

THE NATURAL PROCESS OF DEGRADATION OF AN OVERCONSOLIDATED
CLAY UNDER DIFFERING CLIMATIC CONDITIONS AS ILLUSTRATED
BY THE WEALD CLAY

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ABSTRACT

The Lower Greensand escarpment between Hythe and Aldington, Kent is an abandoned marine cliff. This section of slope illustrates the process of natural degradation under wet temperate climatic conditions. A comparison with inland slopes which have been affected by solifluction activity during former periglacial climatic conditions has identified fundamental differences in the slope processes between the two.

Conditions unique to the periglacial environment are required for the low angled slope processes which develop, but once the shear surfaces are produced movement can be initiated on them, even under the present wet temperate climate, by a modification of the slopes brought about by modern civil engineering development. An understanding of the processes and conditions that have influenced the development of slopes is paramount to the efficient engineering design on or close to them. Geomorphological relationships can provide a useful and rapid tool in the consideration of such developments and can have particular advantages where large areas are involved.

INTRODUCTION

Much of southern and eastern England is underlain by geological materials which can be described as 'soils' with regard to their engineering behaviour. Many of these are overconsolidated clays which were laid down at various periods in the geologic past. These include the London, Gault, Weald, Kimmeridge, Oxford and Lias Clays, also those clayey units within the Barton and the Woolwich and Reading Beds as well as the more recent boulder clay covering extensive areas of East Anglia.

Probably the most important influence on slope formation has been climatic changes in the recent geological past which have affected both slope stability and degradation. If the toe of a slope is steadily removed by erosion and that erosion subsequently ceases, the slope form will degrade under natural processes involving landsliding and soil creep (Chandler 1970a, Hutchinson 1967, 1975, Savigar 1952, and Skempton and Hutchinson 1969) such that the overall slope angle will reduce with time to some ultimate angle of stability. This angle will be affected by a variety of factors but for the relatively uniform character of the overconsolidated clays of south east England the strength of the material and in particular its angle of internal friction will play an important part (Skempton and Delory 1957). Vegetation may also have a marked effect on stability. Crozier (1979), Hutchinson (1967) and Skempton and Delory (1957) have described how deafforestation can spark off instability in previously stable slopes.

Chandler (1972) and Weeks (1969) have described slopes which are flatter than the ultimate angle of stability for the present prevailing conditions, but which contain slickensided surfaces indicating that movement has previously occurred on them. Clearly for these slopes to have developed conditions must have been different during their formation to those acting today, or some other process than mass movement was involved. Consequently, the 'stability' of any slope can be regarded as no more than a temporary state which can change in response to the conditions which act on it. An understanding of the factors and conditions which prevail during the formation of such slopes is often crucial to the satisfactory civil engineering development in their vicinity.

Part of the Weald Clay outcrop in Kent, England, is on the north side of the Romney Marsh. Before the formation of the marsh the outcrop, capped by the Hythe Beds, formed a line of sea cliffs between Aldington in the west and Hythe in the east (Fig 1). As the marsh silted up it protected the cliffs from basal erosion by the sea and allowed them to degrade naturally to a stable slope angle. The marsh has developed progressively from the west as a response to the growth of the Dungeness Foreland (Gallois 1965, Lewis 1932). Since the processes of natural degradation are time dependent the progressively decreasing period of protection along the cliff means that the slope illustrates many of the phases of degradation (Howland 1974). Much of the abandonment has occurred since the last Ice Age, probably in response to the general rise in sea level. Therefore this particular section of the escarpment and the processes of degradation which have acted on it have not been influenced by periglacial conditions and afford an

opportunity for comparison with inland slopes on which mass movement processes under periglacial conditions predominate. This paper summarises the change in surface character of the abandoned slope, compares this to otherwise similar slopes inland and discusses the implications that these have on the processes of natural degradation.

