Axmouth–Lyme Regis, Devon–Dorset

[SY 257 897]–[SY 333 915]

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Introduction

The Axmouth–Lyme Regis stretch of the south coast (Figure 6.18) comprises one of the best known areas of landslipping in Great Britain: it includes the site of arguably the first large-scale landslide ever to have been the subject of detailed scientific description by geologists, and it was the mass-movement site most widely suggested for inclusion in the Geological Conservation Review (Cooper, 1982). It is a National Nature Reserve (declared in 1955), selected primarily for its geological interest, especially its landslides. There has been considerable debate about the mechanisms responsible for the landslides and the development of the complex of landforms found there at 1. the present day.

The site is about 9.5 km in length from west to east, and generally extends inland from the high-water mark for about 500 m. The strata involved consist of a series of easterly dipping 2. early Mesozoic argillites and 'limestones' (Keuper and Rhaetic (Upper Triassic) and Lower Lias (Lower Jurassic)), successively exposed by faulting. These are overlain unconformably by arenaceous and calcareous sediments (Gault and Upper Greensand (Lower Cretaceous) and Chalk (Upper Cretaceous)). The plane of unconformity dips just east of south at about 5°. The present in-situ sea cliffs on the coastal boundary of the area are formed of a more limited range of strata: 3. Keuper Marls, the White Lias division of the Rhaetic, and the Blue Lias division of the Lower Lias ((Figure 6.19); Pitts, 1979).

Description

(a) General

There is a continuous series of landslips along the coast from Axmouth to Lyme Regis, named successively Haven Cliff, Culverhole Cliffs, Bindon Cliffs, Dowlands, Rousdon Cliff, Charton Bay, Whitlands, Pinhay Bay and Ware Cliffs 6. (Figure 6.20). All have histories of large-scale landslipping throughout post-glacial times, and have displayed similar features (Pitts, 1982, 7. 1983a). Although the major component in most or many of the slips has probably been rotational, detailed examination by Pitts (1979) has shown that a wide variety of mass-movement 8. types are present. These include:

1. Rockfalls caused by undermining of relatively competent rocks by erosion of relatively incompetent horizons, typified by falls of Blue Lias calcarenites in the sea cliffs at Pinhay Bay.
2. Rockfalls and clayfalls caused by frost, water or desiccation in multi-jointed or fissured materials. The scale of the falls varies with the frequency of discontinuities, between the relatively widely spaced major fractures of the Chalk and the indurated Upper Greensand facies in the cliffs in the back of the undercliff, to the closely fissured Keuper Marls of Haven Cliff and Culverhole Cliffs.
3. Gully enlargement associated with cliff-top seepage points, as in the Keuper Marls of Culverhole Cliffs.
4. Forward toppling of columns of rock bounded by approximately vertical, continuous fractures, on the seaward edge of Goat Island.
5. Successive rotational slips, as in the Chalk–Upper Greensand–Lower Lias succession of Pinhay Bay, or the Chalk–Upper Greensand–Lias–Rhaetic succession of Charton Bay. These are all renewed movements of the original slipped masses.
6. Retrogressive slips, as in the Chalk–Upper Greensand succession in The Chasm at Bindon Cliffs.
7. Non-circular to translational slides, as at Bindon Cliffs, leaving a relatively undisturbed slipped mass. These represent re-activation of slipped masses.
8. Debris slides with weathering or depositional discontinuities and a mainly disturbed slipped mass, as at the toe failures of Haven Cliff, and the scree-slope failures in front of slipped Chalk and Upper Greensand blocks at Charton

Bay.

9. Mudslides: these are mainly toe features, being the terminal stage of successive rotational slipping where adequate comminution of debris, clay bedrock and seepage tend to occur together, as at the cliff-top at Pinhay Bay, and at beach level at Dowlands.
10. Radial heave and slow, creep deformation at the toes of mudslides at both Dowlands and Pinhay; and small cliff-foot flows from saturated talus beneath seepage points, as at Haven Cliff and Ware Cliffs.
11. Liquefaction: structural collapse of Foxmould and subsidence of overlying strata, as at depth beneath Goat Island in the Bindon slip.
12. Sand-runs: collapse of dried-out non-cohesive arenaceous deposits, especially Foxmould, as at Charton Bay.

At Charton Bay the landform is unusual: the undercliff is two-tiered, i.e. there have been two separate landslips, one above the other, within the 127 m-high cliffs (Pitts, 1986). The upper undercliff is probably of great antiquity, while the lower undercliff formed as recently as 1969.

Two large-scale slips are very well-documented; the slip at Bindon in 1839, and the slip at Whitlands in 1840.

(b) The 1839 slip at Bindon

The Bindon area has a long and very complex history of landslipping, which has been pieced together in great detail by Pitts (1982, 1983a), using documentary sources. Probably the best-documented event, because it has been the most spectacular to take place in modern times, was the landslip at Dowlands and Bindon in 1839 (Pitts, 1974, 1982). Numerous eyewitness accounts of this slip have been documented (e.g. Roberts, 1840), and many illustrations are still extant (Figure 6.21); (Figure 6.22); (Figure 6.23); (Figure 6.24)

The slip is particularly remarkable for its cross-sectional shape. The new main cliff-face at the rear (landward) side was then up to 64 m high, and has in front of it a large depression ('The Chasm') into which about 8 ha of land had subsided. The length of The Chasm is about 800 m, while its breadth increases from 60 m in the east to 120 m in the west. The amount of foundered material, of which some is back-tilted, was estimated at 4.2×10^6 m^3, weighing nearly 8.1×10^9 kg. Most of this is broken into a jumble of small rifted masses and pinnacles of rock, but in places blocks of about one hectare remain intact though tilted. Beyond The Chasm a counterscarp of Chalk borders an isolated upstanding area of 6 ha, which soon became known as 'Goat Island'; it had moved seawards and subsided to some extent, but corn- and turnip-fields and hedges survived (Hutchinson, 1840) (Figure 6.25).

The sea cliffs of the displaced Chalk and Upper Greensand, which had previously stood 15 m to 30 m in height, were now broken and lowered, and thrust 15 m toward the sea. A ridge of the sea shore was pushed up in front of the slip, forming a reef of Upper Greensand. This stretched laterally for nearly 1.2 km, with its outer edge 90 m to 150 m seaward of the previous high-water mark. The beds were much broken, and now dipped inland at angles varying from 30° to 45°, while the surface, which previously had been at least 3 m underwater at low tide, was now raised in places to 12 m above high-water level. The middle of the reef was joined to the mainland by shingle, but one arm extended freely at the western end, and the other to the east enclosed a lagoon which formed a natural harbour. This reef persisted for several years.

Pitts and Brunsden (1987) give a geomorphological map and a geological section of the Bindon slip (Figure 6.26) and (Figure 6.27). They made an examination of the groundwater conditions at Bindon, but unfortunately the quality and quantity of groundwater data are very poor for all parts of the site, including Bindon. Only one well exists for which records are available and that is at Dowlands Farm about 1.0 km to the east and 0.5 km inland from the cliff-top. The water level in the well varies very little. Records cited by Roberts (1840) show that the latter half of 1839 was particularly wet, contributing notably to the Bindon slip: at least 50% more rainfall than average was experienced during that period (Arber, 1939).

Pitts and Brunsden (1987) carried out laboratory investigations as follows: samples of the black shales of the Westbury Formation were obtained for determination of residual shear-strength parameters. The samples were obtained from the slipped block at Culverhole Point but were too weathered and disturbed for peak strength determinations to be reliably undertaken.

Residual shear-strength parameters were determined using a 100 mm square shear box. Reconstituted samples of the Westbury Formation shales were formed by consolidation under high loads. A plane was then cut in the sample and the faces of the cut plane smoothed and polished on a glass plate. The sample was then re-consolidated and sheared several times until a fairly consistent value was obtained. The final pass was made at a low rate of shear. Values of normal stress were increased and the shearing process was repeated. The results obtained for the effective residual cohesion were c_r = 4 kN m^{-2}, and for the effective residual angle of shearing resistance, ø = 4.5°. There must be some doubts as to the validity of such an unusually low value for the angle of shearing resistance, and the rate of shear may have been too great to generate truly drained conditions. Nevertheless, similarly low values were obtained for the Westbury Formation in Somerset by Hawkins and Privett (1985).

Pitts and Brunsden (1987) carried out stability analyses for the 1839 slide at Bindon. The analysis was carried out in terms of effective stresses using the method of Janbu (1973), and Hoek and Bray (1981) for a block slide on a clay layer. Values of pore pressures on the slip-surface were based on water levels recorded in the well at Dowlands Farm. Using considerations detailed by Pitts and Brunsden (1987), this enabled an average value of unit weight, of 20 kN m^{-3}, to be used in analysing first-time slides. In analysis of slips incorporating previously slipped material, a 10% reduction in density was assumed.

