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SOME ESTIMATES OF PERIGLACIAL EROSION IN SOUTHERN AND EASTERN ENGLAND

The extent of periglacial erosion in southern England is difficult to determine, and most estimates have been purely qualitative. Te Punga (1957) suggested that the present relief of unglaciated areas has been mainly produced under periglacial conditions. During interglacials erosion was negligible except along stream courses.

However, the inferences are still largely conjectural. The fact that many periglacial features can be found proves that the period had widespread effects: and the preservation of these features demonstrates that Post-glacial erosion has been minor, at least where the features are found, though obviously it is not easy to know how many features have been removed. These considerations do not preclude the possibility that the slopes and drainage lines are mostly a legacy of Tertiary or interglacial conditions. The erosion of slopes involves the destruction of much if not all of their previous form. The last periods of erosion are necessarily better evidenced than the first even though their contribution to the development of the relief may have been small. Many of the phenomena that Te Punga lists, such as stone stripes and involutions, are superficial ornamentations of the slope on which they occur (Birot, 1960, p. 127), and are not necessarily connected with the evolution of the relief.

The slopes that are now seen could have been produced by temperate processes except for some that appear to have too gentle a gradient. It is hard to find any erosional features that have been definitely produced by periglacial agencies. Most features are small or of ambiguous origin (e.g. altiplanation terraces and tors). They do not show the importance of periglacial erosion so decisively as corries and U-shaped valleys demonstrate the importance of glacial erosion.

In southern England the character of solifluction deposits depends very much on local factors such as rock type, aspect and slope angle. Besides these variations, broad changes in the character and amount of soli-

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fluction seem to occur from east to west across southern England. It is with such changes that the present paper is concerned.

During the last glacial period continuous permafrost appears to have existed in central and eastern England (Williams, 1965, 1968). In the southwest permafrost was probably largely absent except on high ground such as Dartmoor. In the areas without permafrost mass-wasting is likely to have been less intense than elsewhere. It is generally accepted that permafrost promotes soil flowage by preventing subsoil drainage and acts as a slip-plane over which the waterlogged material can slide. In the Arctic at the present day areas without permafrost are said to experience far less severe mass-wasting than adjacent areas with permafrost (Jenness, 1952).

Certain areas of England will now be discussed in more detail with a view to estimating the amount of erosion that has taken place.

SOUTHWEST ENGLAND

In the southwest of England solifluction deposits („head") are thicker and more widespread than elsewhere. At first sight this might suggest that periglacial action was decisive in determining the relief of the southwest, but other evidence suggests the contrary. Many solifluction deposits have moved only short distances from their source. Many have come to rest without reaching the bottom of the slope on which they started. Thick deposits often lie on slopes of considerable angle. In shale and slate areas it is common to see deposits six feet (2 metres) thick resting on slopes of 25 to 35 degrees. All these facts indicate the relative inefficiency of solifluction.

Some of the raised wave-cut platforms along the coast provide opportunities for rough volumetric calculations of the erosion resulting in solifluction deposits. These platforms are frequently covered with thick deposits of head, derived from the steep slopes and degraded cliffs behind, which represent the former coastline. The deposits are deepest at the back of the platforms and thin rapidly towards the sea. In places the platforms are wide enough to hold almost all the head. Where inlets of the sea have cut sections it is possible to calculate roughly the volume of mass-wasting.

Such is the case for instance between Prawle and Start Point in South Devon. A raised wave-cut platforms is covered with head originating from former cliffs of schist behind (Orme, 1960). The head is largely composed of sand and silt but many angular blocks occur. The unsorted

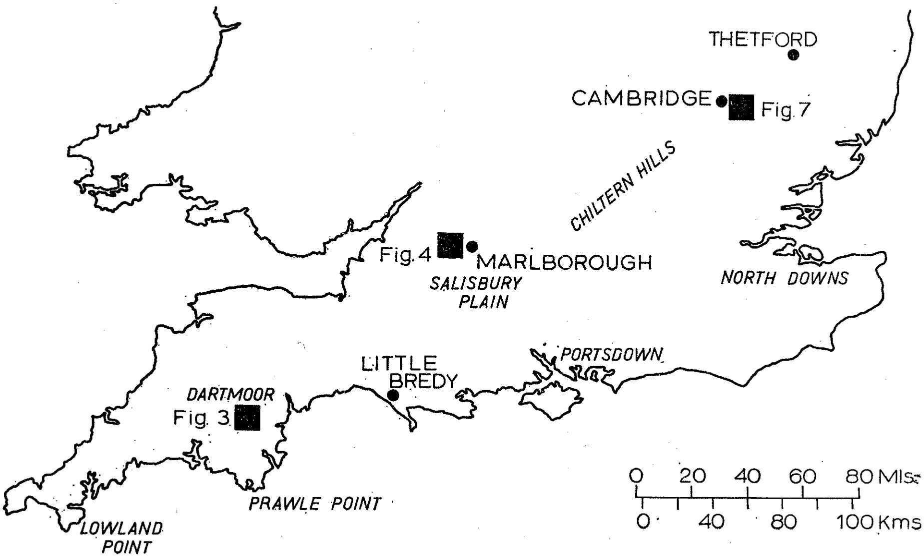

Fig. 1. Location of places mentioned in the text

nature of the material and its lack of bedding suggest that it was deposited by periglacial rather than by Holocene processes — although, as with so many head deposits in the southwest, complete proof is lacking. The surface of the head slopes seawards from an angle of 6° at the back of the platform down to an angle of 1° or less. There is no evidence that this gentle slope has been cut by marine agency: it seems to be merely the angle of rest produced by solifluction. At the back of the platform the degraded cliffs rise about 200 feet (60 metres). Above them, a gentle slope continues to about 350 feet O.D. (110 metres), where it steepens and levels out as a plateau. There is often a narrow zone of flat ground at the foot of this gentle slope along the top of the old cliffs.

At Langerstone Point (Fig. 2A) the coastal platform is about 600 feet wide (180 metres), and along its seaward edge the head is about four to six feet thick (1—2 metres). On either side of the Point the sea has cut back to the line of the old cliffs exposing some 50 feet of head (15 metres) at the back of the platform. The old cliffs must have supplied nearly all this material to the platform. If much had come from the slopes above the old cliffs, the thickness of material on the platform would be greatest where the upper slopes end at the brink of the old cliffs. It would be

