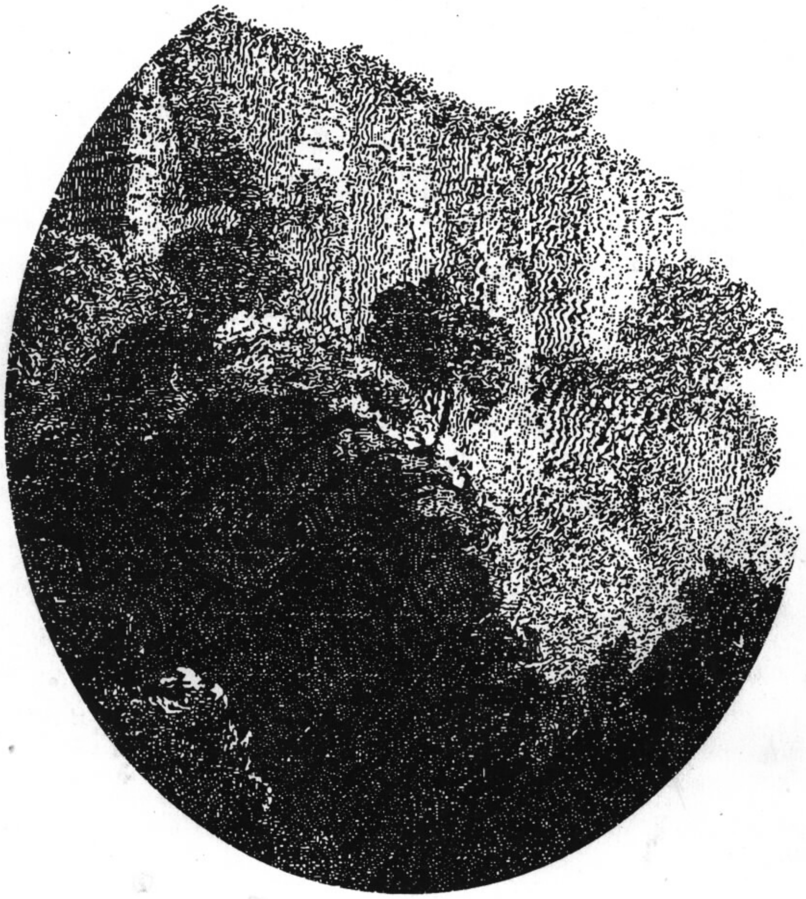
COASTAL LANDSLIP POTENTIAL ASSESSMENT:

Isle of Wight Undercliff, Ventnor



The Landslip, 1810.
"for three days successively the Earth heaved and sank", (Adams, 1856)

TECHNICAL REPORT

by

GEOMORPHOLOGICAL SERVICES LIMITED,

for the

DEPARTMENT OF THE ENVIRONMENT

Research Contract PECD 7/1/272

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EXECUTIVE SUMMARY

Much of Ventnor, Isle of Wight, lies within an ancient landslide complex, known as the Undercliff. Historical records of movement have been collected which indicate that, over the last 200 years, the town has long been subjected to slow ground movements, which have caused damage to property and services in a number of areas.

This study was commissioned by the Department of the Environment as part of its Planning Research Programme, and has 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 work undertaken has involved a thorough review of available records, reports and documents followed by a programme of detailed field investigation comprising geomorphological and geological mapping, photogrammetric analysis, a survey of damage caused by ground movement, a land use survey 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 allowed 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.

It is important to note that whilst Ventnor has a reputation for landslide movement, large areas of the town have remained largely unaffected. Thus, in many areas buildings have survived for long periods, such as Bonchurch Old Church, which is believed to be over 1,000 years old.

In addition, many of the older properties are poorly built with foundations and building styles completely unsuited to accommodating ground movement. 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 Ventnor. These include:

- **modifying the hazard to the community** by means of engineering works, controlling construction activity, preventing water leakage, improved building standards, coast protection etc;
- **effective planning control** to avoid unsuitable areas and control the nature of new development;
- **improving the understanding of the landslide problems,** by means of on-going monitoring and sub-surface investigation;
- **mitigating the costs of ground movement;**

There is no reason why there should not be confidence in Ventnor from a building insurance or financial development point of view. This is true so long as sensible use is made of the technical information presented in this report and obtained from future monitoring exercises, and the proposed landslide management strategies are practiced. Of course, unstable areas must be avoided where possible. More stable areas may be successfully developed, as long as stabilisation measures are adopted, if needed, and the developer is willing to accept, in some locations, a higher level of risk than would be expected in normal circumstances.

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Southern Water

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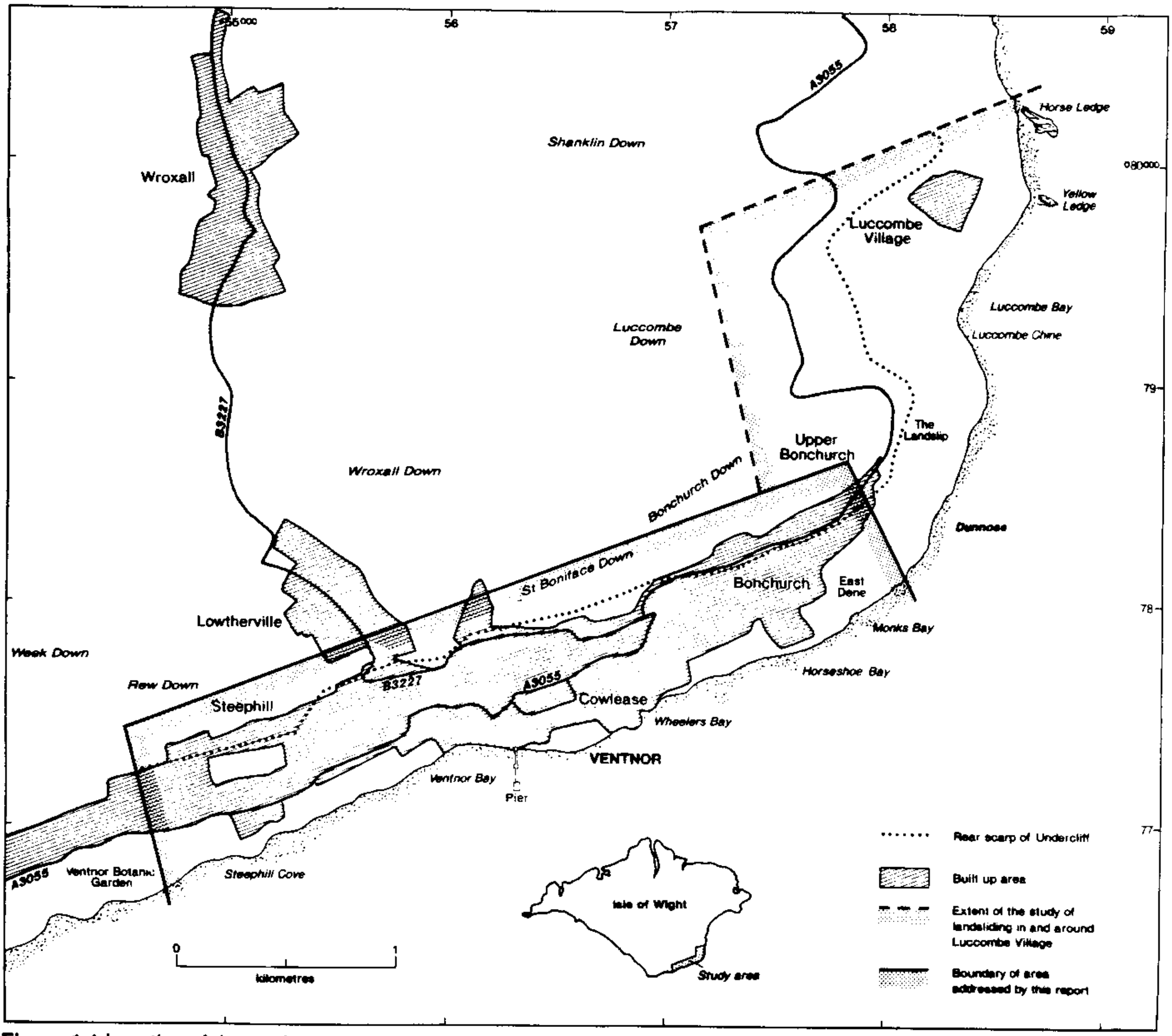


Figure 1.1 Location of the study area

1.1 BACKGROUND TO THE STUDY

The Department of the Environment (DoE) undertakes geological and related research as part of its Planning Research Programme, which includes studies of ground instability. Landslide research commissioned by the DoE has included the recently completed Review of Landsliding in Great Britain, carried out by Geomorphological Services Ltd in association with Rendel Palmer and Tritton. This major review identified a general need to develop improved methods of landslide potential and risk assessment, in order that land instability can be taken into account in land use planning and development decisions (Geomorphological Services Ltd., 1987).

In South Wales the DoE/Welsh Office have funded a series of projects as part of a strategy for landslide management in the region, including an assessment of landslide potential in the Rhondda Valley (Sir William Halcrow and Partners, 1986). This study identified a range of opportunities available to the Local Planning Authorities to reduce landslide risk to the community through land use policies and existing procedures of development control (Sir William Halcrow and Partners, 1988). However, it was thought likely that the methods developed in South Wales could not be simply transferred to other geological settings or geomorphological circumstances. Therefore the DoE commissioned a study of landslip potential for an area of younger rocks subject to coastal erosion.

The review of landsliding in Great Britain identified the Isle of Wight Undercliff at Ventnor as the largest urban development in an area of active coastal landsliding. Ventnor was selected as a suitable location for a study of coastal landslip potential because of the potential problems to existing dwellings and services, together with the need to develop methods for efficient land use planning.

This report presents the results of the DoE research contract PECD 7/1/272 entitled "*Coastal Landslip Potential Assessment: Isle of Wight Undercliff, Ventnor*". It outlines a range of approaches for responding to landslide problems which provide a basis for planning and development decisions in Ventnor, and a general methodology which might be used elsewhere.

1.2 THE AIMS AND OBJECTIVES OF THIS STUDY

The aims of this study were to :

(a) devise a method of landslip potential* assessment which is generally applicable to areas of coastal landslip in successions with interbedded poorly lithified and stronger rocks; and

(b) provide the essential information needed for planning development decisions in the Ventnor area by use of existing results and documents;

The objectives of this study were to :

(a) review and extend the existing database on landsliding in the Ventnor area;

(b) identify essential field investigations and monitoring needed for assessment of landslip potential;

(c) develop explanatory models of landslide processes in the area and to identify the key controlling influences;

(d) interpret the data in terms of landslip potential

(e) apply the methodology to the area and prepare a set of planning maps.

1.3 THE STUDY AREA

The area covered by this investigation is defined in Figure 1.1, and comprises two separate areas; "Ventnor" (from the Ventnor Botanic Gardens to the Monk's Bay area) and "Luccombe" (the area in and around the village of Luccombe). This report presents the results of the investigation of landslide potential within the Ventnor study area. A separate report has been prepared and published which describes the landslide problems in and around Luccombe (Lee and Moore, 1989).

Ventnor and neighbouring Bonchurch are situated on the south coast of the Isle of Wight, within an extensive area of coastal landsliding known as The Undercliff. The area has been an important tourist centre for over 150 years, with visitors attracted by the mild climate and outstanding coastal scenery. Although they both grew rapidly in the nineteenth century, there are important differences in character between Ventnor and Bonchurch.

The development of Bonchurch in the late 1830's and 1840's was influenced by the presence of Queen Victoria and her family on the Island, together with many literary figures such as Tennyson. This attracted many artists, poets and writers to the Undercliff, and brought both "society life" and wealth to Bonchurch. This is reflected by the many large Victorian properties which stand in their own grounds.

By contrast Ventnor owes its rapid development to a paper published by Sir James Clark, in 1829, entitled "The influence of climate in the prevention and cure of chronic disease". The health conscious Victorians flocked to Ventnor to "take the climate". Land from the Ventnor estate was quickly sold off to developers, with land prices rapidly rising from £100 to £400 per acre (McInnes 1989). "Development fever" spread through the town, and Ventnor became known as a place of speculators, jerry builders and bankruptcy (Chambers, 1988).

The diarist Mark William Norman described the town as an "El Dorado", with the town quickly emerging from "Obscurity to notoriety. In consequence there was a rush to it of all sorts and conditions of men from all quarters of the compass. Among them were builders without capital or credit or character, speculators some with capital who never raise a profit, needy adventurers would after engaging in building speculations were 'non est' on a Saturday night without paying their men.....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" (Norman, in Chambers, 1988).

The breakup of the Ventnor estate and its uncontrolled development meant that much of Ventnor was unplanned, and it was not until 1844 that well-ordered improvement works took place, following various Acts of Parliament (McInnes, 1989).

During the 1840's a Ventnor Improvement Committee was founded which attempted to overcome access problems and new roads were constructed (e.g. Mitchell Avenue, Zig-Zag Road). During the later part of the nineteenth century Ventnor developed as a series of long terraces of Victorian houses, often badly planned and poorly built.**

1.4 AN OVERVIEW OF LANDSLIDE PROBLEMS IN VENTNOR

In contrast to other parts of the Undercliff contemporary ground movements within Ventnor have been slight. However since these occur in an urban area with a permanent population of over 6,000, the cumulative damage to roads, buildings and services has been substantial. Over the last one hundred years, at least 50 buildings have had to be demolished because of ground movement. Chandler & Hutchinson, (1984) estimated that between 1960 and 1980 there was £1.5M (at 1980 prices) of landslide damage in the town, including costs of road maintenance and repairs to affected properties.

The problems of ground movement have long been recognised within the town. Evidence given by Aubrey Strahan of the Geological Survey, at the Royal Commission on Coast Erosion and Afforestation in 1906 highlighted the slow creep experienced in many parts of Ventnor; 'observations made upon houses, sewers and the flights of steps..., shows that the mass is still subject to slow intermittent movement' (Royal Commission on Coast Erosion, 1911). The view held at that time was that the problem was directly related to coastal erosion. Indeed, attempts to build a harbour, during the 1860s, in Ventnor Bay by removing a rocky headland (Collin's Point) resulted in beach depletion, increased coastal erosion, and landsliding along the coast (Whitehead 1911). The coastal erosion problems were recognised by Ventnor Urban District Council, which constructed a series of sea defences, including walls and groynes, along parts of the coast. However reports of ground movement continued throughout the first half of this century, especially along the coastal cliffs.

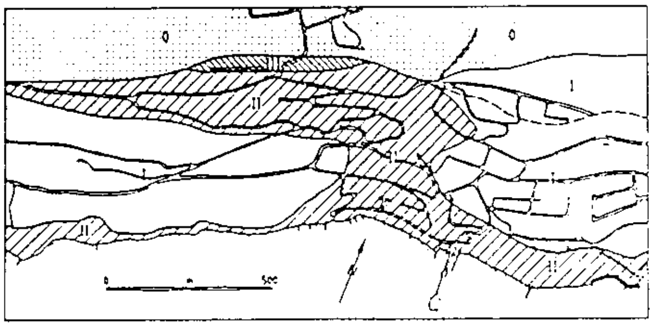
In 1954 the discovery of a series of deep fissures along Whitwell Road over 500m inland, caused considerable concern and gave an indication that the problems may be more complicated than previously perceived. Ventnor Urban District Council asked Edmunds and Bisson of the Geological Survey to inspect these fissures (known locally as vents) and to assess their significance. In a confidential report Edmunds and Bisson (1954) suggested that the vents may be the initial stage of the development of a major landslide, although such a failure has not occurred in the succeeding 35 years.

**FOOTNOTE: In this study hazard is defined as the probability of a landslide event occurring or having occurred in the past. Unstable slopes have, therefore, a potential for landsliding. At Ventnor, which lies on an ancient landslide complex, the hazard already exists and the potential has been realised. Of more significance, therefore, is the need to understand the contemporary ground behaviour i.e. how the landslide complex has behaved in recent years.*

***Further details of the development of Ventnor and Bonchurch are presented in Annex A together with a survey of current land use within the area.*

At the same time, Toms of British Railways was asked to look at the landslide problems in the town (Toms, 1955). He recommended that a comprehensive monitoring programme should be established in order to determine the scale of the problem. Following Toms' recommendations the Local Authority has collected records of structural damage within Ventnor since 1954. However, until recently, this has not included Bonchurch.

Further dramatic movements occurred during the winter of 1960-1961, following extremely high autumn rainfall. The extent of the damage was recorded by J.N. Hutchinson, who at that time was carrying out a series of coastal landslide studies in southern England for the Building Research Station (funded by the Department of Scientific and Industrial Research). At that time insurance claims for landslide damage totalled about £78,000 with a number of houses and hotels having to be evacuated and some subsequently demolished because of the extent of damage. On the basis of his observations and past records of movement along the Undercliff, Hutchinson (1965) felt that the area: "constituted by far the greatest landslip problem in the Isle of Wight, if not in Britain".



SYMBOL	RELATIVE PROBABILITY	DESCRIPTION
0	Negligible	Zone landward of rear scarp of pre-existing landslides, probably affected by ancient, slight movements, but free from current slope movements.
I	Low	Zone seaward of rear scarp of pre-existing landslides, either apparently free of slope movements, or exhibiting some of the conditions for intermittent instability.
II	Moderate	Zone affected occasionally by movements of small-moderate amplitude; or generally affected by diffuse movements; or exhibiting many of the conditions for intermittent instability.
III	High	Zone affected periodically by movements of moderate to large amplitude; or affected frequently by movements of small to moderate amplitude; or exhibiting many of the many of the conditions for general instability.

Figure 1.2: Preliminary landslide hazard assessment of Ventnor *(after Chandler and Hutchinson, 1984)*

Despite this concern no efforts were made to determine the scale of the landslide problems or to prevent further movement, although the Local Authority did continue to improve the coastal defences. Fortunately, after joining the Department of Civil Engineering at Imperial College, London, Hutchinson continued his research interest with the Undercliff landslides. Between 1979 and 1984 M P Chandler undertook an extensive programme of research on the geomorphology of the Undercliff landslides. This work formed the basis of a PhD thesis supervised by Professor Hutchinson, with the assistance of Dr E N Bromhead of Kingston Polytechnic (supported by a grant from the National Environment Research Council).

The main conclusions of Chandler's study have been published as a series of collaborative works with Professor Hutchinson and Dr Bromhead. Of particular importance is an assessment of the landslide hazard at Ventnor published in 1984 (Chandler & Hutchinson 1984), which attempted to divide the town into a series of zones reflecting the potential landslide hazard (Figure 1.2). This hazard assessment was also presented at the Standing Conference on Problems Associated with the Coastline held at Newport, Isle of Wight in April 1985 (Hutchinson *et al* 1985a), making a wider audience much more aware of the potential problems.

In recent years there appears to have been an increase in the ground movements in certain parts of the area, e.g. the Western Cliffs, where coastal erosion has damaged cliff paths (Anon, 1988a, 1988b,) and the continued subsidence of a graben-like feature in Upper Ventnor (Anon 1988c; McInnes 1989). These recent movements appear to have heightened public awareness of the situation. Many householders now face insurance problems, as described in a recent article in the Isle of Wight County Press:

> "just ten years ago subsidence was not a major issue and most mortgages and the subsequent building insurance cover was arranged without much thought given to it. However an increasing number of claims were made in the late 1970's and early 1980's and so, rightly, insurance companies began to give the subject more thought. Unfortunately for many of us some companies have reacted by pulling out of the Island, and, although they might still be covering some properties, they will not extend that cover if the occupant decides to sell up, obviously leaving that householder with a major problem on his hands. Some have taken a more considered view and although they are aware of risks in certain areas, they will look at each case on its merits, sometimes insist on a full structural survey themselves, and then make a final decision. Yet others fall between the two extremes and while they operate a no-go policy in certain areas, do not consider most parts of the island to be at risk. Commercial Union admit they operate a selective policy, refusing to cover property in certain areas although they would not disclose which areas and how extensive they were. The policy has been formulated in the last ten years with no-go areas decided by the number of claims they have paid out in that time".
> *(Anon 1988a).*

Local concerns about landslide problems have reached a point where many fear for the safety of local inhabitants. This fear was dramatically portrayed in an article in the Isle of Wight County Press in the summer of 1987, entitled *"Isle of Wight landslide could kill."*

The scale and extent of ground movements over the last two centuries fails to provide a precedent for this headline. However, it does serve to highlight the need to assess the significance of reported movements in the context of the known behaviour patterns of the landslide system. This can only be achieved by an improved understanding of both the nature and causes of the hazard. The statement also highlights the fact that natural hazards should be considered as predictable events that carry costs both to individuals and communities. Increased awareness of natural hazards is often followed by the need to apportion responsibility for the problems and greater requirement for the local authority or interested parties to reduce the risks.

In the past there appears to have been an *ad-hoc* response to specific landslide events in Ventnor, concentrating on repairing buildings, condemning properties or emergency action. Such crisis management responses after the event are common reactions to infrequent large-scale events throughout the world.

However in Ventnor, where ground movements are a recurrent problem there is a clear need for a coherent and systematic strategy for reducing the landslide hazard.

In Great Britain two studies commissioned by the Department of the Environment have identified appropriate management responses to land stability problems in different environments. In South Wales, Landslip Potential Planning Maps have been produced by Sir William Halcrow and Partners as an aid to planning control in Rhondda Borough (Halcrow, 1986, 1988). These maps were designed to provide planners with the appropriate data required to make effective decisions on the most efficient use of land, in accordance with the DoE Planning Policy Guidance "Development on Unstable Ground" (DoE, 1990). At a more local level, Geomorphological Services Ltd identified a range of landslide management strategies which could be adopted at Luccombe, Isle of Wight, to reduce the impact of continued landslide activity (Lee & Moore, 1989). It is clear that these studies, and others, point the way forward for Ventnor by recognising that **once there is a detailed understanding of the nature and extent of the landslide problems, management strategies can be formulated to reduce the consequences of future movement.**

It is important that the problems experienced in Ventnor are kept in perspective. It is widely appreciated that Ventnor has been built on a massive landslide complex and, as such, the potential exists for any part of the area to be subject to movement. Fortunatly, however, as this study will show the style of landsliding is such that the effects of contemporary instability are concentrated in a few locations and the intervening areas are slowly moving or have shown negligible or no movement in the recent past. The damage associated with ground movement over much of the town is not exceptional in that many other towns face comparable problems of collapsed retaining walls, damaged roads and cracked buildings for a variety of reasons other than from ground movement.

1.5 SCOPE OF WORK

A wide range of approaches are available to determine the nature and extent of unstable ground (Rendel, Palmer & Tritton, 1987). Common practice often involves an initial review of existing data, field investigations (such as geomorphological or geotechnical mapping) sub-surface investigation by means of boreholes and trial pits, laboratory testing of materials and data analysis (see Annex B). However, most investigations do not involve all of these aspects. The scope of the investigation will vary according to the specific study, be it for the design of a proposed engineering scheme or a land use planning application.

The way in which this study has investigated the slope instability problems in Ventnor has been different. It has been directed towards:

a) determining the nature and extent of the landslide complex;

b) understanding the past behaviour of separate parts of the landslide system;

c) formulating a range of management strategies to reduce the impact of future movement.

The work undertaken has involved a thorough review of available records, reports and documents followed by a programme of detailed field investigation comprising geomorphological and geological mapping, photogrammetric analysis, a survey of damage caused by ground movement, a land use survey and a review of local building practice (Figure 1.3). These results have provided an understanding of the landslide complex at Ventnor especially:

(i) the nature and extent of the individual landslide systems;

(ii) the types of contemporary ground movement;

(iii) the magnitude of contemporary ground movement;

(iv) the frequency of landslide events;

(v) the impact of ground movement on the town;

(iv) the nature and extent of property at risk;

(vii) the vulnerability of different styles of construction to ground movement.

The wealth of information gathered on each of these topics has been collated and stored in a computer-based Geographical Information System (GIS) for ease of data retrieval and analysis. By studying the spatial and temporal relationships between these different data sources it has been possible to identify a range of factors that have influenced both where and when landslide events have occurred since reliable records began.

Use of a GIS has allowed a flexible objective approach to assessing contemporary ground behaviour in Ventnor. Thus, it has been possible to avoid making subjective judgements about the relative hazards associated with the different types of ground movement that occur in the town. In addition, through the GIS it is possible to update the database as more information becomes available, and to improve the ground behaviour assessment accordingly.

The detailed understanding of the behaviour of the landslide systems in Ventnor, together with a knowledge of the vulnerability of different styles of construction and the property at risk in different areas, has been used to formulate a range of outline management strategies designed to reduce the impact of future movements. These strategies include:

(a) effective planning control to avoid unsuitable areas and to control the nature of new development;

(b) modifying the hazard to the community by means of engineering works, coastal protection, improved building practice etc;

(c) improving the understanding of the landslide behaviour;

(d) mitigating the costs of landsliding through insurance etc;

(e) co-ordinating community responses to the problems.

Reference has been made to all available and relevant sub-surface information. However, a detailed sub-surface investigation has not formed part of this study because of the prohibitive cost that would be involved if an adequate investigation were to be undertaken on such a large and complex landslide system. It is recognised that without a major research effort to determine sub-surface conditions on which to model the landslide mechanisms, a behaviour map which forecasts future patterns of movement in response to changing environmental conditions is difficult to attain. The models of landsliding presented in this report are, thus, inferences made from the information available at the time of the study. Whilst some aspects of the models can only be verified by detailed sub-surface investigation, they nevertheless do provide a reasonable basis for understanding general planning and development control principles. However, they do assist in identification of parts of the area within which sub-surface investigation are most needed.

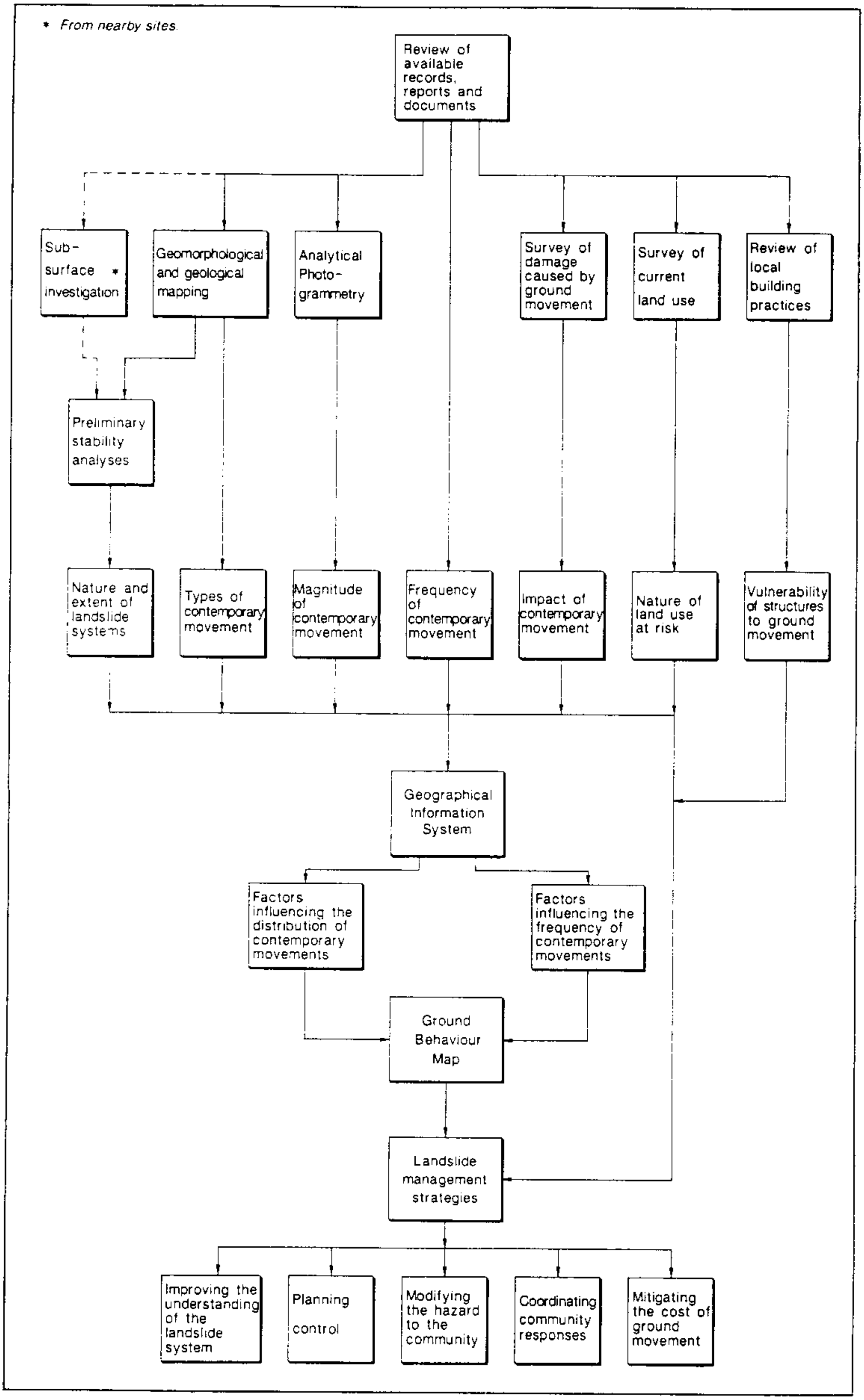


Figure 1.3: The work programme

Further details of the methods of investigation adopted by this study are presented in Annex B.

The results of this study are presented as:

(i) a written report (this volume);

(ii) a suite of four 1: 2,500 scale map sets each comprising two sheets:

"Geomorphology"
"Land Use"
"Ground Behaviour"
"Planning Guidance"

(iii) a series of unpublished Annexes* containing supporting information:

Annex A : Land use in Ventnor.
Annex B : Methods of Landslide Investigation.
Annex C : Previous landslide studies within the Undercliff.
Annex D : Geology and Hydrogeology.
Annex E : Geomorphology.
Annex F : Contemporary ground movement.
Annex G : Damage caused by ground movement.
Annex H : Ground behaviour.
Annex I : Landslide Management.

**FOOTNOTE: The Annexes are held on open file at the following locations for general reference:*

Department of the Environment
2 Marsham Street
London, SW1

South Wight Borough Council
Salisbury Gardens, Ventnor
Isle of Wight

CHAPTER 2
CONTEMPORARY GROUND MOVEMENTS IN VENTNOR

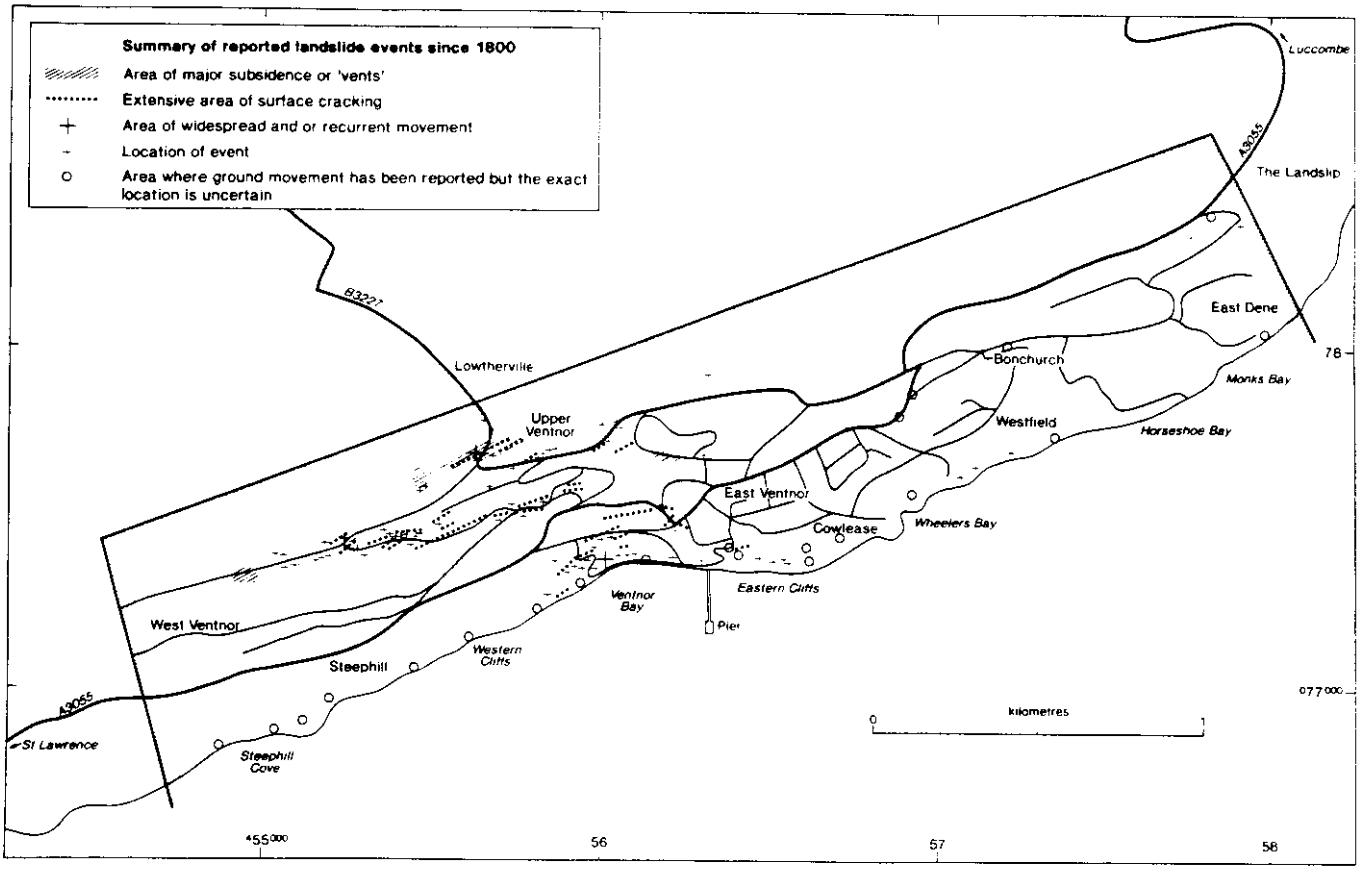


Figure 2.1: Summary of reported landslide events since 1800

2.1 INTRODUCTION

Although Ventnor has been built on an ancient landslide system, it is clear that serious ground movement problems have been confined to a limited number of locations. This suggests that the whole system has not been moving *en-masse* in recent times, rather that some areas are more susceptible to movement than others. In order to pinpoint those landslide units that are particularly sensitive to changes in factors such as climate, coastal erosion or disturbance by man it is necessary to build up a detailed record of all known examples of ground movement in the town. This review of contemporary ground movement has been established from a number of sources, especially a systematic search of local newspapers from 1855-1989 and records maintained by the Borough Surveyors Department, South Wight Borough Council (and the former Ventnor UDC) since 1954*. This data search has focused on obtaining as complete a picture as possible of the distribution, frequency, rate and type of movements that have occurred in the town since the beginning of the 19th century.

There have been nearly 200 individual incidents of ground movement over the last two centuries, the details of which are presented in Annex F. Close inspection of these records reveals that it is possible to define:

(i) distinct periods of landslide activity;

(ii) a range of reported movement rates over the town;

(iii) areas affected by frequent ground movement.

2.2 PERIODS OF PAST LANDSLIDE ACTIVITY

Landslide problems have been recognised in Ventnor for nearly 200 years. The earliest recorded evidence for movement at Ventnor is provided by Webster in 1816 (Englefield, 1816). He noted that in the west of Ventnor Bay 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 areas now known as The Landslip. The first, in 1810, may have involved up to 12ha (Barber, 1834) and "for three days successively the earth heaved and sank" (Adams, 1856). A second and larger landslide occurred in the same area in December 1818, possibly affecting as much as 20ha (Barber, 1834; Wilkins & Brion, 1859). The next recorded event in Ventnor took place in November 1839 when a large movement occurred, probably along Belgrave Road, causing the road to sink 1.5m and a row of cottages to be destroyed (Conybeare & Dawson, 1840).

Reported instances of landslides within Ventnor increase significantly after 1873 corresponding with the rapid growth of the town during the second half of the nineteenth century. The nature of ground movements experienced within Ventnor during the last century were discussed by the Royal Commission on Coast Erosion (1907, 1911). Evidence given by Mr Aubrey Strahan of the Geological Survey in 1906 clearly shows that the nature of ground movement was probably similar to the types of slow movement experienced in recent years:

> "The various rocks have subsided in huge slices ranging from a quarter to half a mile in length; they have subsided to various distances from their original position; some have gone right down to sea-level, others have stuck half-way down. The result of that is that the undercliff consists of a series of

*FOOTNOTE*A detailed list of sources used to establish the pattern of contemporary ground movement is given in Annex B.*
***Since 1954 the Local Authority has maintained a record of ground movements in Ventnor (excluding the Bonchurch area).*

terraces of these slipped masses that have fallen to various levels. Ventnor is built on a succession of terraces of that description.