The slope profile before the 1839 slip was reconstructed using data from contemporary sources, and changes in slope facet positions based on rates of erosion determined from the recession of high-water marks between 1888 (the date of the first 1:2500 plan) and 1972 (the date of the latest aerial photographs of the area) (Figure 6.28). It was assumed that this part of the Axmouth–Lyme Regis Undercliffs area was previously occupied by a small coastal slip extending offshore. The landward extent became the seaward edge of Goat Island in its pre-slipped position. The shear surface was taken to be within the Westbury Formation, and was assumed to develop on bedding partings, a situation in which cohesion values would be very low.

In order to obtain more realistic values of the shear strength of the Westbury Formation, a back-analysis was performed on the simple planar slide which took place at Charton Bay in June 1969 (Pitts, 1986), for which conditions are quite well established. The original profile of this slide was reconstructed from aerial photographs, providing a peak value for the angle of shearing resistance of the bedding of ø = 13°. This value was then used in the analysis for Bindon where peak strengths were required, the cohesion being considered to be zero.

The use of zero cohesive strength throughout the analysis of the failure of Goat Island reflects the probability of sliding along a discontinuity, of progressive strength loss within the Westbury Formation shales by shear creep during the pre-failure period, perhaps during progressive erosion of the toe, and the use of drained strength parameters.

The stability of the slope in front of Goat Island was then investigated using a present-day profile, and a single unit weight was used to represent the slipped material, in conjunction with the residual strength of the Westbury Formation shales along the shear surface. Finally, analyses were undertaken to investigate the state of the stability of the current slope. This considered the three main components of the modern slope: The Chasm, Goat Island, and the slipped mass in front of Goat Island.

A slab slide was assumed despite the existence of some inconsistently back-tilted blocks in the floor of The Chasm. A perfectly planar shear-surface at the base of a deep tension crack sited at the rear of The Chasm was assumed. The results of the back-analysis for the failure of Goat Island and The Chasm produced a value for ø' of 20.8° mobilized at failure, a much higher value than that obtained at Charton Bay for the same material. This disparity may relate to the proposed trigger of the failure.

Several simple stability analyses were carried out to investigate further the order of failure at Bindon. This particularly concerned the hypothesis that the trigger of the main failure of the Goat Island mass was a non-circular rotational failure in front (seaward) of that mass. An analysis of the forces acting on Goat Island when it was unsupported seawards, using the shear-strength parameters from the back-analysis of the Charton Bay slip and the water levels in Dowlands Farm well, in each case produced factors of safety (*F*) of less than 1.0.

An attempt was therefore made to analyse the contribution of the seaward support to the stability of Goat Island. No direct method of analysis seemed to exist that dealt with this contingency. A method was adopted which had been outlined by Hoek and Bray (1981) as a part of a stability analysis procedure for rock masses subject to toppling failure. The formula presented by Hoek and Bray (1981) for calculating the propensity of any of the blocks to slide rather than topple is;

$$P_{n-1} = P_n[W_n(\tan ø \cos\alpha \sin\alpha)]/(1 — \tan^2 ø)$$

where ø is the angle of shearing resistance and the various forces acting on the block are as shown in (Figure 6.29). For the situation prior to the 1839 failure, a factor of safety of 1.15 was obtained for Goat Island.

It is difficult to be sure at what stage of failure the toe block was required to be in order to produce a factor of safety (*F*) of 1.0, that is, the factor of safety at which sliding just begins to occur, for Goat Island. The indication is, however, that the failure of the toe mass would have been almost completed before the slip of Goat Island occurred, a factor of safety of 0.99 being obtained for the pre-failure geometry.

Unfortunately no calculation was attempted to assess the effect of the subsiding masses in The Chasm on the stability of Goat Island. Too little is known about the precise course of events to quantify their effects adequately.

An analysis was carried out on the slope geometry to determine the gain in the factor of safety resulting from the lengthening of the profile and the formation of the offshore reef. Although residual strengths operated throughout the length of the failure surface, the factor of safety (*F*) increased to 1.49.

The slope geometry in front of Goat Island as it exists today has suffered erosion of the reef, about 140 years of marine erosion, and crown loading from degradation of the seaward-facing slope of Goat Island. The factor of safety is very low, around 1.0, and the slope is in a quasi-stable state, if the assumptions made, particularly about shear strengths and groundwater, are realistic.

Finally an analysis was undertaken of the whole slope using the present-day geometry. A value of *F* = 1.23 was obtained, compared to that of *F* = 1.49 for the immediately post-failure situation, a reduction of 17.5% in about 140 years. In view of the apparently less-stable situation in front of Goat Island, some decrease in support by a failure of the toe mass may dramatically decrease the stability of Goat Island in a way similar to 1839, except that now, lower strengths obtain below Goat Island.

(c) The 1840 slip at Whitlands

Buckland (1840) and Conybeare *et al.* (1940) also provide accounts of possibly the largest slip between Axmouth and Lyme Regis: the Whitlands slip which took place on 3rd February 1840. Pitts (1982) has assembled evidence of movements at this site over a long period, and remarks that it has probably the longest period of landslipping between Axmouth and Lyme Regis. He suggests that the extensive slips of 1689, described simply as 'West of Lyme' (Roberts, 1840) may have been at Whitlands. Wanklyn (1927) attributes a description of the effects of this slip to William Pitt the Younger. Records cited by Roberts (1840) show the period 1764–1765 to have been particularly wet. Buckland (1840) makes it clear that the high cliff was not affected, while the undercliff, a mass of Chalk and Greensand 'which had descended in former ages, began gradually to sink downwards'. The scar was over 18 m high and over 400 m long (Conybeare *et al.,* 1840). The slipped material was split into a series of 'irregular ridges and furrows' (Buckland, 1840). Houses on the slipped mass had their floors squeezed upward and their walls were tilted. A nearby garden was converted into a pond of water.

Two reefs close to the shore were seen to 'rise slowly and simultaneously with the slow descent of the subsiding portion of the adjacent under-cliff' (Buckland, 1840). This extended about 0.8 km and 30 m seaward of and parallel to the old sea cliff. Buckland (1840) also suggested that 'the bottom of the sea, for a great distance from the present shore, is composed of large fragmentary masses of subsided Chalk and cherry sandstone brought thither by the destructive action of the sea and of land springs in former ages upon ancient undercliffs'. Pitts (1982) points out that this is supported by Conybeare *et al.'s* description of the seaward of the two reefs which was capped by 'a stratum of chalk capped with angular flint gravel, exactly as would be found on the summit of the chalk downs above the undercliff' (Conybeare *et al.,* 1840).

Before the main landslip on 3rd February, the undercliff at Whitlands was 'broken up into great cracks and fissures' (Roberts, 1840) at Christmas 1839. After the 'continued rains of January 1840' (Roberts, 1840) the main slip occurred on 3rd February.

The most recent major landslip at Whitlands occurred in 1981, starting on 28th February and continuing until about 7th March. A mass of black plastic Lias clay (Macfadyen, 1970), was squeezed up under the beach for a distance of about 450 m. The cobbles disappeared from the foreshore, which was raised by 3–4.5 m. The larger boulders formed a soft cliff varying between 1.8 m and 4.5 m in height on the foreshore (Wallace in Pitts, 1982). In the area of Whitland Cliff Pools, 46–229 m inland from the shore, the cliff was found to have subsided by 6 m (Macfadyen, 1970) and the pools to have lost their water. During the succeeding months, the reef was eroded, but the foreshore boulders were left unstable and in disarray for a long period afterwards (Wallace in Pitts, 1982).

Pitts (1983b) has used Ordnance Survey maps and aerial photographs to examine recent land-sliding along the Axmouth–Lyme Regis coastline. He was able to show that, in general, present movements follow long-established patterns. At Haven Cliffs, it is clear that there have been major phases of block disruption, a process whereby large blocks are successively broken up into smaller blocks as material moves down-slope, as described by Brunsden and Jones (1976). Colluvium has accumulated at the foot of the sea cliff. In the eastern part of Haven Cliffs, this has reduced movement almost to a standstill: scars are degrading and becoming vegetated.

At Culverhole Cliffs, activity has increased since 1905. There are many fresh scars and increased activity around the backscar.

At Bindon, rapid erosion of the reef and the extended toe of 1839 have resulted in steady forward creep of slope elements in front of Goat Island, at an average of 0.3 m a^{-1}, as these elements have been loaded by the degradation of the seaward face of Goat Island by slumping and toppling. As a result, the high-water mark has migrated seawards. Goat Island itself has steadily moved downslope, but the spatial pattern of movement is not uniform: there is a relative lack of movement in the eastern part. This may be due to stabilizing effects of slope movements in the adjacent Dowlands Cliff which took place subsequent to 1839 (Pitts, 1983b).

At Dowlands Cliff there had been relatively little change over the period of analysis. The main activities were rockfalls and rockslides at the rear. The toe block of Chalk is undergoing parallel retreat at 0.1–0.25 m a^{-1}. The main elements of the landslide have descended at 0.075–0.1 m a^{-1}.

At Rousdon the west part of the toe of the landslide is occupied by a mudslide. The toe of the mudslide seems fairly stable in position, so production of mudslide material by surging, and removal of material by the sea, may be presumed to be roughly in balance. At the toe, blocks have been moving downslope at 0.14 m a^{-1}.