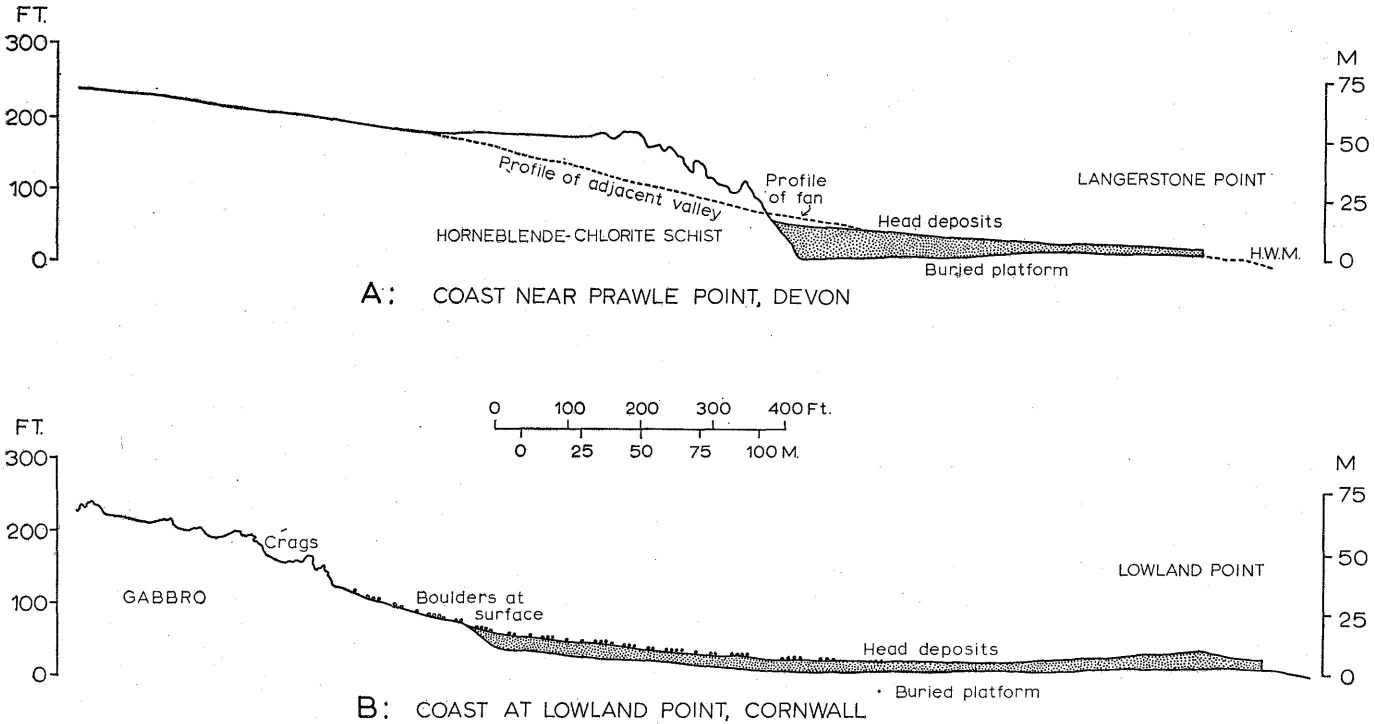

Fig. 2. Two examples of degraded cliffs and head-covered platforms in southwest England

least where the upper slopes end a short way behind the old cliffs and are separated by flat ground on which some of the descending material would have been trapped. As the amount of head does not vary in this way, it is concluded that the upper slopes have fed very little material over the old cliffs. Only where the cliffs are broken by small steep-sided valleys has head from the upper slopes found its way down in quantity, and then by way of the valleys and not directly over the cliffs. At the mouths of these valleys waste-fans rise about ten feet (3 metres) above the general surface of the platform.

The volume of material on the platform, excluding these fans, represents about 30 feet (9 metres) of erosion from the face of the old cliffs after allowing for the difference in density between solid rock and head. Figure 2B shows the profile of a similar head-covered platform and degraded cliff in gabbro at Lowland Point on the Lizard. It is estimated that erosion here has been about 15 feet (4.5 metres) from the face of the cliff. The degraded cliff forms a steep slope broken in places by gabbro crags and tors, presumably created by differential erosion under periglacial conditions. Some of the silt content of the head in this area may be loess (Coombe & Frost, 1956): this has not been allowed for in the calculation. On shales and slates in the southwest, sites have been found where up to 25 feet (7.5 metres) of erosion can be calculated from the volume of deposits.

These figures may give a false impression in several ways of the amount of erosion. They are based on sites with notable thicknesses of head. It is likely that in this respect they are maximum values. Sites are too few and insufficiently random to use to calculate average values. The erosion often acted on steep cliffs, and consequently the amounts calculated are probably more than took place generally. Solifluction was presumably not the only process involved: boulder-falls, debris-avalanching and talus-creep must have added to the erosion. Nevertheless the head is not scree, and the large amount of fines it generally contains implies that solifluction was active. It is not clear how much extra erosion was caused by solution, nor is it clear how much was simply the removal of regolith, produced by interglacial weathering.

The role of periglacial processes on Dartmoor has been discussed recently by Palmer and Neilson (1962) and Waters (1964, 1965). The volume of deposits cannot be used to calculate the amount of erosion, as the form of the ground is unsuitable for trapping full amounts of solifluction debris. Some of the head occurs on valley floors where there are seldom adequate exposures, and where it is uncertain how much each of the sides has contributed to the fill and how much has been brought down the floor of the valley. In addition much of the material may have been carried downstream far beyond the area in question. The long, gently convex slopes further add to the difficulties of calculation. The volume of deposits has to be averaged out over the whole slope, although the probability is that the major part has come from the steeper slope immediately above and that only a little has travelled from the relatively flat interfluve. As a result of this averaging the figure for the amount of erosion loses its value.

Again, the height of the tors fails to give a guide to the amount of erosion. Even though the tors represent resistant masses left after the surrounding slopes have been lowered by erosion (Linton, 1955; Palmer and Neilson, 1962), this erosion may have been only partly periglacial. Also, it cannot be assumed that all the hillside „clitters" (blockfields and blockstreams) and „growan" (disintegrated granite consisting of crystals and crystal fragments) represent materials which have moved downslope and accumulated. Many represent frost-shattered and heaved debris *in situ*.

A clear instance of the last point is provided by the blockfield around Haytor Rocks. Two tors composed of coarsely porphyritic granite crown a hill which is almost entirely formed on the north and west sides of non-porphyritic „blue" granite. The „blue" granite is exposed at the base of the western tor and also in two quarries on the slopes below. The southeast side of the hill seems by contrast to be composed of porphyritic granite, and many of the boulders on this slope appear to be detached masses of exfoliated bedrock but otherwise in place.

The north and west sides are covered by an extensive clitter of „blue" granite blocks. It is remarkable how rapidly porphyritic blocks become scarce as one moves a short distance from the tor. One hundred feet (30 metres) from the base of the tor on the northeast side there are about twice as many porphyritic boulders as non-porphyritic. Some 350 feet (110 metres) away, blue granite outnumber the porphyritic blocks four to one. Further still at 600 feet (180 metres) none of the latter can be found. A traverse to the north or west shows even more rapid reduction in the number of porphyritic boulders. If the tor had been created by the removal of blocks from its surroundings there would be more blocks of porphyritic granite in the slopes below. The absence of these blocks can hardly be due to their destruction by recent weathering as the blue granite is closer-jointed and more susceptible than the porphyritic. It seems that block removal by periglacial agencies (the process favoured by Palmer and Neilson as the cause of slope lowering) was unimportant in the creation of the tor.