"The movement appears to be continuing now 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 stone steps, and they have to put in occasionally a few more steps to complete the staircase. " *(Royal Commission on Coast Erosion, 1907, p.103.)*

Although reports of ground movement prior to 1954** are often limited to generalised references in local newspapers the evidence does suggest that coastal erosion and slow movements have occurred intermittently over the last 200 years. The pattern of reported ground movement over this period is presented in Figure 2.1. Analysis of the records reveals 10 phases of activity, separated by periods of apparent stability:

(i) 1873-1879, probably caused by severe coastal erosion following the unsuccessful attempt to build a harbour in Ventnor Bay. Collins Point, a natural breakwater, was removed to build the harbour. This led to a period of rapid erosion of the sand and shingle beach below The Esplanade. Considerable concern was raised about the safety of the sea front properties, as the Gault Clay became exposed and eroded, causing slippage along the coast (Whitehead, 1911).

Landslide movements were recorded as affecting the west end of the Esplanade, in the vicinity of Undercliff House (now the Spyglass Inn; Anon, 1873a, b) and the sea cliffs east of Collins Point (Anon, 1934). The whole of Devonshire Terrace and a number of properties west of Undercliff House in the Hamborough Estate (in the vicinity of the present La Falaise car park) were badly damaged by the movements during this period and had to be demolished (Anon, 1934).

By 1874 coastal erosion became so serious that a Government enquiry was held, which recommended the replacement of Collins Point by a solid groyne and the construction of three intermediate groynes in the western bay, in order to retain the beach shingle (Whitehead, 1911). These groynes were constructed in 1874 and quickly helped the accumulation of large quantities of sand and shingle (Anon, 1874, 1876). Whilst the restoration of the beach reduced the immediate risk to the shore front properties, ground movement continued to be reported in Ventnor. Cracks appeared in Bath and Belgrove Roads (Anon, 1877a), a slide occurred above the Seaman's Mission Home, Mitchell Avenue (Anon, 1877a), Fox's Hole in Steephill Cove collapsed (Anon, 1877b), and at Jollife's store (probably at the top of Bonchurch Shute) the road sank `a considerable depth' (Anon, 1879a, b);

(ii) 1884-1892, involving a series of reports of movement of the coastal slopes at Cowlease and Wheeler's Bay. In 1884 a slide badly damaged a gas holder at Cowlease Gas Works and there were reports of damage to the coastal footpath near Highport (Anon, 1884). Further damage to the coastal path was reported in 1889 and 1892 (Anon, 1889a,b; 1892a, b);

(iii) 1910-1916, characterised by landslide activity along the coast from Steephill Cove to The Landslip. In 1913, for example, settlement was noted near Buona Vista Villas, above the Eastern Cliffs (Anon, 1913);

(iv) 1926-1927, with coastal landslides reported affecting both the Eastern and Western Cliffs (Anon, 1926a, b);

(v) 1932-1936, involving minor landslide activity in Wheelers Bay and Steephill Cove (Anon, 1932; Anon, 1936) and rockfalls off the cliffs in Kings Bay (Anon, 1933);

(vi) 1952, when a series of rockfalls and slides occurred on the cliffs of Monk's Bay, causing damage to the coastal path and sea wall (Anon, 1952a, b, c);

(vii) 1954, during the period from Easter to November a series of cavities (vents) opened up along Whitwell Road, causing the collapse of small areas of the road surface (Edmunds & Bisson, 1954; Toms, 1955). Cavities were also reported along parts of Ocean View Road, Grove Road and Castle Road. Subsidence and fissuring was reported along a line from Sydney Terrace (now the Havensbush play area) across Newport Road to Steephill Down Road, coinciding with the graben-like feature identified by Chandler (1984). Along Ocean View Road, Seaview Villa showed 15cm of settlement and was later demolished.

Along the coast, large rockfalls were reported off the cliffs below Westfield (Anon, 1954a) and the steps leading down to Steephill Cove were damaged by mudslide activity;

(viii) 1960-1961, the most dramatic periods of accelerated movement in Ventnor occurred during the winter of 1960-1961. Following extremely high autumn rainfall totals, many cliff falls, collapsed walls and subsidences were reported in November and December 1960 (Anon, 1960a,b,c). Cracks appeared along Bath Road, where Hutchinson (1965) noted that the most rapid movement observed was c. 2cm per day for seven days on Bath Road, eventually producing a 30cm drop in level. Damage was caused to a number of properties, including the Hillerslea Hotel, Sydney Lodge and Anglesey Flats. Further movements in late December resulted in these properties being temporarily evacuated by Ventnor Council, with help from the Air Ministry (Anon, 1960c).

Movement was also recorded during January 1961 along Newport Road, Steephill Down Road, Ocean View Road, Gills Cliff Road, Belgrave Road and at St Catherine's Home (Anon, 1961a). Along the Esplanade, The Continental and Monrose Hotels were damaged by heave. Both properties were declared unsafe (Anon, 1961a), the occupants of the latter hotel were evacuated. A major subsidence occurred near the junction of Gills Cliff Road and Newport Road. Many houses along Gills Cliff Road were damaged, including Sea Garth (Anon, 1961b). As a result of continuing movement and retaining wall collapse, two terrace houses in Gills Cliff Road were temporarily evacuated in mid February (Anon, 1961c);

**FOOTNOTE: Full details of this survey of damage caused by ground movements are presented in Annex G.*

*** Damage records were recorded within 10m x 10m grid cells in an attempt to normalise the dataset. Details of the normalisation procedure are presented in Annex A.*

(ix) 1978-1980, appreciable subsidence and cracking was reported throughout Upper Ventnor during this period, particularly along Lower Gills Cliff Road and at the junction of Newport Road with Steephill Down Road. Elsewhere in the town ground movements occurred along Bath Road, causing damage to Sydney Lodge, and at the corner of Alpine Road and Church Street where the Rex Cinema was badly cracked, water mains and sewers fractured, and Grove Lodge affected by major settlement. During this period the new houses in Castle Court and Steephill Court Road began to show signs of damage.

(x) 1987-1990, involving settlement in the Steephill Down Road-Newport Road area, where a line of buildings including the Post Office, were badly damaged and later demolished (Anon, 1987c). Along Lower Gills Cliff Road a 4m deep cavity was detected, causing traffic to be temporarily diverted (Anon, 1987a). Movements were also reported down Bath Road, including extensive cracking near the La Falaise car park (Anon, 1987c).

During the winter of 1989-1990 a number of coastal falls and slides occurred along the Western Cliffs and in Monk's Bay.

2.3 RATES OF CONTEMPORARY GROUND MOVEMENT

The magnitude of contemporary movement is an important consideration in understanding the behaviour of the landslide complex. The review of historical data indicates that slow intermittent ground movement has affected parts of the town, and that much of the coastline has been prone to small falls and slides. However, it appears that the slow, small-scale landslide activity has been accompanied by short periods of accelerated movement, as occurred in the winter of 1960-1961. Estimates of the rates of ground movement, and overall displacements, have been recorded at 209 sites within the study area (Figure 2.2). The results have been collated from a number of sources and include a photogrammetric analysis carried out as part of this study* (Table 2.1). The results from these varied studies are presented in Annex F, and summarised below:

(i) Short-term movement rates; during 1982-1983 Chandler (1984) monitored short-term movement across cracks at seven sites in Upper Ventnor and one site along Bath Road. He used a rod extensometer to measure the differential movement between pairs of reference studs on either side of a crack. The average annual movement rates were:

Newport Road	39.00mm and 19.7mm
Havensbush play area	29.9mm and 26.9mm
Lower Gills Cliff Rd	16.5mm and 8.00mm
Ocean View Road	6.00mm
Bath Road	0.00mm

In 1988 South Wight Borough Council (SWBC) commissioned Malcolm Woodruff (1989) to survey the positions of levelling points around the Winter Gardens, Bath Road and at the junction of Newport Road and Steephill Down Road. The average annual movement rates were:

Winter Gardens	3 - 4mm
Bath Road	0 - 2mm
Newport Road	1- 125**mm

These studies both highlighted the fact that parts of the town, especially Upper Ventnor, have been affected by movement rates of over 10mm per year and possibly as much as 125mm per year;

(ii) long term movement rates; it is unlikely that these results are representative of the town as a whole and it is by no means certain that these short-term rates are maintained over longer periods of time. Fortunately, two different lines of evidence provide information over a longer time scale:

(a) Bench mark survey; the 62 bench marks, located throughout the study area show varying degrees of vertical movement since 1896. Twenty eight bench marks (45%) show minimal or no apparent displacement (Figure 2.2); by contrast seven points have apparently moved over 0.4m over the period of measurement (Table 2.2).

Gills Cliff Road	840mm over 43 years (1939-82)
Bath Road	810mm over 75 years (1907-82)
Steephill Down Road	630mm over 22 years (1960-82)
Newport Road	620mm over 22 years (1960-82)
Albert Street	560mm over 21 years (1939-60)
Ocean View Road	530mm over 43 years (1939-82)
Zig Zag Road	460mm over 75 years (1907-82)

Table 2.2 Locations of benchmarks where over 400mm of movement has been identified.

The annual rates of movement calculated from the bench mark survey range from no apparent movement (12 points) to 44 points moving less than 10mm per year and 6 points at over 10mm per year (Table 2.3);

(b) analytical photogrammetric techniques (Annex F) were used to compare the positions of a point (e.g. the corner of a building) on an aerial photograph taken in 1988 with the position of the same point on photography taken in 1949 and 1968.

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 the study area were selected for measurement and the photogrammetric technique produced point co-ordinates and `discrepancy' vectors for each of the points. Statistical analysis was undertaken to establish whether these discrepancy vectors could be accepted as being `significant' and representative of a real movement.

The movement rates calculated by both of these methods are shown in Table 2.4. Three important points stand out when these results are compared with those obtained from the short-term measurements of Chandler and Woodruff (Figure 2.2):

- although a number of locations appear to have had 10-125mm of movement per year, the majority of locations within the town have probably been moving at less than 1mm per year or have not moved at all.

** FOOTNOTE: The measurement techniques used in each of these surveys are described in Annex F.*

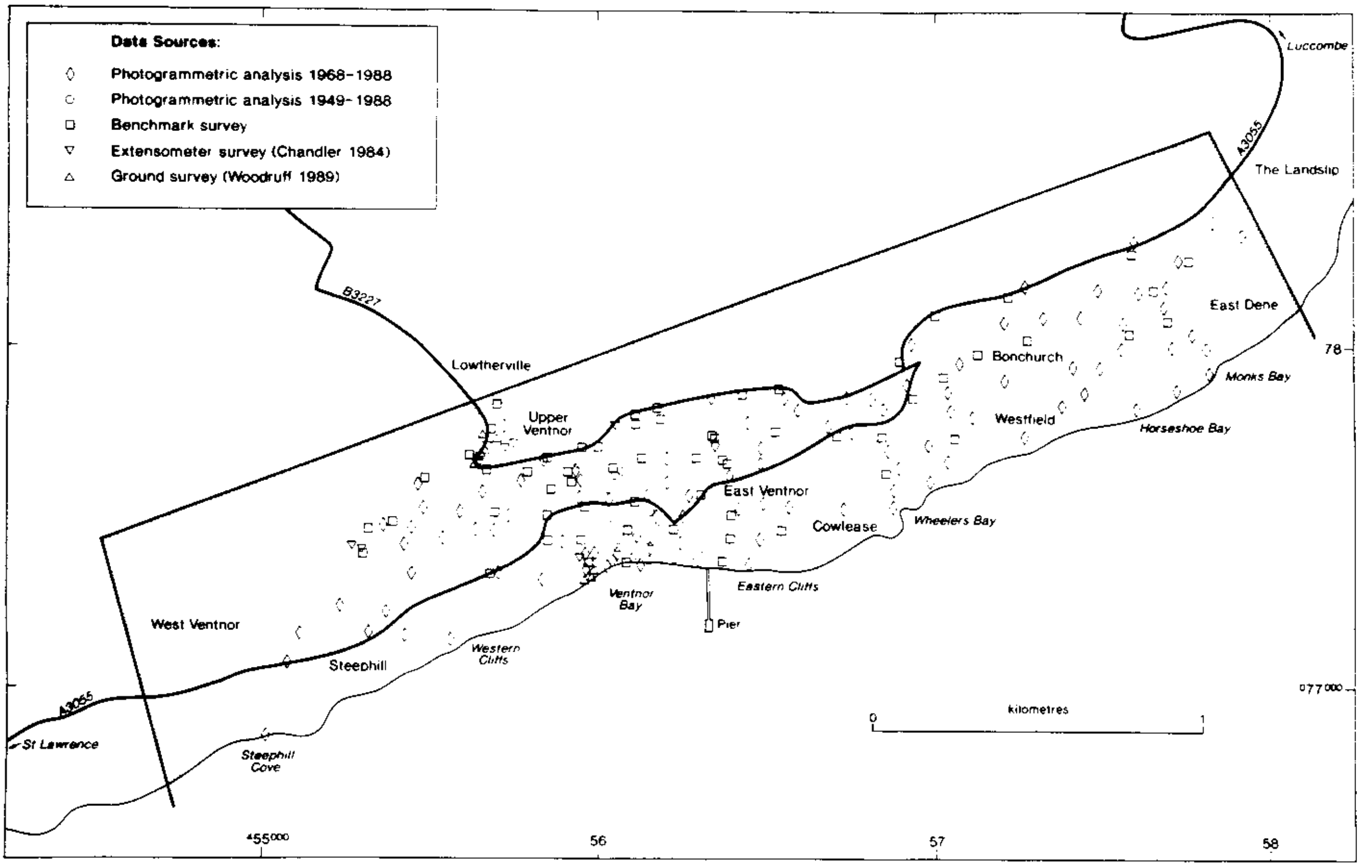
***This rate has been extrapolated from a measurement of 21mm over 2 months and should be treated with caution.*

SURVEY METHOD	DESCRIPTION	NO OF POINTS
Bench mark survey (Toms, 1955; Chandler, 1984; This study levelled many bench during 1981-82.	Comparison of Ordnance Survey bench mark levels from 1896, 1907, 1939 and 1959-60. Additional survey information provided by Chandler (1984) who remarks in Ventnor.	62
Extensometer gauge monitoring (Chandler, 1984)	Measurement of both horizontal and vertical displacements between reference studs in Upper Ventnor during 1981-82.	8
Ground surveying (Woodruff, 1989a)	Regular monitoring of survey stations at the Winter Gardens, Upper Ventnor and Bath Road during March-December 1988.	10
Photogrammetric analysis (this study)	Statistical comparison of the position of points identified on 1988 oblique aerial photography with the position of the same points on earlier vertical aerial photographs (1949 and 1968).	24 (1949-1988 analysis) 105 (1968-1988 analysis)

Table 2.1 Review of sources of ground movement information.

SURVEY METHOD	POINT LOCATION	PERIOD	ESTIMATED ANNUAL RATE OF MOVEMENT (mm/yr)
Bench mark survey	Steephill Down Rd	1960-1982	29
	Newport Road	1960-1982	28
	Albert Street	1939-1960	27
	Gills Cliff Road	1939-1982	19
	Ocean View Road	1939-1982	12
	Bath Road	1907-1982	11
Extensometer survey	Newport Road	1981-1982	39
	Havensbush play area	1981-1982	30
	Havensbush play area	1981-1982	27
	Newport Road	1981-1982	20
	Gills Cliff Road	1981-1982	16
Ground survey	Newport Road	1988	53-125
	Newport Road	1988	12-36
	Winter Gardens	1988	30
	Newport Road	1988	15
Photogrammetric analysis	Ocean View Road	1949-1988	67
	Anglesey, Bath Road	1949-1988	65
	The Esplanade	1949-1988	20
	Belle Vue Road	1949-1988	15

Table 2.3 The location of points within Ventnor which have experienced movement rates of over 10mm per year.



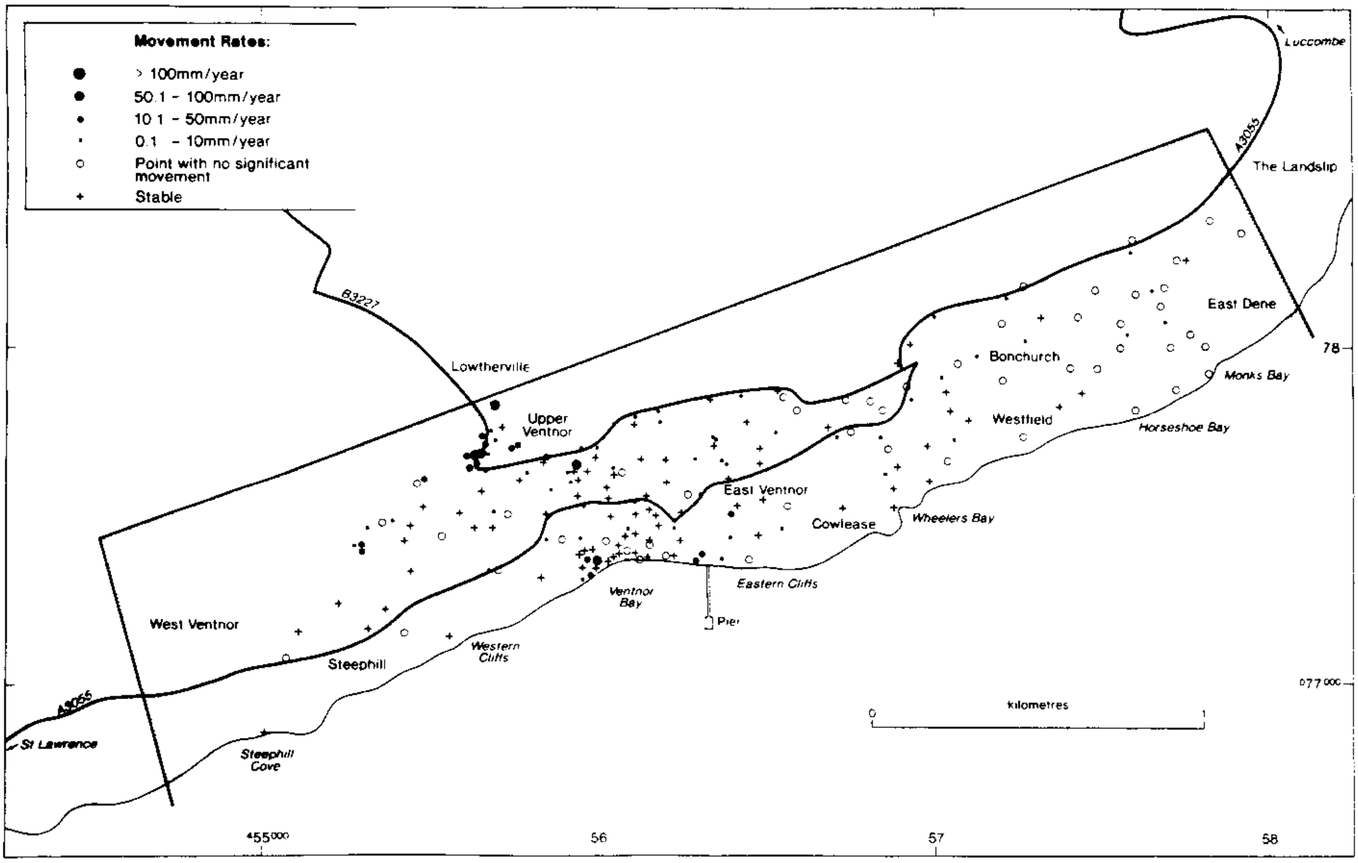


Figure 2.2: Rates of ground movement: data sources (top), movement rates (bottom)

- at many sites the short-term movement rates do in fact appear to be representative of long-term trends. Indeed, the largest overall displacement is a drop of 0.84m over 43 years along Gills Cliff Road (between 1939 and 1982) which gives an estimated annual movement rate of 19mm per year. This figure is comparable with the rates of 8.00mm per year and 16.5mm per year measured along Gills Cliff Road by Chandler in 1981-1982.

- at some sites, such as at the junction of Newport Road and Steephill Down Road, the short-term movement rates of between 53 and 125mm per year are significantly higher than the longer term trend (at the same location) of 28mm per year over the last 22 years.

It must be emphasised that although it has been possible to estimate annual rates of movement, this does assume that movement is continuous over long periods. Movement is more likely to be episodic, with the main displacement occurring over short periods of time followed by periods of relative stability. The results of the various surveys partially support this view as bench marks measured between 1960 (before the 1960-1961 movements) and 1988 appear to have moved more than points in similar locations measured between 1968 and 1988. In addition, many of the greatest movement rates are associated with points that have been only monitored over a short (1-2 year) period.

2.4 AREAS OF FREQUENT GROUND MOVEMENT

It is clear from the records of ground movement that since 1800 there have been eight principal zones of contemporary movement within Ventnor:

(i) Ventnor Bay; significant movements have occurred in the Bath Road - Belgrave Road - The Esplanade area since 1816 (Table F.1; Annex F) causing considerable damage to property such as a row of cottages along Belgrave Road (1839) La Falaise (1921), the Monte Carlo Hotel (1960-1961) and La Venness (1988-1989). The main type of movement appears to be related to the reactivation of a rotational landslide unit, probably involving Upper Greensand blocks, with accompanied toe heave along the Esplanade. Recorded movements rates indicate that parts of Bath Road have subsided by 810mm over 75 years and parts of the Esplanade have been forced up by 780mm of heave between 1949-1988;

	NO OF POINTS	% OF DATA SET
STABLE POINTS	80	41.9
POINTS WITH NO SIGNIFICANT MOVEMENT	51	26.7
0.00 - 1.00mm	27	14.1
1.01 - 2.50mm	7	3.7
2.51 - 5.00mm	7	3.7
5.01 - 10.0mm	8	4.2
10.01 - 50.0mm	8	4.2
50.01 - 100.0mm	3	1.5
	191	100.0

Table 2.4 Long-term annual movement rates (mm per annum) calculated from bench mark levels and analytical photogrammetry

(ii) Eastern Cliffs; the cliffs to the east of Ventnor Bay have been affected by significant movement of a series of deep-seated rotational failures involving Upper Greensand blocks, which have been partially buried by chalky debris. In the past considerable damage has been caused by movement in this area:

1857 at the Parsonage (now the Winter Gardens);
1873 Devonshire Terrace damaged and subsequently demolished;
1913 Settlement recorded at Buona Vista Villas;
1954 Damage to the Winter Gardens.

Measured rates of ground movement indicate that displacements of up to 30mm per year have occurred in the past;

(iii) Upper Ventnor; recorded movements have occurred in this zone throughout the last century, with Aubrey Strahan noting the slow settlement of steps between terraces (Royal Commission on Coast Erosion, 1907, 1911). The movements in this zone are interpreted as being related to the disruption of displaced Upper Greensand blocks, formed by multiple rotational failure in the Gault Clay following downslope unloading. It would appear that movements in this zone have increased since 1954, as indicated by the recent development of the graben form in the Havensbush play area. The main areas of recurrent movement include:

- Steephill Down Road to the Havensbush play area;
- Ocean View;
- Grove Road;
- the Whitwell Road, Gills Cliff Road and Zig Zag Road areas.

Movement rates of between 30-390mm per year have been recorded in this area from comparison of bench mark levels, extensometer data and ground surveying. However, it should be noted that stable points have also been identified;

(iv) Western Cliffs; landslide activity along the stretch of coast between Steephill Cove and Ventnor Bay has occurred throughout the last 150 years. Mudslide activity has been reported in Steephill Cove (1912, 1936 and 1960; Table F.1, Annex F) and Castle Cove (1912 and at present. Rockfalls off the chalky debris cliffs east of Flowers Brook were recorded, in 1877, 1926, 1960, 1961, 1989 and 1990;

(v) Cowlease; the area between the Eastern Cliffs and Wheeler's Bay has been affected by significant ground movements, both inland and along the coast. The inland movements have often been associated with the degradation of landslide units in chalky debris. In general recorded movement rates suggest that displacements of less than 10mm per year have occurred.

In Wheeler's Bay, coastal mudslides developed within the Gault Clay have also caused significant damage in the past, including:

1884; Footpaths damaged at Highport and a gas

holder destroyed at Cowlease Gas Works;
1889; Footpaths damaged in Wheeler's Bay;
1927; Property damaged in Wheeler's Bay;
1960; Cliff Cottage damaged.

(vi) Westfield Cliffs; where rockfalls in chalky debris have been recorded in 1910, 1955 and 1960. This stretch of coast has recently been protected and so the incidence of rockfall activity may be expected to decrease;

(vii) Upper Bonchurch; many parts of Bonchurch, inland of the main village road have been affected by movements associated with the degradation of scarp faces (e.g. the rockfall at Cedarmount in 1959) and the slow subsidence of Upper Greensand blocks (e.g. the settlement outside Jolliffe's Stores in 1879). Estimated annual movement rates suggest that the settlement is very slow, generally less than 10mm per year;

(viii) Monk's Bay and The Landslip; coastal erosion of the *in situ* Lower Greensand cliffs has been a significant problem over the last century, with rockfalls reported in 1940 and 1952, and during the winter of 1989-1990. Within The Landslip shallow mudslide activity probably occurs most years, and represents one of the most active areas of the entire Undercliff.

These areas are quite clearly the most vulnerable parts of the study area, and are associated with three main settings: the coastal cliffs, the area of settlement and heave between Belgrave Road and The Esplanade, and the slowly subsiding terraces which occur throughout the upper parts of Ventnor and Bonchurch. Elsewhere records of ground movement are either very rare or non-existent, implying that there are large areas which are largely unaffected by contemporary movement.

Over the last 200 years or so, sudden dramatic movements have been rare and confined to rockfall activity off the coastal cliffs. Inland movements have been imperceptible with the fastest rate recorded being the settlement at Bath Road at 19mm a day for 7 days during the winter of 1960-1961. In most areas ground movement is less than 1mm a year. There have been no reports of large, catastrophic movements within Ventnor, of the kind which occurred at The Landslip in 1810 and 1818, or at Gore Cliff in 1799 and 1978. The view that movement of the landslide complex could cause fatal accidents has had no precedent in the last 20 years.

CHAPTER 3
EFFECTS OF CONTEMPORARY GROUND MOVEMENT

3.1 INTRODUCTION

The occurrence of widespread, ground movements within Ventnor has resulted in a range of problems to the community. Judging from the historical records it would appear that these problems 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 landslide damage, by concentrating people, resources, assets and services in a limited area.

There is, unfortunately, only a limited amount of information which relates to the financial consequences of ground movement within Ventnor. However, examination of past records clearly indicate that the effects of movement have been largely confined to causing structural damage to private and local authority property. Over the last 50 years the costs incurred as a consequence of ground movement have included:

(i) demolition of unsafe properties along Newport Road, Steephill Down Road and Ocean View Road;

(ii) road maintenance costs and disruption to traffic, as caused by the subsidences along Whitwell Road in 1954. Problems have also been experienced along Newport Road, where settlement within the graben-like feature has caused repeated damage. In addition, minor problems have also been caused by cavities opening along Grove Road (1954), High street (1956), Trinity Road (1956,1965), Castle Road (1975) and The Cascades (1977);

(iii) widening and upgrading of Alpine Road in 1961 to divert through-traffic away from the problem areas along Bath Road and Belgrave Road (Anon, 1961a);

(iv) temporary evacuation of properties along Bath Road (Sydney Lodge and Anglesey Flats), The Esplanade (Monrose Hotel) and Gills Cliff Road (Sea Garth) in the winter of 1960-1961);

(v) compensation for damages and losses incurred as a result of the ground movements in 1960-61. People affected by the movements were advised by the local council to apply for financial relief to the Mayor of Newport's Flood Relief Fund (Anon, 1961a). Approaches were also made by Ventnor Council and the local Member of Parliament to the Ministry of Housing and Local Government, who offered financial assistance to private persons affected (Anon, 1961d). This offer of assistance was described by the Ministry as "neither an acceptance of a continuing liability to make good any further damage which might occur nor a guarantee that the properties could or would be made stable" (Anon, 1961d).

Affected parties were required to apply for a grant, but before any substantial amount was spent on repairs it would have to be established whether the improvements were worthwhile. Grants were available for the full cost of restoration of damaged homes; damage to or loss of furniture or clothing up to £300 a household; damage to or loss of stock intrade of a personal business; damage to business premises up to £2,500, and reasonable value of livestock killed (Anon, 1961e). No grants in any circumstances were to be paid in respect of losses or damage covered by insurance. A total of 115 claims were received of an overall value of £78,000, of which around £69,000 was authorised for payment (Anon, 1961h; Anon, 1962).

In addition to granting financial aid the Ministry also proposed to withdraw existing planning rights to rebuild, in order to avoid similar damage in the future, and compensate owners for the value of their land (Anon, 1961f). This was agreed by the County Council (Anon, 1961g);

(vi) the costs of coastal protection, including maintenance requirements. A significant proportion of the coastline has been protected by groynes and/ or sea walls over the last 100 years or so. In 1987 South Wight Borough Council commissioned Posford Duvivier to undertake a review of the Borough's coastline (Posford Duvivier, 1989). The situation within the study area may be summarised as follows:

- Monk's Bay; a length of sea wall with *ad-hoc* concrete buttressing fronted by three masonry groynes. This section of the defences has been in very poor condition and efforts are currently being directed (in 1990-1991) towards the design and construction of an improved scheme;

- Westfield Cliffs to Wheeler's Bay; a sea wall with, in places, rock armour. This scheme was commissioned by South Wight Borough Council and completed in 1987;

- Wheeler's Bay; a blockwork wall with a short timber breastwork running out from the Fishermans Ramp Wall, which was breached in 1987;

- Ventnor Holiday Villas; an uncased blockwork wall which was reported as having been damaged by ground movement (Posford Duvivier, 1989);

- Collins Point; a reinforced concrete wall with a sheet pile toe. At Collin's Points there is a structure owned by Southern Water which appears to have only marginal success in trapping beach material (Posford Duvivier, 1989);

- Ventnor Bay; two partially encased major groynes (Swale and Limington groynes) fronting the Esplanade sea wall. Parts of this wall have been damaged by ground movement resulting in repair works in 1990;

- Spyglass Inn; a privately owned blockwork wall which was reported as having been affected by a wash-out (Posford Duvivier, 1989);

- Western Cliffs; at the time of writing this stretch of coast is unprotected. However, following erosion in the winter of 1989-1990 South Wight Borough Council have commissioned Posford Duvivier to carry out emergency works and design a long-term defence scheme;

- Castle Cove; works were carried out in 1982 to construct a new breastwork and strengthen the existing structure. This has been subsequently affected by landsliding;

- Steephill Cove; privately owned old shallow footed masonry walls.

Monitoring, maintenance and repair works along the whole stretch of coast can be very expensive. For example, the proposed new sea defences at Monk's Bay were estimated as costing over £800,000 in 1989, involving funding from both South Wight and the Ministry of Agriculture, Fisheries and Food (MAFF);

(vii) insurance claims.

This list is by no means exhaustive, but does serve to highlight the range of impacts caused by the landslide movements. However, undoubtedly the most widespread effect had been the damage to property and structures within the town. Even those sites which have probably experienced annual movement rates of 1mm per year could have moved 50mm over half a century. At the other end of the scale, parts of The Esplanade have risen 780mm between 1949 and 1988 and parts of Bath Road dropped 810mm between 1907 and 1982. Such displacements have caused widespread damage to property, services and structures, as was revealed by a systematic survey of building exteriors, retaining walls and roads*.

3.2 THE PATTERN OF DAMAGE CAUSED BY GROUND MOVEMENT

During the survey of damage caused by ground movement, an attempt was made to assess the intensity of damage at each site. It is readily accepted that, as with all intensity scales, subjectivity cannot be ruled out, but it can be minimised by using a pragmatic classification. In this case a five-fold sub-division was adopted, based on prior experience in the area and guidelines provided by the Building Research Establishment (BRE, 1981) and Alexander (1986). The classification, listed below, reflects increased levels of damage and, by inference, costs of repair . It is worth stressing that the survey recorded damage caused by ground movement and not due to poor building and lack of maintenance. However, in many situations damage due to ground movement has been accentuated by inappropriate building design and materials (see section 3.3).

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, Part 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.

The majority of examples of damage are moderate or lighter, with 2057 out of 2509 cases (82%; Table 3.1). However, there are 452 cases of serious, or worse, damage to property within the town, where extensive repair or partial rebuilding is probably necessary. The pattern of damage through the town is shown in Figure 3.1 (see Appendix 1) which indicates the level of damage recorded within 10m x 10m grid cells superimposed over the whole area.**

	No of records	% of dataset
Negligible	109	4.3
Slight	710	28.3
Moderate	1238	49.4
Serious	261	10.4
Severe	191	7.6
	2509	100.0

Table 3.1 Relative frequency of incidents of damage of different intensities, as a result of ground movement.

It is readily apparent that structural damage associated with ground movement is widespread. Past records tend to suggest that the problems are largely confined to Upper Ventnor, The Esplanade area, the coastal cliffs and parts of Bonchurch. However, this damage survey has revealed that damage problems also occur throughout Bonchurch and in the Steephill area, although much of the damage is moderate in intensity or lighter.

The distribution of cases of significant damage (serious and severe) is similar to the pattern of landslide movement obtained from contemporary records (see Chapter 2). Both sources of information highlight problem areas in:

(i) Ventnor Bay;
(ii) The Eastern Cliffs;
(iii) Upper Ventnor;
(iv) The Western Cliffs;
(v) Cowlease;
(vi) Westfield Cliffs;
(vii) Upper Bonchurch;
(viii) Monk's Bay.

Of significance though, the structural damage survey highlights areas where ground movement has caused problems in:

(ix) East Ventnor (Grove Road, Southgrove Road, St Boniface Terrace);
(x) West Ventnor (Castle Court, Steephill Road);
(xi) Lower Bonchurch (Westfield Holiday Centre, Madeira Vale).

On the other hand, it needs to be emphasised that there are large zones where damage appears to be moderate in inten-

FOOTNOTE: Full details of this survey of damage caused by ground movements are presented in Annex G.

*** Damage records were recorded within 10m x 10m grid cells in an attempt to*

sity or lighter, especially in Bonchurch.
Comparing Figures 2.1 and 3.1 it is possible to recognise a number of problem areas in the town, where significant movement rates have resulted in serious or severe damage. These are:

- the Ventnor Bay area;
- Central Ventnor;
- Upper Ventnor;
- Cowlease;
- Upper Bonchurch.

3.3 CAUSES OF DAMAGE: GROUND MOVEMENT OR POOR CONSTRUCTION?

Although there is widespread property damage throughout Ventnor, it is important to keep the problems in perspective. Whilst there are areas where property has been severely damaged by recurrent landslide activity, large areas of the town appear to have been affected by only very slight movement. Indeed, many properties have survived a century or more without any significant damage, including Bonchurch Old Church (believed to be over 1,000 years old), East Dene and Salisbury Gardens.

Unfortunately the situation in Ventnor is not a simple case of extensive damage to property in unstable areas and no damage in more stable areas. Often it is not clear whether the problems were a direct result of ground movement or simply poor building construction.

Much of Ventnor was developed between 1830 and 1910 often by "jerry builders who ran up houses of inferior order" (Norman in Chambers, 1988). Although much of the town was built rapidly standards did vary. The wealthy could afford proper supervision and construction of their houses, particularly those in Bonchurch. Not all builders were bad. Indeed, the local quality builders, H. Ingrams, were founded in the 1830's and have constructed good buildings ever since.

Early building in the town was mainly in local stone, although a few timber frame and brick constructions were built. The style of housing varied considerably from the large detached properties in Bonchurch, such as Madeira Hall to three and four storey Victorian terrace houses throughout much of Upper Ventnor. Since the end of the last century stone buildings have given way to brick, with cavity walls adopted as early as 1898 (Local Authority Building Regulation Records).

An examination of building plans deposited in the archives of the Local Authority indicate that two main types of foundation were used before 1914:

(i) walls built on large stones set immediately below ground level;

(ii) walls extended into the ground until firm rock base was reached, often at around 2m depth.

There appears to have been no rationale for the selection of foundation type, with adjoining properties often having different foundations. After 1914 foundations were conventional strip footings to a depth of 0.75m, although occasionally raft foundations were used. In many instances properties have been anchored onto stable ground, compounding the problem. However, since 1974 there has been a requirement for designed foundations to take account of ground conditions.

The standard of early wall construction appears to have been very poor. Often cavity walls had no ties and these may now be extremely fragile. The local building stone is particularly susceptible to weathering, and many properties have required frequent and extensive re-pointing or rendering. Often weak mortar mixes and unsuitable pointing techniques have been used, causing problems of rain water penetration and weakening of the whole structure. Few retaining walls are more than freestanding walls. As a result many show signs of distress. Poor design, bad workmanship and lack of maintenance have all contributed to the current problems. However, in the last few years South Wight Borough Council, the Highway Authority and certain private owners have rebuilt major retaining walls to a higher standard.

During the Second World War the radar station on Wroxall Down was a target for German bombers. Properties in the town may have suffered long-term structural damage as a result of misdirected bombing.

In many instances there has been an unusually high rate of property alteration, with some buildings likely to have had up to ten alterations during their lifespan compared with the normal rate of two to three alterations. Many properties have clearly been repaired on more than one occasion, probably because of distress caused by ground movement. However, because houses in many areas are actually expected to suffer damage they are often poorly repaired or renovated.

It is only to be expected that a poorly built Victorian town will have its fair share of defective constructions or potentially dangerous structures. However, in many cases damage appears to worsen with time, as the cumulative effects of imperceptible movement get more and more serious. The issue as to whether 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. Whilst solutions to the problems of moving ground have long been practised in coal mining areas, there clearly has been little attempt to accommodate movement in the design and construction of property in Ventnor. Inadvertently, the most widely used foundation and building types have been completely inappropriate, being particularly vulnerable to ground movement (Table 3.2). This has undoubtedly made the landslide problem appear more serious and less manageable than it could be. When looked at another way, it follows that by improving building standards the impact of future movements can be reduced.

