GEOTECHNICAL STUDY AREA G1

VENTNOR UNDERCLIFF LANDSLIDE COMPLEX -AN OVERVIEW, ISLE OF WIGHT, UK

Plate G1 ***Isle of Wight Undercliff looking West***

INTRODUCTION TO THE ISLE OF WIGHT INSTABILITY STUDY AREAS

The geology of the Isle of Wight is complex, the sedimentary rocks having been uplifted, compressed, folded and faulted over geological time. The processes of weathering and erosion and particularly the impact of rising sea-levels since the last Ice Age have resulted in a unique assemblage of geomorphological features within the relatively small area of the Island. As a result the Isle of Wight forms an ideal location for study in the context of coastal change, climate and instability.

The Isle of Wight instability sites have been selected because of their variety and for their demonstration value in terms of the way that problems have been addressed as well as the variety of circumstances involved and solutions being implemented. The sites comprise the Sandown Bay cliff line on the south-east coast of the Isle of Wight between the towns of Sandown and Shanklin, the Isle of Wight Undercliff and particularly the town of Ventnor, and the Afton Down section of chalk cliffs on the south-west coast of the Isle of Wight near Freshwater.

Within the Ventnor Undercliff more detailed discussions of particular problematical locations are described following an introduction to the Undercliff itself, which comprises the largest urban landslide complex in north-western Europe. The study areas within the Undercliff demonstrate the approach adopted by the Isle of Wight Council in terms of investigation, remedial works, where appropriate, and ongoing management of the landslide itself.

Interesting comparisons can be made with the approach adopted in the other partner states (Italy and France) and with the approach adopted in Switzerland.

A brief description of the experiences (successes, problems and lessons learnt) at each of these study areas is given at the end of the respective description. However, a full discussion of the issues arising from all the partners' sites together with those in Switzerland is provided in Chapters 5 and 8 of Volume 1.

THE VENTNOR UNDERCLIFF LANDSLIDE COMPLEX

1. INTRODUCTION

The Isle of Wight is situated approximately 6km off the south coast of England (lat. 50° 40' N, long. 1° 20' W), extending 36km from east to west and 21km from north to south. A special feature of the Island is the wide variety of scenery around its 110km of coastline. A prominent feature of the Island is the central chalk ridge which extends from the Needles in the west to Culver Cliff in the east. The northern coast of the Island is low-lying with a series of estuaries and inlets running down to The Solent; by contrast the southern coast of the Isle of Wight is dominated by rugged cliff scenery.

A particular feature of the southern coast is the Undercliff, a 12 km (700ha) ancient coastal landslide complex that includes the town of Ventnor (Plate G1). The Undercliff extends from Luccombe in the east to Blackgang in the west (Figure G1.1). The main coastal road A3055 runs from Shanklin (to the north-east) along the Undercliff and represents an important communications route. Ventnor is the main town within the Undercliff with a population of 6,500 whilst approximately 12,000 residents in total live in the Undercliff. The Isle of Wight Undercliff is the largest urban landslide complex in north-western Europe and has been studied extensively by the local authorities on the Isle of Wight as well as by the UK Department of the Environment (now Department of the Environment, Transport and Regions).

The Ventnor Undercliff landslide complex was activated as a result of aggressive coastal erosion following a rise in sea-levels after the last ice age about 10,000 years ago. Slow intermittent ground movements in the vicinity of the town of Ventnor has resulted in much damage to property and services over the last 200 years. Management of the landslide hazard has involved the development of a model of contemporary ground behaviour for the Undercliff, based on geomorphological mapping, site investigations, damage surveys, determination of past movement rates and a review of historical events.

2. THE CAUSES OF INSTABILITY

The large coastal landslides of the Undercliff result primarily from the truncation of the gently dipping Cretaceous southern downs by marine erosion (see Figure G1.2). The Upper Greensand and Lower Chalkbeds overlie the weaker Gault Clay, dipping gently seawards at approximately 1.5°. Multiple rotational slipping occurs in the landward part of the complex, with more translational sliding seawards.

