Trimingham Cliffs, Norfolk

[TG 280 390]

Introduction

(a) General

Along the northern coast of Norfolk there is a continuous line of cliffs from Weybourne in the west to Happisburgh in the east, a distance of 32 km (Figure 9.2). The cliffs are formed in materials of Pleistocene age, principally deposits of the Anglian (antepenultimate) glaciation. They are currently retreating by means of a variety of types of mass movements, but this retreat is potentially at risk from coast protection measures.

The site is one of considerable variety. Firstly, it includes an assortment of mass-movement types, at a wide range of scales. The mass movements represent types that are probably characteristic of sediments which are 'weak', if not actually unconsolidated. Secondly, it includes two of the three categories of coast protection described: in the west the cliff is unprotected, and acts as a feeder bluff for the beach system; in the east the cliff is protected by a revetment, which is intended to limit the rate of cliff recession, while maintaining sufficient input from the cliff to maintain an adequate beach (Figure 9.3).

(b) Stratigrapby and lithology

The detailed stratigraphy of the Anglian deposits has been worked out by Banham (1968) (Table 9.1). In the area around Trimingham the lowest 3 m of the cliff is described by Banham (1968) as consisting of his Second Till. However, Hutchinson (1976) has pointed out that the cliffs to the east of Overstrand (i.e. close to Trimingham) are characterized by the presence of a sill consisting of all or part of the 'Cromer Till' sequence (Banham's First Till–Intermediate Beds–Banham's Second Till) in the cliff-foot. Accordingly, all formations from Banham's First Till upwards are described here. The Second Till is overlain by 4.5 m of Mundesley Sands, and 12 m of the Third Till. This is overlain successively by 3 m of Gimingham Sands, 12.5 m of Brick Kiln Dale Gravels and 3 m of a chalky boulder clay (Solomon, 1932). Above this is 6–9 m of chalky outwash sands and gravels.

(Table 9.1) Geological succession in the cliffs of north Norfolk. After Banham (1968).

Chalky outwash sands and gravels		7.5 m
Chalky boulder clay		3.0 m
Brick Kiln Dale Gravels		12.5 m
Gimingham Sands		3.0 m
Third Till	'Contorted Drift'	12.0 m
Mundesley Sands		4.5 m
Second Till Intermediate Beds First Till	'Cromer Till'	3.0 m

West and Banham (1968) point out, following Reid (1882), that the succession can be broadly divided into a lower relatively undeformed and sub-horizontal zone, a middle zone of intense isoclinal deformation 30–35 m thick ('Contorted Drift'), and an upper zone of more open folding. Banham (1975) considers that the deformations originated through loading by the Gimingham Sands and the overlying gravels, with associated diapirism. The lower and middle zones are separated by a surface of decollement developed within the Mundesley Sands. Along most of the line of cliffs at Trimingham, the geology and structure are uncertain because of poor exposure: the cliffs are covered by mass-movement deposits.

Banham's First Till is a dense, fissured, grey or dark-grey sandy boulder clay resting on the Cromer Forest Bed Series, the Leda Myalis Sands or associated deposits. The Intermediate Beds (see Figure 9.4) and (Figure 9.5) lying above the First Till have been shown by Kazi and Knill (1969) to be laminated lake clays, anisotropic in their physical properties.

The Second Till occurs locally at Trimingham and again between Overstrand and Kirby Hill, east of Cromer. It is a dense, fissured, grey-blue sandy boulder clay which, depending upon the local structure, rests on any of the older formations. Commonly, more than 40% of the till is made up of Chalk pebbles ranging from a few millimetres to 5 cm in length. This till is readily distinguishable from the essentially Chalk-free First Till, particularly in areas where the Intermediate Beds are present. The structural arrangement of the two tills is different as the Second Till typically has both an irregular base and surface and, in addition, appears to have been laid down by an ice-sheet which ploughed into the older formations, thereby locally removing them completely (Kazi and Knill, 1969).

The Mundesley Sands are composed of uniformly textured, medium dense, dirty white silty sands resting on the hummocky surface of the Second Till. There is a local basal conglomerate of chalk pebbles. The sands are variously chalky or carbonaceous, and in the latter case a distinctive greyish tint is imparted to them. When weathered the sands are yellowish-brown in colour. This horizon can be traced at intervals along the cliffs at Trimingham, attaining a maximum thickness of about 13 m near Mundesley, the type locality for the deposit (Solomon, 1932).

The Third Till is characterized by a complex internal structure, frequent erratic masses of chalk and the presence of large-scale undulations. It, and possibly parts of the Mundesley Sands below and Gimingham Sands above, was formerly known as the 'Contorted Drift'. The group is very variable in thickness and ranges to well in excess of 30 m near Cromer. The Third Till locally contains glacial lake sediments.

The Gimingham Sands comprise a unit of loose, stratified pale-yellow sands and gravels resting on the irregular top of Banham's Third Till, often occurring in large basin-shaped hollows in the till. The sands can be traced at intervals along the cliffs at Trimingham. Near Kirby Hill (east of Cromer) the group attains an apparent thickness of about 30 m.

The Brick Kiln Dale Gravels, in the one clear exposure near Trimingham, were shown to consist of 6 m of laminated stoneless and chalky clay, and 3.5 m of gravelly and chalky yellow sands (Solomon, 1932).

The sill described by Hutchinson (1976) is a common but discontinuous feature of the cliff morphology, forming a near-vertical, relatively resistant face up to several metres in height along the cliff-foot (Kazi and Knill, 1969). It is, however, only occasionally exposed at Trimingham; for most of the time it is buried in mass-movement deposits.

The cliffs are of considerable value in the study of the relationship between geological processes and engineering properties and behaviour, because of the variety of mass-movement processes that can be recognized between Trimingham and Overstrand, and new coastal works, which, if not restricted, could lead to stabilization of the cliffs, growth of vegetation and steady deterioration in the geological quality of the exposed section.

Many authors have described the cliffs of the Norfolk coast as consisting of 'unconsolidated' sediments, presumably meaning that there is little or no evidence of strengthening processes like cementation of the sand particles, and loading. However, there is evidence that in fact these sediments are over-consolidated, or at least normally consolidated (i.e. they have at each level the degree of consolidation which would be expected from the depth of the pile of sediments above them, from the ground surface down). Consolidation tests using a conventional oedometer showed that the Intermediate Beds at Cromer are markedly more over-consolidated than at Happisburgh. At both sites the sediments are over-consolidated with respect to the present height of the cliff and it has been suggested (Kazi and Knill, 1969) that the original surcharge included an ice-load. The topography of the cliff-top at Cromer is generally regarded as representing a moderately fresh glacial landscape. As a consequence the present cliff height is held to indicate the maximum loading provided by the glacial drift on the Intermediate Beds. The deficiency of pressure at Cromer is equivalent to an additional ice-load of 90 m (based on unit weights of 2024 kg m^{-3} for the drift, 923 kg m^{-3} for ice, and a groundwater level at the ground surface). At Happisburgh, an equivalent calculation indicates the pressure deficiency is equivalent to about 80 m of ice. Some erosion has occurred at Happisburgh, and a maximum ice-load of about 60 m is probably more reasonable. These thicknesses of ice appear to be generally in accord with knowledge of the thickness of modern glaciers and with the directions of ice movement during the Lowestoft stage (West, 1968). Kazi and Knill's (1969) view has, however, been challenged by Banham (1975), who has suggested that the Cromer landscape is not a fresh glacial surface but was once covered by superincumbent sediments the upper part of which have been removed by glacial meltwater erosion. This removal would have been sufficient to account for the degree of consolidation measured.

