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# LANDSLIDES OF THE DORSET COAST: SOME UNRESOLVED QUESTIONS

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The Dorset Coast includes some of the finest landslides in Britain. They occur at the southern end of the landslide prone strata associated with the Jurassic outcrop. These materials provide many examples where a permeable 'caprock' overlies a clay aquiclude. Because of the structural relationships of these beds along the Dorset coast there is a range of landslide generators each with different properties and styles of failure. This paper describes the individual sites and summarises the existing state of research. The outstanding problems are then outlined. First, there are many sites and materials which have never received adequate research. Secondly there are technical difficulties. More fundamental, however, are the problems which have only become apparent after intensive study and which must be solved if geotechnical science itself is to advance. These include understanding of the mechanisms of the processes of lateral spreading and ductile clay extrusion, the phenomenon of running sand, geochemical controls of material behaviour and the relationship between pore water pressure, shear strength and landslide movement.

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## INTRODUCTION

The Dorset Coast which is one of the most beautiful coastlines in the world is also an area of outstanding geological and geomorphological interest. This scientific interest is based on the remarkable geological sequence, the extraordinary variety of landforms, the history of its discovery and its teaching importance. Foremost amongst these attributes is the display of active landslides.

Although it is certainly an underestimate the Review of Landsliding in Great Britain (GSL 1989.1991) reports that 8835 landslides are recorded in the National documentary archives accessed for the survey by Geomorphological Services Ltd. One thousand, three hundred and two landslides are on the coast, of which 859 are on the south coast, concentrated in a few localities such as Folkestone, Hastings, Christchurch-Bournemouth, the undercliff of the Isle of Wight, Portland, West Dorset, the Landslide Nature Reserve and Budleigh Salterton. Most noteworthy are the slides of the Dorset Coast which, with 291 reported slides, must rank as one of the most important landslide areas in Europe (Figure 1). The reason for this concentration lie in the fortuitous coincidence of factors which promote slope failure.

## CONTROLLING FACTORS

1. The distribution, forms, activity and landslide diversity can only be understood in terms of the sequence of Jurassic and Cretaceous rocks which are so completely displayed along this coast. This is because the sequence shows a rapid alternation between consolidated, fissured, high plasticity clays; thick silty clays of medium to high plasticity, and limestones and sandstones of varying thickness and permeability. This distribution, emphasised by the overstep of the Cretaceous materials, provides almost unlimited opportunity for the classic landsliding formula of permeable beds overlying less permeable clay aquicludes. Important clay members for landsliding are the whole of the Liassic but particularly the Blue Lias, Shales with Beef, Beleminite Beds and Green Ammonite Beds, The Fuller's Earth, the Oxford and Nothe Clays, the Kimmeridge Clay and selectively the Wealden and the Gault.

The type of materials and their physical properties also determines the type of landslide which occurs. Where the Upper Greensand and Gault overlie the Liassic clays the failures are in the form of large, deep-seated rotational slides. The clays typically generate very active mudslides. The outcrop of Chalk or the Middle Liassic sandstones is expressed in shallow, steep angled rockslides and falls. The Portland and Purbeck Beds yield spectacular rockfalls, topples, sags and deep seated slides, depending on the proportion of limestone cap to underlying Kimmeridge Clay exposed in the profile. The depth of the tension zone inland from the cliff is also controlled by this factor.

2. The second major factor is the occurrence of gentle folded structures such as the Marshwood pericline, the Weymouth anticline, the Purbeck syncline, the Shambles syncline and the spectacular Purbeck monocline (Figure 2). Landslide type, pattern, style of headward propagation and activity are strongly dependent on the local attitudes of the strata. These include structurally controlled and lateral unloading sequences (Figure 3). In West Dorset the Marshwood anticline imparts gentle seaward east-south-west dips to the strata which enhances the landslide activity by directing groundwater to the free faces as at Stonebarrow Hill (Figure 4). More subtle are very gentle folds along the axes of the folds. These raise and lower the level of key strata with respect to coastal erosion and concentrate groundwater along the axes of the basins. The Rivers Lym, Char and St Gabriels Water are all guided by structural lows but fainter ripples also act within the landslide complexes. The location of the mudslide axes at Black Ven are partly controlled in this way.

The Purbeck Coast is dominated by the east-west change in dip to the Portland, Purbeck, Wealden and Chalk strata as they react to the Purbeck Monocline. At Durlstone the beds are horizontal and joint-guided rockfalls with shallow slides in the weaker members of the Purbeck are the rule. At St Albans Head the dips are into the slope and the Portland Sand and Kimmeridge Clay both crop out. Here rotational slides appear, often separated by small mudslides. A similar pattern is seen at Hounstout and Gad Cliff although here the distribution reflects a changing proportion of caprock-clay outcrop and the lateral dip. At Lulworth the Portland presents a rampart to the sea, dipping more steeply inland and the failures are often cubic blocks released from a wedge-shaped scar. At White Nothe there are complex structures, but the underlying mudslides and the deep rotational failures in the overlying Cretaceous appears to be propagating both updip and along a fault.

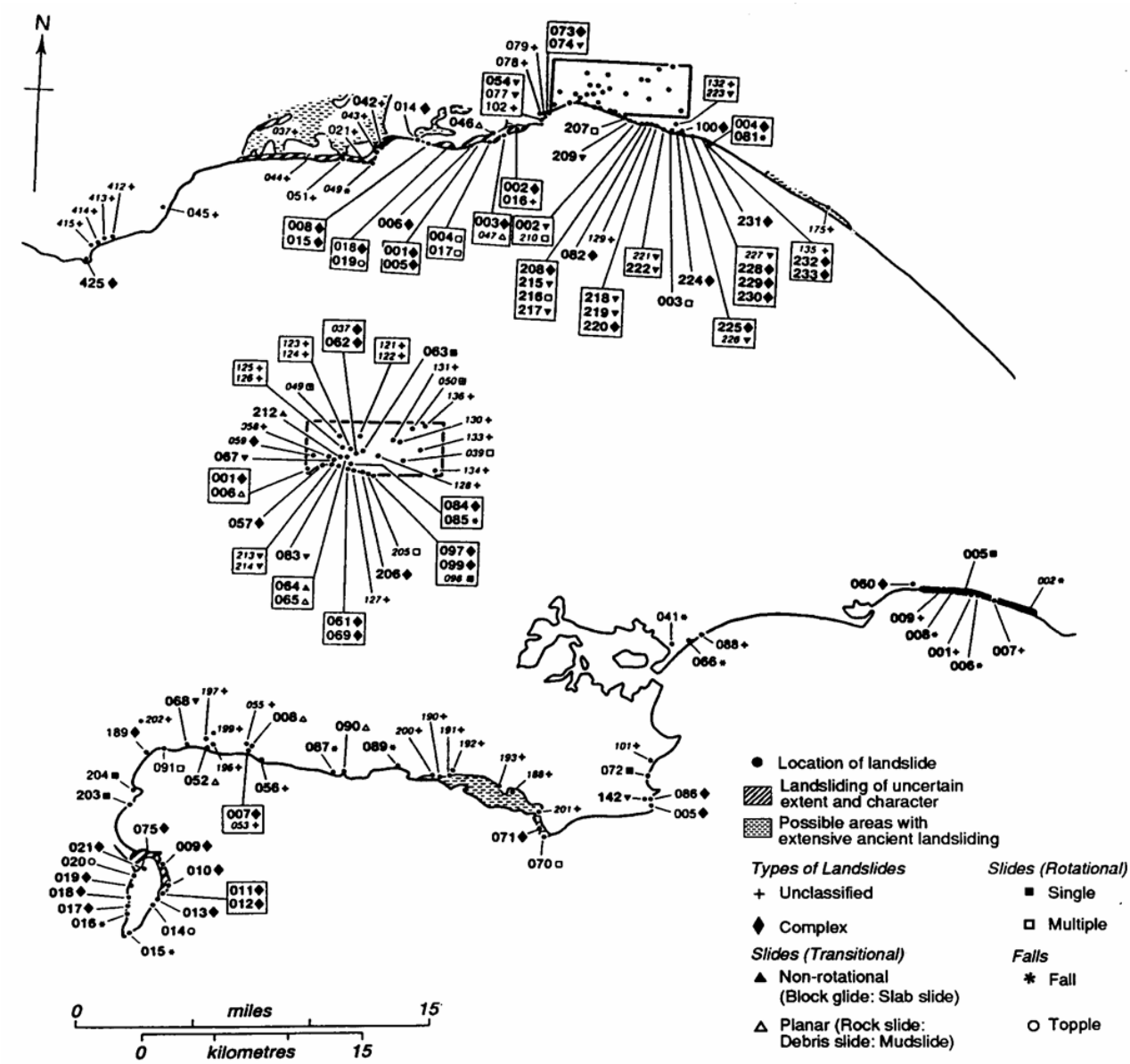



*Figure 1. The distribution of landslides on the Dorset coast. Source DOE/GSL (1986).*