A complex arrangement of overlapping deep-seated landslide systems has been revealed by geomorphological mapping and sub-surface investigation of the Undercliff. This has involved failure along at least two main shear surface levels, involving the following main units (Lee et al. 1998):

- A sequence of deep-seated compound slides mainly composed of displaced Lower Greensand and capped by Chalk and Upper Greensand debris.
- A zone of deep-seated, multiple rotational slides in the upper parts of the Undercliff comprising mainly weak displaced blocks of Upper Greensand and Chalk.

These two layers are separated by a discontinuous scarp slope, up to 20m high, developed in the lower, silty layers of the Gault Clay (the Gault Clay scarp).

There are clear differences in the activity and sensitivity of different parts of the Undercliff, with the most active sections over the last 200 years being the western and eastern ends (Blackgang and the Luccombe landslide systems respectively). One of the principal factors controlling this pattern appears to be (Lee et al. 1998) a broad syncline (downfold) in the rocks along the Undercliff (east to west). This controls the height of the Gault Clay relative to sea-level with the two most active areas occurring where the clay is at its highest elevation at the two ends of the fold.

Factors also controlled and/or resulting from this pattern included the presence of broad, gently sloping "debris aprons" of Chalk and Upper Greensand debris in front of the landslide systems (possibly of periglacial origin), and the varying relative relief along the Undercliff.

The variety of landslide types and processes involved has created a series of discrete 'landslide units' within broader landslide systems. The recognition of these units forms the basis for understanding temporary ground behaviour within the Undercliff.

2.1 Processes of Movement

Various ground movements affect the complex -a combination of periodic creep, surface degradation through small scale slides and, in places, re-activation of pre-existing landslide features. Over the last two centuries over 300 reported incidents of ground movement have occurred (reported in local newspapers and other local records) -major and minor landslide events, localised ground movements, coastal cliff falls and joint widening within the Upper Greensand.

Parts of the Undercliff experienced the process of almost continuous deep-seated creep, with the precise amount dependent on rainfall and groundwater levels. Also, the "cycle" of ground movement is established or renewed with the occurrence of first time failures of the rear cliff (the cycle believed to operate over a time period of around 10,000 years). These three processes have varying probabilities of occurrence (Lee et al. 1988):

- Deep-seated creep is expected to occur during most years, with an estimated annual probability of 0.5 (also dependent on rainfall/groundwater conditions);
- Significant ground movements are expected to occur at various probabilities along the Undercliff from around 0.1 to 0.0025 or less;
- The development of a first time failure has the annual probability of around 0.001 or less.

2.2 Coastal Erosion

The present phase of marine erosion along the south coast of the Island was initiated by the recovery of the glacio-eustatically depressed sea-level of the Devensian towards its present elevation (the Flandrian post-glacial transgression), 8,000 to 5,000 years BP. Rates of marine erosion of coastal areas are dependent on changing sea-level, but also on the exposure and susceptibility of the coastline to erosion. The prevailing wind and the greatest wave fetch come from the south-west. As a result the south-west Undercliff in the vicinity of Niton and Blackgang is the most susceptible to erosion, and the eastward facing sections between Bonchurch and Luccombe are more sheltered. The Lower Greensand is generally weaker and more susceptible to erosion than larger blocks of the Upper Greensand, and parts of the landslide debris can be fairly resistant (Hutchinson 1991). Wind, frost and seepage erosion are also active contributors to erosion along the Undercliff to varying degrees within the different lithologies.

2.3 The Impact of Rainfall

Coastal erosion is a major factor controlling the long-term instability of the Undercliff. It has progressively reduced the overall stability of the slopes, promoting landslide activity. Other important factors have also contributed to this reduction in stability, such as periods of heavy

rainfall, which tend to occur in the winter when higher rainfall totals and lower evaporation rates lead to rainfall being much more effective in raising groundwater levels.

