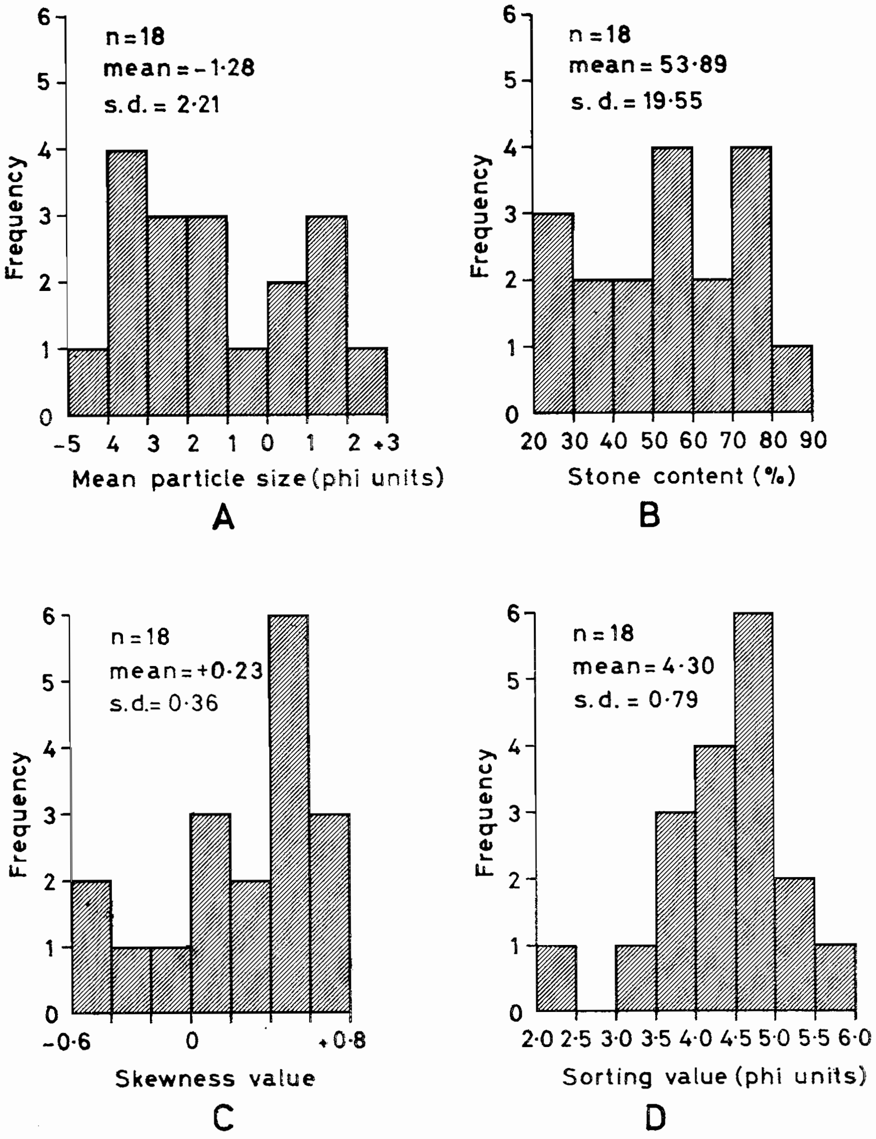

FIG. 4.
Sediment characteristics of Main head.

It is noticeable that the coarsest material tends to be present in the coves, where exposures in the head are close to the old cliff line. At Langerstone Point, some 270 metres out from the slope, the head is comparatively fine, the two samples taken yielding maximum particles of $-5\cdot9\ \phi$ and $-6\cdot3\ \phi$ respectively. At nearby Landing Cove, the largest material in the samples was $-6\cdot7\ \phi$ and $-8\cdot0\ \phi$ respectively.

These observations are supported by the evidence in Figure 5A and B. Here mean particle size and percentage stone content are plotted against distance from former cliff line for eighteen samples. There is a strong correlation with distance in both cases, with r significant almost at the 99 per cent level. Thus the head becomes both finer and less stony with increasing distance of transport.