THE GEOLOGY OF THE WEALDEN DISTRICT

The Wealden District covers much of the counties of Kent and Sussex in south east England. It forms a low-lying fertile vale about 130 km by 40 km bounded by the escarpments of the North and South Downs. Structurally the Weald forms an area of inverted relief being an eroded anticlinorium thrown up at the edge of the Tertiary Alpine Orogeny and carved out by a marine transgression during the Pliocene. The landforms have been subsequently modified by subaerial weathering and erosion to form a concentric pattern of Cretaceous sandstones and clays forming escarpments and intervening vales.

The Weald Clay forms the upper horizons of the Wealden Series within the Cretaceous sequence. It increases in thickness along its outcrop from 120 metres at Hythe to 450 metres at Guildford and is the most argillaceous of the Series. In a weathered state it is a light brown to grey, often mottled heavy clay or silty clay while unweathered it is a dark brown or grey overconsolidated fissured clay which can have a shaley texture. Horizons or nodules of mudstone are found within the unweathered material and the presence of sand has been noted. To the south of Maidstone the Weald Clay becomes somewhat more variable. Although it still consists mainly of clays and shales, the megacyclothems identified by Allen(1959) are more evident. This produces a large scale regular progression of slightly differing lithologies within the general sequence of the clay.

Lying unconformably on the Weald Clay is the mainly bluish-grey and brown, mottled sandy clay and pale-grey, slightly glauconitic Atherfield Clay. The lower horizons at the junction with the Weald Clay are a reddish-brown or chocolate-brown clay. Although slightly coarser in grading, it is generally similar in character to the Weald Clay. The Atherfield Clay passes upwards into the Hythe Beds which consist of alternating beds of a hard, grey, glauconitic, sandy-limestone and a grey glauconitic, argillaceous-calcareous sand or soft sandstone. These beds act as a cap rock to a dominant escarpment within the Wealden District often referred to as the Lower Greensand escarpment. Along much of the escarpment, the Hythe Beds show marked evidence of cambering. Sparse evidence of cambering between Hythe and Aldington arises from the post-glacial removal of cambered material prior to abandonment of the cliff line.

ROMNEY MARSH AND THE ABANDONED SEA CLIFFS

Romney Marsh and the associated Dungeness Foreland are comparatively recent features which have grown to their present size and shape over the last few thousand years having evolved from a wide shallow bay which ran from Hythe to Romney via Appledore (Lewis 1932, King 1966).

Gallois (1965) considered that the marsh originally formed behind a sand bar between Fairlight and Hythe some 3-4000 years BP. This was subsequently breached by a marine transgression which moved the coastline back to its former position along the surrounding cliffs. The bay subsequently again silted up and the earlier marsh deposits formed the buried peat which can now be found throughout the area. Additional evidence (Howland 1974) supports the inference of Horman (1938) that cliffs at Lympe were progressively abandoned by the sea in an easterly direction.

THE GEOMORPHOLOGY AND SLOPE STABILITY OF THE WEALD CLAY

Mass movement along the Lower Greensand escarpment has been recorded since early time up until recent decades (Skempton and Weeks 1976, Weeks 1970). That movement is still occurring between Hythe and Aldington is evident from the tilting of trees and the building up of soil behind trees and masonry walls: a recent slip (post 1966) has occurred on the slope at Lympe to the west of St Mary's Church (TR 128344).

The setting of this section of escarpment is such that many of the variables which might otherwise affect the degradation processes are constant. The height of the slope is consistent at about 95 metres, the regional geological dip is shallow and virtually normal to the strike of the slope. The major geological units within the slope are of fairly constant stratigraphic thickness and are consistent in character along the slope. The slope is continuous with a constant aspect and so is likely to have experienced the same climatic conditions along its length. The base of the slope is bordered by marsh suggesting a similar style of abandonment has occurred throughout. Thus the only important variable which might affect the slope form is the time since abandonment.

If the slope form reflects the slope processes, comparison of the form along the escarpment may give a measure of the variation of these processes with time. Five areas were chosen along the slope from Hythe to Aldington and a sixth, at Linton Park to the south of Maidstone, was also included as its inland character provided a comparison with potentially similar slopes in the marsh study area (Fig 1).