BUILDING TYPE	FOUNDATION TYPE	VULNERABILITY TO GROUND MOVEMENT
FRAMED	RAFT OR GROUND BEAM	LOW
	TRADITIONAL STYLE	MODERATE
	DEEP PILE	HIGH
	MIXED	VERY HIGH
NON-FRAMED (e.g. Brick)	RAFT OR GROUND BEAM	MODERATE
	TRADITIONAL STRIP	HIGH
	DEEP PILE	VERY HIGH
	MIXED	VERY HIGH

Table 3.2 Vulnerability of different building and foundation types to ground movement.

CHAPTER 4
THE PHYSICAL BACKGROUND

4.1 INTRODUCTION

The Undercliff on the southern coast of the Isle of Wight is an extensive ancient landslide complex, on parts of which the town of Ventnor and the village of Bonchurch are situated. The landslides within the Undercliff are developed in the soft Lower and Upper Cretaceous rocks. These consist of considerable thicknesses of Gault Clay (locally known as the `blue slipper'), underlain by sandstones (Lower Greensand) and overlain by massive cherty sandstones (Upper Greensand) and chalk.

The landslide complex is one of a number of large, active mass movement features along the coast of southern England, which have developed in a wide range of sedimentary rocks. These include Folkestone Warren (Hutchinson, 1969; Hutchinson *et al.*, 1980), Fairlight Glen (Moore, 1986), Fairy Dell and Black Ven in south Dorset (Brunsden & Jones, 1976, 1980) and the Landslip Nature Reserve, East Devon (Pitts, 1983; Pitts & Brunsden, 1987) (Figure 4.1). Characteristic of all these sites is the combination of plastic, impermeable clays overlain by thick competent strata. It is likely that all these features developed in response to marine erosion, probably having been initiated during the rise in sea level following the melting of ice sheets at the end of the last ice age.

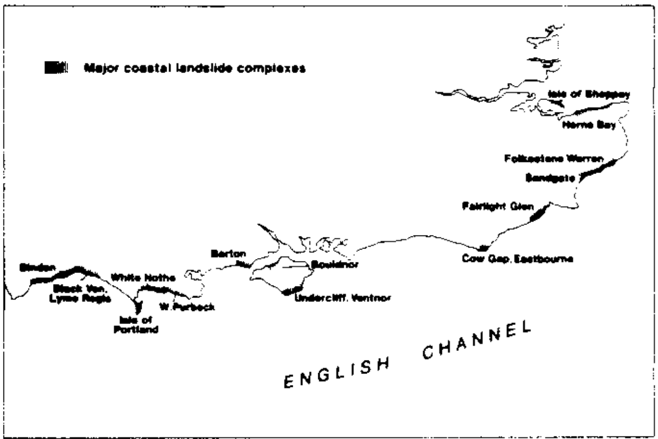


Figure 4.1: Major landslide complexes along the south coast of England

In the past only a few studies have specifically addressed the nature and cause of the problems experienced in Ventnor (e.g. Chandler & Hutchinson, 1984). However, there has been a variety of descriptions, observations, investigations and hypotheses advanced to explain the development of the whole Undercliff (see Annex C). These studies are of great relevance to this investigation as ideas on the causes and mechanisms of failures at specific locations within the Undercliff provide an important starting point in trying to understand the complexity of the landslide units in Ventnor itself. Indeed, it is clear from a review of previous research that the formation of the Undercliff is related to a combination of the geological setting and the evolutionary history of the area, especially over the last 10,000 years or so. These two factors shed important light on explaining both the pattern of landsliding and the variety of landslide forms along the Undercliff.

4.2 GEOLOGY

The Undercliff landslides have developed on the seaward flank of the Southern Downs (Figure 4.2). The details of the Cretaceous formations are presented in Figure 4.3, and briefly described below:

(i) **Ferruginous Sands**; an alternating sequence of weakly cemented muddy sands and dark sandy clays;

(ii) **Sandrock**; this unit appears to vary in thickness and composition along the length of the Undercliff. At Blackgang, in the west, the sequence comprises six separate units, including three thin clay-rich horizons and three sand beds. The overall thickness of the Sandrock at Blackgang is 52m. At Luccombe, in the east, there are three units of pale sandstone, separated by only two bands of dark clay, with an overall thickness of 43m;

(iii) **Carstone**; this is a brown grit interbedded with gritty blue clay layers. The base of this unit is marked by a thin pebbly band. The thickness of the Carstone varies from 3.7m at Blackgang to 10.5m at the eastern end of the Undercliff;

(iv) **Gault Clay**; this unit is a dark blue-grey overconsolidated and impermeable silty clay which varies in thickness from 43.6m at Blackgang to 44.6m at Ventnor. Geotechnical data from Blackgang (Denness, 1969; Humphris, 1979; Chandler, 1984) and Dunnose (Matthews, 1977; Street, 1981; Chandler, 1984) indicates that the Gault Clay can be sub-divided into two main zones:

(a) a silty layer which forms the lower 15-18m of the stratum;

(b) an upper, plastic layer which has a greater clay content than the silty layer below.

(v) **Upper Greensand**; this formation is commonly sub-divided into three main units (Beds 5a-5c; Figure 4.3):

(a) the Passage Beds, comprising around 12m of blue-grey silty to sandy micaceous clays and clayey sands;

(b) the Malm Rock, 23.3-23.9m of firm grey glauconitic sandstone with irregular layers of large calcareous concretions and phosphatic nodules. The uppermost unit of this sequence is known locally as the Freestone;

(c) the Chert Beds, 8.2-8.8m of alternating layers of black or grey chert and soft grey glauconitic sandstone;

(vi) **Lower Chalk**; the slopes of St Boniface Down, Bonchurch Down and Rew Down, are developed in the marly sands, marls and pure limestones of the Lower Chalk.

The geological structure of the Undercliff area is relatively simple with the Cretaceous strata dipping at about 1.5°-2° towards the south-southwest (Reid & Strahan, 1889; Hutchinson *et al.*, 1981a). Superimposed on the general southerly dip there is a NNW-SSE synclinal structure with its axis cutting the coast at Ventnor (Hutchinson, 1965; Chandler, 1984). This structure was accurately surveyed by Chandler (1984), who also verified the presence of the feature from seismic records and a limited number of borehole observations. However, owing to the extensive displacement by landsliding there is only limited reliable information on the relative positions of unaffected strata within the study area.

Although there remain many uncertainties about the variation in thickness and composition of the bedrock units and the broad structure of the Undercliff, it is clear that the geological setting

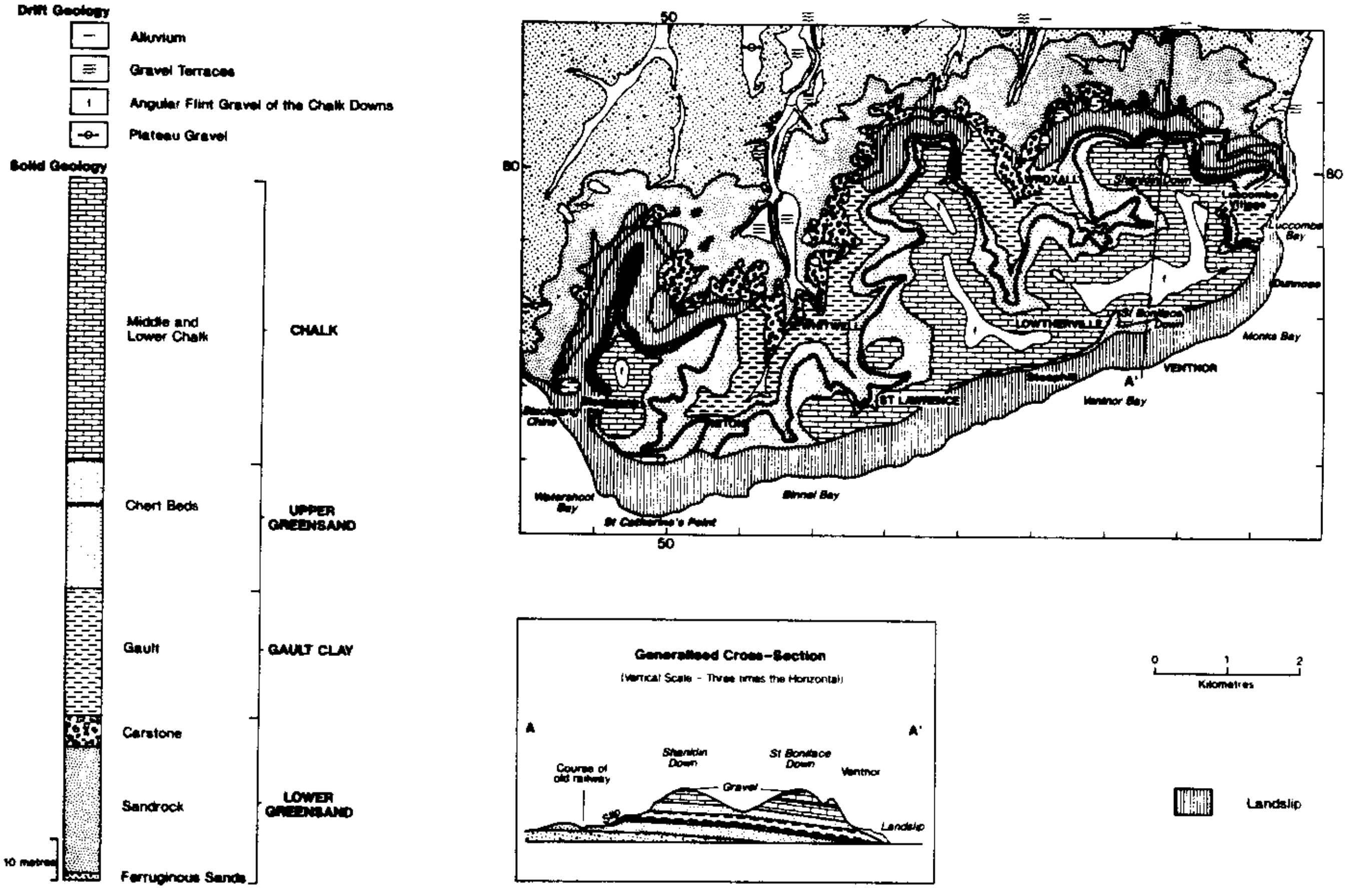


Figure 4.2: The geology of the south coast of the Isle of Wight

STAGE	FORMATION	UNIT	THICK-NESS (metres)	LITHOLOGICAL DESCRIPTION
CENOMANIAN	Chalk		(c. 61m) (Total)	Lower Chalk
		6b	5.5	**Chalk Marl**. Firm grey chalk alternating with thin bluish-grey marls and marly chalk
		6a	2.1	**Glauconitic Marl**. Dark green highly glauconitic marly sand and sandstone to light grey sandy marl
		5c	8.8	**Chert Beds**. Alternating layers of black or grey chert and soft grey glauconitic sandstone at the top a thin layer of greenish-grey glauconitic sand with phosphatized concretions
UPPER ALBIAN	Upper Greensand	5b	23.3	**Malm Rock**. Firm grey glauconitic sandstone weathering to buff, with irregular layers of large calcareous concretions and phosphatic nodules, a prominent 1.5m thick bed of massive fine-grained yellowish-grey sandstone("freestone"), its base 2.4m below the top
		5a	12.0	**Passage Beds** Blue to blue-grey silty to sandy micaceous clays and clayey sands, partly calcareous and nodular and increasingly arenaceous upwards
	Gault Clay	4	44.0	**Gault**. Indistinctly bedded overconsolidated micaceous silty clay, greenish near the top and dark blue or blue below, with scattered white-coated phosphatic concretions pyritic nodules and acicular selenite. Lower 15-18m are more silty and less plastic than layers above
LOWER ALBIAN		3	10.5	**Carstone**. Brown grit with many small pebbles, a thin pebbly band at the base, with thin clayey grit and gritty blue clay interbeds in the upper 2m
		2e	6.4	**Sandrock**. White and yellow sands cross-bedded and interbedded with massive and flat-bedded units, and with laminae of blue-grey clay
		2d	3.0	Thinly bedded white sands interbedded with thicker clay beds, a thin unit of pebbly muddy sand at the base
	Lower Greensand	2c	17.7	Fine and medium white and grey sands, cross-bedded near the top and the base but heavily bioturbated in the middle, flat-bedded unit
UPPER APTIAN		2b	5.1	Homogeneous glauconitic pebbly muddy sand and sandy mud, with a thin quartzite pebble bed at the base
		2a	10.8	White and grey bioturbated sand and sandrock, becoming silty and clayey towards the base
LOWER APTIAN		1c	3.0	**Ferruginous Sands**. Homogeneous dark green glauconitic pebbly sandy mud, containing comminuted plant debris and pyritized wood fragments

Figure 4.3: Generalised geological section

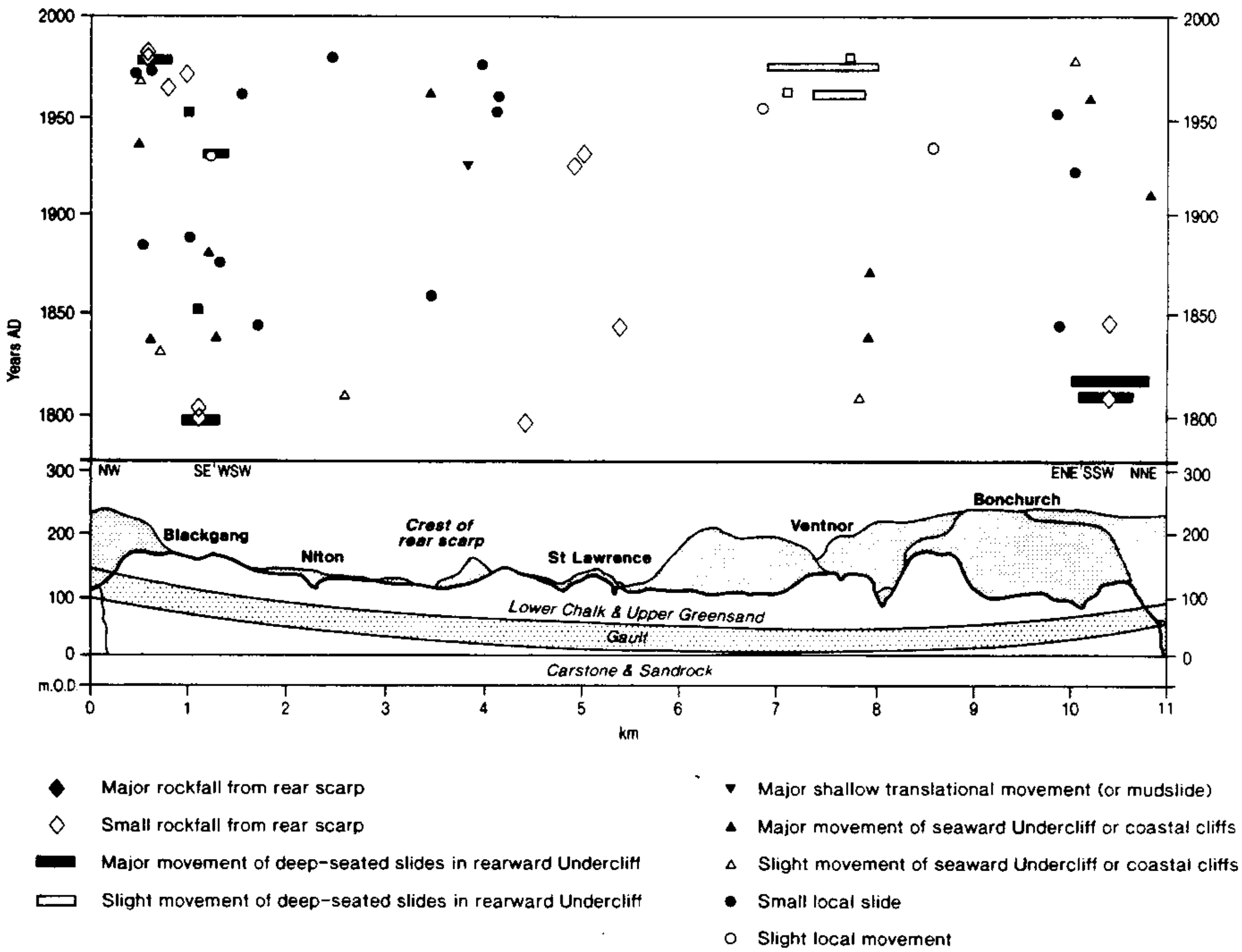


Figure 4.4: Geological cross-section of the Undercliff showing the position of the syncline and it's influence on landslide activity, *(after Hutchinson et al, 1985a).*

exerts a primary control on the development of landsliding. The sequence of over-consolidated Gault Clay overlain by a massive but well jointed caprock of Upper Greensand chert beds and sandstone gives rise to a geological setting which is particularly prone to landsliding. Groundwater is stored above the impermeable Gault Clay and the clayey Passage Beds, in an aquifer developed in the Upper Greensand and Chalk*. Springs issue at the junction of the permeable Upper Greensand with the underlying confining beds, concentrating discharge into the Undercliff. This presumably results in the development of high pore-water pressures and reduces slope stability.

The hydrogeological conditions which result from a combination of impermeable clays and a massive, but permeable caprock are a common factor in some of the largest landslides on the south coast of England. Examples of landslides in this type of geological setting include Folkestone Warren, Kent, the abandoned sea cliff behind Romney Marsh, Fairlight Glen, Fairy Dell, Dorset, the Landslide Nature Reserve, East Devon.

The alternation of weakly-cemented sands and clays within the Lower Greensand formations below the Gault Clay, has led to the development of a series of perched water tables. This setting appears to promote seepage above each clay layer, which has, in places, a significant control on stability. Seepage can result in back-sapping within the overlying sands followed by the collapse of the strata above. This process of seepage erosion has been a major factor in the development of the characteristic "undercliff" form of the Chale cliffs west of Blackgang (Hutchinson *et al.*, 1981b). The presence of perched water tables above the confining clay layers has probably led to the localised generation of high pore water pressures, promoting the formation of large deep-seated landslides, such as at St Catherine's Point, where the basal shear surface is coincident with a clay layer within the Sandrock (Hutchinson et al., 1985a; Hutchinson, 1987a). The possibility of significant under-pressures from this aquifer seems unlikely, but should be explored.

The regional structure has probably played a major role in controlling landslide activity along the Undercliff. Indeed, there appears to have been extreme spatial variability in the occurrence of landslides along the Undercliff, at least over the last 200 years (Figure 4.4). During this period the most active sections of the Undercliff have been the western and eastern ends (Blackgang and Dunnose). By comparison with these two sites, the corresponding landslide activity in the main Undercliff has been, at worst, moderate, and many places appear to have remained relatively stable. On the basis of recorded landslide activity along the Undercliff, Hutchinson (1965) sub-divided the area into three zones reflecting the intensity of contemporary movements (Figure 4.4):

(i) a high level of activity (Blackgang, Dunnose);

(ii) medium level of activity (Monk's Bay to Steephill Cove (the study area), and Binnel Point to St Catherine's Point);

(iii) low level of activity (Steephill Cove to Binnel Point).

FOOTNOTE: Further details of the hydrogeology of the Undercliff are presented in Annex D.*

Hutchinson (1965) related this spatial variability to the changes in height of the base of the Gault Clay along the Undercliff, the position of which was seen to be controlled by the presence of the broad syncline. Although the sub-division of the Undercliff is only based on the occurrence of landslides over the last 200 years it is likely that the controlling influence of the syncline has been a major factor in the long-term development of the Undercliff.

The actual form that slope failure takes is strongly influenced by the configuration of joints within the bedrock. The dominant joint sets are generally very steep, with inclinations ranging between 70° and vertical*. In most areas of the Undercliff these joints are present as orthogonal sets. In the Upper Greensand units cropping out at Gore Cliff and along the rear scarp of the Undercliff the joints are regularly spaced, with the result that the cliff is dissected by a rectangular grid-like fracture pattern. The observation that high angle structures in the Upper Greensand units cropping out at Gore Cliff pass down into and are continuous with less steeply inclined joint sets in the Passage Beds and Gault Clay is particularly significant. This suggests a possible method by which shear surfaces developed within the Gault Clay can propagate upwards through the more competent Upper Greensand strata, and thereby act as a control of the primary failure mechanism along the Undercliff. This situation has also been observed in the Lower Greensand where high-angle structures root into shallower dipping structures.

4.3 ENVIRONMENTAL CHANGES

The origin of the Undercliff landslides is linked to events which have occurred over the last 10,000 years. Indeed, much of the present form may be a legacy of a series of phases of slope instability resulting from the major fluctuations of climatic conditions and sea levels since the end of the last ice age. An understanding of these events which shaped the Undercliff is of obvious importance in evaluating the conditions which influence contemporary and future behaviour of the landslides at Ventnor.

It is generally accepted that the Isle of Wight remained ice-free during the Pleistocene. However, during periods of periglacial conditions broad belts of frozen ground (permafrost) would have developed. Comparison with present-day permafrost areas suggests that summer melting of the surface layers would have resulted in widespread shallow landsliding and solifluction activity, leading to the downslope movement of material forming head deposits and `coombe rock' derived from the frost shattered Chalk. In addition to occurring as fans in front of coombes these deposits would have infilled the floors of valleys within the Chalk uplands. Remnants of a valley network are preserved in the present Undercliff form, notably at the former railway station site, Ventnor and on the south face of St Boniface Down. These valleys are relict features not related to present day catchments or groundwater tables. The considerable depth of relief, particularly in the valley above the former railway station has probably been created by surface run-off during cold, periglacial phases. Snow melt from the Chalk Downs, avalanche activity and debris flows would all have been common phenomena carrying downslope vast quantities of chalky slurry. Today the remnants of such deposits can be seen along many stretches of the coast, such as at St Catherine's Point and the Western Cliffs, Ventnor.

One of the most important consequences of the repeated build up and decay of the Pleistocene ice sheets were major changes in sea level. These fluctuations include major reductions in sea level during periods of ice advance, possibly to in lower than -100m, and higher levels than recorded at present during interglacial times. The most recent phase of major sea level rise, the Flandrian Transgression, followed the decay of the late Devensian ice sheets. This transgression was characterised by rapid sea level rise from -100m at 14,000 BP to around -20m by 8,000 years before present after which the rate of change is believed to have slowed down (Jones, 1981; Figure 4.5). As a result degraded shoreline features were subject to rapid basal erosion and often large-scale mass movement. It is likely that the present pattern of landsliding around the coast of Britain was initiated between 8,000-3,000 BP, particularly the large landslide complexes found on the south coast of England (Figure 4.1).

On the basis of work carried out at St Catherine's Point, Hutchinson (1987a) presented a model describing the late Quaternary-early Flandrian history of the Undercliff. Strong periglacial activity during the Devensian period is thought to have produced considerable masses of predominantly fine debris through solifluction and shallow landsliding. This debris would have buried the remnants of any earlier landslides and produced spreads of material extending southwards over the exposed former sea bed. These aprons of chalky debris would have acted generally as a natural protection and stabilisation measure for the coastal slopes. As sea levels rose during the early Flandrian these debris aprons (together with any remnants of earlier landslides) would have been partially removed by marine erosion, with consequent destabilisation of the coastal slopes.

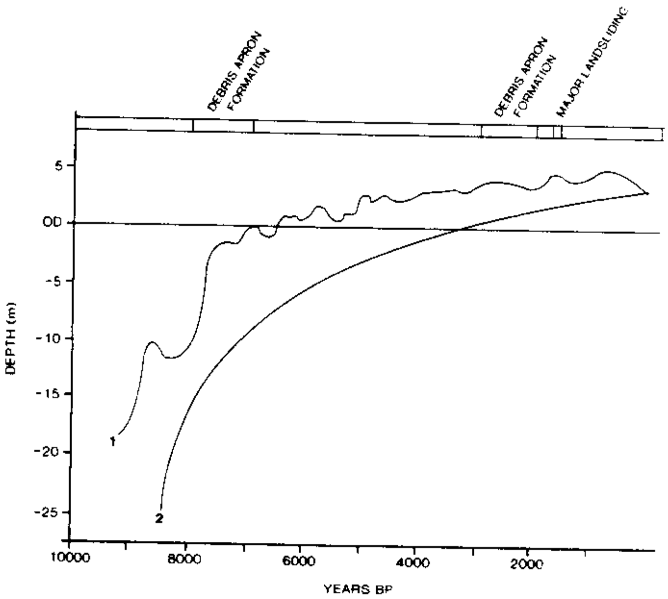


Figure 4.5: Post-glacial sea-level curves (1: NW England, 2: SW England) and phases of major landslide activity along the Undercliff *(after Jones, 1981; Hutchinson et al 1985a;)*

Continuing marine erosion would have then cut into the *in situ* Lower Greensand cliffs to produce the (now buried) shore platform and former sea cliff present at St Catherine's Point (Figure 4.6). The levels of the landward part of this shore platform, around 9m below present sea level, suggest that it may have been formed around 7,000-8,000 BP, possibly during the still-stand in sea levels at approximately this elevation identified elsewhere by Tooley (1978). Hutchinson (1987a) recognised that the main debris aprons at St Catherine's Point were probably initiated around this time (Figure 4.5). Over 13m of chalky material accumulated during this phase of activity, burying the landward portion of the shore platform. This period of landslide activity was followed by a period of relative stability (around 4,000 BP; the sub-Boreal period; Table 4.1) during which soil development took place on the debris aprons. These soils were buried by a second phase of debris apron formation which probably took place in response to the climatic deterioration of

FOOTNOTE Details of a survey of the joint systems observed along the Undercliff are presented in Annex D*

PHASE	DATE	NATURE OF CLIMATE
Sub-Atlantic	500-3,000 BP	Decline in temperature maritime climate, increased wetness, mild winters, cool and damp summers. 700-400 BC frequent storms and floods.
Sub-Boreal	3,000-5,200 BP	Cooler (than Atlantic phase) by 0.5° C, and drier in winter, warmer (0.5-1.0°C) and drier in summer.
Atlantic	5,200-7,500 BP	Warm and wet, spread of elms and oak, 17°C mean July temperature 5°C mean winter temperature. Rainfall 10-20% greater than present.
Boreal	7,500-95.00 BP	Winters milder and summers warmer than those of today.
Pre-Boreal	9,500-10,500 BP	Renewed rise in temperature.
Upper Dryas	10,500-11,300 BP	Colder (9-12°C) in summer, snow line at 495m in central Lake District.
Allerød	11,300-12,100 BP	Warm, (14-17°C) in summer.
Lower Dryas	12,100-14,000 BP	Tundra.

Table 4.1 Dominant climatic phases in post-glacial times.

the early sub-Atlantic period, around 2,500-2,000 B.P (Figure 4.5). A third phase of landsliding is believed to have occurred during the Roman occupation around 1,800 B.P., involving the formation of the major deep-seated slides at St Catherine's Point (Figures 4.5 and 4.6).

4.4 VARIETY OF LANDSLIDE FORMS ALONG THE UNDERCLIFF

The present form of the Undercliff clearly represents the product of at least three main phases of mass movement activity over the last 8,000 years, together with the effects of continuing modification by contemporary process. However, the Undercliff should not be viewed as a simple uniform system, as both the form and the intensity of landslide activity appears to have varied along its length. The combination of spatial variability in the geological framework (both structure and lithology) and a variety of mass movement environments (both through time and space) has been manifest by a wide range of landslide types, including:

(i) debris aprons; broad spreads of unsorted Upper Greensand and Chalk boulders in a partially cemented chalky matrix occur in many places along the lower Undercliff. These aprons probably represent the accumulation zones of a high energy landslide environment, which would account for both the long run-out of the debris and the very low angle of the aprons. It seems likely that the debris aprons were formed as a result of a series of debris flows off the Chalk downs and massive rockfall avalanches, characterised by sudden failure of the cliff and rapid extensive run-out. A possible modern analogy to these failures is provided by the 1928 rockfall at Gore Cliff when debris was initially carried around 270m seawards in a dry state. Within a few months the debris had been transported over 700m.

(ii) Primary failures; the formation of the main Undercliff landslides is considered to post-date the formation of the debris aprons, and can be viewed as deep-seated **first-time** failures involving the previously unsheared bedrock;

(iii) rockfalls and topples from the rear scarp; occasional rockfalls and topples are known to occur from the rear scarp of the Undercliff, with blocks in the range 100-1,000 tonnes failing as a result of loss of basal and lateral support, and possibly frost wedging. Very large rockfalls, involving hundreds of thousands of tonnes are rare, with only two reported instances in the last 200 years: at The Landslip in 1810, and at Gore Cliff in 1928;

(iv) secondary failures; there is a long history of secondary movements within the Undercliff. Many of these failures can be viewed as part of the long-term degradation of the earlier primary landslides, occurring along **pre-existing shear surfaces** where the materials are at or close to residual values. A range of secondary failures can be identified:

(a) rotational failures within the landslide debris, including the 1810 and 1818 failures at The Landslip and the 1839 failure at Gore Cliff. One of the most significant recent events occurred below Gore Cliff on 3rd March 1978 (Chandler, 1984);

(b) shallow mudslide activity occurs at a number of locations along the coast, including Gore Cliff, St Catherine's Point (Chandler, 1984), below The Mirables (Hutchinson, 1983), Castle Cove, Wheeler's Bay, Horseshoe Bay and parts of The Landslip (Chandler, 1984). The position of these slides is controlled by the presence of the Gault Clay, either in situ or in displaced blocks;

(c) vents or fissures; opened joints known as vents have been reported at a number of locations within Ventnor (see Chapter 2). These fractures result from the collapse of superficial debris into open, near-vertical joints in the Upper Greensand and Chalk.

(d) ground subsidence between fissures creating graben forms, as identified by Chandler (1984) in Upper Ventnor along Newport Road and in the Havensbush play area (see Chapter 2);

(v) failure in the *in situ* sea cliffs; the most important cliffs in this category are the Lower Greensand cliffs at

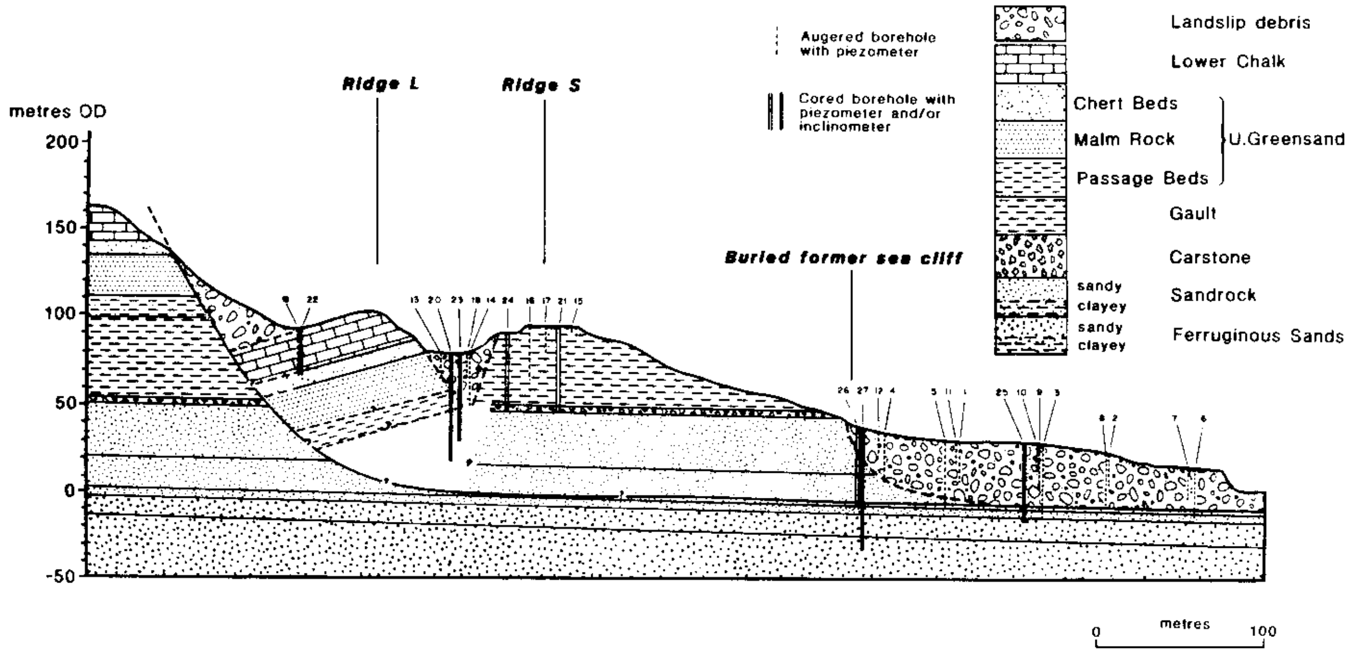


Figure 4.6: Cross-section through the St Catherine's Point landslide *(after Hutchinson, 1987a)*

Blackgang and east of Monk's Bay. Hutchinson *et al.* (1981b) described the main factors influencing the recession of the Lower Greensand cliffs at Blackgang and emphasised the importance of seepage in controlling the cliff form. At Monk's Bay the cliffs appear to retreat through a combination of rockfalls and high-angle rock slides;

(vi) failure in the sea cliffs developed in landslide debris; failures range from fairly minor falls and slides, as between Castle Cove and Ventnor Bay, to more deep-seated movements within the debris aprons as around St Catherine's Point. These failures are controlled chiefly by the composition of the aprons, and especially the extent and position of clayey masses on one hand and resistant blocks on the other.

CHAPTER 5
THE GEOMORPHOLOGY OF THE UNDERCLIFF AT VENTNOR

5.1 INTRODUCTION

A geomorphological map of Ventnor has been produced, which summarises the surface form of the landslide complex and the surrounding area. This map shows the relative positions of the main geomorphological units that occur in the area, and identifies the nature and extent of individual landslide units. It is not possible to confidently model landslide mechanisms throughout the area without an extensive sub-surface investigation. However the spatial pattern of surface features, such as broad terraces, irregular slopes and steep cliffs, give vital clues about the nature of landsliding and the possible mechanisms of failure. In this way, geomorphological mapping has enabled the recognition of a number of different landslide forms and, of equal importance, their inter-relationships.

Different parts of the Undercliff can be expected to behave differently, because the sensitivity to the effects of destabilising factors (such as rainfall) is likely to vary from one landslide unit to another. A clear understanding of the variety of landslide types, their extent and inter-relationships is, therefore, the key to explaining the pattern of contemporary movement in the town. It follows that the geomorphological map provides the framework for explaining variations in:

(i) the scale of recent movement;

(ii) the distribution of recent recorded movement; and

(iii) the pattern of structural damage to road, sewers, water mains, buildings etc., caused by ground movement.

5.2 GEOMORPHOLOGICAL UNITS

The geomorphological map is the product of extensive field survey* supported by an interpretation of aerial photography of the area**. Four main geomorphological zones occur in the study area, each with a characteristic range of landforms and features: the Chalk Downs; an Upper Greensand bench; landslide features and fluvial features. A simplified version of the geomorphological map is presented in Figure 5.1 which highlights the relationship between these main units.

5.2.1 Chalk Downs

As its name suggests, this unit is developed primarily in the Chalk although in places along the Undercliff the Chalk has been eroded exposing the Upper Greensand (as around Niton). The summit height of the Downs varies from c196m at Rew Down, to 235m on St Boniface Down. The rounded crests of these hills are mantled by variable thicknesses of angular flint gravels (White, 1921).

The southern slopes of the Downs are generally convex in form, with slope angles ranging from 17° on the flanks of Rew Down, to 48° on St Boniface Down. At a number of locations (e.g. Bonchurch Down, Ventnor railway station, west of The Heights Hotel on Whitwell Road) it is possible to recognise remnants of a valley network which would have drained the Downs southwards prior to the present (Holocene) phase of cliff retreat.

On the south face of St Boniface Down there is a clear series of landslide backscars, which together probably define an area of shallow translational failure of the weathered chalk.

An example of such a failure occurred in 1877 above the former seaman's mission on Mitchell Avenue (Anon, 1877a).

Slope angles in this area are between 36°and 48°, considerably steeper than the general slope angle within the Downs. It is unlikely, however, that the upper sections of the Chalk Downs are unaffected by deep-seated landsliding.

5.2.2 Upper Greensand Bench

Immediately downslope of the Chalk Downs there is a narrow, 60-180m wide, gently sloping (3-13°) bench, probably developed at the junction of the Lower Chalk with the Upper Greensand Chert Beds. This is not a continuous feature being absent from parts of Upper Ventnor (Figure 5.1). The bench, where present, does not maintain a constant elevation along its length which indicates that it is, in part, displaced by landsliding. Outside the area of major landsliding, the bench, including the area to the landward capped by the Chalk, has been affected by slight seaward rebound movements consequent upon the removal of lateral support by marine erosion and landsliding (Chandler, 1984). This has resulted in the formation of open joints (known locally as vents) and slight subsidence, increasing to seaward, of the intervening blocks. Indeed, joint and fissure measurements in Ventnor railway station (Chandler, 1984) revealed that the Upper Greensand strata were progressively offset, along joint planes, with a total displacement of 2.36m measured over a 106m length.