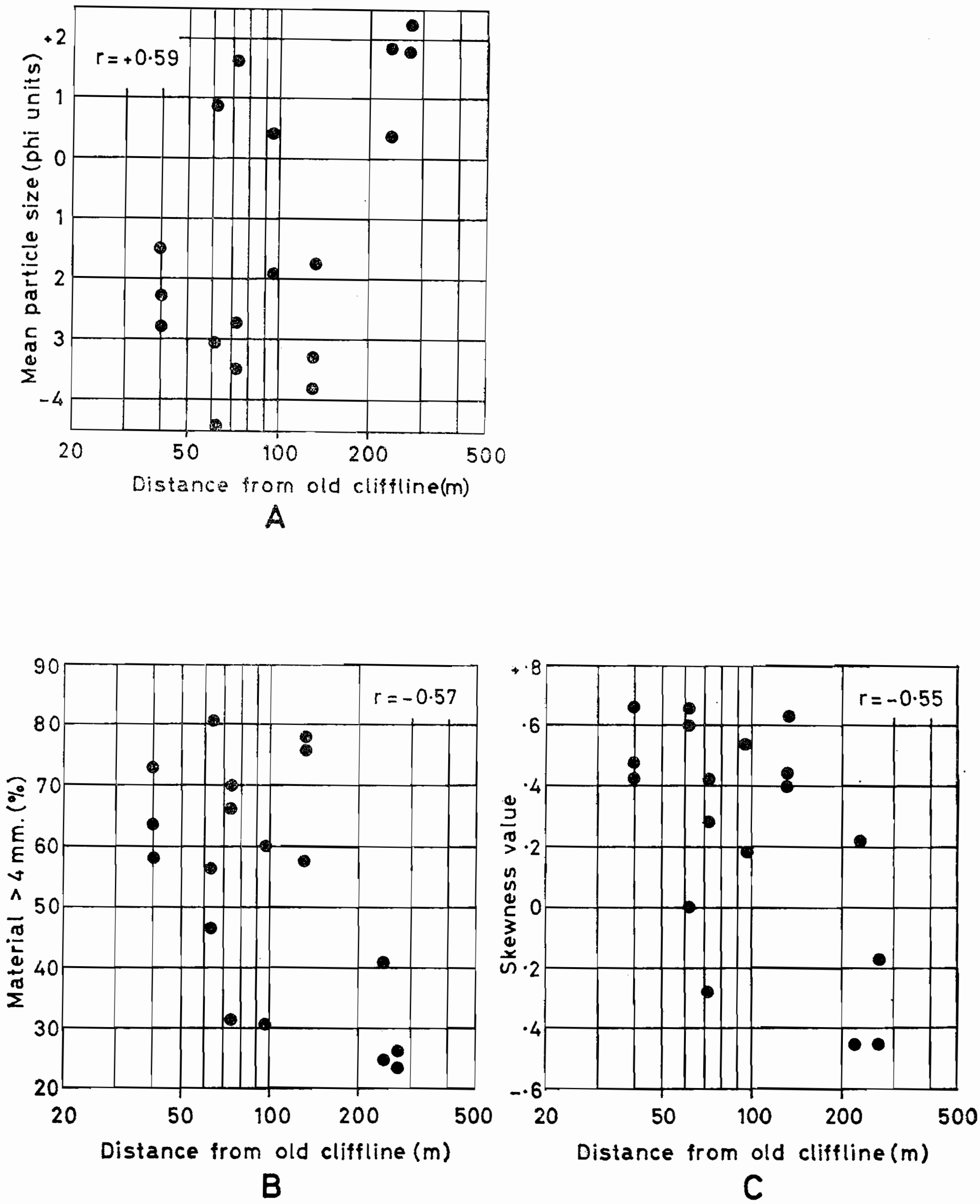

FIG. 5.
Some effects of distance of transport on the Sediment characteristics of Main head.

Figure 5C shows skewness values plotted against distance. There is a correlation (r = —0·55) significant at well above the 95 per cent level showing a change from positive to negative skewness during transport. This ties in well with the work of Krumbein and Tisdel (1940) who have shown the same feature in relation to the transport of coarse fluvial sediments.

In all three cases the scatter of points in a broad band across the graph is a further indication of the variability of the head.

An experiment was carried out to assess the effect of distance on the composition of the head. Two separate samples of fifty stones, of size retained on the 9·5 mm. sieve, were taken from each of two sites, Langerstone Point, and Landing Cove. The object was to determine the proportion of quartz as compared to schist material. The counts of quartz stones obtained were 2 per cent of the total at Landing Cove, and 20 per cent at Langerstone. This disparity may in part result from the differing proportions of quartz in the local bedrock. There is a slightly greater concentration of quartz veins at Langerstone, but this cannot entirely explain the difference. It is therefore inferred that with increasing distance the percentage of quartz stones increases at the expense of the schist.

These changes with increasing distance of transport can be explained in two ways. The decreasing particle size may be due either to progressive comminution during transport, or to a selective transport of the finer material, by which the fine material is removed and the coarser particles left behind. The diagrams of mean particle size and stone content do not enable a discrimination to be made between these two hypotheses.

The correlation between skewness and distance of flow, however, does suggest that some selection takes place during transport. Krumbein and Tisdel suggest that the coarser material wears down more rapidly by abrasion than the finer, leading to an increase in the proportion of finer particles and a consequent negative skewness. Selectivity during transport is demonstrated also by the quartz/schist ratio. This can be explained by differential comminution of the schist, which being less resistant, succumbs to abrasion during transport more readily than the quartz. Hence the concentration of quartz stones increases progressively at greater distances from the old cliff line.

It would appear then that processes of both comminution and selection are at work during the transport of the head.