In order to quantify the variation in slope form a profile was surveyed in each of the areas using an Abney Level and tape. The actual line of the profile was determined by access to the slope and a position where a straight line from the bottom to the top of the slope could be made without being interrupted by obstacles.

The overall angle of each slope was determined by measuring the angle from the sharp break at the plateau surface to the toe at the marsh edge. but in reality the profiles consist of two or more straight segments. The character of each profile is described here:

Profile I rises from the marsh level to the upper plateau surface with an overall angle of 12.5 degrees. The profile is irregular and has a step-like appearance, the size of each step tending to decrease downslope. The lower segment of the slope has an angle of 9.5 degrees and rises sharply from the marsh with a steep face which has a fresh appearance. The surface of this segment has similar steep faced features which are probably due to slips emerging in an accumulation zone. The rest of the slope has a middle segment of 10 degrees and a top segment of 16 degrees.

Profile II has an overall slope angle of 11.5 degrees and the toe emerges less abruptly from the marsh. The Hythe Beds have been incorporated into a rotational slip producing a back tilted block while other smaller back tilted blocks can be found further down the slope. The toe rises less abruptly from the marsh and appears less active although a lobate face emerges on the face of the accumulation zone and has a form very similar to the toe of Profile I.

Profile III is considered to be approaching the assessed ultimate angle of stability. Except for a small segment which has been confused by a small stream flowing transversely across the slope, the whole length is at 8 degrees. The profile is far less steplike than previously noted, being more rounded and subdued. The toe rises gradually from the marsh indicating that the accumulation zone is stable.

Profile IV has an overall slope of 7 degrees, which is shown later to represent the ultimate angle of stability under the present climatic conditions. The toe of the profile at this point is somewhat confused by the presence of the sandy base of the Weald Clay. The slope surface is very subdued in comparison to those to the east.

Profile V has an overall slope of only 5.5 degrees which is lower than present conditions would allow. The slope comprises three segments: an upper at 8 degrees, a middle at 4 degrees and a lower at 1.5 degrees. The toe ends in a small bank but this may be confused by agricultural workings. The overall shape of the slope compares to that of Profile VI and both have strong similarities to the profile of the soliflucted section of the escarpment at Sevenoaks described by Weeks (1969).

Due to its inland position, Profile VI can have experienced no toe erosion in the recent past. The overall slope angle is 3 degrees, although this is not measured to the top of the slope which is confused by cambering of the Hythe Beds. The profile is flat and smooth but with a number of steep banks producing an almost terrace-type surface which are probably solifluction lobes as described elsewhere along the escarpment by Skempton and Weeks (1976).

The overall angle decreases from Profiles I to VI (Fig 2). Slope processes vary according to the slope angle (Skempton and Hutchinson, 1969) and if the slope morphology is a function of the degradation processes acting on the slope, then it is not unreasonable to assume that the surface roughness along the line of a profile (a measure of surface texture) is also a function of the slope process which, in turn, can be related to slope angle.

The roughness of a profile can be taken as the variation of the irregularities from a straight line at the mean angle of the segment. In that way the measured roughness will be independent of the angle of the slope segment. Young (1972) states that an irregularity may be considered in terms of its amplitude and length and can therefore be described by the ratio of amplitude to length (Fig 3). Since each slope segment is made up of a number of irregularities this may be taken into account to give a measure of the surface roughness of the profile called the Roughness Index, RI may be given as:-

$$RI = \frac{\sum \frac{H}{L}}{n}$$

where n = number of irregularities in that segment

Since it is found that a line joining the troughs of each irregularity approximates to the mean angle of the segment, in practice the length L can be taken as the distance between adjacent troughs and H as the amplitude of the intervening peak measured normal to that line. The mean segment angle plotted against the logarithm of the Roughness Index shows there to be a decrease in Roughness Index with a decrease in slope segment angle (Fig 4). This can be explained by the change in slope processes which occurs as slopes degrade to a lower angle. Hutchinson (1967) has shown that as the slope angle reduces then the mode of failure active on the slope face changes from rotational to predominantly translational. The strongly translational nature of movements that occurs on low angled slopes approximates to an infinite slope analysis as determined by Skempton & Delory (1957). This shows the factor of safety for any situation to be sensitive to the pore water pressure acting on the slip surface. In failed material the strength parameters approach the residual condition, which for the Weald Clay can be taken as $c' = 0$ and $\phi' = 14$ degrees. Under wet temperate climatic conditions the limiting condition will occur when the groundwater table is at ground surface and the pore water pressure is controlled by hydrostatic conditions. This can be given by:-