The Isle of Portland must rank as the best example in Britain of structurally controlled landsliding. The jointing along northwest - south-east, north-east - south-west, north-south and east-west master and conjugate sets closely reflects the axis of the Shambles syncline and is a major landform control at all scales, from the occurrence and form of individual rock falls to the shape of the island itself. The Portland coastline has large numbers of landslips whose spatial pattern is spectacularly related to the geology and vary in size and type in a systematic manner as the thickness of clay and the orientation of the dip with respect to the coastline orientation changes (Figure 5).

The folds are separated by major faults such as the Abbotsbury-Ridgeway Fault and, at depth by the newly confirmed Weymouth Bay to Lulworth structure. Particularly important as landslide controls are the north-east - south-west Mangerton Fault at Bridport, at Fault Corner and the small north-west to south-east faulting associated with the Pays de Bray structural trend. These often control both the location and shape of many of the smaller slides or components of the large complexes. Faults at Pinhay, Higher Sea Lane, Stonebarrow, Ridge Cliff, Broom Cliff, Seatown, West Bay and White Nothe are good examples.

3. The third fundamental control of landsliding is the history of sea level rise and the undercutting of the coastal slopes. Although data are restricted to the observation of solifluction deposits, there is little doubt that the coast was abandoned by the sea during the last glacial period. The slopes then evolved under periglacial solifluction conditions and, on the clay slopes, major mudsliding occurred. During postglacial times the landslide scars and the structural benches degraded and became vegetated with some movement as the climate deteriorated. The nature of these slopes is only preserved today at the Spittles, in the slopes behind Chesil Beach and on the side slopes of the main rivers, eg. the north slope of Stonebarrow Hill, the head drapes on the top of Golden Cap or the solifluction slopes of Seatown.

After c. 5500BP the rising sea began to remove the apron of solifluction deposits and resurrected the abandoned preglacial cliffs. The existing pattern of landsliding is therefore partly an inherited one due to the reactivation of old slides (Figure 6). The exact history is, however, one of the unknown features of the coast, the evidence has mainly been lost by erosion or awaits the interpretation of side

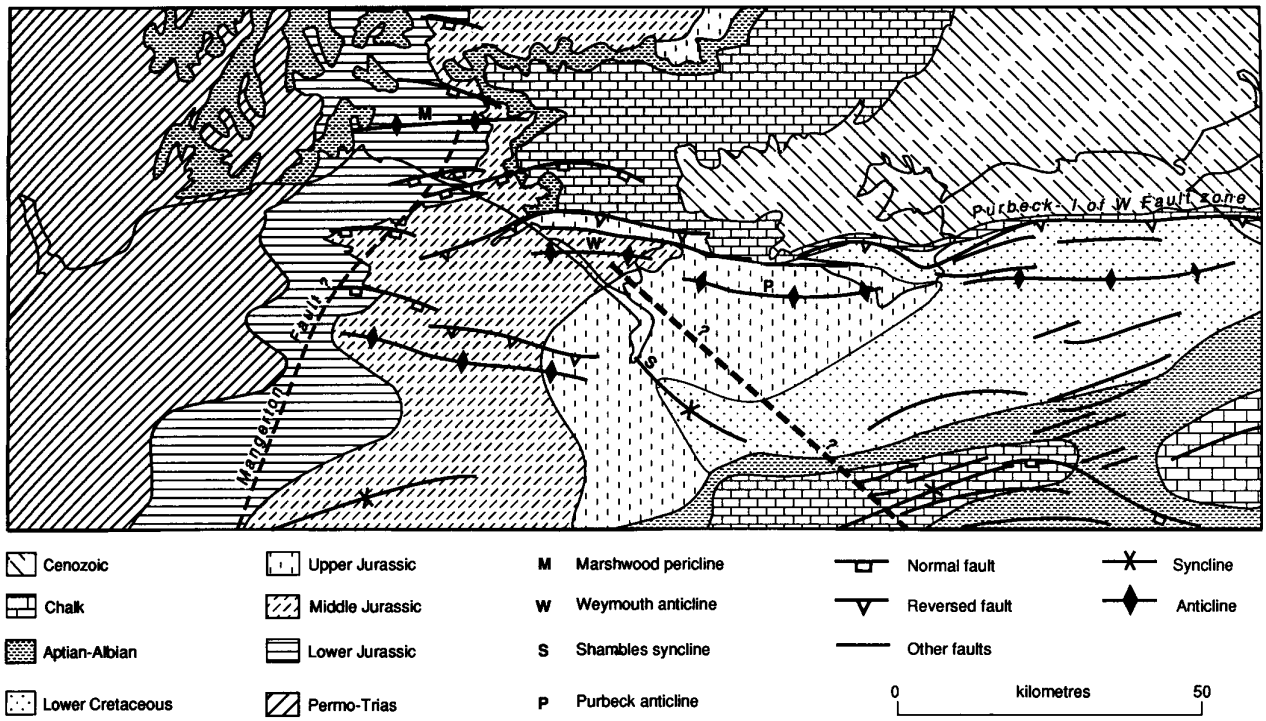



*Figure 2. The generalised structure of the Dorset coast.*

scan sonar records, for the fact remains that the first reliably dated records do not appear until the 17th century.

We are on much more certain ground when we examine current rates of basal undercutting. The main headlands on the Portland Stone show a negligible rate of erosion on historial records, even though rockfalls are know to occur. Their change lines within surveying accuracy. Where clay occurs beneath these slopes rates of 0.1-0.2 mpa are common. Middle Lias sandstone and siltstone cliffs in West Dorset range between 0.20.5 and the vulnerable Lower Liassic clays rise to 0.3-3.0 mpa. Similar rapid rates are known for Hengistbury head, Barton and Highcliffe.

There is no doubt that today, with a rising sea level of c.2 mm per annum, basal erosion is of increasing concern. All the landslide areas suffer retreat of the cliffs at the slope base and removal of landslide debris, so that a stable profile cannot develop. Only where the debris itself is resistant is the cliff protected for any length of time. For example, the lobe of the clay-rich 1958 mudslide at Black Ven was removed by 1969, but the main body of the 1732 slide at East Weares, Portland which contains large blocks of stone has only lost its toe reef and lower body. The average rates also conceal the fact that retreat is very episodic and that the slow rates of continuous basal removal are accentuated in storms and propagated by distinct aggressive waves of cliff activity and slope failure.

4. The historical record emphasises the fourth fundamental control-the climate and its temporal variation (Figure 7). The geomorphological time series extends patchily for 200 years and the precipitation-temperature series to 1890. The series shows an apparent increase of events in the last century and a sequence of troughs and peaks. The trend may reflect the increasing contact of human beggings with landslides or changes in reporting but it does occur in all data banks, periods and areas. On the coast it is reasonable to attribute some of the trend to the influence of sea level rise.