At Charton Bay the lower part of the undercliff slipped in June 1969. This undermined the slip in the higher undercliff. Marine erosion of the toe, however, is inhibited by the high cobble beach, and by a large accumulation of colluvium against the sea cliff. Pitts (1986) reported a stability analysis using the method of Janbu (1973): shear-strength parameters were determined for the Shales-with-Beef at Charton Bay. Using drained reversed shear-box tests, values of residual cohesion, $c_r' = 2$ kN m^{-3} and angle of internal friction, $ø_r' = 14.5°$ were obtained; the stability analysis gave a factor of safety (*F*) of 1.06.

At Humble Point the slope failed in March 1961. There was an apparent advance of the shoreline between 1888 and 1904, which may be an effect of block disruption in the undercliffs, unrecorded elsewhere (Pitts, 1983b). Pitts (1983b) remarks that this slope seems to be in a pattern of evolution towards large-scale slipping. He notes that at Pinhay Bay there was increased mudslide activity in the 1970s, and recession at the toe resulted in 'a substantial re-failure of the face of one of the main blocks within the undercliff. The highly comminuted and weakened nature of much of the slipped material makes its incorporation into the toe mudslide relatively rapid where major seepage from the face of the slope becomes an influence. Major block disruption events at increasingly high upslope positions appear inevitable. The broad, wet, low-angled toe area is being fed by debris which is causing rapid undermining of the upslope blocks. At the same time the crest of the sea cliff continues to recede' (Pitts, 1983b).

Further light is shed on this by Grainger *et al.* (1985: Grainger and Kalaugher, 1995), who report shallow landslide activity that poses a long-term threat to the Hart's Tongue Spring, a large spring of clean water, which issued from the base of a large slipped block of Chalk and Chert Beds, at about 30 m OD and 160 m from the beach, between Whitlands and Pinhay. This source was tapped in 1935 and remains the sole source of water supply to Lyme Regis. Their investigations (survey pegs, temporary bench marks at the pumping station and on large concrete blocks on the beach, continuous-flight auger holes, geomorphological mapping, electrical resistivity and seismic refraction techniques) enabled them to draw a cross-section and reconstruction (Figure 6.30), actual surges of movement being clearly related to rainfall events (Figure 6.31). They were able to conclude that the cliff above the source is currently in a stable condition, but the zone below the pumping station is unstable and unlikely to achieve stability. In this zone retrogressive development of backscarps in the degraded Chalk blocks continues, and at its present rate will reach the pumping station in a few tens of years.

At Ware Cliffs, major block disruption in the lower parts of the slope has been very active since the 1950s. These events have extended the zone of major activity as far back as the public footpath that runs through the Nature Reserve. There is a noticeable boundary between the basically dry and wet parts of the Ware Cliffs slope at a position just downslope of the footpath, from which large amounts of seepage are discharged. Extensive seepage near the toe of the slope and from points in the lower parts of the undercliff are also making the lower slopes unstable. Much material has slipped over the edge of the sea cliff, the effects of which have been transferred upslope and which have resulted in re-routings of the public footpath to positions progressively farther upslope. This pattern seems likely to continue, resulting in the progressive undermining of the major blocks of Chalk and Greensand in the upper half of the undercliff.

Interpretation

Conybeare (1840; and in Conybeare *et al.,* 1840) and Buckland (1840) suggested that the relatively undisturbed state of Goat Island indicated translational seaward sliding over some saturated horizon. They identified the Foxmould (glauconitic sands, lower division of the Upper Greensand) as the most likely candidate, and postulated that it had been reduced to the condition of a quicksand and 'washed out' by heavy rains, causing undermining of the superincumbent strata, and seaward slipping over the underlying argillaceous Lias and Gault. This is probably the first description of liquefaction and metastable sands in the scientific literature. Arber (1940) suggested that the slip is associated with the Cretaceous overstep, and supported the notion of 'washing away' of the Foxmould leading to undermining and translational sliding. A major (but erroneous) challenge to this view came from Ward (1945) who stated categorically that the main movement was rotational and similar to that at Folkestone Warren. This was questioned by Arber (1962), in view of the relatively undisturbed nature of Goat Island, with its (if anything) slightly seaward tilt. The strongest expression of this view is a diagram by Macfadyen (1970; (Figure 6.32)). However, a close examination of a series of ridges running parallel to the edge of Goat Island on its seaward side unfortunately led her to a later acceptance of Ward's view (Arber, 1971). Arber has since pointed out (1973) that the back-tilting of blocks in The Chasm, and the pushing. up of Lower Greensand strata in the reef, support this view, and has suggested that Goat Island may not have moved at all. However, morphological mapping by Pitts (1979) suggests that some foundering and seaward slipping have in fact taken place. It is now widely recognized that the mechanism of 'graben' or 'chasm' formation requires forward movement of the foundered blocks and is a diagnostic feature of non-circular failure. The Macfadyen (1970) model should be discarded.

Pitts (1983b) concludes from his study of recent movements that present-day developments depend primarily on conditions at the toe. The removal of the toe of a landslide, landslide debris, slipped blocks, or even offshore reefs subsequent to a slope failure or the gradual recession of sea cliffs upon which landslides have developed, result in critical fore-shortening of the profiles and a reduction in the factor of safety. Progressive downslope movement of the large, more-competent slipped blocks behind then takes place more easily. Processes at the rear, notably rockfalls from the backing cliffs (rear scarp), and the general accumulation of scree at their foot seem to result in crown loading but this appears to have only a marginal influence on the destabilization of the remainder of the slope. As Pitts (1983b) remarks, this is borne out by the rarity of whole-slope failures which are not demonstrably preceded by a series of increasingly large failures developing rearwards from the toe. He concludes by observing that over the time period which map, aerial photograph and field observation cover, there seems little reason to believe that instability following the currently established patterns will not continue.

With respect to the 1839 Bindon landslide, Pitts and Brunsden (1987) propose that the mechanisms were as follows:

1. An initial non-circular deep-seated failure of the pre-existing undercliff, which reduced the toe support of the block behind.
2. Resultant planar slippage on the underlying Westbury Formation, of the mass known as Goat Island.
3. Subsidence of pinnacle-like masses of Middle Chalk and indurated Upper Greensand rocks into The Chasm from both the rear of Goat Island and the rear cliff.

Additional points which may have a bearing on the interpretations are:

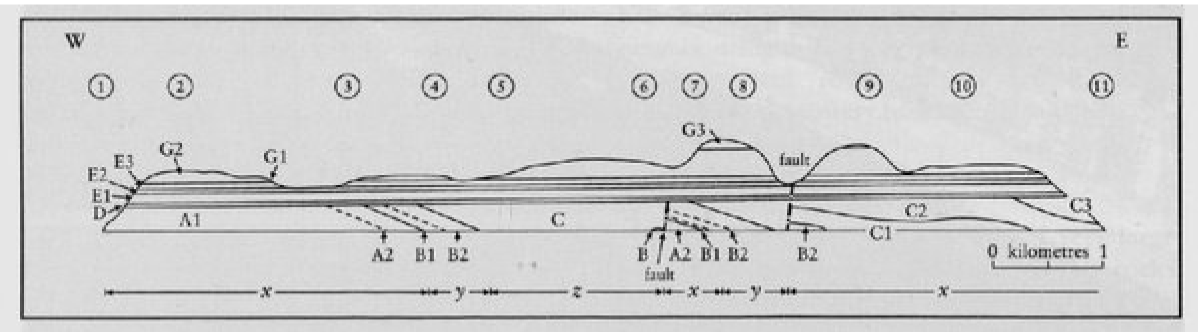
1. Geophysical investigations in Lyme Bay (Darton *et al.,* 1981) have revealed many 'axes' trending roughly parallel to the coast; these were interpreted as being of structural origin. However, as the main structural axes in the pre-Cretaceous strata in the area trend approximately normal to the coast, Pins (1983b) suggests that the 'axes' are the eroded remains of multiple rotational slips, repeatedly planed off by a transgressing sea in immediately post-glacial times.
2. Alternatively (Kellaway *et al.,* 1975) the landslips may have resulted from glacial over-steepening and dissection by meltwaters, but evidence for glaciation is inconclusive.