Description

(a) Cliff hydrology

During the winter, considerable quantities of groundwater discharge along the coast at the junction of the Mundesley Sands and Banham's Second Till beneath them. This is evidently a horizon at which permeability changes substantially, the Mundesley Sands being sandy and highly permeable, while the Second Till, at least in its uppermost part, is of low permeability. This junction forms the 'sill' in the cliff, noted by Hutchinson (1976). The junction varies significantly in level, typically from about 5–10 m above OD, and naturally the main discharges are concentrated at the depressions in the undulating 'sill' surface. As the Mundesley Sands in this area are largely composed of fine-grained sands, the discharge zones at the base of the formation are marked by active seepage erosion and the resultant formation of outwash fans at the cliff-foot. The seepage erosion is accompanied by back-sapping. These processes are generally absent from the areas between the depressions in the Hutchinson (1976) reported that the 'sill' is not the only water-table control in the cliffs. There are groundwater tables perched on the Third Till and on till inclusions and/or erratics in the Mundesley Sands, the Third Till and the Gimingham Sands.

At the depressions in the sill the back-sapping, combined with the effects of porewater pressures in the lower parts of the sand cliff, leads to a series of relatively shallow slides in the sands and consequent degradation of the sand cliff. Between the depressions, however, the sands are well drained, seepage erosion is absent and the sand cliffs stand at much steeper angles. With the progress of coastal erosion, these steeper slopes eventually suffer rotational slips of which the failure surfaces generally descend to about the level of the top of the sill (Hutchinson, 1976). These slips are larger than those associated with the back-sapping, but much smaller than the deep-seated failures that occur from time-to-time in the adjacent cliffs to the west.

At Section I (Figure 9.6) (Hutchinson, 1976), which was located at a depression in the surface of the sill, seepage erosion was very active and had led to the formation of a mudslide of mixed sand and clay (Hutchinson, 1976). As shown, this had eroded clown some distance into the sill. As a result of the back-sapping and resulting shallow slides in the sands, the overall inclination of the cliff was only 24°. In the lower part of the sand cliff the average inclination was about 21°. Such a slope is just stable for an average porewater-pressure ratio, r_u, of 0.37, if the effective shear parameters obtaining are $c' = 0$, $ø' = 34°$ (Bishop and Morgenstern, 1960).

If a small value of *c*'exists, the value of r_u required to cause failure would, of course, be increased. A similar situation is treated by Henkel (1967).

Section III (Figure 9.6) (Hutchinson, 1976) was located on the crest of an undulation in the sill. Seepage erosion and back-sapping were absent and the sand cliff stood at a much steeper angle, averaging about 31° overall. A rotational slip, involving a slice of the cliff-top, had recently occurred in the sand cliff Prior to this slip the average inclination of the cliff was probably about 35°. At this location one would expect the porewater pressure in the base of the sand to be low or even zero. Even so, a small *c′* value, or negative porewater-pressures, would be required for such a slope to be stable if *0′* were again 34° everywhere on a potential slip-surface.

The cliff profile at Section II (Figure 9.6) (Hutchinson, 1976) is similar to that at Section III in being located at a crest in the undulating sill. Section II represents a later stage of development, however, in which a rotational landslip in the sand, as before exploiting the slip-surface in the Intermediate Beds at its toe, had moved farther down the cliff and spilled over the sill (Hutchinson, 1976). This had left the upper cliff over-steepened, at an average inclination of nearly 45°, and probably soon to be involved in a further rotational slip. Assuming that it was not held up by included masses of till, the steep angle of the sand cliff on Section II provides further evidence for the existence of a cohesion intercept in these sands. This may well be made up from a combination of slight cementation with some capillary porewater tensions.

Taking the sand cliff at Section II to have an average inclination of 45° and a height of 35 m, with 0' = 34° and zero porewater-pressures, an average *c'* value of about 10 kN m^{-2} can be inferred to be necessary just to maintain the stability of the cliff (Hutchinson, 1976).

(b) Mass movements

The cliffs at Trimingham expose a variety of Pleistocene sediments, and are subject to active coastal erosion (Figure 9.7). This has resulted in extensive slope instability and the development of a wide range of mass-movement features. Kazi and Knill (1969) have observed blockfalls, seepage failures, mudflows, 'sand glaciers' (their term) and deep-seated non-circular slips along this length of coast, and have carried out detailed analysis of the geotechnical properties of the 'Cromer Till' (Figure 9.8), (Figure 9.8), (Figure 9.10). This rather complex group of interrelated mass movements is responsible for a rate of coastline recession of up to 1.1 m a^{-1} (Hutchinson, 1976). The cliff-top and the cliff-foot are receding at about the same rate, maintaining the overall slope angle.

Another important feature of at least some parts of the cliffs, however, is the presence of the well-marked slip-surface within the Intermediate Beds near the top of the sill (Hutchinson, 1976).

The slip-surface, although largely situated within the sands, follows for some distance at its toe a slip-surface in the Intermediate Beds. As the value of ø' on this latter surface was 19°, the average ø' mobilized in the rotational slip will have been less than 34° and the necessity for some *c*'component of strength, or negative porewater-pressure, to exist in the sand mass will have correspondingly increased.

Where the cliffs are highest, deep-seated rotational slips occasionally take place. Examples between Cromer and Overstrand, where they are also most frequent, were examined in detail by Hutchinson (1976). An example immediately west of Trimingham was noted by Ward (1962). However, between Cromer and Overstrand the main features on the cliffs are a series of rotational slips which generally toe out at about the level of the top of the and large mudslides which from place to place erode down into the 'sill' and run down onto the beach.

(c) Recession rates

Taking measurements from published maps, Cambers (1973, 1976) found that the average rate of retreat of the cliffs from 1880 to 1967 was 0.9 m a^{-1}. Records of former villages recorded in the Domesday Book (1086) and now missing through erosion, as well as other historical accounts, suggest that a similar average rate of erosion has persisted for at least the past 900 years. Clayton (1989) showed that the cliffs at Trimingham had the greatest amount of retreat on the Norfolk coast over the 100 years to 1985 (Figure 9.11). The waves incident on the coastline have cut back the cliffs 1–2 km over the past 900 years. Field sampling on the cliffs by Cambers (1973, 1976) established that the erosion of the Norfolk cliffs provides well over 500 000 m^3 a^{-1} of sediment, and that up to two-thirds of this is sand and gravel which may remain in the beach system. Littoral drift transports this sediment: a small part moves westwards along the north Norfolk coast, but most moves southwards towards Lowestoft (the overall sand budget was calculated by Clayton *et al.,* 1983) (see (Figure 9.12)). Thus the beaches south of the Trimingham Cliffs for the 42 km to Lowestoft are largely, if not entirely, dependent on the cliffs for their throughput of sand. The cliffs act as 'feeder bluffs' for the beaches.

(d) Cliff protection

A total length of more than 14 km of the cliffed Norfolk coast is defended by inclined permeable timber revetments, usually fronted by groynes. The purpose of the revetments is to reduce the energy of the waves reaching the cliff-foot, while the purpose of the groynes is to inhibit down-drift movement of the beach sand. The groynes are of two types: impermeable, which are effective until the beach builds up to a level on the updrift side at which it overtops the groyne, and permeable, which are much less effective for their purpose. Prior to the local government re-organization of April 1974, the coastal defence authority along the Trimingham stretch of coast was Erpingham Rural District Council, which installed timber revetments and permeable timber groynes, the revetments standing on concrete sheet piling on the seaward side, and timber piles on the landward side ((Figure 9.13)a). The revetments are designed to stand a short distance down the beach and far enough in front of the cliff to dissipate as much as possible of the energy of waves breaking at the revetment, before they reach the cliff-foot. This distance is usually between 16 m and 20 m. The revetments have planks, which may or may not have spaces between them; the planks can either run up the face of the revetment, or be placed horizontally. Where each plank is flush against the next, the revetment is essentially 'impermeable', although some waves may overtop it. Where the planks have been fitted with spaces in between them ((Figure 9.13)b), the revetment is 'permeable'. The slope of the face is generally about 45°. The design life is considered to be 40 years (with some repair). The revetments on the Norfolk coast are installed on a coast undergoing erosion where the beach is gradually losing volume; they will therefore be noticeably farther down the beach after 20–30 years (Clayton and Coventry, 1986). By this stage the sheet piling will be exposed when the beach is low, acting as 'hard' engineering: the waves will be reflected rather than having their power absorbed, and increased scour of the beach will result.