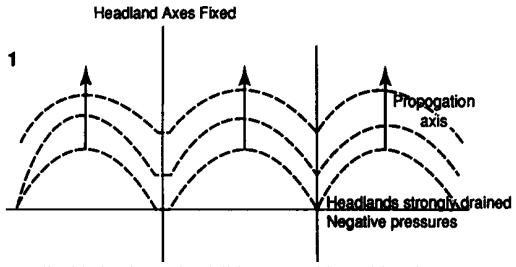
The second feature is the variation in the moisture balance over the record period. Using Isle of Wight data, it can be shown that there was a drying sequence from 1840-1920 with a brief reversal in 1895-80, and a wetter cumulative moisture balance from 1920 to 1995. This broadly corresponds to the increased frequency of landsliding. In addition the series shows that wet years and sequences of wet years are associated with increased geomorphological activity and, one assumes, a rhythm in the sedimentation of Lyme Bay? The South Coast record shows a concentration between 1912-13, 1922-32, 1936-41, 1950-70, 197588 and 1993-5. Wet year sequences occurred in 1877, 1913-5, 1922-32, 1936-39, 1952-4, 1963-70 and 1993-5. The Dorset coast supports this pattern with wet years, sequences and landslides in 1943, 1946-7, 1950-52, 1954, 1958-60, 1963, 1965-70, 1972, 1974, 1977, 1979-82, 1986 and 1993-5. (Figure 7, Brunsden *et al*. 1995).

A central conclusion is that activity takes place every 5-10 years with the period of sediment transfer lasting for 10-15 years activity. Major periods when new landslides occur appear to be every 30-40 years.

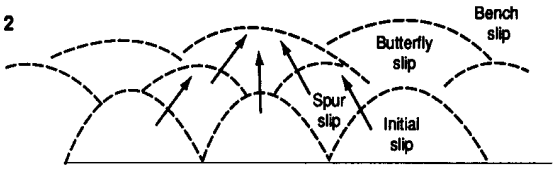
5. The last general influence is the interference with the natural system by human beings. Examples include cut and fill operations as on the Marine Parade of Lyme Regis, or West Bay; the uncontrolled discharge of surface water as at East Cliff, Lyme Regis; interference with the protective sediment flux system on the foreshore particularly between Lyme Regis and West Bay; quarrying as on Portland or simply the use of ancient landslide ground without due consideration of the disturbed slope properties as at Higher Sea Lane, Lyme Regis and the Portland Naval Base. All have led to severe landsliding.

Down-drift landslide sequences are almost the classic Dorset story. Interference with the foreshore sediment transfer system by harbour wall or sea wall and groyne systems has taken place at Lyme Regis, West Bay, Osmington, Christchurch and Barton. All have major landslide problems directly caused by engineering erosion control solutions that were based on incomplete knowledge of the system. In West Dorset (Figure 9) the downdrift repercussions of building the Cobb and the construction of the Marine Parade caused the 1962 Cliff house disaster (Lee, 1992), the continuing instability at Langmore Gardens, the erosion of East Cliff, the 'Burning Cliff slide of 1916, the increasing activity of Black Ven and the 1986 failure of the Spittles. The closure of the piers at West Bay in the 19th century is still being paid for by landslide remedial measures in 1996.

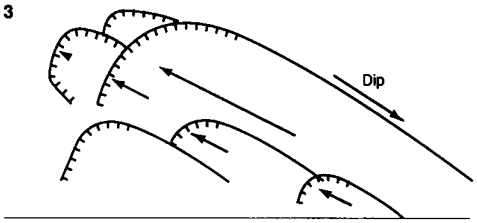
The landslides caused by this erosion do, in turn, feed material



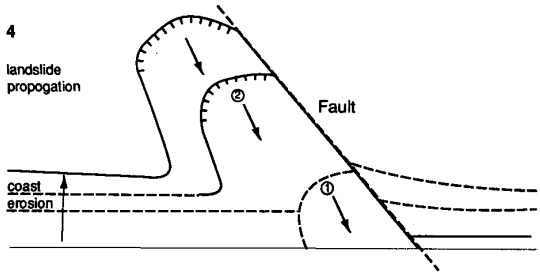

Cyclical behaviour - landslide removal is rapid and allows drainage of headland e.g. Black Ven.
Often occurs where dip in horizontal and materials are uniform.




Initial slides removed slowly, this does not allow negative pressures in spurs but unloading occurs on each side. Spur slips plus initial slip unloads the 'butterfly wing'. e.g. Landslide Nature Reserve. Ventnor, I o W.




Up-dip propagation by asymetrical unloading. e.g. Landslide Nature Reserve, Higher Sea lane, White Nothe.




Fault controlled landsliding. e.g. Higher Sea lane; Seatown

*Figure 3. Some examples of the way in which structure controls the spatial pattern of landsliding. From Brunsden (1996).*

back to the beach to set up a long-lasting complex response, but there is a very strong downdrift sequence in landslide activity as the sediment which builds up on the foreshore after a slide moves alongshore to give varying protection to the cliff base. Black Ven and Stonebarrow both generate this effect along their respective downdrift sea cliffs. Landslides can also completely cut sediment supply by sliding out across the foreshore. A major mudslide below Golden Cap currently isolates Seatown Beach, the beach level is falling and new sliding is taking place to threaten the Anchor public house. Still further along the coast major slides occurred in 1995 below Doghouse Hill and Thorncombe Beacon, followed by three nice rotational failures at Eype.

Quarrying is another dramatic cause of failure on Portland. (Brunsden *et al,* 1996). Here the causes were the mining of stone from the landslides on the undercliffs and the large scale dumping of waste over the cliff edge. As early as 1665 it is possible to identify artificial loading as a cause of failure.

*' ...on Feb. 2nd 1665 the great pier was quite demolished and filled up with rubbish; and rocks that lay 40 yards off in the sea or the pierhead were risen up above the water, so that there was no hope of making good the pier again; and the ways leading up from the piers to the quarries were turned upside down and sunk in several places at about 30 feet. The North pier was cracked but might be repaired. The coast slid into the sea between the two piers, near 100 yards, and continued to do so.. It is conjectured this was occassioned by a great quantity of rubbish thrown over the cliff upon a clayish foundation, which was softened by the violence of the rain, and gave way, and not by earthquakes as some imagined...' (Southwell, 1717)*

Similar passages can be cited for the slides of December 1734, February 13th 1792, the second biggest landslide to be recorded in the UK; and December 26th 1858 when the effect of quarrying was made very clear. In all there are 72 records of landsliding on the Portland coast, many directly related to human activity. The main areas are the Naval Base, West Weares, East Weares and HM Osprey and Penns Cliff-Great Southwells.

## UNRESOLVED PROBLEMS

### *1. Limited Research.*

The most basic problem is that although the landslides are very famous, we have a very limited knowledge of the geomorphological processes and the geotechnical properties of the materials. Only Black Ven and Stonebarrow have up-to-date published mapping. Lyme Regis, Seatown, West Bay, Portland Base and Osmington have commissioned consultancy maps and small scale distribution maps are available for Portland and Lulworth. The value of the latest techniques of analytical and digital photogrammetry for landslide studies has been demonstrated, but has only been applied to Black Ven. (See summary references in Allison, 1992; Brunsden and Chandler, 1996; Brunsden *et al*., 1996) (Figure 9).

Only five sites, Black Ven (eastern slide), Stonebarrow (central mudslide), Seatown (below houses and Worbarrow (small mudslide at eastern end and Portland Base (east of Officers Mess) appear to have been monitored but these are mainly cumulative or spot readings over short periods (1-3 years). Portland has some long term surveying by the PSA but this will soon end. There is some continous monitoring at Black Ven (2 years unpublished), Stonebarrow (1 year unpublished), Worbarrow (3 years, only part published). Measurements include the use of stand pipe and pressure transducer piezometers, ground survey, extensometeis, inclinometers and automatic weather stations, but the spatial coverage and temporal extent are very limited. (Allison, 1990, 1992, 1996; Allison and Brunsden, 1990; Koh, 1992; Rudkin, 1992; McLaren, 1990; Moore, 1991; West Dorset District Council, 1996.)

Geotechnical data remain poor. Excellent consultancy reports have been completed for Cliff House and East Cliff, Lyme Regis, (Lee, 1992) Seatown and Portland and there are some unpublished University research data for West Dorset, but the main volume of data comes from the investigations for the bypasses through the area.