$$\tan \beta = 0.5 \tan \phi'_r \dots\dots\dots(1)$$

Consequently, the ultimate angle of stability, β , under wet temperate conditions is seen to be 7 degrees. To produce failure on a surface at a lower angle than this, Hutchinson (1967), Skempton and Delory (1957), Skempton and Weeks (1976) and Weeks (1969) have demonstrated that excess pore pressures are required at the slip surface.

The pore pressure on a slip surface can be considered in terms of the pore pressure ratio, r_u . For material at residual strength the associated ultimate angle of stability can be determined for varying pore pressure situations by the relationship:-

$$\tan \beta = (1 - r_u) \tan \phi'_r \dots\dots\dots(2)$$

When the groundwater is at ground surface r_u approximates to 0.5 so that equation 2 compares to equation 1.

This again demonstrates that in order to reduce the slope angle below the ultimate angle of stability under wet temperate conditions it would be necessary to develop pore water pressures on the failure surface in excess of those produced under hydrostatic conditions. In the field, artesian pore pressures can be associated with solifluction activity (Chandler, 1972). A number of mechanisms peculiar to the periglacial environment can be considered which may lead to the development of such conditions. The growth of ground ice within clayey materials produces ice lens. If subject to a rapid thaw Skempton and Weeks

(1967) have speculated that the low permeability of the Weald Clay may develop pore pressures in excess of the hydrostatic conditions. It may be that a number of mechanisms actually operate. For example the rapid re-freezing at surface may apply additional loading to the contained moisture in an underlying thawed zone due to the expansion of the ice, thereby producing excess pore pressures. It is likely that the outcrop of the Hythe Beds developed snow packs due to drifting along the escarpment. Skempton and Weeks (1976) have shown that the lobes developed by solifluction activity are associated with the slopes below the Hythe Beds outcrop and the more featureless mantle occur on a more extensive regional scale. It is interesting to speculate that the conditions produced by the presence of the snow packs, perhaps by providing a back-weighting, develop a more localised condition which led to the growth of distinct lobes rather than the mantle of soliflucted material which was perhaps produced under a more regionally applied mechanism.

Reference to figure 4 shows that for Profiles I to IV, where the overall slope is greater than 7 degrees, a regular relationship exists between the segment angle and the logarithm of the Roughness Index. (Two points representing segments lower than 7 degrees in Profiles III and IV were noted in the field as being modified by stream action on the slope. The 12.5 degree segment in Profile IV represents the location of a sand lens in the Weald Clay. Therefore these points are considered unrepresentative and for clarity have been omitted from the diagram).

The plots for Profiles V and VI fall interestingly off the relationship shown by Profiles I to IV. The segment angles from these profiles, except for one, and the overall slope angle of these two profiles are lower than an angle of 7 degrees. These must therefore have been developed under periglacial conditions. It is possible to postulate that the surface roughness for any segment angle is lower where the slope has been controlled by periglacial slope processes. In effect any slope angle will develop a smoother surface texture under periglacial rather than wet temperate conditions. This must be entirely due to the increased dominance of translational processes which follow from past periglacial conditions.

A plot of overall slope angle against position along the slope between Hythe and Aldington produces two families of points (Fig 5). Through the more easterly group, two possible lines can be drawn through the points. One is clearly asymptotic to 7 degrees or thereabouts, the calculated ultimate angle of stability. If time can be substituted and broadly taken as linear on the X-scale, it would indicate that the slope has reached the ultimate angle of stability at this point and as found by Hutchinson (1975), the rate of slope decline slows down as it is approached.