At Trimingham the cliffs are protected by a timber revetment the face of which consists of horizontal slats with gaps in between. This is sufficient to reduce substantially the power of incoming waves, while still allowing waves to reach the cliff-foot. The result is that the rate of cliff recession is lowered, but cliff recession is not halted. It allows the cliff-foot to be eroded by the waves, and a range of mass movements are taking place on the cliff as a result. Although this does not include deep-seated slips, these can be seen in the unprotected stretch of cliffs between the revetment and in front of it. Measurements showed that, by reflecting the waves less efficiently, the four-plank stretches of revetment reduce the amount of beach loss in front of the revetment. So a revetment with a smaller number of planks will reduce beach lowering in front of the revetment by almost half the amount where the full number of planks is in position. It appears, therefore, that the standard 10-plank design is too effective as a reflector of waves and causes rather rapid beach loss in front of the revetment.

(e) Cliff aspect

Clayton (1989) introduces a further distinction concerning the cliffs, based upon aspect with respect to the dominant wave direction. The section of coast to the west of West Runton is almost straight for 7.5 km, and faces on average 4° east of north. There is a gradually increasing curvature through to Overstrand (6.5 km) and then a fairly straight alignment for another 19 km to the end of the cliffs beyond Happisburgh. The first 7 km of this section averages 31°, and the remaining 12 km, south of Marl Point, Mundesley, averages 38°. The north-facing part of the north Norfolk coast is swash-aligned and has low rates of erosion; the NE-facing part of the coast is drift-aligned and has high rates of littoral drift where rates of erosion are high and sea defences are less effective. (Figure 9.14) illustrates how the height of the cliffs is at its maximum at Trimingham, as is the amount of coastal retreat over the 100 years to 1985.

The most important factor influencing the rate of retreat is thought to be retention of Trimingham and Overstrand, part of which is also within the GCR site.

Revetments are seen as 'softer' in character than walls, i.e. less reflective. An experiment was designed by Clayton and Coventry (1986) to measure the effects of reducing the number of planks on a revetment at West Runton. Some stretches of revetment were left with the original maximum of 10 planks, while other lengths had 4 planks; 7-plank stretches provided a physical intermediary between the two. On all of the sections measured, the beach level fell over the three-year period of observations, both behind material (which includes many large flints) on the swash-aligned coast and rapid removal by longshore drift on the drift-aligned coast. The sediment volumes from cliff erosion may be divided into material from the swash-aligned coast and material from the drift-aligned sector. Prior to the construction of defences, 33% of the sediment volume came from the swash-aligned coast. By 1983 this had been reduced to less than 19%, a clear indication that coast protection structures had been more successful on the swash-aligned coast than on the drift-aligned coast. By 1985 the swash-aligned coast was producing only 40% of the 1885–1905 volume (68% of the 1906–1946 volume). The drift-aligned coast, however, was producing 92% of the 1885–1905 volume (83% of the 1906–1946 volume) (Clayton *et al.,* 1983). Accordingly, it seems that the defences (all types of structure) had reduced sediment output by about 50% on the north-facing coast, but only by about 10–15% on the SE-facing coast.

Interpretation

The area of the Trimingham Cliffs mass-movement GCR site overlaps an SSSI which was already in existence at the time of designation. This site, the Sidestrand and Trimingham Cliffs SSSI, comprises a length of cliffs which have been left free of coastal defence works. Referring to the SSSI, McQuhae (1977) remarked that clear geological exposures are maintained so long as mass movements are allowed to occur. Also, investigation of the relationships between the engineering properties of the drift and mass movement is made possible. Coast defences in many places, however, have led to stabilization of the cliffs, and loss of these areas for observation of the different types of failure. She therefore concluded that it is essential that areas like this remain available for study, and that erosion be allowed to continue. The particular variety of types of instability and the value of their study warrants this stretch of cliffs for SSSI status for its mass-movement features.

There is also a practical reason why some cliffs should be allowed to erode. Clayton (1980) pointed out that beach-sand drifts long distances and is highly dependent on eroding cliffs which act as feeders. While these sand feeds ('feeder bluffs') survive, most coastal defence work is reasonably successful and can maintain a good beach. However, if the cliffs were to be fully protected, the entire system would face irreversible decline.

'There have been signs in recent years that the process of extension and elaboration of coastal defences in East Anglia has reached the point where the return on additional expenditure is small or zero. Indeed estimates of the coastal sand budget suggest that any extension of defences that successfully reduced the retreat of the Norfolk cliffs would actually threaten beach stability over a length of coast that eventually could extend to 50 km downdrift. The benefit/cost advantage of accepting continued retreat of feeder bluffs is very considerable: the only alternative would be beach nourishment on a very large scale.'

Here, as in a later article (1991), Clayton (1980) sets out the main points of the argument about leaving feeder bluffs undefended from the sea, so that beaches can form a defence against the sea. If all feeder bluffs are proofed against marine erosion, for example by the construction of concrete walls, the long-term effect on the beach which they feed will be that it will be washed away, not only at the site of the former feeder bluffs, but potentially for many kilometres downdrift. The effects on any holiday resorts and on coastal recreation generally would be catastrophic. Further, unprotected coastline downdrift beyond the extent of the cliffs would be subject to much stronger marine attack, since it would lack the protection provided by a beach.

The argument that some of the cliffs must be left unprotected to act as feeder bluffs for the beach is now largely accepted. Shoreline Management Plans for the Norfolk coast include:

- leaving some cliffs unprotected, so that they can act as feeder bluffs;
- cliff protection of the 'hatd engineering' type (e.g. concrete walls), to protect coastal towns, for example at Cromer;
- cliff protection of the 'soft engineering' type (e.g. timber revetments) in more rural areas, for example at Trimingham.

It is clear from a document produced in 1990 that the then Nature Conservancy Council (NCC) accepted the argument about the need to leave feeder bluffs (McKirdy, 1990). The document (a report to the NCC from HR Wallingford Ltd) made it clear that a coastal mass-movement site would have to be maintained not only in terms of the marine action upon it, but also in terms of groundwater entering it.

An NCC report of 1991 applies the suggestions in McKirdy (1990) to a selection of coastal SSSIs, including the Sidestrand and Trimingham Cliffs SSSI, which 'includes both Sidestrand and Trimingham Cliffs', the latter being 'primarily a mass-movement site'. The preferred option selected is 'the construction of a series of offshore breakwaters', with sufficient space between the breakwaters to allow enough wave action at the cliff-foot for mass movement to continue, but at a reduced rate.

The breakwaters were never constructed, and the relevant local authority, Norfolk County Council, have allowed the wooden revetment on the beach at Trimingham to fall into disrepair, so its effectiveness as a moderator of wave power has diminished. There is evidence that it had never been effective: the construction of the revetment in 1974 was not without problems. Hutchinson (1983) shows an oblique aerial photograph of the sea defences under construction at Trimingham in 1974. Slope stabilization was not then attempted, on the basis of high cost. The revetment and groynes were installed specifically to check toe erosion. The photograph showed that the line of the revetment works was located too close to the cliff-foot: the excavations needed to permit construction of the revetment stimulated further slides by the concomitant unloading (Hutchinson, 1983). Further consequences of this error in positioning persist to the present: from time-to-time mass movements in the lower part of the cliff give rise to accumulations of cliff materials at the cliff-foot that burst through the revetment (causing damage) or even overtop it (Figure 9.3).

Norfolk County Council have adopted a strategy involving the sinking of deep (deeper than usual) drains in the cliff below the village of Trimingham. The result is two-fold: the improved drainage has reduced mass movement on the upper parts of the cliff. The best evidence of this is that the cliff has, in its upper parts, become vegetated, in contrast to the cliffs both to the east and west of Trimingham. The result of the ineffective protection of the cliff-foot by the revetment is that material is being removed from the cliff-foot by wave action, giving rise to mass movements on the lower part of the cliff. In some places these extend far up the cliff. Of the types described by Kazi and Knill (1969), the deep drains seem, so far, to have prevented conditions from arising which would precipitate deep-seated movements of the type described by Hutchinson (1976).