Conclusions

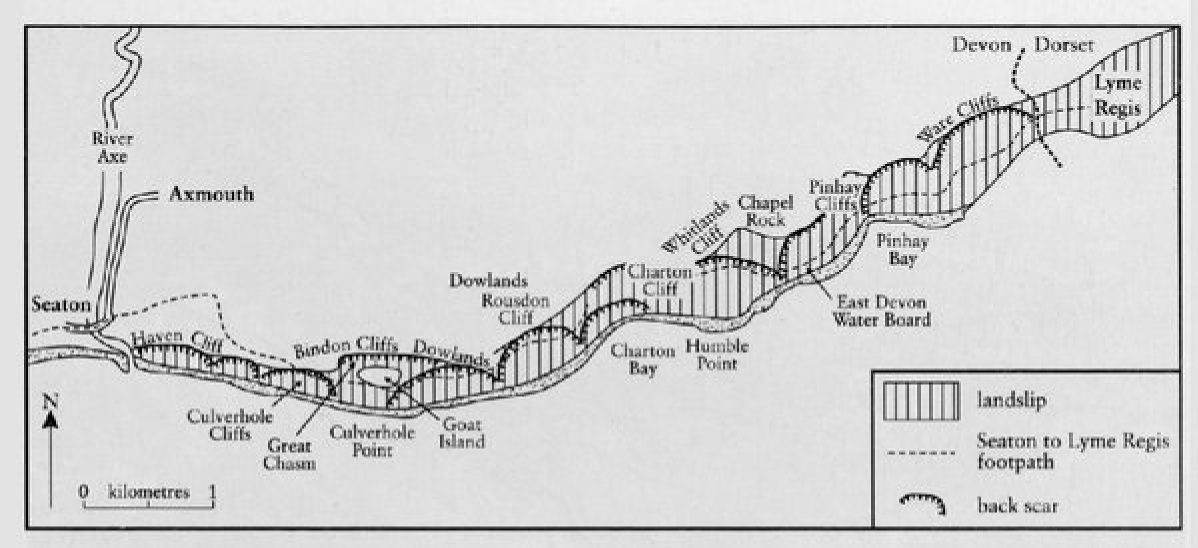
The Axmouth–Lyme Regis site is worthy of GCR status for several reasons, and has additional historical importance. Owing to the extraordinary co-incidence of two eminent geologists (Conybeare and Buckland) being in the vicinity at the time of the major 1839 landslip, the site was meticulously examined and recorded at the time, the first occasion that this had happened with any landslip, worldwide. The results of the slip were scenically so spectacular that many pictures of it were drawn and painted and accounts of the events collected. Conybeare's explanation represents an important landmark in the development of attempts to explain and understand mass movements. Secondly, the existence of Goat Island beyond The Chasm at Bindon has led to an instructive controversy over the nature of the 1839 slip. Thirdly, the entire stretch of cliffs (the Ware Cliffs slides are currently extending eastwards into the gardens of Lyme Regis), shows an astonishing and quite exceptional variety and richness of mass-movement types, as documented above. As noted by Arber (1973), this is chiefly in terms of large-scale, deep-seated slumps, in which many large slices of rock have maintained something of their original shape, and form discontinuous ridges paralleling the inland cliff-line that forms the backface of the slips. It should be noted that at the present day very few of the characteristics and features described 150 years ago can be observed with ease at the site, as the vegetation cover is very thick and in many places virtually or actually impenetrable.

References

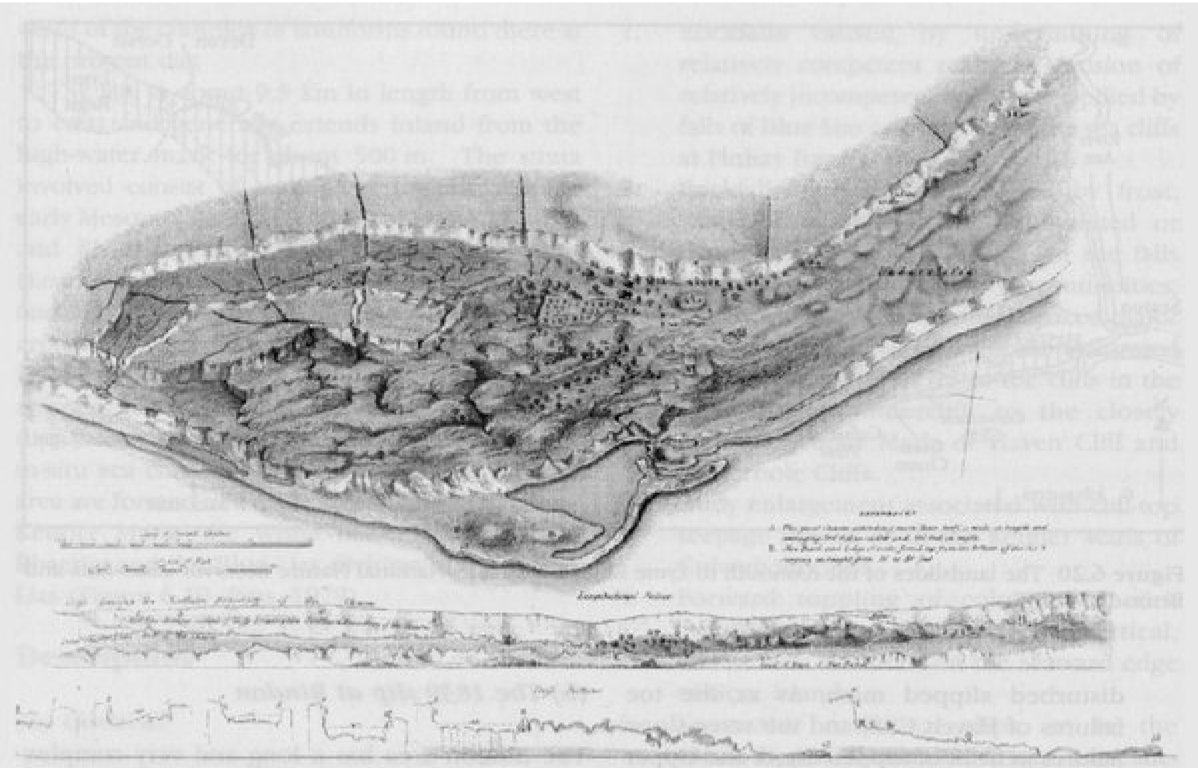
(Figure 6.18) The Axmouth to Lyme Regis Undercliffs region. This photograph shows the famous Bindon Landslide that took place on Christmas Eve 1839. It is probable that this is the first landslide to be fully described in a scientific memoir. (Photo: courtesy of http://wwwukaerialphotography.co.uk.)



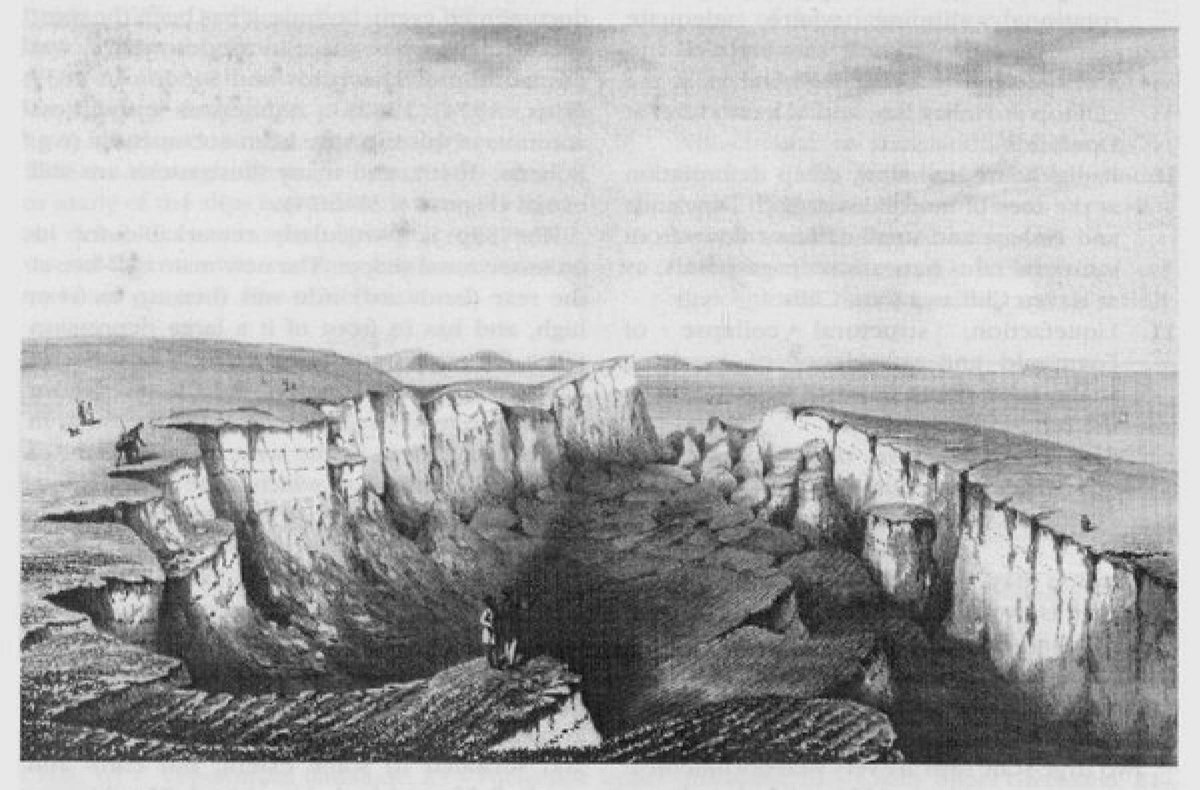
(Figure 6.19) Schematic geological section of the coast between Axmouth and Lyme Regis. (1) River Axe; (2) Haven Cliff; (3) Culverhole Cliffs; (4) Bindon Cliffs; (5) Dowlands; (6) Rousdon Cliff; (7) Charton Bay; (8) Humble Point; (9) Pinhay Bay; (10) Ware Cliffs; (11) Lyme Regis. Geological succession: G3 — Upper Chalk; G2 — Middle Chalk; G1 — Cenomanian limestone; E3 — Phosphatic Upper Greensand; E2 — Cherty Upper Greensand; El—Foxmould; D — Gault; C2 — Shales—with—Beef; C1 — Blue Lias; B2 — Lilstock Formation; B1 — Westbury Formation; A2 — Blue Anchor Formation; A1 — Red and Variegated Marls of the Mercia Mudstones Group. After Pitts (1979).



