COASTAL LANDSLIP POTENTIAL ASSESSMENT:

Isle of Wight Undercliff, Ventnor.

REPORT ON THE STUDY OF LANDSLIDING IN AND AROUND LUCCOMBE VILLAGE

by

THE DEPARTMENT OF THE ENVIRONMENT,

March 1989

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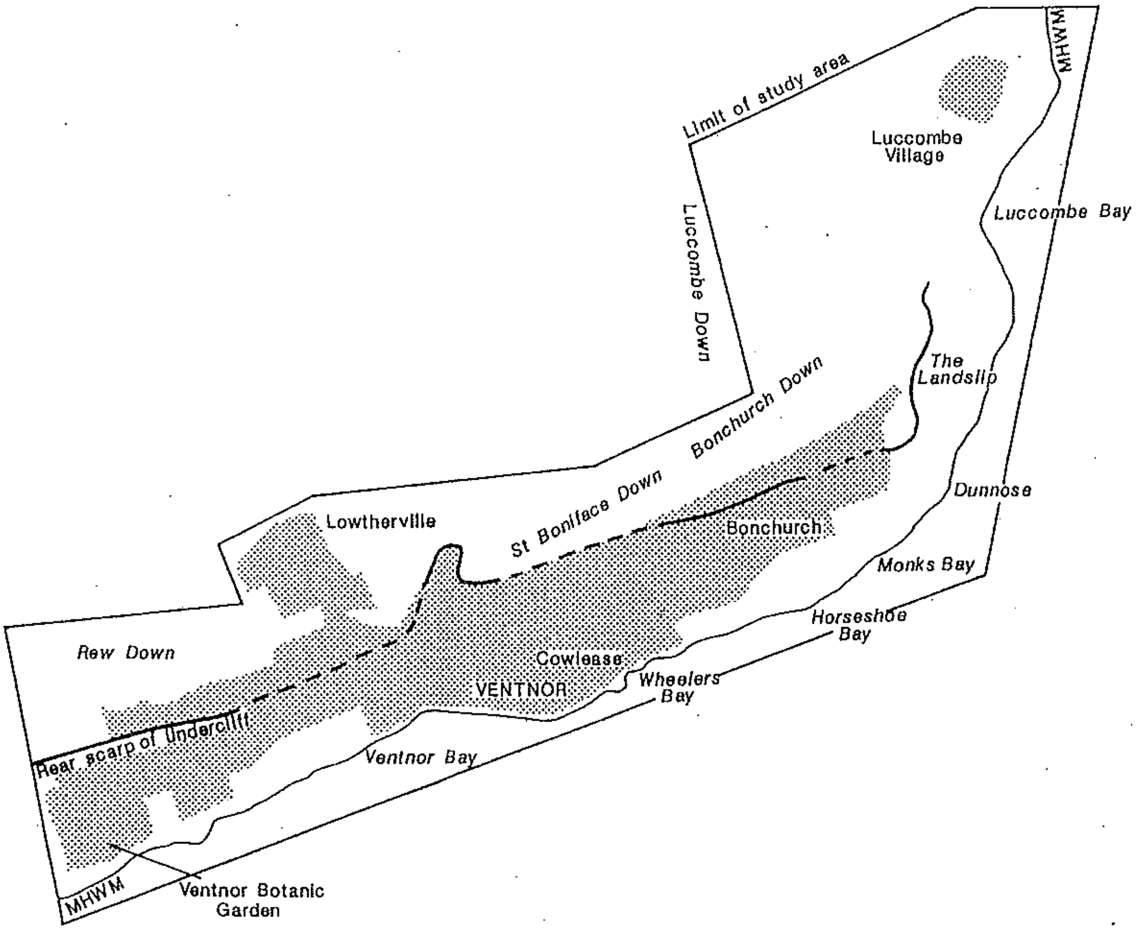

REPORT ON THE STUDY OF LANDSLIDING IN AND AROUND LUCCOMBE VILLAGE

by

GEOMORPHOLOGICAL SERVICES Ltd,

for the DEPARTMENT OF THE ENVIRONMENT,

Research Contract PECD 7/1/272

March 1989.

COASTAL LANDSLIP POTENTIAL ASSESSMENT

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DRAFT REPORT ON THE STUDY OF LANDSLIDING IN AND AROUND LUCCOMBE VILLAGE

DISCLAIMER

GEOMORPHOLOGICAL SERVICES LIMITED cannot be held responsible for any consequence of actions or decisions taken on the basis of interpretation, inferences, extrapolations, comments, statements or recommendations contained within this report.