The coastal cliffs are sensitive to variations in groundwater levels within the slope, and to sequences of wet and dry years (the impact of past, present and future climatic patterns). However the relationship between landslide activity and winter rainfall is not a simple one, with some sections of the Undercliff showing signs of significant movement frequently, and some only during extreme conditions. For example, in the westernmost system at Blackgang, significant movements are a frequent occurrence, and the minimum rainfall threshold needed to initiate significant movements appears to have been historically a 1 in 1.1 year event.

The probability of landsliding taking place is not only dependent on the amount of rainfall, but the range of preparatory and triggering factors. The operation of preparatory factors progressively reduces the margin of stability of the Undercliff slopes, so the size of the event needed to trigger movement decreases. So, triggering events of the same size may not necessarily lead to landslide events, as triggers of a particular magnitude are redundant until preparatory factors lower the margin of stability to a critical level. Landslide activity is due to the variable interaction of a range of destabilising forces over a variable time period, including importantly the antecedent conditions (Lee et al. 1998).

3. THE ROLE OF KEY AGENCIES

The **Isle of Wight Council** is responsible for managing the Isle of Wight coastline including the Undercliff. The Isle of Wight Centre for the Coastal Environment within the Directorate of Environment Services co-ordinates coastal management including research, instability monitoring, new works and maintenance. The Directorate is responsible for implementation of the Town and Country Planning Act 1990 which provides powers for local authorities to control development. Since 1991 the Council, has been developing and implementing a Landslide Management Strategy for the whole of the Undercliff as part of a wider coastal zone management strategy. A key element of the landslide management strategy has been the effort to co-ordinate the response of the local community with the aim of maintaining and improving the infrastructure within the landslide system.

A detailed review of ground movement problems in Ventnor was commissioned by the **Department of the Environment** (DoE) between 1988 and 1991. The Department of the Environment (now the Department of the Environment, Transport and Regions) undertakes geological and related research as part of its planning research programme, which includes studies of ground instability. Landslide research commissioned by the former DoE has included a 'Review of landsliding in Great Britain', which identified the general need to develop improved methods of landslide potential and risk assessment, in order that land stability can be taken into account in land use planning and development decisions (Geomorphological Services Ltd 1987).

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 in the UK. 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. The report published by the DoE (Research Contract PECD 7/1/272) entitled "Coastal Landslip Potential Assessment : Isle of Wight Undercliff, Ventnor) outlined a range of approaches for responding to landslide problems, which provided a basis for planning and development decisions in Ventnor and a general methodology, which might be used elsewhere.

The findings of this pilot study of central Ventnor were published in March 1991 with the full co-operation of the Local Authority, and indicated that the current knowledge of ground behaviour in the town was based on an understanding of past events. Technical and summary reports were published detailing a methodology for assessment of coastal landslip potential that has been developed from a thorough review of all available published and archived site investigations, reports, photographs and documents and following an extensive programme of

field investigation, including geomorphological mapping, photogrammetrical analysis, structural damage and land use surveys and a review of building practice. The DoE report also detailed practical advice aimed at organisations and individuals with an interest in the instability problems.

The DETR has continued to take an active interest in the management of the Isle of Wight Undercliff, which was initiated by their pilot study. The local authorities have taken forward this work and expanded its scope, also taking on board advice issued in a range of further publications by the DETR, particularly including the recent publication "Environmental Geology and Land Use Planning - A Good Practice Guide" (DETR 1998).

Southern Water Services Ltd has a key role to play in terms of management of instability within the Ventnor Undercliff. The company is responsible for provision and maintenance of both water supply and mains sewerage and are activity involved in programmes of new works, maintenance and monitoring of the conditions of the infrastructure including leakage from pipes into the ground. The Water Authority are a member of the Undercliff Landslip Management Committee which was established following the development of a Landslide Management Strategy for the area in 1993.

