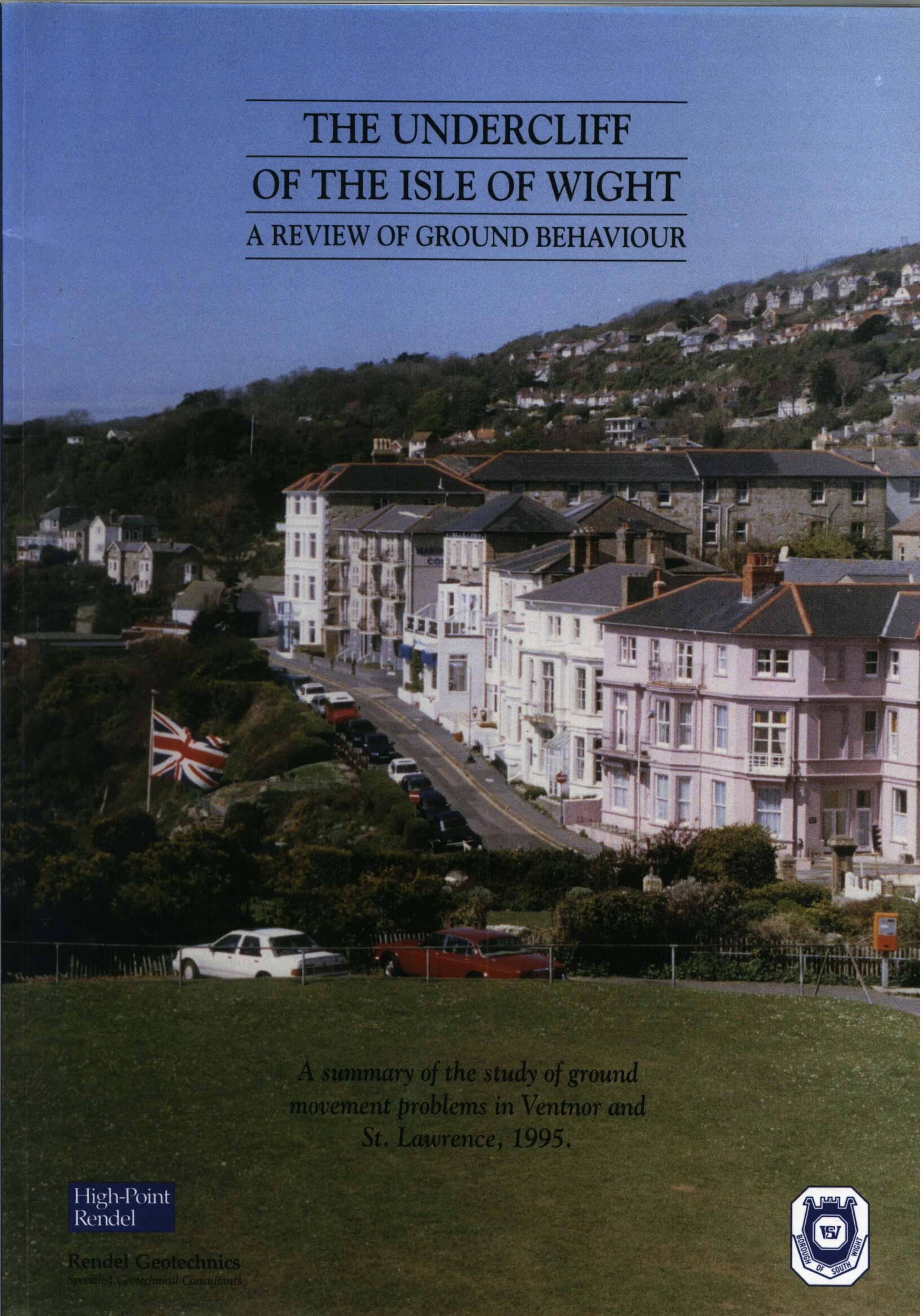

THE UNDERCLIFF OF THE ISLE OF WIGHT

A REVIEW OF GROUND BEHAVIOUR

A summary of the study of ground movement problems in Ventnor and St. Lawrence, 1995.

High-Point Rendel

Rendel Geotechnics
Specialist Geotechnical Consultants

Borough of South Wight

SOUTH WIGHT BOROUGH COUNCIL

THE UNDERCLIFF OF THE ISLE OF WIGHT : A REVIEW OF GROUND BEHAVIOUR

JANUARY 1995

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PHOTO CREDITS

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Plate 11	-	Elaine David Studio, Shanklin
Plate 12	-	Robin McInnes
Plates 16, 17, 18, 19, 21, 22	-	South Wight Borough Council Collection

PREFACE

Following the publication of the Department of the Environment's research into ground movement in Ventnor in 1991, South Wight Borough Council took on board the recommendations of that report and commissioned its consultants Rendel Geotechnics to develop a Landslide Management Strategy for the Ventnor Undercliff. The strategy includes such important aspects as increasing public awareness, the need for additional coast protection, improved drainage, monitoring and further research.

A Ventnor Landslip Management Committee of professionals involved with engineering, building, planning and related matters within the Undercliff was established in order to develop a co-ordinated approach to works and planning in the area. In 1992 South Wight Borough Council commissioned Rendel Geotechnics to undertake a major extension of the Department of the Environment study of Ventnor to include the whole of the Undercliff from Luccombe to the entrance to Niton. Contributions to the cost of this research were received from members of the Ventnor Landslip Management Committee (including the Association of British Insurers, the Isle of Wight County Council, Southern Water Services Ltd., and British Telecom).

This report and the new suite of maps which accompany it provide a wealth of information on the St.Lawrence to Niton Undercliff for the first time. In addition the report describes how the Council has, over the intervening period, taken up many of the recommendations proposed by the Department of the Environment.

Over the last three years the Council, with the assistance of the Isle of Wight County Council and the Ministry of Agriculture, Fisheries and Food, has invested heavily in protecting and strengthening coastal defences along the Ventnor Undercliff, a key factor in relation to ground stability. In addition the installation of monitoring equipment and commissioning of further research has increased our understanding of the nature of physical processes and the impact of human influences within the Undercliff. It is hoped that this new report will form a valuable contribution to the benefit of residents, commercial interests and science.

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CONTENTS

EXECUTIVE SUMMARY

Much of Ventnor and St. Lawrence, Isle of Wight, lies within an ancient landslide complex known as the Undercliff (Frontispiece and Plate 2). Historical records of landslide events have been collected which indicate that, over the last 200 years, the area has been subjected to ground movements which have caused damage to property and services in some developed areas.

Detailed assessments of ground movement problems in the Ventnor Undercliff have been taking place since 1988 when the Department of the Environment (DoE) commissioned a study at Ventnor, as part of their planning research programme, to incorporate land instability matters within the planning system. The findings of the Ventnor Study were published in 1991 and since then the local authority, South Wight Borough Council, has commissioned an extension study, widening the coverage of the earlier work to include St. Lawrence and the Undercliff towards Niton. Both studies have involved:

- **determining the nature and extent of the landslide problems;**
- **understanding the past behaviour of separate parts of the Undercliff;**
- **formulating a range of management strategies to reduce the impact of future movement.**

The programme of work has comprised a thorough review of available records, reports and documents followed by a programme of detailed field investigation involving geomorphological and geological mapping, assessment of ground movement rates, a survey of damage caused by ground movement, and a review of local building practice.

Detailed knowledge of the size and frequency of ground movement events over the last 200 years, and an understanding of the geomorphology of the Undercliff has enabled the production of a 1:2,500 scale map of Ground Behaviour. This summarises the nature and extent of the different landslide processes that occur in the area and their impact on the community. The studies have shown that the landslides are developed in Cretaceous rocks of the Upper and Lower Greensand upon weak clay-rich layers within the Gault Clay and Sandrock strata respectively.

It is important to note that whilst some areas of the Undercliff have had a reputation for landslide movement, much of the developed areas at Ventnor and St. Lawrence have remained largely unaffected by major events. Thus, in many areas buildings have survived for long periods, such as Bonchurch Old Church which is believed to be over 1000 years old. In other locations, property damage may not necessarily reflect serious landslide problems as many of the older properties were built with foundations and building styles quite unsuited to accommodating ground movement. Other properties were not well built or have been poorly maintained over the years. As a consequence, the landslide problems have appeared to be more serious and less manageable than they should.

This report outlines a range of approaches for managing the landslide problems which provide a basis for planning and development decisions in the Undercliff, reducing the hazard and minimising the impact of ground movement in developed areas. A summary Planning Guidance map from Luccombe to Niton is presented which takes account of the ground behaviour constraints for future development proposals and provides pragmatic advice on the level of stability information that may be required for future development.

The report incorporates the findings of the St. Lawrence extension study and provides an update on the management initiatives implemented by South Wight Borough Council since 1991. The format of the report follows that of the summary report 'Ground Movement in Ventnor, Isle of Wight', published by Geomorphological Services Limited in 1991, which is intended for the educated lay person with supplementary detail contained within information boxes.

The report is supported by a suite of detailed 1:2500 scale maps entitled Geomorphology, Ground Behaviour and Planning Guidance; these maps should be inspected as part of the procedures for assessing the suitability of particular sites for development. A total of 5 sheets have now been completed for the Undercliff which can be viewed on request from South Wight Borough Council. The coverage of the sheets is as follows:

Sheet 1	-	Ventnor
Sheet 2	-	Bonchurch
Sheet 3	-	The Landslip
Sheet 4	-	St. Lawrence
Sheet 5	-	Old Park

Although summary Ground Behaviour and Planning Guidance maps are presented in this report these provide only general guidance on stability conditions along the Undercliff and decision makers will need to refer to the more detailed 1:2500 scale maps.

There is no reason why there should not be confidence in Ventnor and St. Lawrence from a building insurance or development point of view. This is true so long as sensible use is made of the technical information and recommendations presented in this report and accompanying maps, and that the landslide management strategy continues to be practised and developed. Of course, unstable areas must be avoided where possible. However, more stable areas may be successfully developed, so long as necessary stabilisation, protection and monitoring measures are adopted, and the developer is willing to accept, in some locations, a higher level of risk than could be expected in other circumstances.

CHAPTER 1
THE SCALE OF THE PROBLEM

The History of Ground Movement

Ground movement has been recognised as a localised problem in the Undercliff for nearly 200 years with notable consequences for the communities at Ventnor, St. Lawrence and nearby Luccombe. In his evidence to the Royal Commission on Coast Erosion in 1906, Mr Aubrey Strahan of the Geological Survey provided a clear description of the situation in Ventnor at the time[1].

> "The movement appears to be continuing ... very slowly. I do not know that in the observation of any one living man these large masses of rock can be seen to have moved, but it is the experience of the surveyor and other officials in Ventnor that flights of steps which are taken straight up and down the cliff have occasionally to be lengthened. The ground by moving downwards leaves gaps in these flights of steps, and they have to put in occasionally a few more steps to complete the staircase."

This study traces the history of past ground movement events in the Undercliff and brings observations up to the present day (Figure 1). Although archaeological finds suggest that ground movements occurred during prehistoric times (see **Box A**), the earliest recorded event was provided by Worsley[2] in 1781. He reported that; "huge fragments of rock and earth frequently fall from the cliffs" between Binnel to Steephill.

Early evidence of ground movement in Ventnor is provided by Webster in 1816[3]. He noted that in the west of Ventnor Bay (Plate 3) a large amount of clay had "slid down, and ... had occasioned the falling of a part of the sandstone stratum above". Around the same time two major landslides occurred to the east of Bonchurch, in the area now known as The Landslip. A second and larger landslide occurred in the same area in December 1818, possibly affecting as much as 20ha[4,5]. In 1840 Rickman[6], referring to the Undercliff near Mirables, reported "subsidences of the cliff have occurred so repeatedly ... they form terraces ... and have succeeded each other over long intervals of time".

Box A **Archaeological Evidence of Ground Movements**

A number of archaeological finds in and around Ventnor provide evidence for a long history of ground movement in the area:

- *along Belgrave Road a number of crushed skeletons (dating from c.300 AD) were found buried by fallen rocks[19];*
- *in Bonchurch a man's skeleton was found beneath a large rock[20];*
- *near the former Ventnor railway station human remains were discovered, in 1910, buried beneath debris[21].*

During the early half of this century, a number of landslide events were reported to have occurred between St. Lawrence and Niton. These include rockfalls from the steep cliffs behind St. Lawrence, subsidence of the Undercliff Road and coastal cliff falls. Of particular note was the dramatic collapse of the Undercliff Road west of St. Lawrence in January 1926[3,7] which occurred overnight and was estimated to involve '100,000 tons of earth' (Plate 5). Between 1928 and 1934 the former railway line to St. Lawrence was frequently closed due to rockfalls following heavy rain[8,9] (Plate 6).

Perhaps the most dramatic period of movement in recent years occurred during the winter of 1960-61. Cliff falls, collapsed walls and settlement were reported throughout the Undercliff in November and December 1960, following the heaviest autumn rainfall since records began in 1839. In Ventnor, cracks appeared along Bath Road, and damage was caused to a number of nearby properties, which were temporarily evacuated by the Council with help from the Air Ministry[10]. In January and February 1961 movement was reported along Newport Road, Steephill Down Road, Ocean View Road, Gills Cliff Road and Belgrave Road[11]. Serious settlement occurred near the junction of Gill's Cliff Road and Newport Road, where many houses were damaged[12]. Along The Esplanade, the Continental and Montrose hotels were damaged and declared unsafe[11].

Growing public awareness of the problems has been matched by an increase in the number of reported incidents of ground movement. Within the developed areas the most notable sites have been Steephill Down Road, Newport Road and the Havensbush playground (Plate 4) where slow settlement seems to have been an almost continuous problem. Besides resulting in road repairs almost every year, a number of properties, including a sub-Post Office, have been demolished. In January 1994 localised

Plate 2. The Undercliff at Steephill.

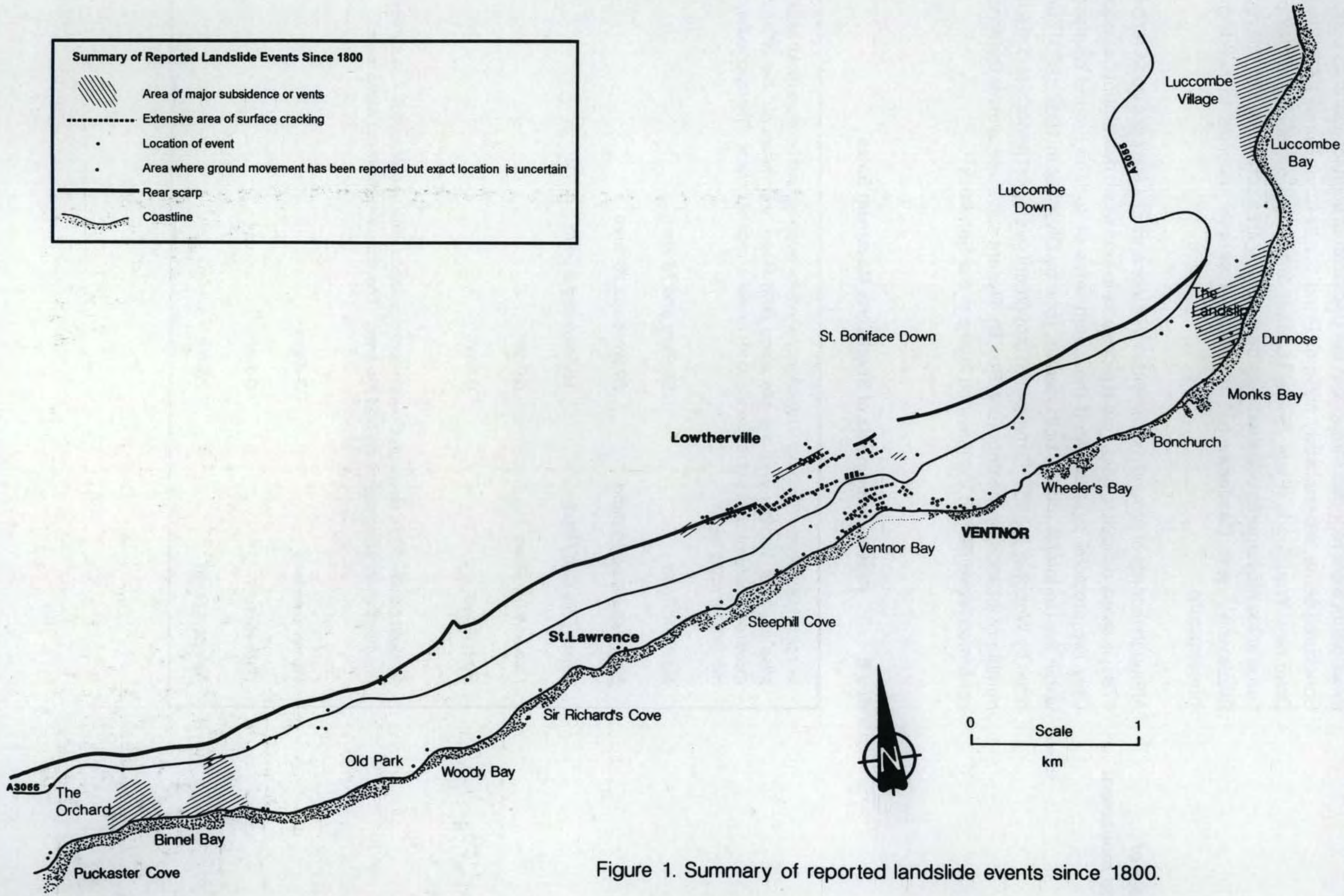

Figure 1. Summary of reported landslide events since 1800.

movements were reported throughout the Undercliff at such locations as Luccombe, Bonchurch Shute, Wheelers Bay, Newport Road, Castle Cove (Plates 2 & 8), Undercliff Drive near Woodlands (Plate 7) and Mirables following a prolonged rainfall period. Large scale movements occurred outside the study area considered by this report at Blackgang[13] and Castlehaven[14] resulting in serious damage to buildings and infrastructure.

The rate of ground movement

Although records of ground movement in Ventnor and St. Lawrence go as far back as 1781, it is very difficult to gain a clear picture as to how much movement has occurred. Only two previous studies report measured rates of surface ground displacement within the Undercliff, though both studies, (one by Chandler in 1982-1983[15] and the other by Woodruff in 1989[16]) measured movement over short periods and at a limited number of locations in Ventnor (see **Box B**). Recent sub-surface investigations have confirmed movement in the clay-rich layers in the Sandrock[17].

Box B Past Measurements of Short Term Movement Rates

In 1982-1983 Martin Chandler[15] monitored short-term movement across cracks at seven sites in Upper Ventnor and one site along Bath Road. He measured the differential movement between pairs of reference studs on either side of a crack. The reported annual movement rates were:

Newport Road	*39.0mm and 19.7mm*
Havensbush playground	*29.9mm and 26.9mm*
Lower Gills Cliff Road	*16.5mm and 8.0mm*
Ocean View Road	*6.0mm*
Bath Road	*0.0mm*

In 1988 South Wight Borough Council commissioned Malcolm Woodruff[16] to survey the positions of levelling points around the town. The annual movement rates were:

Winter Gardens	*3-4mm*
Bath Road	*0-2mm*
Newport Road	*28mm*

It is unlikely that these short-term movement rates are maintained over longer periods of time. Fortunately, two different lines of evidence provide information over a longer time scale. The first approach allows bench mark heights, shown on the current Ordnance Survey maps of the Ventnor and St. Lawrence area to be compared with the heights of those same bench marks on earlier editions of the maps in 1862, 1896, 1907, 1939, 1971 and 1977. The second approach involves the use of the latest analytical photogrammetric techniques[18] (see **Box C**) to compare the positions of a point (e.g. the corner of a building) on aerial photographs of Ventnor taken in 1988 with the positions of the same point on photography taken in 1949 and 1968. The surface movement rates calculated by both of these methods are shown in Table 1 and Figure 2, although it should be noted that analytical photogrammetry was not used for the St. Lawrence extension study. Three important points stand out when these results are compared with those obtained from the short-term measurements of Chandler and Woodruff:

- The majority (91%) of locations within the Undercliff have probably been moving at less than 5mm per year or have not moved at all (Table 1).

- At many sites the short-term movement rates appear to be representative of long-term trends. The largest overall displacement is a drop in a bench mark height of 0.84m over 43 years at Gills Cliff Road (between 1939 and 1982) which gives an estimated annual vertical movement rate of 19mm per year. This figure is comparable with the rates of 8.0mm per year and 16.5mm per year measured along Gills Cliff Road by Chandler in 1982-1983[15].

Plate 3. Ventnor Bay.

- At some sites, such as at the junction of Newport Road and Steephill Down Road, short-term movement rates of 53mm to 125mm per year measured by Chandler (1982-1983) are significantly higher than the longer term trend (at the same location) which has been estimated at 28mm per year over the last 22 years.

South Wight Borough Council, as part of their landslide management strategy (see Chapter 5) have established a network of automatic ground movement monitoring stations in parts of Ventnor which has enabled a more reliable picture of the rates of movement to be established. Since March 1992 the gauges have detected ground movement at several sites the results of which are summarised in **Box D**. The magnitude of these movements, when adjusted to annual rates, are generally within the annual rates previously reported at some of these sites.

