Cliff Recession on the Isle of Wight SW Coast

Retraite des Falaises sur le Littoral S-O de l'Ile de Wight

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SYNOPSIS The paper draws attention to the power of seepage erosion to cause instability in natural slopes. A 2 km length of actively retreating coastal cliffs, between 55 and 110 m high, in gently inclined Lower Cretaceous (Upper Aptian and Lower Albian) strata near Chale, Isle of Wight is examined. These cliffs exhibit a marked bench between a lower, sea cliff and an upper, rear scarp. The role of seepage erosion in forming this bench and the processes by which the resulting debris is moved across the bench into the sea are explored. The discussion centres around the lithological, structural and hydrogeological controls operating, the history of coast erosion and cliff recession, and the nature and mechanics of the mass movements taking place.

INTRODUCTION

The length of coast between Atherfield Point and Blackgang Chine (Fig.1) suffers a high rate of recession. This arises partly from the lithology and hydrogeology of these Lower Greensand cliffs and partly from their extreme exposure to Atlantic storms. When elucidating the stratigraphy, Fitton (1847) made some perceptive comments on the morphology and wastage of these cliffs but no subsequent work has been carried out. This paper reports the results of an exploratory engineering geological and geotechnical study of the SE half of the above length, from Walpen Chine to Blackgang Chine (Figs.2-4), which will be referred to as Chale cliffs.

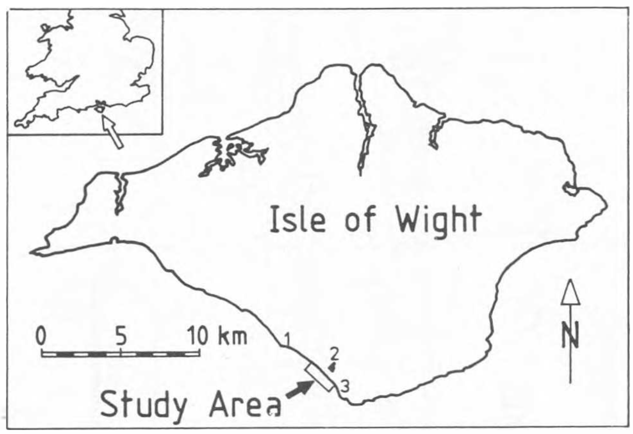


Fig.1 Key map: 1. Atherfield Point, 2. Chale village, 3. Blackgang Chine.