The Norfolk coast between Happisburgh and Cromer has been critical in two related debates about how the coastline is to be best conserved. The first debate concerns coast protection to prevent loss of land, which is important because of the relatively rapid rate of cliff retreat in these cliffs, which has led to considerable loss of land over the last 900 years, and indeed over the 100 years to 1985. This characteristic is shared with the till cliffs of Holderness in east Yorkshire. It appears necessary to protect the cliffs from wave action, i.e. basal removal, in order to reduce or actually halt cliff recession and so protect the cliff-top and the land behind it.

The second area of debate is concerned with the conservation of the cliffs and their characteristics for their own sake, particularly for their scientific and/or pedagogic value, be it biological or geological. There is one area of general agreement: grading of the cliffs, with protection of the cliff-foot by a hard structure like a concrete wall, would be inimical to such interests. The reason for this is obvious in the case of the conservation interest of the cliff: such interest would be destroyed.

Clayton (1995) points out that the Royal Commission on Afforestation and Coastal Erosion stated in 1911 that it is only possible to protect parts of the coast if other parts are left to erode and so supply sediment to adjacent beaches. He continues:

'Yet our ambitious coastal engineers have protected very high proportions of our eroding coastline and ignored this longstanding wise advice. The history of coastal engineering shows that at most it wins two or three decades of stability, but by the end of that period the problems are increasingly intractable; indeed, after storm damage, most rebuilt coastal defences are set back by the very same amount that nature would have achieved year by year had things been left alone.'

Acceptance of the need for 'soft' engineering and sustainable coastal defences has in recent years become recognized by both government and the coastal engineering profession. In part this has been brought about by the institution of Shoreline Management Plans (SMPs) in England and Wales (MAFF, 1995), drawn up by 'responsible authorities' for a set of 'sub-cells' of littoral cells defined by Motyka and Brampton (1993). The process involves public consultation. It is described in some detail by Hooke and Bray (1995). English Nature [now Natural England], which was one of the sponsors of the guidelines for Shoreline Management Plans (MAFF, 1995), recognized that such guidance could include an obligation for local authorities to take cliff conservation (and hence 'soft' engineering in coast protection works) into account (Leafe and Radley, 1994; Swash *et al.,* 1995). By 1998 it was apparent that wide acceptance of this had been achieved (Leafe, 1998). Also, Richardson (1996) explains how the UK policy for sustainable development applies to coast protection, and how in many situations it necessitates consideration of 'soft' engineering solutions.

Therefore the Trimingham Cliffs mass-movement site, the western half of which is in a section of unprotected cliff while the eastern half is protected by an unmaintained revetment, should provide an interesting opportunity for monitoring the development or maintenance of mass-movement types and forms, and the effect or success of the conservation/protection policy.

An independent description on the situation at Trimingham is given by Younger (1990):

'...attention has now turned to the area between Sidestrand and Trimingham. Here is the last undefended stretch of north-east Norfolk, together with an area of decaying and derelict revetments. The land at the cliff-top is high quality agricultural land, together with the village of Trimingham, clustered around a mediaeval parish church, with a substantial minority of new four-bedroomed houses and bungalows.'

The view that measures to reduce or eliminate cliff recession would be unwise is perhaps counter-intuitive, and depends upon the argument detailed above. As Clayton (1980) remarks, such arguments are unlikely to find favour with those who live in the vicinity of the eroding cliffs, and Hutchison and Leafe (1996) extend the point: 'An operating authority [responsible for the production of an SMP] is currently unlikely to consider the relocation of property in order to allow continued erosion as an input to the sediment budget.'

However, Lee (1998) has sounded a warning note, pointing out that coast protection schemes such as those now advocated, which slow down rather than stop marine erosion, can result in changes in the rates and types of processes acting on a cliff. This can lead to the development of new cliff forms, and, in the context of mass movements, could change or destroy the mass-movement interest.

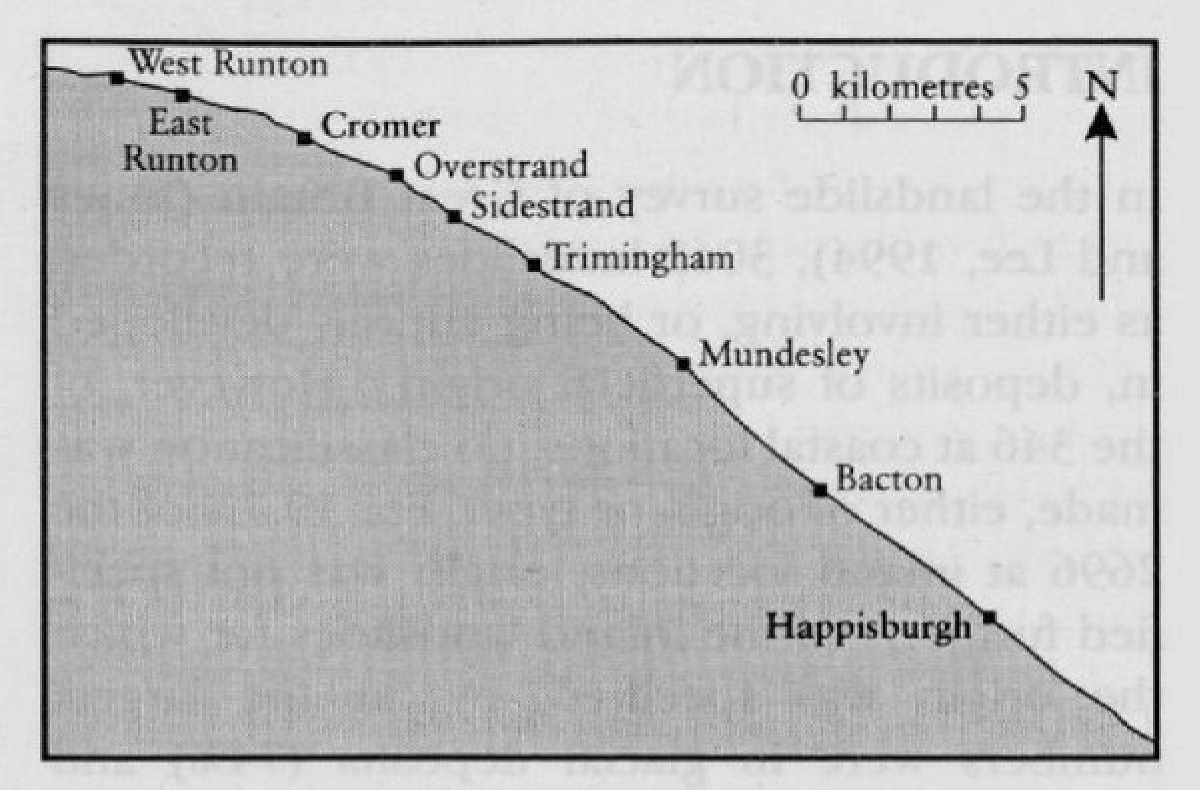
Conclusions

In summary, the cliffs at Trimingham are worthy of conservation as an example of soft rock degradation, with a characteristic set of different types of mass movement. To this may be added a second conservation imperative, that the site should continue to be allowed to contribute sediment to the beach, in order that the beach itself, and the coast which it fronts for many kilometres to the south, is protected from accelerated erosion. The risk noted by Lee (1998) is probably worth taking in this case, as each length of cliff is different, and the mass movements on the cliffs at Trimingham are dynamic features. Any changes in the style of cliff retreat in the protected part of the site will become apparent by comparison with the unprotected cliff, which will act as a control for comparison.