5.2.3 Landslide Features

The main Undercliff landslides lie immediately below the Chalk Downs and Upper Greensand bench (Figure 5.1). From morphological evidence together with sub-surface investigations from elsewhere in the Undercliff, the following features can be recognised.

(i) **multiple rotational landslides** (Figure 5.2a); rotational landslides develop where slope failure occurs along a well-defined, curved slip surface. This surface, being concave upwards, imparts a degree of backward rotation or tilt to the failed mass, which is accompanied by sinking at the rear and heaving at the toe (Hutchinson, 1988). In the study area multiple rotational landslides occupy a broad

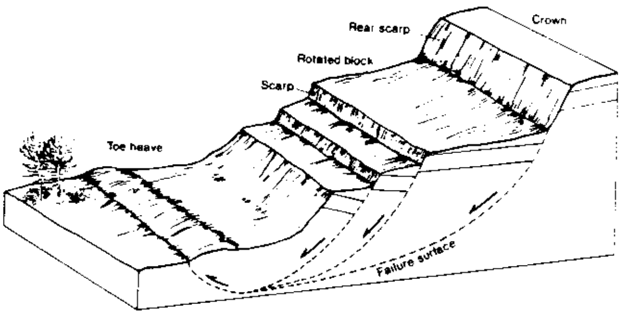


Figure 5.2a: Multiple rotational slide

zone in the upper parts of the Undercliff giving rise to linear benches separated by intermediate scarps. These units chiefly comprise back-tilted blocks of Upper Greensand and Chalk. Evidence of back-tilted strata within Ventnor is widespread, with all the exposures of Upper Greensand in this zone showing northwards dipping bedding, contrary to the dip of the *in-situ* strata (Table D.1, Annex D).

*FOOTNOTE * Further details of the techniques involved in a geomorphological survey are presented in the Geological Society Working Party (1982) and Cooke & Doornkamp (1990).*
*** Flight No. RC8 c1:4,000 scale photos. 117-125, flown on 15.4.81 and held by Cambridge University Committee for Aerial Photography.*

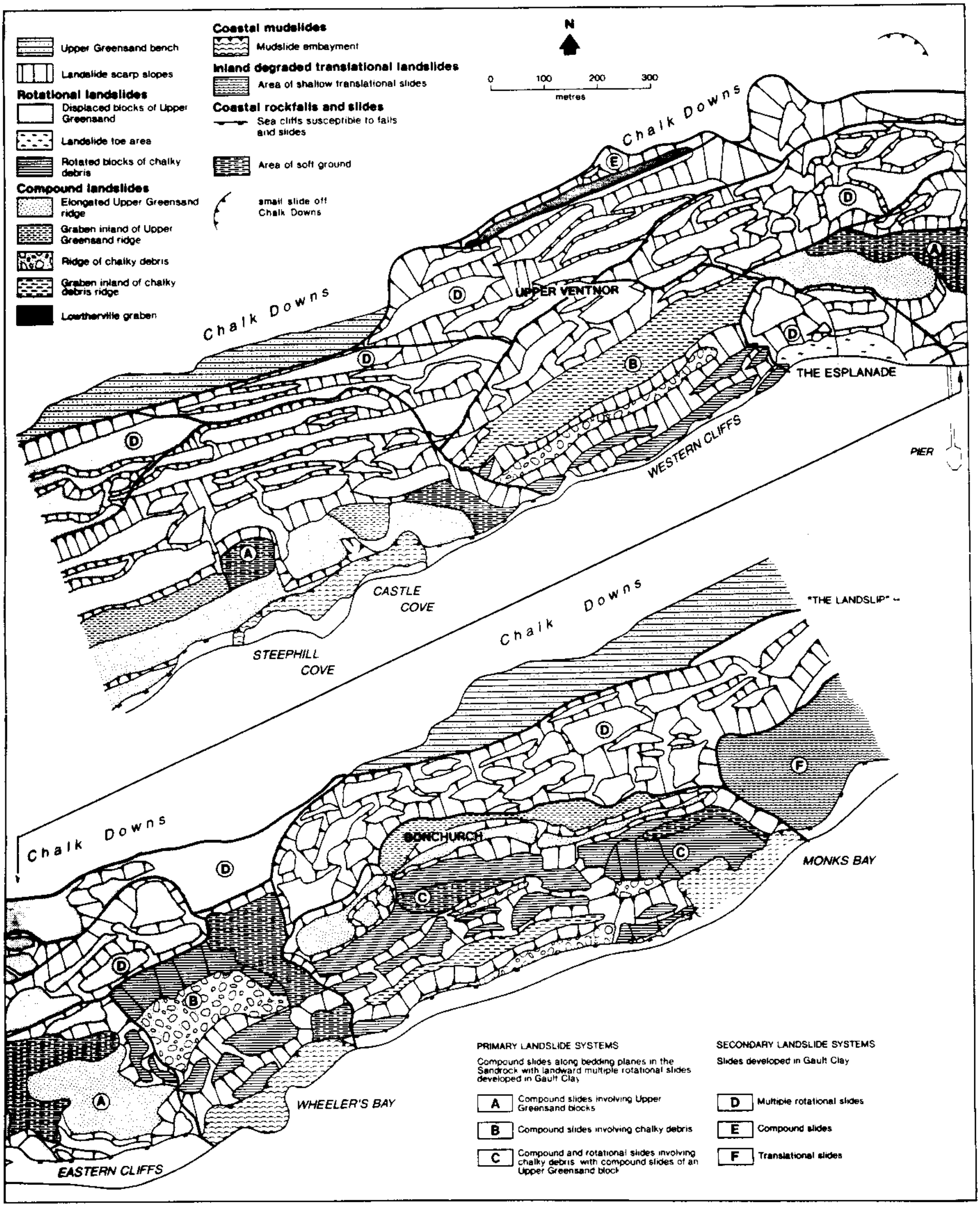


Figure 5.1: Simplified geomorphological map of the Undercliff at Ventnor.

This type of failure generally results in the development of a series of slipped blocks with a common curved shear surface. Multiple rotational failures are usually characteristic of situations where the strata are sub-horizontal and consist of a relatively thick layer of stiff fissured clay (Gault Clay) underlain by a more competent stratum (Carstone) and overlain by a substantial capping stratum of well jointed strong rock (Upper Greensand);

(ii) **compound landslides;** Compound landslides are characterised by markedly non circular slip surfaces formed by a combination of a steep planar rearward part and a flatter sole (Figure 5.2b; Barton, 1984; Hutchinson, 1988). Such landslides generally reflect the presence of strong structural control within the slope. The combination of sequences of sub-horizontal bedding and thin layers of clay separated by sandstones in the Sandrock appear to have controlled the development of this type of failure, at depth. By contrast, shallower failures in the thicker Gault Clay have been able to develop in the classical rotational manner.

In the study area such slides generally comprise a long linear ridge parallel to the coastline formed by forward movement of a block of material along a sub-horizontal planar slip surface. The forward movement of this ridge would have created a graben or chasm behind, in which landslide debris has accumulated as a result of failure of both the rear scarp and the landward side of the linear ridge.

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 (Figure 5.1). In Bonchurch, this zone comprises a near continuous ridge, 800m long, 10-15m high and parallel with the coastline, apparently composed of displaced Upper Greensand, with a graben-like depression behind (landward). Seaward of this ridge there is a series of similar, but smaller features apparently involving Chalky debris. One of these ridges is exposed along the coast between Wheeler's Bay and Horseshoe Bay.

Broad ridges occur in the centre of the town in the North Street and the Dudley Road to Alpine Road areas, comprising Chalky debris and Upper Greensand blocks respectively. The latter feature has been separated into two units by the course of a small stream valley.

Inland of the Western Cliffs there is a single continuous ridge apparently involving Chalky debris, about 500m long and 15-20m high, backed by a broad graben-like depression (the Ventnor Park area).

Between Flowers Brook and the Botanic Gardens there are a series of broad ridges, probably developed in Upper Greensand blocks covered by Chalky debris (as seen in the cliffs west of Steephill Cove). These features are also backed by low-lying graben areas.

The low-lying areas inland of these features probably contain peat and other soft sediments;

(iii) **Lowtherville graben;** in Upper Ventnor a graben-like feature appears to have developed by Chandler (1984). This comprises a 20m wide subsiding block bounded by parallel fissures and extends parallel to the coast for over 500m. This unit exhibits the most serious ground movements recently experienced in the town (Chapter 2). It seems likely that a compound slide is gradually developing here;

(iv) **mudslides;** mudslides are defined by Hutchinson (1988) as relatively slow moving, commonly lobate or elongate masses of accumulated debris which advance chiefly by sliding on discrete bounding shear surfaces (Figure 5.2c). These features generally have a steeper back slope down which debris is supplied (by falls, shallow slides and mudslides) to a more gently inclined front slope forming the accumulation zone (Hutchinson 1970). Mudslides are especially well developed on slopes containing stiff fissured clays because of the ease with which such materials break down to provide a supply of debris.

Within the study area mudslides tend to occur where the Gault Clay has been exposed or lies close to the ground surface at four main locations:

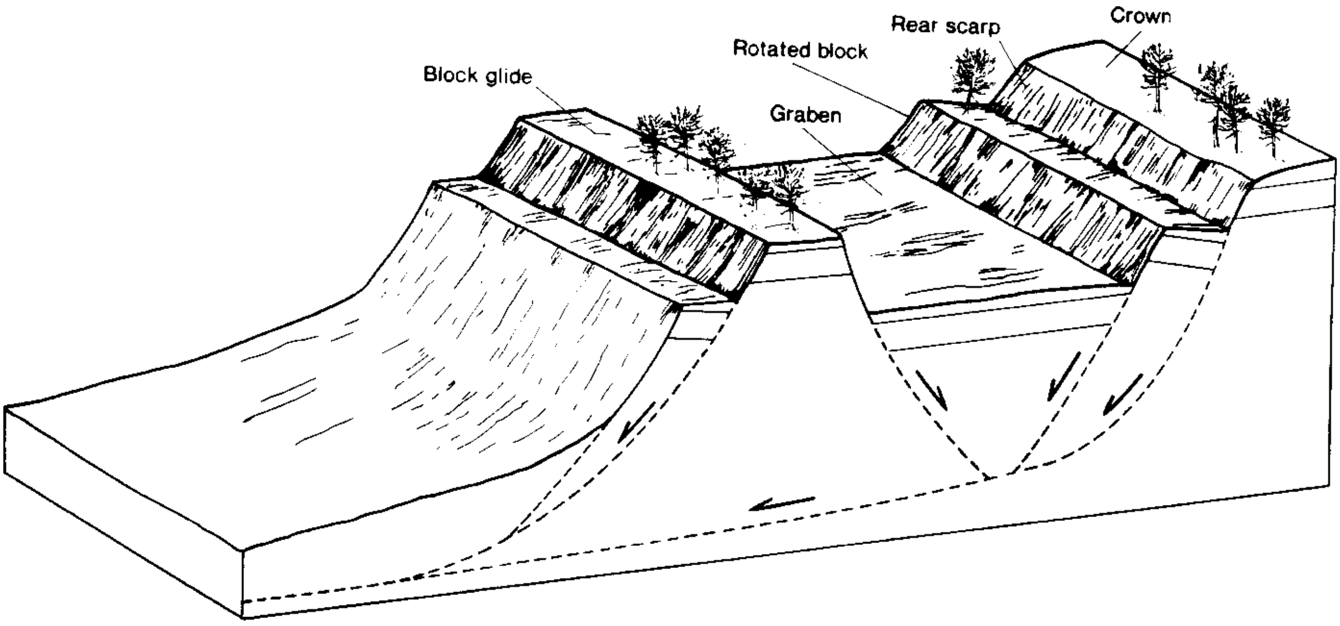


Figure 5.2b: Compound landslide

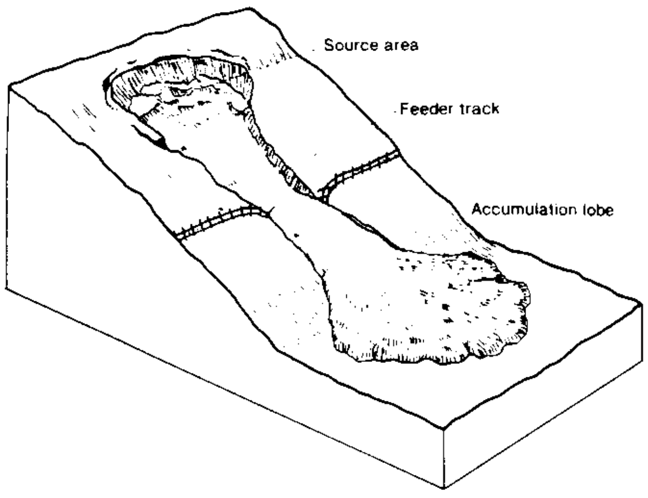


Figure 5.2c: Mudslide

Steephill Cove; a degraded, well vegetated mudslide can be recognised above the line of beach front houses in the cove;

Castle Cove; an active mudslide system occurs within the cove and, in places, has overrun the existing sea defences;

Wheeler's Bay; the sea-cliffs from Cliff Cottage to Ventnor Holiday Villas comprise a series of shallow mudslide embayments, with many parts of the area showing signs of active movement;

Horseshoe Bay; a series of partially stabilised mudslide embayments occur along this stretch of coast.

These mudslides are generally high-angled (25-30°), which suggests that they involve the lower silty beds of the Gault Clay which are relatively hard with low plasticity (see section 4.2). Most sites (except Castle Cove) are thickly vegetated indicating that they are relatively inactive;

(v) **degraded translational landslide systems;** the area inland of Monk's Bay represents the degraded form of a low-angle mudslide system developed in the Gault Clay, as identified by Hutchinson et al (1981a). The system comprises a series of rotated blocks of Upper Greensand in the source area, which degrade downslope into shallow mudslides and small rotational slips. The morphology of this area is very different from the rest of the study area, and closely resembles parts of The Landslip;

(vi) **coastal rockfalls and rockslides** (Figure 5.2d); steep cliffs occur along most of the coastline, with the exception of Ventnor Bay, ranging in height from c.10-15m (Western Cliffs) to c.40m (Eastern Cliffs and Westfield). Much of this cliffline is developed in landslide debris, including remnants of debris apron (e.g. Westfield) and exposed Upper Greensand landslide blocks (e.g. Eastern Cliffs). These cliffs are susceptible to large falls, spalling and slides, especially where unprotected from marine erosion (e.g. Western Cliffs).

Within the study area the only stretch of coast developed in *in situ* material is in Monks Bay, where the 17-26m high cliffs are developed in the Carstone and, further east, the Sandrock. The cliffs are particularly susceptible to marine erosion through a combination of

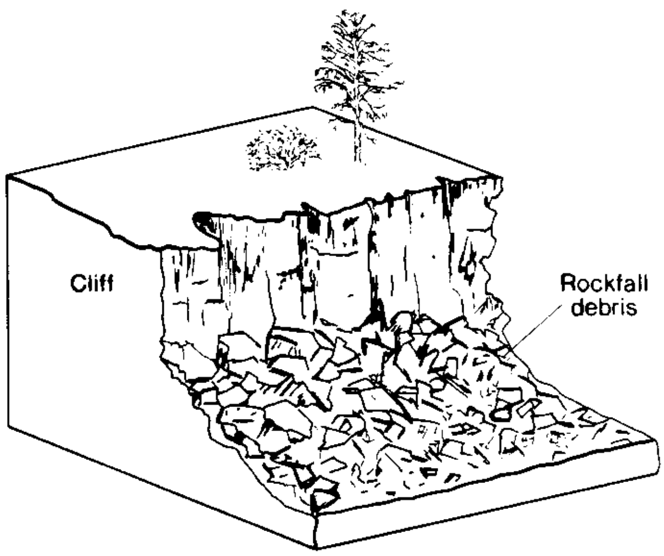


Figure 5.2d: Rockfall

rockfalls, topples and high-angle slides (as occurred in the winter of 1989-1990). Where unprotected Hutchinson *et al* (1981a) estimated an average rate of cliff retreat of 0.18m per year over the period 1862-1980.

5.2.4 Fluvial Features

Within the study area it is possible to recognise a range of features (valleys, springs, ponds) related to fluvial processes rather than landsliding. These features are of considerable significance as they represent preferential drainage paths through the landslide complex. The most important features include:

(i) a major relict stream valley occurs in the centre of Ventnor, with water once flowing from the coombe above the railway station, past St Catherine's School and over the sea cliffs at the Cascades. There is no surface flow along this valley now, although it is likely to act as an important route for sub-surface flow. Soft sediments, including peats and alluvium should be anticipated throughout this valley;

(ii) the low lying ground inland of Trinity Road is considered to have once been an area of ponds and marshland. From surface evidence it is possible that there may have been an overflowed route to the south (following Madeira Road) which crossed the sea cliffs at King's Bay. Soft sediment should be anticipated in this valley, particularly north of Trinity Road;

(iii) Flowers Brook, which drains the low-lying graben area inland of the Ventnor Park ridge. This stream flows westwards towards Steephill, but after an abrupt change in course crosses the sea cliffs west of Myrtle Bay;

(iv) Bonchurch Pond was once a withy bed where local fishermen collected rushes for lobster and crab pots. In the 19th century, the pond was recognised as a source of infection and it was cleaned out. The pond is probably fed by a series of sub-surface flows from Bonchurch Down.

5.3 TYPES OF CONTEMPORARY GROUND MOVEMENT

A wide variety of types of contemporary ground movement have been identified from the descriptions presented in local newspapers or other sources, together with an understanding of the geomorphological context of these movements. The various forms of movement that have occurred in Ventnor are shown in Figure 5.3 and involve:

Type 1: shallow translational slides in soil and weathered chalk on the steep slopes of the Chalk Downs, e.g. above the former seaman's mission on Mitchell Avenue in 1877 (Anon, 1877a).

Type 2: slow settlement of the Upper Greensand bench, accompanied by joint widening and the development of vents. The most widely reported example occurred along Whitwell Road in 1954 (Edmunds & Bisson, 1954; Toms, 1955).

Type 3: differential movement of Upper Greensand blocks, including:

Type 3a: rotation, forward tilt, torsion and differential settlement. This type of movement has taken place in many parts of the town, most notably in Upper Ventnor. Clear examples of such movements were reported along Gills Cliff Road, Ocean View Road, Castle Road and Zig Zag Road in the winter of 1960-1961 (SWBC records).

Type 3b; settlement within the Lowtherville graben, where movements of up to 84mm per year (and 21mm over 2 months) have been recently recorded (Woodruff, 1989).

Type 3c: uplift and heave in the toe areas of individual landslide systems. Along the Esplanade for example, 780mm of uplift occurred between 1949 and 1988.

Type 4: degradation of Upper Greensand landslide scarps, by means of:

Type 4a: rockfalls. Despite the large number of vertical rock faces only three minor falls have been reported since 1855.

Type 4b: slow superficial movements resulting in bulging and cracking of retaining walls. An example of this type of movement occurred behind Sea View in Grove Road during 1954 (Anon, 1954c).

Type 5: differential movement of landslide blocks in chalky debris. This type of movement has resulted in slight damage to property in parts of Bonchurch.

Type 6: degradation of landslide scarps in chalky debris. This is mainly confined to slow superficial movements which may lead to bulging and cracking of retaining walls, as was the case behind No. 13 St Catherine's Street in 1987 (Anon, 1987b).

Type 7: consolidation of soft ground within low-lying graben areas. This has caused damage to property in a number of areas, including the centre of Ventnor.

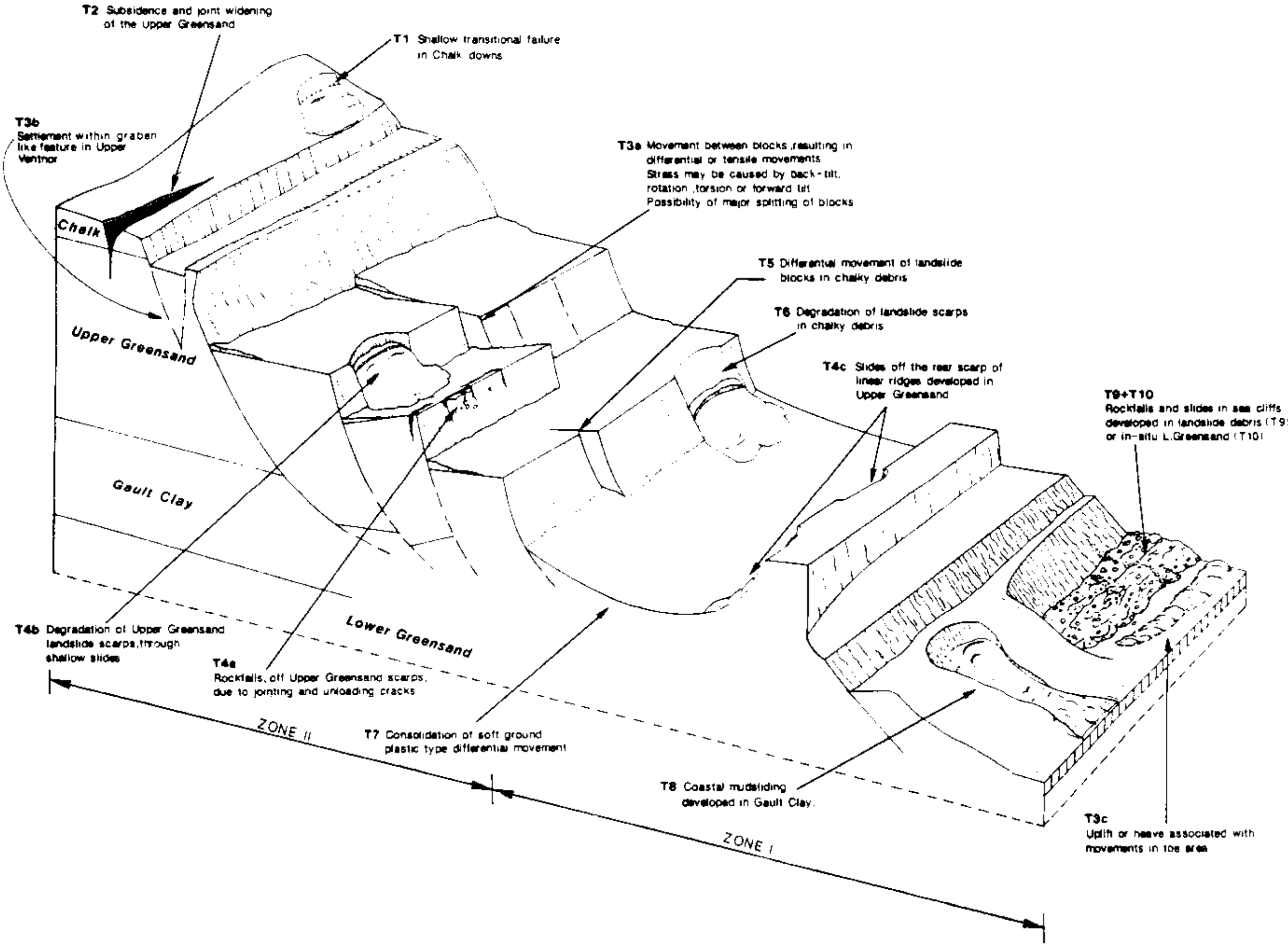


Figure 5.3: Diagrammatic section through the Undercliff showing the principal types of contemporary ground movement in Ventnor

Type 8: intermittent slow movement within the coastal mudslide systems at Steephill Cove, Castle Cove and Wheeler's Bay.

Type 9: minor rockfalls and slides off the coastal cliffs developed in landslide debris, such as occurred along the Western Cliffs in the winter of 1989-1990.

Type 10: rockfalls and slides off the *in-situ* Lower Greensand cliffs in Monk's Bay. Examples of this type of movement took place in the winter of 1989-1990.

5.4 LANDSLIDE DEVELOPMENT

The present form of the Undercliff represents the product of at least three main phases of mass movement activity over the last 8,000 years, together with the continuing modification by contemporary processes. In addition there has also been marked spatial variability in the nature of landslide activity, as is demonstrated by the record of the last 200 years. The Undercliff should therefore be seen as a highly complex, multi-faceted landslide system, reflecting the legacy of a wide range of mass movement processes which have developed under contrasting climatic and/or geomorphological conditions. Each subsequent phase of activity will have removed, reworked, masked or re-emphasised the effects of earlier phases. The complexity of form present within the Undercliff is a reflection of this polygenetic evolution. The development of the system cannot, therefore, be explained in terms of simple models which are broadly applicable along its whole length.

The Undercliff landslides owe much of their present character to the interplay of climatic fluctuations in and subsequent to the Pleistocene, together with the effects of marine erosion during the Flandrian transgression (Hutchinson, 1987a). In broad terms, it is inferred that the coastal slopes became fronted by large aprons of landslide and solifluction debris during the periods of low sea level in the last glacial period. These aprons would have acted generally as a natural protection and stabilisation measure for the coastal slopes. the post-glacial Flandrian recovery of sea level brought the forces of marine erosion once more into play in the region of the landslide toes. Parts of the apron and, in places, even the landslide masses and solid strata thus tended to be eroded away, with the consequent partial destabilisation of the coastal slopes. The available dates (4-7km to the west of Ventnor at Binnel Point and St Catherine's Point) (Hutchinson et al., 1985a; Freece, 1986; Hutchinson *et al.*, 1991), suggest that major post-glacial landsliding in the Undercliff commenced between 8,000 and 4,500 BP.

It is clearly not possible to model reliably the true nature and mechanics of the landslides without an extensive sub-surface investigation. In the absence of this, a combination of the reasonably well defined geology and structure with detailed geomorphological mapping, together with the limited amount of sub-surface information (e.g. Woodruff, 1986) and recent investigations of landslides elsewhere on the Undercliff, particularly at Gore Cliff (Bromhead *et al.*, 1991; Figure 5.4) and St Catherine's Point (Hutchinson *et al.*, 1991; Figure 4.6), it is possible to advance tentative models of the landslides in the Ventnor area*. These are considered generally to be at least two-tier, involving:

Zone I: compound failures along clay layers within the Sandrock in the seaward part of the Undercliff, following broadly the St Catherine's Point model.

Zone II: multiple rotational and compound failures, to the landward, on slip surfaces within the Gault Clay, following the Gore Cliff model where the basal slip surface is 15-18m above the base of this unit as distinct from close to its base as in the related, but lithologically different, Folkestone Warren landslides (Hutchinson, 1969).

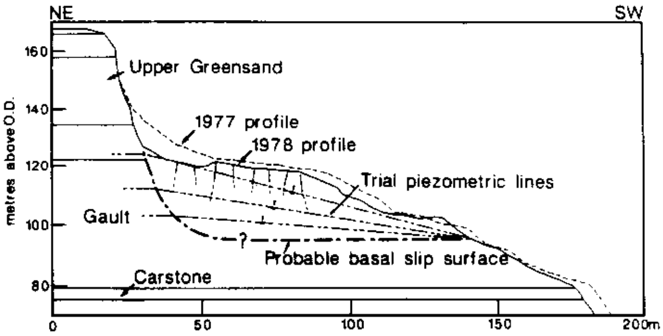


Figure 5.4: Cross-section through the landslide at Gore Cliff *(after Hutchinson et al 1985a)*

The exception to this pattern occurs inland of Monk's Bay where the slopes comprise Zone II-type landslide features. Here, mudslides and rotational slides have developed in the Gault Clay. No Zone I-type failures appear to have developed here, with only minor rockfalls and slides occurring on the Lower Greensand cliffs.

In the past the landslide complex of the Ventnor Undercliff has been viewed as a single landslide system dominated by laterally extensive terraces of displaced Upper Greensand blocks subparallel with the coast. However, the detailed geomorphological mapping, carried out as part of this study, allows a new interpretation to be made in which the Undercliff is seen to consist of a relatively simple pattern of intimately related, but individual landslide systems (Figure 5.1). These different landslide systems vary in the nature of materials involved and the depth of the basal shear surface. Clearly they do not represent landsliding under a single set of environmental conditions or a single system, i.e. there is no simple evolutionary model for the whole area.

Possible schematic sections at four locations in the Undercliff are shown in Figure 5.5 which indicate the close relationship between landslide units at different levels. It is felt that coastal erosion during the Flandrian Transgression would have resulted in the unloading of the inland slopes, promoting the development of a series of major deep-seated compound landslides on the lower slopes (Figure 5.1). The arcuate backscars of these lower slope landslide systems appear to have isolated a series of broad, triangular spurs. These spurs may have subsequently failed as a result of the unloading on either side caused by movement of the landslide systems downslope (Figure 5.6). It is considered likely that this second series of slides have developed along slip surfaces within the Gault Clay. They have taken the form of multiple rotational failures, giving rise to the terrace-like form of the upper parts of the Undercliff. A further tier of terraces appears to have developed upslope of these spurs in response to continued movement and unloading (Figure 5.6) and appear to have involved both rotational and compound failure mechanisms. In this context, the formation of the graben-like feature in Upper Ventnor (Figure 5.1) is considered to be the result of the long-term development of a compound failure in the Chalk, Upper Greensand and Gault Clay as a result of unloading downslope.

5.5 PRELIMINARY STABILITY ANALYSIS

**FOOTNOTE: A review of previous explanatory models is presented in Annex E.*

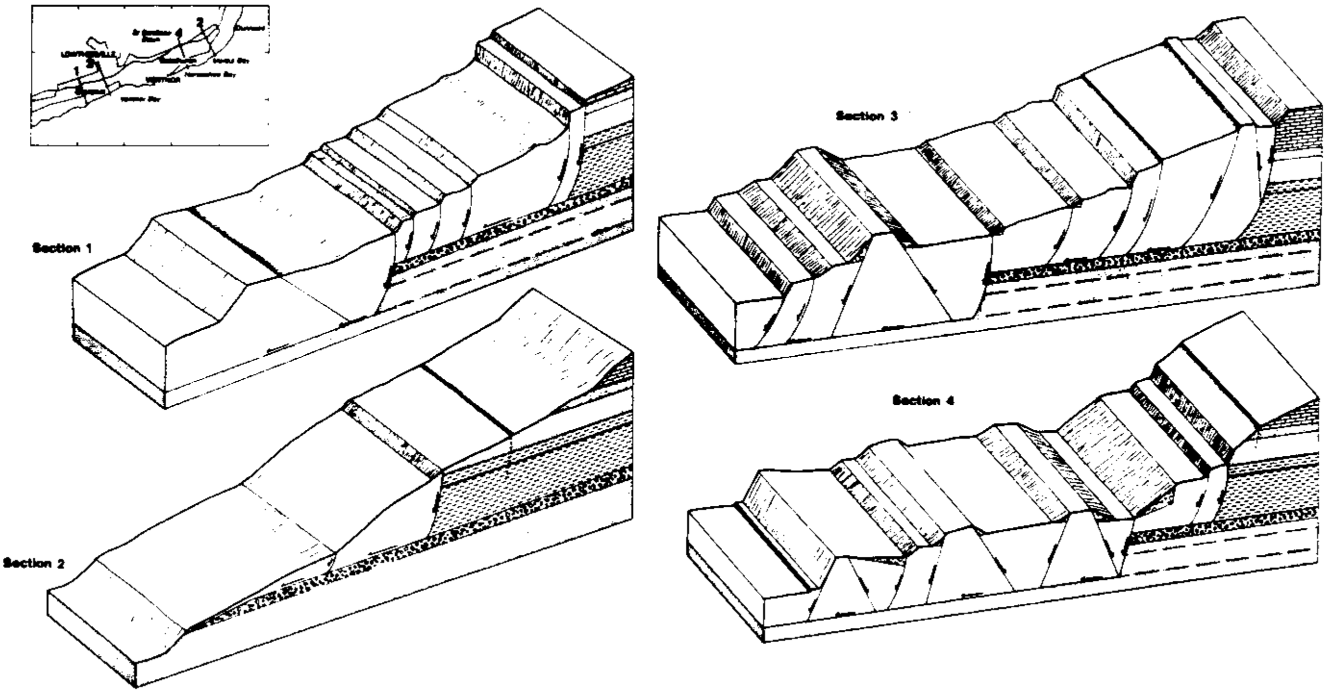


Figure 5.5: Schematic sections through the Undercliff showing proposed models of failure (geological units as in Figure 4.2)

A section of the Undercliff through the Western Cliffs and Lowtherville has been chosen for preliminary stability analyses, largely to test the validity of the proposed two-tier model. The section (Figure 5.7) shows the expected geology, four potential levels of basal slip surface, the piezometric surfaces for the assumed perched and confined groundwater tables and the main rear, intermediate and toe shears. Morphologically the section divides into the two main zones identified above. Zone I comprises a compound failure, seated in clay layers in the Sandrock and giving rise to the formation of the large elongate ridge in the Ventnor Park area (subsequent marine erosion has caused a series of rotational slides from the seaward flank of this ridge): Zone II consists of multiple rotational failures seated within the Gault, giving rise to the sequence of narrow terraces in Upper Ventnor, backed by the Lowtherville Graben.

Two-dimensional stability analyses using the methods of Morgenstern & Price (1967) have been carried out on both one- and two-tier combinations of these various slip surfaces. The preliminary values of geotechnical parameters taken are:

Density	= 21 kN/m^3
$c'_r = 0, \phi'_r$*	= 10° within and at the base of the Gault
$c'_r = 0, \phi'_r$	= 10° on clay layers in the Sandrock.

Pore-water pressures are taken as hydrostatic beneath the piezometric line (PL) for the perched groundwater table in the Upper Greensand and landslip masses, and hydrostatic beneath the PL for the confined groundwater table in the Lower Greensand. Within the Gault, the higher value of pore-pressure is taken.

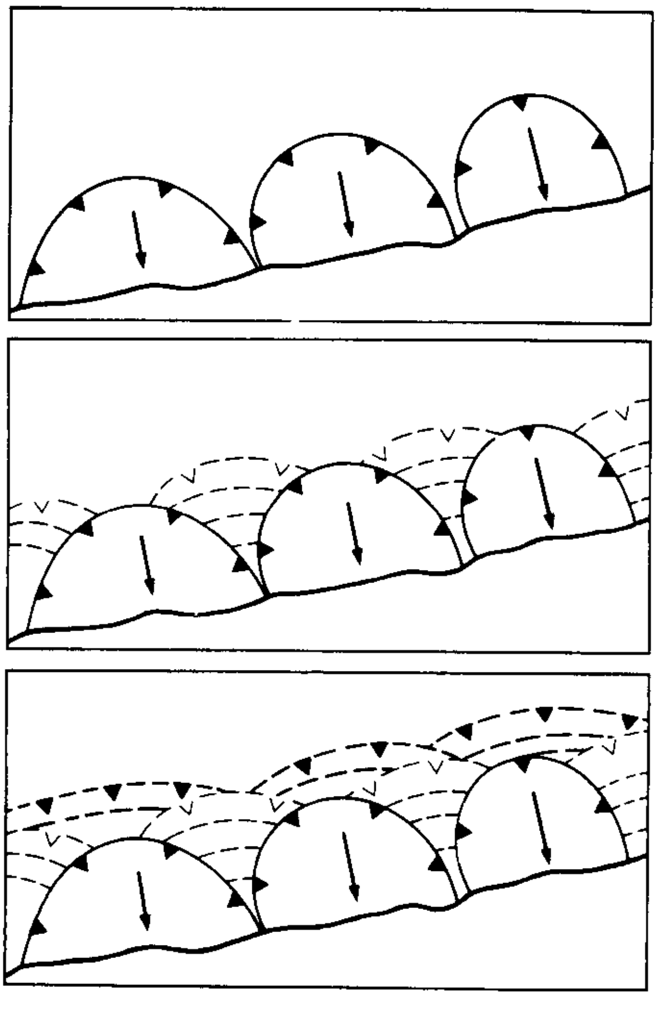


Figure 5.6: Landslide development in the Undercliff

**FOOTNOTE: c'_r = cohesion, ϕ'_r = residual strength. Details of the methods adopted and the results obtained from the stability analyses are presented in Annex E.*

Because of the fairly high B:L ratio (Skempton & Hutchinson, 1969) of the slips and the preliminary nature of the analyses, a three-dimensional analysis was not used at this stage. The results of the analysis on this section are summarised in Table 5.1.

Considering the large numbers of assumptions made in the analyses, it is encouraging that the Factors of Safety fall generally quite near to the expected value of, or a little above, unity. This suggests that the proposed models are reasonably valid. While too much confidence should not be placed on the precise values in the Table, there is some tendency for the deeper slip surfaces to be more critical. A consideration of all available factors points to the likelihood of the main failure surfaces in this part of Ventnor being seated in a clay layer within the Sandrock in the seaward Zone I, and rising to a surface within the Gault in the landward Zone II.

POSITION OF SHEAR SURFACES	FACTOR OF SAFETY
A1-A2-A3-F	0.90
B1-B2-B3-F	0.89
A1-A2-E	1.08
B1-B2-E	1.17
C1-C2-C3-F	0.98
D1-D2-D2-F	1.05
D2-D3-F	0.84
A1-A2-C2-C3-F	1.06
A1-A2-D2-D3-F	1.11
B1-B2-C2-C3-F	1.01
B1-B2-D2-D3-F	1.05

Table 5.1 Results of preliminary stability analyses for the Western Cliffs-Lowtherville section, Ventnor. For details of shear surface locations see Figure 5.7.