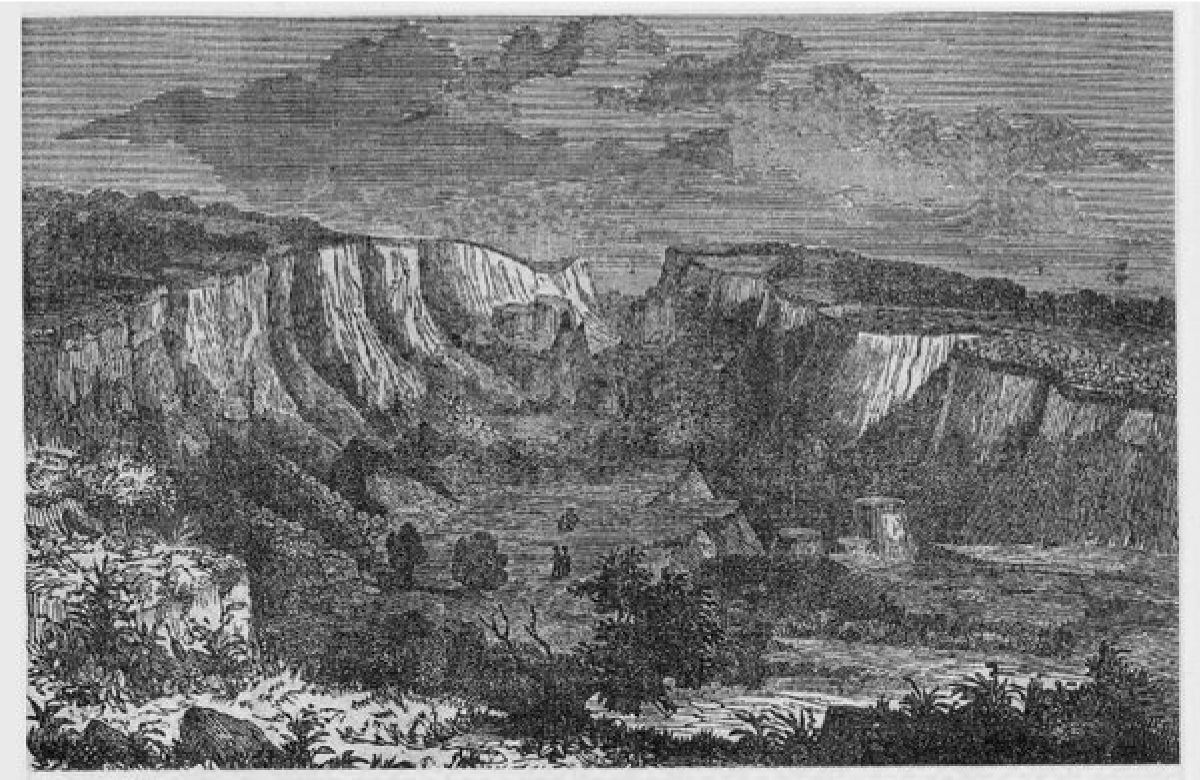
(Figure 6.20) The landslides of the Axmouth to Lyme Regis Undercliffs National Nature Reserve. After Pitts and Brunsden (1987).



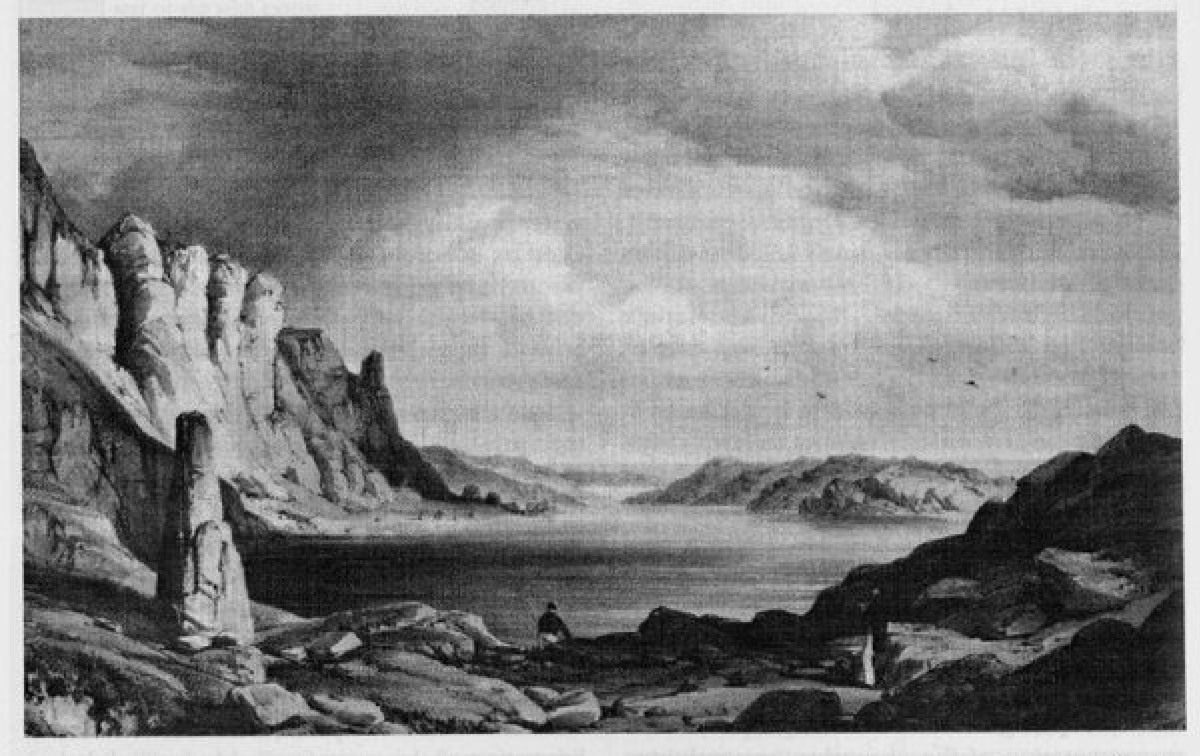
(Figure 6.21) Ground plan and section of the Bindon Landslip (1839). From Conybeare et al. (1840), reproduced with permission of Lyme Regis Museum.



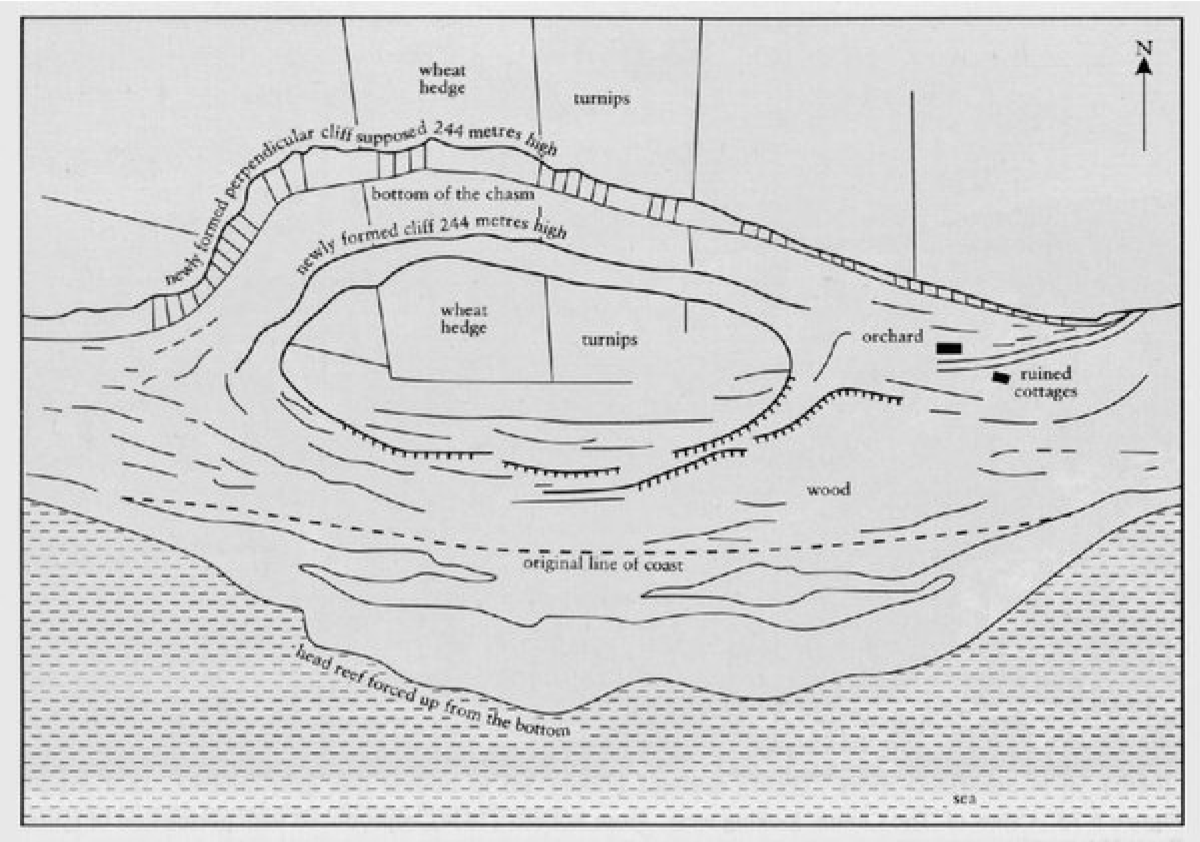
(Figure 6.22) A view of 'The Chasm' looking west. From Conybeare et al. (1840), reproduced with permission of Lyme Regis Museum.