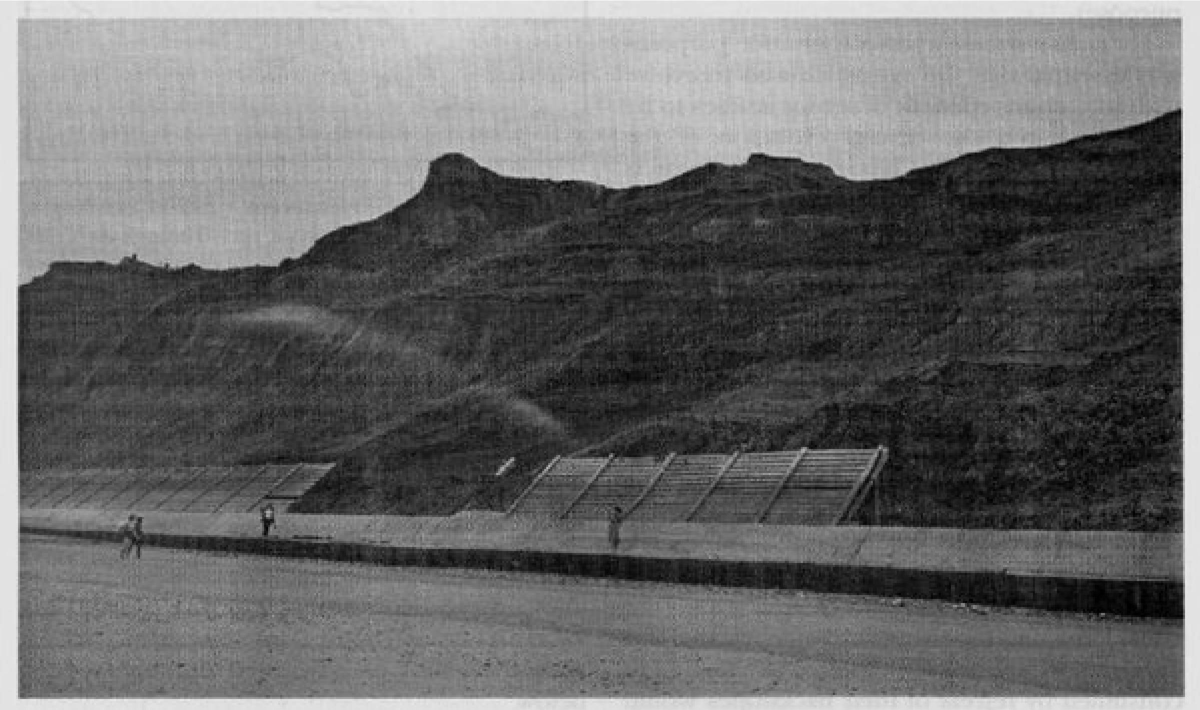
The decision to leave a length of cliff in an unprotected state so as to act as a feeder bluff for a long length of beach is secondary but opportune in the present context. As a result of this pragmatic decision, which has no geological conservation intention, conservation of a suite of mass-movement types is served.

In this reference list the arrangement is alphabetical by author surname for works by sole authors and dual authors. Where there are references that include the first-named author with others, the sole-author works are listed chronologically first, followed by the dual author references (alphabetically) followed by the references with three or more authors listed chronologically. Chronological order is used within each group of identical authors.

References



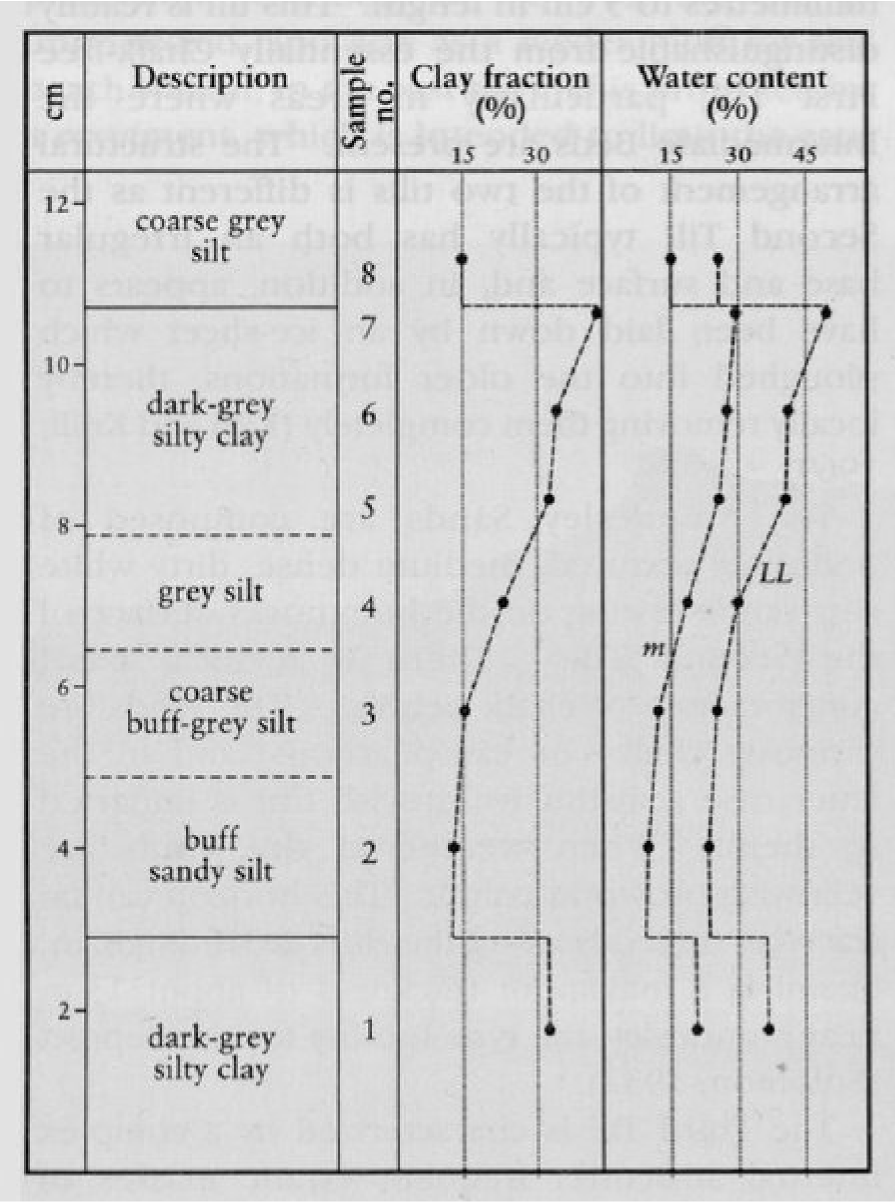
(Figure 9.2) Locality map of the Happisburgh–Cromer area of the north Norfolk Coast. After Kazi and Knill (1969).