The second possible line could be extrapolated through the points as a straight line and would suggest that solifluction is a direct continuation of normal landsliding processes and that all slopes can and will degrade below the ultimate angle of stability. As has been shown this is clearly not the case. Therefore it can be concluded that east of Easting 090, the base of the slope has been eroded since the last period of solifluction during Zone III 10,300 - 10,800 years BP so removing any solifluction deposits which would previously have been present. In contrast, the area to the west has undergone no such erosion and the slopes have remained stable and unmodified since. A date of abandonment can be put on at least one part of the former coastline. The area below Manor Farm (TR 090354) must have been abandoned by the sea about 10,500 years ago. By inference this area has only just reached a state of ultimate stability, the process of natural degradation in Weald Clay can therefore be estimated at about 10,000 years.

The influence of agricultural activity must be considered in a discussion of this type. Chandler (1970b) notes that certain agricultural activities may modify the surface texture by smoothing the irregularities. Indeed the land use of Profiles V and VI does differ from those of Profiles I to IV, except for the 8 degree segment of Profile V. Profiles I to IV and the 8 degree segment of Profile V are under rough pasture and so unmodified. The low angled segments of Profile V are under arable grazing while Profile VI was taken through Parkland. It is not possible to assess the modification by the differing land use but the Parkland is unlikely to have been subject to extensive ploughing and the 8 degree segment of Profile V has a similar land use to Profiles I to IV but still shows a lower Roughness Index. This suggests that the different trend between Roughness Index and slope segment angle is related to the differing slope processes, and is not significantly affected by land use differences.

THE INFLUENCE ON CIVIL ENGINEERING DESIGN

The existence of pre-existing landslides on many of the natural slopes of south east England is becoming increasingly recognised. Unless these features are recognised or the potential for their presence is understood they can produce drastic effects when the conditions of slopes are modified by civil engineering development. An early indication of their influence occurred when construction of the Sevenoaks Bypass reactivated solifluction deposits along the Lower Greensand escarpment (Skempton and Weeks 1976). The scale of many engineering works is such that significant modifications can be produced either to the drainage or the stress conditions within a slope which are able to induce failure in otherwise stable situations. In order to

adequately assess the likelihood of this occurring it is necessary to understand the regional setting of the slope and the mechanisms and conditions that have influenced its development. Geomorphological relationships such as those discussed here between the surface roughness and the slope processes are useful indicators. Although they may often have no general applicability to areas outside those on which they were developed the methods available are relatively inexpensive often fairly rapid to undertake and have the major advantage that where large areas are to be assessed they can provide an understanding of the area not always possible from more conventional point sampling techniques. This advantage is becoming increasingly important as congestion or economics force lines of communications to cross landslipped areas or the growth of industrial or urban areas encroach on hillsides.

CONCLUSION

The Lower Greensand escarpment between Hythe and Aldington, Kent, forms the abandoned sea cliff of a bay, which has since silted up to form Romney Marsh and the Dungeness Foreland. A logarithmic relationship has been found to exist between the slope angle and a measure of the surface irregularity called the Roughness Index. Where periglacial processes have acted the Roughness Index is reduced as a result of the fundamental differences in slope processes from those acting in wet temperate conditions. Since the western end of the slope has characteristics of solifluction activity it indicates that abandonment at that point occurred before the end of periglacial conditions probably about 10,500 years BP. To the east any such activity has been removed by marine action and the slopes subsequently degraded under the prevailing temperate conditions to an ultimate angle of stability assessed to be 7 degrees for the Weald Clay.