Waters (1964) puts forward an interesting hypothesis concerning the distribution of coarse material in head on Dartmoor. He argues that the head is the result of the stripping of successive layers of weathered bedrock, in which the material becomes less profoundly weathered, and therefore coarser, with increasing depth. Each layer is removed by solifluction, and redeposited; first the fine, very weathered material from the surface is removed, followed by the coarse less weathered material from below. Thus the former distribution of coarse material in the weathering profile becomes inverted. The coarsest material, removed and redeposited last, occurs at the top of the head (Fig. 6).

The head of South Devon does not generally appear to conform with this hypothesis. In many places the coarsest material is at the base. This probably means that the head has not travelled very far, and the weathering profile has moved *en masse*. Here the distribution of coarse material probably reflects directly the weathering profile. At a few points, as for example, Landing Cove, the coarsest material does appear to be at the top of the exposure. But nowhere does there appear to be a regular progression to coarser material higher up the cliff. Often there is an apparently random distribution of coarse material throughout the cliff, suggesting that the horizons of the former weathering profile are completely mixed up. Thus the stripping and transport of weathered rock here are not as simple as Waters envisages. The degree of mixing of weathered rock during solifluction precludes any simple explanation.

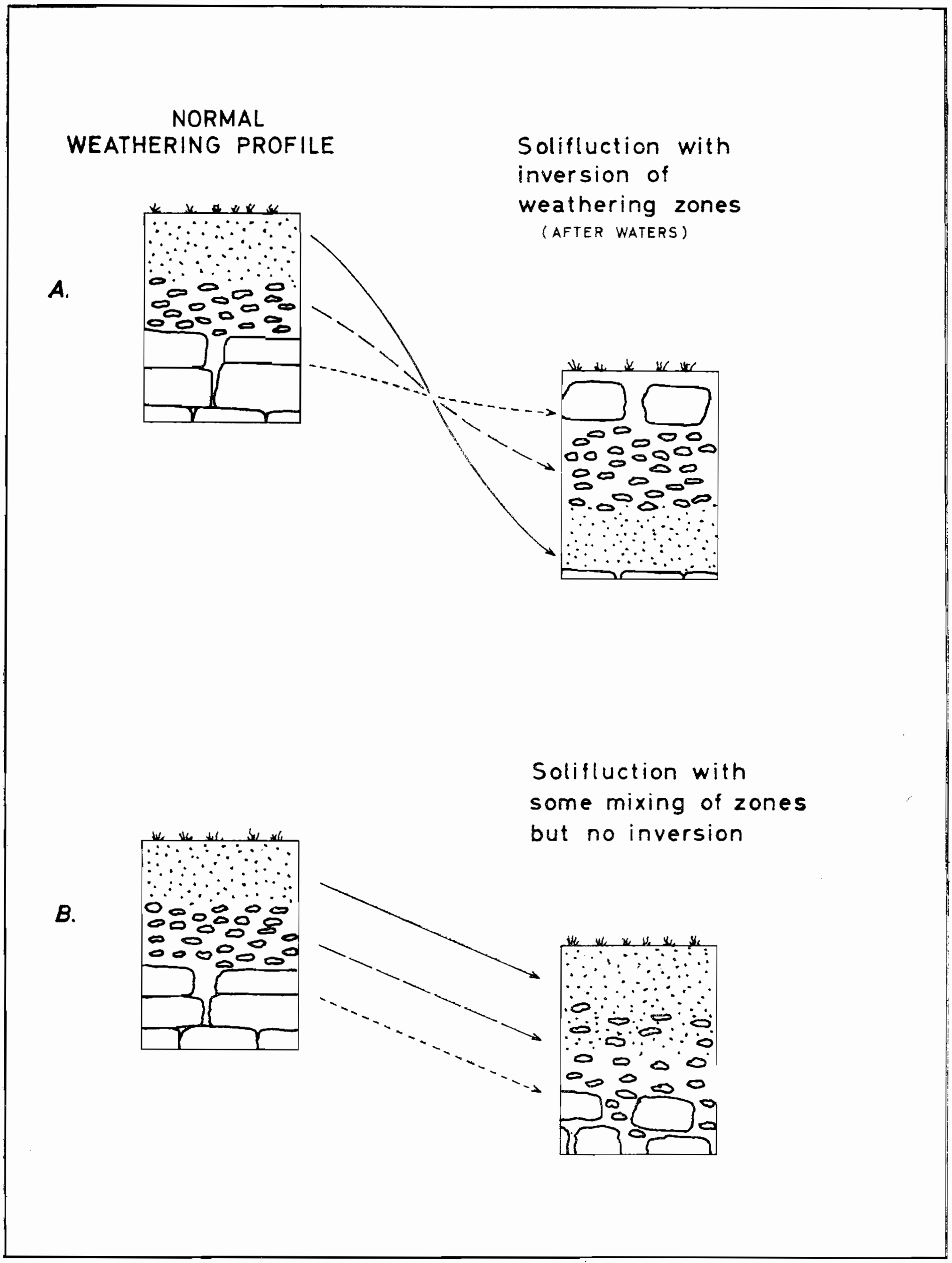

Fig. 6.
Inversion of weathering profile as postulated by R. S. Waters.