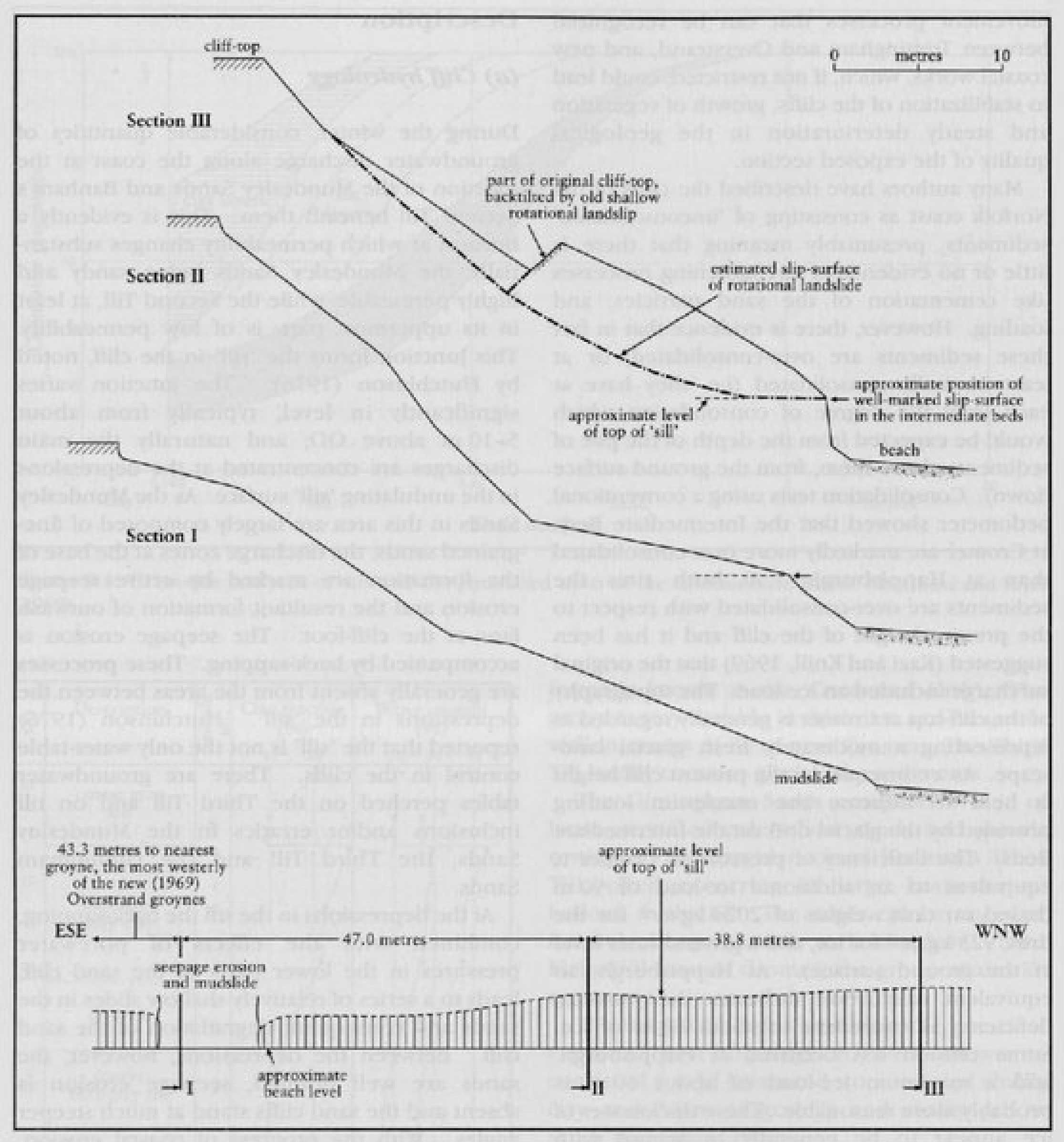
(Figure 9.3) Trimingham Cliffs, showing mass movement around and over the revetment. (Photo: R.G. Cooper.)

Chalky outwash sands and gravels		7.5 m
Chalky boulder clay		3.0 m
Brick Kiln Dale Gravels		12.5 m
Gimingham Sands	'Contorted Drift'	3.0 m
Third Till		12.0 m
Mundesley Sands		4.5 m
Second Till	'Cromer Till'	3.0 m
Intermediate Beds		
First Till		

(Table 9.1) Geological succession in the cliffs of north Norfolk. After Banham (1968).

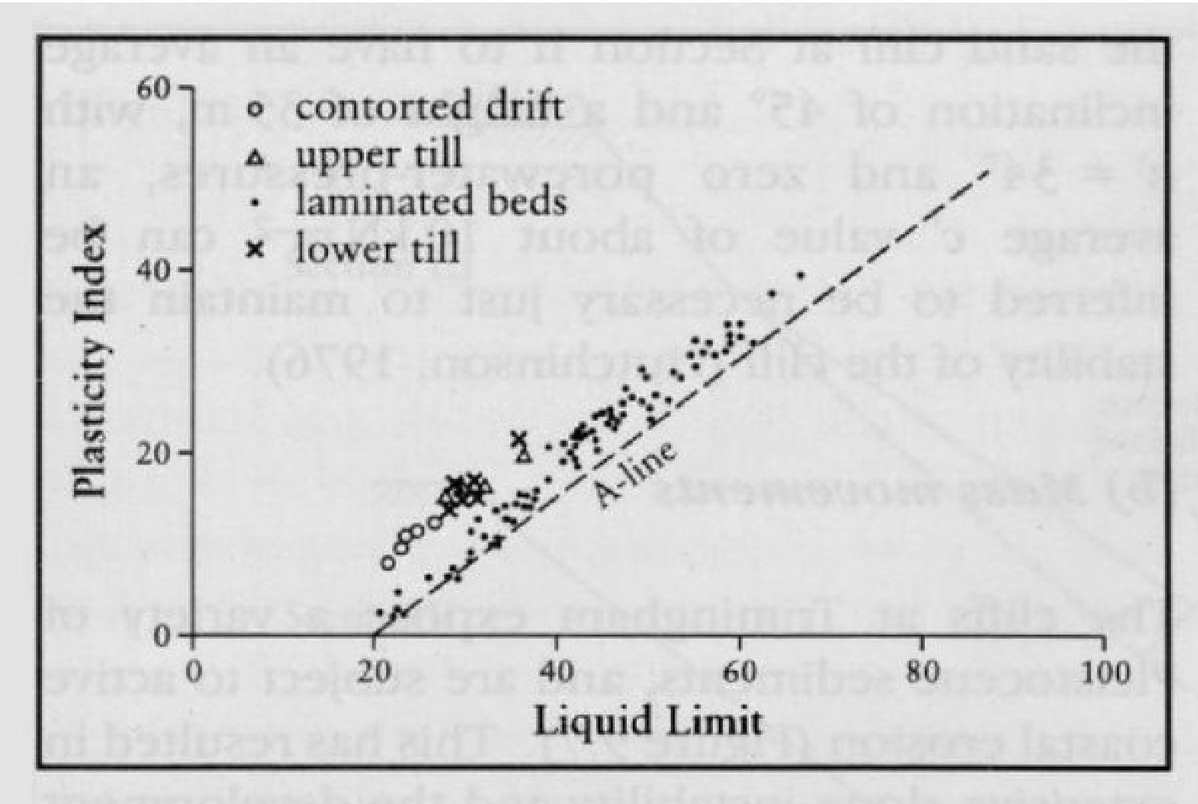


(Figure 9.5) Variation of clay content, natural moisture content (m) and liquid limit (LL) through the individual graded bed in the Intermediate Beds. After Kazi and Knill (1969).