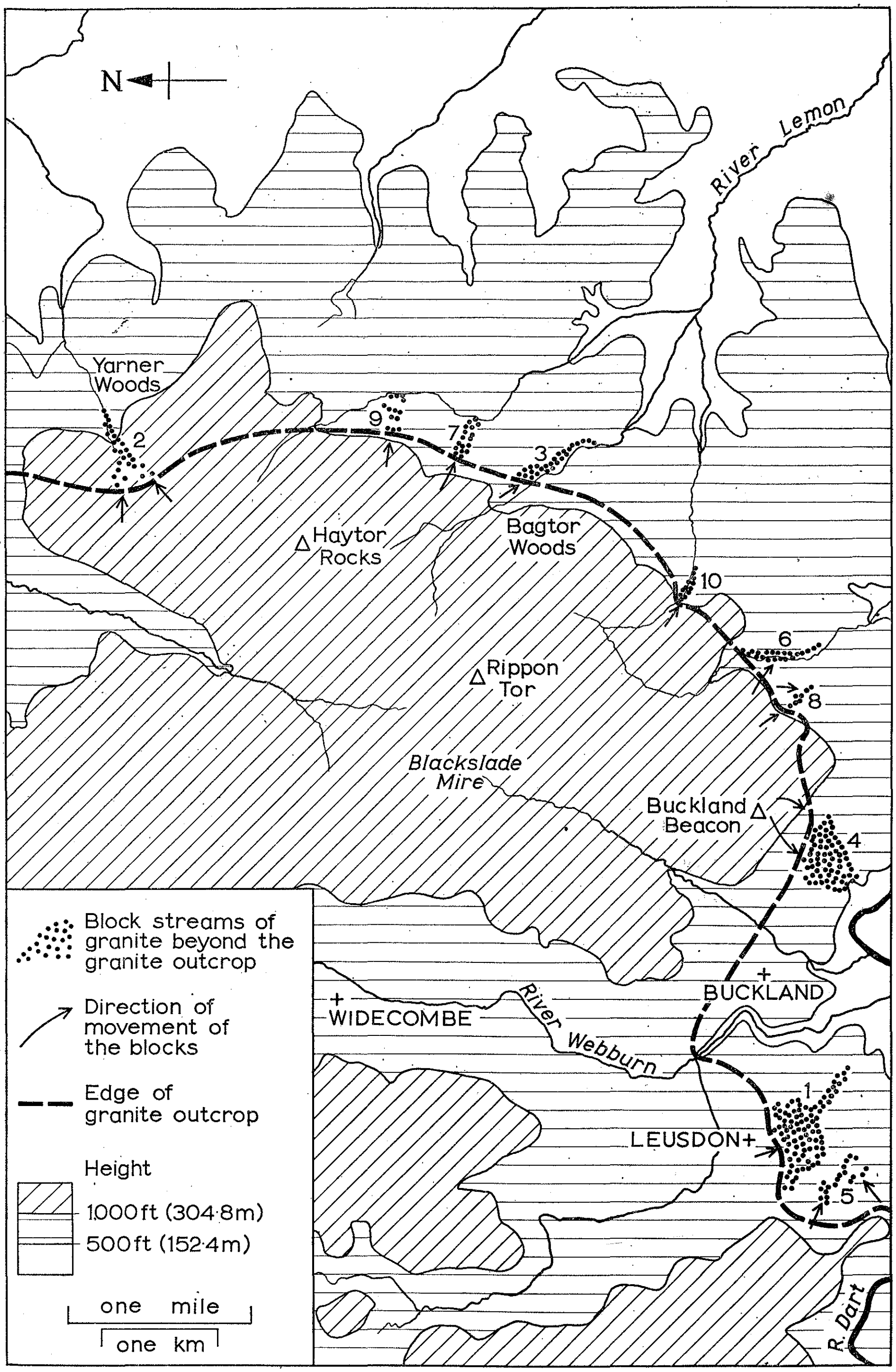

Fig. 3. Map of part of eastern Dartmoor showing block streams from the granite extending on to surrounding rocks
The numbers refer to Table I

Over much of Dartmoor the uniformity of the granite makes it impossible to identify the source of the clitters, and therefore impossible to calculate their movement. However on the edge of the granite area, the block streams often crossed downhill on to metamorphic rocks. The part of the movement below the contact can readily be measured.

Fig. 3 shows the location of the ten longest block streams in an eight mile (13 km.) section of the granite contact between the Bovey and Dart Rivers. The distances moved below the contact by the furthest blocks in each stream are listed as Table I. Some of these streams are the longest on the Moor.

Tabel I

Lengths of ten longest block streams extending below the granite contact between the rivers Bovey and Dart on Dartmoor

Locality	Identifying number in fig. 3	Distance moved by furthest blocks from the contact	Average slope	Distance of contact from watershed (if less than 1,000 feet)
Leusdon Common	1	3,000 ft. 915 m	7°30′	200 ft. 60 m
Yarner Woods	2	2,500 ft. 760 m	11°30′	500 ft. 150 m
Bagtor Woods	3	2,300 ft. 700 m	6°	—
Buckland Beacon	4	1,700 ft. 520 m	11°30′	—
Poundsgate	5	1,700 ft. 520 m	8°30′	100 ft. 30 m
Ashburn Valley	6	1,300 ft. 400 m	11°	—
Lemon Valley	7	1,300 ft. 400 m	10°	1,000 ft. 305 m
Welstor	8	1,000 ft. 305 m	10°	—
Pinchaford	9	1,000 ft. 305 m	11°30′	—
Langworthy Brook	10	1,000 ft. 305 m	8°30′	—

In the area the granite upland falls away in a steep front to a hilly, dissected lowland on the Culm Measures. The contact is nearly vertical and metamorphism is rather limited in its extent and in its effect on relief. Unmetamorphosed shales can often be found within a quarter of a mile of the granite. A number of streams from the interior of the Moor cross the upland front in valleys of varying depth, and there are also some streams which start on the front itself. The block streams are of two kinds: some are confined to the hillslopes, whilst others reach the valley floors and follow them downhill. It is probable that the boulders which reached the valley floors have been moved partly by periglacial stream action as well as by solifluction. Even present-day floods may be capable of moving them (Worth, 1930, p. 108; 1953, p. 440).

The processes responsible for moving the blocks down the hillsides have often been debated. Many slopes are too gentle for the blocks to have fallen or slid on a snow-cover, but this may have happened in other places. Albers (1930) was the first to suggest that solifluction and frost-creep have been active. The „block scallops" described by Te Punga (1957) appear to be remnants of the lobate fronts of former solifluction terraces.

It is difficult to judge from the movement of the blocks the distance that the finer material has travelled. Some clitters occur immediately next to the tor, the slopes below being devoid of blocks but covered with a head of finer material. Where blocks do occur on the lower slopes they are often found only in the surface layers of the head. This may be because the movement of blocks was slower than that of the fines, or because it was a late stage in the evolution of the slope. Waters (1964) and Linton (1966) have suggested that the head deposits represent deep-weathering profiles overturned by solifluction. The blocks lie at the surface because progressive solifluction of the weathering profile first removed the upper layers of fines and only subsequently removed the basal layers with core-stones.

However, there may be another reason. Any vibration of a mixture of coarse and fine material will bring the coarse material to the top. It may be that it is solifluction combined with frost-heave that has brought the blocks to the surface. Indeed, once at the surface the blocks probably moved faster than the substrata, in a similar fashion to the so-called „gliding blocks" common on high grassy slopes in mountain Britain. Such blocks, apparently moved by frost creep, push up the turf in front of themselves and leave a scar of bare ground to their rear.

The Table I shows that the maximum length of any block stream in the area between the Bovey and Dart Rivers is only 3000 feet (915 metres) as measured from the contact. Obviously the boulders may have travelled some distance over the granite before reaching the contact, but in many cases the nearness of the watershed limits the extra distance severely. The distance travelled by the average block below the contact is difficult to estimate but, since the blocks are more widely spaced down the valley, it is certainly less than half the total length of each block stream. This is a relatively small amount of movement, and is not consistent with a hypothesis of major alteration of relief by block removal. The steep slopes and the clayey regolith on the Culm Rocks should have facilitated the migration of blocks if solifluction had been important.

The question remains how much growan has been removed. There is evidence only of small amounts. Within a short distance downslope of the contact granite debris usually becomes a minor constituent of head deposits on both slopes and valley floors. For instance, in Yarner Woods the valley fill is almost entirely composed of Culm material less than 3000 feet (915 metres) from the contact.

Despite the difficulties of making quantitative estimates the impression the evidence leaves is one of only slight erosion on Dartmoor, of the order of ten or fifteen feet (3 to 4.5 metres). This is less than the erosion which seems to have taken place on the surrounding shales and slates. The coastal sections suggest that this may have been about 20 to 35 feet (6 to 10.5 metres). The fact that Dartmoor forms higher ground than the surrounding Devonian and Carboniferous sediments presumably reflects the relative resistance of the rocks. If this is so, the difference between the estimates of erosion on the granite and the sediments is not surprising.