It is clear that measured or calculated annual movement rates can be misleading, not least because they imply uniform displacement. This, undoubtedly, is not the case in reality. Such overall rates probably hide periods of relative stability, characterised by no, or extremely slow, movement, separated by short periods of accelerated movement, as occurred in the winters of 1960-1961 and 1993-1994. The historical record also indicates that large dramatic movements in excess of 10m at a time do occur in parts of the Undercliff but fortunately and, perhaps not surprisingly, these areas have remained largely undeveloped (eg. The Landslip, Mirables).

Table 1 Summary of Long Term Movement Rates, mm Per Year

	NO. OF POINTS	%
No movement	100	45.6
Points with no significant movement (see Box C)	51	23.2
0.0 - 5.0mm	49	22.4
5.01 - 10.0mm	8	3.7
10.1 - 50.0mm	8	3.7
50.1 - 100.0mm or more	3	1.4
	219	100.0

This summary table indicates that 91% of the data set show movement rates of 5mm or less or no movement at all.

Sources: OS bench marks; Analytical Photogrammetry

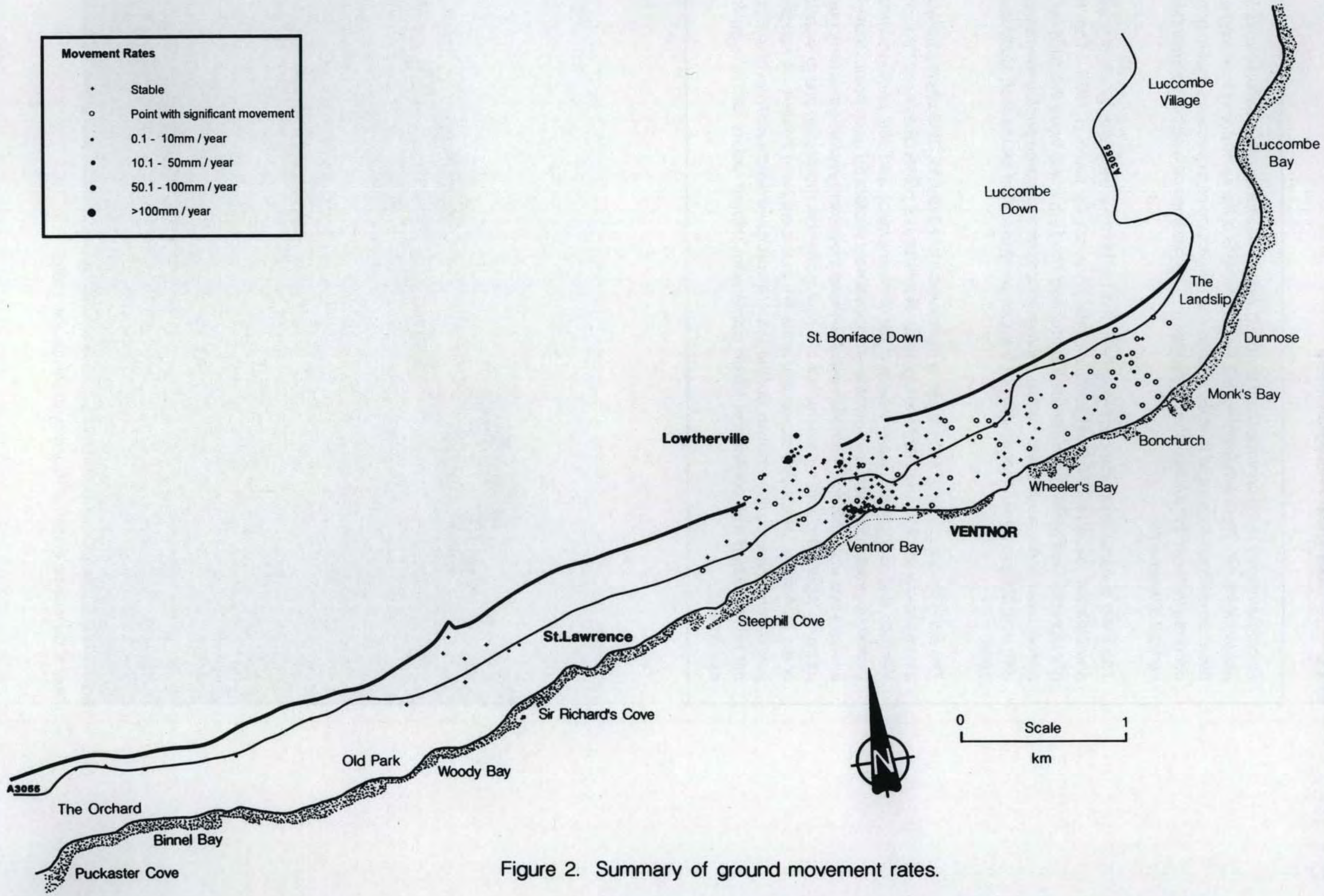

Figure 2. Summary of ground movement rates.

Box C Analytical Photogrammetry

Photogrammetry is a technique used to obtain 3-dimensional spatial measurements from photographs[18,22]. The method compares the 3D positions of the same points in photographs taken on different dates and thereby detects the magnitude of movements that may have occurred between the dates of the photography. This provides data on both horizontal and vertical movements.

The most suitable historical photographs found for Ventnor were sets of oblique aerial photographs taken in 1949 and vertical aerial photography taken in 1968. The 1949 photography was restricted to central Ventnor and The Esplanade while the 1968 survey covers most of the study area. These photographs were compared photogrammetrically with new oblique aerial photographs of Ventnor commissioned for the DoE study in July 1988.

The analysis consisted of two stages: a comparison of 1949 and 1988 photography and a comparison of 1969 and 1988 photography. A total of 129 points distributed throughout Ventnor and Bonchurch were selected for measurement and the photogrammetric technique produced point co-ordinates and movement vectors for each point. Statistical analysis was undertaken to establish whether these movement vectors could be accepted as being 'significant' and representative of a real movement rather than due to limitations of the technique. Recorded movement rates are incorporated in Table 1. A number of points were shown to have moved, but the actual amount and direction of movement could not be calculated with confidence. Such points were termed "points with no significant movement".

Plate 4. Developing graben at Havensbush playground, 1988.

The Impact of Ground Movement

The occurrence of ground movement within the area has resulted in a range of problems for the Undercliff communities (see **Box E**). Judging from the historical review it appears that these problems may have increased over the last century or so. This is undoubtedly a reflection of the fact that urban development itself has increased the vulnerability of the community to ground movement damage by concentrating people, resources, assets and services in a limited area. A principle aim of the Landslide Management Strategy (see Chapter 5) is to counter this.

For the majority of the urban area in Ventnor, Bonchurch and St. Lawrence ground movement rates are very low (Table 1). Towards the other end of the scale, parts of the Esplanade in Ventnor (Plate 3) have risen 780mm between 1949 and 1988 and parts of Undercliff Drive, west of St. Lawrence, dropped nearly 3m in 1926 (Plate 5). Such displacements have caused a range of damage to property, services and structures (Plates 9 & 10), as was revealed by the systematic survey of building exteriors, retaining walls and roads throughout Ventnor and St. Lawrence. The survey classified the observed damage caused by ground movement (not other factors) on a simple five-fold scale from negligible to severe based on increased levels of damage and, by inference, costs of repair (see **Box F**).

The results of the damage survey are presented in Table 2. The data indicates that much of the Undercliff area (79%) is unaffected or only affected by slight to negligible damage due to ground movement. Around 6% of the study area was affected by moderate damage while the remaining 15% was affected by serious or severe damage

Table 2 Area and Frequency of Damage due to Ground Movement (see Box F for Intensity Definitions)

	NO. OF DAMAGE RECORDS	*AREA (ha)*	*AREA (%)*
Negligible or no damage	*115*	*262*	*58.9*
Slight	*726*	*90*	*20.2*
Moderate	*1321*	*26*	*5.8*
Serious	*438*	*24*	*5.4*
Severe	*197*	*43*	*9.7*
	2797	*445*	*100*

due to ground movement. In respect of the latter it is possible to recognise a number of localised areas within the Undercliff where significant ground movement rates have in the past resulted in serious or severe damage. These include:

- Luccombe
- The Landslip
- Monks Bay
- Bonchurch Shute (part)
- Wheelers Bay
- Upper Ventnor (part)
- Bath Road/Esplanade (part)
- Castle Cove
- Castle Court (part)
- Undercliff Drive, near Mirables
- the Binnel Bay and Mirables area

It is emphasised that serious movement and damage is generally concentrated in a few localised places, most of the intervening areas have shown negligible or no damage due to ground movement. Thus in many areas buildings have survived for long periods without evidence of damage, (eg. Bonchurch Old Church, which is believed to be over 1,000 years old). In those areas that have suffered damage it is also the case that the foundations and building styles are often unsuited to accommodating ground movement.

Box D South Wight Borough Council's Automatic Surface Monitoring Network

What the monitoring has shown:

Since March 1992 valuable information on the rate of ground movements and the influence of climatic and groundwater fluctuations have been obtained. Since March 1992 the annual movement recorded is as follows:

- *Newport Road - 44mm per year*
- *Bath Road - 10mm per year*
- *Winter Gardens - 3mm per year*
- *Castle Court access road - 54mm per year*

It is clear from these observations that surface movement varies from place to place. Movement rates also vary in time, as shown in the plot below, which summarises the monthly movement recorded at Newport Road. Periods of accelerated movement generally coincide with wet winter periods, extreme rainfall events and associated high groundwater levels.

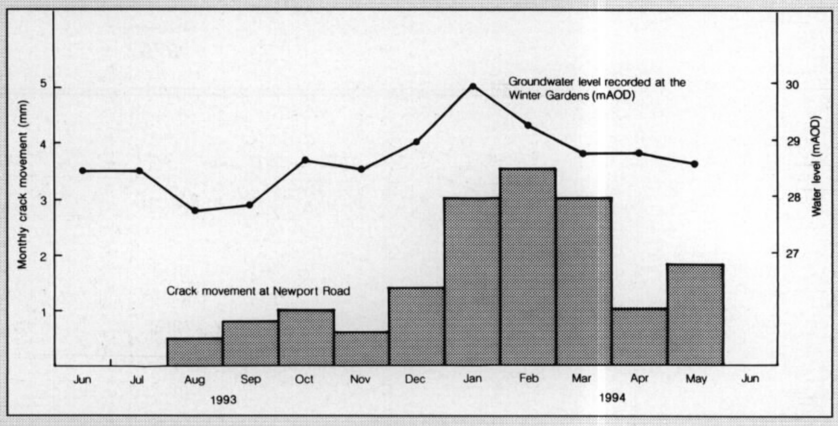

Plate 5. Undercliff Drive near Mirables, 1926.

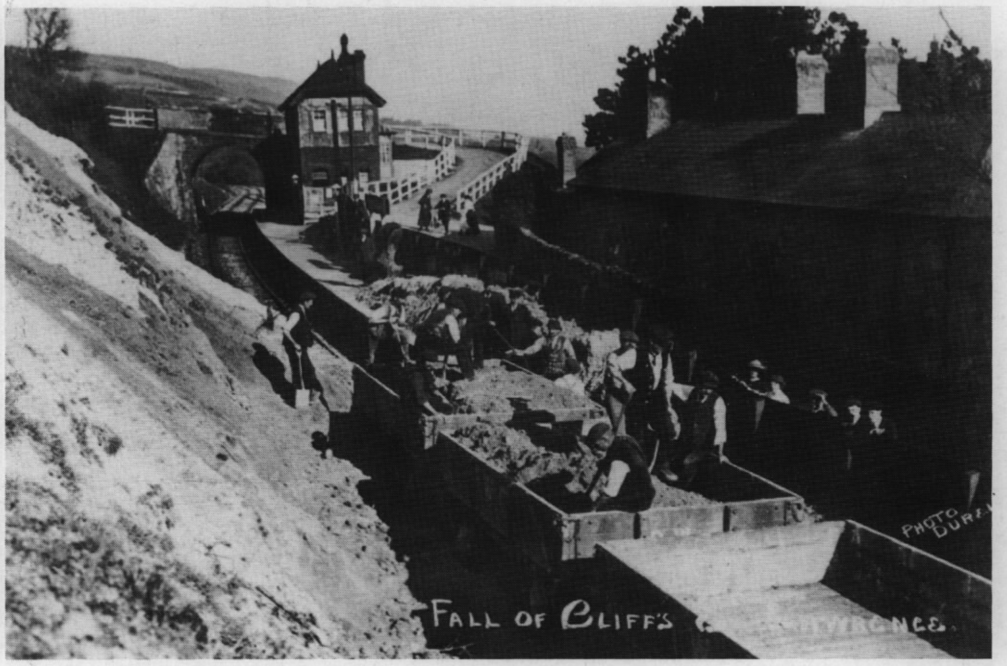

Plate 6. Cliff fall at St. Lawrence railway station, 1912.

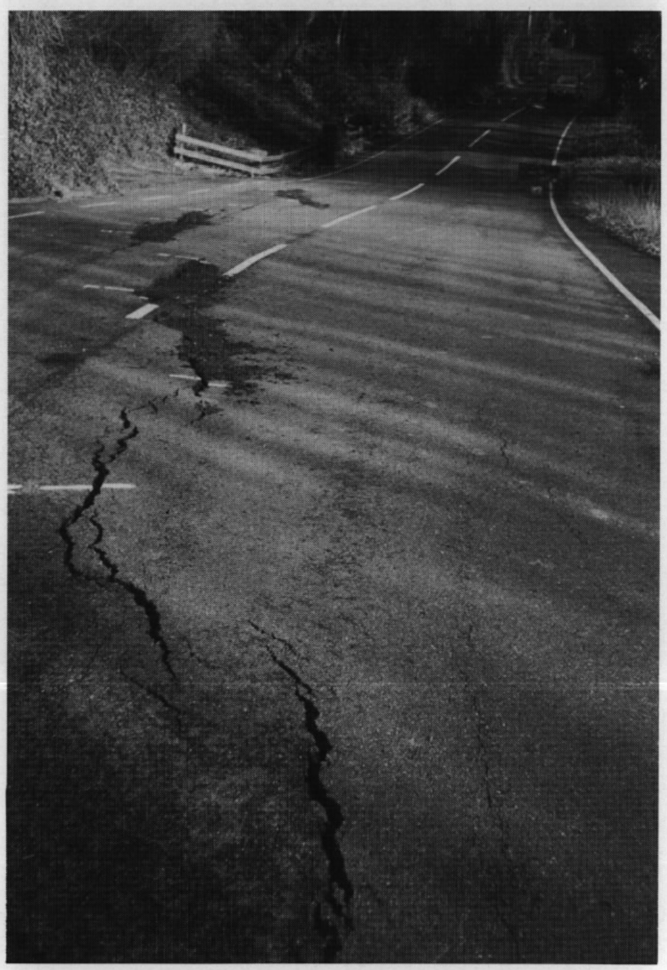
Plate 7. Undercliff Drive, St. Lawrence, 1994.

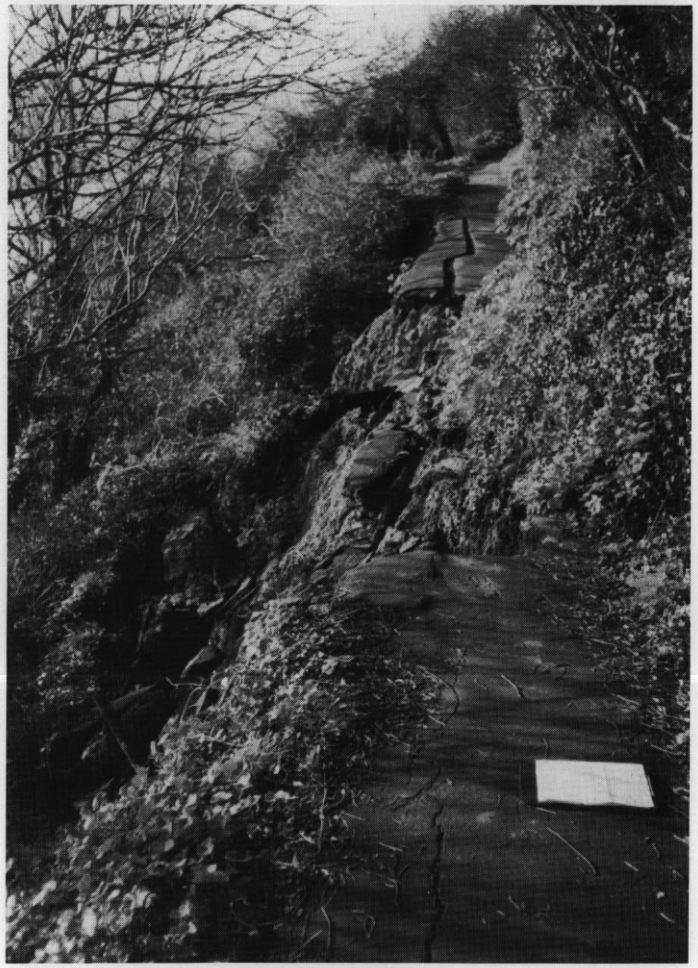
Plate 8. Castle Cove near Steephill, 1994.

Box E **Financial Costs of Ground Movement**

Little information on the financial costs of ground movement within Ventnor or St. Lawrence is publicly available. Over the last 50 years the known losses incurred as a consequence of ground movement have included:

- *demolition of unsafe properties along Newport Road, Steephill Down Road, and other sites;*
- *the need for construction and maintenance of coastal protection schemes;*
- *road maintenance costs and disruption to traffic and services, especially along Undercliff Drive;*
- *compensation for damages and losses incurred in 1960-1961 and 1993-1994;*
- *insurance claims.*

Considering both the historical record and the patterns of property damage, the ground movement problems within the Undercliff can be sub-divided into three broad groups:

- areas of very slow, intermittent ground movement where property, services and structures have remained largely unaffected by instability problems;

- areas of slow but significant ground movement which has caused moderate and occasionally serious damage to property, services and structures;

- areas of recurrent severe and often dramatic ground movement which can lead to problems for property, services and structures. These sites are situated almost exclusively within the largely undeveloped Undercliff between St. Lawrence and Niton and between Bonchurch and Luccombe.

The sub-division highlights the fact that the Undercliff is not a simple landslide, but one that responds differently, for example, to periods of heavy rainfall along its entire length. Recognition of the variation in the scale and intensity of potential problems along the Undercliff is central to the successful development of landslide management strategies that are flexible enough to address these major differences rather than adopting a blanket approach.

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Plate 9. Structural damage to string course, arch and keystone.

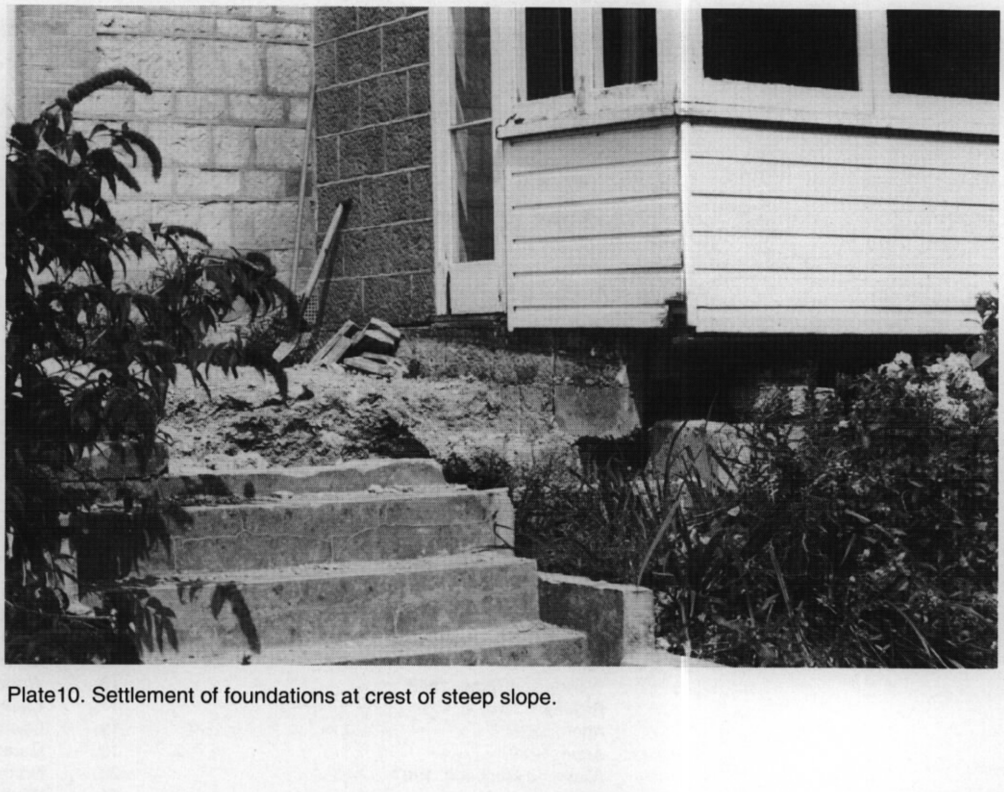


Plate10. Settlement of foundations at crest of steep slope.

Plate 11. Wheelers Bay to Bonchurch cliffs and seawall.

Box F **Building Damage Survey**

A survey of damage to the outside of buildings, retaining walls and roads was undertaken in 1989 at Ventnor and 1993 at St. Lawrence. A five-fold sub-division of damage intensity was used.