4. THE STUDY AREA

4.1 Geology

The Isle of Wight Undercliff extends from Luccombe in the east to Bonchurch in the west, a distance of approximately 12km and comprises an area of approximately 700ha. The Undercliff lies within the southern part of the Hampshire-Dieppe Basin, and is composed of rocks of early Cretaceous to early Oligocene age beneath some Pleistocene cover (Hutchinson 1991).

The solid geology and structure of the Isle of Wight is dominated by a strong east-west monocline (the asymmetrical Sandown and Brighstone anticlines), formed by tectonic activity in the Cainozoic, probably in several phases from the early Palaeocone to late Oligocene or early Miocene (Hutchinson 1991). This asymmetric anticline folds the rocks over the southern half of the Island. The edges of the resistant layer of Cretaceous Chalk around the eroded core of this anticline forms two ranges of hills; firstly, the east-west ridge that runs through the centre of the Island, dividing the Palaeogene (Eocene and the Oligocene) strata of the north from the Cretaceous strata of the south; and secondly the Southern Downs (Ventnor Downs), formed from the gently dipping southern limb of the asymmetric anticline. The Cretaceous sequence of rocks through the Southern Downs is almost flat lying, with a slight dip of approximately 1-2° to the south. The sequence comprises thick permeable Chalk and Upper Greensand beds overlying thinner, impermeable Gault Clay beds and clay layers in the Sandrock.

4.2 Stratigraphy

1. The base of the lower sequence is the Lower Greensand comprising weakly cemented sandstones with clayey layers. The Lower Greensand (rich in Glauconite and weathering from green to orange brown) is often divided into the Ferruginous Sands, Sandrock and Carstone and incorporates several clay beds.
2. The Gault above is a soft, fissured, impermeable dark grey clay, 44m thick.
3. The Upper Greensand strata comprise generally silty, brown-green sandstones with some very hard layers. They are sub-divided into the Passage Beds (12m), the overlying Malm Rock (24m) and the Chert Beds (8m).
4. Above an unconformity, the permeable Lower Chalk is composed of white limestones, with some grey marls, particularly in the lower strata, with 2m thick Glauconitic Marl at its base.

5. White limestones of the Middle Chalk are present at the top of the sequence in the clifftop of the eastern Undercliff (Hutchinson 1991).

The Isle of Wight was not glaciated during the Quaternary, but was affected by several periods of intense periglacial activity with the associated global, glaci-eustatic changes in sea-level (Hutchinson 1991). Gravels, sands and clays have been deposited over parts of the Island's surface throughout the past 10,000 years. The Island was separated from the mainland during the transgressions of the late quaternary (Velegrakis et al. 1999).

4.3 Permeability and Groundwater

Permeable Upper Greensand and Chalk form a major aquifer (groundwater body) perched on top of the impermeable Gault and connected to the landslide masses through a springline located in the Passage Beds in the base of the Upper Greensand. The Gault forms an impermeable barrier, below this level the strata have a high permeability, parallel to their near-horizontal bedding. These strata outcrop in the sea-bed just off-shore, so their groundwater/piezometric levels are expected to be related to sea-level and considerably lower than in the perched aquifer above, but also to vary locally due to clay layers and the dip of the rocks.

5. MONITORING OF GROUND INSTABILITY

Field monitoring of ground movements, water levels and weather events continue to be necessary to:

- Establish an integrated network of continuous recording of movement rates, water levels and weather events to provide advance warning of potential problems and to improve the understanding of ground behaviour in the Undercliff.
- To assess the regional and periodic ground movement rates through the Undercliff using ground surveys and photogrammetry.

It was recognised that the scope and budget costs of works for the periodic survey of ground movement rates by photogrammetry would not be economic. It was recommended, however, that a policy for re-survey should be formulated comprising regular aerial surveys, analysis and interpretation of regional ground movement patterns. Apart from improving the understanding of ground behaviour such monitoring would provide reassurance for the community. Survey points could cover the whole Undercliff but would be concentrated in areas of known movement.