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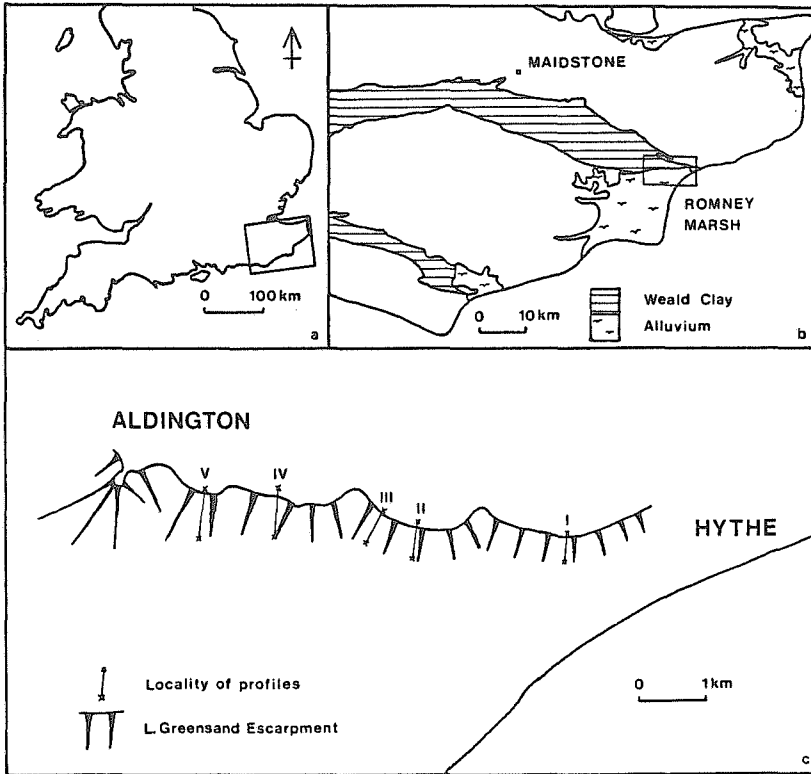


Fig.1 The Lower Greensand escarpment between Hythe and Aldington:

- a) Location map
- b) The outcrop of the Weald Clay to the north of Romney Marsh and the location of inset c and its position relative to the inland profile VI at Linton near Maidstone
- c) The escarpment between Hythe and Aldington showing the localities of profiles I to V.

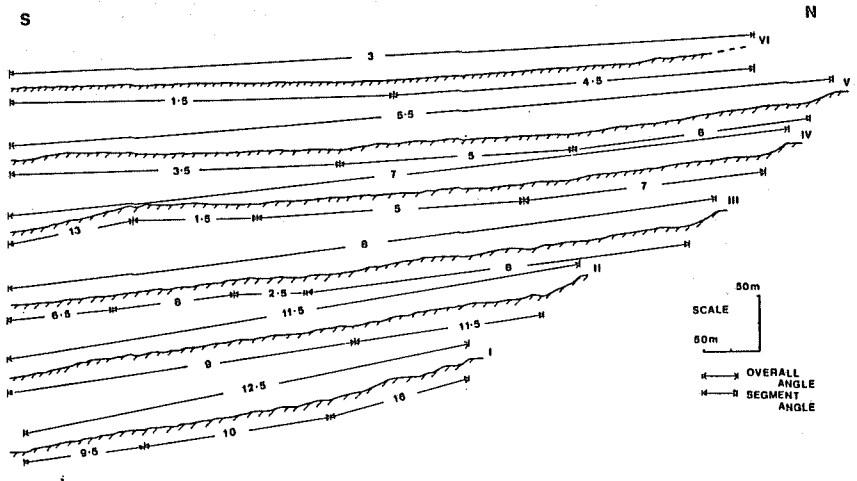
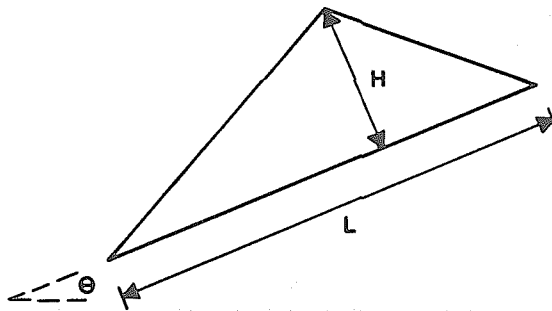


Fig.2 Slope profiles surveyed by Abney level and tape between Hythe and Aldington (I-V) together with the slope of the escarpment at Linton, south of Maidstone (VI) showing the overall slope angle and the segment angles determined for each.