Negligible *- hairline cracks to roads, pavements and structures with no appreciable lipping or separation.*

Slight *- occasional cracks. Distortion, separation or relative settlement apparent. Small fragments of debris may occasionally fall onto roads and structures causing only light damage. Repair not urgent.*

Moderate *- widespread cracks. Settlement may cause slight tilt to walls and fractures to structural members and service pipes.*

Serious *- extensive cracking. Settlement may cause open cracks and considerable distortion to structures. Walls out of plumb and the road surface may be affected by subsidence. Parts of roads and structures may be covered with landslide debris from above, repairs urgent to safeguard the future use of roads and structures.*

Severe *- extensive cracking. Settlement may cause rotation or slewing of ground. Gross distortion to roads and structures. Repairs will require partial or complete rebuilding and may not be feasible. Severe movements leading to the abandonment of the site or area.*

CHAPTER 2
THE EVOLUTION OF THE UNDERCLIFF

The Undercliff Landslides

The town of Ventnor and the adjoining area were developed during the early 1800's on an ancient landslide system known as the Undercliff. Ground movement problems within the Undercliff may be related to a range of factors such as slope instability, subsidence, heave or ground compression (see **Box G**). Scientific studies[1,2] suggest that the Undercliff was formed as a result of two main phases of landsliding which took place after the last Ice Age around 8,000-4,500 years ago and 2,500-1,800 years ago, following major changes in climate and sea level and consequent effects on marine erosion along the Island's southern coast.

The landslides within the Undercliff are developed in Lower and Upper Cretaceous rocks (Figure 3). These consist of over 40m of Gault Clay (known locally as 'Blue Slipper'), underlain by sandstones (Lower Greensand) and overlain by massive cherty sandstones (Upper Greensand) and Chalk. Of particular importance is the presence of thin clay layers within the Sandrock (Lower Greensand) which together with the Gault Clay have a very important influence on the stability of the area.

Geomorphological maps of the Ventnor and St. Lawrence areas have been produced at 1:2,500 scale in order to define the surface form of the ancient landslide complex. A much simplified version of the maps is presented in Figure 4, for part of the study area at Ventnor, with schematic cross-sections through different parts of the Undercliff presented in Figure 5. These highlight the relationship between three main geomorphological units: the **Chalk Downs**, **Upper Greensand bench** and the **landslide features**. Although it is not possible to predict the actual mechanics of the original failures from surface evidence alone, the spatial pattern of surface features such as broad terraces, elongate ridges, back-tilted blocks, low-lying depressions and steep scarp slopes give vital clues about the nature of landsliding.

The **Chalk downs**, as the name suggests, have been developed in Chalk rock. The upper sections of the south-facing slopes are unaffected by deep landsliding, although shallow slides in weathered chalk, soil erosion and soil creep may occur occasionally.

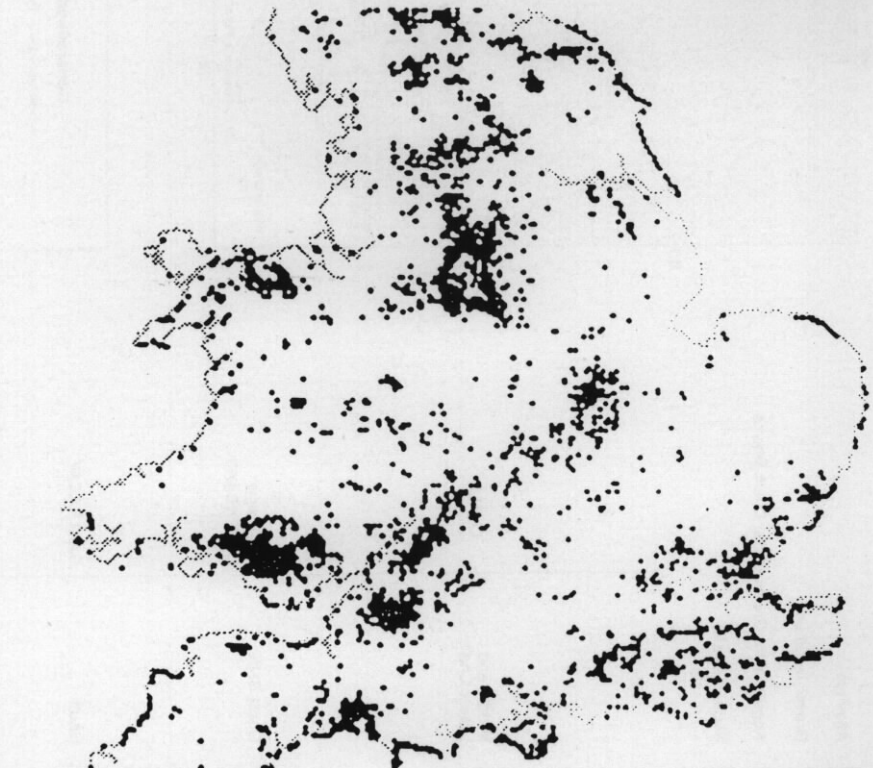
The **Upper Greensand bench** lies immediately below the Chalk downs. This is a narrow (60-180m wide) gently seaward-sloping bench. It is not a continuous feature, being absent from the central part of the Ventnor area and largely absent in St. Lawrence. Where present, the bench varies in elevation along its length, indicating that it is partly displaced by subsidence. Over a long period of time the movement of the landslide features downslope has led to the removal of lateral support for the bench. This has resulted in the formation of open joints ('vents') and subsidence (increasing seaward) of the intervening blocks.

The main Undercliff landslide complex lies immediately below these two geomorphological units. From surface evidence and borehole investigations in the Undercliff[2,3], a range of separate landslide features (see **Box H**) can be distinguished.

Box G **What is a Landslide?**

All slopes are under stress due to the force of gravity. Should the forces acting on a slope exceed the resisting strength of the materials that form the slope, the slope will fail and a landslide occurs. A slide involves the displacement of a body of relatively coherent material, the underside and margins of which are marked by rupture surfaces or zones known as shear surfaces. Thus, blocks of material move en masse over a shear surface, although displacement inevitably leads to internal stresses which results in the break-up of the moving mass.

In general the resisting strength of material decreases as the clay content rises. Clay slopes, therefore, are particularly prone to landsliding. Slides also occur frequently on slopes developed in a combination of impermeable fissured clays overlain by massive, well jointed caprocks of limestone or sandstone[5]. Throughout Great Britain there are known to be about 8,800 recorded landslides (see map extract of Southern Britain below) some of which present a similar problem to those faced in the Undercliff where development has encountered unstable land. Classic examples of landslides formed in these settings include the massive coastal slides at Folkestone Warren and along the Devon coast. Similar conditions occur along the south coast of the Isle of Wight, where the Gault Clay is overlain by massive cherty sandstones (Upper Greensand) and Chalk. The presence of the Gault Clay and thin clay layers in the underlying Sandrock of the Lower Greensand, have been largely responsible for controlling the nature and scale of landsliding within the Undercliff.



Distribution of recorded landslides in Southern Britain, as identified by the National Review of Landsliding[6].

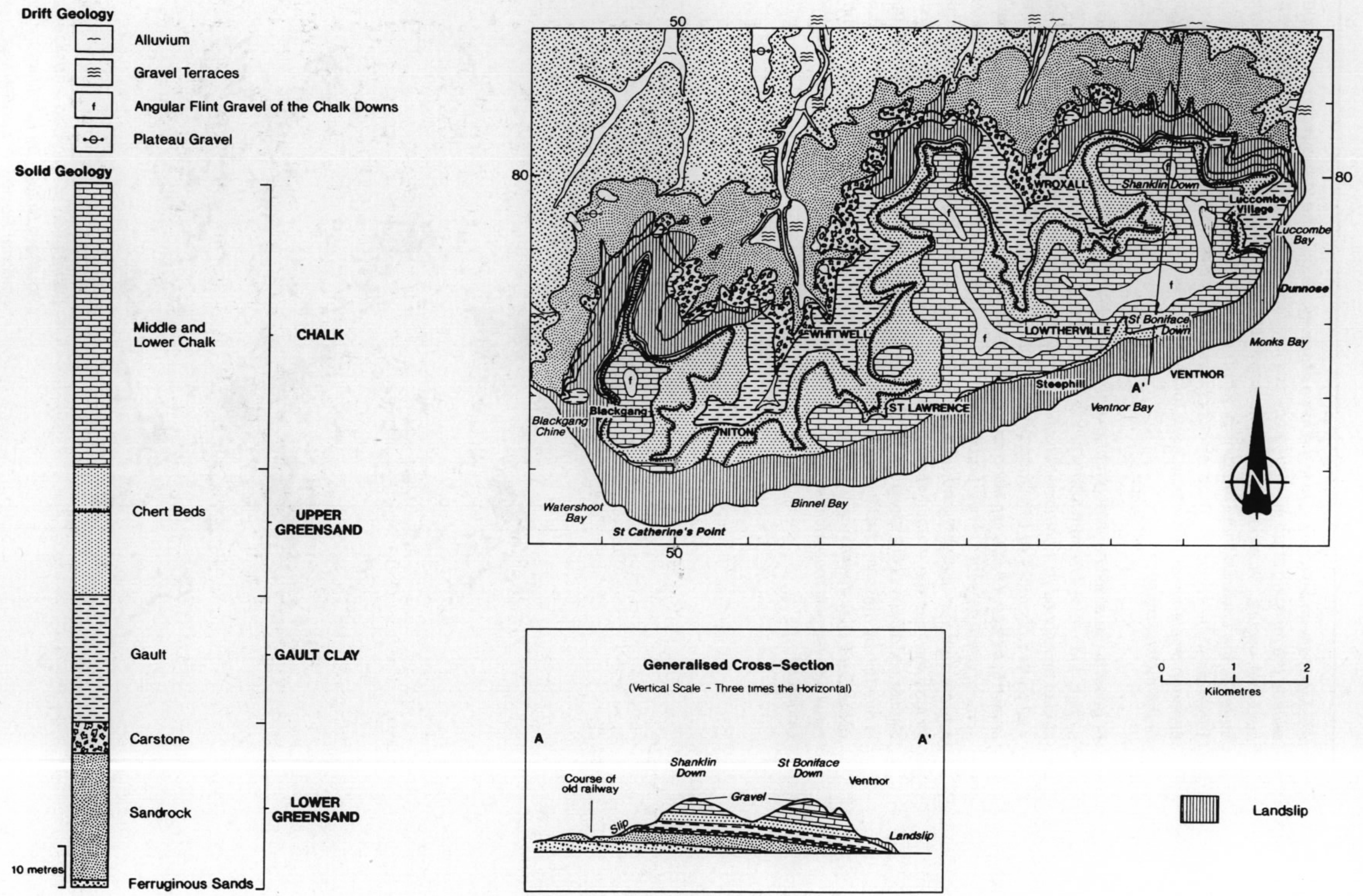


Figure 3. The geology of the southern Isle of Wight.

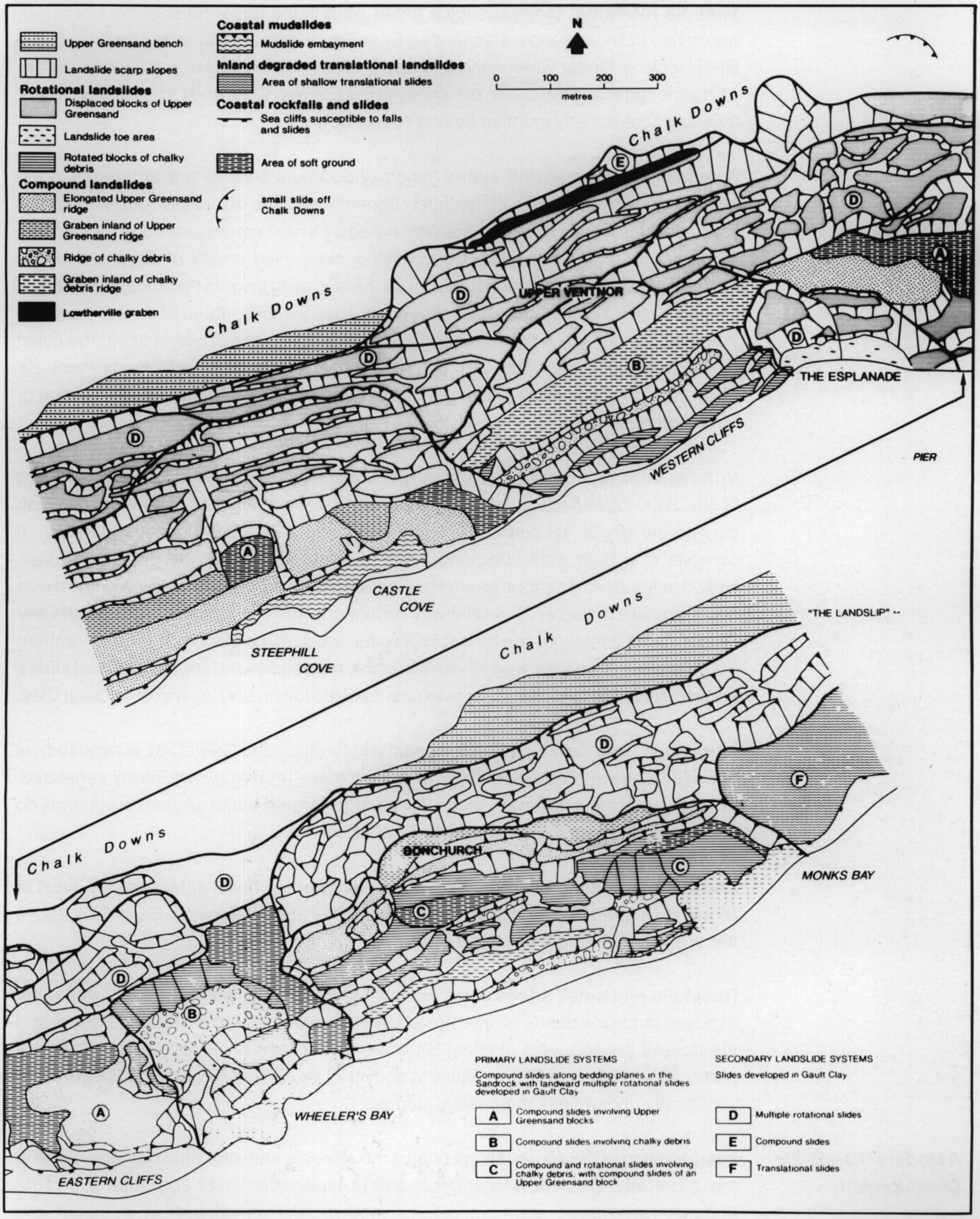


Figure 4. Summary geomorphological map of the Undercliff at Ventnor.

Multiple rotational slides occupy a broad zone in the upper parts of the Undercliff, giving rise to linear benches separated by scarp slopes. These units comprise back-tilted blocks of Upper Greensand and Chalk. Rotated blocks of Upper Greensand are also exposed along the coast, especially in the Eastern Cliffs and Orchard Bay, where they are occasionally mantled by fine chalky debris.

A sequence of **compound slides** generally occupy a zone of similar breadth in the lower part of the Undercliff, immediately beneath the zone of multiple rotational slides. In Bonchurch, this seaward zone is dominated by a near continuous ridge, 800m long, 10-15m high and parallel with the coastline, composed chiefly of displaced Upper Greensand, with a depression (graben) on the landward side. In the Ventnor Park area there is a single continuous ridge capped by chalky debris, about 500m long and 15-20m high, backed by a broad graben. Similar features are exposed along the coast at the Westfield Cliffs (Plate 11), central Ventnor, Bonchurch and Woody Point, St. Lawrence. The grabens landward of these ridges are likely to be infilled with peat or other soft materials.

In Upper Ventnor, a graben-like feature (the **Lowtherville Graben**) occurs just landward of the zone of multiple rotational slides. This feature runs from the Havensbush playground (Plate 4), across Newport Road and along Steephill Down Road. It consists of a 20m wide subsiding block of material bounded by parallel fissures. Historically the most serious ground movement problems experienced in Ventnor have occurred here (Chapter 1). A relatively continuous steep scarp slope (**the Gault Clay Scarp**), up to 20m high, can be traced through much of the Undercliff west of Ventnor. The scarp slope is occasionally the site of active **mudslides** and small **rotational slides** and is believed to mark the surface exposure of the lower, silty layers of the Gault Clay.

Mudslides have developed on the coast where displaced Gault Clay is exposed, as at Castle Cove and Wheelers Bay. In places, these mudslides are thickly vegetated, indicating that they are largely inactive, although periodic major ground movements do occur, as in the winter of 1993/94 at Castle Cove.

Degraded mudslide systems also occur inland of the coast at Monks Bay, west of Binnel Point (Plate 13) and at Mirables, where they are developed in Gault Clay above the *in situ* Lower Greensand sea cliffs.

Rockfalls and small slides occur along much of the coastline, especially where the exposed landslide debris is unprotected from marine erosion, as at Castle Cove, and the coastal section west of Steephill Cove to Puckaster. Slides and rockfalls are particularly frequent at Woody Point, Woody Bay and Binnel Bay where active erosion continually undermines the coastal slopes.

A Model of Landslide Development

Interpretation of the observations of past movements and structural damage made in the Undercliff rests on developing a consistent explanation which accounts for all of the features (geological, geomorphological and ground movement) in a logical and scientific way. "Models" of landslide form have been developed based on the geomorphological evidence within the Undercliff and borehole investigations at Gore Cliff[3], St. Catherine's Point[2] and Ventnor[4]. These models allow theories of ground

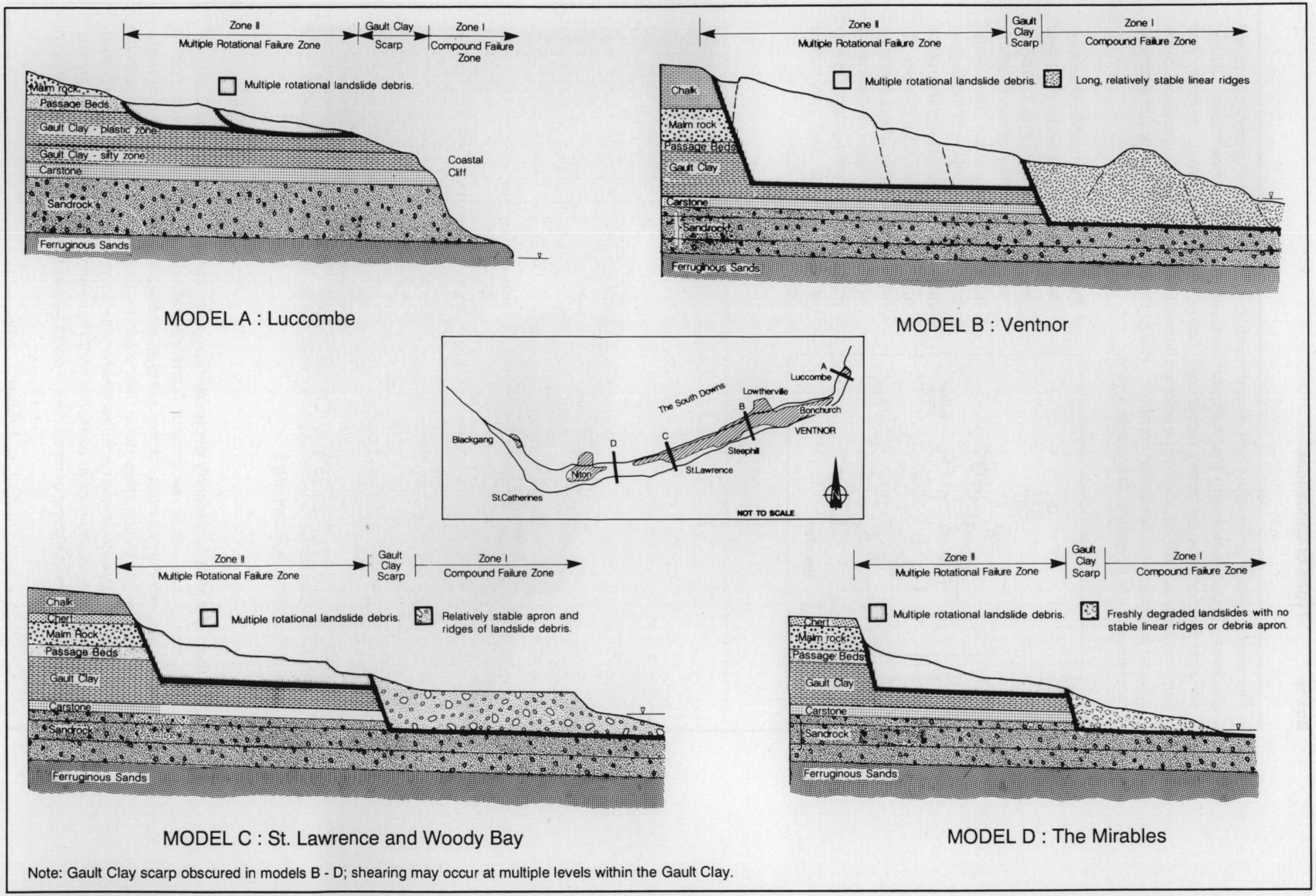
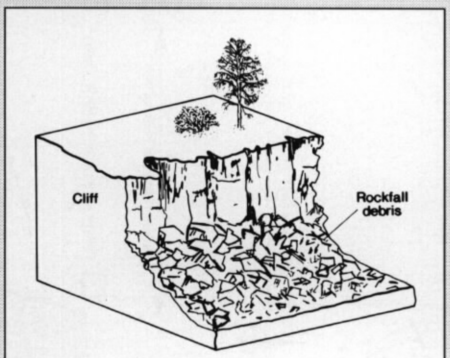


Figure 5. Landslide models in the Undercliff.