It is important to recognise that the existing Undercliff represents a remnant of a previously more extensive landslide system. Continued erosion of the coastline over the last 2,000 years or so, since the main landslide units were formed, will have removed large portions of the toe areas and accumulation zones of these units. All that is left today is the marginally stable upper sections (see section 6.2); what is left of the landslide toes is probably below the sea bed, well offshore (Figure 5.8). It is impossible to calculate the overall Factor of Safety for this system as a whole, for no analyses exist whereby the relative effects of a trimming of the lower part of the landslide system (by sea erosion) can be judged against those of an increase in toe loading by the mass of the sea water itself resting on the lower parts of the landslide system.

5.6 SUMMARY

Ventnor is built almost entirely on the complex of old coastal landslides termed the Undercliff. These landslides involve uppermost the capping strata, the Chalk and Upper Greensand. The landslides owe much of their present character to the interplay of late Pleistocene climatic events and marine erosion which recommenced in the early- to mid-Post-glacial period. In the Ventnor area, the Undercliff has long been subject to slow movements which have caused considerable cumulative damage to buildings, roads and services in some areas.

The geomorphology of the landslides of the Ventnor Undercliff suggests, in combination with geological and geotechnical evidence, that they comprise broadly a seaward system of compound landslides, seated in a clay layer in the Sandrock (Lower Greensand), backed by a landward system of multiple rotational landslides, seated within the Gault Clay. Detailed mapping shows that discrete landslide systems can be distinguished in a longshore, as well as a downslope direction. This is of considerable importance in the understanding of past behaviour of the Undercliff.

Preliminary stability analyses were carried out on a characteristic section through Ventnor, using assumed geological, hydrogeological and geotechnical parameters. The results provide some support for the inferred geomorphological/geological proposed model. However, sub-surface investigations are needed to further substantiate this.

A wide variety of types of contemporary ground movement appear to occur within the landslide complex, including:

(i) first-time failures off the Chalk Downs;

(ii) subsidence and joint widening (vent formation) within the Upper Greensand strata;

(iii) rotational or compound landslide blocks moving slowly *en masse* along pre-existing shear surfaces;

(iv) degradation of pre-existing landslide features by a variety of processes e.g. sliding and falls off scarp faces or mudslides.

The geomorphological assessment of the inter-relationships between the relict landslide features and the nature of contemporary movement (type, magnitude, frequency and impact) provides the framework for understanding the behaviour of the landslide complex over the last 200 years. This has been expressed as a Ground Behaviour map, the basis of which is described in Chapter 6.

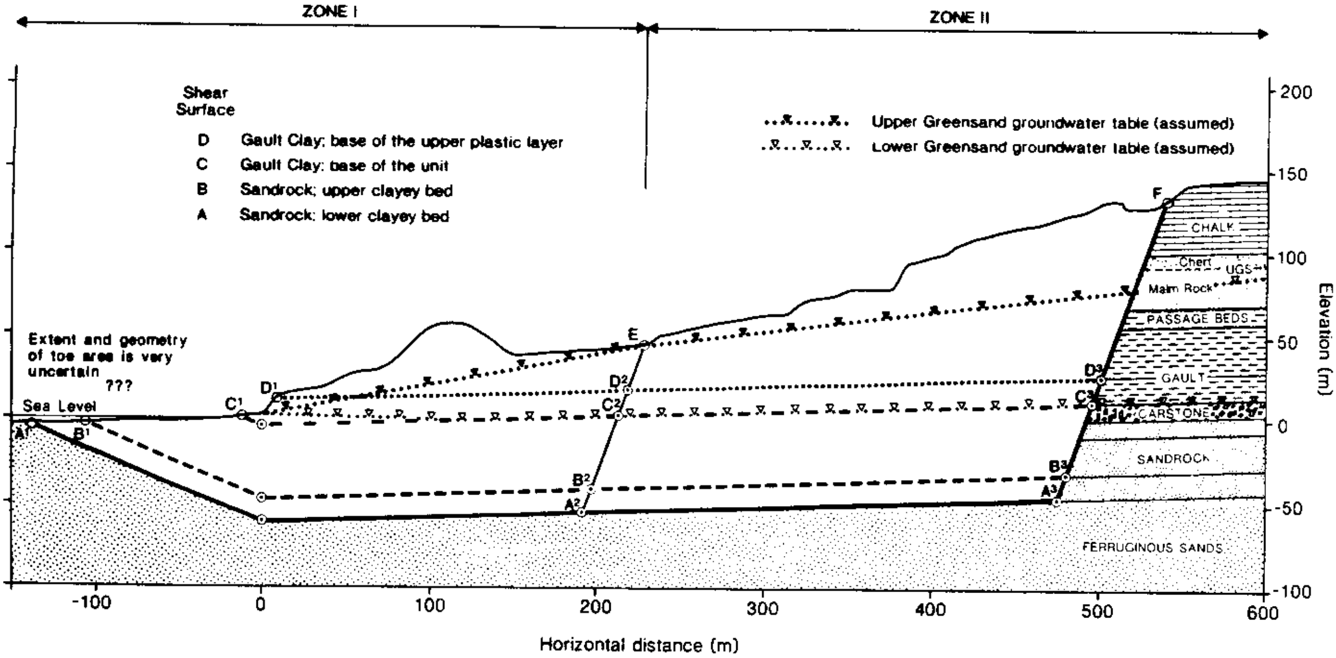


Figure 5.7: Preliminary stability analysis: cross-section from the Western Cliffs to Lowtherville showing the relative positions of possible shear surfaces and ground water levels.

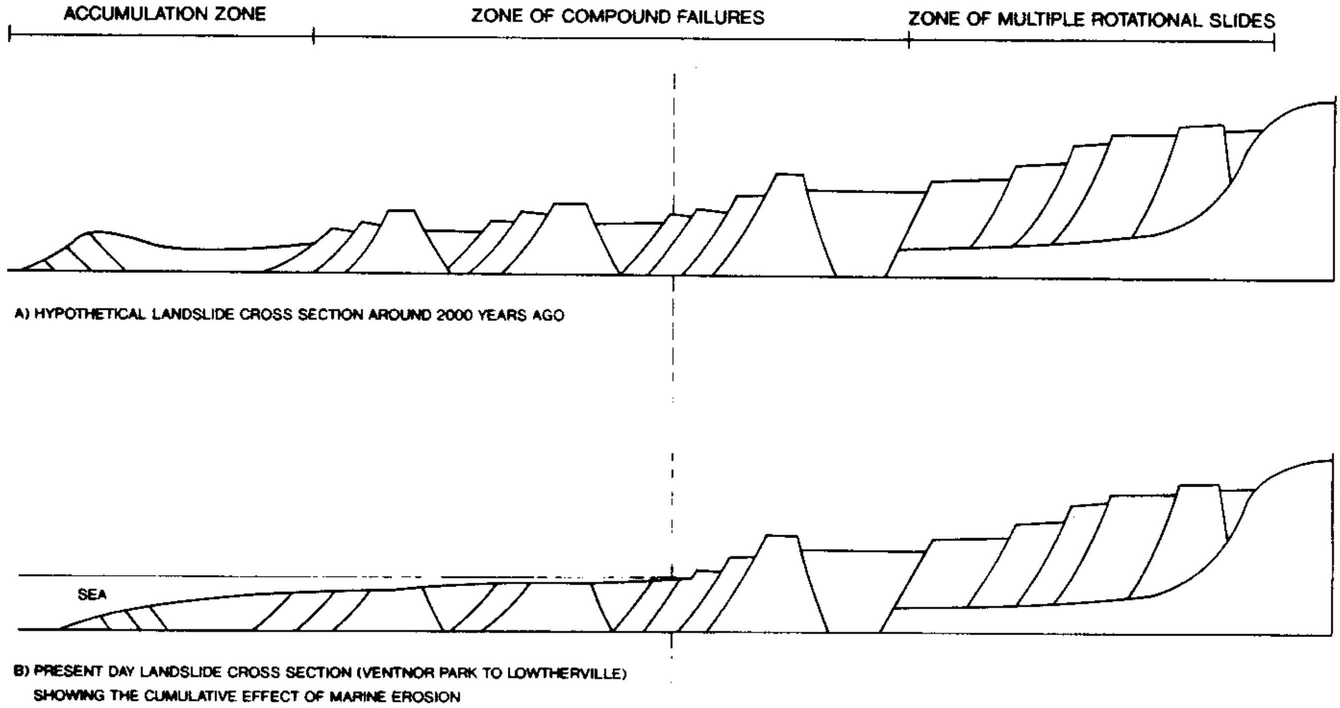


Figure 5.8: Diagrammatic section demonstrating how marine erosion may have removed large portions of the original landslide system.

CHAPTER 6
GROUND BEHAVIOUR

6.1 INTRODUCTION

A simple map showing the likelihood of a particular type of landslide event occurring in a specific area and during a given period is of obvious value in defining the nature of ground movement problems faced by the local community. Similar maps produced in other parts of Great Britain have been described as landslide hazard maps (e.g. Conway, 1976 for part of the Dorset coastline) or landslip potential maps (e.g. Halcrow, 1986, 1988 in South Wales). The latter study is of direct relevance to the problems facing Ventnor, as the maps attempt to provide guidance on the relative potential of instability in the Rhondda Valley and indicate what actions should be taken by the local authorities to control development in vulnerable areas. These maps were prepared at 1:10,000 scale and show the locations of known active and dormant landslides, together with four ranges of "landslip potential" for intervening areas which indicate the susceptibility to movement.

The basis for the approach adopted by Halcrow in South Wales is that, once identified, landslides or potentially unstable areas can be avoided by future development or developed only if appropriate engineering measures are adopted. Ventnor is, however, an unusual case where the whole of the town lies within an ancient landslide complex and the landslides have not and cannot be avoided. The problems are related to the control of the nature of development in parts of the town which have been shown to be particularly susceptible to ground movement. This difference in objectives, between the South Wales and Ventnor studies, required different approaches to defining the degree of hazard in the two areas. This study has concentrated on understanding the **contemporary behaviour of an existing ancient landslide system, rather than assessing the potential for new landslides to occur at a particular site.**

6.2 CAUSES OF GROUND MOVEMENT

Landslides occur when the force of gravity acting on a slope exceeds the strength of the slope material. 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, will help to change a slope from a less stable to a more stable state. No further movement will occur unless changes take place which, once again, affect the balance of opposing forces.

In many inland situations landslides can remain dormant or relatively inactive for thousands of years, as is the case for many examples on the north-facing slopes of Shanklin Down (Figure 4.2). However, in the case of coastal landslides such as the Undercliff, on-going marine erosion (in the past) removed material from the lower parts of the slopes, thereby removing passive support and allowing repeated movement. As described in Chapter 5, over thousands of years this can lead to the area of instability extending inland, progressively affecting a larger area until the passive support provided by the earlier and lower slides in the sequence reduces the potential for further failure. That is, of course, until marine erosion at the base of the slope causes the reactivation of the landslide complex.

The stability of the Undercliff can be viewed in terms of its ability to withstand changes in transient factors such as climate and coastal erosion. Individual sections can, therefore, be described in terms of their ability to withstand potential changes:

(i) stable; where the margin of stability* is high enough to withstand all transient forces in the short to medium term (i.e. hundreds of years), excluding excessive human activity;

(ii) marginally stable slopes; where the slope will fail at some time in response to transient forces attaining a certain level of activity;

(iii) -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 bases of their role in promoting slope failure. These two categories are:

- 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;

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

Before considering those factors which cause ground movement in Ventnor, it is important to stress that the town is built on an inherently unstable slope. As the materials along the landslide shear surfaces are at their residual strength the slopes can be made to move under conditions that they could have resisted prior to failure. Thus, events which cause ground movement in Ventnor, or along the Undercliff, will not necessarily cause problems on intact slopes of similar materials elsewhere**.

By establishing a long-term record of ground movement (over the last 200 years) it is possible to identify those events which appear to have promoted distinct phases of instability (Table 6.1). Coastal erosion has long been appreciated to be an important factor in long-term destabilisation of the Undercliff (Chapter 2). As a result, much of the coast has now been protected by sea defences and it is unlikely, therefore, that marine erosion remains as a significant cause of movement in these areas. However, both the Western Cliffs and parts of Monk's Bay remain unprotected and uncontrolled erosion (estimated to result in cliff retreat of around 0.3m per year) may still act as a destabilising influence on the landslide slopes further inland*.

**FOOTNOTE: The ultimate cause of all landsliding is the downward pull of gravity. The stress imposed by gravity is resisted by the shear strength of the material. A stable slope is one where the resisting stresses 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 movement is assumed to be 1, with progressively higher values representing more and more stable situations with greater margins of stability. In other words, the higher the value the greater the ability of slope-forming materials 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.

***Of note, landslides on pre-existing shear surfaces generally exhibit limited slow displacement upon failure (Hutchinson 1987b) which is consistent with the pattern of recorded movement in Ventnor.*

Erosion of the shore platform may be as significant as cliff retreat with regard to ground behaviour, because it results in unloading of the landslide toe areas. It is important to stress that this may be effective even when there are well maintained sea defences.

Despite all the coastal protection efforts of the last hundred years, or so, much damage has already been done by coastal erosion. Undoubtedly the Undercliff has been created as a result of coastal erosion, which initiates "waves of aggression" (Brunsden & Jones, 1980) that move inland from the sea cliffs. As has been demonstrated in Chapter 5, unloading at the base of the cliffs eventually promotes retrogressive failure further upslope as the impulse is transmitted inland.

Many coastal landslide complexes in southern England (Figure 4.1) have developed in this way. However, in comparison with these sites (and even elsewhere along the Undercliff) the landslide complex at Ventnor appears to be remarkably inactive. Here the expression of long-term coastal erosion has been slow and intermittent because the impulse is not being transmitted through actively eroding clay sea cliffs but through massive and deep landslide system involving resistant Upper Greensand blocks**. Hence, the effects of coastal erosion may take a long time to work their way to the rear of the Undercliff.

Although erosion may have been checked by coastal protection, destabilising impulses are likely to be still working their way inland. This cannot be prevented by coastal protection 'after the event'. All that can be done in this context is to maintain the status quo and prevent further deterioration of the situation.

Although coastal erosion has progressively reduced the overall stability of the slopes (i.e. acted as a preparatory factor), actual incidents of ground movement appear to be triggered by other factors, such as periods of heavy rainfall. Unfortunately, owing to the slow intermittent nature of ground movement and the lack of precise monitoring information it has not been possible to relate landslide activity with individual landslide activity with individual rainfall events. However, there appears to be a close relationship between phases of increased landslide activity and periods of heavy rainfall and inferred higher groundwater levels. A comparison of the 4-month antecedent effective rainfall (AER) for months when landslide events were either reported or absent*** suggests that, since 1855 (the date when newspaper records begin), the occurrence of ground movement can be defined by three broad classes (Figure 6.1):

Class 1 - when there has been a 1 in 50 (2%) chance of movement. This corresponds to conditions between May and October every year and November to April when the AER is less than 130mm;

Class 2 - when there has been a 1 in 12 (8%) chance of movement. This corresponds to conditions between February and April when the AER exceeds 130mm and November to January when the AER is between 130-350mm. Such conditions have occurred 1 year in 1.2;

Class 3- when there has been a 1 in 1.7 (60%) chance of movement, corresponding to conditions between November and January when the AER exceeds 350mm. Such conditions have occurred 1 year in 22.

Very wet conditions in the autumn are clearly a highly significant factor in explaining the frequency of landslide activity over the last 135 years, with over 80% of all recorded landslide events having occurred during periods when the 4-month AER exceeded 130mm. However, this relationship does not account for the occurrence of all periods of landsliding within Ventnor, as movements have been recorded during periods of very low antecedent rainfall conditions. Such movements may have been either of a type which is less sensitive to long-term rainfall patterns (e.g. coastal falls) or due to human activity.

It is probably no coincidence that the number of reported landslide events was found to have increased with the spread of the town over the past 100 years or so. This partly reflects better records of ground movements and the fact that buildings are a very sensitive indicator of movement. However, 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 1860's caused beach depletion, rapid coastal erosion (Whitehead, 1911) and an increase in reported landslide activity in the 1870's (Chapter 1).

Throughout Ventnor, 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 by changing the surface profile of a landslide slope to a less stable configuration.

However, potentially the most serious destabilising activity associated with development has been artificial recharge of the groundwater table. Uncontrolled discharge of surface water through soakaways and highways drains has contributed to raising the groundwater table to a level where heavy winter storms could trigger movement. In addition, 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 example, during the winter of 1960-1961, over 3M gallons of water from the flooded Ventnor railway tunnel were pumped into the back of the landslide system (Anon, 1960c). This, together with the exceptionally high autumn rainfall preceded the most dramatic movements in recent years (Chapters 1 and 2).

6.3 CAUSES OF DAMAGE

Unfortunately the situation in Ventnor is not a simple case of extensive damage to property in unstable areas and no damage in more stable areas. Often it is not clear whether some of the reported problems with buildings were a direct result of ground movement or simply due to poor building construction (Chapter 3)****.

It is clear, however, that in many areas the pattern of damage to property and structures reflects a range of stress conditions related to a variety of forms of ground movement. These include differential vertical and horizontal movement, rotation, torsion, forward tilt and ground heave. There appears to be a strong relationship between cause of damage (rotation, heave etc.), the type of landslide movement and a particular geomorphological setting. This indicates that each geomorphological unit has its own characteristic range of stress conditions affecting structures and a characteristic type of damage. For example, the types of stresses associated with the differential movement of multiple rotational slides include:

**FOOTNOTE: Hutchinson et al. (1981a) and Chandler (1984) demonstrated the significance of coastal erosion in reactivating the Undercliff landslides by means of a series of stability analyses. If unchecked, erosion could be expected, in the long-term, to reactivate the landslide system (see Annex E).*

***Of interest, where the available height of the clay and Sandrock cliffs increases, there is rapid transmission of aggression (i.e. Blackgang and The Landslip). This increase is, of course, related to the synclinal form along the Undercliff (Chapter 4) and also due to the absence of chalky debris aprons protecting the toe areas.*

****Details of the analysis of rainfall and landslide activity are presented in Annex H.*

*****The survey of damage discussed in Chapter 3 recorded only those cases where problems had been caused by ground movement. Many other causes of damage are known or suspected to occur in the town such as foundation failure, bomb damage, poor maintenance or general wear and tear.*

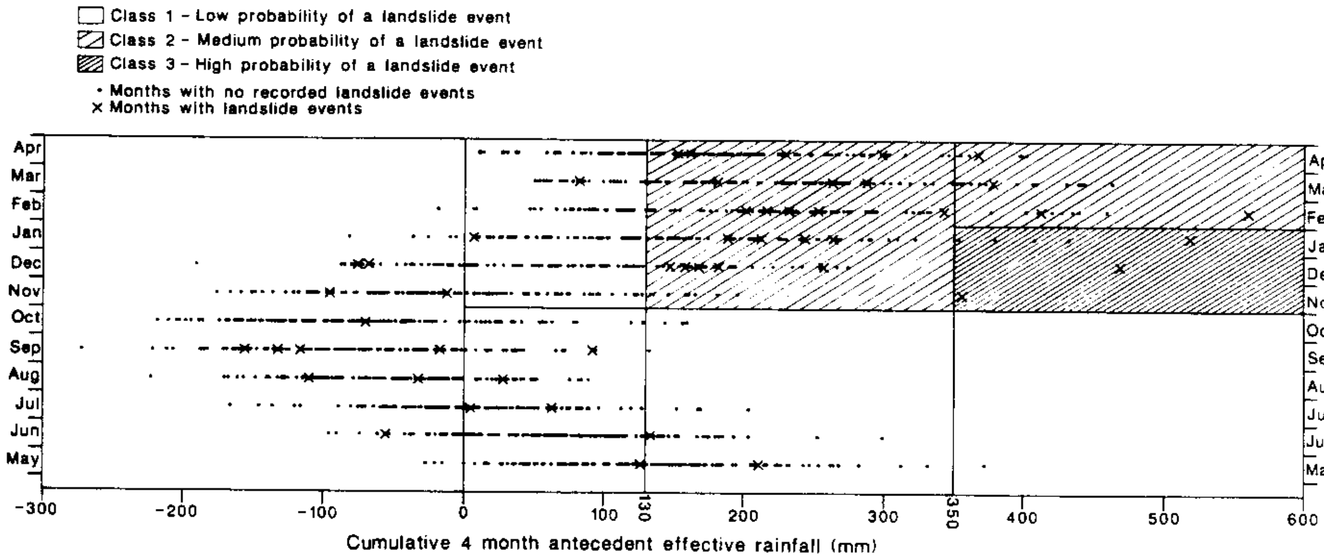


Figure 6.1: The relationship between antecedent effective rainfall and landslide activity.

PERIOD	AREA	DESCRIPTION
1873-1879	Ventnor Bay Eastern Cliffs Western Cliffs	Landslide activity probably caused by severe coastal erosion, following an unsuccessful attempt to build a harbour.
1884-1892	Wheeler's Bay	Mudslide activity.
1910-1916	Coastal cliffs	Rockfalls and slides.
1926-1927	Eastern Cliffs Western Cliffs	Coastal slides.
1932-1936	Wheeler's Bay Steephill Cove	Mudslide activity.
1952	Monk's Bay	Rockfalls and slides.
1954	Upper Ventnor	Fissuring along Whitwell Road, settlement in the graben
1960-1961	Coastal cliffs Upper Ventnor Ventnor Bay	Rockfalls and slides. Extensive settlement. Heave along The Esplanade, settlement along Bath Road and Belgrave Road.
1978-1980	Upper Ventnor Ventnor Bay	Settlement and cracking. Settlement along Bath Road and cracking of Rex Cinema.
1987-1988	Upper Ventnor Ventnor Bay	Settlement. Movements along Bath Road.

Table 6.1 The main periods of contemporary landslide activity in Ventnor.

- stress from vertical and horizontal movements;
- stress caused by backtilt, rotation and torsion;
- stress caused by forward tilt;
- stress from differential subsidence within the graben;
- stress caused by splitting of major blocks;
- stress and plastic deformation caused by uplift or heave of ground in the slide toe area.

Examinations of damage to property within the small landslide system in the Ventnor Bay area has revealed that many properties have been affected by a range of ground movements, including heave, subsidence, rotation and tilting (Building Surveys Ltd, 1990). The most severely affected area was found to be along the seafront where many properties were tilted forward, probably as a result of the heave of the toe of a small rotational landslide unit. The buildings at the crest of this landslide system appear to have been affected by settlement and rotational (contra-tilt) movements. However, towards the middle of the slope, outward movements of 300mm were calculated, with only limited evidence of tilting. These three examples of contrasting forms of movement over a short distance (300m) highlight the range of ground movements that occur within the town and the need to interpret these movements in the context of the spatial pattern of individual landslide systems and the overall mechanics of the landslide complex. In the Ventnor Bay area, the pattern of movement clearly reflects the slow reactivation of a multiple rotational landslide unit, resulting in settlement of the head, outward displacement about midslope and heave in the toe area (Figure 6.2).

Perhaps the most variable ground conditions occur on the major landslide blocks, where it is possible to recognise narrow bands of greater hazard within broader zones of lesser activity. This is well illustrated in Figure 6.3 which indicates that the degree of hazard can vary dramatically within even a metre of the surface exposure of intermediate 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 act merely as passive blocks which are slowly moving but not deforming.

6.4 GROUND BEHAVIOUR MAP

One of the main problems with many landslide hazard assessments is that subjective comparisons are made between magnitude and frequency of different processes within the confines of a simple scale of hazard. For example, Chandler and Hutchinson (1984) devised a preliminary zonation of Ventnor, using four classes of probability (negligible, low, moderate and high) and magnitude (slight, small, moderate and large) of future movements (see Figure 1.2). The use of such arbitrary subjec-

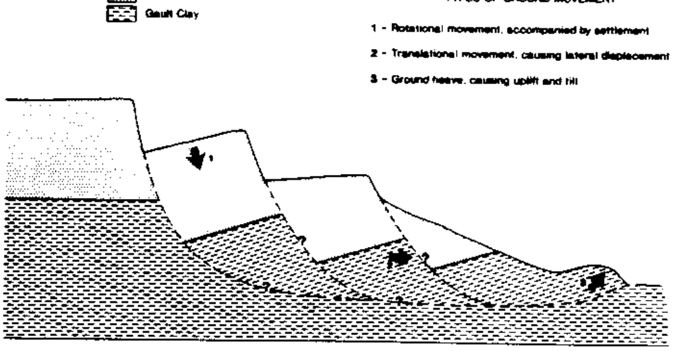


Figure 6.2: The relationship between type of ground movement and the position within a multiple rotational landslide system

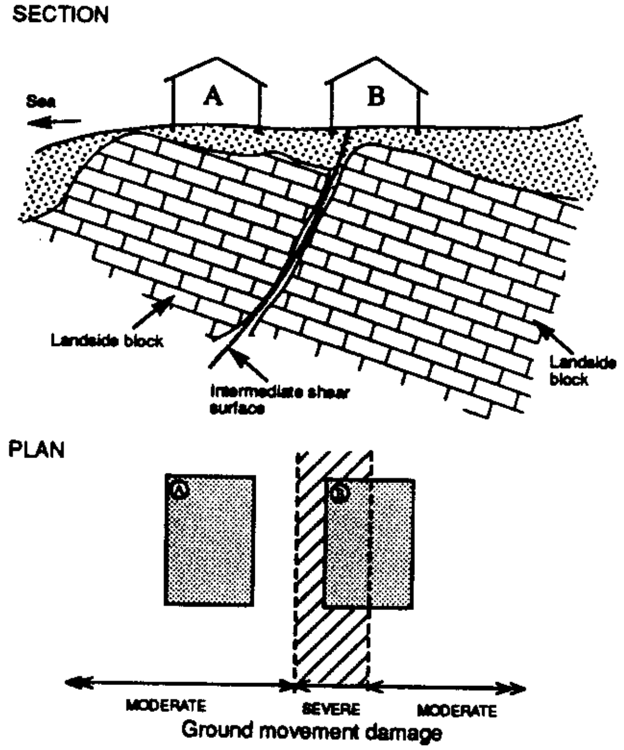


Figure 6.3: Variability of ground movement damage in relation to position on a landslide block *(after Hutchinson and Chandler, 1991)*

tive scales can cause serious difficulties as perceptions of what actually constitutes a "high" probability or a "small" movement will vary considerably.

This can lead to misunderstandings and unnecessary alarm amongst those the maps are intended to help, namely the general public. For these reasons this study has attempted to avoid subjective scales and has concentrated on analysing and presenting the wealth of available objective information on movements within the town. A computerised Geographical Information System (GIS) (Figure 6.4) has been used to provide a means for the analysis of the following data sets:

- Geomorphology;
- Landslide units;
- Contemporary ground movements
- Damage caused by ground movement
- Land use;
- Meteorological data;
- Rates of coastal erosion.

A ground behaviour map has been produced at 1:2,500 scale which attempts to define the hazard resulting from ground movement*. This map presents the following information:

(i) the nature and extent of different landslide features which form the Undercliff (multiple rotational slides, compound failures, mudslides etc. Figure 5.1);

(ii) the different landslide processes which have operated within the town over the last 200 years (joint widening within the Upper Greensand bench, blocks of material moving *en masse* along pre-existing shear surfaces, degradation of landslide features etc. Figure 5.3);

**FOOTNOTE: Further details of the calculation of the structural damage index are presented in Annex H*

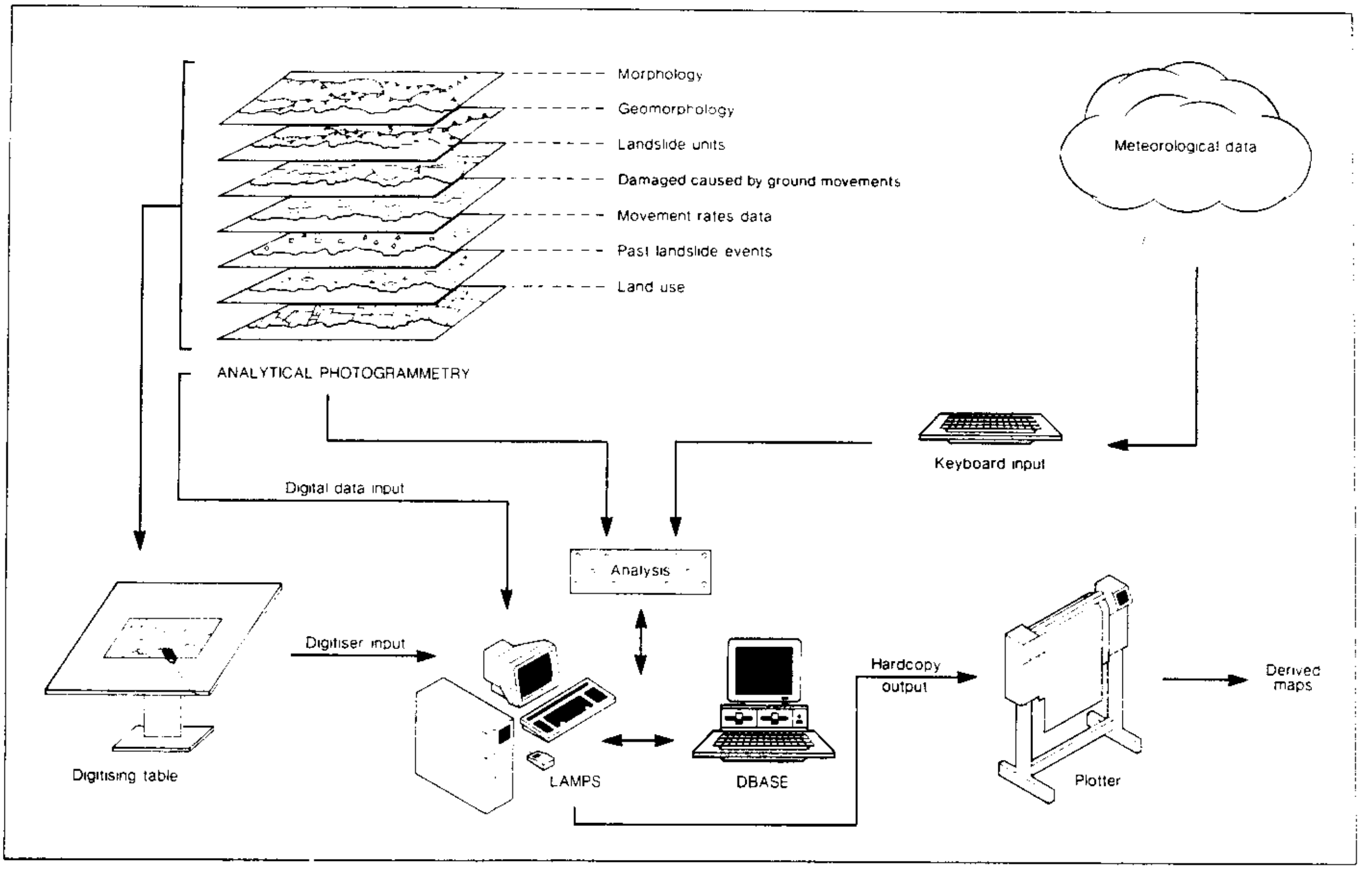


Figure 6.4: Schematic representation of the Geographical Information System

(iii) the location of ground movement events recorded in the last 200 years (Figure 2.1);

(iv) the rates of ground movement recorded in different areas of the landslide system (Figure 3.1);

(v) the intensity of damage to property caused by ground movement in different areas of the town (Figure 3.2);

(vi) the causes of damage to property as a result of ground movement (torsion, rotation, heave etc. Figure 6.2);

(vii) the relationship between past landslide events and antecedent rainfall (Figure 6.1).

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. This assessment has been based on:

- a review of direct evidence of ground movement i.e. measured movement rates, records of past landslide events etc;

- a review of the impact of past movements on property within the town i.e. the nature and extent of structural damage.

A structural damage index for each geomorphological unit was obtained by dividing the study area into a series of 10 x 10m grid cells and summating the recorded damage scores within each cell. An estimate of the relative vulnerability of different geomorphological units was achieved by dividing the total structural damage score for each unit by the area of that unit occupied by property and other structures*.

The Ground Behaviour Map summarises both the nature, magnitude and frequency of contemporary processes and their impact on the local community (Table 6.2). It is of interest to note that the variation in sophistication of the ground behaviour assessment between geomorphological units is a reflection of both their importance (i.e. extent of developed area) and amount of available information. Thus it was possible to recognise five classes of rotational slide blocks on the basis of movement rates, past events and the structural damage, whereas the coastal mudslides could only be divided into areas which are either regularly or infrequently affected by movement. The ground behaviour map naturally presents a complicated picture, reflecting the variety of responses of the ground to the landslide processes operating within the study area. The potential problems resulting from ground movement vary from place to place, according to the geomorphological setting.

6.5 SUMMARY

Although the pattern of contemporary degradation of the Undercliff at Ventnor is very complicated, it is possible to identify four key points which are central to the understanding of ground behaviour:

- the frequency of movement is related to the occurrence of transient events which temporarily lower the stability of landslide systems;

- the pattern of ground movement is related to the varying sensitivities of individual landslide systems to these transient events;

- the form of movements (rotation, heave, settlement etc.) is related to the position within the landslide system;

- the degree and nature of hazard varies according to the different landslide processes operating within the town.

*FOOTNOTE: *Details of the way in which this map was produced are presented in Annex H.*

The nature of ground behaviour portrayed on the map is essentially a statement of contemporary behaviour, based on data for the last 200 years or less. Given that the landslide is at least 2,000 years old, it is important to note that significant changes in landslide behaviour may occur. Thus there is a need to continually update all the data bases. For the same reason, the maps are not true hazard maps in the sense defined by Varnes (1983) in that the probability of some forms of landslide processes cannot be determined without subsurface investigation. However, the costs of ground behaviour mapping of the entire landslide complex are probably comparable to a limited ground investigation of one individual system.

Concern has been expressed in the past that the whole landslide system could be reactivated, with devastating consequences for the town (Chapter 1). However, the behaviour pattern of the landslides over the last 200 years is well established, with detailed information available on the magnitude, frequency and impact of past movements. A massive failure has not taken place in Ventnor over this time period, although large landslides have occurred at the Landslip (1810, 1818) and Gore Cliff (1799, 1839, 1928). If the past and present hold the key to the future then such an event is unlikely to occur in Ventnor.

It would be unwise, however, to rely on the past behaviour to continue unchanged in the future. Patterns of ground behaviour could alter significantly over the next hundred years, particularly in light of the climatic changes which are predicted to occur over the next few decades or increased development of the area.

It must be stressed that a positive approach to landslide management needs to be maintained. This should involve monitoring of future behaviour and the adoption of strategies to minimise the risks of further ground movement (Chapter 7). In this context the Ground Behaviour Map is of particular use as a management tool. Indeed, the understanding of ground behaviour is an essential prerequisite for all subsequent policies for tackling the landslide problems.

Table 3: Ground behaviour: contemporary processes and impacts

CONTEMPORARY PROCESS CATEGORIES	IMPACT
CHALK DOWNS	
1. Predominantly stable slopes, although soil creep and surface erosion is widespread.	Minimal.
2. Areas which could be sites of flash flooding and debris flow activity in **exceptional** storm conditions.	Property downslope may be damaged by flood water or rapidly flowing debris.
3. Areas susceptible to shallow translational slides involving soil and weathered chalk. Only one example of this type of failure has been reported in the last 200 years.	Minimal, although fast moving debris may damage property or block roads at the base of the slope.
UPPER GREENSAND BENCH	
4. Areas prone to slow settlement, probably less than 1mm per year. Gradual extension of master joints within the Upper Greensand can lead to the development of fissures or vents, up to 40m deep. Only a limited number of vents have been recorded in the last 200 years.	Properties situated within these areas have been affected by differential horizontal and vertical movements, together with forward tilt. This has resulted in light structural damage. Collapse of the ground surface into fissures or vents constitutes a significant threat to safety.
ROTATIONAL SLIDES	
5. Major scarp slopes. Degradation of scarp slopes is generally limited to slow superficial movements. In places these slopes may be susceptible to rockfall or debris slide activity, although only 3 such events have been recorded in the last 200 years.	Where scarp slopes have been supported by inadequately designed retaining structures, failure has resulted in slow bulging and cracking of walls. In a number of cases failure of the retaining wall has led to rapid ground movement, causing damage to property downslope.
6. Landslide bench; area affected by intermittent settlement of displaced blocks of material along pre-existing shear surfaces, which can lead to the formation of fissures, tension cracks and gradual subsidence.	Property situated on these benches has been affected by differential horizontal and vertical movements, rotation, torsion, forward tilt and subsidence. Differential movement has been greatest at the back of the bench where the shear surface meets the ground surface. The cumulative effects of this movement have resulted in serious and severe damage to property.
7. Landslide bench; areas where imperceptible ground movement (< 10mm per year) has been reported in the past, although for much of the time these benches are inactive.	Most properties situated on these benches have been largely unaffected by ground movement. However, in places the cumulative effects of ground movement has resulted in moderate and light damage to property.
8. Landslide bench; no landslide events have been recorded in these areas during the last 200 years. These areas have been either inactive or subject to imperceptible movement.	Most property has been unaffected by ground movement, although in places the cumulative effects of ground movement may result in light damage to property.
9. Landslide bench; no information is available with respect to the occurrence and rate of past movement.	The effects of ground movement, if any, are unknown. Further investigations will be necessary to assess ground behaviour.
10. Landslide toe; area which has been prone to uplift and ground heave in the toe area of a landslide unit. Parts of this area have risen up to 100mm per year.	Property situated within this area has been affected by differential uplift and forward tilt. These movements have resulted in serious and severe damage to buildings, a number of which have had to be demolished or extensively repaired.