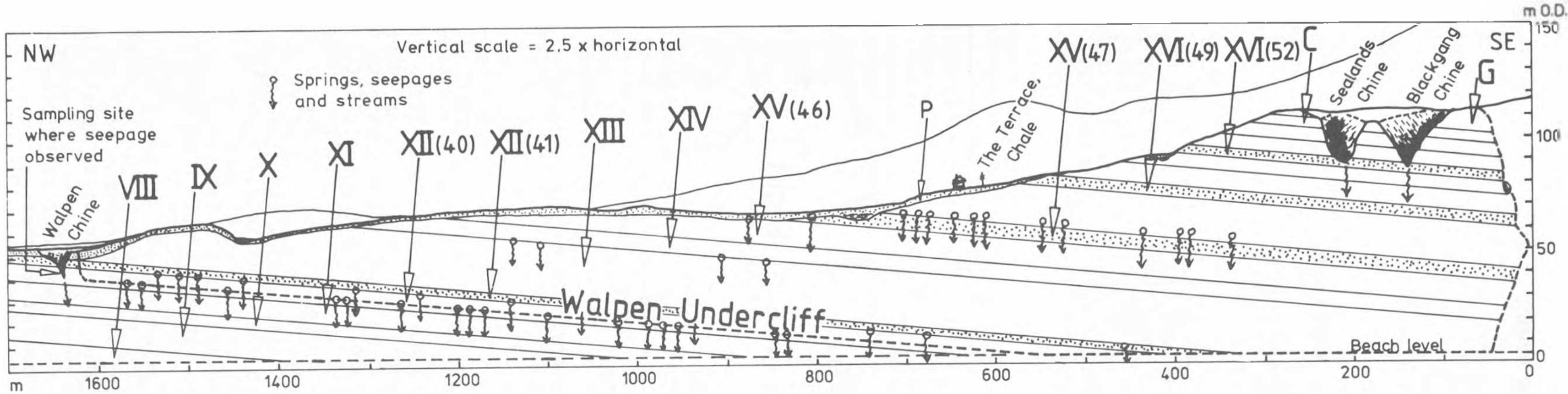
GEOLOGICAL AND HYDROGEOLOGICAL SETTING

Chale cliffs trend approximately NW-SE and rise in height towards the SE from about 55 m at Walpen Chine to 110 m at Blackgang Chine (Fig.3). They constitute essentially a dip section through the SE end of the Brixton anticlinal dome, which is situated largely offshore (White 1921). The apparent dip of the strata in the cliffs of 2 to $2\frac{1}{4}^{\circ}$ to the SE is therefore close to the true dip, and the component of dip normal to the coastline is inappreciable. Apart from a thin capping of Quaternary deposits, the cliffs are composed largely of the upper two-thirds of the Lower Greensand (Lower Cretaceous). The lithology of these sediments consists generally of alternations of rather weakly cemented sands with clayey sands and clays. This has led to the development of a number of perched water tables, probably sustained by infiltration into the outcrop of the Lower Greensand to landward, the presence of which is inferred from seepage lines in the cliff face. The more persistent of these are indicated in Fig.3. The existence of a reservoir of ground-water in the Lower Greensand here is indicated by a well in this formation at Pyle Farm, about 2 km N of the cliffs, which has a rest water level of + 43 m O.D.

ORIGIN OF THE WALPEN UNDERCLIFF

The most striking feature of the Chale cliffs is the presence of a debris-covered bench (or "undercliff", to use the local term) which separates a precipitous rear scarp from a steep sea cliff (Fig.5). This bench, known as the "Walpen Undercliff", descends concordantly with the dip of the strata from near the cliff top just SE of Walpen Chine to about beach level below Blackgang Chine (Fig.3)*. Its width increases fairly steadily from a few metres at its NW end to about 100 m at its SE limit (Fig.4). Particularly in the SE third of this length, subsidiary benches tend to develop in the rear scarp. Currently the most important of these extends from just NW of CS3 to about CS4 (Fig.4): it is shown, partly developed, in CS3. During the 19th century and the early part of the 20th, this and other subsidiary

*The NW extension of the length of cliff considered here exhibits similar benches.