It was further recommended that an integrated monitoring network should target several areas, including key locations in the Undercliff at Luccombe, Bonchurch, central Ventnor, Steephill, St Lawrence, Niton and Blackgang. Instrumentation is in place which provides daily or automatic readings of surface movements, groundwater levels and weather events. The influence of weather events on groundwater levels was particularly relevant in this respect.

Records of ground movement events were recognised as being important in understanding ground behaviour. Future reviews of ground behaviour depend very much on records of damage to infrastructure. It is important, therefore, that the performance of engineering structures can be regularly assessed. New cases of damage to structures are recorded along with renewed damage to previously affected structures; photographic records are kept where possible. This information is collected in the form of an integrated geographical information system.

The current approach with respect to monitoring within the Ventnor Undercliff comprises the development of a co-ordinated strategy involving both manual and automatic monitoring means, together with associated collation of weather data. With the assistance of this project advice and best practice is being formulated which will assist in improving further the approach being adopted by the Isle of Wight Council and others to the collation of instability data.

6. CURRENT STATUS AND APPROACH TO THE PROBLEM

6.1 The Landslide Management Strategy

Following the completion of the DoE study in 1991, the former South Wight Borough Council took on board the recommendations of that report and commissioned its consultants to prepare a Landslide Management Strategy for the Isle of Wight Undercliff (Plate G1a). The principal aims of the Landslide Management Strategy were to:

- Reduce the likelihood of future movements by controlling the factors (both natural and man-induced) that cause ground movement.
- Limit the impact of future ground movement through the adoption of appropriate planning and building controls.

The implementation of a strategy requires careful co-ordination, bearing in mind that it would influence the attitudes and behaviour of the whole community: the Planning Authority, developers, financiers, insurers, property agents, local builders, the service industries and not least the general public.

A recommendation of the strategy report was that a computerised geographical information system or databank should be established for the Undercliff to allow the efficient storage, retrieval and presentation of landslide data and associated information. It was emphasised that some data was available already from the previous pilot study of central Ventnor commissioned by the Department of the Environment, and although an interactive computerised system had not been developed for that purpose, such a facility could provide easy access to existing data for a variety of users, make provision for the addition of new data, allow for the revisions of ground behaviour and planning guidance maps as more information became available and assist in the analysis and integration of data with landownership and service industry information. As a result of this recommendation, a geographical information system was established in 1994 and has been maintained by the Council, proving to be of particular value since that date.

A further recommendation of the Landslide Management Strategy was the need for effective monitoring in the long term. Three distinctive applications for monitoring were recognised:

1. Field-based monitoring to assess ground movements, water levels and weather events.
2. Monitoring of damage to infrastructure.
3. Monitoring the effectiveness of the Undercliff Landslide Management Strategy.

A further monitoring aspect was the need to assess the value of the Undercliff Management Strategy concentrating on:

1. Planning and building control procedures.
2. Public and professional awareness.
3. The financial implications of landslide management.
4. The future benefits to the community in terms of the improved availability of insurance.

As a result of these recommendations, the **Ventnor Undercliff Landslide Management Committee** was established in 1994 comprising professionals involved with engineering, building, planning and related matters in the Undercliff and was established to ensure the landslide management strategy was successfully implemented and monitored, and so to develop a co-ordinated approach to works and planning in the area. The Committee comprises representatives from the Isle of Wight Council, local estate agents, the Building Employers Confederation, the Association of British Insurers, representatives of service industries (gas, water, electric and Telecom) and the Council's consultants as observers.

6.2 Further Investigations

Following the 1991 DoE pilot study of Ventnor, a further series of studies were commissioned by the former South Wight Borough Council and then the Isle of Wight Council in order that the whole of the Isle of Wight Undercliff could be mapped on a scale of 1 : 25,000 in terms of geomorphology, ground behaviour and planning guidance. All this information has now been incorporated within the geographical information system. In 1995 the former South Wight Borough Council published a new report on the Undercliff providing a position statement at that time. The report entitled "The Undercliff of the Isle of Wight - A Review of Ground Behaviour" still provides a valuable source of reference for all those interested in development and instability issues in the area. In addition, the report describes how the Council has, over the intervening period, taken up many of the recommendations that were proposed by the Department of the Environment in their original report.