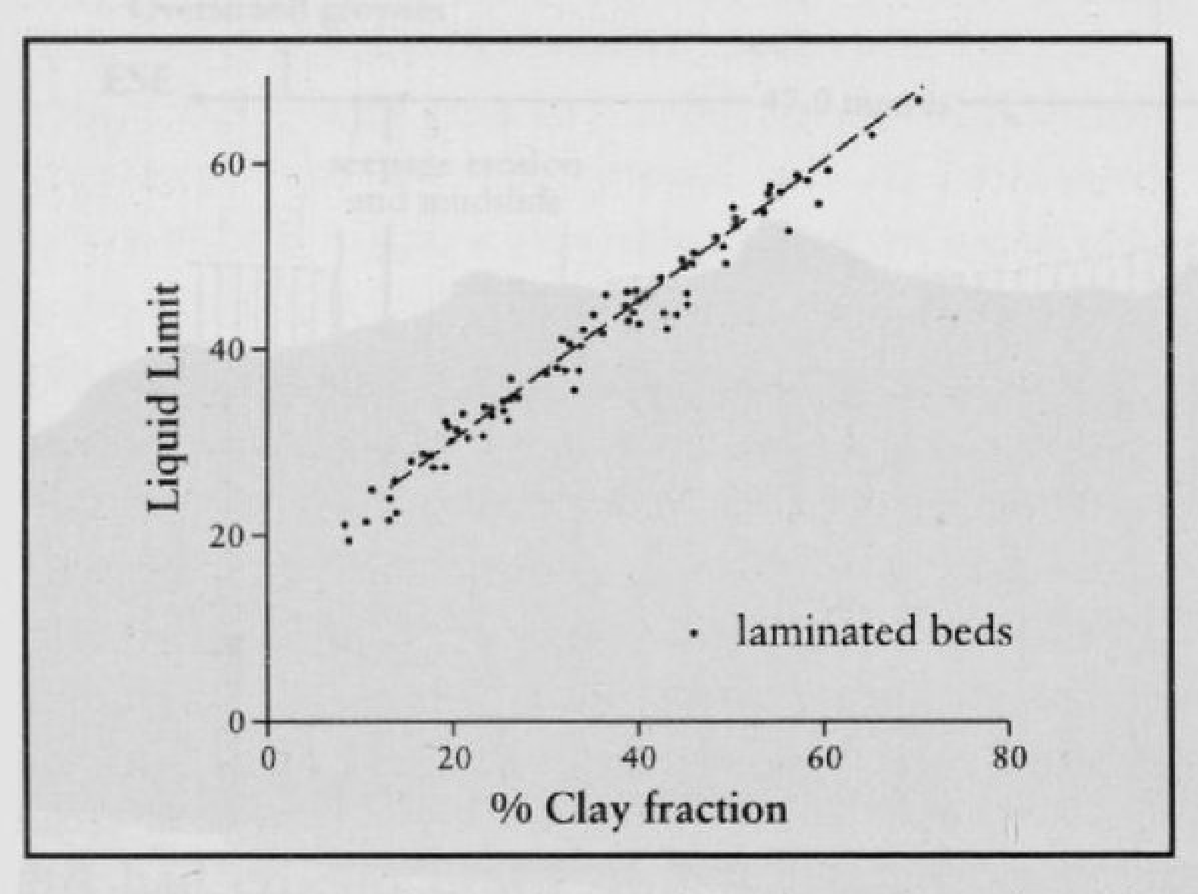


(Figure 9.6) Section through the eastern cliffs at Trimingham. After Hutchinson (1976).

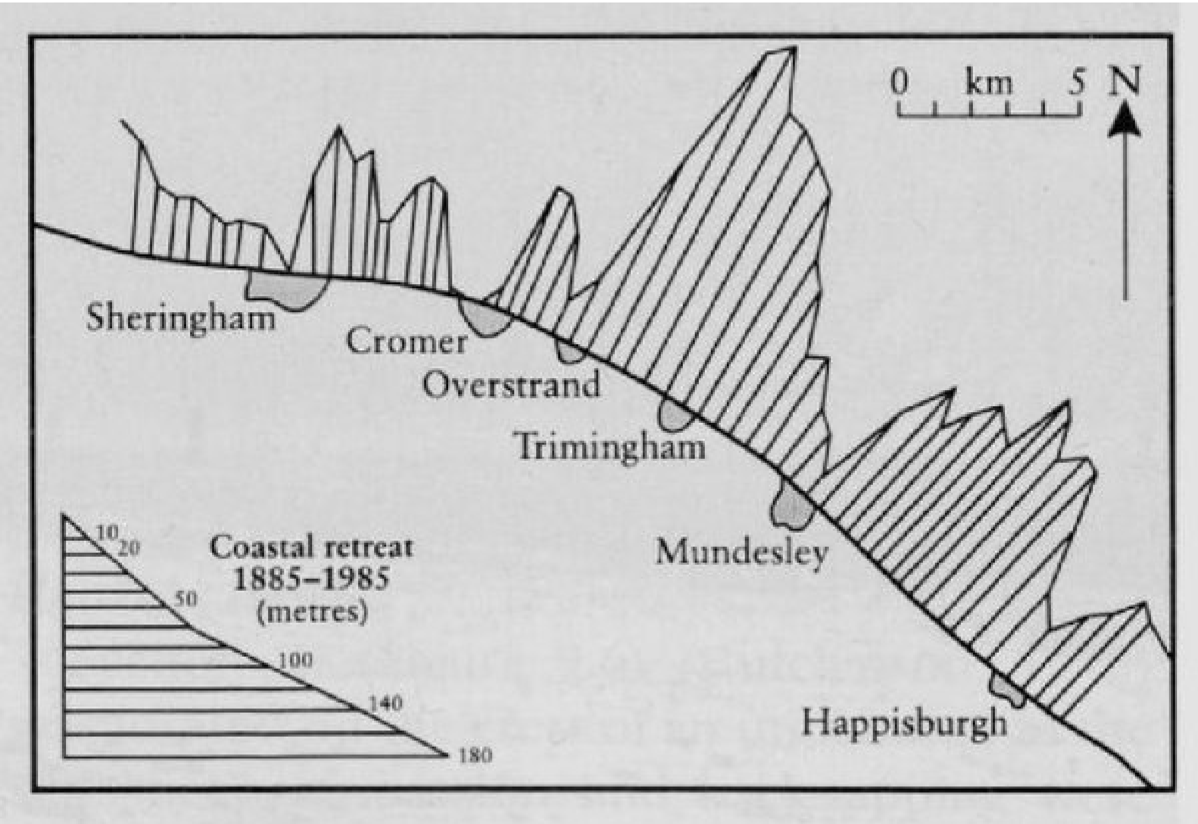
(Figure 9.7) Erosion, undercutting, and, in the background, toe erosion at the Trimingham Cliffs GCR site. (Photo: R.G. Cooper.)



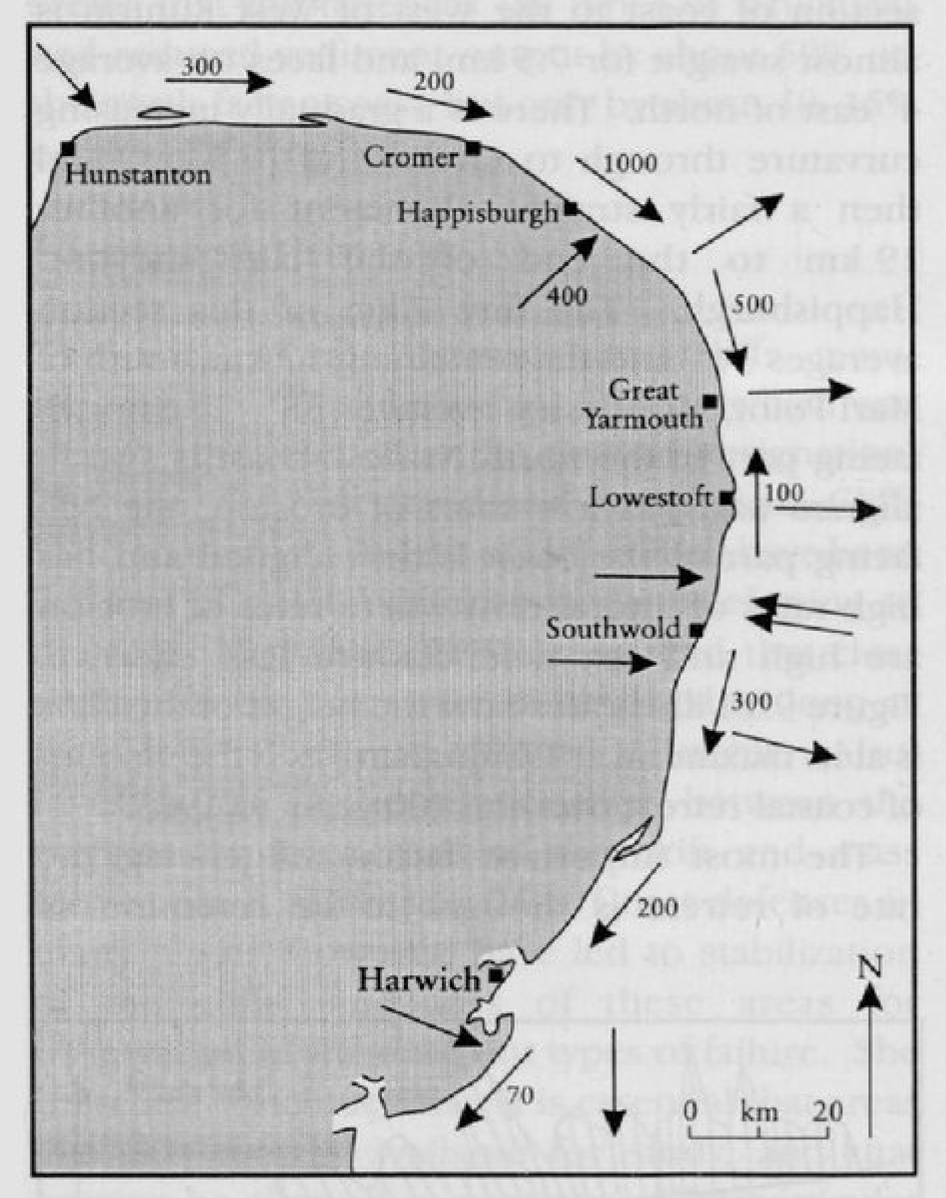
(Figure 9.8) Plasticity charts for tills and Intermediate Beds. After Kazi and Knill (1969).