CONTEMPORARY PROCESS CATEGORIES	IMPACT
COMPOUND SLIDES	
11. Elongate ridges and scarps of Upper Greensand or Chalky debris; ground movement problems have been minimal along the ridges, although slow superficial movements have been recorded on the scarp slopes.	Most property situated on these ridges has been unaffected by ground movement. However, shallow slides on the scarp slopes may cause light damage to property downslope.
12. Elongate ridges and scarps; no information is available with respect to the occurrence and rate of past movement.	The effects of ground movement, if any, are unknown, further investigations will be necessary to assess ground behaviour.
13. Landslide bench; currently unstable area of settlement between two parallel fissures: the Lowtherville Graben. Rates of ground movement of between 50-100mm per year have been recorded in recent years.	Differential subsidence and fissuring within the graben area has resulted in severe damage to buildings (a number of which have had to be demolished) and the public highway.
DEGRADED TRANSLATIONAL LANDSLIDE	
14. Areas of currently inactive shallow mudslides and small rotational slips. Only limited information is available with respect to the occurrence and rate of past movement.	Little is known of the behaviour of these areas.
COASTAL MUDSLIDES	
15. Areas which have been affected by recurrent slow mudslide movement, although rapid movement could occur in exceptional circumstances.	Property situated within these areas has been affected by differential horizontal and vertical movement, especially footpaths which cross the mudslide units. Movements may result in property at the head of the units being undermined. At the foot of the slopes, fast moving runout may cause serious damage to structures.
16. Areas of very rare or no records of contemporary mudslide movement.	The effects of ground movement, if any, are unknown. Further investigations will be necessary to assess the impact of development in these areas.
COASTAL CLIFFS	
17. Unprotected coastal cliffs which have been prone to rock and debris falls, slides and spalling.	Falls and slides represent a threat to public safety. Property adjacent to the cliff top may be undermined by coastal erosion.
18. Coastal cliffs protected by sea walls, which have been prone to occasional rock and debris falls, slides and spalling.	Falls and slides represent a threat to public safety. Property adjacent to the cliff top may be undermined by degradation of the cliff face.
SOFT GROUND	
19. Areas which have been subject to imperceptible settlement (< 1mm/year) of soft ground.	Property situated within these areas has been affected by very gradual vertical movement and tilting. In the past this has resulted in light and negligible damage, although localised cases of moderate and severe damage have occurred.
20. No information is available with respect to the occurrence and rate of past settlement	The effects of settlement, if any, are unknown.

CHAPTER 7
LANDSLIDE MANAGEMENT

7.1 INTRODUCTION

The landslide management approach proposed below is based on the view that the problems are not Acts of God; unpredictable, entirely natural events that can at best only be resolved by avoidance or large scale engineering works. The hazards caused by landsliding need to be seen in the context of the community which they affect, as any solution to the problem cannot be divorced from the existing political, economic or administrative framework.

The scale and complexity of the landslide system at Ventnor dictate that conventional engineering solutions to the contemporary instability problems are unlikely to prevent any further movement. However, more realistic aims would involve reducing the size and frequency of future movements and minimising their impact. It would benefit the local community to appreciate the potential problems and the need for continued landslide management.

This chapter presents a range of strategies which are available for the management of the landslide problems. In essence the approaches suggested are based on:

(a) controlling the natural factors which influence landslide behaviour;

(b) minimising the effects of human disturbance on the landslide behaviour;

(c) reducing the impact of future ground movement.

The strategies available include: modifying the hazard to reduce the costs; effective planning control; reducing the hazard by improving the understanding of the problems, mitigating the costs through insurance, and co-ordinating the community's response to the problems. What is very clear is that implementation of some, or all, of these strategies would need careful co-ordination, bearing in mind that they involve influencing the attitudes and behaviour of large sections of the community. They involve the participation of the whole community: the planning authority, developers, local builders, insurance companies, the statutory services and the general public.

It is important to stress, however, that the results of this study are generalised and have not been based on specific ground investigations. Amendments may prove necessary as a result of future events and investigations. Therefore the results should only be used for general guidance and not for site specific purposes. Consideration of individual sites will need specific study, investigations or advice.

7.2 MODIFYING THE HAZARD

It has already been shown that the hazards associated with ground movement range from the opening of vents, the slow settlement of blocks to very rare rockfalls (Chapters 5 and 6). Considerable benefit can be gained by attempting to reduce the frequency of such events by engineering works designed to improve the overall stability of the landslide system, avoiding construction activities which may promote instability, preventing leakage of water into the landslide system and coast protection. A complementary approach is to reduce the effects of future events through reducing the vulnerability of existing structures and improved building standards in future development.

Both of these approaches are directed towards a long-term benefit to the community. However, there are a number of areas where the degree of hazard necessitates that immediate action should be taken to prevent possible injury:

- the Lowtherville Graben; an early warning system should be installed in the area of settlement along Newport Road to prevent road accidents if the graben suddenly subsides;

- the Upper Greensand bench; a shallow geophysical survey and appropriate physical investigations should be carried out along a number of roads to identify the position of any previously unrecorded vents before they collapse;

- steep scarp slopes; individual property owners should be encouraged to commission regular inspections of scarp slopes for potential rockfalls and unstable debris;

- retaining walls; a structural survey of the retaining walls in Upper Ventnor and The Esplanade area (at least) should be commissioned, as sudden collapse could cause serious injury.

7.2.1 Engineering measures

In the long term, engineering stabilisation of the Undercliff may need to be considered as there could be a limit to the effectiveness and success of alternative management strategies. However, it is recognised that given the size and the complexity of the landslides at Ventnor, major remedial schemes are likely to prove very expensive and may be difficult to justify in benefit-cost terms in the present situation. In addition, it is difficult to assess the most effective stabilisation scheme or value the benefits in the absence of more detailed quantitative data on landslide behaviour obtained from sub-surface investigations.

Without more detailed information about the sub-surface conditions and the relationship between groundwater levels and rainfall, it is difficult to make judgements about what type of measures would be most appropriate. However, it is likely that two approaches could prove successful in improving stability:

- adding weight to the toe areas of individual landslide systems. However, two obvious problems need to be overcome. The exact positions of the landslide toes are unknown and it is not possible, without sub-surface investigation, to estimate what size of weighting would be needed. Toe weighting of one landslide system could load the head of another;

- lowering the groundwater levels by means of horizontal drains, drainage galleries or pumping*. Such measures could only be contemplated after a thorough investigation of the hydrogeology of the area. Considerable success in groundwater lowering could also be achieved by preventing water leakage, especially from water mains and sewers (section 7.2.3).

A note of caution needs to be added at this point. The information presented in this report is not sufficient to enable the design of large-scale engineering solutions. There is also a danger of misinterpreting stability analysis based on limited sub-surface and geotechnical data and threshold groundwater levels derived from limited past records. Such information can only be obtained

**FOOTNOTE: The possibility of increased groundwater extraction by Southern Water should be explored as it may have a beneficial effect on the stability of the Undercliff.*

from extensive site investigation. The overall effect of loading small sections of the landslide system may be minimal in terms of improving the stability of the whole Undercliff at Ventnor, and might, sometimes, be detrimental. However, it is possible that appropriate areas could be targeted for less ambitious, but nevertheless important drainage schemes.

7.2.2 Construction activities

Control of construction activity within the town is an important aspect of reducing the possibility of slope failure. It is recommended that the local authority ensures that the following improvements be made to existing practice:

(i) inappropriate cut and fill operations; in broad terms loading the head of a landslide unit will tend to destabilise it whilst loading the toe will have a stabilising effect. The corresponding unloading will have the opposite effects. Such operations obviously need to be planned with reference to the particular geomorphological setting of each development;

(ii) timing of operations; it is recommended that moving operations may need to be restricted during November-April, as during the winter months slopes appear to be more prone to failure (Chapter 6). Winter operations should be restricted during periods of heavy rainfall and only resumed after a sufficient period of improvement in the weather;

(iii) removal of vegetation from scarp faces; in many instances vegetation acts to bind a slope, reducing the potential for superficial failure. The planning authority should advise developers, builders and property owners that removal of vegetation can adversely affect surface slope stability, and in certain circumstances may need planning permission;

(iv) open trench excavation; due to the potential effects on infiltration, groundwater levels, slopes and retaining structures, it is considered that a degree of control must be exercised over the planning and execution of open trench excavation. It is recommended that South Wight Borough Council should be a statutory consultee for all public utility road openings. This should include receipt of advance proposals and all opening notices. A voluntary code of practice should cover matters such as:

- siting; avoidance of open trenching in sensitive areas, such as adjacent to the crest or toe of slopes and retaining structures, where temporary loss of support, increased water infiltration, and a continuing zone of weakness may be caused;

- when such siting cannot be avoided, adoption of measures to minimise the effects, such as temporary support and adequate drainage;

- limitation of open excavation, with regard both to phy ical extent and duration, particularly in the more sensitive areas as outlined above;

- reinstatement, including adequate and timely backfilling, compaction and surface sealing.

7.2.3 Preventing water leakage

The majority of ground movements appear to occur in response to high groundwater levels within the landslide system. It follows, therefore, that a major effort should be directed towards preventing the leakage of water into the landslide system, either through water mains, service pipes, sewers, soakaways or highway drains:

(i) water supply; a code of practice should be established with Southern Water with the aim of reducing leakage from the supply network, improving standards of design, construction, maintenance and monitoring the flow within the network to identify areas of leakage;

(ii) sewers; given the ground movement that has, and will continue to occur, some damage to existing drainage systems will almost certainly have occurred and future damage may be unavoidable. All existing drains need inspection and, probably, overhaul. The extent of future damage can however be kept to a minimum by careful layout and specification:

- selection of materials: rigid pipes with flexible joints can tolerate some movement. Flexible materials tend to collapse whilst rigid pipes are likely to fracture. To further reduce the risk of fracturing the pipes should also be fully embedded in a granular material suitable for flexible pipes;

- layout: many of the drainage systems installed have inadequate provision to accommodate the steep slopes of the town. The use of drop man holes would also increase the flexibility of the drain runs and provide convenient stages for repair/remedial works as required. Where possible drainage systems should run parallel to, rather than cross, landslide units;

(iii) surface water; many forms of storm water drainage exist in the town. If the systems are to be effective and the underlying problem of ground water remedied, storm water drains will need to be laid in accordance with the recommendations for foul drains (see above). Adequate collection areas and gulleys should be provided at the base of any slopes or hard standings to prevent surface water from ponding in localised areas. Soakaway, French drains and other natural percolation methods must be avoided, storm water outfalls should be taken down to the sea before being discharged. Existing soakaways, French drains and highway drains should be connected to the sewerage system. Consideration should be given to the slope of pipes and overflow pipes.

The importance of preventing water leakage into the landslide complex, either through water mains, service pipes, sewers, soakaways or highway drains cannot be over emphasised. Such actions are likely to be the most cost-effective way of reducing the occurrence of damaging ground movement events.

7.2.4 Protecting the coastline

It is very important to prevent marine erosion of the landslide complex. This one factor alone has probably had the greatest influence on the development and continued instability of the Undercliff (Chapters 4 & 5).

The coastline is a highly dynamic environment. Over its length it contains areas of erosion, which act as sources of sand and gravel (e.g. Chale Cliffs), and areas of accumulation where beaches have formed (e.g. Ventnor Bay, Steephill Cove). These beaches can act as an excellent natural protection measure for the slopes inland. However, if the supply of beach material is reduced, either by protecting erodible cliffs or disrupting the transport and build up of sediment, then the beaches can quickly disappear. As has already been pointed out, such a situation occurred when Collin's Point was removed in the 1860's, during the construction of Ventnor harbour and led to considerable ground movement problems (Chapter 2).

Managing the coastline needs to involve a consideration of the whole system of supply, transfer and accumulation (known as a coastal process unit) and not just individual elements of the system. In this context it is important to stress that marine erosion can involve both erosion of the cliffline and the shore platform. Coastal protection schemes need to take both factors into account.

Where protection schemes are already present they need to be regularly inspected and their performance reviewed. Unprotected stretches of the coastline at Ventnor clearly need to be protected. At the time of writing (1991) schemes are actually being designed for both the Monk's Bay area and the Western Cliffs.

It must be realised that such schemes will not improve the stability of the Undercliff, but merely prevent it from being reduced by continued unloading. Other approaches are needed. The most appropriate solutions will probably involve a combination of all of the approaches described in this section.

7.2.5 Improving building standards

Unlike many areas with mining subsidence, for example, local developers are not experienced in designing or constructing buildings that are able to successfully accommodate ground movement. An advisory code could significantly improve the overall standards of design and construction, and thereby reduce the effects of further movement.

It is envisaged that the proposed code would be advisory in nature and related purely to good building practice; it would not constitute a full design guide or textbook for construction within the landslide complex. Compliance with the code would not guarantee the continued stability or absence from damage of a building for a particular design life.

The responsibility for determining the suitability of a site and for the detailed design of any development should clearly remain with the developer and the developer's professional advisors notwithstanding any advice which may be given and/or enforced by the Local Authority (see section 7.3). Such advice might include minimum levels of site investigation and minimum levels of design competence, in addition to the proposed code of good practice. Nevertheless, it is considered that general adherence to a code of good practice would produce a significant overall improvement to standards of development in Ventnor, even if it did not guarantee the adequacy of design and construction of each individual building.

It is urged that both the code itself and any enforcement notices should clearly set out the nature, the purpose and the limitations of the code in order to avoid misleading developers or undermining their responsibilities. Such a code would also serve to increase public awareness of the problems that exist.

Experimental building plots could be established to determine the most suitable building and foundation types to accommodate ground movement. Such a facility could also be used to demonstrate good building practice to local developers.

The proposed code of good practice would be in the form of a series of recommendations that must be considered, covering a number of areas of design and construction practice. The scope of the code would be expected to address as a minimum

(1) Siting:
- recommendations intended to avoid unsuitable siting of buildings within a development plot, such as adjacent to a landslide scarp, adjacent to the crest of a steep slope, close to a near vertical face from which rockfalls may occur;
- advice on the nature and sources of information and types of investigation which will assist in determining suitable siting;

(2) Earthworks:
- the importance of earthworks control in connection with general site preparation and also with landscaping;
- the avoidance of fill operations near the crest of existing slopes, and of excavation at the toe of steep slopes;
- the need for balanced earthworks over the development site;
- restrictions on the length of trenches excavated along the contours of steep slopes;

(3) Retaining walls:
- the avoidance of loading behind, or unloading in front of existing retaining walls, unless the design, construction and condition have been properly investigated and any necessary remedial or strengthening measures carried out;
- advice on the correct design of new retaining walls;
- recommendations covering the adequate consideration of ground-water during design, in the detailing of drainage measures, and during construction;

(4) Groundwater control:
- provision for free drainage of groundwater;
- re-routing, repair and reconnection of existing sewers, and water supply network;

(5) Drainage:
- provision for positive drainage off-site of surface water;
- prohibition of septic tanks and soakaways;

(6) Service connections:
- provision of flexible service connections from buildings;
- provision of flexible jointed pipes capable of sustaining small movements without leakage;

(7) Foundation design:
- the requirement for raft foundations, designed where appropriate for potential partial loss of support;

(8) Building form:
- identification of building forms that are unsuitable for landslide areas and advice on those forms that are more appropriate;
- restrictions on height and foundation loading;

(9) Structural form:
- advice concerning both unsuitable structural forms and those that are more appropriate.

Table 7.1 Suggested good practice for building in Ventnor the aspects outlined in Table 7.1. Two fundamental principles need to be adopted to:

(i) ensure complete rainwater runoff to reduce groundwater recharge;

(ii) design structures to accommodate movement and not resist it.

A great deal can be done to limit the effects of ground movement. The most important is the adoption of raft-type foundations which can "float" over the movement. Another improvement would be the adoption of framed structures to mitigate against damage when movement does occur.

Appropriate design features are needed throughout structures like the adoption of simple rectangular plan shapes, minor reinforcement in concrete and the appropriate articulation of walls. The detailed design is a question of degree. Rigorous adherence to the highest possible standards will be prohibitively expensive and is unnecessary. A practical balance must be struck, based on experience, between expenditure and utility.

By way of illustration, some aspects of building construction are discussed below. These details are not exhaustive and there are many other details which can be adopted or aspects considered in the design of works in this particular area. Great care must be taken to ensure that problems are not created when traditional details are modified or material specifications changed:

(a) rafts; structures built on a reinforced concrete raft should be able to absorb minor ground movement. The design does not need to be so strong and rigid that the raft is capable of acting like a bridge between the two extremities of the structure. But it does need to be able to span the minor voids that may form below the raft;

(b) jacking points; some sites may be considered particularly vulnerable to ground movement. In such situations jacking points may be included below the ring beam or the foundation slabs (both of which need special additional design). Re-levelling of the structure can then be carried out should tilt occur;

(c) frames; fully framed buildings are the structural form which is best suited to the problems of the area. Their advantage lies in the inbuilt structural integrity. By moving as a whole, they are capable of resisting fracturing when subsidence occurs.

With framed buildings an external envelope is required for protection. Traditionally, brick veneers have been used around timber framed homes. However, on rafts likely to move, masonry elements are best avoided. Sheet materials are likely to give least difficulty in the future, adding to the structural strength. Hung tiles are also effective although repairs can be problematic.

Timber frames need to be fabricated with great care. The construction requires breathing paper, insulation, vapour barriers, lining and cladding all correctly positioned and protected;

(d) structural form; the more uniform the shape of the property on plan, the more likely it is to accommodate torsion damage from movement. Simple rectangular slabs within design parameters should be adopted. Where more complex plan forms are unavoidable, the floor slab/raft foundation should be divided up into a series of rectangular bays. Where garages cannot be incorporated as part of the main structure they should be constructed on a separate raft totally independent of the main dwelling. In any event the separation of the garage is preferred as it minimises the slab size for the house.

Where large structures are required, there are established designs for the accommodation of movement with, for example, spring loaded braces inserted to accommodate stresses on the frame. All junctions between frame members should be pin jointed for maximum flexibility. Stairs should be hinged or sleeved to accommodate movement between floors. Finishes attached to the frame should have tolerances appropriate for the degree of movement anticipated;

(e) height; although tilt is rare in the area, it is possible. Consequently, it is recommended that structures are kept as low as possible, certainly not exceeding three storeys and preferably only two storeys;

(f) wall types; the more flexible and resilient the wall type, the more able it is to resist damage from movement. A brick wall will show damage long before a plywood panel. It must be appreciated that although a reinforced concrete raft is designed to limit movement of the structure it supports, some movement is unavoidable as the raft itself flexes under load. Slight cracking of brickwork is therefore likely although generous provision of movement joints in masonry may be sufficient for movement not to show;

(g) ceilings; generally, the first part of a building to show damage is the ceiling, mainly due to the fragile nature of plasterboard. Slight movement of the walls causes fracturing. The damage can be minimised by setting the plasterboard back from its normal junction with the walls and completing the junction with coving. Any future cracking can then be "stopped" and the need for renewal of the ceiling avoided;

(h) concrete; concrete should have a minimum thickness of 100mm for footpaths and 150mm elsewhere. It should be laid in rectangular bays of as small a size as possible. The smaller the size, the less vulnerable is the concrete to cracking. Typically joints should be formed at a maximum of 2 metre centres. All concrete should contain mesh reinforcement. Dowel bars may be advisable in some instances. Movement joints should be formed with bitumen impregnated fibreboard and be topped with mastic asphalt;

(i) gutters; special attention needs to be paid to the design of gutters. Almost all properties in the area have inadequately sized gutters. The traditional design was based on rainfall from a 2" per hour storm. Today the standard is 75mm (3") per hour but this standard means that occasional overflows will occur during severe rain. Because of the infrequency of major storms, it is not considered generally necessary to design gutters of a larger size.

However, in the Bonchurch/Ventnor/St Lawrence area, it is precisely this rainfall from severe storms which needs to be trapped and channelled away. Gutters should therefore be designed to a higher standard of perhaps 100 or 125mm per hour, with special arrangements for valley gutters. Any design decisions in the selection of components should veer towards higher capacity.

The question arises as to whether and in what manner such an advisory code could be enforced. There would appear to be three main options:

- voluntary compliance;

- imposition as a condition of planning permission;

- imposition by local by-law.

At first sight the adoption of the voluntary approach may appear attractive. It would avoid the need for a statutory and administrative framework and also places the onus for adequate design and construction clearly on the developer. However, it is questionable whether a voluntary system would achieve a significant and consistent overall improvement, given the situation as it exists at present in Ventnor. Evidence from other landslide areas where some form of development building control is enforced also suggests that a voluntary scheme is likely to be largely ignored, misunderstood or misused. If the need for statutory enforcement is accepted, it is suggested that the Local Authority and the DoE should enter into discussions in order to agree the most appropriate form of enforcement.

In the meantime, it is recommended that consideration should be given to the introduction of the advisory code on a voluntary basis for a limited number of years. During this period the statutory and administrative framework for enforcement could be agreed and implemented, the operation of the code could be monitored, and a programme of education in its purpose and application could be carried out for those in planning, development, design and construction.

7.2.6 Repairs and maintenance

Much can be done to existing buildings to reduce the effects of ground movement. Repairs and precautionary measures can reduce maintenance costs and should prolong the life of the property. A list of possible works is presented in Table 7.2. The actual extent of repairs or precautionary works needed at any property will require careful and independent professional advice. Indeed, decisions on detail will vary from property to property depending on its size, location, construction and value. However, any repairs must be carried out in the knowledge that ground movement may continue.

Maintenance of individual properties is considered to be of great importance, as neglect can often lead to instability problems. A series of suggestions for good practice are presented in Figure 7.1. Possibly the most important of these is for property owners to refrain from discharging <u>any</u> water directly into the ground. A permanent and voluntary hose-pipe ban could only do good.

7.3 EFFECTIVE PLANNING CONTROL

Most proposed developments in Great Britain require planning permission. Local planning authorities are 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 controlling particular aspects of development. When reviewing an application for planning permission the local planning authorities, in England and Wales, have a duty to take into account a range of material considerations, including instability problems (e.g. landsliding). The main aims of considering potential landslide problems at this stage in the planning process are to:

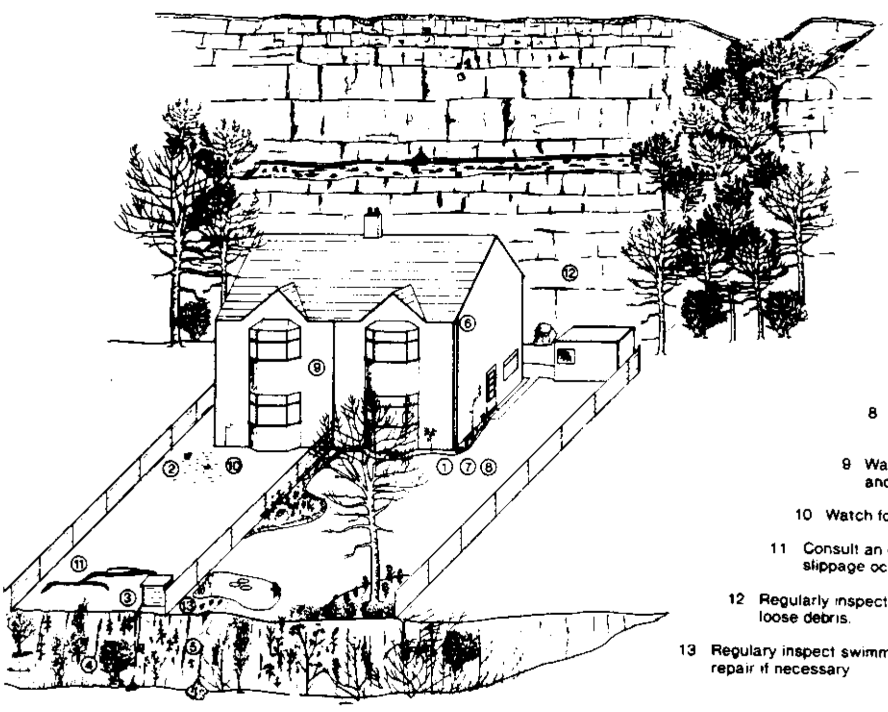
- minimise the risks and effects of landsliding on property, infrastructure and the public;

- help ensure that various types of development should not be placed in unstable locations, without appropriate precautions;

- bring unstable land, wherever possible, back into productive use;

- assist in safeguarding public and private investment by a proper appreciation of the site conditions and necessary precautionary measures.

The Department of the Environment have recently issued Planning Policy Guidance (DoE, 1990) which advise 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



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 Dont clear vegetation off slopes without replanting.

DO's

6 Check roof drains, gutters and downspouts to make sure they are clear.

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 7.1: Suggested good maintenance practice for home owners

Foundations	Build on rafts to 'float' over slight movement; subdivide rafts into simple rectangular shapes.
Structural form	Framed construction has better resistance to damage than masonry construction. Avoid complex plans and designs. Allow for possible slight tilt. Avoid tall structures. Allow for future repairs and movement. Allow extended bearings for supports. Consider design features which provide integral buttressing.
Property walls	Provide movement joints as frequently as possible/practicable. Subdivide complex structures with movement joints.
Freestanding walls	Provide weep holes at upper and lower levels; build in suitable designed movement joints.
Joinery	Design to provide flexibility with large rebates, dry jointed frames and loose pin hinges. Allow for future use of folding wedges. Generally use accessible screw fixings. Consider glazing with beading, soft mastic or gaskets.
Ceilings/Linings	Consider matchboarding or sheet materials. Cut gap around old ceilings with cove over. Overboard old ceilings. Avoid tight fitting of all cladding; loose fit with removable fixings.
Renderings	Incorporate expanded metal reinforcement.
Gutters	Provide gutters substantially in excess of BRE recommendations to ensure that all rain water is collected in heavy storms [suggested design standard: 125mm/hr]
Hardstandings	Provide frequent waterproof movement joints, perhaps at 2m centres. Subdivide all concrete into rectangular shapes; incorporate light steel mesh reinforcements.
Drainage	Inspect and repair existing drains. Ensure that all areas are properly drained. Landscape surfaces to provide falls towards drain inlets.
Sealants	Almost all sealant materials require periodic renewal; allow for access; choose appropriate materials.
All professional advice should warn that precautions can only mitigate damage; if serious movement occurs, structural precautions will be ineffective and failure will be inevitable.	

Table 7.2 Precautionary works and repairs

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 suitable for a proposed development lies with the developer and/or the landowner.

7.3.1 The role of the local authority

There are considerable opportunities to prevent or reduce damage to new development by incorporating the knowledge of ground behaviour, presented in Chapter 6, within the existing planning framework.

It is recommended that, in Ventnor, ground stability is taken into consideration at all stages of the planning process. This should involve:

(i) development plans; policy statements should be introduced to provide a basis for broad decisions on development within the study area. Such statements could await the next revision of the Isle of Wight Structure Plan or take the form of an interim policy statement. The following policies should be considered for adoption:

- the stability of the ground will be a material consideration in determining applications for planning permission;

- possible remedial measures to areas suffering ground movement should be considered in areas where there is a risk to property which can be realistically and economically reduced;

- unstable ground not capable of beneficial development should be identified in development plans and used for low-risk purposes.

The Local Development Plan for the Ventnor area should be consistent with the policy statements incorporated within the Structure Plan. The plan should therefore:

- state that the results of this study, particularly the ground behaviour map will form the primary source of information in considering applications for planning permission;

- state explicitly that any developer will need to satisfy the Local Planning Authority that a development can be constructed without being damaged by, or causing ground movements in or around the proposed site;

- state the criteria which the Local Planning Authority will use to determine individual applications for planning permission;

(ii) control of development; the Local Planning Authority (LPA) needs to take instability into consideration when dealing with planning applications. The results of this study should provide the background information necessary to make planning decisions, although it is recognised that specialist advice will probably be needed in certain circumstances.

The recommended procedures for the handling of applications for development on land which is known, or suspected, to be unstable is outlined in the DoE's guidelines (DoE, 1990) and summarised in Figure 7.2. A number of points are worth emphasising:

- the value of prior consultation between the developer and the local planning authority before an application is submitted;

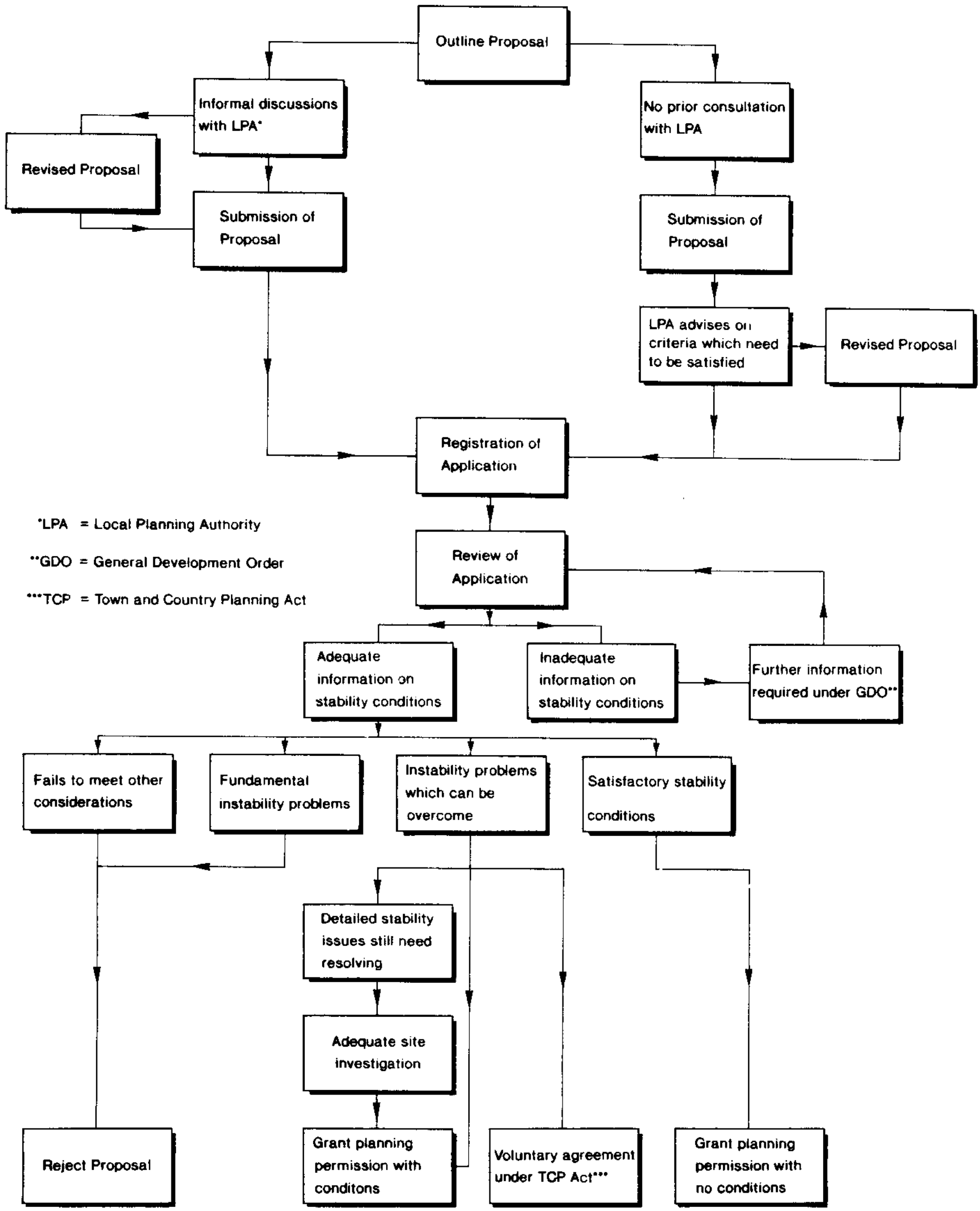


Figure 7.2: Procedures for reviewing development in areas of unstable ground (after DoE, 1990)

- the need for the developer to provide sufficient information to enable the authority to review the application. Indeed, the authority is entitled to require the developer, at the developers expense, to provide suitable expert advice on stability matters;

- if the developer's stability report indicates that ground movement can be avoided or accommodated, planning permission may be granted. However, it is suggested that each permission should be conditional on the incorporation in the detailed design of any remedial measures recommended in the stability report and that local codes of good building practice are observed;

- a flexible approach should enable agreement to be reached in circumstances in which the predicted effects must be minimised in advance and when it may be appropriate to accept the possibility of a small future risk. When planning permission is granted a notice should be issued to the applicant stating that:

"the responsibility and subsequent liability for safe development and secure occupancy of the site rests with the developer and/or landowner" (DoE, 1990).

It should also warn the applicant that:

(a) although the LPA has used its best endeavours available to it, this does not mean that the land is free from instability;

(b) that the LPA's consideration has been on the basis of the development proposed and that these considerations might be different in relation to any other development;

(c) the question of stability has been a material planning consideration and resolution of this issue does not necessarily imply that the requirements of any other controlling authority would be satisfied;

(d) the granting of planning permission does not give a warranty of support or stability.

Internal procedures within South Wight Borough Council should ensure that any special measures within the design of the development recommended to overcome or accommodate ground movements, are brought to the attention of the Borough Surveyor, so that these can be checked during inspections;

(iii) development outside planning control; several types or areas of development do not require planning permission and would therefore lie outside the controls which the above procedures would provide. These include:

- development with deemed planning permission;

- various development with "Permitted Development" rights granted by the Town and Country Planning General Development Order, 1988;

- some activities of a "de minimis" nature, such as the construction of a swimming pool or tennis court;

-various other operations not constituting "development" as defined by the Town and Country Planning Act, 1971. These may include activities associated with agriculture, forestry and the maintenance of roads and infrastructure. There is clearly the potential for many of these activities to have an adverse effect on stability. Consideration needs to be given as to how they can be controlled and the identification of organisations responsible for their regulation.

In some cases, the local authority might give serious consideration to making a direction under article 4 of the General Development Order, 1988, which would remove specific development rights within the area and would require planning permission to be obtained, thus enabling control by the methods referred to above. In other cases, an advisory code of good practice may be appropriate (e.g. with regard to the safe discharge of water from swimming pools such that it does not enter the ground and thereby cause instability);

(iv) building control; The Building Act (1984) empowers local authorities and approved Inspectors to administer and enforce the Building Regulations. Two methods are currently practised by South Wight Borough Council (SWBC) for complying with the requirements of notifications under the terms of the Building Regulations*:

- issuing formal approval of an application; SWBC require the application to be accompanied by a thorough site investigation report prepared by a suitably qualified engineer. This report should demonstrate that all stability matters are adequately researched and dealt with;

- when a Building Notice is submitted by the developer formal approval by SWBC is not needed. However, SWBC still require a thorough site investigation report. Providing this procedure is carried out there should be no cause for delay when the Council's Building Control Officer is requested to visit the site to carry out the necessary statutory inspections.

In neither case can the SWBC be held responsible if the building should be affected by future ground movement.

The Building Regulations are mainly intended to "ensure the health and safety of people in or about the building". As far as ground movement is concerned, they require that movements of the subsoil caused by swelling, shrinkage or freezing will not impair the stability of any part of the building (Requirement A2, Schedule 1). Building Regulations, therefore, would not cover situations where:

- the ground beneath the building could move for reasons other than the causes listed in Requirement A2; e.g. where ground movement occurs beneath the building, as a result of reactivation of part or parts of the landslide system;

- the development, although on marginally stable ground with no history of movement, could become threatened during its design life, by instability originating outside the area of the development, e.g. the encroachment of a debris slide or rockfall from upslope.

The Borough Surveyor's Department of South Wight Borough Council are well aware that the Building Regulations cannot assist in controlling building devel-

*FOOTNOTE: *Standard letters are issued by SWBC to potential developers when Building Regulation Applications are submitted. These are reproduced in Annex I.*

	DEVELOPMENT PLAN	DEVELOPMENT CONTROL
A	Areas likely to be suitable for development. Contemporary ground behaviour does not impose significant constraints on Local Plan development proposals.	Results of a desk study and walkover survey should be presented with all planning applications. Detailed site investigations may be needed prior to planning decision if recommended by the preliminary study.
B	Areas likely to be subject to significant constraints on development. Local Plan development proposals should identify and take account of the ground behaviour constraints.	A desk study and walkover survey will normally be needed to be followed by a site investigation or geotechnical appraisal prior to lodging a planning application.
C	Areas mostly unsuitable for built development. LocalPlan development proposals subject to major constraints.	Should development be considered it will need to be preceded by a detailed site investigation, geotechnical appraisal and/or monitoring prior to any planning applications. It is likely that many planning applications in these areas may have to be refused on the basis of ground instability.
D	Areas which may or may not be suitable for development but investigations and monitoring may be required before Local Plan proposals are made.	Areas need to be investigated for ground behaviour. Developments should be avoided unless adequate evidence of stability is presented.