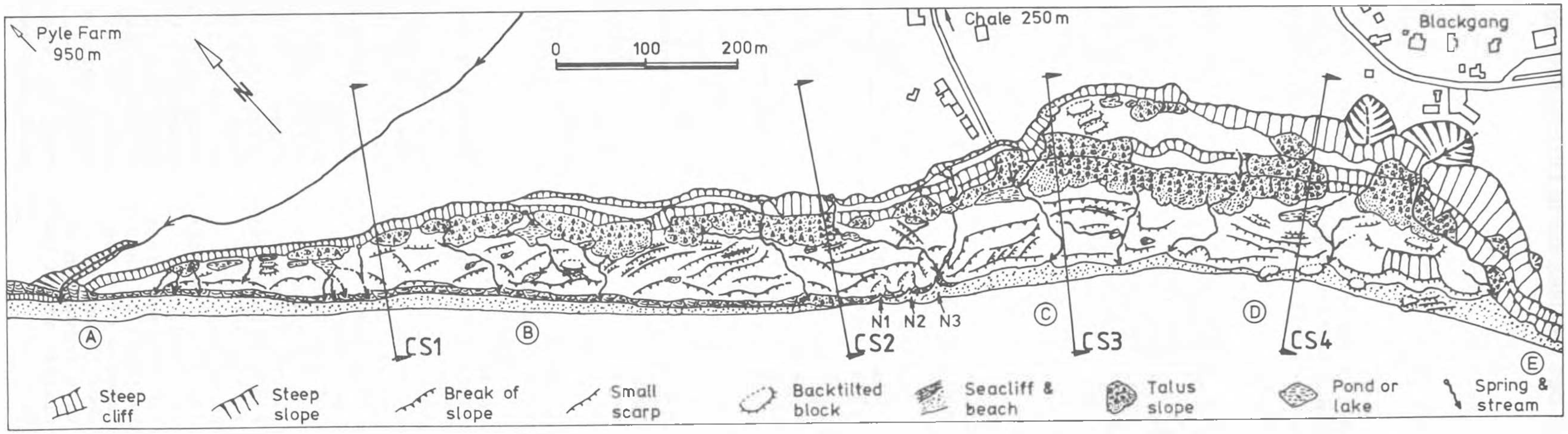


Fig.3 (upper). Geological elevation of the Lower Greensand in Chale cliffs. The scheme of Fitton (1847) is used, with later modifications by Casey (1961) and others:
Ferruginous Sands: VIII Upper Crioceras Group (14.0m), IX Walpen and Ladder Sand (12.8m), X Upper Gryphaea Group (4.9m), XI Cliff End Sand (8.5m), XII(40) Foliated Clay and Sand (7.6m), XII(41) "1st sandrock of Fitton" (3.0m), XIII Sands of Walpen Undercliff (24.1m), XIV Ferruginous Bands of Blackgang Chine (6.7m), XV(46) upper sandy clay (11.3m);
Sandrock Series: XV(47) "2nd sandrock of Fitton" (6.4m), XV(48) muddy sand and sandy mud (18.0m), XVI(49) "3rd sandrock of Fitton" (4.9m), XVI(50) fine yellow sands (8.5m), XVI(51) silty clay (6.7m), XVI(52) "4th sandrock of Fitton" (4.3m), XVI(53) yellow sands (5.5m), XVI(54) muddy sands (6.4m);
Carstone: C. ferruginous pebbly sands (3.7m);
Gault: G. P. indicates the Pleistocene capping.

Fig.4 (lower). Morphology of the Walpen Undercliff.

higher benches were much more extensive and sufficiently stable to be built upon (Fig.5,CS4).

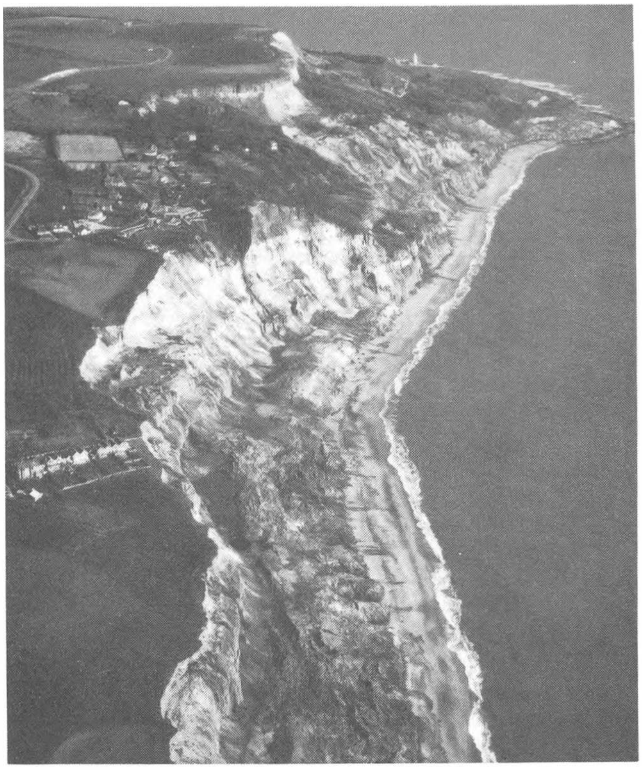


Fig.2 View SE to St Catherine's Point. In the foreground Chale cliffs and Blackgang village. Photographed 7th May 1978 (Cambridge University Collection: copyright reserved).

Fitton (1847) suggested that the benches in these cliffs are produced by the presence of certain less permeable beds within generally more pervious strata..."the water thus kept up carries off a part of the lower mass, undermining that above; and the result is the production of a shelf or terrace, between two ranges of cliffs, one of them supporting 'the Undercliff', the second forming a remoter vertical face behind". Fitton also observed that in the Walpen Undercliff the less permeable bed was provided by the clays of the Foliated Clay and Sand (Bed XII(40)). This still applies although the in situ bench surface, beneath the debris, is located generally only a few metres above the base of Bed XII, the upper half to two-thirds of this having been eroded away (Figs.3 & 5). It is more difficult to check that seepage erosion is taking place at the rear of this bench, back-sapping, undermining and bringing down the rearward cliff, as the seat of any such process is generally buried beneath metres of debris and located directly below an unstable cliff. Fortunately the stream in Walpen Chine has cut down about half-way into Bed XII (Fig.3). At this point seepage erosion was found in March 1980 to be active within a 60mm thick layer of fine sand in a laminated clay/sand series. This layer was located about 0.8m above the talweg of the stream, just in from the cliff face. Seepage erosion was then confined to the up-dip (NW) side of the chine. This is doubtless the reason for the asymmetry of the chine, its NW side being the less steep. The fine sand being transported away by the outflowing groundwater and the resultant undermining of the superincumbent strata are shown in Fig.6. The grading curve for the eroding sand, which is similar to the curves for other such sands reported in the literature (e.g. Ward 1948, Masannat 1980), is given in Fig.7.