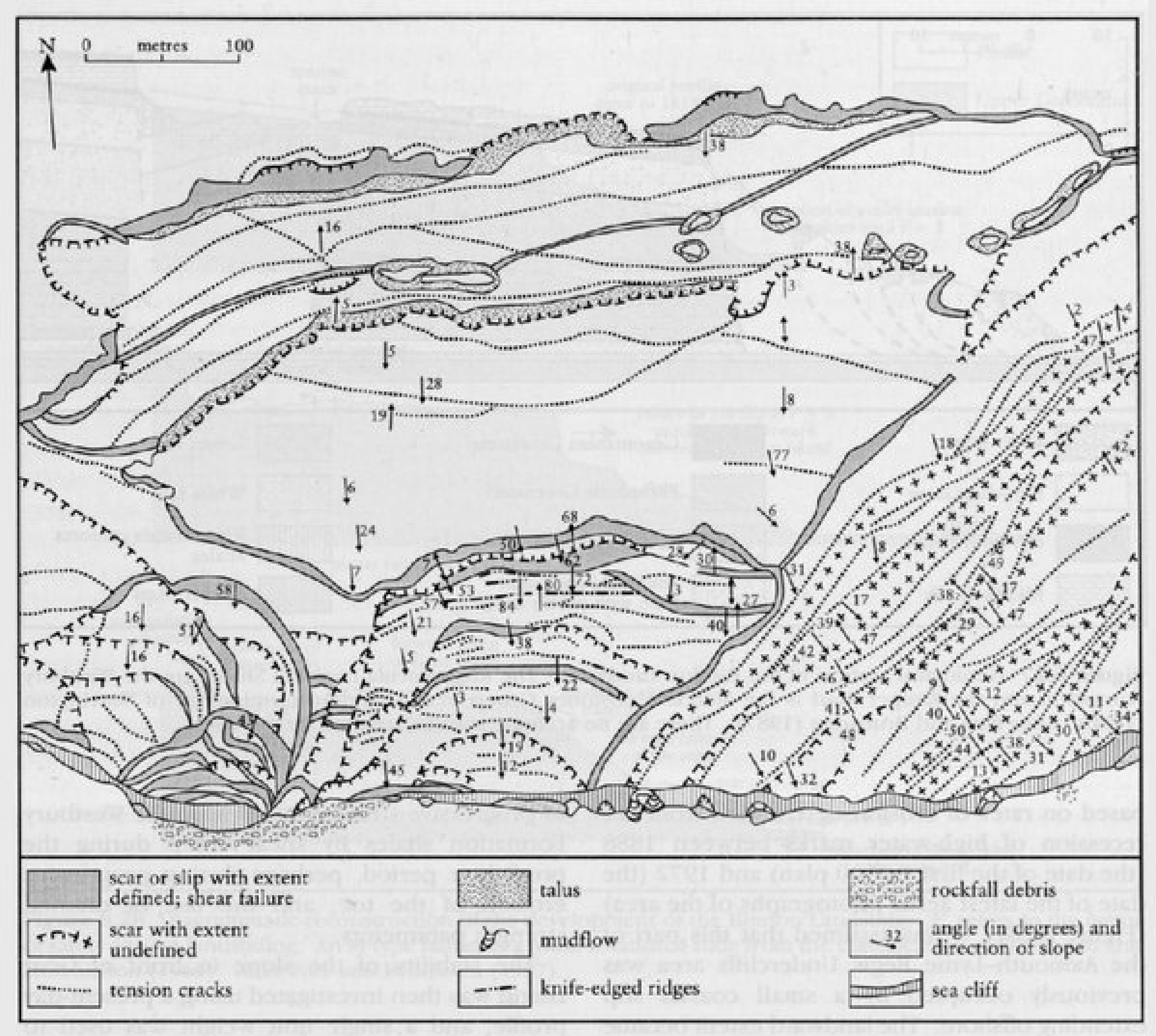
(Figure 6.23) A view of 'The Chasm' looking west. From Roberts (1840), reproduced with permission of Lyme Regis Museum.



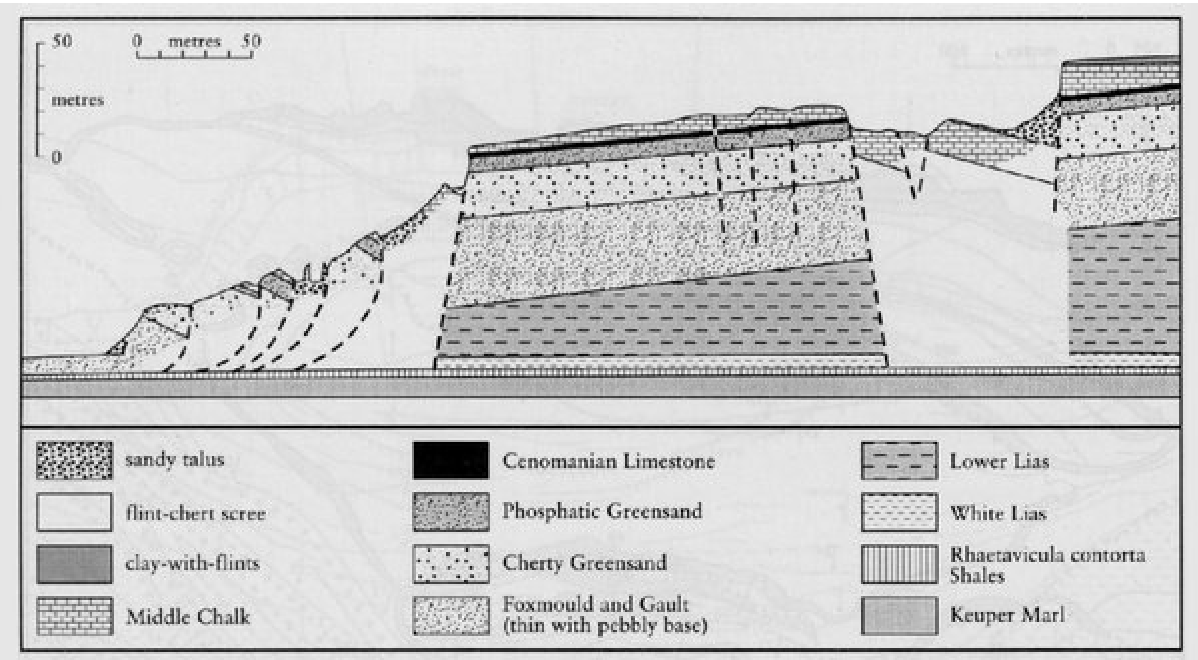
(Figure 6.24) The reef and lagoon at Culverhole Point looking east. An engraving on stone by G. Hawkins jr, reproduced with permission of Lyme Regis Museum.