SOUTH-CENTRAL ENGLAND

Periglacial action was more intense in this area than in the southwest. Discontinuous permafrost was probably widespread. Thick solifluction deposits are less frequent on hillslopes than in the southwest. The greatest accumulations seem to have occurred in the valley bottoms or on flat ground at the base of the scarps. Volumetric calculations are generally prevented by the absence of platforms wide enough and flat enough to trap all the solifluction debris. A notable exception is the Portsmouth plain south of the chalk ridge of Portsdown (Edmunds, 1929). This plain is covered by solifluction deposits which must derive from the general wasting of the southern side of Portsdown since there are no major valleys dissecting it. Edmunds mapped these deposits, estimated their mean depth, and calculated that at least 35 feet (10.5 metres) had been stripped from the southern side of Portsdown.

The characteristics of the site are largely responsible for the usefulness of the result. The Portsmouth plain was so flat and undissected before periglacial times that solifluction accumulated on it without getting washed away. The periglacial deposits have survived under temperate conditions because of the low slopes and scarcity of streams. Few other sites appear as favourable for study.

In the Marlborough area of Wiltshire the amount of solifluction on the Chalk can be estimated by using the movement of sarsen blocks as a guide. The relief of the area is typical of Chalk country with gentle slopes and shallow dry valleys, though there is slope asymmetry in places. Sarsen blocks are found buried in the clay-with flints which covers some of the high ground, and they also occur at the surface on bare slopes (Fig. 4). Many stones have collected as block streams on the valley floors as a result of movement down the slope.

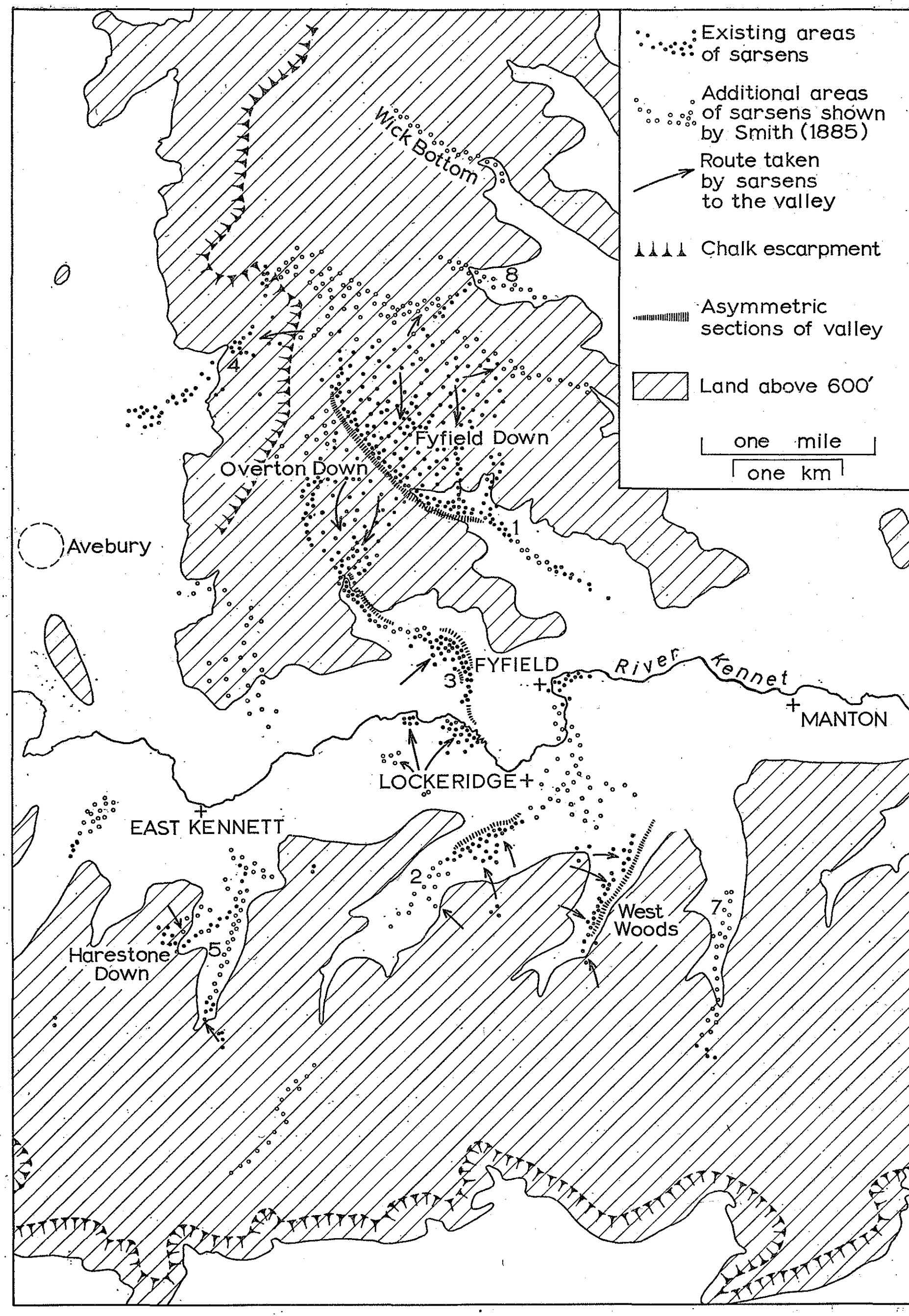

Fig. 4. Map of the district west of Marlborough showing the distribution of sarsen stones
The numbers refer to Table II

Sarsens occur singly or in sparse groups in the Chilterns and in the North and South Downs, but it is only in the Marlborough area and near Little Bredy in Dorset that they are numerous. It has been recognized for some time that the sarsens are the remnants of small patches of Tertiary silcrete and are probably the same age as the "grès quartzites" of the Paris Basin (Pinchemel, 1954). They are mostly ordinary quartzites, but a few flint comglomerates with quartzitic matrix occur (White, 1925). The blocks are frequently vesicular and often have the woolsack or bi-convex shapes characteristic of silcrete boulders. Probably the silcrete never occurred as an extensive and unbroken sheet. It may have formed on the floors of shallow intermittent lakes as in the northern Kalahari today (King, 1962). The sarsens weigh on average between one third and one half of a ton, about the same as their granite counterparts on Dartmoor. Some large blocks weigh up to one and a half tons.

The sarsens presumably developed on the mid-Tertiary peneplain which may be partly preserved on the higher summits. Their movement down the slope seems to have been the result of solifluction. The periglacial origin of the block streams was suggested in 1912 by H. B. Woodward and independently in 1957 by Te Punga. Present processes seem quite incapable of moving the blocks which lie half-buried in the vegetation and soil. Even the floods which occur in some winters in certain of the valleys have no effect. Clark Lewin and Small (1967) found at Clatford Bottom that deep solution pipes have developed in the Chalk beneath the sarsens which suggests that the sarsens have not moved for a long time.

For the most part the distribution of sarsens is natural, although some fields have been cleared and the stones heaped into the hedgerows. In places great numbers have been taken and used for building-stone and road-metal. Stones have been used since early times but their greatest removal has been in the last hundred years. Fortunately, an early map of the distribution of sarsens exists. Some years before 1883, the Rev. A. C. Smith mapped all the antiquities of the district on a scale of six inches to the mile and included the natural occurrences of sarsens (Smith, 1885). His map is not entirely accurate as it fails to show a few areas of sarsens which can still be found at the present day. But it is probable that most of those areas which he does show are correctly mapped, and his work considerably assists the conclusions that follow.