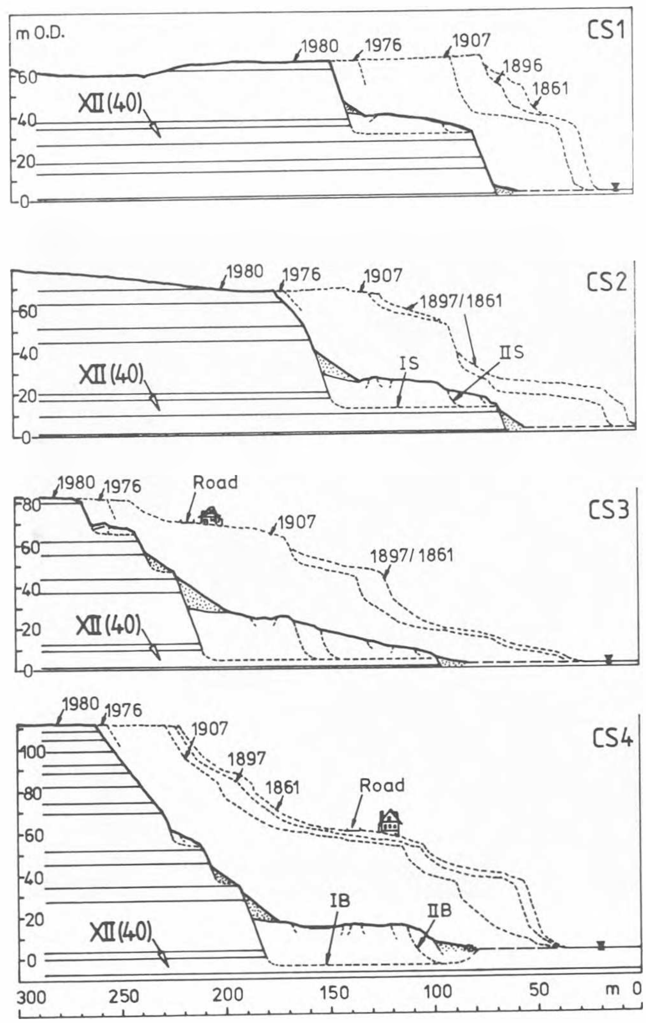


Fig.5 Cross sections CS1-4 with inferred slip surfaces and former cliff profiles. (For stratigraphy see Fig.3).

Other factors consistent with the occurrence of this mechanism are:
1. The lithology of the cliffs, with clayey beds occurring within a generally sandy sequence, is predisposed to such a development.
2. The bench supporting the Walpen Undercliff is located within one such clayey bed, the Foliated Clay and Sand.
3. Along the top of the sea cliff, strong seepages of ground-water issue from beneath the debris of the undercliff along its contact with the underlying, clayey, bench surface.
4. A reservoir of ground-water at a sufficient head is available inland.
5. Much water is present towards the rear of the

undercliff, particularly in its lower, SE parts.
6. Where the undercliffs are cut by deep chines, there is a tendency for a length of stable cliff to exist immediately down-dip from the chine, after which the undercliff reforms. This suggests that drainage to the chines suppresses the seepage erosion on their down-dip sides (Fitton 1847). Our own observations in Walpen Chine, described above, support this inference.
7. The alternative, and more general, mechanism of producing an undercliff, by deep-seated, usually multiple rotational slipping (Hutchinson 1968), requires the presence of a cap-rock and a thick substratum of clay. Except where noted below, the latter is generally absent in the Walpen Undercliff and so this mechanism is inhibited.