Shape

The shape of the coarse material in the head is significant. As the rock breaks up it tends to shatter along planes of weakness, joints and lines of cleavage, to yield characteristic shapes. The boulders tend to be blocky and rectangular in form; smaller material tends to fracture along the lines of the schistose structure, giving splinter and bladed forms. A further description of stone shape is that of roundness, which can vary between the very angular and well rounded.

Measurements of roundness confirm subjective observations that the coarse material within the head is largely angular (Table 1). The method used was that described in 1953 by M. C. Powers (see Appendix).

Table 1. *Particle shape*

Class	Class limits	Mica schist			Green schist		
	Index of roundness	(a)	(b)	(c)	(d)	(e)	(f)
Very angular	0·12–0·17	4	—	5	1	1	—
Angular	0·17–0·25	39	48	43	30	35	35
Sub-angular	0·25–0·35	7	2	2	19	13	15
Sub-rounded	0·35–0·49	—	—	—	—	1	—
Rounded	0·49–0·70	—	—	—	—	—	—
Well rounded	0·70–1·00	—	—	—	—	—	—
Mean roundness value		0·217	0·214	0·206	0·243	0·239	0·239

The modal class in every case is angular, and the mean roundness value in each case falls within the angular category. The mean roundness of the green schists is consistently different from the mica schists. In part this is accounted for by the greater amount of quartz within the mica schists, for it is the quartz fragments which fall into the very angular class. But the green schists show a consistently higher value in the sub-angular class. Thus even when the quartz stones are excluded, the green schists have a higher roundness value. This can be attributed to their mineralogical composition, which renders the green schists less resistant and more easily abraded.

Orientation

The disposition of coarse particles within the head is characteristic in that the well marked long axes of the rock splinters tend to parallel the direction of flow. This is most easily seen where the exposure cuts transverse to the direction of movement and the elongated particles can be seen projecting directly out of the cliff.

Measurements of orientation of the long axes were made on samples of fifty stones at several exposures. The length of the vector along each azimuth represents the number of stones lying in that direction. All of these show a marked peak in the direction of maximum slope when plotted as a rose diagram (Fig. 7). The figure also shows that the mean orientation of stones varies according to the trend of the slope down which the head has flowed.

The orientation of the long axis of the stones takes place during solifluction. The stones tend to arrange themselves along the line of least resistance to pressures in the moving mass. Hence the longest sides and, therefore, the long axes, tend to parallel the direction of movement.

G. S. P. Thomas (1967) has developed a method for describing the strength of orientation of the stones (see Appendix). He devised a percentage scale where 0