EXECUTIVE SUMMARY

In 1987/1988 landslide movements occurred seaward of Luccombe Villageand affected a number of properties. These movements were not an isolated event in the area. Geomorphological mapping and analysis of historical documents, including newspapers and postcards indicates that the village is built on an ancient landslide system and that there have been intermittent movements several times this century. Between 1950 and the present day there have been three major phases of land-sliding within the village in 1950/1951, 1961 and 1987/1988. During this time the landslide movements have taken the form of periodic reactivations and upslope extension of earlier failures, and have thereby been progressively affecting a larger area of the village. In addition to the obvious landslide damage there has been gradual subsidence which has affected all the properties within the village.

The present study has identified a continuing potential for landslide activity in and around Luccombe Village, involving:

(i) seasonal movements below the coastal path;

(ii) periodic movement along the rear scarp feature at the head of the landslide. Such movements are likely to occur particularly after a prolonged period of heavy rain;

(iii) slow gradual subsidence upslope of the immediate landslide area.

The future risks associated with further movements range from likely building damage to the possiblity of personal injury.

In the past there has been an ad-hoc response to specific landslide events, primarily related to repairing building damage or condemning properties rather than preventing further movements. However, the nature and scale of the recent movements, accompanied by the continuing potential for further movement indicates that there is a clear need to identify:

(a) the most appropriate strategy to reduce the problems;

(b) to identify who may be responsible for financing and undertaking any future operations.

This report outlines a number of strategies which could be adopted, including:

(i) landslide monitoring and forecasting;
(ii) planning controls;
(iii) engineering measures;
(iv) acceptance of risk.

From our assessment of the site we consider that the following courses of action are necessary to reduce the risk to the local residents and to establish the viability of stabilisation measures:

(a) the development of an efficient monitoring and early warning system whereby rapid on-site assessment of the initial stages of slope failure can be used to predict major movements and instigate preventative measures, thereby reducing the risk of personal injury and damage to property;

(b) the implementation of a detailed site investigation to determine the causes and mechanisms of the recent movements together with their relationships with the ancient landslide systems and coastal retreat as a basis for defining engineering measures;

(c) a detailed assessment of the financial implications of continued movements should be made, taking into account building damage, insurance, on-going maintenance costs etc.

The results of these investigations would provide clearer information as to whether there could be a cost-effective solution to the problems at Luccombe Village. However, it must be emphasised that full stabilisation of the village may prove to be not financially viable.

THE STUDY OF LANDSLIDING IN AND AROUND LUCCOMBE VILLAGE

CONTRIBUTORS TO THIS VOLUME

AUTHORS:

Mr E M Lee	Geomorphological Services Ltd
Dr R Moore	

With contributions from:

Prof J N Hutchinson	Dept of Civil Eng., Imperial College London
Dr J S Griffiths	Geomorphological Services Ltd
Dr R E Mathews	
Mr S Guest	Rendel Geotechnics Ltd
Mr N Noton	Noton and Associates

Report Production:

Mrs J Mynard	Geomorphological Services Ltd

Cartography

Mr J Taylor	Open University
Mr A Lloyd	

This project was directed by Dr J C Doornkamp and managed by Dr J S Grifiths

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ANNEX A	Photographic record of historical and recent landslide movements within Luccombe Coombe
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CHAPTER 1
INTRODUCTION

1.1 THE BRIEF

This report is a product of the research carried out for the Department of the Environment under research contract PECD 7/1/272 entitled "Coastal Landslip Potential Assessment: Isle of Wight Undercliff, Ventnor". As part of this research a separate investigation has been undertaken with the specific objective of reporting on the landsliding in and around Luccombe Village (Task 13, see section 1.6).

1.2 BACKGROUND

The Department of the Environment (DoE) carried out geological and related research as part of its Planning Research Programme, which included studies of ground instability. Landslide research commissiond 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 Sir William Halcrow and Partners were commissioned to carry out a DoE/Welsh Office contract for the study of landslip potential of an area in the Rhondda Valley (Sir William Halcrow & Partners, 1986). However, it is likely that the methods developed cannot be simply transferred to other geological settings or geomorphological circumstances. Therefore, the DoE have 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 landsliding. As a consequence of the potential problems to dwellings and services the Ventnor area was selected as a suitable location for a study of coastal landslip potential.

The results of this study are intended to provide landslide potential and risk assessment techniques which are more generally applicable, but also a valuable basis for planning and development decisions in the study area.

1.3 THE AIMS

The aims of this study of Coastal Landslip Potential are:

a) to 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;

b) to provide the essential information needed for planning development decisions in the Ventnor area in a form which can be easily understood by individuals who have little or no training in geology and geotechnics.