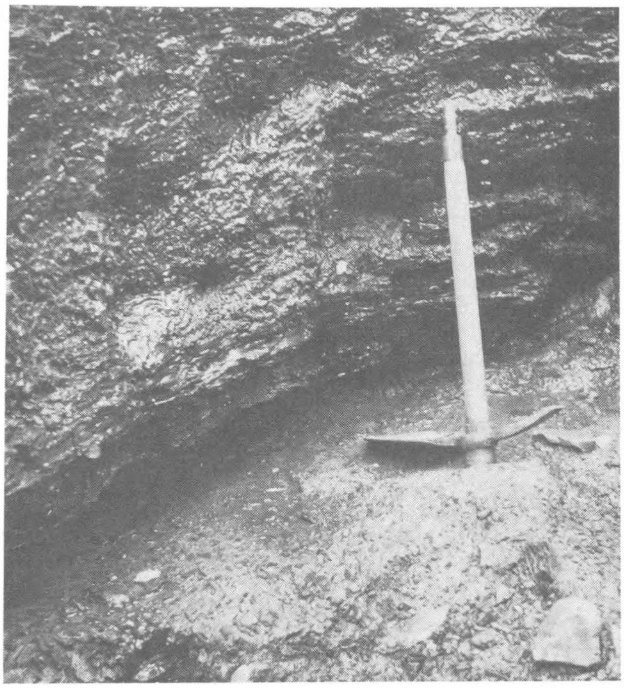


Fig.6 Erosion of fine sand in NW side of Walpen Chine. Undermining 0.18m, length of tool handle 0.46m.

PRESENT PROCESSES AFFECTING WALPEN UNDERCLIFF

It is convenient to discuss these processes under the following headings:

Sea Cliff

The *in situ* sea cliff declines from a height of around 35 m at A (Fig.3) to zero in the vicinity of C where the bench surface passes below beach level. It is formed by the middle part of the Ferruginous Sands. Further SE the sea cliff is composed of landslide debris which, as noted later, is considerably less resistant to marine erosion. This cliff is attacked by waves at most high tides. The available data on the positions and rates of recession of the sea cliff since the mid-19th century, derived from the 1:2500 Ordnance Survey maps, are shown in Fig.5.

The measurements for the *in situ* sea cliff (CS1 & 2) indicate an average retreat of about 51 m in the 119 years from 1861-1980 (0.43 m/yr). The contrast between the rates of recession in 1861-1907 and 1907-80 is marked, these being respectively 0.21 m/yr and 0.57 m/yr.

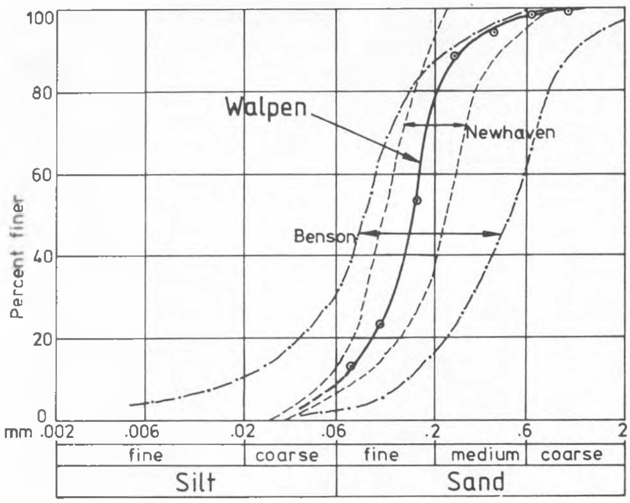


Fig.7 Gradings of eroding sands from Walpen Chine; Newhaven, Sussex (Ward 1948); and Benson, Arizona (Masannat 1980).

Rear Scarp

In its NW length, the rear scarp has a relatively simple, precipitous profile. It rises in height from about 15 m near A to around 55 m at C and consists chiefly of the upper Ferruginous Sands and the lower Sandrock Series (Fig.3). In the remaining SE length, the height of the rear scarp rises to about 90 m, bringing in the rest of the Sandrock Series, the Carstone and the lowest part of the Gault. This renders its profile and modes of collapse correspondingly more complex.