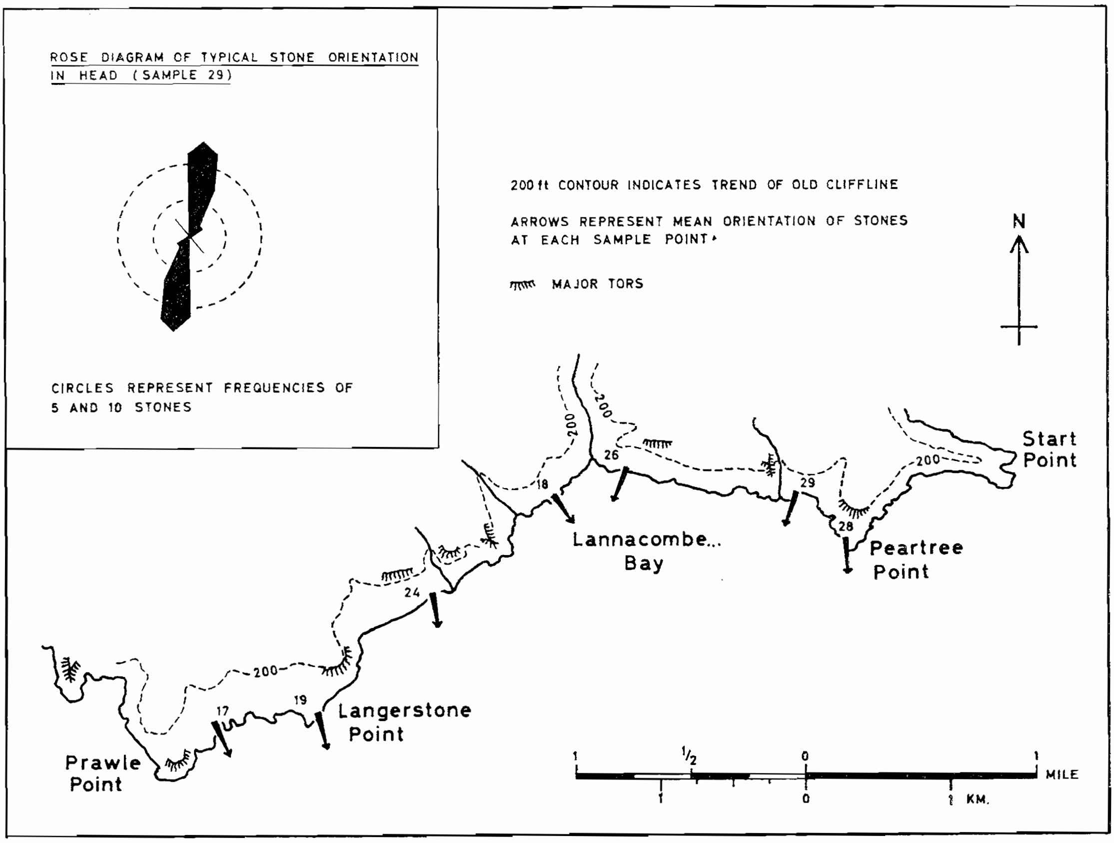

Fig. 7.
Variations in orientation of stones in the Main head along the coast.

represents a uniform distribution around the compass, and 100 represents a distribution where all the axes lie in the same direction. The frequency distribution of orientation strength values is shown in Figure 8. The mean strength of orientation of stones in the head sampled is 55 per cent, and in most cases the strength is greater than 40 per cent, a higher value than is found in most other types of coarse subaerial sediment.

In addition to the orientation of the large particles, their dip is also a fairly regular feature, and tends to parallel the dip of the rather crude bedding of the head. Where the head lies on a rather steep slope, then the axis dip of the stones tends to parallel the downslope direction, as for example in sections at Decklers Cliff (758 365). Where the bedding is horizontal, so is the dip of the stones. Dips in the reverse direction occur where the head has flowed out across the wave cut platform and up over projections upon it. An example of this reversed dip may be seen at Landing Cove.

Stratigraphy

The head shows a kind of crude bedding in places. On the tongue of head which projects out at Landing Cove, the stratification is picked out by concentrations of coarse material at different levels and its near horizontal attitude. At the east side

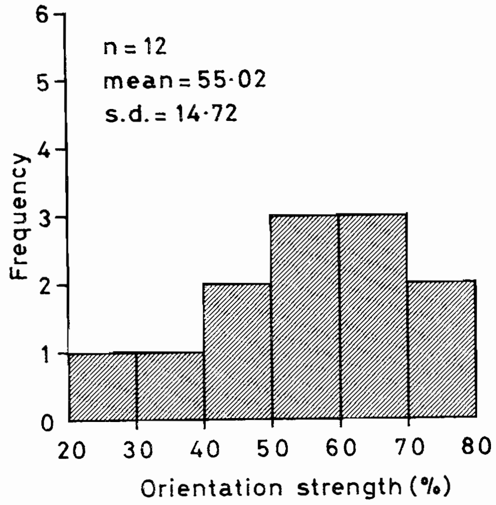

Fig. 8.
Frequency distribution of orientation strength values.

of Rickham Sand (755 367) the stratification can be picked out by difference in colour of the included stones. Layers of mica schist are interbedded with layers of hornblende schist head. Clearly these two types of bedrock are juxtaposed upslope. The thickness of the strata varies between 30 and 60 cm. approximately, and it is suggested that each layer represents one individual flow. It appears, therefore, that the head is built up of a number of fairly shallow flows of material at this point. In many other places, however, there is no evidence of bedding, which suggests that movement may have been massive.

Often associated with the coarse head is a much finer sediment, frequently 30–100 cm. in depth. This can occur at the top of the head, as at Horseley Cove (787 361), or as a lens within the head, as at Peartree Point. Table 2 summarizes the major distinctions between Main and Upper head. The characteristics which show best the distinction are mean particle size, stone content, and the silt content expressed as a percentage of the fines (the less than 2 mm. fraction).

Table 2. *Comparison of sedimentary characteristics of Main and Upper Head*

	Main head	Upper head
No. of samples	18·00	4·00
Mean particle size	—1·28ϕ	3·50ϕ
Mean skewness value	0·23	0·04
Mean sorting value	4·30ϕ	4·30ϕ
Mean stone content %	53·90	11·70
Silt % fines	41·80	63·30

The fact that this material differs from the Main head suggests that different processes have been at work in its formation. It is possible that it is the result of slope wash by running water. This could account for the high proportion of fine, and the absence of very coarse, material since the water would be unable to transport material of large calibre.

The blocky fracture evident in the section at Horseley Cove is reminiscent of a windblown silt or loess. True loess is composed almost entirely of silt grade material whereas the material described here has a considerable proportion of sands and clay within it. Nevertheless the fines do contain a much higher percentage of silt (63 per cent) than the fines of the Main head (42 per cent) and this suggests that there may have been some addition of windblown silt.

The fact that clay, sand and stones also occur suggests that mixing has occurred, and this may well have taken place during solifluction. It is possible that this fine Upper head represents a phase of dry cold conditions with deposition of windblown silt, followed by a moister cold phase with renewed solifluction. A silt layer at the top of sections in head has been described in the Cardigan Bay area (Watson, 1967), is well known in the coombe deposits of Sussex and Kent, and is particularly well developed in the Scilly Isles (Orme and Mitchell, 1967) and the Lizard Peninsula (Coombe and Frost, 1956).