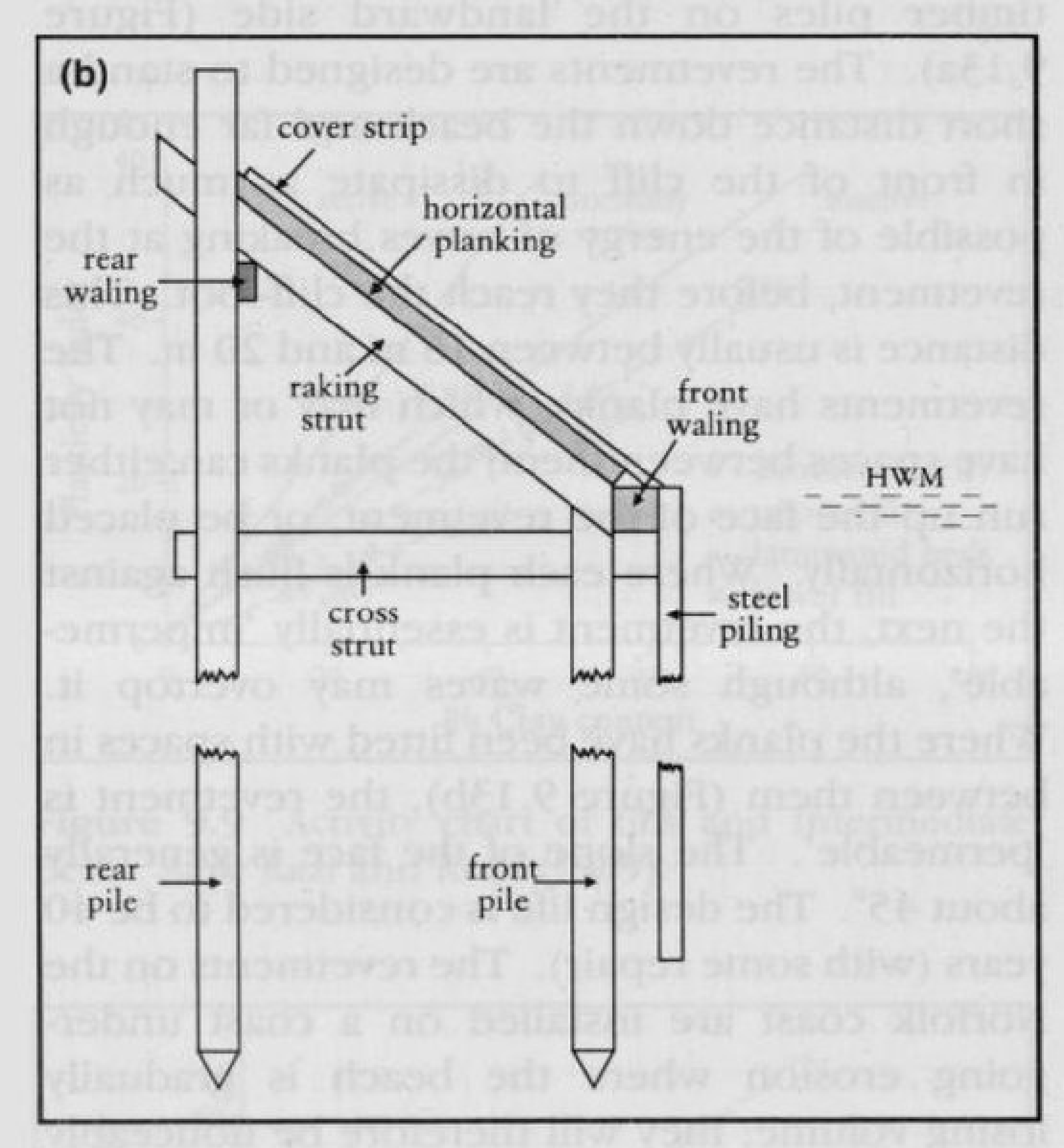
(Figure 9.10) The relationship between the clay fraction and liquid limit for the Intermediate Beds. After Kazi and Knill (1969).



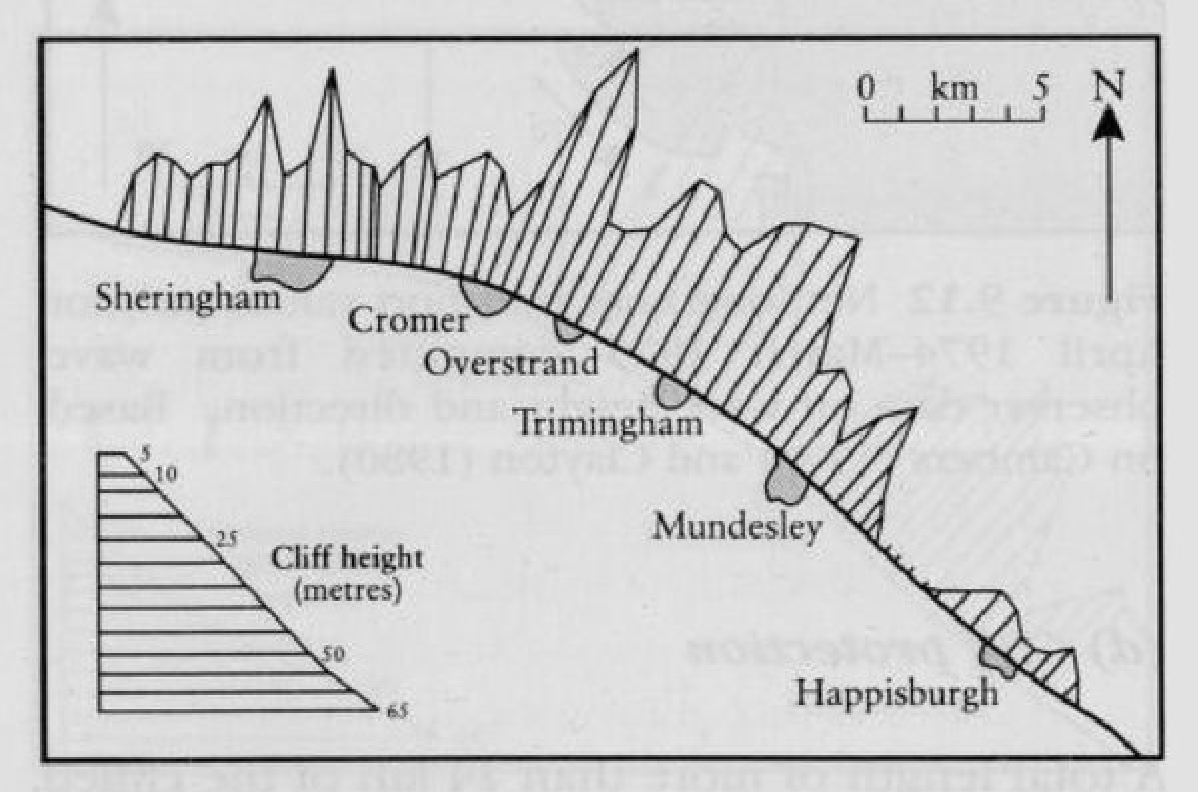
(Figure 9.11) Total coastal retreat between 1885 and 1985 based on the First Ordnance Survey at 1:10 560 scale and field survey in 1985. After Clayton (1989).



(Figure 9.12) Net longshore transport values (m^3) for April 1974–March 1975 computed from wave observer data on wave height and direction. Based on Cambers (1976) and Clayton (1980).



(Figure 9.13) (a) Design of the timber revetments used on the Norfolk Coast (after McKirdy, 1990). (b) Design of the timber revetments used at West Runton (after Clayton and Coventry, 1986).



(Figure 9.14) The height of the cliff of north-east Norfolk plotted for each measurement cell. After Clayton (1989).