Box H **Types of Landslides**

The term landslide is merely a convenient name for a wide range of gravity-controlled processes (mass movement) that transport relatively dry material downslope. Three principle mechanisms are widely recognised: falling, sliding and flowing. In reality it is common for an area of instability to be affected by many different types of landsliding. Such an area is known as a ***landslide complex.*** *Within the Undercliff two principal landslide mechanisms are dominant: falling and sliding.*



Rockfall

Falls *occur when material becomes detached from cliff faces (left) and occurs wherever the coast is retreating, but often leaves no lasting trace. Falls also occur from inland cliffs within the Undercliff the largest recorded example having taken place at Gore Cliff in July 1928 (below). All falls, both coastal or inland, display a well-developed magnitude-frequency distribution with common small events at one extreme and rare large collapses at the other.*

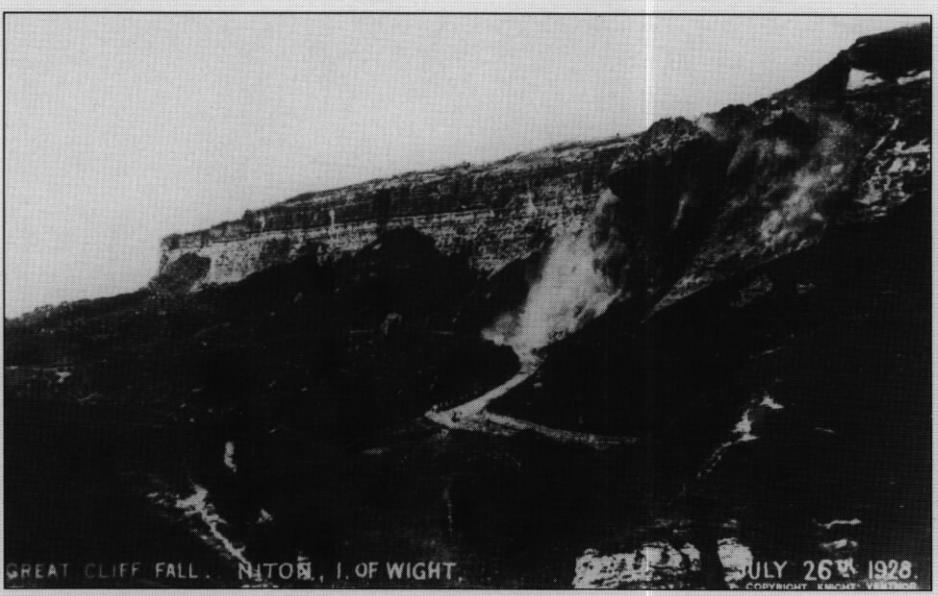
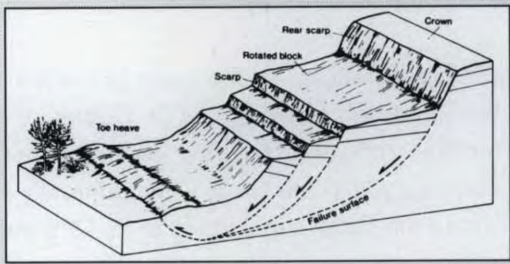


Plate 12: Rockfall at Gore Cliff, 1928.

The form of a ***slide*** *is generally dependent upon the shape of the basal shear surface. Three main groups can be recognised.* ***Translational,*** *where the shear surface is planar and parallel with the ground surface or along an inclined bedding plane in the rock mass.* ***Rotational,*** *where sliding takes place over a curved (concave) shear surface, with the result that the displaced mass becomes tilted or rotated as it moves.* ***Compound*** *or* ***non-rotational,*** *where sliding involves elements of both translational and rotational mechanisms, although the principal plane of movement is controlled by the bedding and angle of dip of the rock mass.*

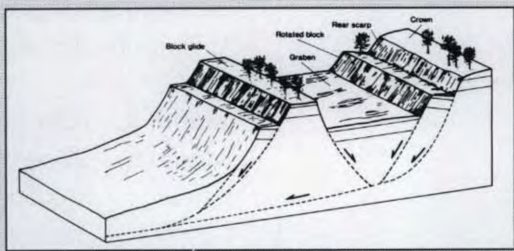
Box H Types of Landslides

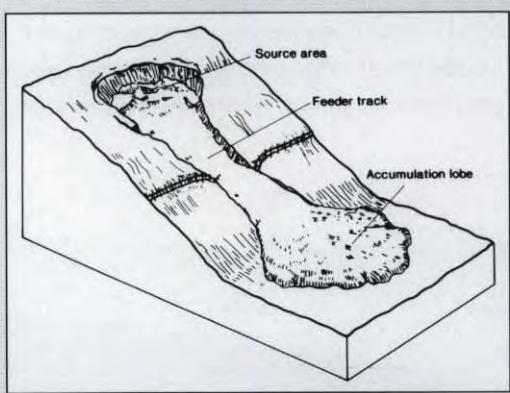
The Undercliff comprises three main types of slide:



Multiple rotational slides *(left) involving a series of slipped, back-tilted blocks each underlain by a circular failure surface that merge to form a common basal shear surface. These mainly occur at the rear of the Undercliff.*

Compound slides *(right) characterised by markedly non-circular shear surfaces. This type of slide involves the lateral displacement of a block forming an elongate ridge and the creation of a low-lying depression or graben immediately upslope.*





Mudslides *(left) are relatively slow moving, lobate masses of clay-rich debris sliding over translational shear surfaces. These slides generally comprise a steep source area from which debris is supplied, a feeder track and a more gently inclined accumulation zone or lobe. They are commonly found on the Gault Clay scarp and along the coast where they occur on displaced blocks of clay.*

behaviour patterns to be developed (see Chapter 4).

Throughout the Undercliff the style of landsliding suggests a two-tier system, usually involving a combination of two different mechanisms of failure at different elevations separated by the Gault Clay scarp:

Zone I; compound failures on the lower Undercliff slopes upon clay layers within the Sandrock, following the St. Catherine's Point model[4].

Zone II; multiple rotational failures, on the upper Undercliff slopes upon slip surfaces within the Gault Clay, generally following the Gore Cliff model where the basal slip surface is 15-18m above the base of this unit[3].

The arrangement of landslide features along the Undercliff is not constant; as the landscape changes so does the model of landslide form; schematic sections at four locations are shown in Figure 5 which indicate that a range of models can be developed to describe the variable landslide conditions along the Undercliff:

Model A; dominated by Zone II failures with no Zone I type failures.

Model B; Zone I comprises long, relatively stable linear ridges, parallel to the coast, fronting a suite of Zone II failures arranged as a broad series of narrow terraces separated by high, steep scarp faces;

Model C; Zone I comprises an extensive, relatively stable apron and ridges of landslide debris, fronting a relatively narrow series of Zone II failures which form broad, but low terraces;

Model D; Zone I comprises freshly degraded landslide and mudslide forms with no stable linear ridges or debris apron, fronting a series of Zone II failures arranged as broad, relatively high, marginally stable terraces.

Plate 13: Binnel Bay to Puckaster and St. Catherine's Point.

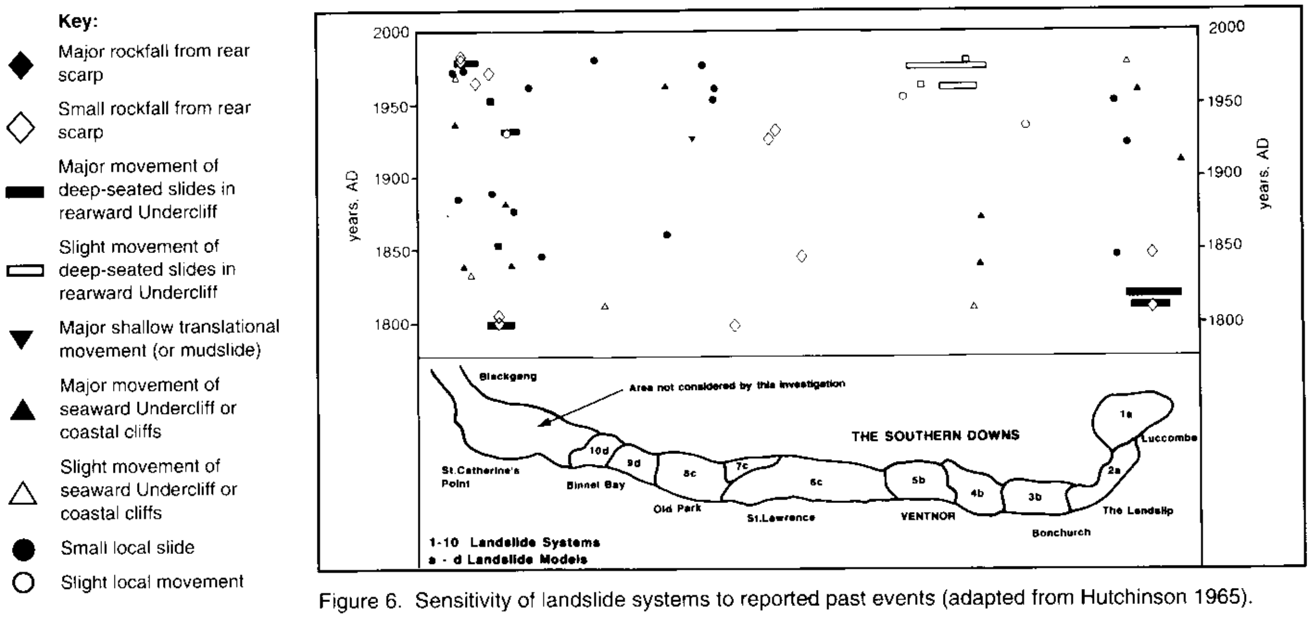


Figure 6. Sensitivity of landslide systems to reported past events (adapted from Hutchinson 1965).

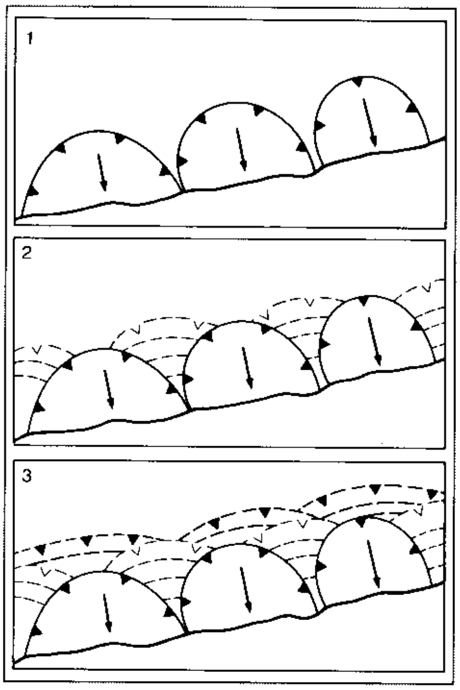
The boundary between the Zone I and II failures coincides with a generally steep **Gault Clay scarp** which can be defined along much of the Undercliff. Recent evidence provided by this report and the recent landslide events at Blackgang and Castlehaven in January 1994 has demonstrated the importance of the Gault Clay scarp as a major influence on the mechanism and models of landsliding. The observation of the Gault Clay scarp, where exposed along the Undercliff, indicates that the depth of the basal shear surface in Zone II may occur at a higher level in the Gault than previously thought, although the exact elevation of the shear surface will be dependent on the location and model of landsliding within the Undercliff landslide complex.

The evolution of the landslide models is believed to be related to the interplay of climatic changes and sea level rise over the last 20,000 years or so. During periods of low sea level in the last "ice age" the coastal slopes became fronted by large aprons of landslide debris which would have acted as a natural protection to the slopes. However, the rise in sea level after the ice melted would have caused parts of the aprons and even the coastal slopes to be eroded away. As a result of this erosion, the slopes probably became partially destabilised and major deep-seated landslides developed on the lower section (Zone I). The curved backscars of these lower landslide systems appear to have isolated a series of broad, triangular spurs. These spurs have subsequently failed as a result of the unloading on either side caused by the movement of the earlier slides (**Box I**). In this way a pattern of closely related **landslide systems** has developed (Figure 6) in response to the gradual unloading of the lower portions of the Undercliff.

The general extent of these systems can be recognised from the marked changes in topography and surface form that occur along the Undercliff, although precise system boundaries need to be confirmed by borehole investigations. Figure 6 sub-divides the Undercliff from Luccombe to the Orchard into ten landslide systems which have then been classified according to the models of landslide form that best describes the local ground conditions.

Box I **Landslide Systems and Units**

The geomorphological mapping of the Undercliff has highlighted a series of discrete landslide units within much broader landslide sytems. Landslide systems are often marked by a prominent arcuate scarp slope which can generally be traced from the rear scarp of the Undercliff extending down either side of the landslide towards the coast, defining the lateral boundaries of the system. The curved backscars of the landslide systems have in places isolated a series of broad, triangular spurs. These spurs have subsequently failed as a result of ground movement and unloading on either side. In this way a pattern of closely related landslide systems has developed in response to the gradual unloading of the lower portions of the Undercliff.



Within each landslide system there is a complex arrangement of individual landslide units which reflect the wide variety of landslide types and processes (e.g. rotational landslide blocks, toe areas etc). The recognition of these units along with the nature of the ground conditions and past history of movement has formed the framework for understanding the ground behaviour of the Undercliff.

1. *Development of deep-seated primary slides*
2. *Unloading of spurs, leading to multiple rotational failure*
3. *Futher unloading leading to retrogressive multiple rotational failure*

Since the development of the Undercliff (over 20,000 years ago) the landslide features have been affected by episodes of relatively small-scale movements (Figure 6), some of which were described in Chapter 1. Most of these movements should be viewed as involving the relaxation, settlement or degradation of the landslides rather than involving the creation of new landslides. Here, it is useful to consider how a landslide system can be divided into a number of **sub-systems** and then into individual **landslide units (Box I)**. In many parts of the Undercliff the contemporary problems involve the movement of separate landslide units (e.g. the slow settlement of Zone II landslide blocks in the Castle Court area) and only occasionally the movement of a sub-system (e.g. Castle Cove). Only at the extreme ends of the Undercliff, at The Landslip and Blackgang, do historical events suggest the movement of a whole landslide system.

REFERENCES:

1. Chandler, 1984
2. Hutchinson, 1987
3. Bromhead et al. 1991
4. Hutchinson et al. 1991
5. Jones and Lee, 1994
6. GSL, 1987

CHAPTER 3
THE CAUSES OF GROUND MOVEMENT

Factors Influencing the Pattern of Movement

Landslides occur when the force of gravity acting on a slope exceeds the strength of the slope materials (see **Box J**). In these circumstances the displaced material moves to a new position so that equilibrium can be re-established between the destabilising forces and the residual strength of the rock and or soils along the surface of movement. A landslide, therefore, is a process that changes a slope from a less stable to a more stable state. No subsequent movement will occur unless changes take place which, once again, affect the balance of opposing forces.

In many inland situations on the Isle of Wight and mainland Britain landslides can remain dormant or relatively inactive for thousands of years, as is the case for many examples on the north-facing slopes of the Southern Downs. However, in the case of coastal landslides such as the Undercliff, marine erosion removes material from the lower parts of the slopes, thereby removing passive support and promoting further movement. Over thousands of years erosion at the toe of the slope can lead to the area of instability progressively affecting a larger area. The presence of passive support or toe weighting provided by landslide debris aprons reduces the potential for slope instability. That is, of course, until continued marine erosion at the base of the slope causes the reactivation of the landslide complex.

The fact that all parts of the Undercliff do not show similar frequencies or magnitudes of landslide activity emphasises the importance of other factors than just coastal erosion. The most active sections of the Undercliff over the last 200 years have been the western and eastern ends (Blackgang and The Landslip respectively), where the physical processes have historically been far greater than in the intervening areas. This variation is influenced by the presence of a broad concave down-fold (syncline) in the rocks which controls the height of the Gault Clay relative to sea level[1]. The two most active areas occur where the clay is at its highest elevation along the coast.

Certain landslide systems are more prone to movement than others. These differences in ground behaviour highlight variations in the **sensitivity** (see **Box K**) of the four contrasting models of landslide form to periods of heavy rainfall or high groundwater. This is self evident from the events in January 1994 when historically-known unstable areas have experienced significant movements and more stable areas have been largely unaffected.

Causes of Ground Movement

Before considering those factors which cause ground movement in Ventnor and St. Lawrence, it is important to stress that the towns are built on an ancient landslide complex. As the materials along the landslide basal shear surfaces are probably at or close to their residual strength the slopes can be made to move under conditions that they could have resisted prior to the formation of the Undercliff. Thus, events which cause ground movement along the Undercliff would not necessarily cause problems on intact slopes of similar materials elsewhere.

Box J **Causes of Landslides**

The ultimate cause of all landsliding is the downward pull of gravity. The stress imposed by gravity is resisted by the ***strength*** *of the material. A* ***stable slope*** *is one where the resisting forces are greater than the destabilising stresses and, therefore, can be considered to have a* ***margin of stability****. By contrast, a slope at the point of failure has no margin of stability, for the resisting and destabilising forces are approximately equal. The quantitative comparison of these opposing forces gives rise to a ratio known as the 'Factor of Safety' (F):*

$$\text{Factor of Safety} = \frac{\text{Resisting forces}}{\text{Destabilising stresses}} = \frac{\text{Shear strength}}{\text{Shear stress}}$$

The Factor of Safety of a slope at the point of failure is 1. On slopes of similar materials, progressively higher values represent more and more stable situations with greater margins of stability. In other words, the higher the value the greater the ability of the slope to accommodate change before failure occurs. These changes are usually divided, for the sake of convenience, into internal and external groups. External changes increase the stress placed on slope-forming materials, while internal changes reduce or weaken their resistance to movement. The majority of landslides are therefore the product of changing circumstances or alterations to the status quo.

The shear strength of a material depends upon both the nature of the material itself and the presence of water in fissures and pores. A slope is only as strong as its weakest horizon, often a clay. Clays such as the Gault Clay are known as ***brittle*** *materials because once they have been subject to more than the maximum stress they can withstand and have failed, further displacements are possible at lower levels of stress. In other words the shear strength of the clay declines from a* ***peak*** *value to a lower* ***residual*** *value.*

Water contact has a major influence on reducing shear strength, not because of 'lubrication' as is often stated, but due to the fact that water in the ground exerts its own pressure which serves to reduce the amount of particle to particle contact. Within saturated horizons the pore-water therefore bears part of the load by exerting an upthrust or buoyancy effect known as ***pore-water pressure****. Although soil or rock particles can resist both normal and tangential (shearing) forces, fluids can support compression forces but cannot resist shearing forces. Therefore, frictional resistance to movement depends on the difference between the applied normal stress and the pore-water pressure. This difference, or that part of the normal stress which is effective in generating shear resistance, is known as the* ***effective stress****.*

Two contrasting sets of conditions are often used to describe landslides:

- *first-time failures in previously unsheared ground, when the material fails at* ***peak*** *strength;*
- *reactivated failures in which movement occurs along pre-existing shear surfaces where the materials are at* ***residual*** *strength.*

The importance of this distinction is that once a slide has occurred it can be made to move under conditions that the slope, prior to failure, could have resisted. In other words, reactivations can be triggered much more readily than first-time failures.

As slope movements are the result of changes which upset the balance between

Continued/...

resistance and destabilisation, the stability of a slope is often described in terms of its ability to withstand potential changes:

- ***stable**; when the margin of stability is sufficiently high to withstand all transient forces in the short to medium term (i.e. hundreds of years), excluding excessive alteration by human activity;*
- ***marginally stable**; where the balance of forces is such that the slope will fail at some time in the future in response to transient forces attaining a certain level of activity; and*
- ***actively unstable slopes**; where transient forces produce continuous or intermittent movement.*

This perspective makes it possible to recognise that the work of destabilising influences can be apportioned between two categories of factors on the basis of their role in promoting slope failure (Figure 7).

These two categories are:

1. ***preparatory factors** which work to make the slope increasingly susceptible to failure without actually initiating it (i.e. cause the slope to move from a stable state to a marginally stable state), eventually resulting in a relatively low Factor of Safety;*

2. ***triggering factors** which actually initiate movement, i.e. shift the slope from a marginally stable state to an actively unstable state.*

*When considering the actual cause of landsliding this relative simplicity gives way to complexity as there is a great diversity of causal factors. In broad terms, however, they can be sub-divided into **internal** causes which lead to a reduction in shear strength and **external** causes which lead to an increase in shear stress.*

Factors Leading to a Decrease in Shear Resistance (Internal):

1. ***Materials:***
   - *strata which decrease in shear strength if water content increases (clays, shale) e.g. when local watertable is artificially increased in height by reservoir construction, or as a result of stress release following slope formation;*
   - *low internal cohesion (e.g. consolidated clays, silts, porous organic matter);*
   - *weaknesses in bedrock: faults, bedding planes, joints, foliation in schists, cleavage, brecciated zones, and pre-existing shears.*

2. ***Weathering changes***
   - *weathering reduces effective cohesion and to a lesser extent the angle of shearing resistance by the absorption of water leading to changes in the fabric of clays (e.g. loss of bonds between particles or the formation of fissures).*

3. ***Pore-water pressure increase***
   - *higher groundwater table as a result of increased precipitation or as a result of human interference.*

Continued/...