The fine head, where it exists, must be carefully distinguished from topsoil, which is often present to a depth of 30 cm. or more. This soil represents the depth of cultivation, and is characterized by a general lack of structure, and its dull brown colour, in contrast to the red or red/brown colour of the Main head, and the buff Upper head. It often contains rounded flints and beach pebbles, which are the result of human interference. Seaweed has been transported up from the beach and used as top dressing in the fields and with it came a certain number of recent beach pebbles. Clearly these have no geomorphological significance.

Within the head at Peartree Point, there is an interesting sedimentary structure which is typical of periglacial frozen ground conditions. The silt band and the underlying head are caught up in a series of gentle ripples or festoons in the section. This type of structure may be produced by frost heave taking place at depth and disrupting the formerly horizontal sedimentary layers.

The head/bedrock contact

The relationship between the head and the material it overlies is worthy of examination. At Outer Hope Cove (675 401) the transition between weathered bedrock and material moved by solifluction is well displayed. Here the head overlies a highly weathered schist, in which the cleavage and jointing are predominantly vertical. As the rock becomes progressively more weathered near the surface, so the joints become wider, and there is a higher proportion of fines to solid fragments. Individual strata can be traced upwards, then turning over from the vertical, they persist in the horizontal plane for several centimetres downslope, where they form the basal layers of the head. The overlying head material is rather different in nature, containing many angular chunks of vein quartz. The fact that this kind of quartz is not present in the subjacent rock means that it must be derived from further upslope. Thus the head here contains an immediately locally derived basal layer, above which lies material from some distance upslope.

Raised beach deposits

At several places between Prawle Point and Start Point the head overlies directly a raised marine bench cut into solid rock. At one point near Dutch End (785 357) the head incorporates into its base large angular blocks of schist, which were just being detached from the old wave cut surface. The basal layer of the head here is choked with large fragments of unweathered rock.

The two sections just described illustrate that during solifluction material is caught up from the surface over which the head is flowing, and incorporated into its base. Thus in addition to its functions as a means of transporting available weathered material, solifluction also acts as a minor erosional process, shaving the underlying surface.

The third type of relationship existing at the base of the head is with the raised beach material. This can be distinguished from the head by the rounded nature of the old beach pebbles, and by the presence of material such as flint from farther afield. Sometimes the beach is represented by a well-sorted coarse reddish brown sand, and sometimes by a sandy clay of variable colour.

At Sharpers Cove (786 357) and Gorah Run (791 364) the head is interbedded with raised beach. The section at Sharpers Cove is shown in Figure 9. In this section horizons ii and iv are interpreted as primarily raised beach material. Horizons i and v are considered to be mixed raised beach and head, whilst horizons iii and vi are entirely head. The basal layer suggests that the head was flowing out on to the 4·3 m. shore platform and being incorporated into the raised beach. There are few fines in this layer since they will have been washed by the sea. Above this layer there is a sharp junction, followed by the clayey sand. This may represent a transgression by the sea which buried the underlying deposit under marine sediments. This was followed by yet another solifluction layer, which flowed on top of this material and tended to settle into it, giving a less well defined junction. This is followed by another sharp junction with further sands overlying it, representing another transgression by the sea. Above this the angular head gravel and the marine sand are finely interbedded, suggesting that once again the head was flowing out across a beach, and the head material was being sorted as it was washed by the sea. The next stage represented here was the massive flow of head which buried all the earlier deposits. Finally, at the top of the section there is a deposit of upper head.

At Gorah a similar sequence of interbedded deposits occurs. An interesting feature here is the presence of two lenses of head within the beach deposits. These are respectively 10 m. long by 50 cm. deep, and 20 m. long by 150 cm. deep. Their lenticular form suggests that these are former solifluction lobes which flowed into the sea and were buried under marine deposits before the soliflucted material had been dispersed by coastal processes. Recent marine erosion has then re-exposed the lobes in frontal section.

ENVIRONMENT AND PROCESS

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Page 447, bottom line:

for "flowing" read "growing" . . .