Table 7.3 Planning guidance categories

opment in areas of unstable ground, as they are restricted to issues related to the site. They have no provision for dealing with the overall setting (GSL, 1987), hence the importance of the need for stability to be taken into account in the planning process. However, it has been shown earlier that many of the current ground movement problems have arisen, or been made worse, because of the poor standard of building and repair work within the town (Chapter 3). Whilst the Building Control Officers at South Wight Borough Council are well aware of the problems raised by inappropriate building or foundation types, there appears to be limited knowledge or experience within the local building profession of good design or construction practice to deal with ground movement. The ways in which building standards could be improved, thereby reducing the impact of future movement have been discussed in section 7.2. Such improvements would need to be administered through the Building Regulations.

A Planning Guidance Map has been produced which relates categories of ground behaviour to forward planning and development control (sections (i) and (ii) above)*. The Planning Guidance Map indicates that different areas of the landslide system need to be treated in different ways for both policy formulation and development control (Table 7.3). Areas are recognised which are likely to be suitable for development, along with areas which are either subject to significant constraints or mostly unsuitable. Advice is also provided on the level of stability information which should be presented with planning applications in different areas.

7.3.2 The role of the developer

Obviously it is in a developer's own interests to determine whether a site is on unstable land as any future movement will affect the value of the site and both its development costs and maintenance. If there are any reasons for suspecting instability problems the developer should instigate appropriate investigations to determine whether:

- the land is capable of supporting the loads to be imposed;

- the development will be threatened by unstable slopes on, or adjacent to, the site;

- the development will initiate slope instability which may threaten its neighbours.

The assessment of landslide problems and the associated risk requires careful professional judgement. Developers should seek expert advice about the likely consequences of proposed developments within the town. This advice will generally involve some form of <u>investigation</u> into the nature of the problem. This should provide an indication as to whether the site is suitable or whether a <u>management strategy</u> is needed to prevent problems affecting the site or the neighbouring land.

The developer should provide sufficient information on stability matters to enable the local authority to review the planning application (Figure 7.2). Indeed, the authority is entitled to require the developer to seek suitable expert advice. It is important to stress, at this point, that the developer needs to investigate not only the stability of the proposed site but also whether the development could adversely affect the surrounding land (e.g. as a result of accidental water leakage or removal of support).

If the developer's stability report indicates that ground movement can be avoided or accommodated, planning permission may be granted, unless the application fails to meet other considerations. In some cases, planning permission may be conditional on the incorporation of any remedial measures (recommended in the stability report), in the detailed design, and that local codes of practice are observed.

Advice on the level of stability information which should be presented with applications should be sought from the local authority at an early stage. In general, three levels of investigation have been incorporated into the Planning Guidance Map, based on the severity of the potential problems:

*FOOTNOTE:*The Planning Guidance Map has been prepared using six basic principles outlined in the DoE's Planning Policy Guidance Note 'Development on Unstable Land' (DoE, 1990), and described in Annex I.*

- desk study; developers and their consultants should review the potential instability problems in and around the proposed development site. This will involve consulting this report and, where relevant, reviewing the significance of any additional information on ground movement since 1990. An assessment of the implications of the proposed development on slope stability may be required;

- walk-over survey; involving the inspection and mapping of a site and the surrounding area to determine the geomorphological context of the proposed development and to identify any recent (post-1990) ground cracking or structural damage to property. An assessment of the implications of the proposed development on slope stability may be required;

- ground investigations; typical ground investigations are likely to involve a combination of subsurface investigation, surface monitoring, hydrological monitoring, laboratory testing and stability analysis (Table 7.4). The scale of any ground investigations should be discussed beforehand with the local authority, and will depend on the nature of the problem at a particular site. However, it is of great importance that the objectives of any investigation are realistic, otherwise the costs of obtaining stability information might act as a restriction on development.

It is recommended that the planning authority adopts a flexible approach to determining what constitutes an appropriate investigation. Judging from past experience in the town, proposed developments can be either of the types. First, small-scale developments which may be affected by instability or cause localised instability problems and large-scale developments which may affect the stability of the landslide complex. On this basis at least two types of investigation could be needed. Although each case will need to be judged on merit, the following general guidelines are suggested:

(a) small-scale development e.g. a single house. The objectives of such investigations should be to determine ground conditions within the site (e.g. depth of overburden, presence of fissures, drainage features), the stability of adjacent scarp slopes (upslope or downslope) and to identify whether services will have to cross over geomorphological unit boundaries;

(b) large-scale developments e.g. covering a number of geomorphological units or schemes which propose to alter the natural environment (e.g. marinas or offshore developments). Site investigations for such projects must be of sufficient standard to quantify their possible impact on the landslide system and are likely to prove very expensive.

Should a planning application be accepted on the grounds that instability problems can be overcome and will not affect neighbouring properties, then it will be necessary to design and

APPROACH	TECHNIQUE	USAGE
SUB-SURFACE AND IN-SITU TESTING	TRIAL PITS TRENCHES	Sampling and logging of exposures. Most useful in investigating shallow instability in soils and soft rock or locating boundaries of disturbed ground.
	BOREHOLES	Sampling and logging of disturbed or undisturbed core samples. Useful in investigating deeper instability problems. Variety of techniques eg. shell and auger, rotary drilling etc. allows use in all rock types, although core recovery can be a problem.
	ADITS	Large excavations to establish sub-surface conditions in major, deep seated landslides. Very expensive and are generally used as a drainage measure.
SURFACE MONITORING	TOPOGRAPHIC SURVEY	Measurement of displacement rates between surveyed points. Problems of vandalism.
	EXTENSOMETERS	Measurement of enlargement of tension cracks, building cracks etc. Problems of vandalism.
	ANALYTICAL PHOTOGRAMMETRY	Retrospective analysis of displacement of points on photography of different dates, usually aerial but can be hand-held. Expensive, taking considerable computing effort. Not sensitive to very small displacements.
SUB-SURFACE MONITORING	INCLINOMETERS AND SLIP RODS	Identification of zones of movement, monitoring of displacement rates.
	PIEZOMETERS	Monitoring groundwater levels and pore-water pressures.
HYDROLOGICAL MONITORING	TRACER EXPERIMENTS, PUMP TESTS ETC.	Enables groundwater flow monitoring for design and investigation of remedial measures.

Table 7.4 Commonly used ground investigation techniques.

APPROACH	METHODS
EXCAVATION AND FILLING	- Remove and replace slipped material. - Excavate to unload the slope. - Fill to load the slope.
DRAINAGE	- Lead away surface water. - Prevent build up of water in tension cracks. - Blanket the slope with free draining material. - Installation of narrow trench drains aligned directly downslope, often supplemented by shallow drains laid in a herring bone pattern. - Installation of interceptor drains above the crest of the slide or slope to intercept groundwater. - Drilling of horizontal drains into a slope, on a slightly inclined gradient. - Construction of drainage galleries or adits, from which supplementary borings can be made. - Installation of vertical drains which drain by gravity through horizont drains and adits, by siphoning or pumping.
RESTRAINING STRUCTURES	- Retaining walls founded beneath unstable ground. - Installation of continuous or closely spaced piles, anchored sheet or bored pile walls. - Soil and rock anchors, generally pre-stressed.
EROSION CONTROL	- Control of toe erosion by crib walls, rip-rap, revetments, groynes. - Control of surface erosion. - Control of seepage erosion by placing inverted filters over the area of discharge or intercepting the seepage.
MISCELLANEOUS METHODS	- Grouting to reduce ingress of groundwater into a slide. - Chemical stabilisation by liming at the shear surface, by means of lime wells. - Blasting to disrupt the shear surface improve drainage. - Bridging to carry a road over an active slide. - Rock traps to protect against falling debris.

Table 7.5 Principal methods of slope stabilisation.

construct measures to reduce the potential hazard. A wide range of such remedial measures are available (Table 7.5), although the most appropriate methods are likely to include a combination of drainage and the construction of restraining structures. In certain circumstances modification of the slope profile by excavation or filling may be suitable although it is very important to ensure that cuts and fills actually achieve their intended purpose and do not initiate further ground movement.

7.3.3 Problems associated with planning control

Effective enforcement of planning decisions is of major importance, otherwise problems may occur. However, both implementation and regularising breaches of planning control are difficult areas to administer because they require supervision, and often development can take place without the planning authority being aware of it. It should also be emphasised that the area covered by this study does not encompass the whole of an administrative unit and that there may be a requirement for the limits of the current study area to be extended to an appropriate planning unit, to ensure comparability of treatment.

7.4 IMPROVING THE UNDERSTANDING OF THE PROBLEMS

The ground behaviour map represents the most complete picture available to date of the nature and extent of the landslide problems experienced in Ventnor. This map has been based on a considerable amount of data of various forms, ranging from historical records to geomorphology and structural damage. However, the predicted effects of climatic change suggest that it may prove more and more difficult to predict future behaviour from what has happened in the past. It is considered very important that further information should be collected, including:

(i) sub-surface conditions in support of the mechanisms of landslide behaviour proposed in this study; our knowledge of the mechanisms and behaviour of the landslides is, at present, limited by the lack of sub-surface information. Due to the complexity of the landslide system, as revealed by these geomorphological studies, it would be very difficult and extremely expensive to investigate adequately all the sub-surface conditions at Ventnor. However, a ground investigation would be a pre-requisite for any large-scale remedial measures or for major development projects within the town;

(ii) evaluating the possible effects of environmental change; although there remains great uncertainty about the effects of global warming, it is clear that significant changes could occur around Britain's coastline. A rise in sea-level is widely believed to be the inevitable result of the greenhouse effect (Doornkamp, 1990; Figure 7.3).

There is also considerable concern about the predicted increase in storm events, as storms on top of a higher sea-level will pose a greater threat and possibly cause increased damage through coastal erosion. Such predictions clearly indicate that there should be a reassessment of the effectiveness of the coastal defences at Ventnor, as any increase in erosion will obviously destabilise the landslide system. As a result there may need to be modifications to existing defence works, especially the older sections. Sea-level rise may be accompanied by a rise in groundwater levels within the landslide system, which again could affect the stability of parts of the Undercliff.

Global warming also appears to be linked to an increase

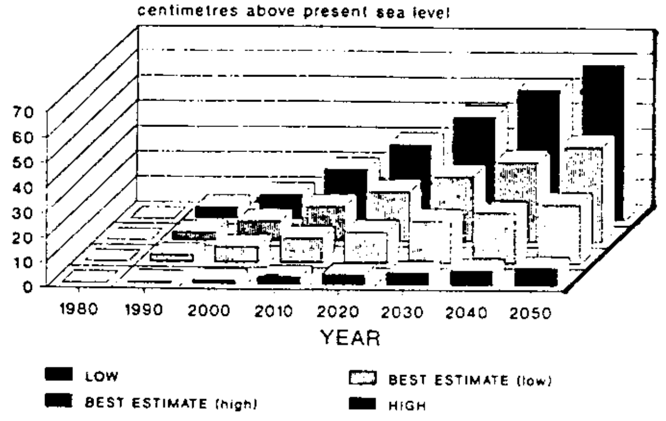


Figure 7.3: Estimates of global sea-level rise *(after Warrick et al, 1989)*

in rainfall in temperate latitudes (Doornkamp, 1990), and this may bring about higher groundwater levels, and thereby increased pore water pressures. This may promote an increased tendency for renewed landslide movement.

(iii) monitoring ground movements; it must be strongly emphasised that the ground behaviour map is based on an understanding of past movement events. Present trends in climatic change clearly demonstrate that judging future behaviour from what has happened in the past may be unwise. It is, therefore, very important that the ground behaviour map is regularly reviewed and updated. This could involve:

- a co-ordinated monitoring programme (Table 7.6);
- the maintenance of detailed records of ground movement events;
- recording all forms of structural damage to property.

(iv) forecasting ground movements; the relationship between antecedent rainfall and landslide events examined in Chapter 6 may provide the basis for a rudimentary forecasting technique. However, this approach to forecasting is likely to be of restricted value to management because of the complexity of the landslide system, the slender historical base (the exact date of many past events is unknown), the limited understanding of the triggering factors and the fact that environmental conditions may change in the near future. Fundamental to an improvement in forecasting is a full understanding of the landslide system and this would require both sub-surface investigation and monitoring. It must be stressed that in the case of Ventnor, monitoring needs to be accepted as a long-term continuing management necessity;

(v) economic appraisal; at present there is only a limited amount of information relating to the financial cost of landsliding in Ventnor. This is a significant obstacle to making any evaluation of the benefits of major capital investment in stabilisation measures and coastal protection schemes. A review of the financial implications of a minimal action approach (i.e. keep on as normal) needs to be estimated in order to be able to assess the economic sense of pursuing the various landslide management strategies.

7.5 MITIGATING THE COSTS

One way to plan for offsetting the costs arising from ground movement is through insurance schemes. In Great Britain, insurance cover for slope failure is usually a part of the household insurance policy and is termed 'subsidence, heave or landslip', though landslip due to coast erosion is normally excluded from cover. The premium to be paid will depend upon the insurer's perceived degree of risk. Any 'excess' borne by the insured in the case of a claim will be governed by the same factor. Thus, whilst insurance is obtainable against landsliding, the size of the premium and of the other payments to be made may discourage its purchase. Where a property is affected by repeated ground movement a number of claims will be made. The first claim may be met but it will generate a higher premium requirement that may preclude further insurance cover. Another drawback to insurance is that policy renewal is often conditional on damage being made good. This too can be very expensive.

Within Ventnor many householders have had great difficulty in arranging insurance, with many companies refusing to cover properties in certain areas. Commercial Union, for example, operate a selective policy with no-go areas decided by the number of claims they have paid out over the last ten years (Anon, 1988d). It is felt that the results of this study, particularly the ground behaviour map, could be of benefit to insurance companies in assessing the level of risk of landslide damage in different parts of the town. It is important that a sensible and realistic approach is taken to property insurance in the area. Although landside damage occurs, much is minor and substantial areas have not experienced any damage over a very long period. It is not logical, therefore, to impose any 'blanket' measures for the whole area when risks vary greatly within it. Insurance companies should consider each application for insurance on its merits bearing in mind the results of this study and the existing condition of the property.

A note of warning, however, has to be introduced based on the experiences of hazard insurance schemes elsewhere (GSL, 1987) since these schemes have been fraught with problems, and have often required government intervention. However, before any moves can be made to use insurance to influence development decisions or attitudes to hazard zones, it would be necessary to consult with the insurance industry.

On occasions attempts are made to mitigate costs through litigations. Typically, the plaintiff seeks redress from local government, adjacent landowners, property developers or an insurance company for losses suffered because of ground movement. The most usual grounds for legal action are negligence or strict liability. Defendants may be seen as not having exercised sufficient care and attention in their professional duties or to have infringed legal provisions regarding the use of land. Thus, those who work with, or are responsible for the implementation and observance of planning and building regulations may well find themselves liable to prosecution if they are not adhered to.

The publication of information on relative landslide hazard in Ventnor could well have legal implications for all those concerned, from the issuing agency to the property tenant. Such information, if it were to be widely available would appear to impose a duty of care on those who have to consult technical documents concerning ground conditions. Those with such responsibilities include estate agents, solicitors, builders, civil engineers and planners. For such professional not to consult the landslide hazard information may constitute grounds for an action in negligence.

This report is certainly not the forum for discussing the possible areas of litigation which could arise following the publication of

PURPOSE	TECHNIQUE	COMMENTS
GROUND MOVEMENT	Ground survey	Repeated levelling between survey stations
	Photogrammetry (e.g.annual)	Monitoring the displacement of points by analysis of sequential aerial photos
	Extensometers	Regular measurement across tension cracks etc. to determine rate of movement.
SUB-SURFACE MOVEMENT	Inclinometers	Regular measurement of displacement along shear surfaces
CLIMATE AND GROUNDWATER	Weather station	Daily rainfall , temperature and evaporation records
	Piezometers	Monitoring the fluctuations of both the Lower Greensand and Upper Greensand aquifers in response to seasonal rainfall patterns.
SERVICES	Metering	Monitoring flow in water mains to identify areas of water loss.
	Television survey	Survey of drains and sewers to identify areas of disruption, negative gradient, leakage etc.
	Inspection	Service installations in known problem areas should be inspected regularly.

Table 7.6 Suggested forms of landslide monitoring

the results of this study. However, an increased tendency to apportion responsibility which is inherent in many of the landslide management strategies suggests that such cases may well occur.

7.6 CO-ORDINATING THE COMMUNITY'S RESPONSE

7.6.1 Conflict

When a period of landslide activity causes damage to property within the town, the community's response will be wide-ranging depending on the varied ways in which different sectors perceive the problems and solutions. Few individuals will blame themselves for their misfortune, but will seek assistance from the government or local authority, as in the winter of 1960-1961. Differences in perception between the central government, local government, consultants, developers, builders, estate agents, pressure groups and individual homeowners can result in disputes.

Difficulties will undoubtedly arise over both the interpretation of the problem and the solutions that could be adopted. Experience from other areas where geomorphological hazards affect urban communities, such as in Los Angeles, indicate that:

> " almost every proposed solution carries the seeds of conflict, and with good reason, because not only is one man's solution often to the detriment of another, but there are commonly differences of opinion about the effectiveness of proposed solutions amongst professional environmental managers. " (Cooke, 1984)

Conflict will also arise between the adoption of short-term and long-term strategies. In general, the former may be more acceptable than the latter, often because immediate action demonstrates that something is being done about the problem.

Within Ventnor it is important that these political conflicts are recognised and that a balance is achieved that is acceptable to the community. One obvious potential problem is that the results of this study could give rise to fears that may affect property values in certain areas. This may be acceptable in areas where landslide damage has been long recognised, as in the Lowtherville Graben area*. However, in undeveloped areas where instability problems are not so readily apparent, such as the grounds of East Dene, the logic of the designation will need to be clearly explained to those affected.

Disagreements almost certainly will arise over the zonation shown on the Ground Behaviour Map as subsequent planning decisions may result in land becoming unsuitable for certain intended purposes. If planning consent for alternative uses is refused, the land or property owner may serve a purchase notice on a local planning authority requiring it to take the land, which has become incapable of 'reasonable beneficial use' in its existing state.

It must be strongly emphasised that to effectively reduce the impact of ground movements in the town, planners, developers, estate agents and property owners should liaise and recognise the needs of all the parties involved. If private individuals are to be responsible for the stability of their own property then a clear statement as to the role of the local authority and professional bodies is required.

7.6.2 Public awareness

A positive approach to coordinating the community's response to the landslide problems is considered essential. Central to this should be a programme of public awareness. The aim should be to ensure that the purpose and potential benefits of the proposed management strategies is fully understood by and acceptable to the general public, developers, builders, estate agents, solicitors and financial institutions.

It is recommended that the following points should be considered as part of the public awareness strategy:

(1) The problems facing Ventnor as a result of its location on a complex landslide should be identified and explained.

**FOOTNOTE: South Wight Borough Council has been purchasing land unsuitable for rebuilding, for amenity space.*

This should involve a series of public meetings and exhibitions targeted for specific groups. This information should be set firmly in the context of a town that has existed on a landslide for many years and in which much of the development has survived and performed adequately. This should allay unnecessary fears, reduce unfounded reactions and lead to the greater understanding of landslide behaviour and associated problems.

The public education programme should be supplemented by publication of a booklet explaining in simple terms the history of the landslide, the results of the present study, and the policies adopted by the Local Authority;

(2) A booklet should be published by the Local Authority to explain the overall aim of the policies it is adopting to control and encourage development in the town;

(3) Contingency plans should be formulated, based on a range of possible scenarios;

(4) The proposed planning and building control procedures should be fully explained to all potential developers and their professional advisors, possibly in the form of a freely available leaflet, which would be distributed with all planning application forms.

The aim of the proposed advisory code of good building practice and control of construction activity should be presented as a leaflet aimed at design and construction professionals. Training in the application of the code should be considered;

(5) There will be a need to explain both the aim and the application of the proposed code of practice for reducing water leakage to those involved;

(6) There will be a need to produce a leaflet outlining to owners the value of low-cost repairs and good maintenance practice;

(7) The Local Authority may wish to hold meetings with professionals involved in the property business, such as lawyers, insurance companies, building societies, estate agents etc. in order to explain the real extent of the problems and discuss the contribution they could make to improving development prospects in the town.

It would also be beneficial to attempt to adopt a more positive approach to the landslides at Ventnor. At present they are seen as a negative resource which carry a cost to the community. However, the landslides create an attractive landscape and present a unique tourist and educational opportunity. This may be turned into an attraction by means of:

- visitor centres; explaining the nature, history and impact of the landslide problems;

- study centres; the Undercliff offers unique opportunities for the study of geology, geomorphology, marine biology etc. at both secondary school and university level;

- nature trails; the main features of the Undercliff landslides could be explained with a series of display boards;

- publicity; explaining the innovative responses to landslide hazard management, through the popular scientific media, may well promote a positive attitude towards solving the problems within the local community and attract visitors, as well as informing others affected by landslides elsewhere of how problems can be addressed.

CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

8.1 INTRODUCTION

Ventnor is situated within an ancient landslide system, the Undercliff, which stretches from Dunnose to Gore Cliff (Figure 4.2). This area is one of a series of large landslide complexes along the coast of southern England which developed in response to the rise in sea-level following the melting of the ice sheets at the end of the last ice age (Figures 4.1 and 4.5).

The Undercliff, at Ventnor, comprises a variety of landslide forms: multiple rotational slides, compound failures, degraded translational slides, mudslides and coastal rockfalls/rockslides. These different landslide types vary in the nature of materials involved, the mechanism of failure and the depth of the basal shear surface. **They do not represent landsliding under a single set of environmental conditions or a single landslide system, but should be viewed as the product of at least three main phases of landslide activity over the last 8,000 years** (Chapters 4 and 5).

Throughout much of Ventnor the pattern of landsliding suggests a two-tier system (Figures 5.3 and 5.5), involving:

Zone I: compound and rotational failures along clay layers within the Sandrock in the seaward part of the Undercliff, following the St Catherine's Point model (Figure 4.6).

Zone II: multiple rotational or compound failures, to the landward, on slip surfaces within the Gault Clay, following the Gore Cliff model (Figure 5.4) where the basal slip surface is 15-18m above the base of this unit.

The exception to this pattern occurs inland of Monk's Bay where the slopes comprise Zone II-type landslide features. Here, mudslides and rotational slides have developed in the Gault Clay. No Zone I-type failures appear to have developed here, with only minor rockfalls and slides occurring on the Lower Greensand cliffs.

Preliminary stability analysis of a section line between Ventnor Park and Lowtherville (Chapter 5) indicates that parts of **the Undercliff may be close to a threshold of instability.**

Contemporary ground movement has largely been confined to a limited number of locations (Upper Ventnor, Ventnor Bay, Central Ventnor and parts of Upper Bonchurch and the coastal cliffs). This indicates that some areas of the landslide systems are more sensitive to changes in factors such as climate, coastal erosion or human disturbance, than others. A wide variety of types of contemporary ground movement have been identified from descriptions presented in local newspapers or other sources, together with an understanding of the geomorphological context of these movements (Figure 5.3). The degree and nature of the hazards to the local community vary according to the different landslide processes operating within the town, these include:

- first-time failures off the Chalk Downs;

- subsidence and joint widening within the Upper Greensand;

- blocks of material moving *en masse* along pre-existing shear surfaces;

- degradation of pre-existing landslide features by a variety of processes e.g. sliding and falls off scarp faces, mudslides.

Throughout much of the town the long term rates of ground movement have been less than 10mm per year and many areas have apparently remained inactive over the last 100 years or so. However, in a number of areas rates of movement of over 10mm per year have been measured: the Lowtherville Graben, Gills Cliff Road, Ocean View Road (all Upper Ventnor), Bath Road and the Winter Gardens (section 2.2; Table 2.4). It must be emphasised, however, that although it has been possible to estimate annual rates of movement, it is unlikely that movement will be continuous. **Movement will probably be episodic, with the main displacements occurring over short periods of time followed by periods of relative stability.**

Ten main periods of landslide activity have been identified since 1800 (Chapter 2), separated by periods of apparent stability. It is widely appreciated that they correspond to periods of heavy winter rainfall and coastal erosion. As much of the coastline is now protected it is unlikely that present coastal retreat has a significant influence on promoting future ground movement in Ventnor (although erosion of the shore platform may remain an important factor). There does appear to be a close relationship between landslide activity and periods of high antecedent rainfall conditions. A comparison of the 4-month antecedent effective rainfall (AER) for months when landslide events were either reported or absent suggests that, since 1855 (the date when newspaper records began), the occurrence of ground movement can be defined by three broad classes (Figure 6.1):

Class 1 when there has been a 1 in 50 (2%) chance of movement. This corresponds to conditions between May and October every year <u>and</u> November to April when the AER is less than 130mm;

Class 2 when there has been a 1 in 12 (8%) chance of movement. This corresponds to conditions between February and April when the AER exceeds 130mm <u>and</u> November to January when the AER is between 130-350mm. Such conditions have occurred 1 year in 1.2;

Class 3 when there has been a 1 in 1.7 (60%) chance of movement, corresponding to conditions between November and January when the AER exceeds 350mm. Such conditions have occurred 1 year in 22.

Over 80% of all landslide events recorded in the Ventnor area have occurred during periods when the antecedent rainfall total exceeds 130mm. This condition is a major threshold, influencing the frequency of landslide activity. If it were possible to identify the corresponding groundwater level and maintain it below this threshold then the majority of all future landslide events may be avoided.

This relationship does not account for the occurrence of all landslide events in the town, as movements have also been recorded during periods of very low antecedent rainfall conditions. Such movements must be either of a type which is less sensitive to long-term rainfall patterns or due to human activity. It is probably no coincidence that the number of reported events has increased with the spread of the town over the last 100 years or so. Indeed, as the town spread, so the potential for damage (and hence records) increased. **Coastal disturbance, cut and fill operations and quarrying have probably all contributed to the instability problems. However, whilst small developments such as house building may have caused localised problems, large-scale schemes (such as the abortive harbour scheme of the 1860's) may have affected the stability of the whole landslide system.**

Potentially the most serious destabilising activity associated with development has been artificial recharge of the groundwater table. Uncontrolled discharge of surface water through soakaways and highway drains may have contributed to raising the groundwater table to a level where heavy winter storms could trigger movement. In addition, 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.

The occurrence of intermittent, slow ground movement has resulted in a range of problems to the community (demolition of unsafe property; road maintenance and upgrading; temporary evacuation of houses; compensation for damage; insurance claims; costs of coastal protection; see Chapter 3). Judging from the historical records it would appear that problems have increased over the last century, probably because **urban development itself has increased the vulnerability of the community to landslide damage by concentrating people, resources, assets and services in a limited area.**

There is, unfortunately, only a limited amount of information relating to the financial cost of ground movement, although Chandler and Hutchinson (1984) estimate losses of over £ 1.5M for the 20 years between 1960 and 1980. This figure is likely to be an underestimate of the real cost, particularly in light of the fact that a landslide damage survey has identified widespread structural damage to buildings, retaining walls and roads (Chapter 3; Figure 3.1). As would be expected the most serious damage occurs in those areas where the largest ground movement rates have been measured (Upper Ventnor, Ventnor Bay, Upper Bonchurch and the coastal cliffs), although significant damage was also recorded in parts of Central Ventnor, West Ventnor and Lower Bonchurch. **However, it must be emphasised that there are large zones where damage appears to be negligible, especially in Bonchurch.**

Although there can be no doubt that the town lies within a slowly moving landslide complex, **many contemporary problems are heightened by human failings.** Whilst solutions to the problems of moving ground have long been practised in coal mining areas, there clearly has been little attempt to accommodate movement in the design and construction of property in Ventnor. The standard of construction is generally very poor; a legacy of Victorian jerry builders (Chapter 3) and, inadvertently **the most widely used foundation and building types have been completely inappropriate, being particularly vulnerable to ground movement.** However, in recent years appropriate advice has been given by the Borough Council.

A ground behaviour map has been produced which attempts to define the hazards resulting from landslide events. This map presents a complicated picture, reflecting the wide range of natural ground conditions and landslide processes operating within the area. **The potential problems resulting from ground movement vary from place to place, according to the geomorphological setting;**

<u>Chalk Downs</u>; shallow translational slides with potential for debris affecting properties below;

<u>Upper Greensand bench</u>; slow settlement and the gradual opening of fissures or vents, up to 30m depth. These features are of particular concern as they may only be discovered when the ground surface collapses into the vent, as occurred along Whitwell Road in 1954. There is a clear need to detect such features before they cause serious damage or injury;

<u>Rotational slides (scarps)</u>; degradation of scarp slopes is generally limited to slow superficial movements. Where such slopes have been supported by inadequately designed retaining structures failure has resulted in slow bulging and cracking of walls. In a number of cases failure of the retaining wall has led to rapid movement, causing damage to property downslope. Rockfalls or fast moving debris slides represents a serious threat to public safety. Fortunately such failures are not common;

<u>Rotational slides (benches)</u>; the main hazard relates to the effect of large displaced blocks of Upper Greensand or Chalky debris moving *en-masse* along pre-existing shear surfaces. Although rates of movement are generally imperceptible, the cumulative effects can result in considerable damage to properties on the block. The cause of damage ranges from rotation, torsion, forward tilt to settlement. Differential movement is greatest at the back of a bench, where the shear surface meets the ground surface;

<u>Rotational slides (toe area)</u>; slow uplift and ground heave may occur in the toe area of landslide systems and can result in considerable damage to property, as experienced in the Ventnor Bay area ;

<u>Compound failures</u>; the elongate, linear ridges of Upper Greensand or Chalky debris appear to be relatively stable at present. However, rockfalls or fast-moving debris off the steep scarp slopes can present a threat to public safety, although such events are very rare;

<u>Lowtherville graben</u>; a currently unstable area of settlement between two parallel fissures, where movement rates of up to 125mm per year have been recorded. Differential subsidence has resulted in severe damage to buildings (a number of which have had to be demolished) and the public highway;

<u>Coastal mudslide systems</u>; slow minor displacements have often caused damage to footpaths or property within the mudslide systems. Rarer, larger displacement have resulted in debris affecting structures below, as in Castle Cove;

<u>Degraded translational landslide systems</u>; little is known of the behaviour of these areas,although the similarity in form with The Landslip does suggest that major movements could occur;

<u>Coastal cliffs</u>; rockfalls and rockslides represent a threat to public safety, as along most cliff shorelines in Great Britain;

<u>Settlement of soft ground</u>; imperceptible settlement of unconsolidated materials can cause damage to properties with unsuitable foundations.

Concern has been expressed in the past that the whole landslide system could be reactivated, with devastating consequences for the town. However, the behaviour pattern of the landslides over the last 200 years is well established, with detailed information available on the magnitude, frequency and impact of past movements. **Whether such behaviour will continue in future is unknown, particularly in light of the climatic changes which may occur over the next few decades. Ongoing monitoring is clearly required to detect any change in rates.** No evidence has been found that catastrophic failure has occurred over the last 200 years and it is felt that there is no need to warn the public of impending failure in a manner that might cause widespread concern or panic. It would be prudent, however, to consider all eventualities and it would be most sensible to monitor future ground behaviour and regularly review the implications of the results.

In the past there has been an ad-hoc response to specific landslide events, concentrating on repairing buildings, condemning properties or emergency action. Such crisis management responses after the event are common reactions to infrequent problems throughout the world. **However, in Ventnor, where ground movements are a recurrent problem there is a clear need for a coherent and systematic strategy for reducing the landslide hazard.** To this end a range of outline management strategies have been presented to reduce the impact of future movements. These strategies are discussed in Chapter 8 and include:

(a) modifying the hazard to the community by means of engineering works, coastal protection, improved building practice;

(b) effective planning control to avoid unsuitable areas and control the nature of new development;

(c) improving the understanding of landslide behaviour;

(d) mitigating the costs of ground movement through insurance etc;

(e) co-ordinating community responses to the problems.

It is important that the landslide problems faced in Ventnor are kept in perspective. The town is built on a massive landslide complex and as such the whole area should be viewed as **marginally stable** (see section 5.2). Fortunately the geological setting and the style of landsliding is such that movements are often concentrated in a few zones, and that intervening areas have shown negligible or no movement over the period of the survey. Thus in many areas buildings have survived for long periods, such as Bonchurch Old Church which is believed to be over 1,000 years old. In addition, many properties are poorly built with foundations and building type completely unsuited to accommodating ground movement, thus the landslide problems have appeared to be more serious and less manageable than they should do. Indeed, there are few Victorian towns that do not show damage to structures, roads or retaining walls for a variety of other reasons such as clay shrinkage, subsidence, dewatering etc.

In the past it has been stated that Ventnor constituted the greatest landslide problem in the Isle of Wight, if not in Britain (Hutchinson, 1965). It is certainly true that it is the largest inhabited landslide in Britain. However, it must be stressed that the ground behaviour over the last 200 years or so has allowed the growth of a town with a population of over 6,000.

There is no justifiable reason why there should not be confidence in Ventnor from a building insurance or financial development point of view so long as sensible use is made of the technical information presented in this report and obtained from future monitoring exercises, and the proposed landslide management strategies are practised. Of course, unstable areas must be avoided where possible. Conversely more stable areas can be successfully developed, as long as appropriate building designs and stabilisation measures are adopted, if needed, and the developer is willing to accept, in some locations, a higher level of risk than would be expected in normal circumstances.

8.2 RECOMMENDATIONS: VENTNOR

The scale and complexity of the landslide system at Ventnor dictate that conventional engineering solutions to the contemporary instability problems are unlikely to **prevent** any further movements. More realistic aims would involve **reducing** the size and frequency of landslide events and **minimising** their future impact. To achieve these aims there is a clear need for the local community to manage the problems. This should involve considering the following recommendations:

HAZARD REDUCTION

(1) **It is recommended that immediate action should be taken to prevent possible injury to members of the public in those areas where the degree of hazard is judged to be higher than normal. These include:**

(1a) **An early warning system** should be installed in the Lowtherville Graben, to prevent accidents along Newport Road if the graben suddenly subsides;

(1b) **A shallow geophysical survey** should be carried out along a number of roads to identify the position of previously unrecorded vents before they collapse;

(1c) South Wight Borough Council and individual property owners should **regularly inspect scarp slopes** for potential rockfalls and unstable debris;

(1d) **Condition and ownership of the retaining walls** in Upper Ventnor and The Esplanade area (at least) should be surveyed as sudden collapse could cause serious injury.

(2) **Considerable benefit can be gained by attempting to reduce the frequency that landslide events occur, and minimising their impact. This should involve:**

(2a) **Engineering stabilisation of sections of the Undercliff** may need to be considered, at a future date, as there may well be a limit to the effectiveness and success of alternative management strategies;

(2b) **Construction activity;** control of construction activity is seen to be an important aspect of reducing the possibility of slope failure. The local authority should ensure that the following improvements are made to existing construction practice:

avoid inappropriate cut and fill operations;

restrict the timing of earth moving operations during periods of heavy winter rainfall;

restrict the removal of vegetation from scarp faces;

establish a code of practice for open trench excavations;

(2c) **Preventing water leakage;** it is strongly recommended that a major effort should be directed towards preventing leakage of water into the landslide system, either through water mains, service pipes, sewers, soakaways or highway drains;

(2d) **Coastal protection;** where protection schemes are already present they need to be regularly inspected and their performance reviewed. Unprotected stretches of the coastline at Ventnor need to be protected with schemes that take into account erosion of both the cliffline and shore platform;

(2e) **Improved building standards;** an advisory code of good building practice should be adopted. Adherence to this code would produce a significant overall improvement to standards of development. Such a code could be enforced by either voluntary compliance, as a condition of planning permission or by local by-law;

(2f) **Experimental building plots** could be established to determine the most suitable building and foundation types to accommodate ground movement. Such a facility could also be used to demonstrate good building practice to local developers etc;

(2g) **Improving existing structures;** significant low-cost improvements could be made to existing structures, roads and services. The local authority should encourage property owners to undertake such repairs;

(2h) **Property maintenance;** maintenance of property is of great importance, as neglect can result in serious instability problems. A series of suggestions for good practice are presented in this report, and it is recommended that the local authority encourages property owners to carry them out;

PLANNING CONTROL

(3) There are considerable opportunities to prevent future damage to new development by incorporating the knowledge of ground behaviour within the existing planning framework. **It is recommended that ground instability is considered at all stages of the planning process, in accordance with the Department of the Environment's Planning Policy Guidance** (DoE, 1990). This would involve:

(3a) **Development plans;** the ground behaviour map and the planning guidance map should be taken into account in the preparation of future development plans (Isle of Wight Structure Plan; South Wight Local Plan) or incorporated within an interim policy statement;

(3b) **Control of development;** the Local Planning Authority should take instability into consideration when dealing with planning applications. The results of this study should provide the background information needed to make planning decisions, although it is recognised that specialist advice will probably be needed in certain circumstances. The recommended procedures for handling of applications for development on land which is known, or suspected to be unstable is outlined by the DoE (1990). It is recommended that the planning authority adopts a flexible approach to determining what constitutes an appropriate investigation of instability problems prior to the submission of a planning application. It is recognised that it is important that the objectives of any site investigation are realistic, otherwise the requirement of detailed stability information will act as a restriction on development;

(3c) **Development outside planning control;** many activities which do not require planning permission may have an adverse effect on stability (e.g. construction of a swimming pool, removal of vegetation from a scarp slope). Consideration should be given to making a direction under Article 4 of the General Development Order, 1988, which would remove specific development rights within the area and require planning permission to be obtained;

(3d) **Building control;** many of the current ground movement problems have arisen, or been made worse, because of the standard of building and repair work in the past. It is recommended that the Building Regulations are also used where possible to ensure that appropriate foundation and building types are constructed in problem areas.