Before the sarsens began to descend the slope under periglacial action, they seem to have occurred as localised spreads of boulders on the interfluves. The position of most of these spreads can be determined easily because many blocks still remain on the surface or lie buried in the clay-with-flints. Typically, the route taken by the stones to a valley is marked

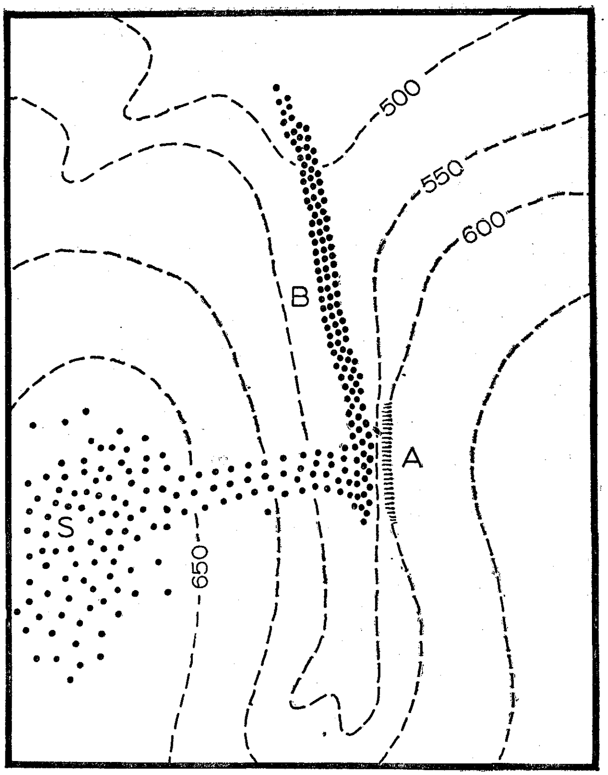

Fig. 5. Diagrammatic map of a sarsen-filled valley

From a hilltop source (S), stones join the valley at (A) and continue down the floor as a block stream (B). At (A) the valley side opposite the slope carrying the stones is oversteepened; the asymmetry of the cross-profile of the valley disappears above and below this stretch

by scattered sarsens leading down the hillside to join the head of the block stream in the valley (Fig. 5). Some blocks continued to move from this point along the floor of the valley to their present positions in the block stream.

There is frequently a strong asymmetry in the sides of the valley at the point where sarsens enter. Above and below this place the valley sides are normal. The slope carrying the stones down to the valley floor is also unexceptional. It is the slope opposite this which is anomalous in being steepened. The asymmetry in the cross-profile of the valley is confined to the place where the stones enter, and disappears before the end of the boulder stream is reached. To find the reason for the asymmetry involves a consideration of the valley deposits.

Excavations in the valley floors have been made in Clatford Bottom by Clark, Lewin and Small (1967) and in Lockeridge Dene by the author. Both valleys show chalky solifluction debris overlain by about two feet (0.5 metres) of brown loam. This loam is full of flints and sarsen fragments and is probably soliflucted clay-with-flints now much altered into soil. The underlying solifluction debris is almost flintless and very chalky. Sometimes it is rubbly and sometimes a finely divided sludge. In Lockeridge Dene the base was not reached at six feet (2 metres). In Clatford Bottom, Clark, Lewin and Small report solifluction debris at least nine feet (2.7 m) deep merging beneath into weathered chalk rubble *in situ*. The sarsens are found only at or near the surface, as they are at Lockeridge.

The same sequence of chalky solifluction debris overlain by flinty loam extends up the gentler slope of both valleys, but is absent from the steeper slope. This happens also in the West Woods valley. Here, towards the top of the gentler slope, the chalky solifluction debris thins and disappears, whilst the flinty loam thickens and passes into clay-with-flints.

The steep slopes in Lockeridge Dene and West Woods are cloaked in Holocene deposits. These consist of several feet of chalky debris with many flints. Snails such as *Pomatias elegans*, and *Discus rotundatus* occur, indicating conditions duiing deposition that were at least as warm as at present.

Much solifluction debris reached the trunk valley of the River Kennet which is now deeply infilled. A small thickness (1 to 4 feet) of recent alluvium partly conceals it. The debris consists of angular flint gravel with a highly chalky, sometimes clayey, matrix. The flints are more angular and broken than those to be seen in the slope deposits. Fragments of sarsens and lumps of chalk are common in the gravels. There are large sarsens in the top of the gravels and projecting into the overlying alluvium. Unlike the sarsens in the dry valleys they look worn, and no weather pits can be seen. Many more may be buried at depth.

The maximum thickness of the deposit is not known for certain but two wells at Lockeridge at the edge of the valley floor show that it exceeds 30 feet. Sarsens and chalk gravel are seen in the river bank at many places between East Kennett and Marlborough, so that the deposit must extend at least this distance.

One may picture a moving belt of waste on the valley floors, probably alternating seasonally with a small stream which may have caused the asymmetry. The asymmetry cannot be due to any climatic phenomenon (such as differential insolation or snow drifting) which was suggested for the Chiltern valleys by Ollier and Thomasson (1957). Nor is it geological. The asymmetry in Lockeridge Dene occurs where the valley runs approximately southwest to northeast. That in Clatford Bottom is almost at right angles to this direction, whilst in West Woods the valley is parallel to this direction but the asymmetry has developed in the opposite way.

Seemingly the only possible explanation is that the entry of the stones diverted a stream across the valley floor, causing it to undercut and steepen the opposite slope. Many of the sarsens are too heavy to have been moved by a small stream. A small stream flowing over still frozen ground during the spring thaw would not be deeply incised, and solifluction later in the summer might destroy all trace of its bed without obliterating the asymmetry.

The stream could not have been large or it would have overturned some of the sarsens, which has not happened. This is shown by the fact that the proportion of stones having weather pits on the top is approximately the same amongst those on the valley floors as amongst those on the hillslopes. At the most only a few stones can be found in any valley with weather pits on the side (Te Punga, 1957), and these may have been overturned by human agency. The stones must have been moved by solifluction. Their alignment in the boulder streams shows the same kind of orientation as is found on the hillside where it was caused by solifluction.

Several of the sarsen-filled valleys have no asymmetry where the stones come in. In some this seems to have been because the sarsens were too few to divert the stream, but in two cases (one outside the Marlborough area) the stones were abundant. These are the valley of East Kennett in the Marlborough area and, in Dorset, the valley of Little Bredy. The significant respect in which they differ from the valleys with asymmetry appears to be the slightly steeper angle of their floors. In both it is between 2° and 3°. The corresponding figure for the asymmetric sections of Clatford Bottom, Lockeridge Dene and West Wood is 1° to 2°. This is a small difference but it may be critical. It is well known that solifluction is capable of moving material on very gentle slopes, and it had no difficulty for instance in bringing down the sarsens on the 3° slope into Clatford Bottom. The congestion which brought about the asymmetry seems to have been caused by stones entering the valley floor faster than those already there could be moved away. There was presumably just enough movement on the 2°—3° floors of the East Kennett and the Little Bredy valleys to prevent the stones from accumulating so as to divert the stream.

In a typical sarsen-filled valley the stone stream in the valley bottom is twice as long as the spread of stones down the valley side. If one makes two rough assumptions:

(1) the solifluction layer moved down the hillsides in one piece and supported the sarsens on top so that they moved at the same rate;

(2) solifluction on the valley floor because of its gradient (1.5°) proceeded only half as fast as on the sides: — it follows that, during the time it took the stones to spread down the valley floor to form the boulder stream, a thickness of four times the depth of the solifluction layer was stripped from the hillside. Judging from the deposits it seems that this solifluction layer was about six feet deep (2 metres). This gives a figure for the erosion of 24 feet. A further 6 feet would have been removed before the first stone reached the valley bottom from the interfluve. A removal of 30 feet (9 metres) of strata by periglacial action is thus quite possible. The figure is only conjectural and may well be too low, but it is interesting that it corresponds to Edmunds' estimate for Portsdown.