Box J **Causes of Landslides**

Factors Leading to an Increase in Shear Stress (External):

1. ***Removal of lateral or underlying support***
   - *undercutting by water (e.g. river, waves), or glacier ice;*
   - *washing out of granular material by seepage erosion;*
   - *man-made cuts and excavations;*
   - *drainage of lakes or reservoirs.*

2. ***Increased loading (external pressures)***
   - *natural accumulations of water, snow, talus;*
   - *man-made pressures (e.g. tip-heaps, rubbish dumps, or buildings).*

3. ***Transitory earth stresses***
   - *earthquakes;*
   - *continual passing of heavy traffic.*

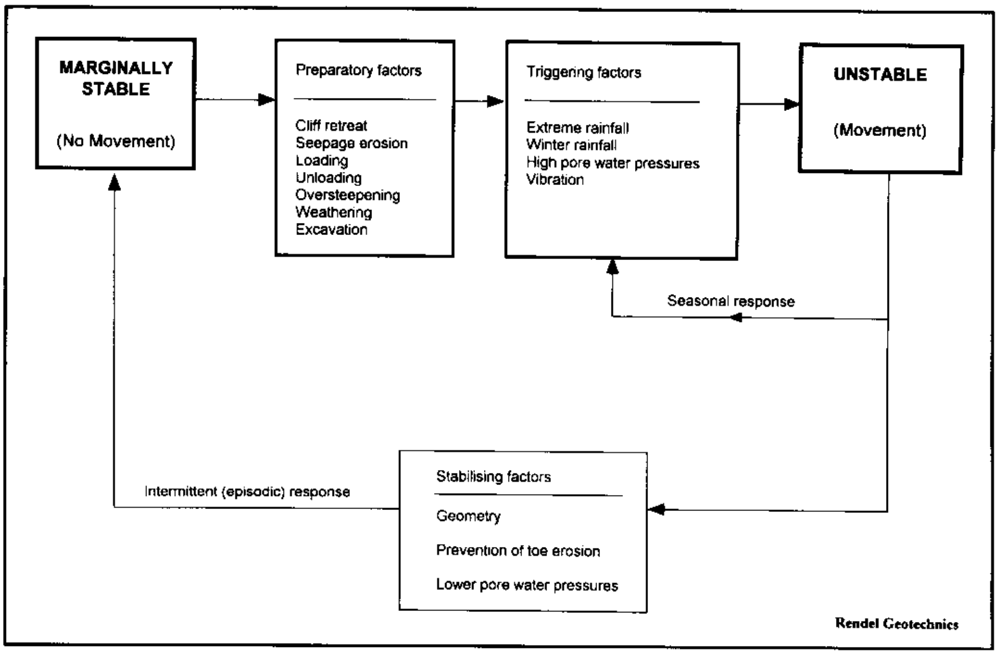


Figure 7. Causal responses of pre-existing landslides.

Coastal erosion has long been appreciated to be a major factor in the long-term instability of the Undercliff[2,3]. Most of the urban frontage of the Undercliff has been protected by coastal defences and it is unlikely, therefore, that marine erosion remains a significant cause of slope instability in these areas provided that they are adequately maintained. However, the coastal sections from Monks Bay to Shanklin and west of Steephill Cove (Plate 14) remain unprotected and unchecked marine erosion (estimated to result in an average retreat of the coast by around 0.3m per year) is likely to act as a major de-stabilising influence on the largely undeveloped landslides in these areas (Plate 15).

Coastal erosion has progressively reduced the overall stability of the slopes, and together with other factors, such as periods of heavy rainfall, has promoted landslide activity. This tends to occur in the winter when rainfall totals are higher and evaporation rates are lower, and consequently much more of the rainfall is effective in raising groundwater levels. The relationship between landslide activity and winter rainfall is not a simple one. Some landslide systems are more sensitive to rainfall events whilst others appear only to show signs of movement during extremely rare conditions. The differences in sensitivity to rainfall can be seen in Figure 8 which compares the return period of different winter rainfall totals with the known history of landslide events in different landslide systems since 1839 (see **Box K** and Figure 6). This suggests that:

- periods of accelerated ground movement have not occurred in Ventnor and St. Lawrence (Landslide systems 3-8; Figure 6) during winter rainfall conditions that can be expected one year in 100 or more (Figure 8);

- major movements at Luccombe Village (system 1) have occurred during conditions that can occur one year in four (Figure 8);

- major movements in The Landslip and near Mirables (systems 2 and 9; Figure 6) have occurred in response to winter rainfall totals that can be expected around one year in 1.5 or less (Figure 8);

The sensitivity map of the Undercliff shows how different landslide systems have been susceptible to movement events since the 1800s (Figure 6). Within individual landslide systems however, there will be variations in sensitivity because of the nature of local ground conditions, an example of which is the Undercliff Drive, near Mirables, where the road crosses a small mudslide unit. The road has been locally affected by ground movement caused by rainfall conditions that can be expected once every 1.5 years (Figure 8).

That ground movement does not always occur when the winter rainfall **thresholds** shown on Figure 8 are exceeded highlights the importance of other factors in controlling landslide activity. Here, it is useful to consider rainfall events as **triggering** movement (**Box J**) in systems where the effects of coastal erosion or human activity have **prepared** the slopes for failure by reducing the factor of safety.

It is probably no coincidence that the number of reported landslide events was found to have increased with the spread of development throughout the Undercliff over the

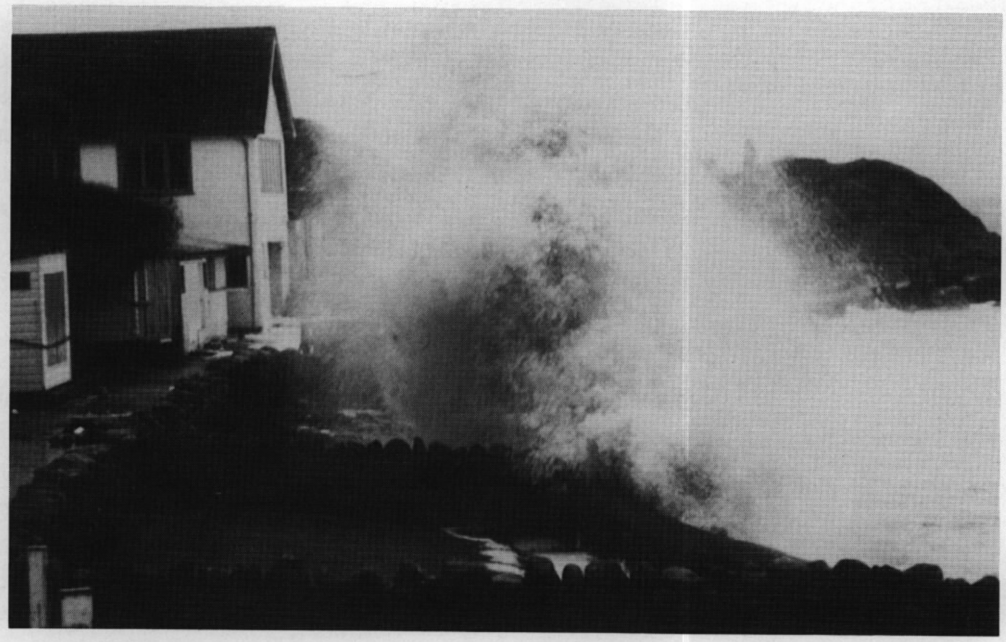


Plate 14. Storm impact, Steephill Cove.

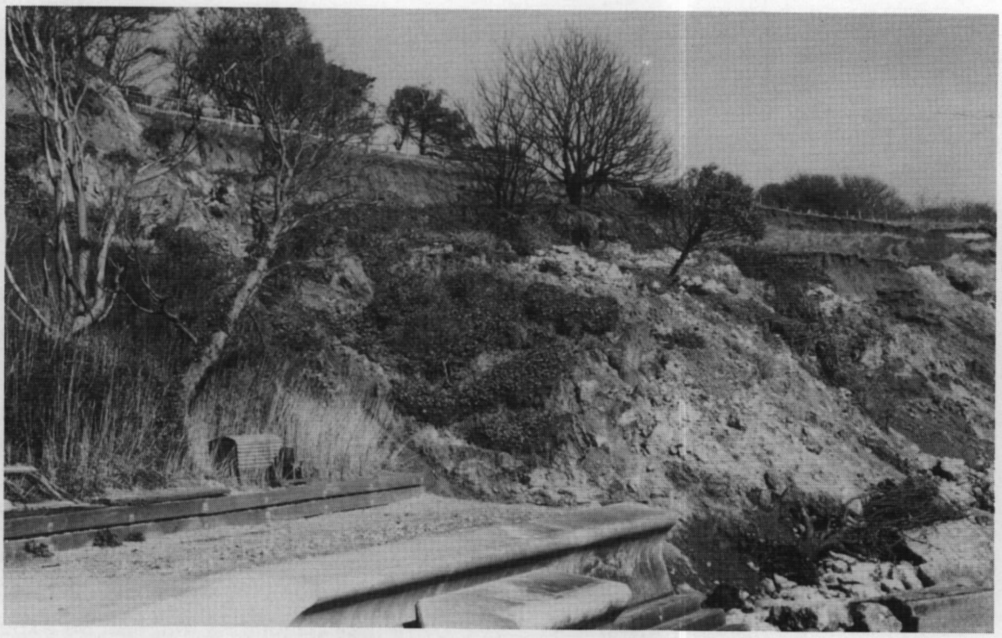


Plate 15. Coastal slip, near Monks Bay, 1989.

Box K Landslide Sensitivity

Landscape sensitivity is a general term used to describe the ability of earth surface processes such as earthquakes, volcanoes, floods or landslides, to bring about landform change. The sensitivity analysis of the landslide systems forming the Undercliff attempts to highlight the spatial and temporal susceptibility of each system to ground movement which has operated over the past 200 years or so.

The landslides forming the Undercliff can be considered to be marginally stable, whereby the resistance to change just exceeds or balances the disturbing forces operating at any time. Occasionally the disturbing forces (such as extreme rainfall) exceed the resistance of the landslide and ground movement or landslide events occur to bring about a new equilibrium or more stable landform. Within the Undercliff, some landslide systems are more resistant to disturbing forces than others (Figure 6). This fact is supported by contemporary field evidence and the past records of landslide events and ground movement.

Figure 8 shows the winter rainfall totals that may be expected to be equalled or exceeded, on average, for particular recurrence intervals. By using a non-linear horizontal axis the relationship can be defined by a straight line. The winter rainfall total which is expected to be equalled or exceeded, on average, every 100 years (ie. around 800mm) has a return period of 100 years. This total could occur any year, but the probability of its occurrence during 100 years is clearly much greater than during a single year.

The winter rainfall associated with recorded ground movement events in particular areas are indicated on the diagram to emphasise the varying degrees of sensitivity of different parts of the Undercliff. Thus winter rainfalls that may be expected to be equalled or exceeded, on average, every year can lead to ground movement at a number of highly sensitive areas including The Landslip and near the Mirables. Elsewhere, on low sensitivity areas such as Upper Ventnor and the Orchard, near Niton, ground movement has been associated with winter rainfall totals that have occurred, on average, every 50 years or more. During extreme winter rainfall periods many more landslide systems may become active as witnessed in 1960/1961 and in January 1994. For this reason any reduction in the volume of water articifially introduced into the groundwater table (e.g. from leaking water pipes or sewers) is of considerable significance.

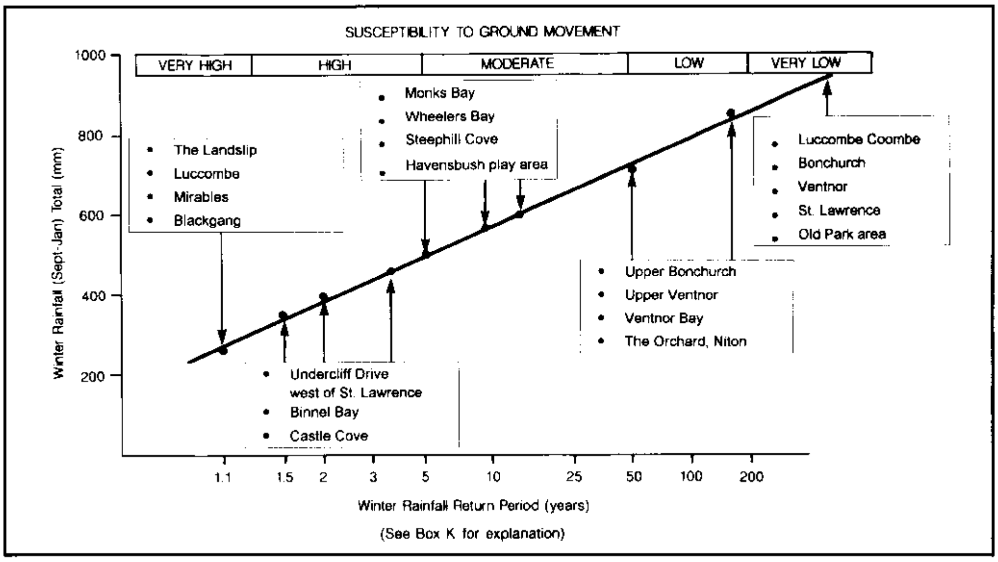


Figure 8. Return period rainfall and susceptibility of landslide systems.

past 100 years or so. Whilst this partly reflects better records of ground movements, it is also true that development itself has acted as a destabilising influence in parts of the town. For example, it is widely recognised that the removal of Collins' Point in Ventnor Bay, during the construction of an artificial harbour in the 1860s, caused beach depletion, rapid coastal erosion[3] and an increase in reported landslide activity in the 1870s.

Throughout the Undercliff, development has involved cut and fill operations to establish level plots for houses or acceptable gradients for roads. These operations have promoted local instability problems in some cases by changing the surface profile of the landslide slopes to a less stable configuration.

Potentially the most serious destabilising activity associated with development has been the artificial recharge of the groundwater table. Uncontrolled discharge of surface water through soakaways and leaking drains may have contributed to raising the groundwater table to a level where heavy winter storms could trigger movement. The progressive deterioration and leakage of services such as foul sewers, storm sewers, water mains and service pipes are considered to have added to the problems. As an extreme example, during the winter of 1960-61, over 3 million gallons of water from the flooded Ventnor railway tunnel were pumped into the back of the landslide system[4]. This, together with the exceptionally high autumn rainfall preceded the most dramatic movement in the town of Ventnor in recent years (Chapter 1).

Defective Construction

Within the Undercliff it is not always a simple case of damage to property occurring in unstable areas and no damage in more stable areas. Often it is not clear whether some of the reported problems with buildings are a direct result of ground movement or simply due to poor construction.

Like many English coastal resorts, Ventnor was developed rapidly between 1830 and 1910. In the case of Ventnor this followed the publication of "The influence of climate in the prevention and cure of chronic disease" by Sir James Clark in 1829, as well as the popularity of sea bathing and improved communications. A vivid description of the early years of the town is provided by the diarist Mark William Norman[5], who wrote:

> "there was a rush to it (Ventnor) of all sorts and condition of men from all quarters of the compass. Among them builders without capital or credit or character. The place was infested with jerry builders who ran up houses of inferior order, mortgaged them and which generally fell into the mortgagee or lawyers hands"[5].

It is only to be expected that a rapidly built Victorian town had its fair share of defective constructions. However, in many cases damage appears to worsen with time, as the cumulative effects of imperceptible movement and inadequate maintenance become more and more serious. The issue as to whether such damage to property is due to ground movement or poor construction is not one that is easily resolved, mainly because in most cases the two are inexorably linked. Although there can be no doubt that the town lies within a slowly moving landslide complex, many contemporary problems are probably heightened by human failings. The large number of substantial Victorian properties in the town present particular maintenance problems for owners.

In Bonchurch and St. Lawrence most properties are understood to be built on simple non-reinforced foundations. Whilst in the great majority of cases these properties have suffered little or no damage, it is likely that in some cases damage due to ground movement might have been avoided or reduced if the foundations had been designed to accommodate the ground conditions. Wastewater and stormwater drainage in Bonchurch and St. Lawrence is generally limited to septic tanks and soakaways (only twenty to thirty properties in St. Lawrence are connected to mains sewerage) concentrating discharge to the ground and potentially causing problems of localised settlement which collectively can lead to a more serious problem of land instability.

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1. Hutchinson, 1965
2. Royal Commission on Coast Erosion, 1907; 1911
3. Whitehead, 1911
4. Anon, 1960
5. Norman, in Chambers, 1988

CHAPTER 4
DEFINING THE LANDSLIDE HAZARD

Types of Contemporary Ground Movement

The nature of ground movements within the Undercliff can be separated into two distinct groups, namely;

- subsurface movements associated with the deep seated creep of the entire landslide complex;

- surface or superficial movements arising from the erosion or failure of steep slopes and the differential movement and potential collapse (vents) between landslide blocks.

The impact of subsurface movements in the developed areas at Ventnor and St. Lawrence is relatively insignificant when compared with the more active landslide systems at the extremities of the Undercliff (e.g. The Landslip). Within Ventnor and St. Lawrence contemporary problems arising from slope instability tend to result almost entirely from superficial movements. The nature of these is illustrated in Figure 9, and involve:

Type 1; shallow translational slides off the Chalk downs involving the movement of soil and weathered Chalk on over-steep slopes, e.g. above the former Seaman's Mission in Mitchell Avenue, Ventnor in 1877[1].

Type 2; settlement of the Upper Greensand bench, involving slow movements accompanied by joint widening and the development of vents. The most notable example occurred along Whitwell Road in 1954[2,3]. Large scale settlement of Upper Greensand and Chalk has been taking place at Newport Road, where subsidence of the Lowtherville graben has been measured at rates of around 44mm per year (see Box D).

Type 3; rockfalls off the rear scarp. These may occur along the steep cliff faces behind St.Lawrence where a number of incidents have been reported, including the rockfall in 1912 which damaged the former railway line[4].

Type 4; degradation of Zone II multiple - rotational landslides involving the differential movement between blocks caused by back tilt, forward tilt, torsion and settlement. This type of movement has taken place in many parts of the Undercliff but most notably in Upper Ventnor.

Type 5; degradation of the Gault Clay scarp. Slow superficial movements resulting in cracking and bulging of infrastructure. Undermining may occur at the crest of the scarp while toe heave may be apparent at the base of the slope. Mudslides have developed on the Gault Clay scarp west of Binnel Point and seaward of the Mirables.

Type 6; degradation of Zone I compound landslides involving the outward horizontal movement of blocks causing damage through torsion and differential settlement.

Type 7; consolidation of soft ground within low-lying graben areas seaward of the Gault Clay scarp.

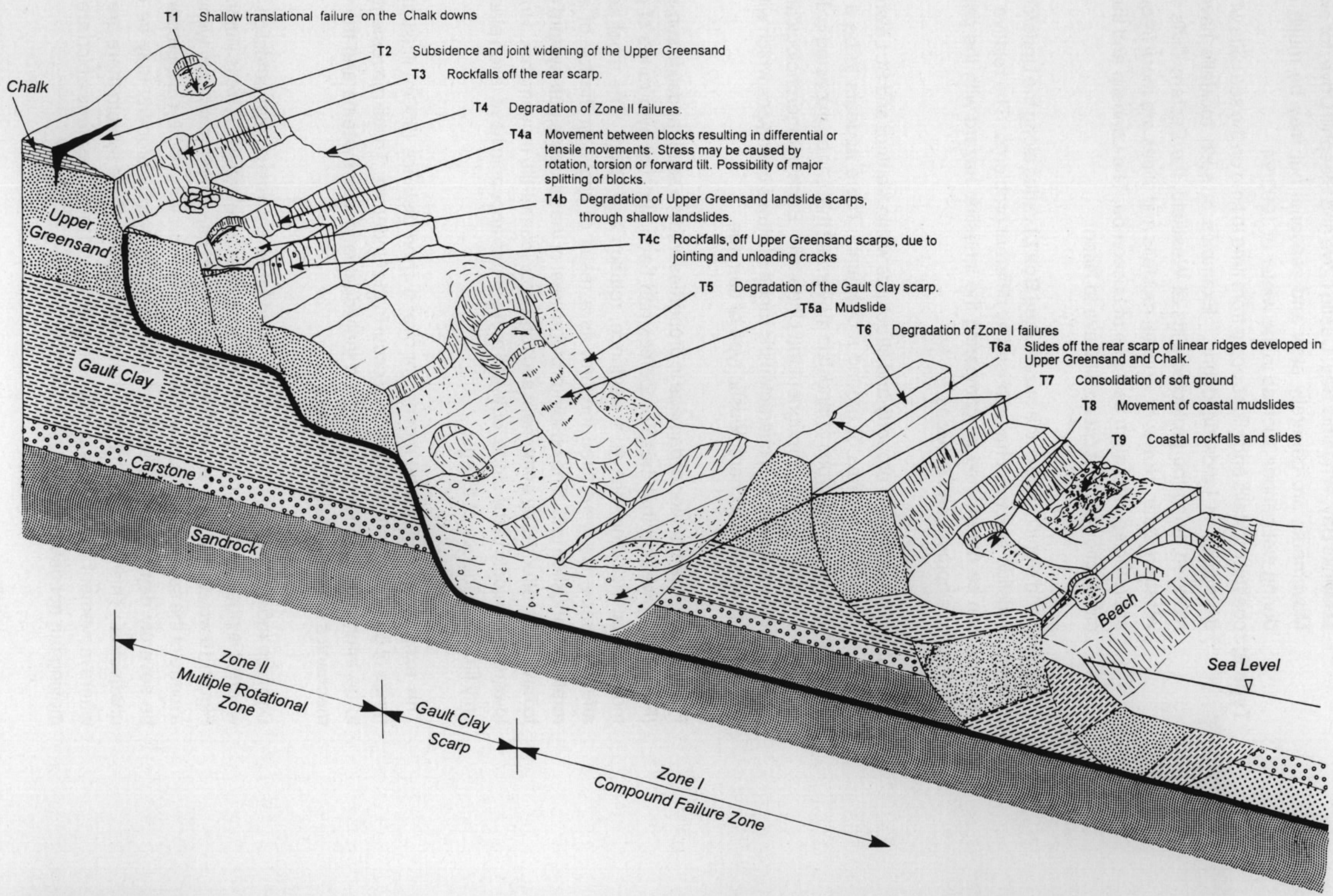

Figure 9. Types of contemporary ground movement in the Undercliff.