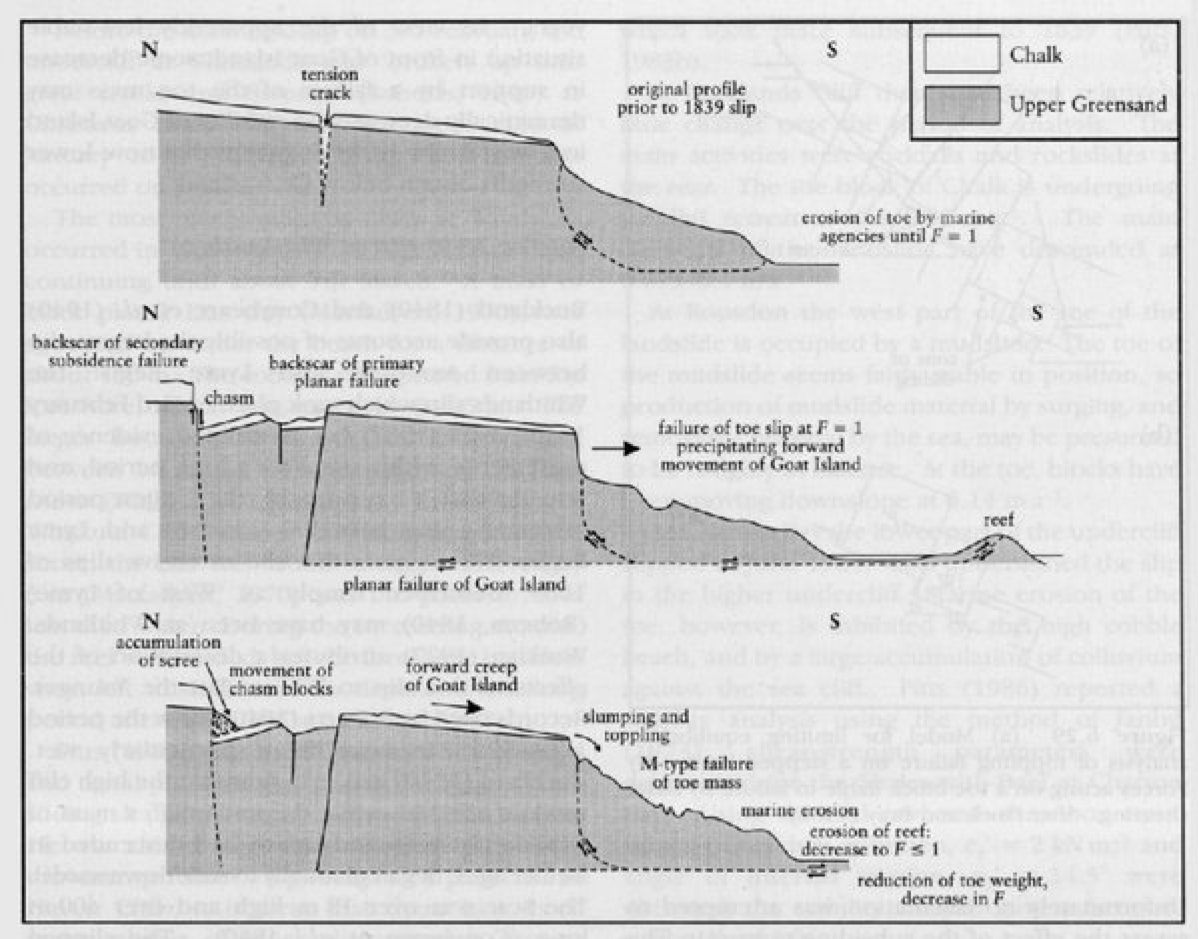
(Figure 6.25) Plan of the landslip near Axmouth, Devon. After Anon (1840), from Pitts (1974).



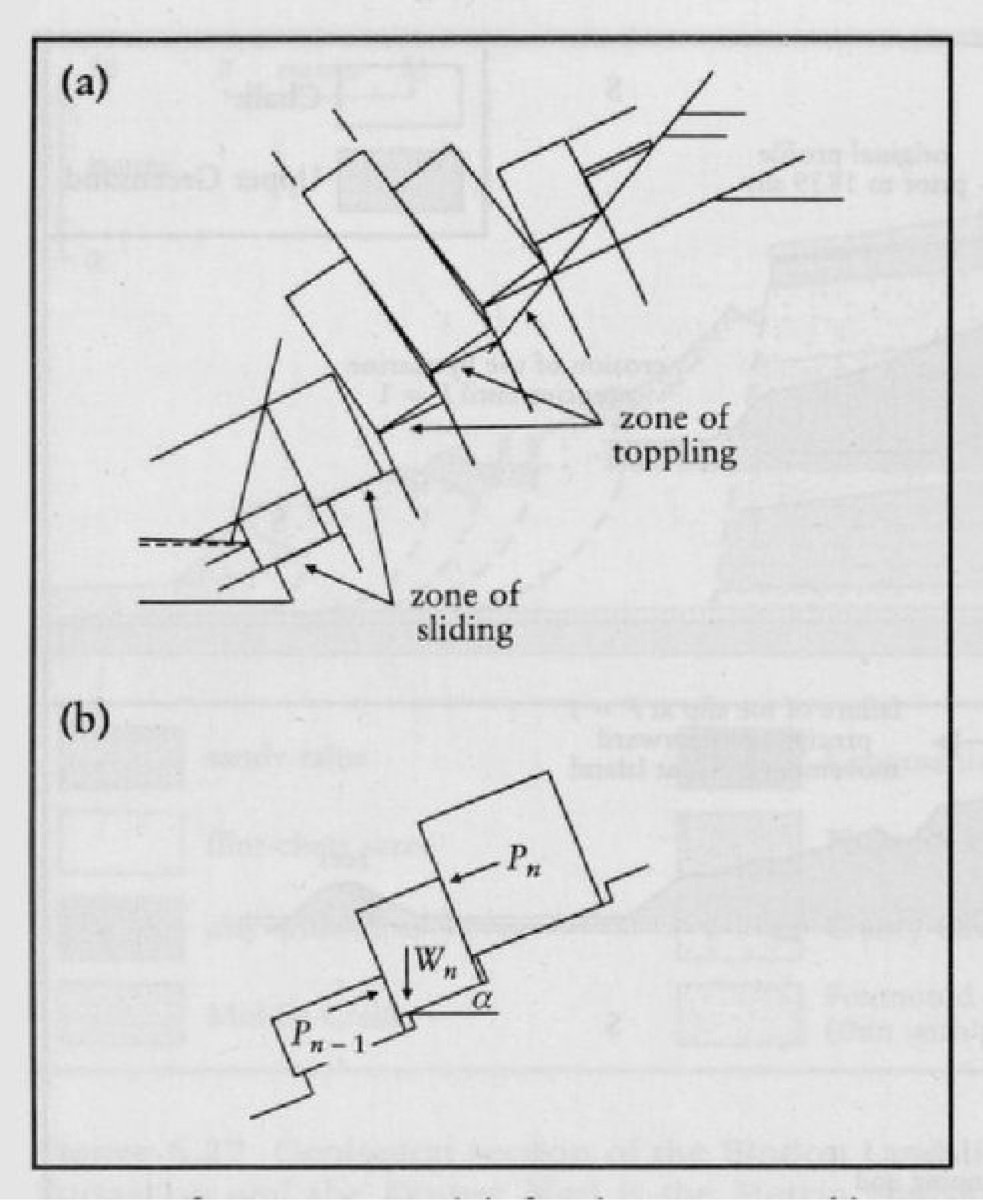
(Figure 6.26) Geomorphological map of the Bindon Landslide. After Pitts and Brunsden (1987).



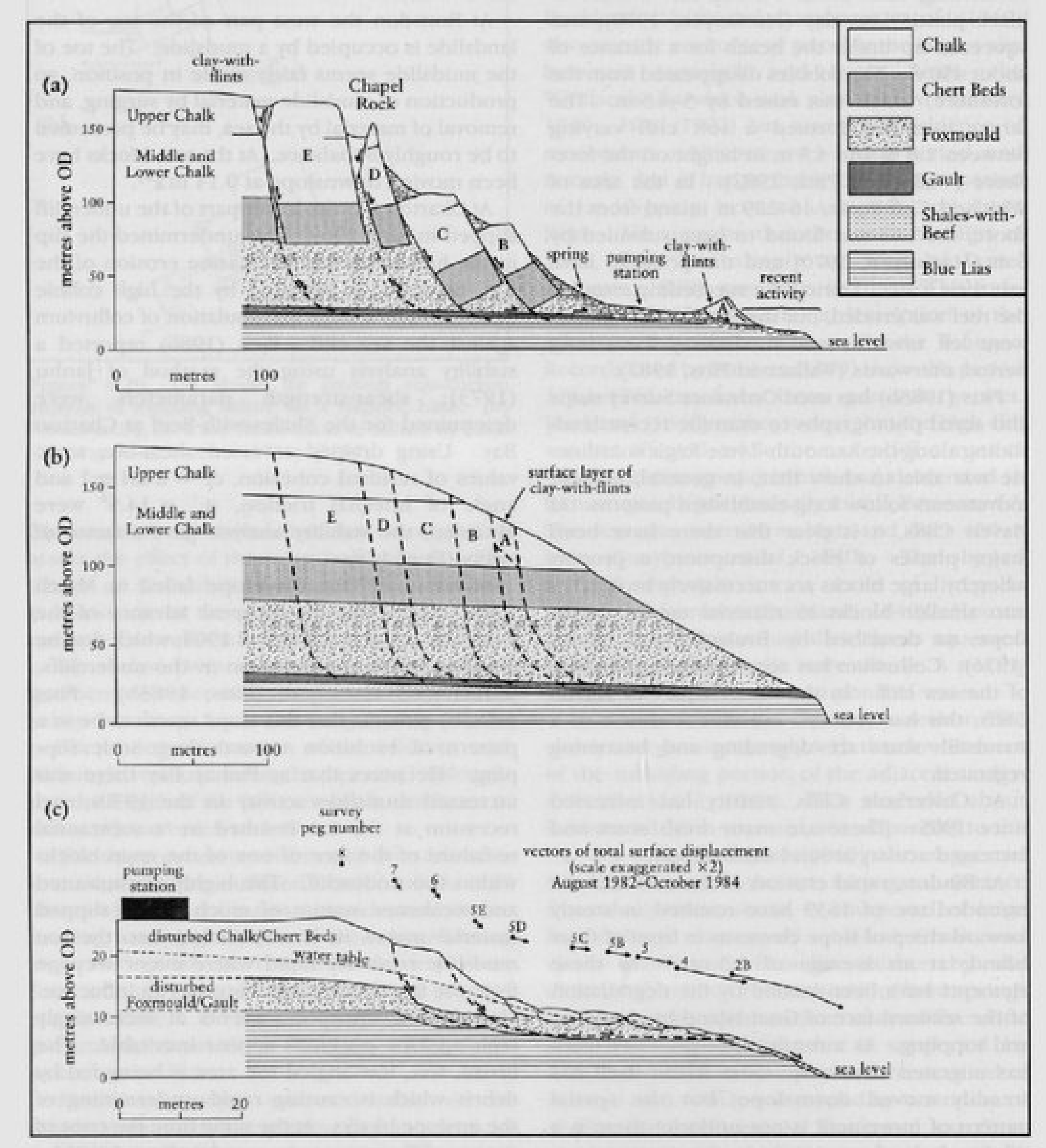
(Figure 6.27) Geological section of the Bindon Landslide. The Rhaetavicula contorta Shales are the Westbury Formation and the Keuper Marl is the Mercia Mudstones Group in the modern terminology of Warrington (1980). After Pitts and Brunsden (1987). There are no accurate sub-surface data for this slide.