6.3 Coastal Defence

The Isle of Wight Council has invested heavily in protecting and strengthening coastal defences along the Undercliff, over the last ten years. Approximately £12m has been spent on this function, bearing in mind that coastal erosion is a key factor in terms of promoting ground instability. Coastal protection has ben undertaken with the assistance of grant aid from the Ministry of Agriculture, Fisheries and Food under the Coast Protection Act 1949. The Isle of Wight Council as Coast Protection Authority and Operating Authority for the Isle of Wight has promoted these schemes which must be technically and environmentally sound and show a positive benefit cost.

In 1995 the Isle of Wight Council commissioned a Shoreline Management Plan (Coastal Defence Strategy) for the entire coastline of the Island to provide a framework for the development of sustainable coastal defence policies. The plan detailed the physical conditions and coastal defence policy for each sub-section (management unit) of the Isle of Wight coast and considered each management unit in terms of the appropriateness of a range of strategic coastal defence policy options. The policy for the developed parts of the Undercliff was to "hold the line" with coastal defences being provided, maintained or strengthened. Undeveloped parts of the Undercliff coast where there is no economic justification for undertaking works and where the environmental quality of the coastline is particularly high have not been subject to coast protection.

7. EXPERIENCES, SUCCESSES AND PROBLEMS WITH CURRENT APPROACH

Throughout much of the developed Undercliff long term movement rates have been less than 5mm a year and many areas have remained inactive over the last 100 years. Periods of instability have been related to heavy rainfall and coastal erosion. By developing a rainfall and ground movement monitoring programme as part of an overall Landslide Management Strategy, a systematic approach has been adopted towards the reduction of landslide hazard. This strategy has involved:

1. Modifying the hazard to the community by means of engineering works, coastal protection, improved building practice.
2. Effective planning control to avoid development in unsuitable areas and to control the nature of new development.
3. Seeking to improve understanding of landslide behaviour.
4. Mitigating the cost of ground movement through insurance and other means.
5. Co-ordinating the community response to the problems.

The development and implementation of the Landslide Management Strategy has involved education, physical works (eg. coast protection and drainage) and monitoring, together with improved planning and building procedures, which have all assisted in raising confidence in Ventnor from an insurance and financial development point of view. The use of sophisticated monitoring equipment for ground movement and rainfall recording will, in time, assist in improving prediction of ground movement events and enable changes to be monitored more accurately.

A positive reproach to co-ordinating the community's response to the landslide problems was considered essential. Indeed, to effectively reduce the impact of ground movements in urban areas, planners, developers, builders, service industries, estate agents, solicitors, insurers and property owners must liaise and recognise the need for all parties to be involved.

The co-ordinated Landslide Management Strategy that has been developed and implemented for the Undercliff is helping to minimise the risk to the communities through:

1. Guiding development away from unsuitable locations.
2. Ensuring that existing and future developments are not exposed to unacceptable risks.
3. Ensuring that public safety considerations are addressed in potentially vulnerable areas.
4. Ensuring that development does not increase the risk to the community.

The Isle of Wight Council has recognised that it is important for public and financial institutions to be fully aware of the nature of ground conditions in this area. Existing properties in unstable areas will probably continue to experience damage due to ground movements; such areas are being avoided in terms of future development. More stable areas are likely to remain free from significant building damage and may be successfully developed as long as necessary measures are adopted and that the developer is willing to accept in some locations a high level of risk than would be expected in other circumstances.