Table II

Lengths of the ten longest block streams in Wiltshire and Dorset

Locality	Identifying number in fig. 4	Distance moved by the furthest blocks from the interfluve	Average slope
Wiltshire			
Clatford Bottom	1	13,000 ft. 4,000 m	1°30′
Lockeridge Dene	2	10,500 ft. 3,200 m	1°30′
Piggledene	3	10,500 ft. 3,200 m	1°45′
Near Monkton Down	4	7,500 ft. 2,300 m	2°45′
Near East Kennett	5	6,500 ft. 2,000 m	2°15′
West Woods	6	6,000 ft. 1,800 m	2°0′
Near Manton	7	6,000 ft. 1,800 m	1°45′
Temple Bottom	8	6,000 ft. 1,800 m	2°45′
Dorset			
Valley of Stones, Little Bredy	—	6,000 ft. 1,800 m	2°0′
Portesham	—	4,000 ft. 1,200 m	6°15′

Table II lists the distances that the sarsens have had to travel to reach the ends of the longest block streams in the Marlborough area and includes two examples from Dorset. The figures are calculated for the whole route travelled by the sarsens from the interfluves down the sides of the valleys and along their floors. It will be seen that the sarsens have moved distances up to four times greater than the granite blocks on Dartmoor, on slopes only a quarter as steep.

EAST ANGLIA

Giant patterns of polygons and stripes are abundant on the Chalk north of the Chilterns (Williams, 1964; Watt, Perrin and West, 1966). The situation is strikingly different from south-central England where not a single instance of these patterns has yet been found. The polygons and stripes clearly indicate by their preservation that Post-glacial erosion has been unimportant at sites where they occur. In addition, solifluction has been unimportant since their formation, as is shown by various pieces of evidence. When stripes reach level terrain the pattern either disappears or turns abruptly to polygons. No case is known of stripes being continued from a slope on to flat ground, yet solifluction is never halted immediately on reaching the base of a hillslope, but tends to continue for at least a short distance. The immediacy with which the polygons appear at the bottom of slopes suggests that the slopes must have been stable during pattern development. Confirmation of this is provided by the underground structures which are only slightly dragged out downslope. It is also proved by departures of the patterns from the exact line cf maximum slope. Some stripes meander, some bifurcate, some are joined by cross-partitions. None of these forms would be present if solifluction were important in the formation of the stripes.

However, these facts do not mean that periglacial erosion has always been negligible. At the base of slopes containing chalkland patterns it is quite common to find solifluction deposits. Evidently the patterns were only temporary features, developing relatively rapidly whenever slope processes become inactive. They appear to indicate that slopes had been reduced by solifluction to such a low angle that erosion had practically ceased. Even if periglacial conditions were to return to East Anglia these slopes would remain unchanged. The abundance of the patterns shows that much of the chalkland is in a state of periglacial maturity.

Figure 6 shows a typical example of a stable slope. The hillside overlooks the town of Thetford, Norfolk, and building construction has provided many temporary sections in the deposits in the last few years. The slope is gentle, about 2° near the top, falling to less than 1° near the river. On the upper slopes Chalk occurs at the surface and is disturbed by stripes and involutions. The patterns are filled with wind-blown sand. The lower part of the hillside is swathed in a sheet of sandy gravel of solifluctional origin. The deposits have a dirty, unsorted appearence and vary greatly in lithology over short distances. Wind-blown sand overlies them. The slope evidently underwent considerable evolution in periglacial times but its angle has not changed appreciably since. The former active layer

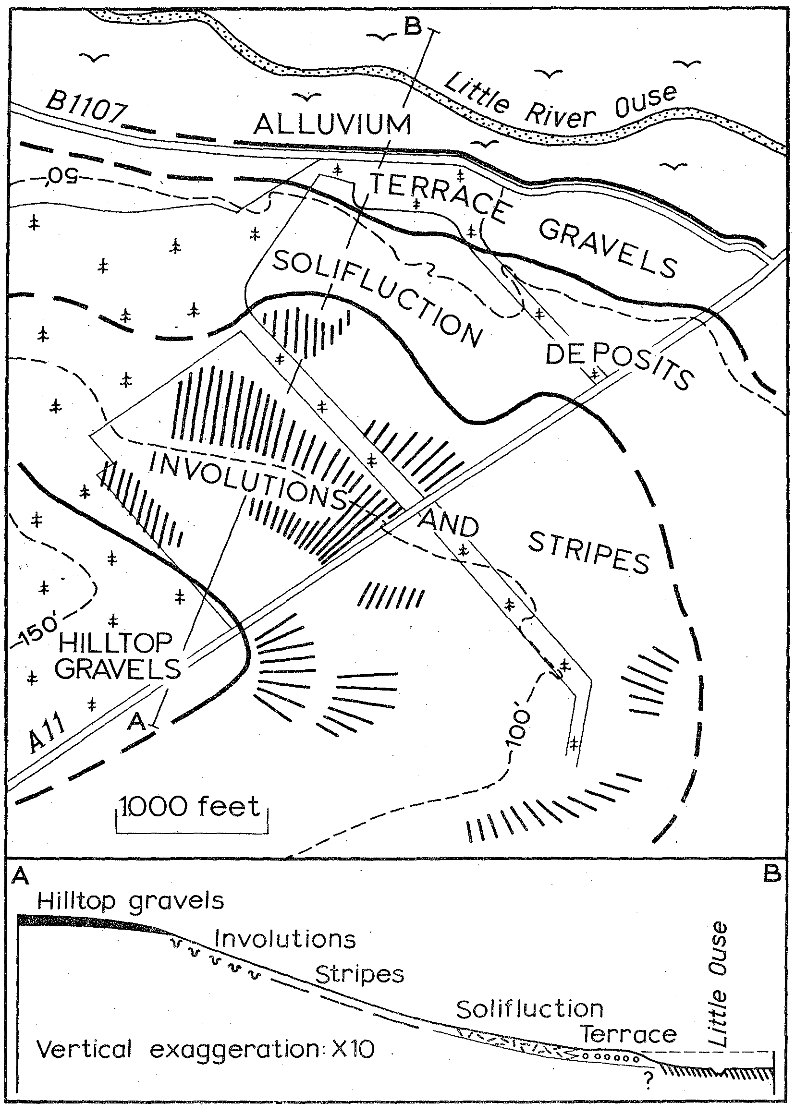

Fig. 6. Slope deposits, Redcastle Furze, near Thetford, Norfolk
This map does not show recent factories and housing

is represented not only at the top of the slope by the patterns in the Chalk but lower down by involutions in the upper part of the solifluction gravels.

The solifluction deposits show signs of sorting and bedding in places, particularly towards the base of the hill where they pass laterally into well-washed sands and gravels on the former valley floor. These now form a terrace a few feet above the level of the river. Such a transition is typical of many slopes in the area. Small fossil ice-wedges are abundant in the terrace and occur at many different horizons. It is clear that a large amount of solifluction was able to reach the valley floor and was sorted out by a contemporaneous river. This river seems to have migrated from side to side as it aggraded. Presumably the ground was dry when each horizon of wedges formed. When the river returned they thawed out, forming a cast, and a further layer of sand and gravel was deposited. Abandonment by the river led to a new generation of wedges. The alternative explanation that each wedge represents a separate climatic oscillation is scarcely likely in view of their numerous horizons.

Neither the solifluction deposits nor the terrace sands at Thetford contain much chalk although they have not been subsequently decalcified. However, one may not deduce from this that the Chalk formation was unaffected by freeze-thaw. Even during present winters, Chalk in quarry faces readily disintegrates under frost-action. Laboratory experiments show that only a few cycles of freeze—thaw are needed to reduce blocks to masses of silt (Tricart, 1956). Large quantities of pulverized chalk must have been freed on slopes by periglacial action. The fineness of this debris would have given it considerable mobility down all but the gentlest slopes. Presumably sheetwash and solution were instrumental in removing the chalk debris, leaving the coarser materials to move by solifluction. Many solifluction deposits have travelled great distances over the chalk on slopes as low as half a degree.