Associated with this are very real problems of instrumentation. Many of the landslides are very big, inaccessible and too costly to allow thorough subsurface investigation. Large funds for deep boreholes are not available because there is often no threat to life or structures. In addition, some of the slides are very active and it is difficult to obtain data before the equipment is destroyed. It is known that there are very complex response patterns on the seasonal mudslides, including the observation from the high density Worbarrow record that when continuous measurements are made of water pressure and movement there is not a direct relationship or a good correlation (Figure 10). Instead the record has to be interpreted as a sequence of events in which feedback from previous states, dynamic thresholds, rates, intensities, durations, stabilisation points and lags need to be established. So far we do not have sufficient data to ask or answer the correct research questions! This is particularly true of physico-chemical causes of failure and self-loading along the length of the slide.

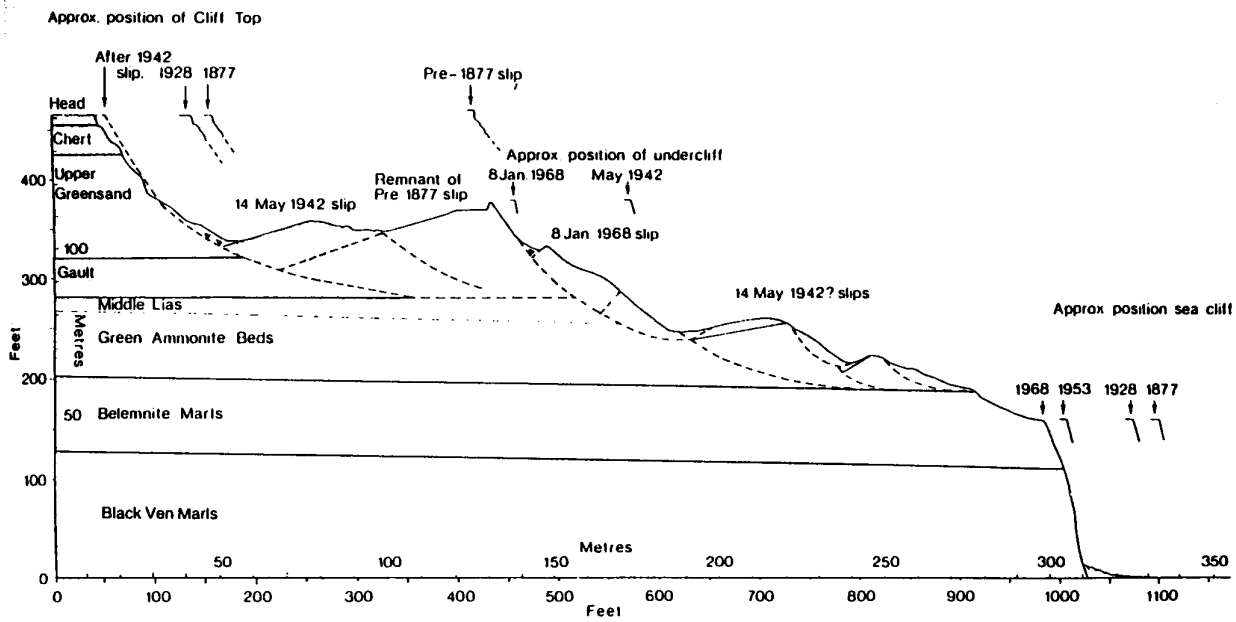



*Figure 4. The structural and lithological control of landsliding at Stonebarrow Hill, Dorset. From Brunsden and Jones (1976).*

## 2. Physicochemical controls of landsliding.

This raises the first fundamental research question about the relationship between geochemical controls of material behaviour, shear strength, pore water pressure, landslide initiation and dynamic maintenance of movement.

Moore (1991) working at Worbarrow Bay on a small shallow mudslide in the Weald Clay, was able to confirm that the residual strength of clays is in part determined by the pore water chemistry and the clay mineralogy of the system. It is now suggested that the residual strength parameter should be considered to be dynamic, with increases and decreases in strength occurring in response to environmental change. This involves both the available exchangeable ions and the dilution factor of excess water (Figure 11). The problem therefore involves both a weathering question and a seasonal or climatic mechanism.

So far it is known that:-

- chemistry controls the strength values of clays;

- that there can be a difference of 2°-5° in the residual angles of internal friction of weathered and unweathered materials;

- that different salts in the pore water yield different strengths for the same clay, for example, up to 4.7% in $0'_r$ for calcium- and sodium- saturated clays;

- that the strength of unweathered clay could change by 510% and weathered clay by 12-14% as a direct consequence of changes in pore water concentration.

- that there was a change of strength between high and low concentrations of salts (Figure 12).

These conclusions have very important implications for testing procedures because they imply that there should be very strict control of the water chemistry and that the samples should be tested in the worst case conditions of the ground itself.

The tests also allow quite sophisticated questions to be formulated about the actual mechanisms involved in triggering and maintaining movement, at least in shallow sensitive systems. Moore and Brunsden (1996) used these results to build a model of mudslide behaviour. They observed:

- that immediately after movement and during stability dose range ionic bonds re-developed from the disturbed chemical system.

- during the winter period easily available ions from the disturbed clays and from winter storms often led to an increasing strengthening of the system, so that higher and higher water pressures were needed to trigger and maintain movement as the season progressed.

- in summer, however, the pore water became progressively more dilute as the system was flushed and equilibrated with the *in situ* groundwater and rainfall. There are no storms to deposit sodium ions

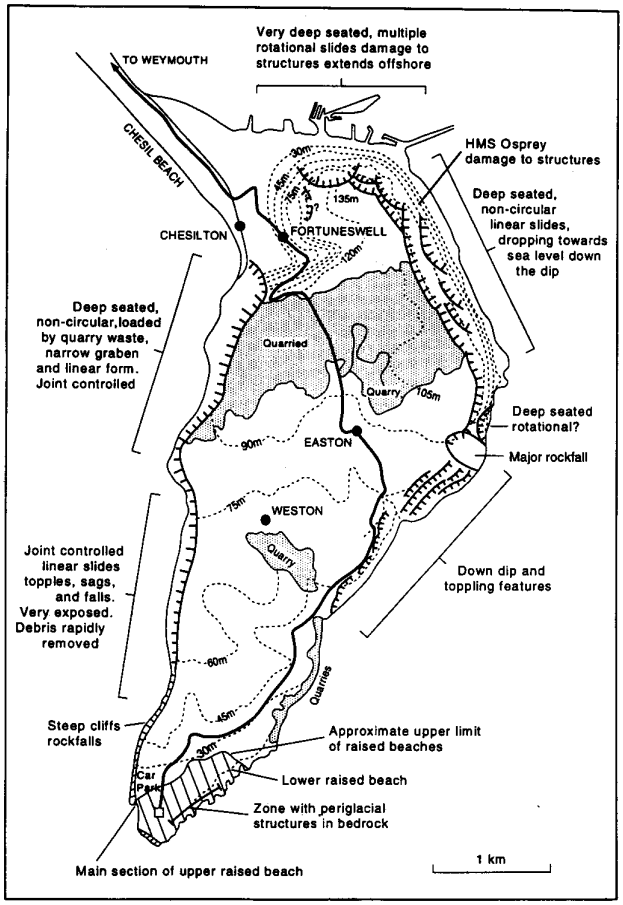



*Figure 5. Structurally guided landslides on the Isle of Portland. From Brunsden et al (in press).*