Type 8; coastal mudslide systems have developed on displaced blocks of Gault Clay at Monks Bay, Wheelers Bay, Castle Cove and Steephill Cove, for example. Movements are generally slow and seasonal but may be much greater during wet periods such as in the winter of 1993/94.

Type 9; coastal rockfalls and slides occur from time to time on the sea cliffs which are developed in landslide debris. Examples of such rockfalls have been reported along the protected cliffs at Westfield, the Eastern Cliffs and the Western Cliffs. However, coastal rockfalls and slides are more frequent on unprotected cliffs such as those at Luccombe, The Landslip and the entire cliff section west of Steephill Cove to Niton.

The nature and significance of the hazard (see **Box L)** varies along the Undercliff, with different landslide systems characterised by different problems. The relative risks in the area can be determined by comparing the landslide hazard with the pattern of existing development and services.

The pattern of damage to property and structures within Ventnor and St. Lawrence is related to the various forms of ground movement. There appears to be a strong relationship between the types of landslide movement that can be expected in different geomorphological settings throughout the Undercliff. Each geomorphological unit or landslide feature has its own characteristic range of stress conditions which will affect structures, producing a characteristic type of damage.

For example, examination of damage to properties within a small landslide sub-system (Figure 10) revealed that these properties had been affected by a range of ground movements, including, heave, subsidence, rotation and tilting. The most severely affected properties were tilted forward, as a result of heave at the toe of a small rotational landslide unit. The buildings at the crest of the landslide sub-system appear to have been affected by settlement and rotational (contra-tilt) movements. However, towards the middle of the slope, outward movements appear to have taken place, with only limited evidence of tilting.

This example of contrasting movement over a short distance (300m) illustrates the range of ground movements that may occur in the Undercliff. These movements need to be interpreted in the context of the individual landslide systems and the overall mechanics of the landslide complex.

Damage most commonly occurs at the boundaries between major landslide blocks where it is possible to recognise narrow bands of severe hazard. This is illustrated in Figure 10 which indicates that the degree of hazard can vary dramatically within even a metre of the surface exposure of inter-block shear surfaces. Whilst one property may be severely damaged by differential movement, a nearby property may be largely unaffected. This highlights the fact that within any landslide system there are zones where movement is greatest e.g. at their margins, and there are areas which are slowly moving but not deforming.

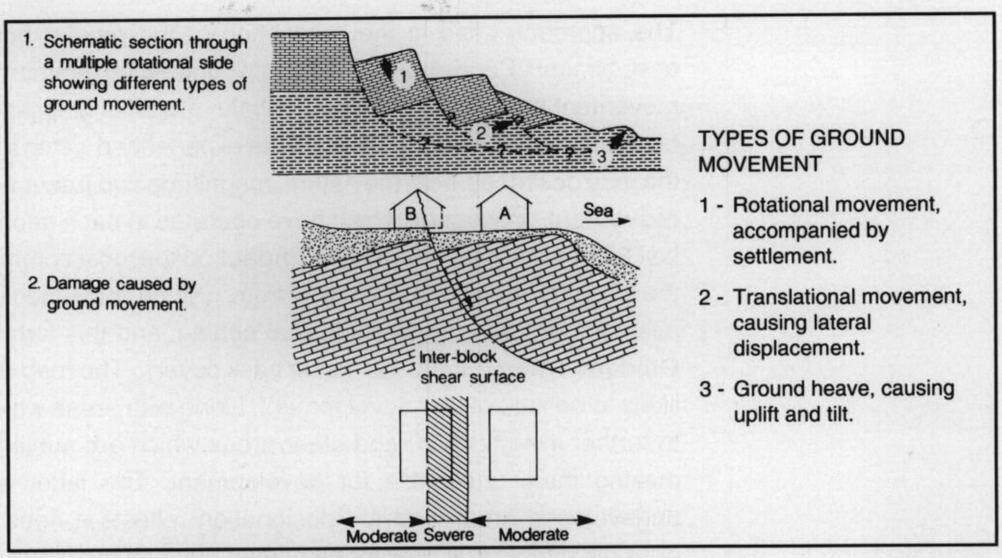

Figure 10. Variability of damage caused by ground movements.

Ground Behaviour

The nature of the landslide hazard (see **Box L)** faced by the local community has been defined by producing maps of contemporary ground behaviour. These maps are based on a thorough review of available records, documents and reports, followed by a programme of detailed field investigation comprising geomorphological and geological mapping, a survey of damage caused by ground movement, photogrammetric analysis (for the Ventnor area only) and a review of local building practice. Through these methods an understanding of the following components of landslide hazard and risk has been achieved:

- the extent of the landslide complex, systems and the processes involved in its evolution;
- the types of contemporary ground movement;
- the magnitude of contemporary ground movement;
- the frequency of landslide events;
- the causes of landslide events and their temporal variation;
- the impact of ground movement in built-up areas;
- the nature and extent of property at risk;
- the vulnerability of different styles of construction to ground movement.

The ground behaviour maps were produced at 1:2,500 scale but for the purpose of this report a summary map of the Undercliff is presented in Figure 11. The map is a synthesis of the following information:

- the nature and extent of different landslide features which form the Undercliff (e.g. multiple rotational slides, compound failures and mudslides; Figure 4);
- the different landslide processes, which have operated within the Undercliff over the last 200 years (Figure 9);
- the location of past ground movement events (Figure 1);
- the recorded rates of ground movement (Figure 2, Table 1)
- the intensity of damage to property caused by ground movement (Table 2)
- the causes of damage to property as a result of ground movement (e.g. torsion, rotation and heave; Figure 10).

The approach used in the production of the ground behaviour map involved the assessment of landslide activity within contrasting geomorphological units, i.e. ground movement problems within the multiple rotational landslide units can be expected to be fundamentally different from those experienced within a mudslide unit. In essence, the map describes both the nature, magnitude and frequency of **contemporary mass movement processes** which have operated in each geomorphological unit over the last 200 years or more and their **impact** on the local community. It shows clearly that the potential problems, resulting from ground movement, vary from place to place according to the geomorphological setting, and this forms the basis of a **Planning Guidance Map** (Figure 12; inside back cover). The map recognises areas which are likely to be suitable for development, along with areas which may be suitable subject to further investigation, and other areas which are subject to significant constraints making them unsuitable for development. The latter generally correspond with undeveloped areas and the designation reflects a need to be cautious about the possible effects that development may have on the stability of adjacent land. Advice is also provided on the map on the level of stability information which should be presented with planning applications in different areas (see Chapter 5).

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1. Anon, 1877
2. Edmunds and Bisson, 1954
3. Toms, 1955
4. Allen and MacLeod, 1967
5. Varnes, 1983

Box L The Relationship Between Landslide Hazard and Risk

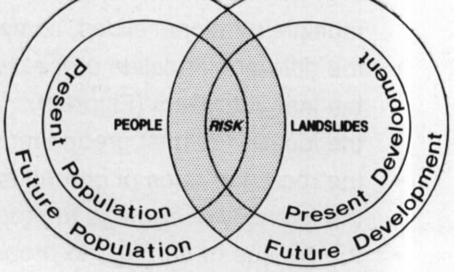
The terminology used when discussing natural events and their impact on society can be very confusing. It is not uncommon for terms like hazard, risk and vulnerability to be used to describe the same concepts. In this book the following definitions are used [5].

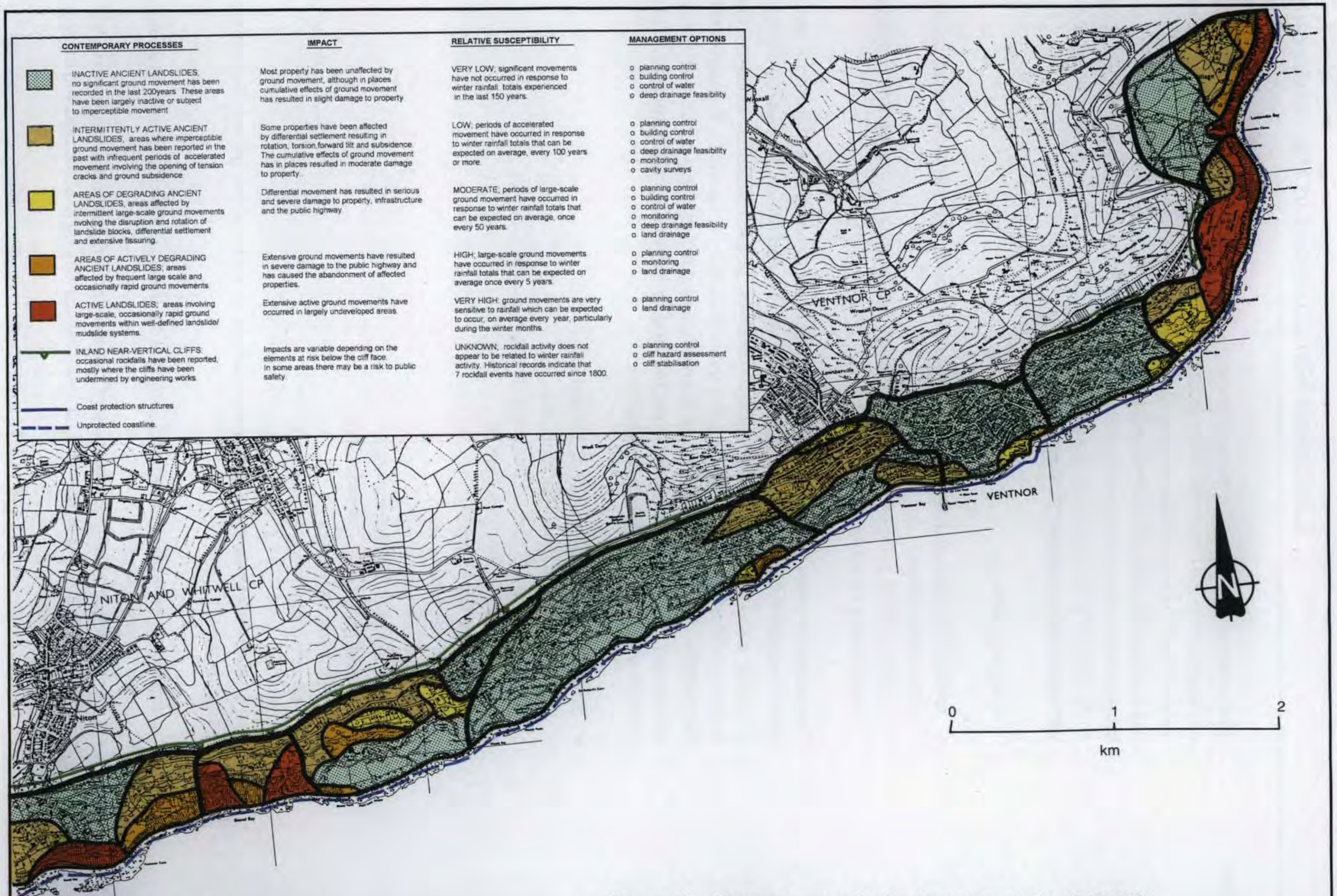
*A **hazard** describes the chance of a potentially damaging ground movement event occurring within the area, i.e. ground movement constitutes a hazard.*

***Risk** means the possible losses arising as a result of ground movement, i.e. the community is at risk from ground movement.*

***Vulnerability** describes the degree of loss or damage to a particular element of the town or community (e.g. buildings, services, economic activity) i.e. different elements will face different levels of risk from the ground movement hazard.*

The concept of risk as the interaction of the human environment with the physical environment is illustrated below. Only when the two systems are in conflict does landsliding become a threat to the community. Of particular importance is the fact that as urban development increases or intensifies the potential impact of landsliding is much greater.





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Specialist Geotechnical Consultants

Figure 11. Summary ground behaviour map of the Undercliff.

Chapter 5
Landslide Management in the Undercliff

Introduction

1991 saw a major change in the way landslide and ground movement problems were managed within the Undercliff. Prior to that date individual problems were viewed as "Acts of God" : unpredictable, entirely natural events; and were tackled on a "one-off" basis. Since the publication of the results of the DoE Study[1] on the problems encountered in the Ventnor area, a range of landslide management techniques (**Box M**) have been promoted by the local authority, South Wight Borough Council, as part of a coordinated **Landslide Management Strategy**.

The Strategy aims to:

- reduce the likelihood of future movement by controlling the factors that cause ground movement;
- limit the impact of future movement through the adoption of appropriate planning and building controls.

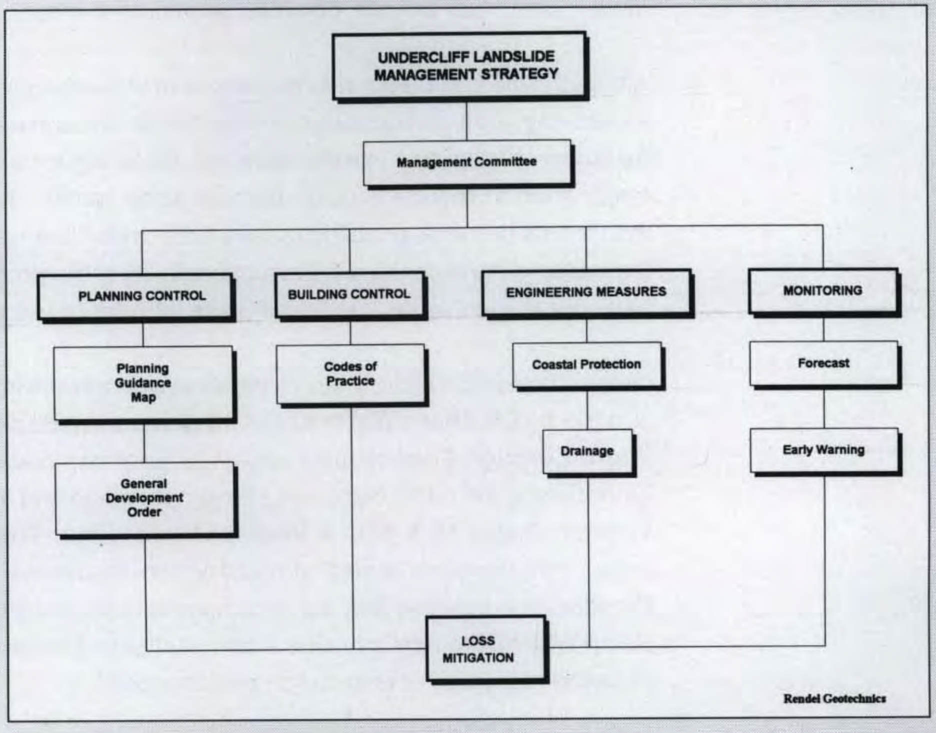
The implementation of the strategy has required careful coordination, bearing in mind that it involves influencing the attitudes and behaviour of the whole community: the planning authority, developers, insurers, lenders, property agents, builders, the statutory undertakers and not least the general public. A **Landslip Management Committee** meets three times a year to enhance professional and public awareness of how the strategy is being implemented and to monitor its effectiveness. This committee comprises representatives from:

- South Wight Borough Council (Chairman)
- The Isle of Wight Joint Planning Unit
- County Surveyor's Department, Isle of Wight County Council
- Southern Water Services Limited
- British Gas (Southern)
- British Telecom
- Southern Electric
- Association of British Insurers
- Building Employers Confederation
- Nationwide Surveyors
- Rendel Geotechnics (observers)

The strategy involves a variety of approaches to address the ground movement problems by:

- **improving ground conditions** through the control of water in the ground and coast protection measures;
- **preventing unsuitable development** through planning control and building control;
- **monitoring ground movement** and weather conditions at automatic and manual recording stations;
- **raising professional and public awareness** through displays and meetings.

Box M Landslide Management



Responsibilities of Key Agencies

Local Authority	• *tighter planning control* • *improved building standards* • *coast protection* • *early warning system (graben)* • *monitoring* • *forecasting* • *control of construction activity* • *retaining walls* • *shallow geophysics* • *swimming pools* • *groundwater lowering*
Water Authority	• *water supply* • *sewers*
Developers & Builders	• *adequate site investigation* • *improved design of buildings and structures* • *adequate slope treatment measures*
Property Owners	• *repairs and precautionary measures* • *maintenance*
Estate Agents, Solicitors, Insurers	• *awareness of variable ground movement problems* • *flexible approach*

Improving Ground Conditions

The cause of many of the ground movement problems can be linked to a combination of high groundwater levels and erosion by the sea, as described in Chapter 3. Measures which control these factors are likely to reduce the likelihood of future movements; they will not, however, eliminate the risk.

Although little can be done to prevent rainfall seeping into the ground and raising the water table, artificial surcharge of water levels through leaking pipes can be controlled. **Southern Water** has introduced water metering for all properties and has made a major effort to reduce leakage from its water mains. A telemetry system is used to monitor the network, enabling repairs to be undertaken promptly. Water services from the meter to the property are the responsibility of the **property owner**. Here, metering has encouraged owners to repair leaks in order to reduce their water bills.

Concerns over the state of the Victorian sewer network in Ventnor has led to two recent surveys by **Southern Water** to identify damaged pipe sections. In early 1991, **South Wight Borough Council** (then agents for Southern Water) carried out a major scheme for replacing the badly disrupted sewer network in and around the Esplanade area of Ventnor (Plates 16 & 17). A **Ventnor Wastewater Treatment Scheme** is currently under consideration, aimed at meeting the requirements of the EC Bathing Water Directive; the scheme may be accompanied by a programme of sewer replacement. South Wight Borough Council is also investigating the possibility of providing first time sewerage for parts of Bonchurch and Steephill.

Roofwater is normally disposed of through soakaway drains. These arrangements are not best suited to conditions within the Undercliff, because of the need to control water entering the ground. The council has, therefore, recognised the need for new properties to be connected to an existing system wherever possible to try and ensure that stormwater is directed into natural drainage channels rather than directly into the ground.

Following the recommendations made by the DoE study, special efforts have been made to reduce the effects of coastal erosion along the developed Undercliff. **Coast protection schemes** undertaken by South Wight Borough Council with financial assistance provided by the Ministry of Agriculture, Fisheries and Food (MAFF) and the Isle of Wight County Council have been completed at:

- **the Western Cliffs**; a 1.1km frontage protected by 30,000 tonnes of rock armour (Plate 18);
- **Monks Bay**; a combined scheme involving the construction of a rock breakwater, rock groynes, beach nourishment and slope stabilisation measures.

Improvements to seawalls have been undertaken at Steephill Cove (Plate 19), part of the Western Esplanade at Ventnor, and at Wheelers Bay. Further protection measures are planned for Horseshoe Bay at Bonchurch, the Eastern Esplanade in Ventnor, Ventnor seafront, Castle Cove at Steephill and Woody Bay at St. Lawrence. It is estimated that £5.5 million will have been spent on improving the coastal defences along the Undercliff by 1995.

Plate 16. Sewer improvement works, Ventnor Esplanade.

Plate 17. Flexible joint connections to main sewer.

Plate 18. Coastal protection works, Western Cliffs, 1990.