It is common for solifluction deposits in East Anglia to contain only small amounts of chalk, but in a few places there are thin deposits composed largely of chalk. The mobility of the chalk debris seems to have prevented thick accumulations. There must have been sufficient water action to wash away nearly all the chalk stripped from the hillsides. The thin deposits remaining have been made largely unrecognizable by soil development, ploughing and solution since periglacial times. The thickest solifluction deposits in the area of the Chalk outcrop are formed of clayey sand and gravel derived from plateau gravels and tills. Chalk is generally only a minor constituent of such deposits even where the solifluction crossed considerable tracts of Chalk before coming to rest.

Extensive sand and gravel accumulations fill the valley floors of eastern England. Chalk is largely absent from these deposits also. The cross-bedding and good sorting testify to the efficiency of the rivers in washing the debris fed in laterally by solifluction from the slopes. Similarly, large sand and gravel accumulations occur in south-central England, but, in sharp contrast, chalk is often a major constituent of such deposits (e.g. the fill of the Kennet valley above Marlborough). Instead of being carried downstream, chalk was deposited unsorted along with other materials. Permafrost was less extensive in south-central England and perhaps runoff and sheetwash were reduced. This might explain why there was less water in the rivers to sort the material.

The great aggradations in the river valleys of eastern and southern England seem to indicate wide floodplains with braided rivers following an erratic course across their own deposits. Sparks and West (1965, p. 36) have described the case of the River Cam which appears to have built up its floodplain to such a height that it diverted itself into a new course.

There is evidence in eastern England of several periods of aggradation and rejuvenation during the last glaciation. The sequence has been worked out very fully in the neighbourhood of Cambridge (Lambert, Pearson and Sparks, 1963; Sparks and West, 1965). The last interglacial deposits were mainly silts and muds with almost no gravel. They were deposited on a flood-plain resembling that of the present River Cam but at a higher level. With the beginning of the last glacial period sand and gravel began to be laid down over the silts and muds. Rejuvenation caused an incision of the river and left the previous deposits as the Barnwell Terrace. This incision was followed by aggradation and the deposition of further sand and gravel. A second phase of rejuvenation left these beds as the Intermediate Terrace and caused the deposition at a lower level of the Barnwell Station beds. The latter beds, mainly sand and gravel, are overlain by the alluvium of the present Cam.

Two periods of aggradation can be distinguished in the deposits on the slopes above the Cam valley. Patches of solifluction gravels (Taele gravel) occur on a number of low spurs and slight hills along the slope of the Chalk scarp from Newmarket Heath to Royston (Fig. 7). Till capping the escarpment mostly at levels above 300′ is apparently Gipping (Saale) in age. The topographic position of the solifluction gravels makes it quite clear that they have been slightly dissected subsequently; their erratic content indicates they are later than the till. Along the floors and sides of the shallow valleys which dissect the gravels are well-developed chalk-land polygon and stripes, demonstrating a later period of frost climate. Further evidence is provided by a number of old pits in the district which show the solifluction gravels to be strongly contorted by involutions and partly incorporated in the underlying Chalk.

The following sequence of events seems to have occurred:

(1) cold conditions: deposition of an apron of solifluction (Taele gravel);

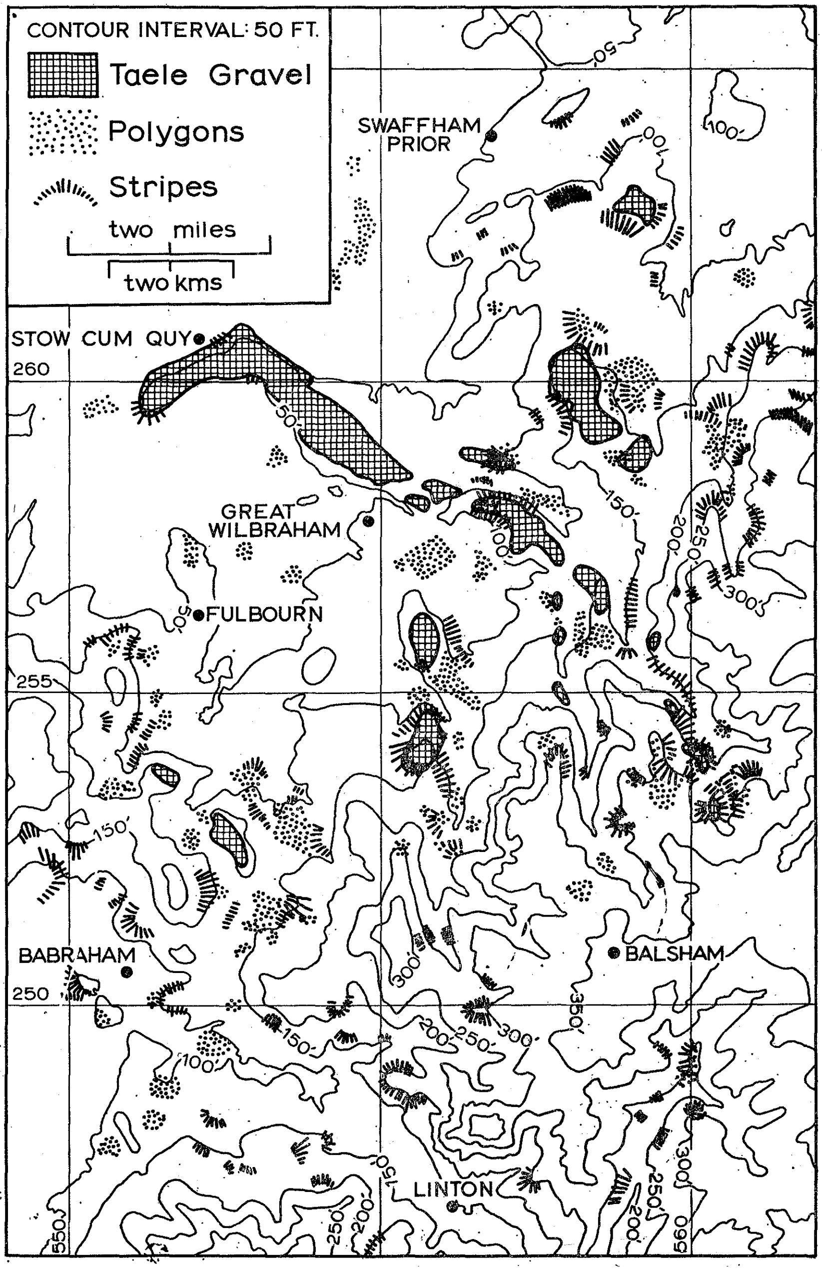

Fig. 7. Solifluction deposits (Taele gravel) and chalkland patterns in part of eastern Cambridgeshire

(2) climate uncertain: dissection of solifluction deposits by shallow valleys;

(3) cold conditions: formation of patterned ground, further solifluction.

An obvious date for the formation of the Taele gravels would be at the end of the Gipping glaciation just after the retreat of the ice to the north of the district (Sparks, 1957). It is suggested here however that the whole sequence may belong to the Vistulian period. The Taele gravels may belong to the same period as the Barnwell Terrace. The solifluction, the dissection and the final period of cold are not events of sufficient magnitude to involve necessarily more than one cold period.

CONCLUSIONS

The regional descriptions in the foregoing pages suggest that periglacial erosion was less in the west than in the east. In Devon and Cornwall up to 10 or 15 feet (3 or 4.5 metres) may have been removed from granite and gabbro, and up to 25 or 30 feet (7.5 or 9 metres) from shales, slates and schists. In south-central England 30 to 35 feet (9 or 10.5 metres) were apparently lost on the Chalk through solifluction. This figure does not allow for solution, for which it is difficult to estimate. Rapp (1960) found that the loss through solution at present in northern Sweden is at least as much as that through solifluction; but to apply this to periglacial England would make the total erosion 60 to 65 feet (18 or 20 metres), which looks too high. In East Anglia no figures for the amount of erosion have been obtained, but the fact that solifluction had largely ceased north of the Chilterns before periglacial conditions ended points to the removal of considerable amounts.