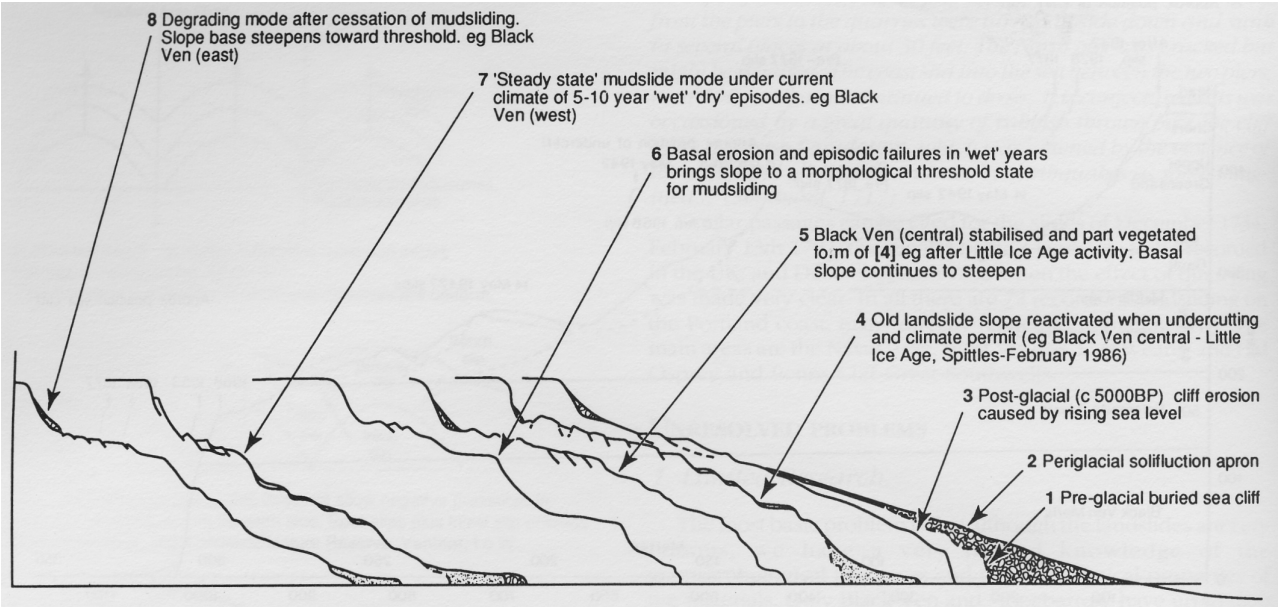



Figure 6. The evolution of the inherited landslide pattern of the West Dorset coast. From Brunsden and Chandler (1966)

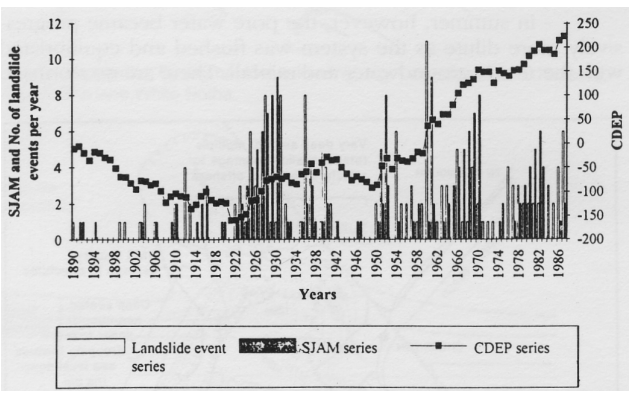



Figure 7. Sequences of landslides and wet years on the Dorset Coast.

in the system and no renewals of calcium due to movement. The bond strength became dependent on the weaker hydrogen bond and the diffuse double layers.

- therefore as the ground water levels increased in autumn they coincided with the system at its weakest, the weakened bonds began to break, stick-slip movement occurred followed by surges at zero cohesion.

- however, this movement provided an increase in concentration, a strength gain and a mechanism for the slide to halt.

It is now believed that this explains why higher water pressures are needed to trigger subsequent movement events and why movement can cease whilst pore pressures remain high.

The problems associated with this exciting idea are however that the data come only from one small mudslide at Worbarrow with some confirmation from a slide in London Clay on the North Kent coast and a few papers in the literature. (Steward and Cripps (1983). The data cover only one season. The chemical system is a coastal one based on calcium-rich clays and sodium. There is no information about the other chemical systems of the Dorset coast, especially the pyrite system or for any of the other clays. There has been no work on the use of the idea to develop stabilisation methods.

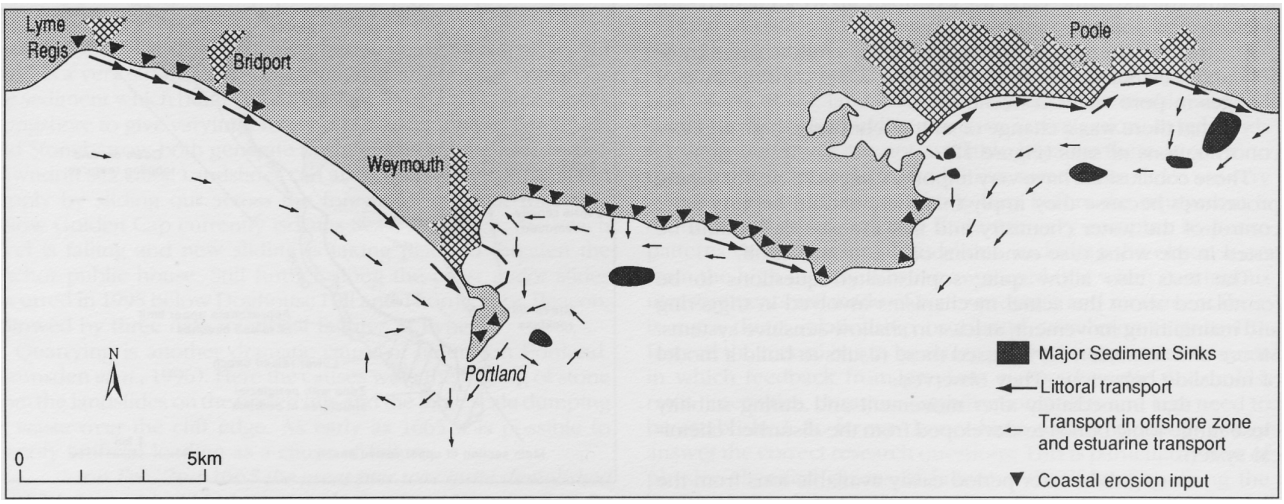



Figure 8. The sediment flux system of West Dorset and the relationship to landsliding from Bray (1991, 1992).

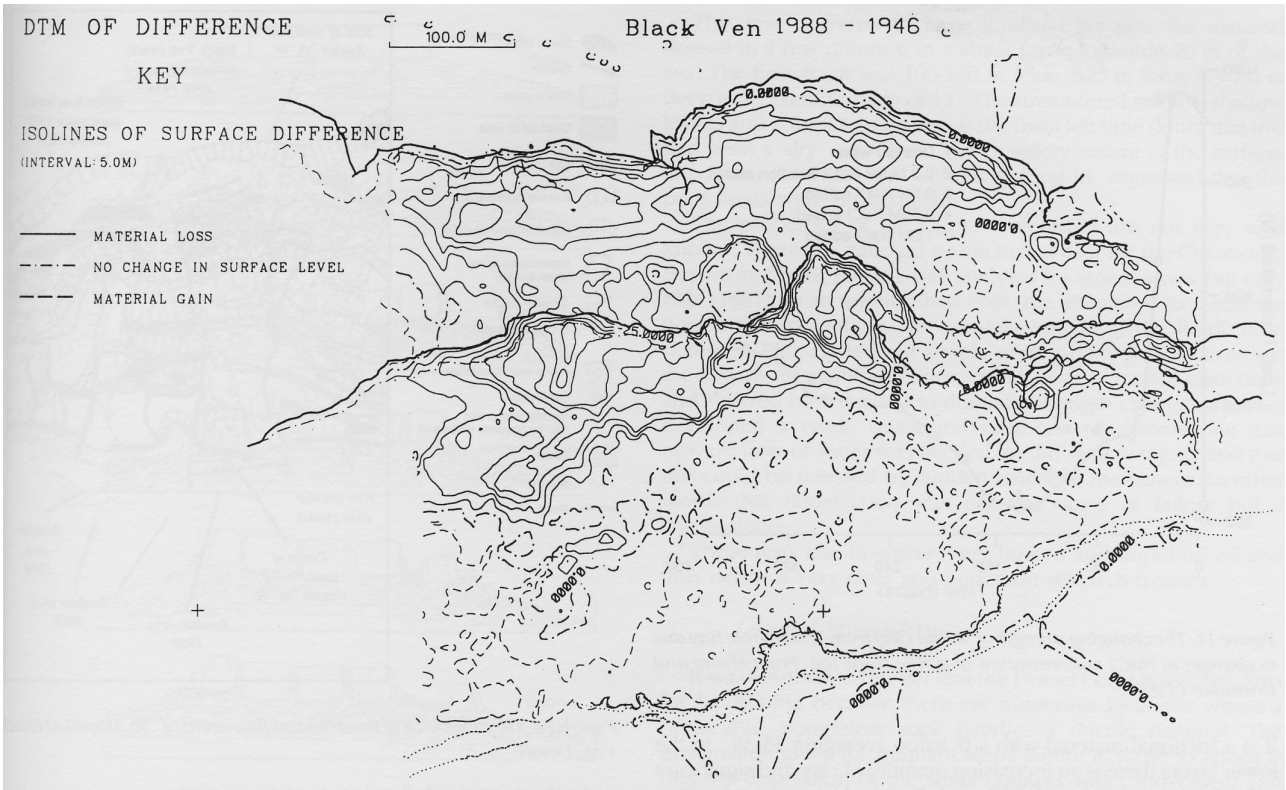



*Figure 9. Summary erosion map of Black Ven drawn using advanced photogrammetric techniques. From Brunsden and Chandler (1996).*