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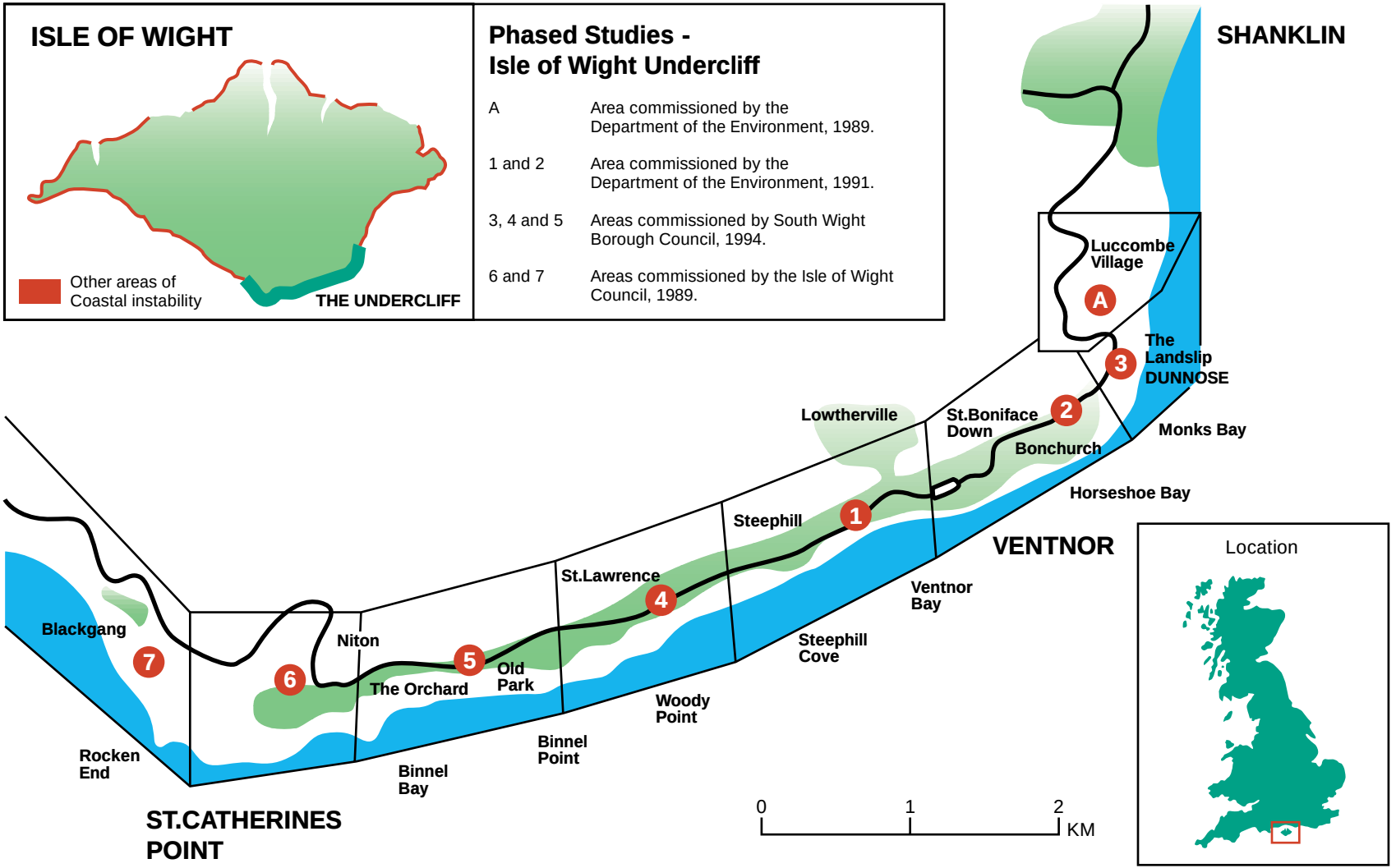
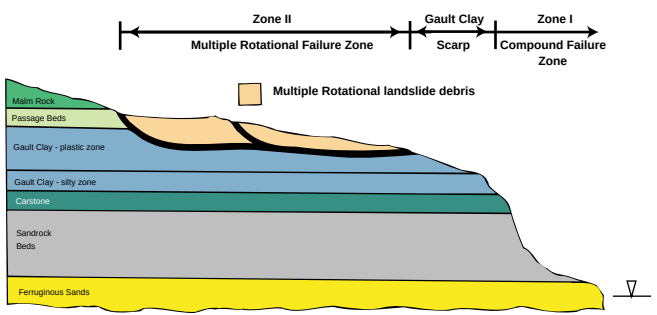
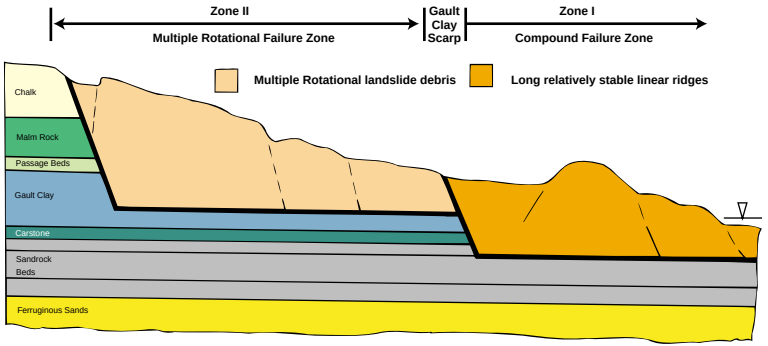