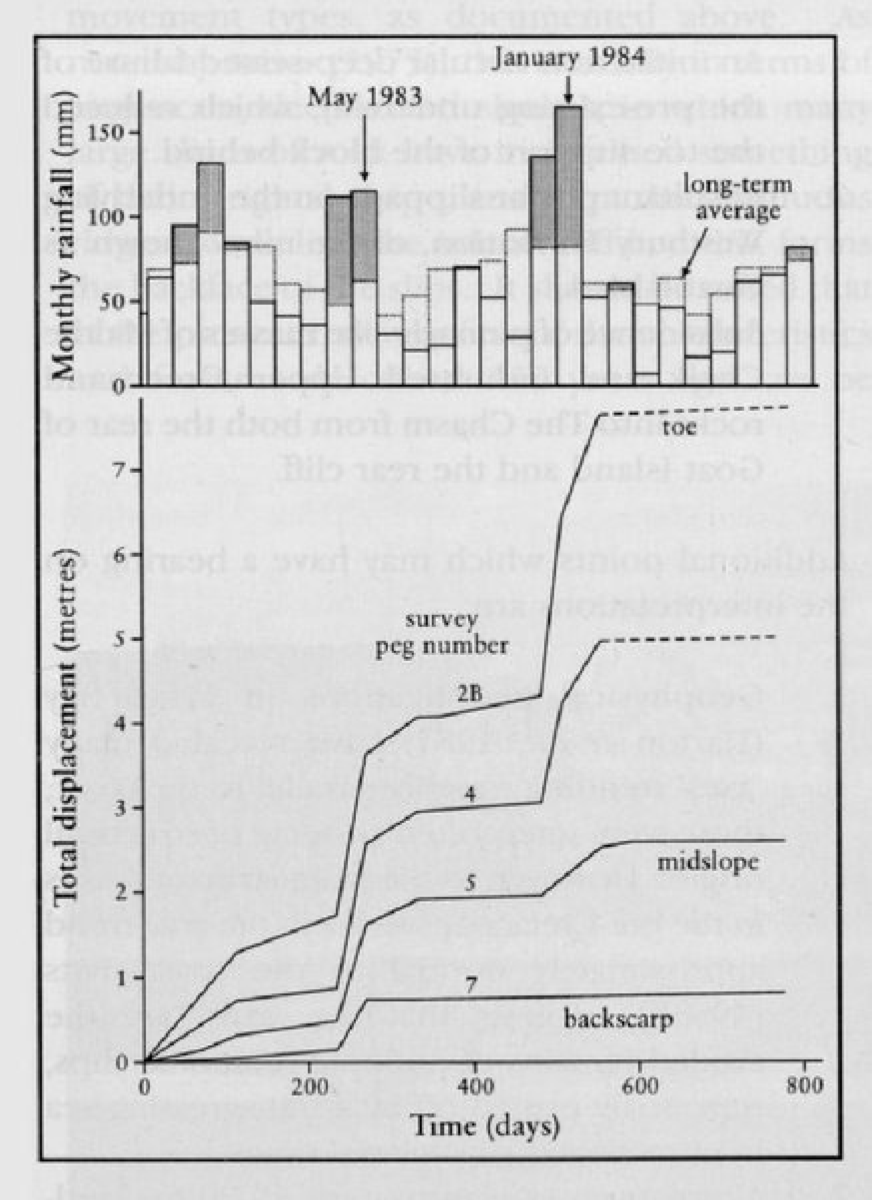
(Figure 6.28) Diagrammatic reconstruction of the development of the Bindon Landslide. 'F' refers to the factor of safety against landsliding. An M-type failure is a multi-rotational slide from the classification of Skempton and Hutchinson (1969). After Pitts and Brunsden (1987).



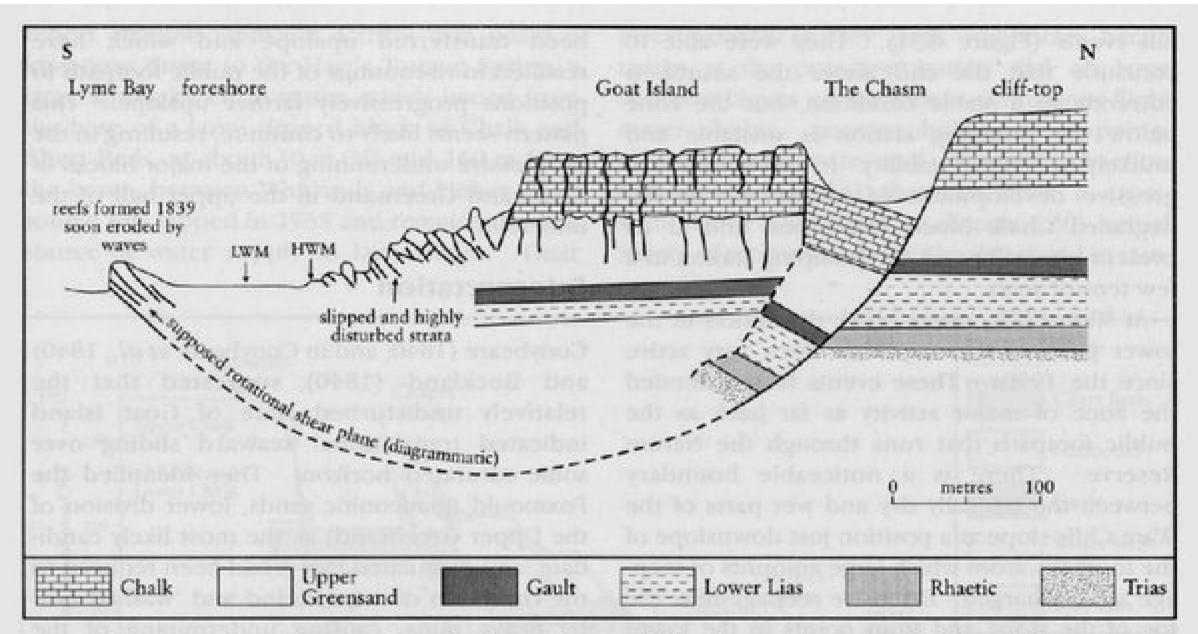
(Figure 6.29) (a) Model for limiting equilibrium analysis of toppling failure on a stepped base. (b) Forces acting on a toe block liable to failure by basal shearing. After Hoek and Bray (1981).



(Figure 6.30) Cross-sections and evolutionary reconstruction of the Chapel Rock landslide and the surveyed movements at the undercliff water pumping-station. Note the loss of the Foxmould by flow or extrusion. After Grainger et al. (1985).



(Figure 6.31) Comparison of rainfall and ground movement of the lower slopes of the landslide between Humble Point and Pinhay. After Grainger et al. (1985).



(Figure 6.32) Hypothetical section through the Bindon Landslide showing a rotational failure mechanism (after Macfadyen, 1970, from Pitts, 1974). The model is not substantiated by sub-surface information. Note that the model does not explain the toe slips, nor why the strata in Goat Island remain horizontal when subject to rotational movement. The graben is diagnostic of a non-circular failure on the bedding.