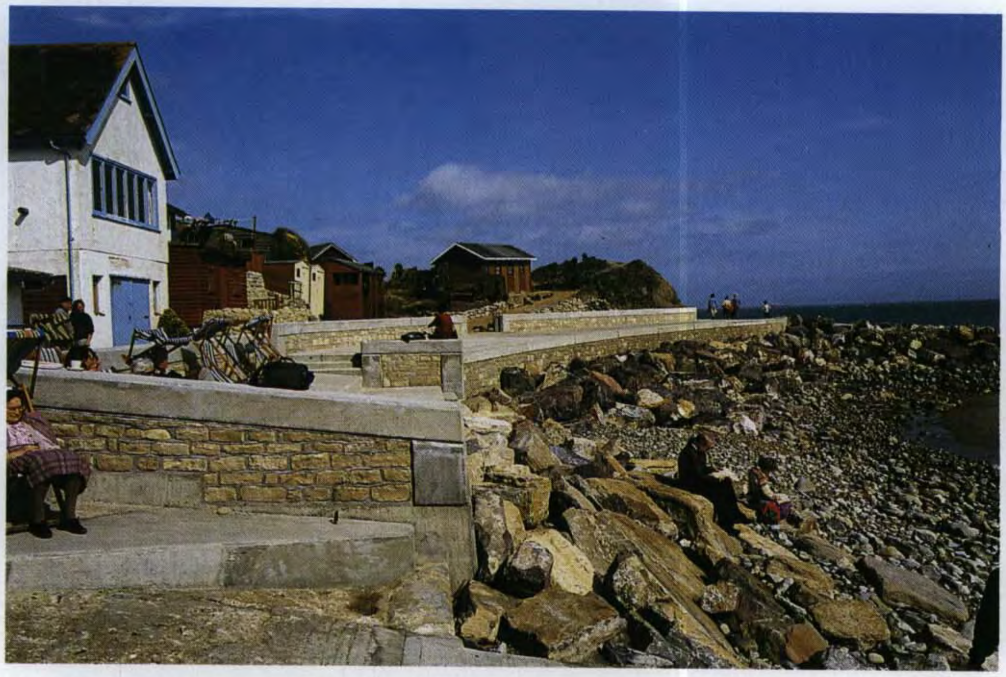


Plate 19. Coastal protection works, Steephill Cove, 1991.

Preventing Unsuitable Development

A central theme of the Undercliff landslide management strategy is to ensure that development is compatible with ground conditions and is not encouraged where the likelihood of movement is high. New property within the Undercliff must be capable of withstanding movement and not lead to a worsening of slope stability at the site or on adjoining land. These requirements are overseen by the Council through the **Planning System** and application of the **Building Regulations (Box N)**.

Developments in Great Britain require planning permission. Local planning authorities are required and empowered under the Town and Country Planning Act 1990 to control most forms of development and are responsible under the Building Regulations and the Housing Acts for ensuring standards of construction of development. When reviewing an application for planning permission the local authorities, in England and Wales, have a duty to take into account a range of material considerations, which include potential land instability problems (e.g. ground movement and landsliding). The main aims of considering potential landslide problems at this stage in the planning process are:

- to minimise the risks and effects of landsliding on adjoining property, services, structures and the public;
- to help ensure that various types of development should not be placed in unstable locations, without appropriate precautions;
- to enable unstable land to be appropriately used;
- to assist in safeguarding public and private investment by a proper appreciation of site conditions and the necessary precautionary measures.

The Department of the Environment has recently issued Planning Policy Guidance[2] which advises local authorities, landowners and developers on the role of planning controls as a landslide management tool. The purpose of the guidance is not to prevent development (although in some cases this may be the best response) but to ensure that development is suitable and to minimise undesirable consequences such as property damage or degradation of the physical environment. However, the responsibility for determining whether land is physically suitable for a proposed development and the appropriate technical measures to protect that development, lies with the developer and or the landowner.

The basic principle of the Isle of Wight Structure Plan (which is currently in deposit draft form) is that development should take place within existing built up areas and the remainder of the island is considered countryside where there is a general presumption against development. In addressing all instability matters over the Island the County Council's approach is clearly set out in policy D9 of the plan which states:

> "Development of areas known to suffer from instability will not normally be permitted, unless the local planning authority can be satisfied that the site can be developed and used safely and not add to the instability of the site or adjoining land".

South Wight local planning policies are also currently under review for inclusion within a Unitary Development Plan Part II and may contain policies that recognise the issues of instability and poor ground conditions. Detailed areas have been identified on

Box N Background to the Planning System and Building Regulations

The Planning System

The planning system is designed to regulate the development and use of land in the public interest. It is an important instrument for protecting and enhancing the environment, and reconciling the interests of conservation with development. The principal planning legislation is contained in the Town and Country Planning Act 1990. Important amendments are contained in the Planning and Compensation Act 1991.

The powers provided by the 1990 Act are exercised by local planning authorities (Isle of Wight County Council and South Wight Borough Council). The two most important functions of planning authorities are the preparation of development plans, and control of development through the determination of planning applications. All planning decisions must be made in accordance with the policies and proposals presented within the development plan, unless material considerations indicate otherwise.

Recent DoE planning guidance has stressed the need to take instability issues into account at all stages of the planning process (PPG 14 "Development on Unstable Land"). This document unequivocally states that:

"the stability of the ground, in so far as it affects land use, is a material consideration which should be taken into account when deciding a planning application" (PPG 14 para 20).

The aim of the advice contained within PPG 14 is not to prevent the development of unstable or potentially unstable land, though in some cases this may be the appropriate response. Rather it is to ensure that development is suitable and that both natural and man-induced physical constraints on land use are considered at all stages of planning.

Local planning authorities do not owe a duty of care to individual landowners when granting planning permission and are not liable for losses caused to neighbouring landowners. However, where development is proposed on unstable or potentially unstable land, the planning authority should ensure that a number of issues are adequately addressed by the proposal (PPG 14 para 22):

- *the physical capability of the land to be developed;*
- *possible adverse effects of instability on the development;*
- *possible adverse effects of the development on the stability of adjoining land, and;*
- *possible effects on local amenities and conservation interests of the development and of any remedial or precautionary measures proposed.*

The third procedure involves submitting a Building Notice together with a site plan and certain specific information to the local authority. The work will normally be inspected as it proceeds, although an approval notice will not be given. This approach does not give the developer the protection afforded under the 1984 Act (S.36(5)) (i.e. that the local authority may not issue a Section 36 Notice (to pull down work) if the work is built in accordance with plans they have passed.

The local authority must be given a Commencement Notice 48 hours before proceeding with the works. In addition notification must be provided at least 24 hours in advance before covering the excavations for foundations or a damp course. Further notification requirements are listed in the Regulations.

Continued/...

The Building Regulations

Building regulations are made by the DoE and Welsh Office to secure "the health, safety, welfare and convenience of persons in and about the building" (The Building Act 1984, S1(1)) and provide a complementary mechanism to the planning system for addressing instability issues during development. The 1991 Building Regulations drew the building industry's attention to the problems that landslides and subsidence may cause to a building and the surrounding area:

"The building shall be constructed so that ground movement caused by:
(a) swelling, shrinkage or freezing of the subsoil; or (b) landslip or
subsidence, in so far as the risk can be reasonably foreseen, will not
impair the stability of any part of the building" (Requirement A2).

Landsliding clearly is a factor that needs to be taken into account before proceeding with the design of certain buildings or their foundations. Indeed, the 1991 Regulations drew attention to the availability of relevant information held in the National Landslide Databank for Great Britain.

The Building Regulations apply to building work in general, control of services and fittings and material change of use. However, there are exemptions such as greenhouses and agricultural buildings, temporary buildings, small detached buildings and extensions. The local authority Building Control Department has to see that building work complies with the Regulations. If the work fails to comply, the developer may be required to alter or remove it.

A person intending to carry out building work or make a material change of use may either:

- *deposit full plans with the local authority;*
- *use the private certification procedure;*
- *give a building notice.*

For a full plans application, plans need to be drawn up showing all constructional details. The application should be submitted to the local authority who will thoroughly check the plans and, if they comply with the Regulations, issue an approval notice. In other instances a conditional approval may be issued. A notice of rejection must specify the defects or grounds on which the plans have been rejected. The local authority will normally inspect the work as it proceeds.

The private certification procedure is controlled by the Building (Approved Inspectors) Regulations 1985. The only Approved Inspector at present is the National House-Building Council (NHBC). The system involves the developer and inspector jointly notifying the local authority by the issue of an Initial Notice. Once that has been accepted by the local authority, the Approved Inspector is responsible for the supervision of the building work and will issue a final certificate when the work is completed.

1:2,500 scale maps of Ground Behaviour and Planning Guidance that have been prepared for much of the Undercliff. Areas are identified which are likely to be physically capable of development along with areas which are either subject to significant constraints or are likely to be unsuitable.

The determination of planning applications for development in the Undercliff will need to take possible ground movement problems into account even if acceptable in land use policy terms. The Council may reject outright any built development proposals in areas considered to be unsuitable or insist on particular conditions being met before granting planning permission. In all instances it is the developer's responsibility to investigate the potential problems on and around a site and to satisfy the planning authority that adequate attention has been paid to ground movement in the proposed building design.

The nature of investigation required by the planning authority will depend on the type of development that is proposed and the potential instability problems anticipated at the site, taking into account the ground conditions shown on the 1:2,500 scale maps of **Ground Behaviour** and **Planning Guidance**. Three levels of investigation may be required, as follows:

- desk study; involving a review of available information relating to instability problems in and around the proposed development site;
- site survey; an inspection of the site and surrounding area should be carried out to assess the geomorphological context of the proposed development and to identify any recent ground cracking or structural damage to property;
- ground investigation and subsurface investigations involving trial pitting, boreholes and groundwater monitoring may be required in certain areas of the Undercliff. However, it is recognised that the extent of any investigation should be realistic, otherwise the cost of obtaining stability information might act as a restriction on development.

These criteria are being used by the planning authority to ensure that development is suitable and does not lead to further instability problems. For example, proposals for the major capital investment programme associated with the Ventnor Wastewater Treatment Scheme have been accompanied by extensive geotechnical investigations to establish the potential problems that need to be considered in designing the various elements of the project.

The procedure for handling planning applications is shown in Figure 13 which highlights the value of prior consultation between developers and the planning authority **before** the application is submitted. The authority then determines whether a proposed development should proceed, taking into account all material considerations of which instability is only one. If development is approved, it is then the authority's responsibility under the **Building Regulations** to determine whether the detailed design of the structure can be built and used safely. Even though the local authority may have granted planning permission, the responsibility and subsequent liability for safe development and secure occupancy rests with the developer and or landowner. The Building Regulations are made by the DoE to secure "the health, safety, welfare

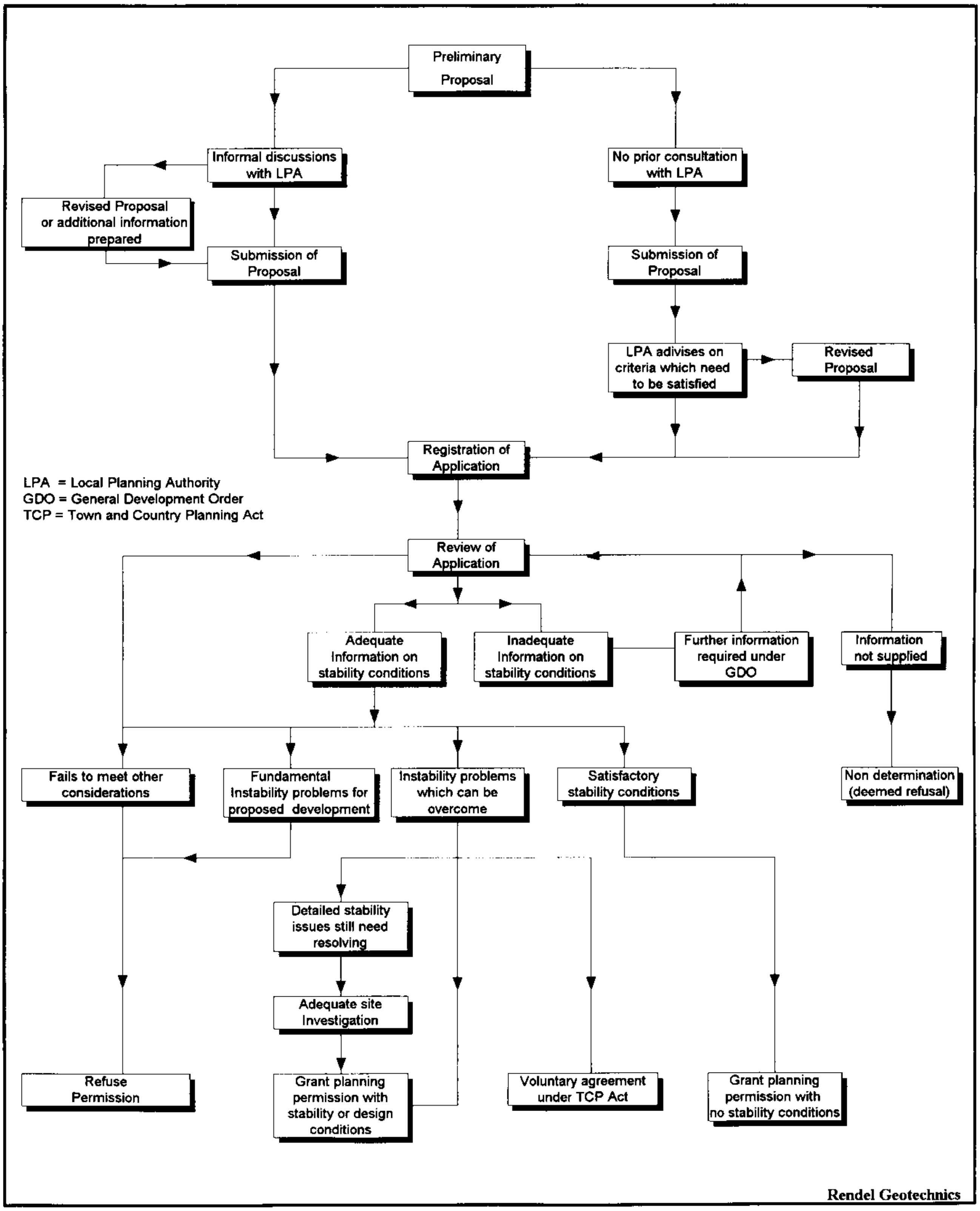
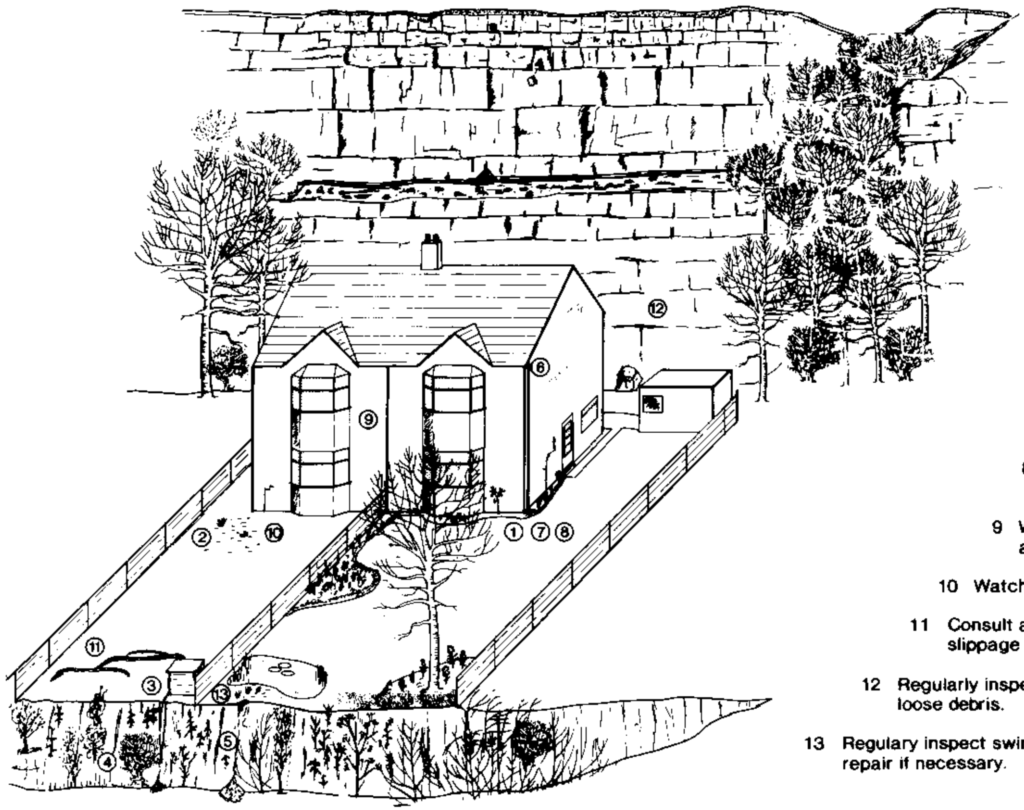


Figure 13. Procedures adopted for the handling of planning applications within the Undercliff.



DON'Ts

1 Don't block or alter ditches or drains.

2 Don't allow water to collect or pond.

3 Don't shift your water or soil problems downslope to your neighbours.

4 Don't landscape the slope without notifying the Local Authority.

5 Don't clear vegetation off slopes without replanting.

DO's

6 Check roof drains, gutters and downspouts to make sure they are clear, particularly prior to each winter.

7 Clear drainage ditches and check them frequently during winter.

8 Make inspections during winter– this is when problems can occur.

9 Watch for water back-up inside the house at sump drains and toilets, since this indicates drain or sewer blockage.

10 Watch for wet spots on the property.

11 Consult an expert if unusual cracks, settling or land slippage occurs. Inform Local Authority of any problems.

12 Regularly inspect scarp slopes for potential rockfalls or loose debris.

13 Regulary inspect swimming pools and ponds for leaks and repair if necessary.

Figure 14. Suggested good maintenance practice for homeowners.

and convenience of persons in and about the building", under the Building Act 1984. They provide a complementary mechanism to the planning system for addressing ground movement problems, by ensuring that appropriate foundations and building types are used in problem areas and that they are properly checked during construction. Improvements in building standards and home maintenance (Figure 14; Plate 20) can lead to a reduction in the impact of future ground movement and, hence, an advisory **Code of Practice** is currently being prepared by South Wight Borough Council. It is expected that this code would cover siting of buildings, earthworks, retaining walls, groundwater control, drainage, advice with respect to septic tanks and soakaways, flexible service connections, foundation design, building form, height, loading and structure.

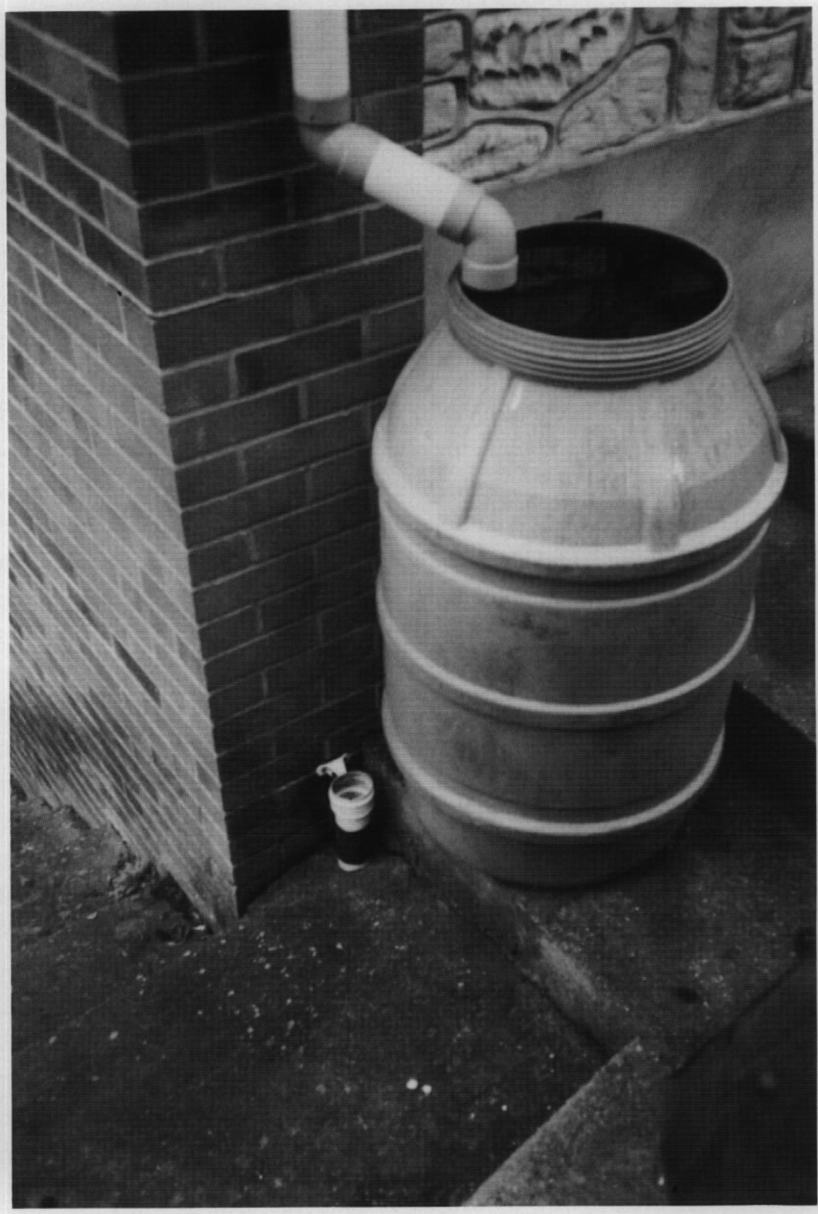


Plate 20. Water butt with no overflow connection.

Monitoring Ground Movement

Although the maps of Ground Behaviour developed by the DoE study were based on the most complete picture of the nature and extent of ground movement problems in Ventnor, it was recognised that there was little reliable information about the precise rates of movement and the effects of specific rainfall events. As a result an automatic surface monitoring network was installed by South Wight Borough Council in Ventnor in March 1992, comprising an automatic weather station at Ventnor Park (Plate 21) and surface movement recording stations (Plate 22) at Newport Road, Bath Road, the Winter Gardens and Castle Court (**Box O**).