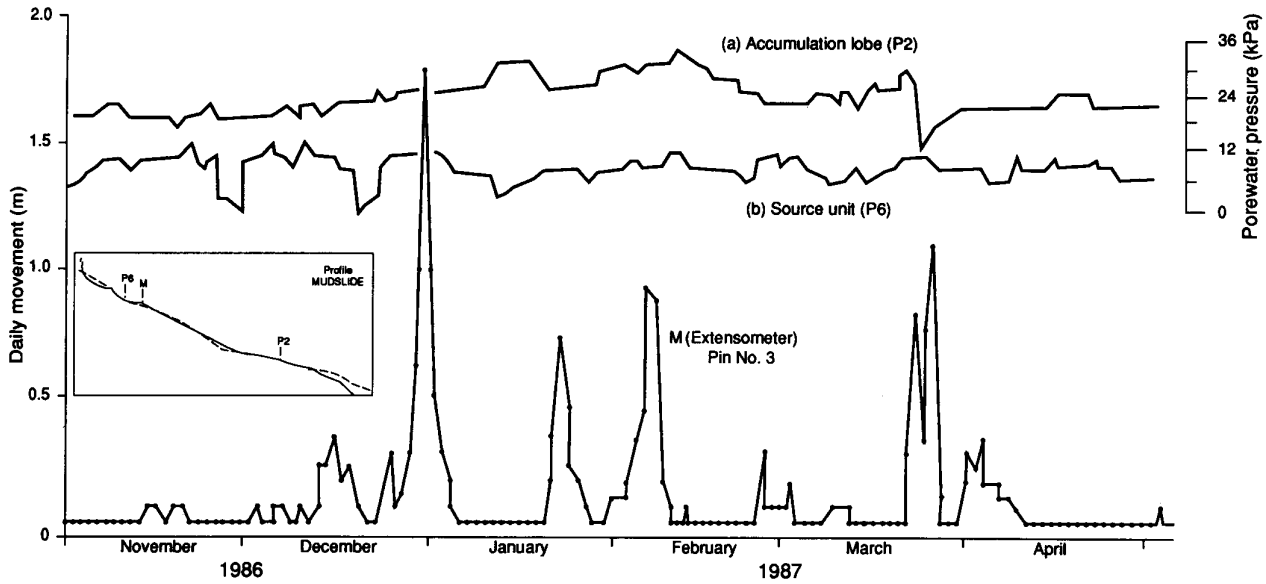



*Figure 10. The poor correlation between pore pressure and movement revealed by continuous monitoring at Worbarrow Bay, Dorset. From Moore and Brunsden (1996).*

Clearly, there is a research frontier here which is of more than local interest. It is noteworthy, however, that the mechanism only came to light when the level of monitoring allowed a real time comparison between the causal and response (movement) data. When we consider that this level of data is only available for one small slide in Worbarrow, the magnitude of the task before us becomes clear.

### 3. Running Sand.

The hilltops of West Dorset and East Devon are capped by Cretaceous deposits. In coastal Dorset most of the Chalk has been removed and the hills have a characteristic steep upper slope formed by the Upper Greensand and Gault. The Upper Greensand consists of c.10 m of Chert overlying fine, occasionally silty, glauconitic sand. This sand is sometime called Foxmould, which indicates its ability to stand in steep slopes and to support cavities.

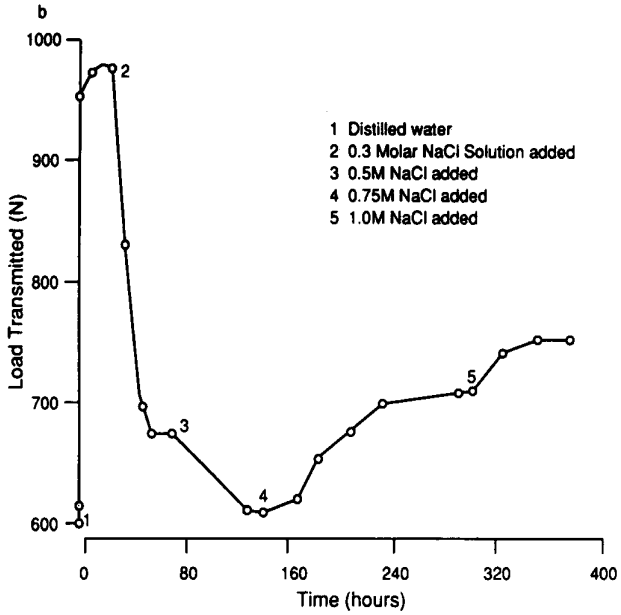



*Figure 11. The changing strength of Weald Clay from Worbarrow Bay due to changes in NaCl concentration in a ring shear test. From Moore and Brunsden (1996).*

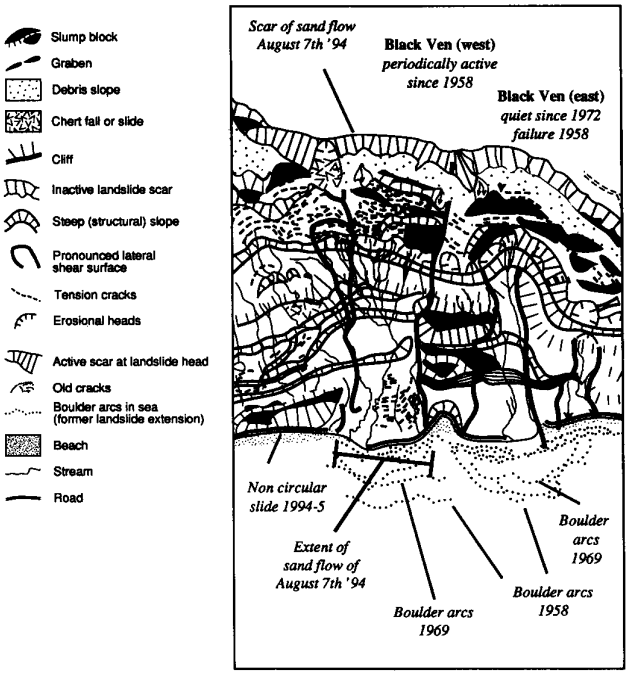



*Figure 12. The flow track of the dry sand flow event of 7th August at Black Ven, Dorset.*

It is a frictional material with a 0' value averaging 33-35°. In the lower layers there is an increasing quantity of clay and significant cohesions can develop (6-23Kn/m). Residual friction angles 0' as low as 12 have been recorded for these materials. The sands form escarpment slopes at 33° and the clay rich materials form footslopes of 10-15° where they are not obscured by debris. Such steep slopes reflect the frictional properties of the clean but slightly cemented nature of the sand.

Curiously, however, the Upper Greensand has a second meaningful local name. This is 'running sand' which is associated with extreme and sudden instability when saturated or affected by high water pressures. In such places it is possible to make the ground 'quake' by sudden movement so that sand squirts out of any tension cracks whilst supporting body weight on any convenient turves. Firm but wet sand can suffer sudden liquefaction and develop a quicksand condition by repetitive movement.