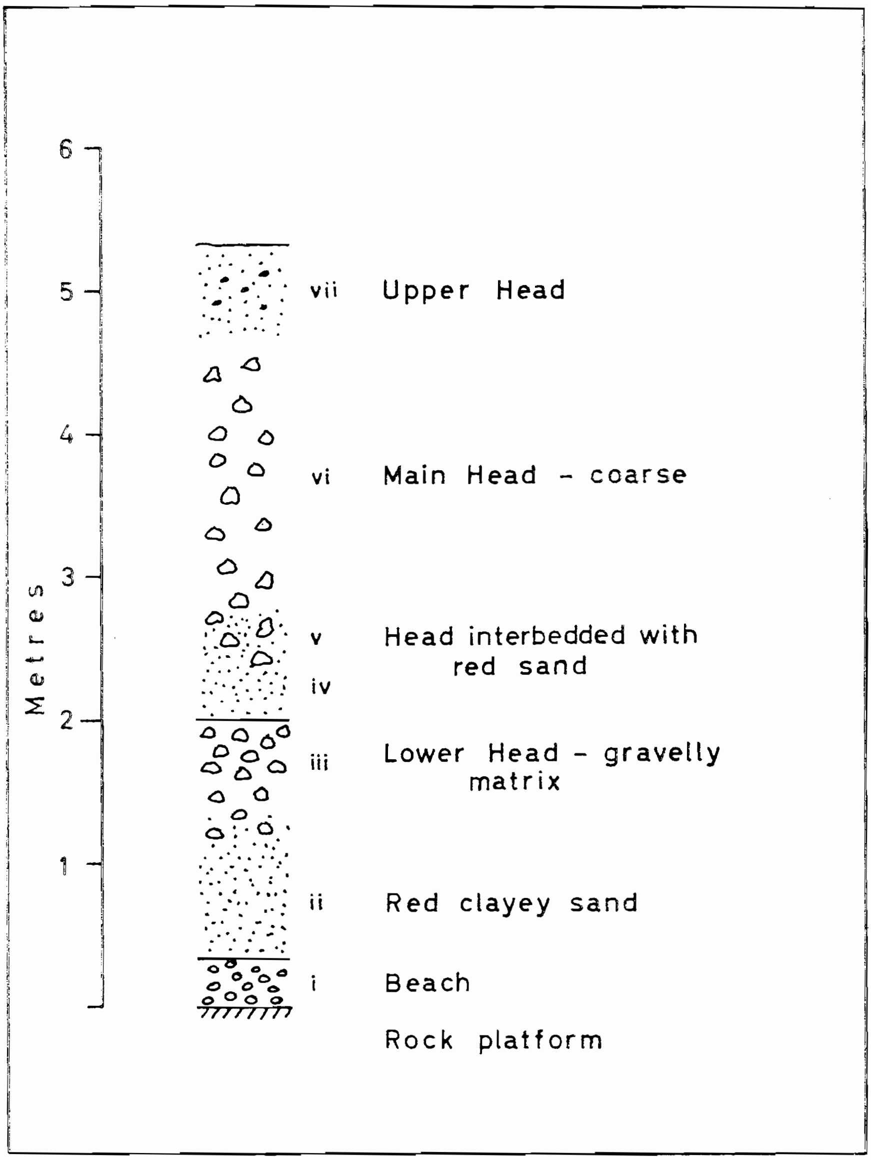

FIG. 9.
The section at Sharpers Cove.

gated ice depends upon the availability of sufficient moisture, and on the size of the pore spaces within the soil, which are largely dependent on the particle size distribution of the soil. Beskow (1935) and Cailleux and Taylor (1954) have defined the particle size distribution of soils which are susceptible to the formation of segregated ice.

Figure 10 compares the particle size curves derived from the less than 2 mm. fraction of the head deposits. It can be seen that all the samples fall within the range of frost-heaving materials. Thus in environmental conditions which produce deep seasonal frosts, and available soil moisture, these sediments would be prone to the

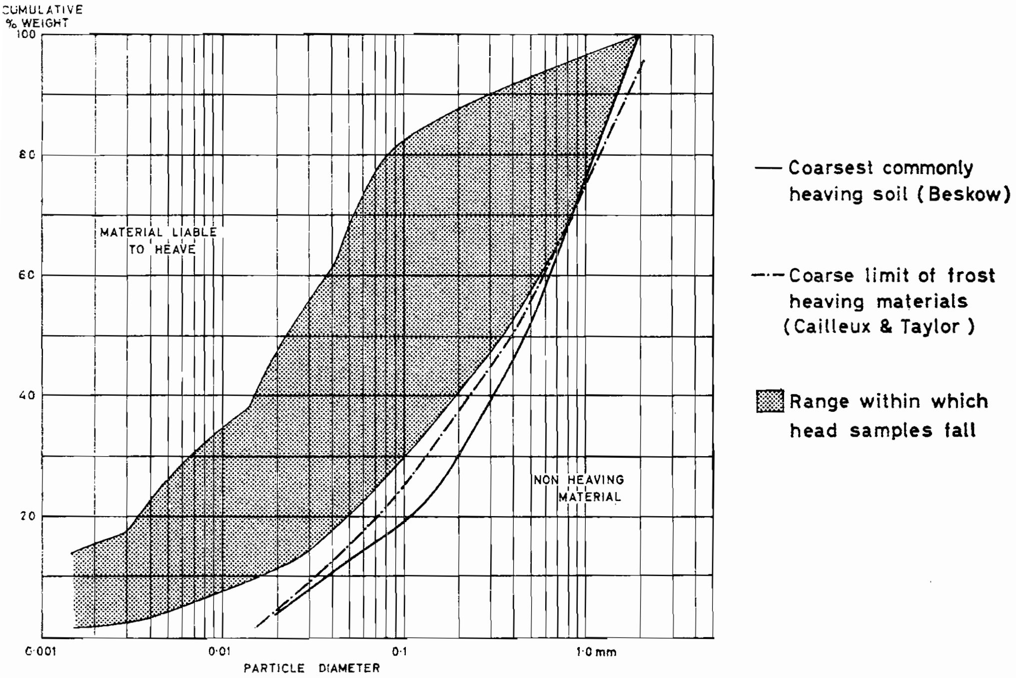

Fig. 10.
Frost heave curves.