1.4 THE OBJECTIVES

The objectives of this study are:

a) to review and extend the existing database on landslippage in the Ventnor area by use of existing results and documents;

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

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

d) to interpret the data in terms of landslip potential;

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

1.5 THE STUDY AREA

The area covered by this study is defined by Figure 1.1, and comprises two areas:

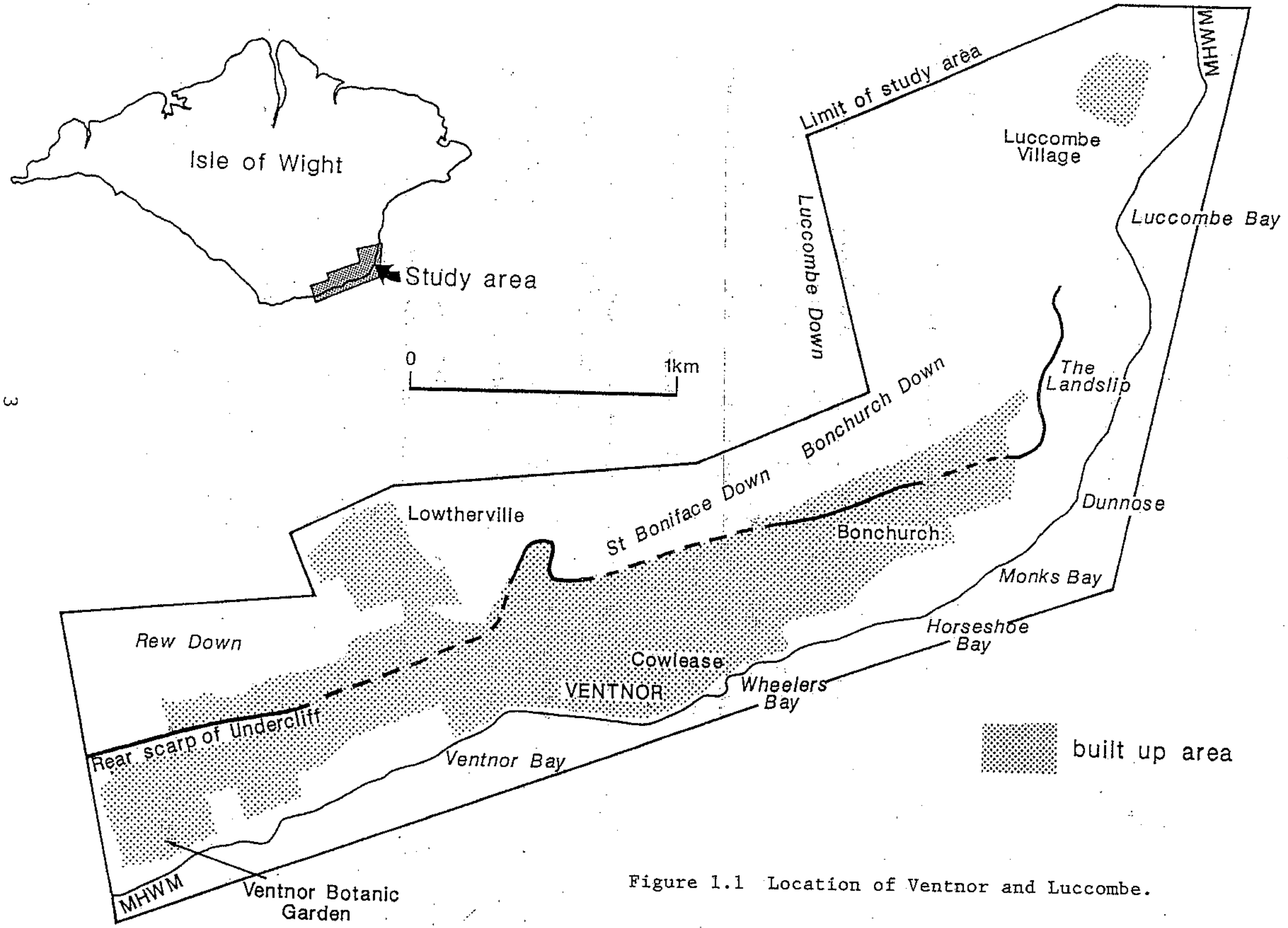


Figure 1.1 Location of Ventnor and Luccombe.

(i) **Ventnor;** the Undercliff from Ventnor Botanic Gardens in the west, to the western edge of "The Landslip" at East End;

(ii) **Luccombe;** the coombe around the village of Luccombe.

This report is restricted to the investigation of landsliding in and around Luccombe Village (Figures 1.2 and 1.3).