FURTHER INFORMATION

(4) Although the ground behaviour map represents the most complete picture of the nature and extent of the landslide problems in Ventnor, there remains a distinct lack of information on:

(4a) **Understanding the mechanics of the landslide system;** knowledge of the mechanisms and behaviour of the Undercliff, at Ventnor is limited by a lack of sub-surface information. This deficiency can be overcome by:

-sub-surface investigations in order to verify the models of landslide development advanced by this study (although costs will inevitably be large);

-the collation and storage of all future investigations of ground conditions in a computerised database.

(4b) **Evaluating the effects of environmental change;** the ground behaviour map is based on an understanding of past events. Predictions of climatic changes over the next few decades indicate that judging future behaviour from what has happened in the past may be unwise. It is considered very important that the ground behaviour map is regularly reviewed and updated, by means of:

-a co-ordinated monitoring programme, involving ground surveys, climate and groundwater measurement etc;

-maintaining detailed records of future ground movement events;

-undertaking surveys to record structural damage to property.

(4c) **Forecasting ground movement;** a simple relationship between landslide events and winter rainfall has been established. It is recommended that effort be directed towards establishing a rudimentary method of forecasting ground movement, by reviewing future sub-surface investigation and monitoring information (there should be a requirement for all site investigation reports to be submitted to the local authority);

(4d) **Groundwater levels;** the majority of recorded landslide events have occurred when the antecedent rainfall exceeds 130mm. It is recommended that the equivalent groundwater level should be established in areas of known instability (e.g. Upper Ventnor and The Esplanade) and the feasibility of lowering the water table below this threshold should be evaluated by means of a detailed sub-surface investigation including pump testing;

(4e) **Economic appraisal;** at present there is only a limited amount of information relating to the financial cost of landsliding in Ventnor. A review of the financial implications of a minimal action approach (i.e. keep on as normal) needs to be estimated in order to be able to assess the value of pursuing the various landslide management strategies.

INSURANCE

(5) In recent years many homeowners have experienced difficulty in obtaining insurance cover. **It is recommended that insurance companies should reconsider their position in the light of the results presented in this report, and in particular, the varying levels of risks within the area.**

PUBLIC AWARENESS

(6) **It is considered essential that in addition to the other landslide management strategies, efforts should be directed towards increasing public awareness of the problems. This should involve:**

a series of public meetings explaining the results of this study;

publication of a booklet explaining the landslide problems and the policies adopted by the Local Authority;

publication of a leaflet explaining the proposed planning and building control procedures. This should be distributed with all planning applications;

publication of a leaflet explaining the proposed code of good building practice and control of construction activities;

publication of a leaflet explaining to property owners the value of low-cost repairs and maintenance;

a series of meetings with professionals involved in the property business (lawyers, insurance companies. building societies, estate agents etc.) to explain the results of this study;

(7) **It is recommended that the local community should be encouraged to adopt a positive approach to the landslides at Ventnor.** The landslides do represent unique tourism and education opportunities and may be turned into a local attraction by means of visitor centres, study centres and nature trails.

(8) **It is recommended that contingency plans should be formulated by the local authority, based on a range of possible scenarios.**

GENERAL RECOMMENDATIONS

(9) **It is recommended that a computerised Geographical Information System (GIS) should be established** by South Wight Borough Council to allow the efficient storage, retrieval and presentation of the landslide information. This facility would provide:

-a means of storing all the future monitoring and site investigation data, plus records of landslide events and structural damage;

-the ability to update the ground behaviour map and planning guidance map as more information becomes available;

-the opportunity for combining the ground behaviour information with land use data to undertake a risk assessment, if required.

It is recommended that access to the GIS should be provided to developers, insurance companies and to professional involved in the buying and selling of property.

(10) **It is recommended that a research project should be funded** to monitor the success of those landslide management strategies that are adopted, concentrating on:

- the effectiveness of the planning control system;
- the financial implications of landslide management;
- the changing perceptions of the problems throughout the community;
- future benefits to the community in terms of improved availability of insurance etc.

8.3 RECOMMENDATIONS: ISLE OF WIGHT

(11)The ground movement problems experienced in Ventnor are only one of a number of landslide problems around the coast of the Isle of Wight (e.g. Luccombe, Sandown-Shanklin, Blackgang, Freshwater Bay etc.). **It is recommended that the local authority should adopt a co-ordinated strategy for dealing with these problems, involving:**

(11a) **Ground instability should be considered at all stages of the planning process: development planning, control of development and building control;**

(11b) **It is recommended that all the information on coastal landslide problems in the South Wight Borough are collected and stored in a computerised Geographical InformationSystem.** This information could be used as the basis for planning decisions concerning development in areas of known, or suspected instability problems;

(11c) **Efforts should be directed towards identifying ways of reducing the existing landslide problems around the coast (e.g. engineering stabilisation, foreshore management, improved building standards etc.);**

(11d) **South Wight Borough Council should fund a research project to review the possible effects of sea-level rise on the existing coastal defences and unprotected shorelines.**

8.4 RECOMMENDATIONS: NATIONAL

8.4.1 Landslide investigation

Perhaps the most innovative aspect of this study has been the recognition that when people have to live and work in areasof unstable ground (such as an ancient landslide complex, area of subsidence, peat shrinkage, coastal erosion etc.) there is much that can be done to alleviate the problems if the geomorphological system is fully understood. Many mistakes in the past have been made by a lack of knowledge of the natural systems or by modifying the environment. Clearly the old adage 'forewarned is forearmed' is often true when looking at the long list of schemes that have been delayed or abandoned because of ground instability (e.g. the closure of the A625 Manchester-Sheffield Road at Mam Tor). Many problems can be prevented if the potential difficulties are appreciated in advance.

(12)The assessment of landslide problems and of the associated risks requires careful professional judgement. **It is recommended, therefore, that developers should seek expert advice about the likely consequences of proposed developments on sites where landsliding is known or suspected.** This advice will generally involve some form of **investigation** into the nature of the problem. This should provide an indication as to whether the site is suitable or what **management strategies** may be needed to prevent problems affecting the site or neighbouring land.

Obviously it is in a developers own interests to determine whether a site is on unstable land as any future movement will affect the value of the site and its development costs. If there are reasons for suspecting instability problems the developer should instigate appropriate investigations* to determine whether:

- the land is capable of supporting the loads to be imposed;

- the development will be threatened by unstable slopes on or adjacent to the site;

- the development will initiate slope instability which may threaten its neighbours.

The way in which this study has investigated the problems in Ventnor has been directed towards determining the nature and extent of the landslide, understanding the past behaviour of separate parts of the landslide system and formulating a range of management strategies to reduce the impact of future movement. The work undertaken has involved a thorough review of available records, reports and documents followed by a programme of detailed field investigation comprising geomorphological and geological mapping, photogrammetric analysis, a survey of damage caused by ground movement, a land use survey and a review of local building practice (Figure 1.3). These aspects of the study were specifically geared towards obtaining, as clearly as possible, an understanding of the landslide system at Ventnor especially:

(i) the nature and extent of the landslide system;

(ii) the types of contemporary ground movement;

(iii) the magnitude of contemporary ground movement;

(iv) the frequency of landslide events;

(v) the impact of ground movement on the town;

(vi) the nature of property at risk;

(vii) the vulnerability of different styles of construction.

The wealth of information on each of these topics has been collated and stored in a computerised Geographical Information System (GIS) for ease of data retrieval and analysis. By studying the spatial and temporal relationships between these different data sources, it has been possible to identify a range of factors that have influenced both where and when landslide events have occurred since reliable records began. A rudimentary landslide forecasting method has been developed based on the close relationship between high winter rainfall and landslide activity.

A ground behaviour map has been produced which describes the nature and extent of hazards associated with different contemporary landslide processes, and their impact on the town. This detailed understanding of landslide behaviour, together with a knowledge of the vulnerability of different styles of construction and the property at risk in different areas, has been used to formulate a range of outline management strategies designed to reduce the impact of future movements.

It is clear that this method of investigation is essentially a **geomorphological approach**, which has relied on an understanding of surface features and a thorough review of available documentation to arrive at a model of landslide mechanisms. The absence of a detailed sub-surface investigation does mean that this model has yet to be fully verified. However, a thorough sub-surface investigation of landslides as complicated as those found in Ventnor is likely to be prohibitively expensive.

This study has demonstrated that the geomorphological approach to landslide investigation can provide detailed information for general land use planning and development decisions without detailed and costly sub-surface investigation. The geomorphological approach, though, is not an alternative to such investigations, rather it should be used as a cost-effective way of identifying whether instability problems at a site are likely to prove too expensive to overcome. Alternatively, if, as in many cases, the instability problems at a site can be overcome, the geomorphological study can give an indication of the nature and scope of the ground investigation that may be needed to enable the design of remedial or preventative measures.

The scale of any subsequent ground investigation will clearly depend on the nature of the problem facing the developer. However, typical ground investigations for landslides are likely to involve a combination of sub-surface investigation, laboratory testing, monitoring of ground movement and groundwater studies (Table 7.4).

The decision to proceed with a costly ground investigation clearly needs to be made after a preliminary economic appraisal of the viability of the project. This logical sequence highlights a 3-stage approach which is felt to be the most appropriate way to investigate areas of landsliding or potential unstable ground (Figure 8.1), and would involve:

(i) an initial geomorphological investigation;

(ii) a preliminary economic appraisal;

(iii) a ground investigation (if required) specifically designed to test the preliminary landslide model advanced following the geomorphological investigation.

The extent of these stages will obviously vary according to the complexity of the landslide problem and the nature of the hazard. For example, it would not be relevant to carry out photogrammetric analysis to determine the magnitude of contemporary movement in areas where the landslides are essentially dormant, as in many inland situations. In many instances the economic appraisal could be superfluous because of overwhelming instability problems, such as at Black Ven on the Dorset coast. The ground investigation, too, will reflect the conditions at the particular site and the nature of the problem; investigation of a cliff fall problem or debris flow hazard would obviously require only limited sub-surface investigation, but greater emphasis on understanding the nature of the materials.

(13) **It is recommended that this model for landslide investigation and responses could be used as a basis for landslide management in other coastal and inland settings in Great Britain, regardless of the geomorphological setting.**

8.4.2 Landslide management

Instability problems are not Acts of God; unpredictable, entirely natural events that can, at best, be resolved by avoidance or large-scale engineering works. Although it may be possible to control the natural factors which influence landsliding through remedial measures (Table 7.5), man's role in initiating or reactivating many slope problems should not be underestimated. Approaches should be considered which try to minimise the effects of human disturbance and reduce the impact of future ground movement.

(14) The landslide management approach presented in this report has a broader relevance than reducing the impact of

FOOTNOTE: A review of standard investigation techniques is presented in Annex A.

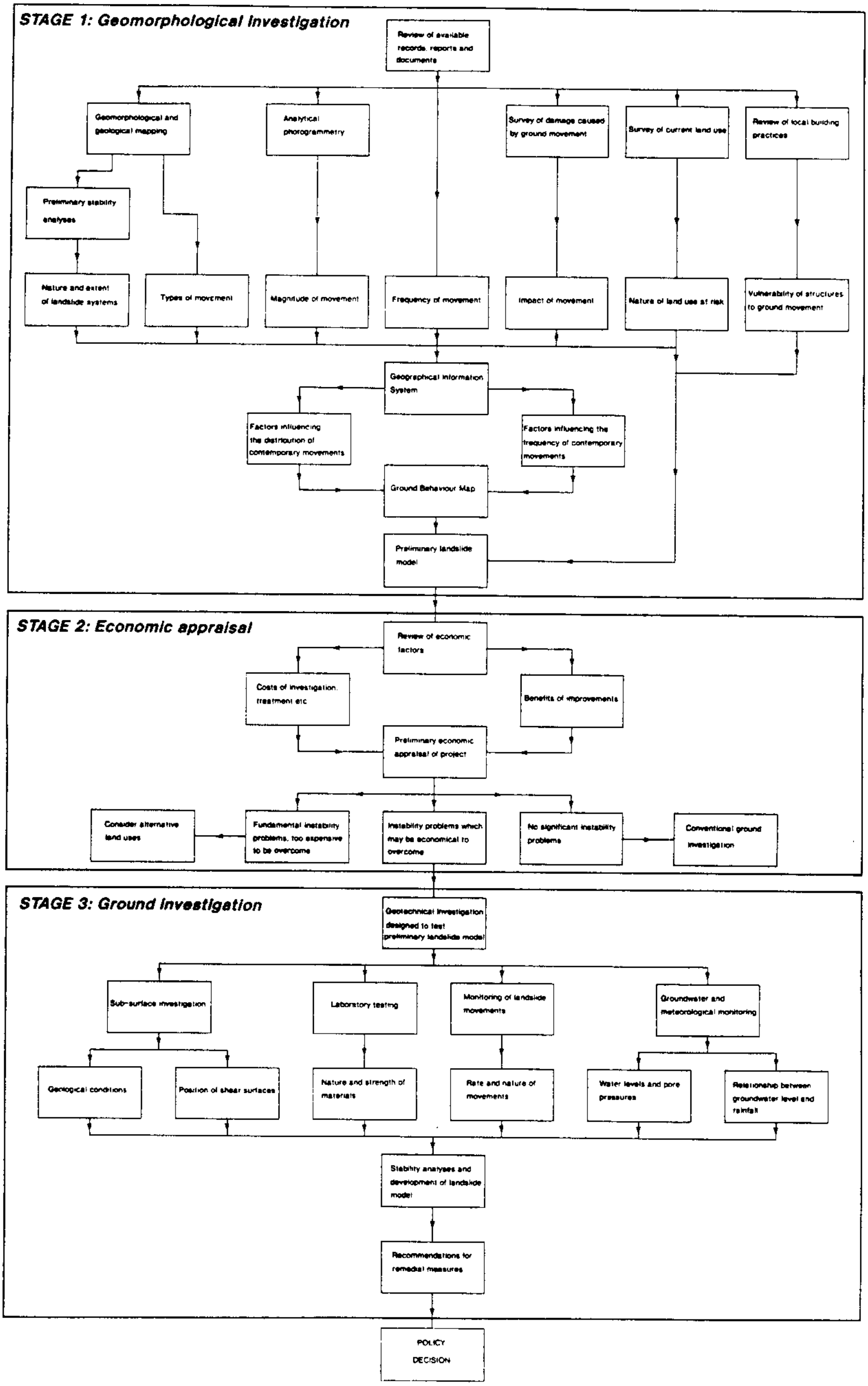


Figure 8.1: Procedures for the evaluation of potentially unstable ground

ground movement in Ventnor. **It is recommended that local authorities, landowners and developers should consider the concept of managing landslides or other geomorphological systems such as coastal process units.** The most cost-effective strategies are likely to involve a combination of planning control, control of development, preventing water leakage improved building standards and property maintenance.

(15) Managing landslides or other natural systems can lead to difficulties over the responsibility or needs of interested parties. **It is recommended, therefore, that a public awareness programme should be an essential part of any such strategy.**

(16) The DoE Planning Policy Guidance Note PPG14 (DoE, 1990) recommends that local authorities consider instability problems at all stages of the planning process. However, the specific policies and practices to be adopted by a local authority are for them to decide in the light of local circumstances. **It is recommended that the guidance in PPG14 should be further developed with specific reference to landslide management and planning, and outlining the ways in which an understanding of the geomorphological context of a site or area can be of value for general land use planning decisions.**

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GLOSSARY

Antecedent rainfall: the cumulative total of rainfall occurring, over a given period, prior to a specific date, e.g. the total rainfall over the four months before December 1.

Aquifer: a water-bearing strata of bedrock which stores and allows water to pass freely through the rock mass.

Cohesion: that component of shear strength related to the forces holding soil particles together in a solid mass. It is caused by chemical attraction of particles and is not controlled by compressive forces holding particles together.

Creep: is the slow, imperceptible, downslope movement of superficial soil and rock debris in response to gravity.

Effective rainfall: the total rainfall, minor evapo-transpiration which is available for groundwater recharge.

Episodic event: an event which occurs discretely in time with intervening periods with no events.

Extensometer: a surveying device which monitors the distance and movement between two anchored points in soil or rock.

Factor of Safety: is an equation describing the stability of slopes or the 'Factor of Safety' against landsliding (F):

$$F = \frac{R}{D}$$

where R represents the resisting forces and D the disturbing forces. If $F = 1$ the forces are equal and the stability of the slope is critical.

Geographical Information System: a computerised system for the storage, analysis and display of spatially related information.

Geomorphological Unit: an area characterised by similar slope forms and materials.

Graben: a block of land downthrown between parallel faults or fissures.

Inclinometer: a device used to monitor the sub-surface 3-dimensional deformation of a tube installed in a borehole.

Internal friction: that component of shear strength related to the interlocking of soil particles. It is proportional to the normal force holding particles together.

Landslide: is the generic term embracing those downslope movements of soil or rock masses as a result of shear failure at the boundaries of the moving mass. Landslides comprise almost all varieties of mass movement on slopes, including some, such as rockfalls, that involve little or no sliding. Slope movements caused by creep and subsidence are excluded.

Landslide complex: an assemblage of landslide systems forming an extensive area of landslide terrain. The Undercliff at Ventnor is such a complex, measuring 12km wide and extending up to 700m inland.

Landslide system: a discrete landslide bounded by shear surfaces and characterised by a rear scarp and source area, blocks and scarps, and toe area.

Landslide sub-system: distinctive units within a landslide system such as blocks separated by scarps due to the disruption of the landslide system.

Peak strength: the maximum shear strength of material for a given load prior to the shear failure of one part of the mass relative to another.

Piezometer: a sub-surface permeable tube and standpipe or sensor used to measure and monitor water levels or pressures in soil and rock.

Pore water pressure: the pressure exerted by water contained in the voids and interstices of soil or rock, which under saturated conditions will force particles apart.

Residual strength: the minimum shear strength along a failure surface attained after a large displacement under a given set of environmental conditions.

Shear strength: is the resistance of soil and rock to shear stress or movement provided by the weight of the mass under the influence of gravity (normal load) and the physio-chemical properties determining the internal friction and cohesion between particles.

Shore platform: an erosion/deposition surface formed below the high water mark by marine processes. At Ventnor the shore platform is the remnant of former coastal cliffs formed of landslide debris.

Transient factor: factors such as climatic events and earthquakes whose magnitude and frequency varies considerably with time.

APPENDIX 1: DISTRIBUTION OF DAMAGE CAUSED BY GROUND MOVEMENT

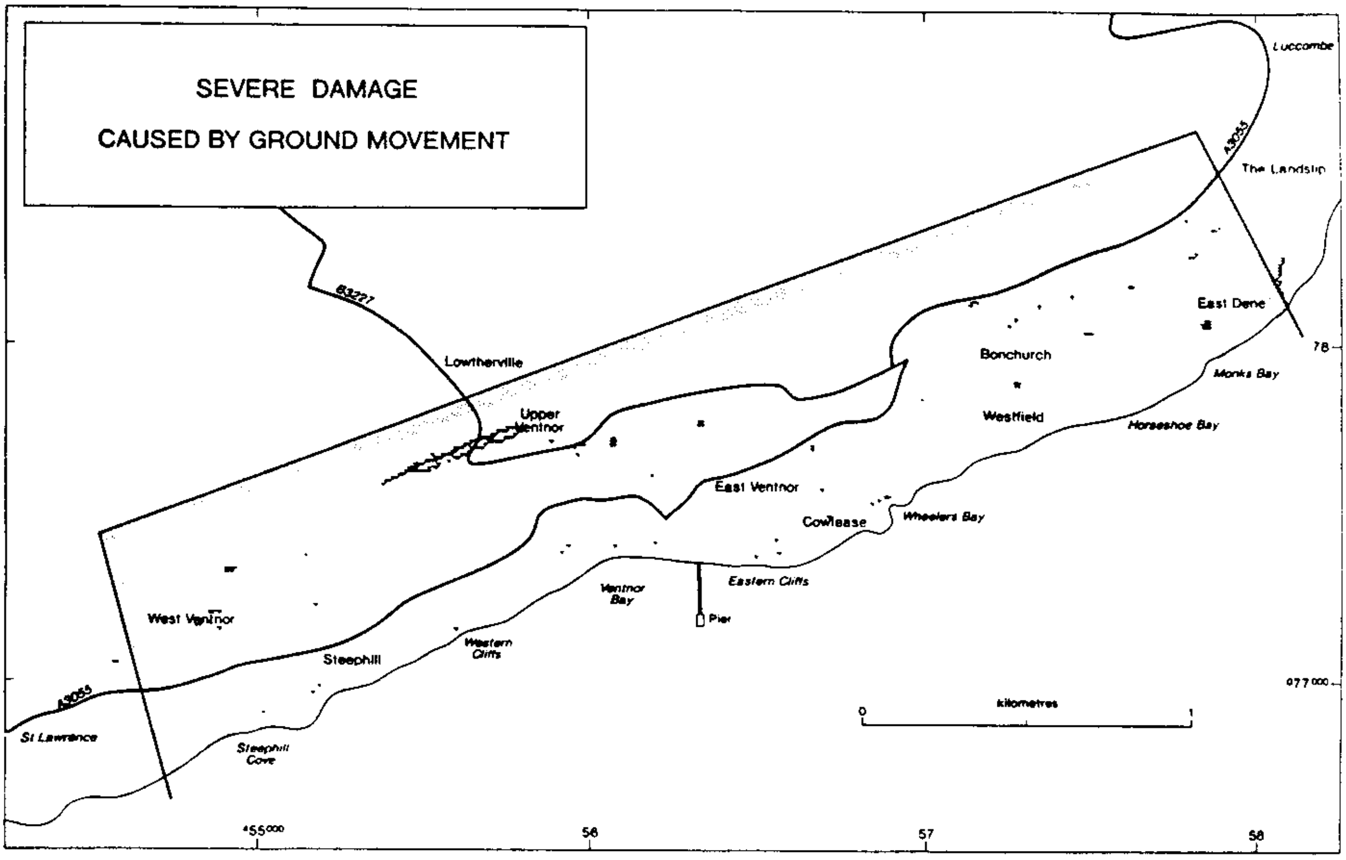

Figure 3.1a: The distribution of severe damage caused by ground movement

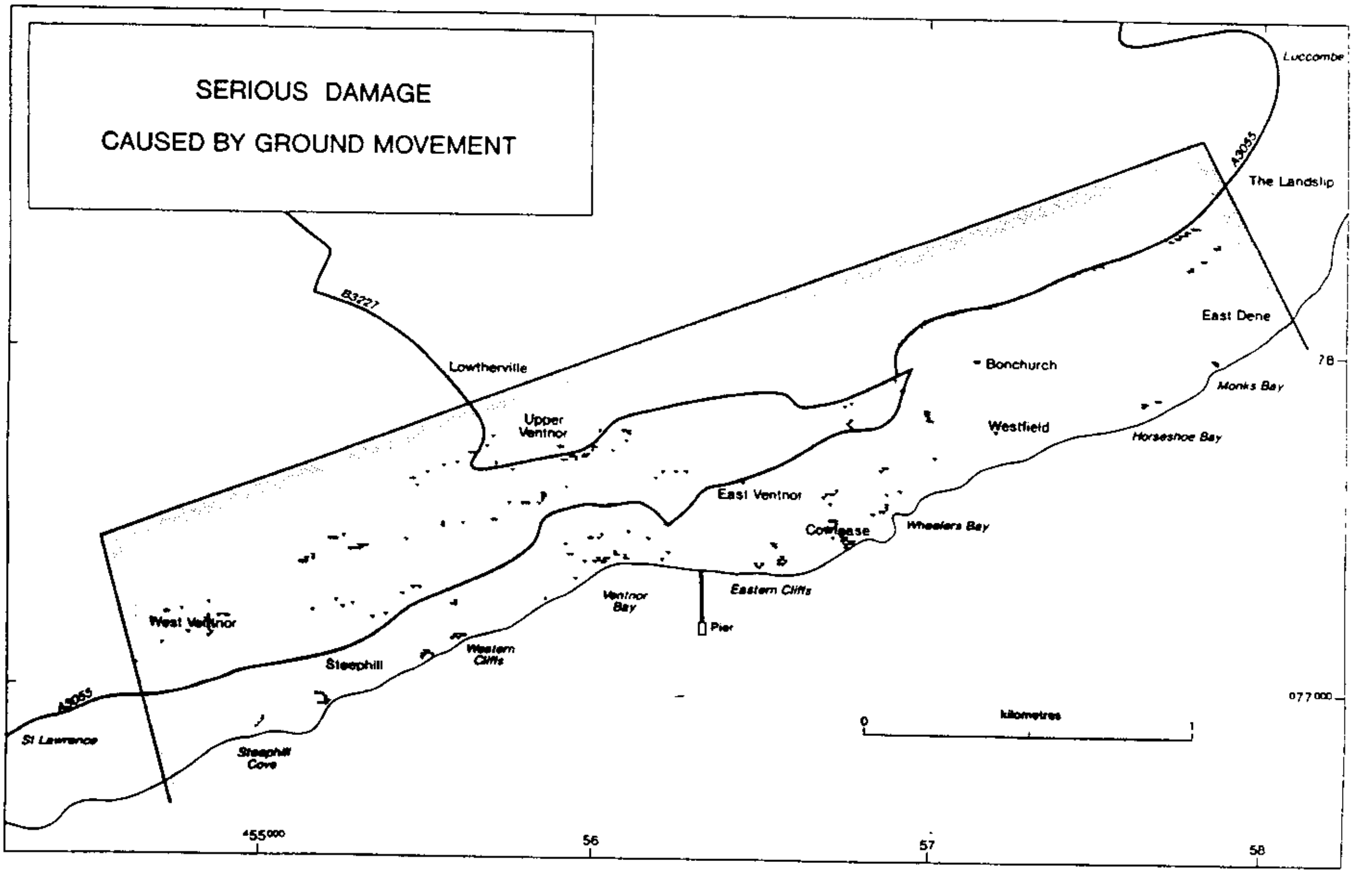

Figure 3.1b: The distribution of serious damage caused by ground movement

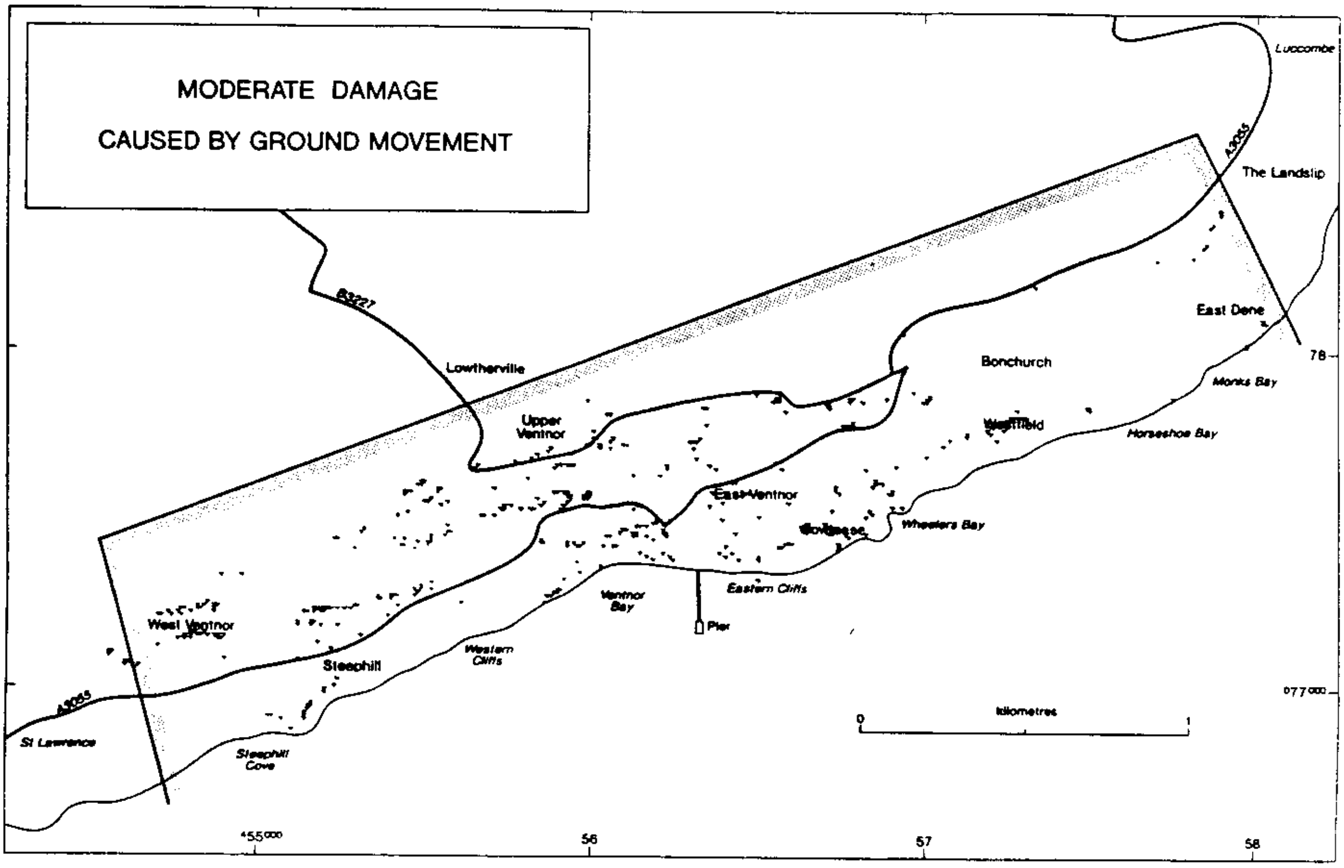

Figure 3.1c: The distribution of moderate damage caused by ground movement

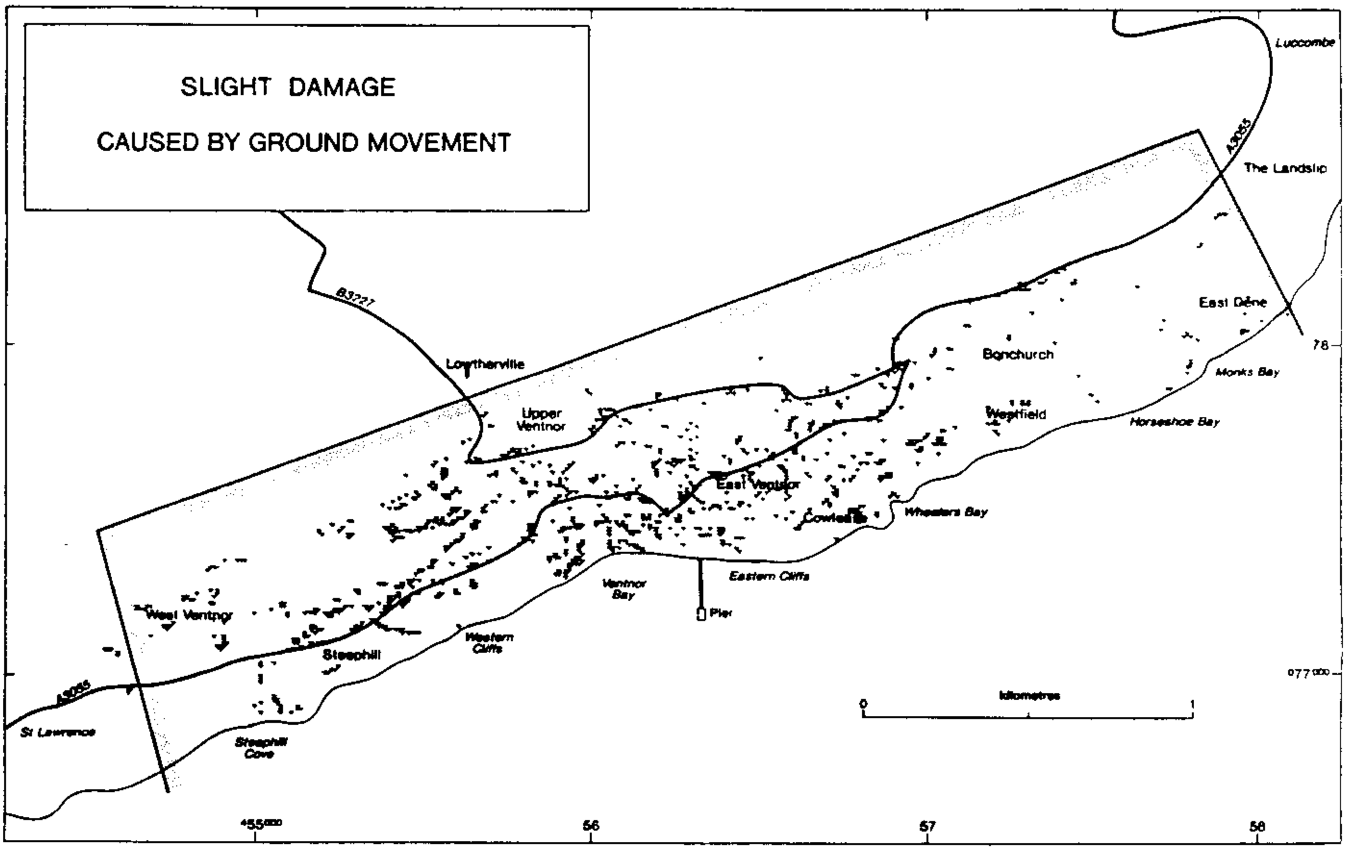

Figure 3.1d: The distribution of light damage caused by ground movement

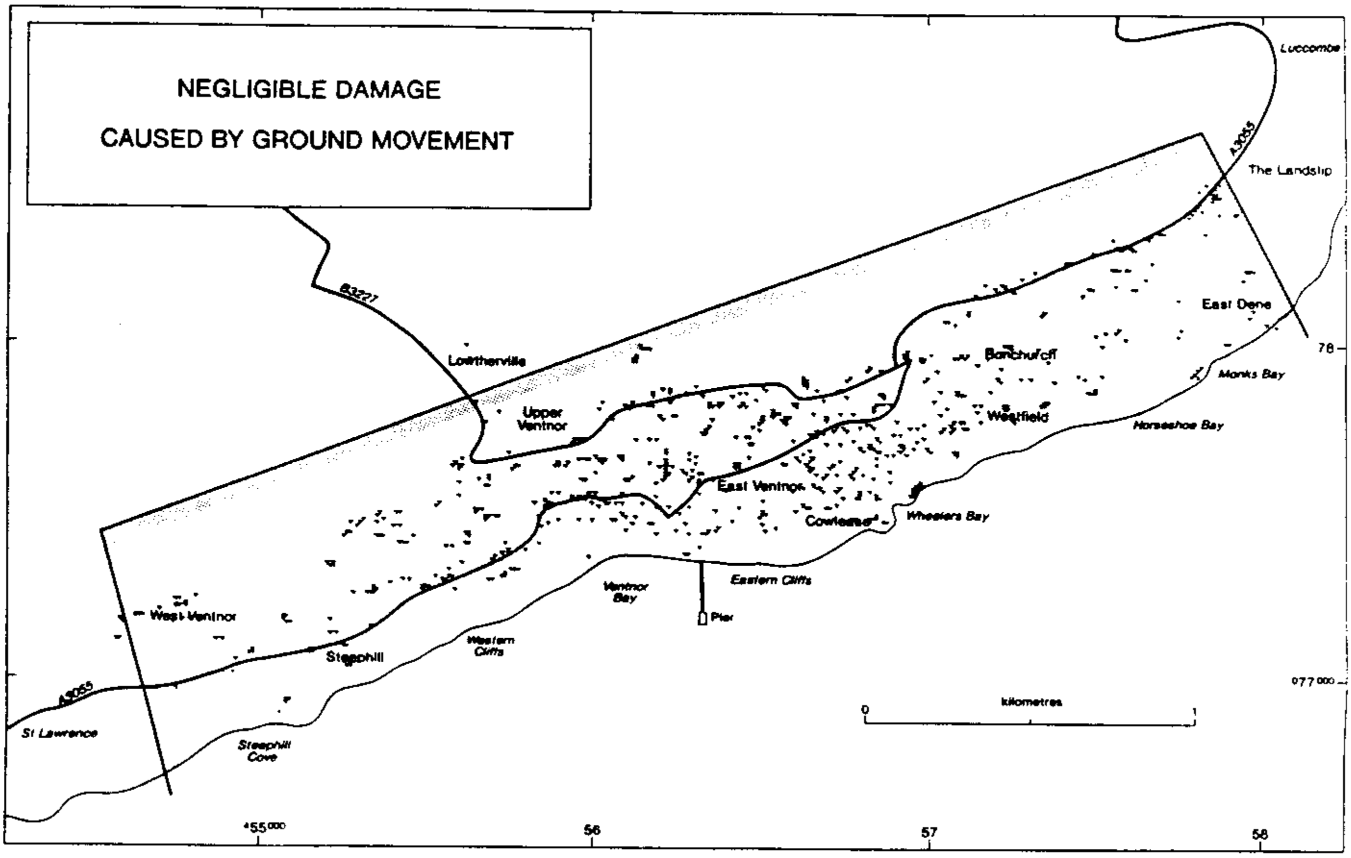

Figure 3.1e: The distribution of negligible damage caused by ground movement