formation of segregated ice. Where the sediments lay on a slope, the frost heaving would result in mass movement downslope.

The response of a sediment to varying water content can be defined with reference to the liquid and plastic limits, and the plasticity index, together known as the index properties (see Appendix). The most important factors influencing index properties are the type and proportions of clay minerals present.

The index properties of six samples of head are set out in Table 3.

Table 3. *Index properties of mainhead*

	LL	PL	PI	% clay
QM	29	19	10	6
QM	26	19	7	14
QM	26	17	9	14
HC	28	17	11	9
HC	21	17	4	8
HC	26	17	9	3

The plasticity index is in all cases low (in many clays it attains values of 50 or more). There is no significant difference between the two types of schist. The low plasticity index can be attributed to the fact that clay never forms a large proportion of the sediment, reaching a maximum of 14 per cent in the samples tested.

The low values of the liquid limit are also important. This means that an amount of water equivalent only to 25–30 per cent by weight of the sediment is sufficient to cause the sediment to pass into the liquid state and thus start to flow. Under periglacial conditions, surface water during the summer season is often abundant due to the thawing out of the frozen ground. Since low summer temperatures retard evaporation, and the permafrost layer prevents downward penetration, the meltwater tends to remain in the upper layers of the soil, saturating it. Thus when susceptible materials are present, saturated flowage will take place.

As downslope movement takes place, so comminution of the moving material occurs, as demonstrated earlier, together with selective abrasion of the less resistant schist particles. The fact that the stones are consistently angular throughout the deposit, with the angularity preserved even after considerable movement, suggests that little rounding by abrasion or attrition takes place during transport of the material. Perhaps frost shattering continued during the process of solifluction, never allowing the stones to become rounded to any extent. Further material is added to the solifluction layer by erosion of the slope over which the material is passing. In this way the slopes are gradually stripped of their weathered mantle, and a deposit of the removed material builds up on the valley floors.

Towards the end of the period of accumulation of the Main head there appears to have been an addition of wind blown silt, indicating drier conditions. This was followed by a moister phase when it became mixed with clay, sand and some stones to form the layer of Upper head.

AGE

It is not possible to date the head with any great precision, for clues as to its age are rather sparse. Neither is there sufficient evidence to state whether the head was formed within one cold period, or whether it accumulated gradually during several cold periods.

A relative date for the head can be derived from its stratigraphical relationship with the raised beaches. Both Orme and Masson-Phillips agree that there are marine benches at heights of approximately 4·3 m. (14 ft.) O.D. and 7·4 m. (24 ft.) O.D. At certain places, e.g. Sharpers Cove, the head is contemporaneous with the high sea level of the 4·3 m. beach. Masson-Phillips follows Zeuner in suggesting that these beaches were formed during warm interstadial periods associated with the Wurm glaciation. Recent work by N. Stephens (1966), however, suggests that shore platforms of similar altitude in North Devon may be early Pleistocene in age. So the age of the beaches must yet remain in doubt.

A minimum date for head deposits is available from the nearby regions of Dartmoor (Simmons, 1964) and Bodmin Moor (Conolly, Godwin and Megaw, 1950) where comparable head is overlain by blanket peat. The earliest peats are dated by pollen analysis as Zone IV (10,000 B.P.) and Zone II (12,000 B.P.) respectively, and indicate that formation of head must have ceased before these dates. It is probable that on lower ground, with milder temperatures, periglacial conditions and formation of head terminated at an earlier date.

APPENDIX OF TECHNIQUES

APPENDIX 1. *Particle size distribution*

Sites sampled for particle size distribution are indicated in Figure 1. At most sites two or more samples were taken to take account of vertical variations in the head. On account of the variability of the deposits, as described in the text, a single sample from a particular site will not necessarily yield the same results. Only when a sufficiently large number of samples is taken are the random variations reduced to manageable proportions.

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. An example of such a graph is Figure 10.

For the statistical analysis, the grain size data were transformed to phi 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 (ϕ 10 etc. indicates the ϕ value of the 10 per cent point (etc.) on the cumulative percentage scale.)

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

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

$$\text{Sorting} = \frac{\phi 85 + \phi 95 - \phi 5 - \phi 15}{5 \cdot 4}$$

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 greater 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, as in Figure 7.

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
$\bar{x}$ means 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 texts 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.

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