In the west the distances moved by solifluction debris were very much less than in the east. On Dartmoor the boulders have not been proved to have moved more than 3000 feet (915 metres) whilst in the Marlborough area the similar sarsens travelled up to 13,000 feet (4.0 kms.). Although figures for the movement of finer debris are not strictly comparable with those for boulders they do show that flowage was considerable in the east. Thus in west Kent, the vale of the Weald Clay is covered by thin deposits of sand and chert derived from the Hythe Beds escarpment to the north (Bird, 1963). These deposits are clearly of solifluctional origin and have been transported at distances of up to 21,000 feet (6.4 kms.) down slopes averaging less than 1°. Arkell (1947, p. 232) described and mapped much thicker solifluction sands and gravels at the foot of the Chilterns at their southern end near Wallingford. The deposits consist of transported clay-with-flints and chalk debris brought down from the crest of the escarpment. They have travelled a maximum of 29,000 feet (8.8 kms.) over a one degree slope. Their volume suggests that some 50 to 75 feet (15 to 23 metres) was eroded from the escarpment face. Since their deposition, possibly in the early Vistulian, valleys have been cut in the gravels in places to a depth of 40 feet (12 metres). Possibly this later dissection was also periglacial. In Cambridgeshire, the Taele gravels at Thriplow were carried up to 18,000 feet (5.4 kms.) from their source area on the Chalk uplands down a slope averaging less than one degree. The furthest spread of all was at Stow-Cum-Quy where gravelly sands were carried a maximum of 34,000 feet (10.3 kms.) on a slope of only about half a degree.

These results need to be approached with a good deal of caution. First, the data are only rough. Some areas of southern England have not been studied. Many types of rock remain to be considered. Ideally, a survey would need to be based on random sampling. This requirement is not easy to meet. Information on deposits has to be gathered chiefly from available sections, because augering and hand digging are unsatisfactory. The available sections are usually anything but a random sample. Quarries are often concentrated on steep slopes, or in places with a shallow overburden.

Secondly, the erosion is unsatisfactorily dated. In southwest and south-central England it is impossible to distinguish the effect on slope development of each successive cold period. What is now observed is the effect of all the periods. In all probability the head deposits belong largely to the last or last two glacial periods, and the figures for erosion likewise. But this cannot by proved. In East Anglia the position is a little clearer. In the last glaciation the area was free of ice sheets except along the extreme northern coast. During the preceding glacial period, the Gipping, an ice sheet covered the area north of the Chilterns and removed much of the evidence of previous periglacial erosion. Nearly all the periglacial deposits now found belong either to the period of the retreat of the Gipping ice or to the last glacial period. But it is difficult to date them more specifically, as the description of the Cambridge district showed.

Finally, it has to be remembered when interpreting the figures that the initial form of the ground greatly influenced the amount of periglacial erosion. The figures for south-central England refer to slopes which were already gentle before solifluction began; the figures for the southwest, to slopes which were much steeper and sometimes even cliffed. Glaciation may have left East Anglia with lower slopes and lower drainage densities than anywhere else in the south. How much erosion the ice sheets accomplished is uncertain, but it is suggestive that slopes greater than 8° on the

Chalk are practically absent from the glaciated area and yet are quite common in the Chilterns and further south. Ice erosion may well have played a large part in creating the very gentle slopes of the glaciated area, even though it is solifluction which was responsible for their final development. This may explain why, in contrast to districts further south, the Chalk of East Anglia appears to be in a state of periglacial maturity.

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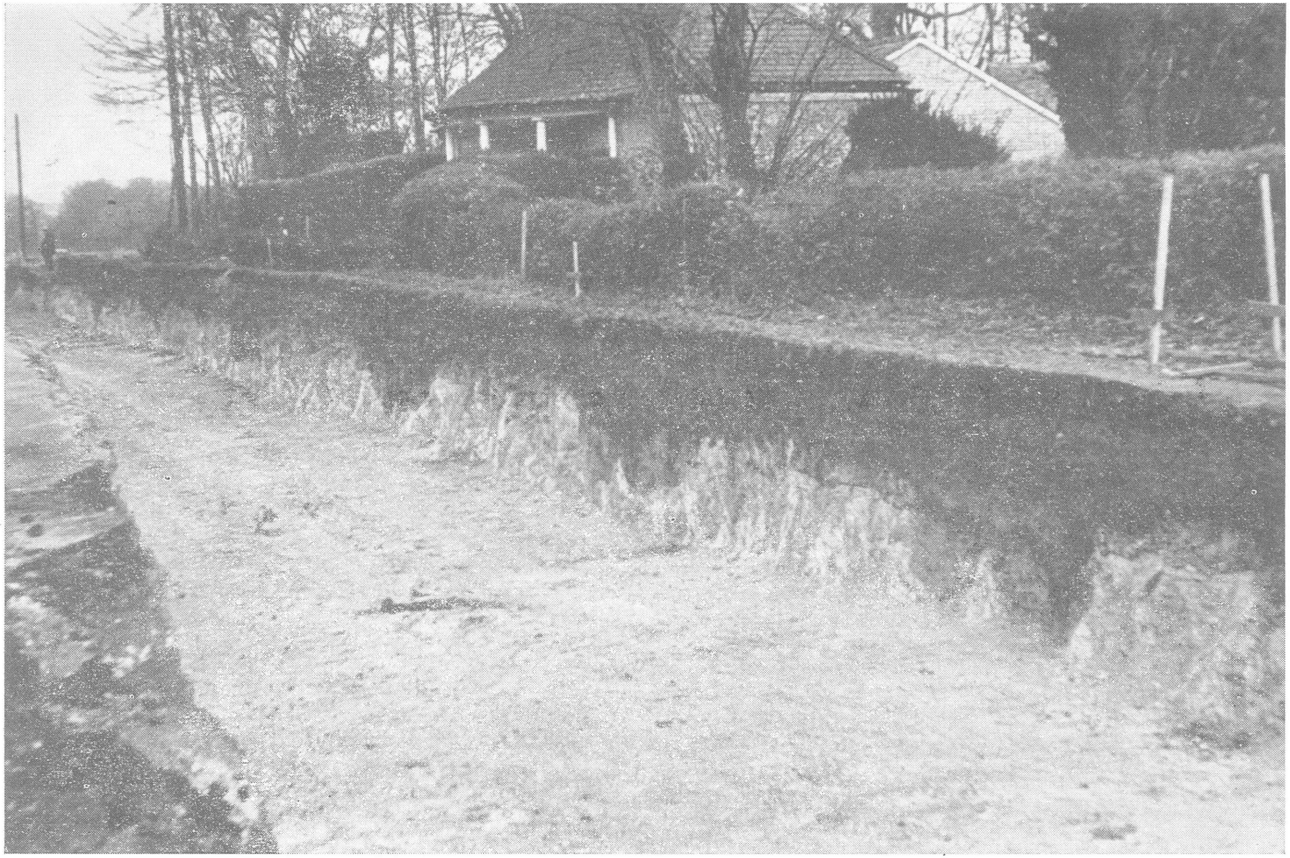
Pl. 1. Lockeridge Dene near Marlborough, showing the asymmetry of the valley sides

Sarsen stones enter the valley on the right of the picture down a gentle slope of 6°. The opposite slope is 18°

Pl. 2. Clatford Bottom near Marlborogh. Sarsen stones cover the valley floor and the gentle slope to the left of the picture. The opposite slope is 20° steeper



Pl. 3. Vertical section of chalkland stripes near Babraham, Cambridgeshire

The height of the face is six feet (2 metres). The road bed marks the level of undisturbed Chalk. The dark troughs are filled with sand and correspond to the dark stripes seen on air photographs of bare fields (see Williams, 1964). Between the troughs the Chalk is disturbed by involutions which consist of flame-like masses of chalk debris se parating pockets of chalky sand