The objectives of the monitoring are:

- to provide early warning in areas where ground movement could lead to the disruption of services and infrastructure, as at Newport Road;
- to determine the rate and scale of ground movements in vulnerable locations;
- to identify links between ground movement, rainfall and groundwater levels that can be used to develop a method of landslide forecasting;
- to provide the necessary information to update the Ground Behaviour and Planning Guidance maps;
- to monitor the effectiveness of the landslide management strategies.

In addition to the automatic systems, the Council have initiated a policy for periodic surveys of vulnerable sites and re-survey of Ordnance Survey bench marks to monitor any changes in ground elevation throughout the Undercliff.

Raising Professional and Public Awareness

Following the publication of the DoE Study it was recognised that central to the success of the work was the dissemination of information to the community. Following publication of the Ventnor Study in March 1991 seminars were arranged by South Wight Borough Council to explain the results and implications of the work to the Town, Borough and County Councillors; statutory undertakers; local estate agents; engineers; surveyors and solicitors; the Association of British Insurers; and the Press.

A free information leaflet was produced which advised the public on what the survey revealed and what they should do to try and control the problems, emphasising the need to prevent water leakage. South Wight Borough Council also funded a three month public awareness programme during which time a shop was rented in Ventnor High Street and manned by two of the consultant's team who had carried out the study. Display boards explaining the results of the study were mounted on the walls, together with copies of the 1:2,500 scale Geomorphology, Ground Behaviour and Planning Guidance Maps. Over 2,000 people visited the shop where they were able to view the display and discuss the results of the study with the geotechnical consultants; residents found this consultation exercise extremely valuable.

The landslide management committee has provided a forum for the coordination and dissemination of information amongst the professional agencies, such as the statutory undertakers, the NHBC and Association of British Insurers, whilst the local authority maintains a close association with the Press.

Plate 21. Automatic weather station, Ventnor Park.

Plate 22. Movement monitoring logger station.

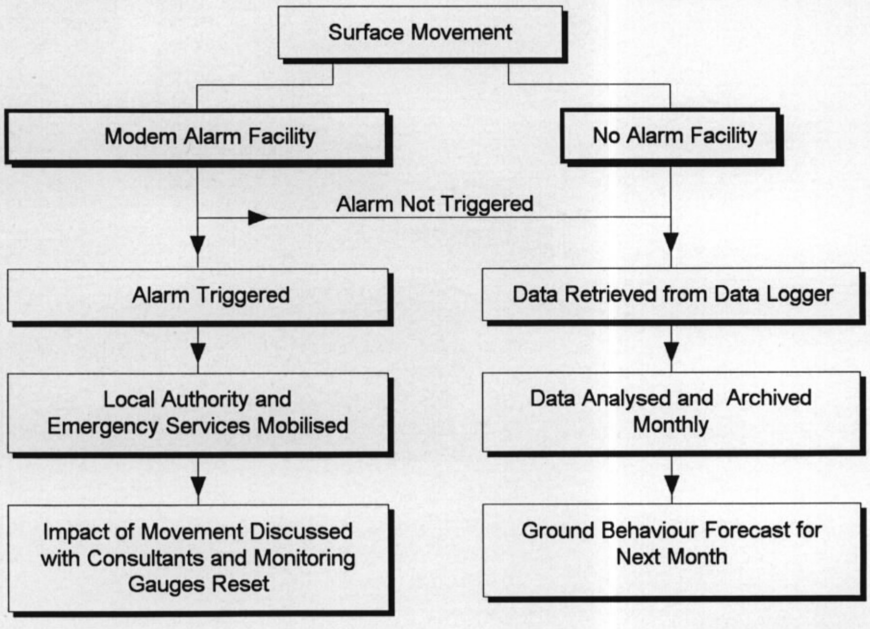
Box O South Wight Borough Council's Automatic Surface Monitoring Network

An automatic monitoring network was installed in Ventnor in March 1992. The system comprises a weather station at Ventnor Park and surface movement monitoring stations at Newport Road, Bath Road, the Winter Gardens and Castle Court. Fluctuating groundwater levels are also recorded at the Winter Gardens. Vertical and horizontal movements are recorded by means of ***settlement cells*** *and* ***crackmeters****, respectively. Readings are taken automatically at 30 minute intervals at all stations and recorded on* ***data loggers****.*

The types and number of gauges installed at each site are as follows:

- *Newport Road* - *2 settlement cells*
  - *2 crackmeters*
- *Bath Road* - *1 settlement cell*
  - *1 crackmeter*
- *Winter Gardens* - *1 settlement cell*
  - *2 piezometers*
- *Castle Court* - *1 settlement cell*
  - *1 crackmeter*

A monitoring strategy has been put in place and involves the monthly review of weather data and ground movement. An alarm facility and telemetry link has been installed at the Newport Road Station to provide an early warning of ground movement should this exceed a predetermined amount (50mm movement between consecutive readings). In this way the appropriate authorities and services will be immediately notified when significant ground movement take place, and appropriate action taken.



Rendel Geotechnics

In 1993 South Wight Borough Council carried out a survey of some thirty insurers to determine whether the results of the DoE study were influencing their attitudes to the problems in Ventnor. This survey revealed a number of interesting points:

- many insurers now recognise that some past claims were due to factors such as neglect and poor building rather than landslide damage;
- some insurers now use the land categories shown on the Planning Guidance maps to support their decision-making. This is seen as a positive move, with the assessment of insurance risk now reflecting the variation in ground behaviour within the Undercliff and not based on an unrealistic picture of the problems such as by postcode;
- insurers are now increasing the level of excess (i.e. the amount of each claim paid by the policyholder) to encourage owners to maintain their properties rather than allow them to deteriorate and then seek relatively small claims for "landslip and subsidence".

Concern has been expressed throughout Great Britain over the use of **postcodes** for zoning insurance. The Ventnor postcode, for example, extends some 9km inland from the Undercliff leading to an unrealistic and arbitrary assessment of landslide risk over much of the area. The publication of the Consumer's Association magazine "**Which**" in 1993 highlighted these issues and appears to have led to some insurers reappraising their procedures. Several companies have taken positive action and have visited the Council to discuss it's landslide management strategy, with a view to providing a more realistic and factual basis for assessing premiums.

Clearly it will be many years, involving a long term education exercise, before building standards and household maintenance standards improve sufficiently to reduce insurance claims and premiums. The publication by the Council of a code of good practice for property repair and maintenance, and for new construction within the next year is seen as a key aim. However, it should be stressed that positive steps are being made towards ensuring that insurance companies, together with mortgage lenders, estate agents and solicitors, support their decision-making with an awareness of the range of ground conditions within the Undercliff, recognising that many areas have remained largely unaffected by the effects of ground movement over the last 200 years or so.

The results of the Ventnor Study and the more recent work have also been widely presented at conferences and in journals with national and international audiences[3,4,5,6,7]. In April 1991 the Institution of Civil Engineers held their annual conference at Shanklin, on the Isle of Wight, entitled Slope Stability Engineering[3]. Eleven papers were presented on topics about the Undercliff during an Isle of Wight session, six of which were on the DoE Ventnor Study[1]. Guided tours were also held during which the geotechnical consultants and Borough Surveyor's staff illustrated the findings of the work.

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2. DoE, 1990
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5. Moore, Lee and Clark, 1992
6. Clark, Lee and Moore, 1994
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CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

Introduction

Ventnor, St.Lawrence and Bonchurch lie within an ancient landslide complex known as the Undercliff, which extends from Dunnose in the east to Blackgang in the west. Whilst the largely undeveloped extremities of the Undercliff have been subject to large scale movements (eg. the Blackgang Landslide in January 1994), historical records of movement rates show that over the last 200 years most of the area has suffered only slow to insignificant movement. Indeed many of the old buildings within the Undercliff show little or no sign of structural damage. In other locations many of the Victorian properties were built with foundations and building styles quite unsuited to accommodating ground movements while other properties were not well constructed or have suffered from inadequate maintenance. As a consequence the landslide problems have appeared to be more serious and less manageable than they should.

Throughout much of the developed Undercliff the long term rates of ground movement have been less than 5mm per year and many areas have remained inactive over the last one hundred years. Periods of instability have been related to heavy rainfall and coastal erosion. By developing a rainfall and ground movement monitoring programme as part of an overall Landslide Management Strategy a systematic approach is being adopted by South Wight Borough Council towards the reduction of landslide hazard. The strategy involves:

- modifying the hazard to the community by means of engineering works, coastal protection, improved building practice;
- effective planning control to avoid development in unsuitable areas and control the nature of new development;
- improving the understanding of landslide behaviour;
- mitigating the costs of ground movement through Insurance, etc;
- co-ordinating the community responses to the problems.

Recent research commissioned by South Wight Borough Council has increased the knowledge and extent of understanding beyond the built-up area of Ventnor to include most of the Undercliff from Luccombe to Blackgang. Media coverage of the landslide events at Blackgang in January 1994 could lead to a public perception that the whole of the Undercliff (and indeed the Isle of Wight) is affected in this way. It is most important that the landslide problems affecting the Ventnor area are kept in perspective.

The town is built on a large landslide complex but fortunately the geological setting and the style of landsliding is such that movements are often concentrated in a few locations, and the intervening areas show negligible or no movement. Of the areas affected by movements a number of sites are already public open space or have been acquired for this purpose. Indeed there are few Victorian towns around the British coast which do not show damage to structures, roads or retaining walls for a variety of reasons such as clay shrinkage, subsidence or changes in ground water levels. It is also the case that many areas of the United Kingdom suffer from problems of instability, with most counties in England being affected to a lesser or greater degree.

The development and implementation of a Landslide Management Strategy by South Wight Borough Council involving education, physical works (eg. coast protection, drainage) and monitoring, together with improved planning and building procedures will assist in raising confidence in Ventnor from an insurance and financial development point of view. The use of sophisticated monitoring equipment (for ground movements and rainfall) will, in time, improve prediction of ground movement events and enable changes to be monitored.

Could the Pattern of Ground Movement Change?

A positive approach to co-ordinating the community's response to the landslide problems is considered essential. Indeed, to effectively reduce the impact of ground movements in the urban areas, planners, developers, builders, utility companies, estate agents, solicitors, insurers and property owners should liaise and recognise the needs of all the parties involved.

The behaviour pattern of the landslides over the last 200 years or so has been well established by the earlier DoE study and the subsequent extension study carried out for this report, with detailed information available on the magnitude, frequency and impact of past events. A major landslide has not taken place in Ventnor over this time period, although large landslides have occurred at The Landslip (1810, 1818), Luccombe (1950, 1988), Gore Cliff (1799; 1839; 1928), Castlehaven (1994) and Blackgang (1978, 1994). If the past and present hold the key to the future then such events are unlikely to occur in Ventnor, Bonchurch and St.Lawrence in the medium term, especially if the landslide management strategies outlined in this report are adopted.

It may be unwise, however, to rely on past ground behaviour continuing unchanged in the future. Patterns of ground behaviour could alter significantly over the next hundred years, particularly in view of the climatic changes which are predicted to occur over the next few decades or in the event of increased development. Clearly, an on-going programme of monitoring and review of the ground behaviour and planning guidance maps is required.

The Benefits of Landslide Management

The co-ordinated landslide management strategies that have been developed and implemented by South Wight Borough Council for the Undercliff should help minimise risks to the communities through:

- guiding development away from unsuitable locations;
- ensuring that existing and future development are not exposed to unacceptable risks;
- ensuring that public safety considerations are addressed in potentially vulnerable areas;
- ensuring that development does not increase the risk to the rest of the community.

It is important that the public and financial institutions are fully aware of the nature of ground conditions throughout the Undercliff. Existing property in unstable areas will probably continue to experience damage due to ground movement; such areas must be avoided by future development. More stable areas are likely to remain free from significant building damage and may be successfully developed, so long as necessary stabilisation and monitoring measures are adopted and the developer is willing to accept, in some locations, a higher level of risk than would be expected in other circumstances.

Recommendations for hazard reduction

It is recommended that prompt action is taken to reduce hazard by commissioning the following surveys:

- a shallow geophysical survey to be carried out along a number of key access roads into Ventnor to identify the location of any unrecorded vents;
- a survey should be undertaken of all swimming pools and wells within the Undercliff to identify problems with leakage, and owners should be advised on drainage or emptying arrangements as appropriate;
- a survey should be undertaken to identify ownership and condition of all retaining walls to safeguard against a risk of collapse;
- a survey should be made with the assistance of property owners of scarp slopes, offering advice on management, and treatment if appropriate.

The following additional measures should be investigated in the short term:

- the extension of the monitoring system to key sites within the St. Lawrence Undercliff with particular reference to highway infrastructure;
- extend the existing monitoring to include a global monitoring system using satellite fixing of position and elevation;
- completion of plans in consultation with Southern Water Services Ltd., for first time sewerage schemes for Bonchurch and Steephill as identified by South Wight Borough Council;
- taking into account the additional information on ground behaviour, discussions should take place with the Planning Authority over the suitability of development within parts of the Undercliff, particularly with respect to drainage provision;
- management options should be prepared for resolving the problem of instability affecting sections of the A3055 Undercliff Drive at locations between St. Lawrence and Niton.
- investigation of drainage in the Niton Undercliff as part of the stability study of the Castlehaven area;
- discussions should be held with Southern Water Services Ltd., over the condition of water supply pipes and sewers within the Undercliff with the aim of developing an agreed programme for renewals as required;
- publication and distribution of advice to residents of the Undercliff with respect to the control of water leakage through service pipes, sewers, septic tanks and soakaways;
- discussions with the Highway Authority over the extent and condition of highway drainage provision.

Recommendations for further research

The effective management of ground movement problems in the Undercliff requires further research in a number of areas, including:

- the development of a GIS system to store and manipulate the monitoring information, including a capability to redefine ground behaviour classes, where appropriate, taking advantage of the existing DoE Coastal Planning Database for this purpose;

- to complete the study of the whole of the Isle of Wight Undercliff by commissioning a third and final phase from Niton to Blackgang, thereby providing the Niton Undercliff with similar detailed ground behaviour and planning guidance information. The available information on Castlehaven and Blackgang would enable this research project on the Undercliff to be completed economically;

- the development of a reliable method of landslide forecasting based on information provided by South Wight Borough Council's monitoring of ground movements, rainfall and groundwater;

- the consideration of the relative risks associated with rockfall activity along the Undercliff rear scarp;

- the examination of the priorities for coast protection along the Undercliff, taking account of conservation interests;

- the consideration of the costs and benefits of an engineered solution for the improvement of slope stability of the Undercliff by lowering groundwater levels, to include the consideration of drainage galleries or pumping from wells;

- the development of a Code of Practice for those involved with engineering, architectural and building works within the Undercliff, including the wider applications of this research within the EC;

- the development of experimental buildings plots in partnership with landowners in order to determine the suitability of foundation types and construction techniques with the aim of advising on good practice;

- the publication of a leaflet on basic property maintenance, particularly with respect to drainage, for distribution to residents;

- the publication of notes on coastal management and landslip issues for sale to students and schools to improve understanding and reduce the time currently allocated to student enquiries/interviews;

- to investigate the effect of sea level rise on coastal defences;

- to investigate the benefits of rock armour for beach development as well as coast protection;

- ongoing provision of data to the World Landslide Inventory and to partners within the Conference of the Peripheral Maritime Regions of Europe (CPMR) with the aim of establishing common themes for EC bids;

- the examination of the social implications of the results of this study and the DoE study and the effectiveness of the results in influencing decision-making by financial institutions.

Other general recommendations

- the local community should adopt a positive response to landsliding which has resulted in the magnificent Undercliff scenery. The coastal landslides represent a unique tourism and educational opportunity, through study centres, nature trails and short breaks. The publication of a colour guide to the unique geological features of the Undercliff and the habitats created should be considered;

- a series of meetings should be arranged with professional groups on the Isle of Wight to explain the results of research including insurers, building surveyors, architects, engineers, lawyers, estate agents and builders;

- the techniques adopted for management within the Undercliff could be adopted elsewhere on the Isle of Wight with these recommendations being considered when the Isle of Wight Shoreline Management Plan is prepared.

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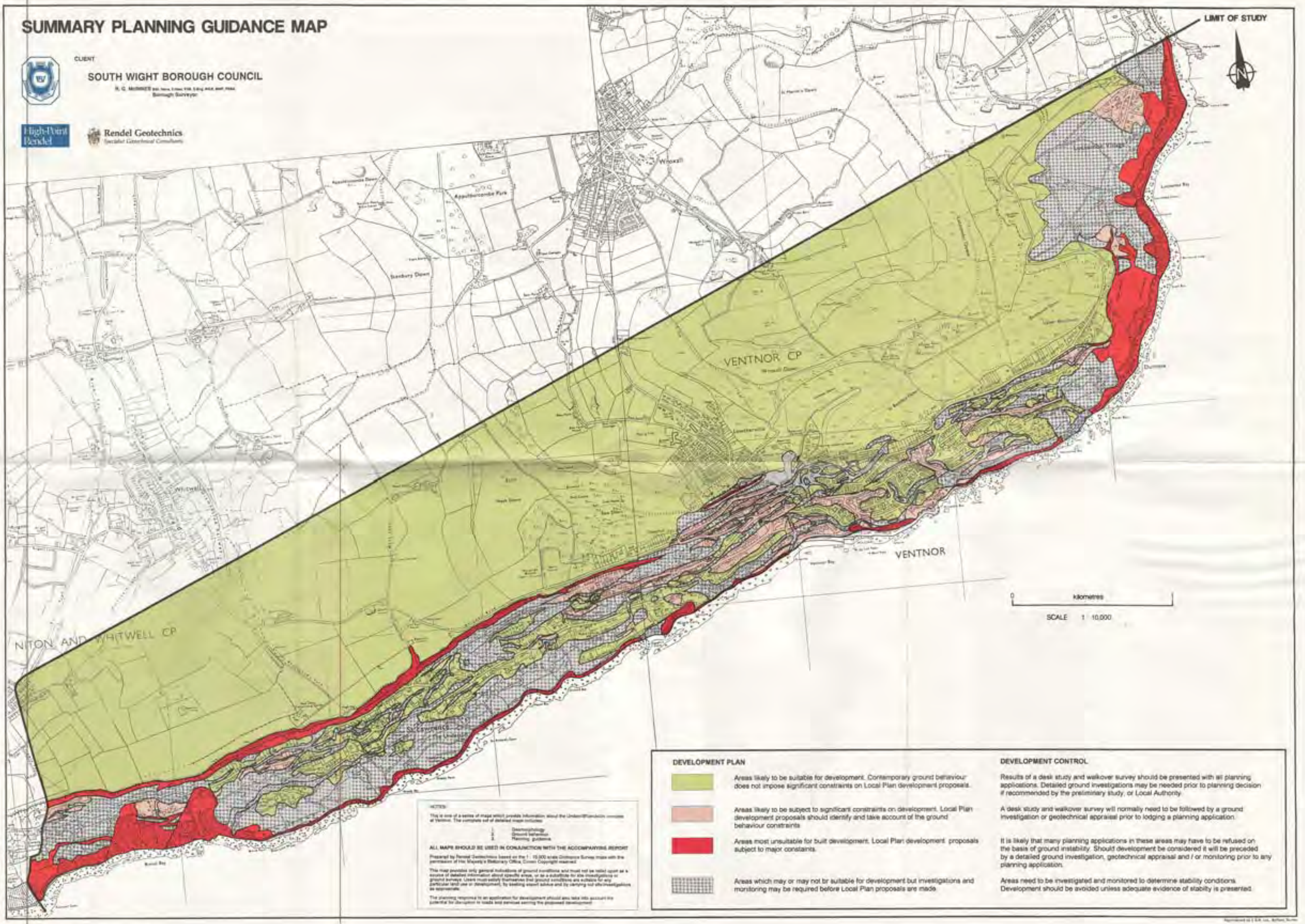
SUMMARY PLANNING GUIDANCE MAP
CLIENT
SOUTH WIGHT BOROUGH COUNCIL
Borough Surveyor
Rendel Geotechnics
LIMIT OF STUDY
VENTNOR CP
VENTNOR
NITON AND WHITWELL CP
kilometres
SCALE 1 : 10,000
NOTES
ALL MAPS SHOULD BE USED IN CONJUNCTION WITH THE ACCOMPANYING REPORT
DEVELOPMENT PLAN
Areas likely to be suitable for development. Contemporary ground behaviour does not impose significant constraints on Local Plan development proposals.
Areas likely to be subject to significant constraints on development. Local Plan development proposals should identify and take account of the ground behaviour constraints.
Areas most unsuitable for built development. Local Plan development proposals subject to major constaints.
Areas which may or may not br suitable for development but investigations and monitoring may be required before Local Plan proposals are made.
DEVELOPMENT CONTROL
Results of a desk study and walkover survey should be presented with all planning applications. Detailed ground investigations may be needed prior to planning decision if recommended by the preliminary study, or Local Authority.
A desk study and walkover survey will normally need to be followed by a ground investigation or geotechnical appraisal prior to lodging a planning application.
It is likely that many planning applications in these areas may have to be refused on the basis of ground instability. Should development be considered it will be preceded by a detailed ground investigation, geotechnical appraisal and / or monitoring prior to any planning application.
Areas need to be investigated and monitored to determine stability conditions. Development should be avoided unless adequate evidence of stability is presented.