As argued above, seepage erosion and back-sapping at about the level of the undercliff bench are probably the dominant processes bringing about rear scarp collapse and retreat. The degree of activity of these will be influenced by the rate of recession of the sea cliff, resulting from marine attack. If this is less than the corresponding rate of retreat of the rear scarp, the thickness of saturated debris at the rear of the widening undercliff will tend to build up, thus reducing the out-of-balance pore-pressures across the face of the eroding sand stratum and eventually inhibiting further seepage erosion there, and *vice versa*. Seepage erosion at higher horizons, above the level of the rear of the undercliff and thus little affected by the behaviour of the sea cliff, also contributes to some extent to the retreat of the rear scarp, particularly in its SE parts.

It is unlikely that all failures of the rear scarp stem from seepage erosion. Shallow debris slides occurring in less competent above more competent strata and falls of slabs of rock of the order of a metre thick which separate off from the parent mass are probably the result of weathering and stress relief. No toppling failures have been seen in the Chale cliffs. Because of their generally weakly cemented nature the masses which fall from the rear scarp tend to disintegrate into a relatively fine scree. Thus, with the exception of a steep ridge of almost intact rock close to the SE end of the undercliff (Fig.4), there is a marked absence of slip blocks in the debris. The available data on the positions of the rear scarp are shown in Fig.5. These indicate that over the period 1861-1980, its recession averaged 48.4 m (0.41m/yr). Again, there is a marked difference between the rate of recession in the early part of this period, averaging 0.16 m/yr between 1861 and 1907, and that from 1907-80 which averaged 0.57 m/yr.

Undercliff

Evidence that the debris on the undercliff is moving seaward is provided by the patterns of scarps, fissures and side shears (Figs 2 & 4); the position of material, now halfway across the undercliff, that has fallen from the houses lost at the end of Chale Terrace; and the spillage of debris, particularly during the winter, over the sea cliff onto the beach. From the attitude of the bench, one would expect the direction of movement in the superincumbent debris to be inclined obliquely to the line of strike of the bench surface. That this is, indeed, the case is indicated by the scarp and fissure patterns in the undercliff debris and is reflected in the choice of section lines, particularly for CS1 and 2. Further evidence for this obliquity of movement is provided by the three notches (N1 to N3, Figs 2 & 4) which have been cut in the sea cliff by localised stream erosion. A metre or two of the bench surface on the down-dip side of the notches is exposed, probably by wave action, while their up-dip sides are completely buried by debris.

On the Walpen Undercliff two main types of mass movement can be distinguished (Fig.5):
I - Strongly non-circular, compound slides with a horizontal sole following the bench surface, and affecting the whole width of the undercliff.
II- Rotational slides, tangenting the bench surface, and affecting only the seaward margin of the undercliff.
These can be either slope or base failures (indicated by the suffixes S or B).

Slides of types IS and IIS are generally present from A to about C. The length from C to D is a transition zone, while between D and E worn down, back-tilted blocks of dark clay (probably part of stratum XII) may be seen in the beach (Figs 4 & 5), indicating that slides of types IB, and probably IIB, have taken place there. This SE end is thus distinct from the rest of the undercliff in having a strong component of deep-seated landslipping. This arises largely because the stress levels and pore-pressures are high enough there to induce such landslips in this predominantly clayey stratum, despite its being strong enough to resist such failures under the lower stresses which obtain to the NW. Shallow mudslides may develop in the SE part of the undercliff where there is both more water and stronger toe erosion.

The degree of stability of the undercliff tends generally to decrease from the vegetated length, A-B, towards the SE. This reflects the increase in height and instability of the rear scarp, the greater amount of ground and surface water and the stronger erosion of the slide toes especially between C and E, where the debris is no longer protected from marine attack by a resistant sea cliff. The resulting shallow bay cut in the slide debris there is well seen in Fig.4. Exceptions to the above trend are the deep-seated base failures between D & E. When seen in the spring and summer of 1980 these were evidently worn down, partly by streams and mudslides and partly by marine attack, and currently inactive.