H - amplitude

L - length

Θ - mean angle of the slope segment

Fig.3 The general form of irregularity on the surveyed slope profiles.

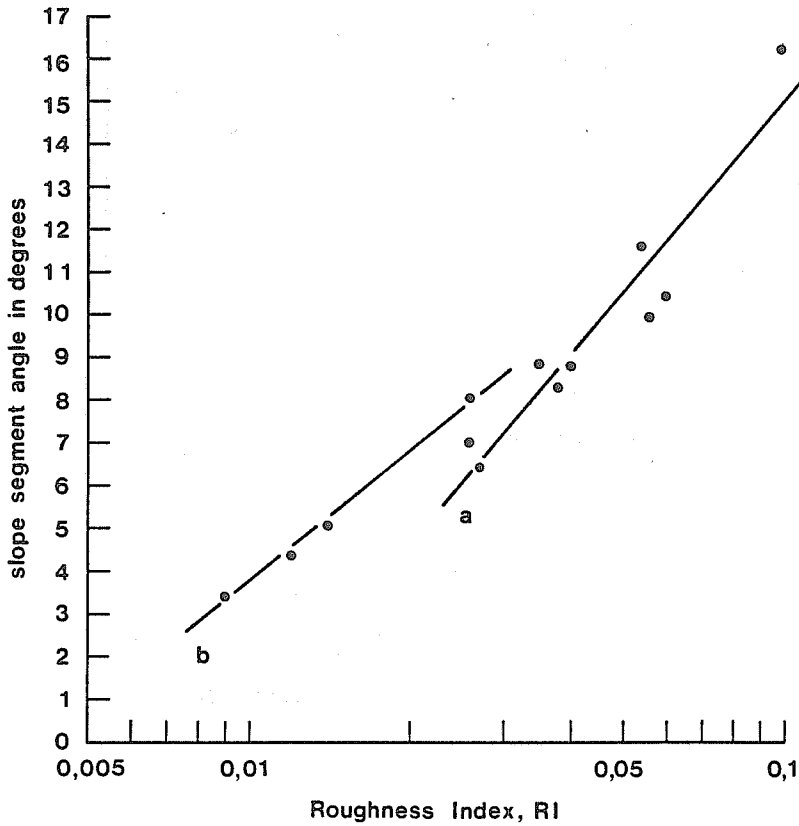


Fig.4 The roughness Index against segment angle for
 a) wet temperate conditions
 b) periglacial conditions
 Only representative points are plotted.

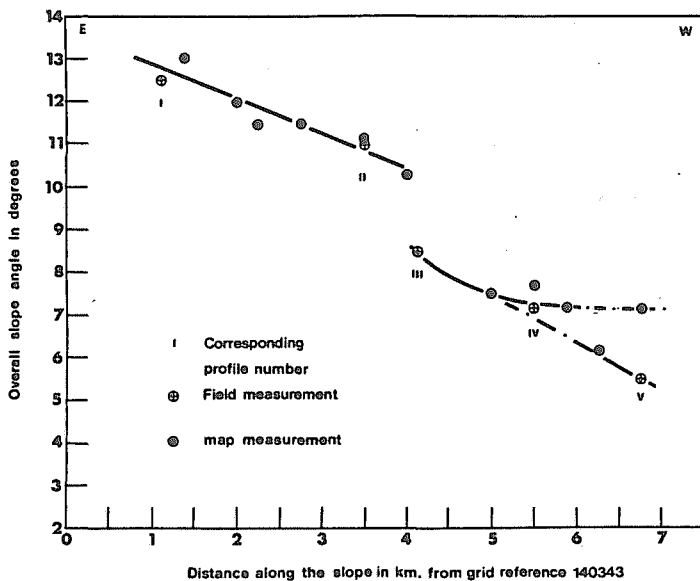


Fig.5 The overall slope angle westwards along the Lower Greensand escarpment between Hythe and Aldington against distance from a datum point (TR 140343). Measurements taken from the surveyed profiles have been supplemented with additional measurements abstracted from Ordnance Survey mapping of the area.