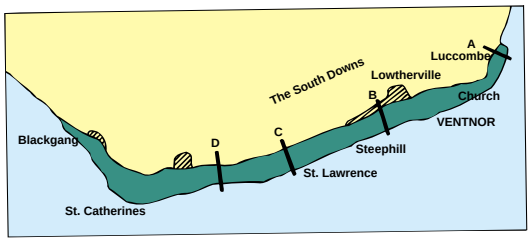
Figure G1.1 Phased studies of the Undercliff.

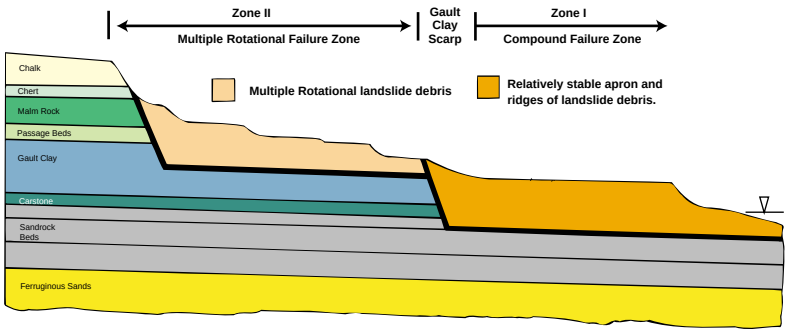


MODEL A: Luccombe

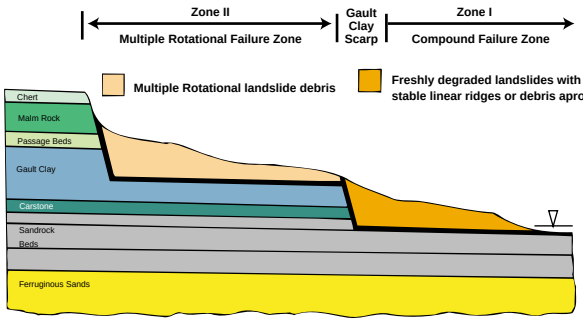


MODEL B: Ventnor





MODEL C: St. Lawrence and Woody Bay



MODEL D: The Mirables

0 100
metres

Note: Gault Clay Scarp obscured by debris in Models B-D; shearing may occur at multiple levels within the Gault Clay

Figure G1.2 Landslide models for the Ventnor Undercliff.

Plate G1a ***Aerial view of the town of Ventnor***