Stability analyses, using the method of Morgenstern and Price, have been carried out on nearly all the type I and type II landslides shown in Fig.5, assuming the slip surfaces to be at residual. The calculations were made for three different assumptions as to the value of r_u; a) $r_u=0$, b) $r_u \simeq 0.5$ and c) as for b) except at the rear of the undercliff where an undrained loading (UDL), with $\bar{B}=1.0$, is taken. The back-analysis results are given in Fig.8 where the results of drained residual ring shear tests carried out in a Bromhead apparatus are also shown. The clay sample used was taken from a clayey facies of the Foliated Clay & Sand in Walpen Chine. These results confirm that slide types I and II can be expected to be active on CS1 to 3 whenever r_u in the debris is greater than about 0.25, even without the further effect of undrained loading. The results for CS4 are consistent with the field indications that the type IB & IIB slides there are currently inactive.

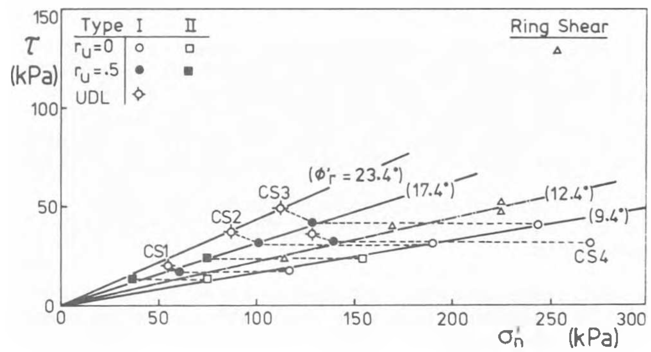


Fig.8 Stability analyses of sections CS1-4 with ring shear residual data (on clay of ω=25, ω_L=63, ω_P=31, fraction <2μm=31%)

An important feature of the rear of the undercliff is an irregular linear depression which runs along most of its length. This is occupied by several ponds, and is followed by some of the streams which traverse the undercliff (Figs 4 & 5, CS2). Counterscarps a few decimetres high run along much of its seaward margin. In view of the shape of the type I slides, the feature is probably a landslide graben. It has been modified however and possibly deepened in places by stream erosion. The counterscarps are probably connected with the graben, but in some cases they may reflect shallow slides moving in a landward direction into the associated streams. By this mechanism, by direct fluvial erosion and by irrigating the mudslides, the streams are probably responsible for moving a significant volume of debris across the bench into the sea.

The more intense erosion this century was accompanied by the destruction of several major intermediate undercliffs. Thus, on CS3 (Fig.5), there were four undercliffs in 1907, the highest of which was built upon. The lowest of these undercliffs corresponded to the horizon of the present one. By 1980 the intermediate ones had been consumed by the development of the lowest one, apart from a small remnant of the uppermost. Similar trends can also be seen on CS2. Cliff development of this nature is probably characteristic of a situation where the dominant mass wasting process is seepage erosion associated with the lowest undercliff. Finally it is noted that the sea cliff and the rear scarp have generally been retreating at different rates, rather than in a steady state fashion. The present data do not allow firm conclusions to be drawn. There may be a tendency in the NW length, where the sea cliff is in situ and seepage erosion is the dominant process in the rear scarp, for the latter to have retreated faster than the former, while further SE, where the sea cliff is cut into slide debris and seepage erosion is accompanied by deep-seated base failures, the reverse seems to apply.

CONCLUSIONS

1. Seepage erosion in fine sand layers within the Foliated Clay and Sand stratum of the Ferruginous Sands is the main factor causing collapse of the superincumbent rear scarp and hence in the formation of the Walpen Undercliff.

2. The resultant debris moves, generally, obliquely, across the undercliff bench by compound slides embracing the whole width of the undercliff and by rotational slides in its seaward margin. Some debris is also transported across the undercliff by mudslides and by stream action.

3. The sole of the compound slides is inferred to follow a clayey layer of the Foliated Clay and Sands.

4. Analyses indicate that the inferred sliding of the debris will occur when the r_u value exceeds about 0.25. Undrained loading, although likely to be assisting the movements, is not a pre-requisite for these.

5. At the SE end of the length, where the cliffs are higher and the bench surface has dipped below sea level, the continuity of the bench is broken by deep-seated base failures.

6. Rates of recession have increased about threefold from the 19th to the 20th century and the sea cliff and the rear scarp generally retreat at different rates. Where seepage erosion is active in the rear scarp, this retreats the faster.

ACKNOWLEDGEMENTS

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