The special properties of the Upper Greensand have been suspected ever since the report of the 1839 Bindon landslide in East Devon by Conybeare and Buckland (Conybeare *et al*., 1940) and others, as the following quotations portray:-

*'Disturbances of the surface arising from the agency of waterpercolating through the strata, and causing dislocation and motion among them, may be produced either by its directly undermining agency, or by moistening the soft interstrata and thus causing them to slide one over the other when previously loosened and rifted'*. (Conybeare *et al*., 1940).

*'Under these circumstances, let us examine what must be the necessary conditions of this bed of loose sand or fox mould; the water percolating through its upper portion would find vent wherever the surface of the ground occupied by it favoured by its configuration the emission of land springs'*. (Conybeare, 1940).

*'thus reducing the lower region of the arenaceous mass into the state of quicksand'*. (Conybeare,1940).

*subsidence takes place into a bed of 'soft quicksand, or mud or a quagmire'*. (Hutchinson. 1840).

Several authors noted that great volumes of liquid sand squirted

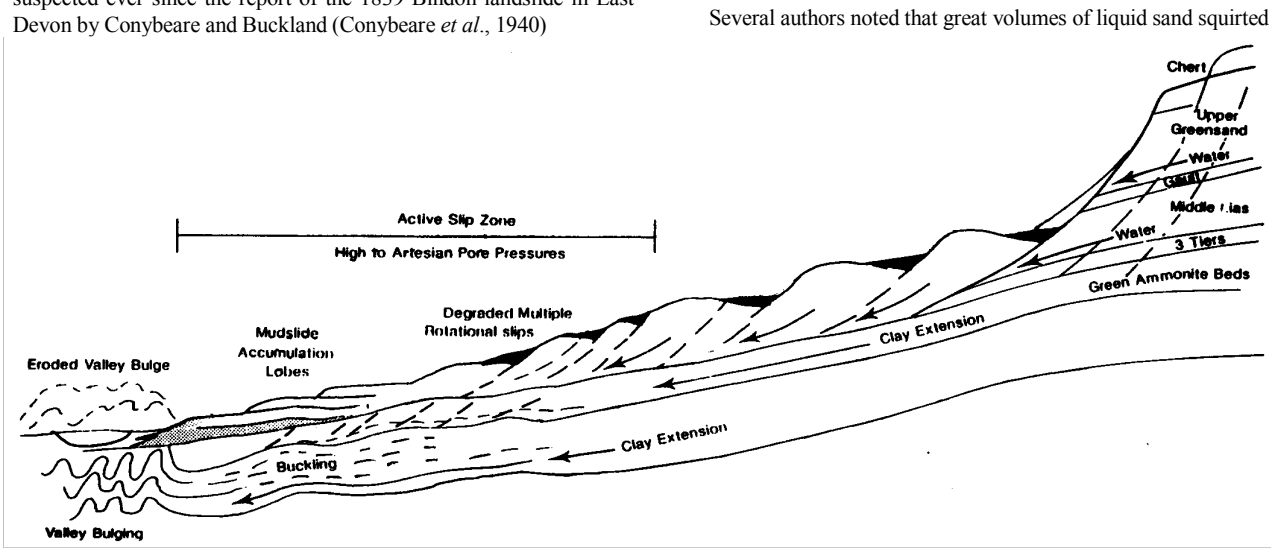



*Figure 13. The morphological features associated with clay extrusion in an underlying, ductile clay layer.*

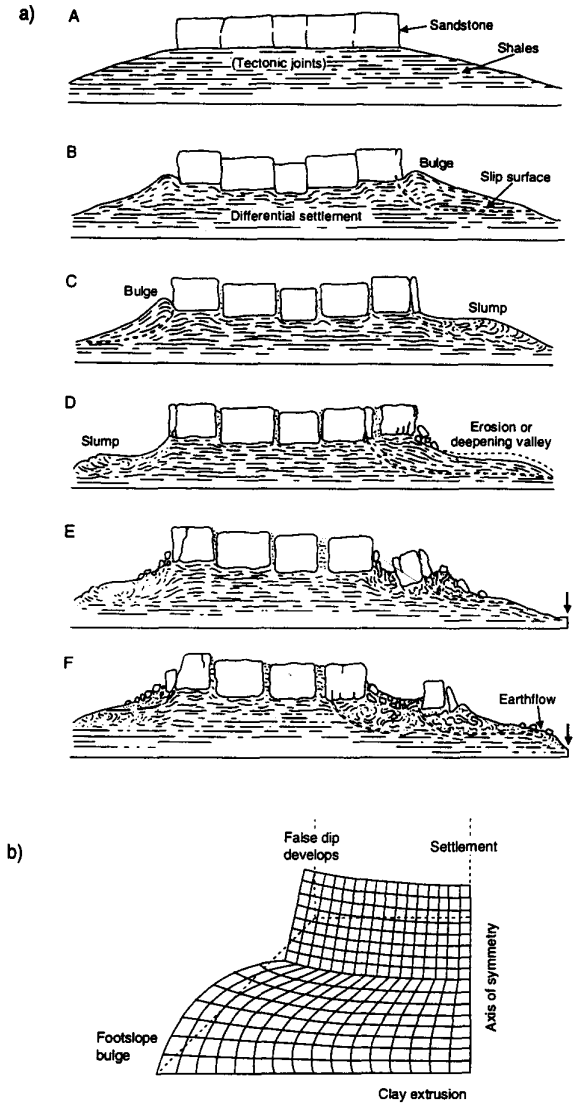



*Figure 14. A description of lateral spreading given by Cancelli and Pelleguini (1987).*

out from the abundant fissures during the subsidence of Goat Island. Although Pitts (1974, 183a-b; Pitts and Brunsden, 1986), who reviewed the modem evidence for cause of failure attributed the movement to failure of the Rhaetic Clay, they nevertheless ascribed the production of the famous subsiding pillars of the chasm to settlement into the sands liquified by the displacement.

In Dorset similar explanations were offered, in part, for the movement of wet sands over the Lower Lias clays at Black Ven, Stonebarrow and Golden Cap by Arber (1941, 1973), and Lang (1928), but the subject was only treated as a minor matter and the implications of the Bindon observations were largely forgotten.

Then on August 7th 1994 a major and frightening event took place at Black Ven when the system suffered a dramatic, large scale, rare sand flow (Figure 12). The previous winter had been one of the wettest years on record with movement throughout the landslide cascade. Rivulets of sand poured over the Belemnite Marl cliff and during January and February 1994 a tension crack some 100 m long opened up across the edge of the Lyme Regis golf club. The detached piece settled c 10 metres down the face. A dry summer followed and so it was a geotechnical surprise in August when a mass of some 5000 m rapidly descended the cliff, loaded the accumulated debris on the Upper Greensand bench and shunted c.60, 000 m forward for 40-50 m until it fell 50 m over the Belemnite Marl cliff.

This mass appears to have fluidised because the material flowed in a few minutes, in a sheet form, to within 20 m of the sea. The flow track was 100-120 m wide, 525 m long, 0.3-1.0 m deep at an average angle of 13°. The streamlined surface, shallow levees and abrupt termination at the front left little doubt that this had been a 'dry' sand flow. The powdery nature of the surface, impossible to walk over without sinking in, suggested that the pore fluids were probably air.

The properties of the Upper Greensand are not very well known. There are standard geotechnical data for the Charmouth Bypass and basic particle size analyses for Stonebarrow but only Pitts (1981), in an unpublished PhD, has attempted to assess the liquefaction potentials. No one has examined the fluidization potential. Pitts carried out simple permeability tests to examine the downward washing of fines, carbonate cements and glauconite and showed how this led to dramatic strength changes. He also developed a crude quicksand tube test to demonstrate that upward flow of water was needed for the sand to liquify and that this could be released by sudden landslide movement. In other words that liquefaction was not the cause of failure but a consequence.

These tests are, however, very limited and unpublished and thus define a very clear and important research frontier.

## *4. Lateral Spreading.*

It was emphasised earlier that the Dorset Coast is a classic area for landsliding because there are numerous locations where a permeable, competent rock overlies a ductile material. The explanation given for frequent slope failure in these locations is that the disposition of the strata controls water movement and allows the build up of high pore pressures at the aquiclude.

Yet if this hypothesis is carefully examined it rarely stands up to rigorous tests. For example, if the water passes easily through the permeable beds but is excluded from the 'impermeable' clays, as it is implicit in the argument, then it will move sideways to emerge at the clay junction as a line of springs and will not be the cause of high pore pressures **within** the clay. In these circumstances it will be the beds above that fail and there is a strong implication that internal erosion will be a powerful cause of movement.

The strange fact, however, is that it is almost impossible to find a section through a slide which shows a failure plane in the cap rock. Always the analyst selects a weak layer, usually clay, often well below the aquiclude and the water system analysed is the clay system.

In many cases this is correct, but two other observations are important. First, several authors (eg. Hutchinson, 1988; Vaughan, 1991) have noticed that in some back analyses of first time slides it is not possible to recover peak shear strength parameters, implying that there may have been some loss of strength before failure. Secondly, that sea cliffs and escarpments formed where cap rocks overlie ductile materials, often exhibit these expansion features and even the types of slope failure are related to the exposed thickness of the weak underlayer.

These features have been described as 'the decompression zone' (Macquare, 1992); 'rebound phenomena' (Peterson, 1958; Nichols, 1980; Hutchinson, 1988); 'mass or translational creep' (Ter-Stepanian, 1965); 'denudational unloading and lateral expansion' (Peterson, 1958; Ringheim, 1964; Peck, 1969; Burland and Hancock, 1977; Jones, 1980) and 'cambering and valley bulging' (Hollingsworth *et al*., 1944; Horswill and Horton, 1976).

The diagnostic forms include the development of depressions well away from the slope edge; some degree of joint opening and fissuring to produce 'gulls', trenches or graben along structural weaknesses in the land immediately above the slope; opening of the cliff edge itself in 'hinge-slips' and topples; a slope bulge in the ductile materials immediately under the cap rock; a sag at the foot of the slope and valley floor bulging. The association of these phenomena with landsliding has been noted by many authors (see Brunsden *et al*., 1996) (Figure 14).

In Dorset, Williams and Kellaway (1994) reworked the mapping

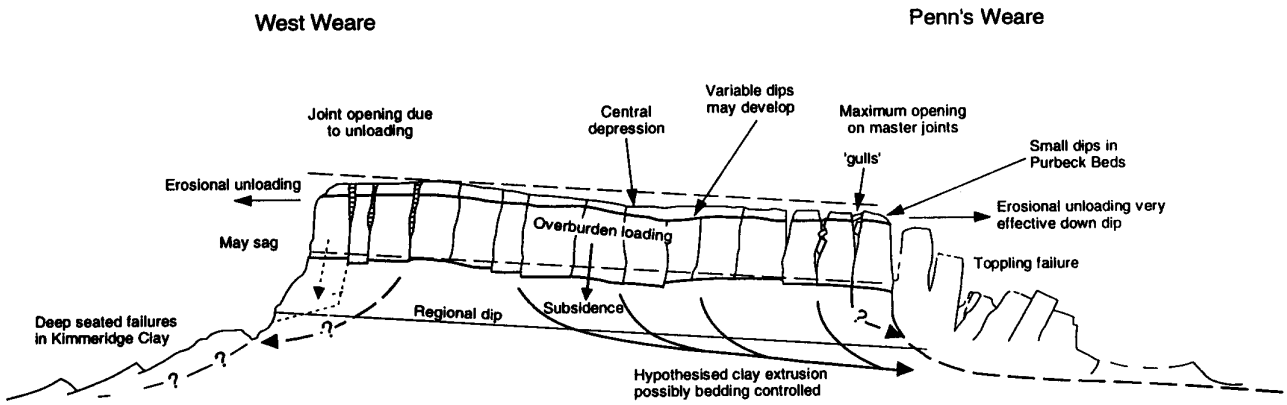



*Figure 15. A tentative model for the origin of lateral spreding features on Portland Bill (Brunsden et al., 1966).*

of Lang (1914) and Welch (Lloyd *et al*., 1940) to show how the slopes of Stonebarrow Hill were cambered with hinge slips, landsliding, slope sagging and valley bulging. Their diagrams clearly indicate that the ductile underlayer had moved toward the valley to undermine the Upper Greensand cap rock and to deform in the valley bottom as a series of tight folds. The importance of this is the idea that shear zones can be developed by the extrusion of clay from under a cap rock which, like flexural shears, can subsequently be used for landsliding (Hutchinson, 1988).

This has recently been demonstrated for the Channel Tunnel by Griffiths *et al*., (1955) and the implication is that many first time landslides do not fail at peak strength because shear zones or deformed weak layers of clay may already have been reduced to a residual strength condition prior to their use by landslides. There are serious implications here for any project requiring the analysis of first time slides in such geological conditions!

In the English literature cambering and valley bulging have been regarded as a 'special' process that does not occur today and should be ascribed to periglacial conditions during the last glacial period (Hutchinson 1988). This is because the deposits are often associated with the occurrence of 'head' and extensive landsliding. Often, however, the evidence is coincidental rather than definitive and there are few dates to actually support the case.

Recent Italian research (Figure 14) does not feel that it is necessary to restrict the cause to periglacial conditions. All that is required is long term deformation of the ductile materials and clay extrusion under the load of the overlying materials. Some topographic relief and a suitable cap rock thickness or load is needed and the process requires sufficient time to develop. In other words it is unlikely to be observed on new sea cliffs.

In Britain any cliffs which have been evolving for sufficient time are likely to be pre-glacial in origin, such as the Ventnor Undercliff, the Isle of Portland and The Landslide Nature Reserve, Axmouth - Lyme Regis. Indeed it may be that the process is a necessary precursor for many slides to occur and may be a determinant of the episodicity of slide occurrence. The important Italian research is summarised in Agnesi *et al*. (1984); Poisel and Eppensteiner (1988); Menotti *et al*. (1990); Conti and Tosatti (1991, 1993, 1994); Canuti (1993). These authors call the mechanism 'Lateral Spreading'.

One description is very important in the Dorset context.

*'The Casido is a tectonically fractured rock slab overlying soft shale. In the beginning the slab behaves as a superficial raft on a compressible medium which slowly deforms sideways. This is followed by a 'remarkable sinking of blocks' in the central part of the slab. The settlement is in the form of differential movement of vertical rock prisms along pre-existing or new joints. Bulging or extrusion phenomena occur in the shales outcropping at the edge of the slab where they are not laterally confined. Deep seated deformations then occur giving slumping and lateral spreading on the cliff edges. Here also the trenches, gulls and joints open and become partly filled with debris from above or contain squeezed up clay from the bottom (Querricchio, 1982). The whole process is considered to be due to a long-term plastic deformation of the clays under the load of the overlying limestones. The open gulls are cliff edge unloading features, the tight joints due to central compression. At the edges vertical rock prisms can immerse in the plastic clays, fail at the base, sag backwards and topple forwards.'* (Cancelli and Pelleguini, 1987).

This is an almost perfect description of the Isle of Portland (Figure 15). There is a central depression to the island. In the quarries in the centre, master joints which open downwards and have upward-swelling clays can be observed. Toward the edges there are many wide open gulls infilled with collapsed debris. At the base of the cliff the Black Nore beds and the Kimmeridge Clays are often bulging, associated with topples which are clearly subsiding into the deforming ductile layer and are the cause of landslides acting episodically over centuries.

Here too there is the added ingredient of the regional dip, which yields a variation of landslide type around the island. It is reasonable to suggest that any clay extrusion would preferentially take place along the south-east dip of 1.5° and that there would be more open gulls to the south-east? The observation in the field is that columnar toppling, major landslide ridge displacement toward the sea, foundering into the clays and clay bulges occur preferentially, but not exclusively, along those portions of coast oriented along the strike and down dip. All these conditions are satisfied at Great Southwall, Church Ope Cove and Shepherd's Dinner.

The hypothesis that the cliffs and landslides of Portland and, by extension those of Purbeck, can be explained by the overburden loading- clay extrusion-lateral spreading model has not been tested by detailed field mapping, laboratory testing, by monitoring or by subsurface exploration. Perhaps we have defined yet another research frontier?

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