1.6 THE SCOPE OF WORK

The work undertaken during this study of coastal landslip potential has involved the completion of the following tasks:

- compile and review the existing database (Task 1)
- carry out geomorphological mapping (Task 2)
- determine past ground movements from air photographs (Task 3)
- carry out land use mapping and building damage surveys (Task 4)
- develop an explanatory model of landsliding (Task 5)
- prepare a landslip potential map (Task 6)
- identify and make recommendations on necessary additional work (Task 7)
- assess the efficiency of remedial techniques and the vulnerability of structures and services (Task 8)
- prepare a landslip risk map (Task 9)
- devise a general model of landsliding (Task 10)
- prepare a set of visual aids for use in dissemination (Task 11)
- prepare working and final reports and maps (Task 12)
- carry out a study of landsliding in and around the village of Luccombe (Task 13)

This report presents the results of the investigation of landsliding in and around the village of Luccombe (Task 13).

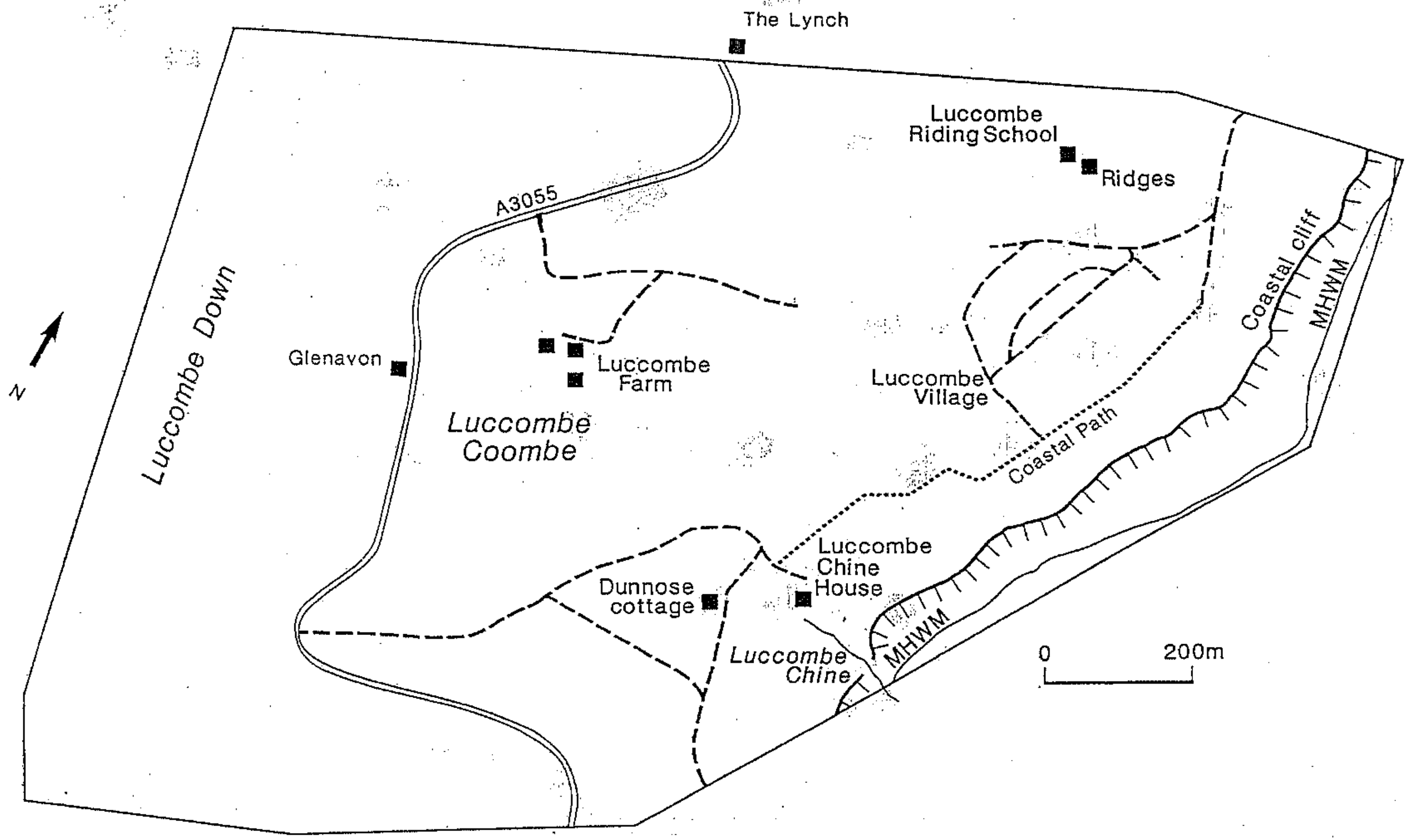
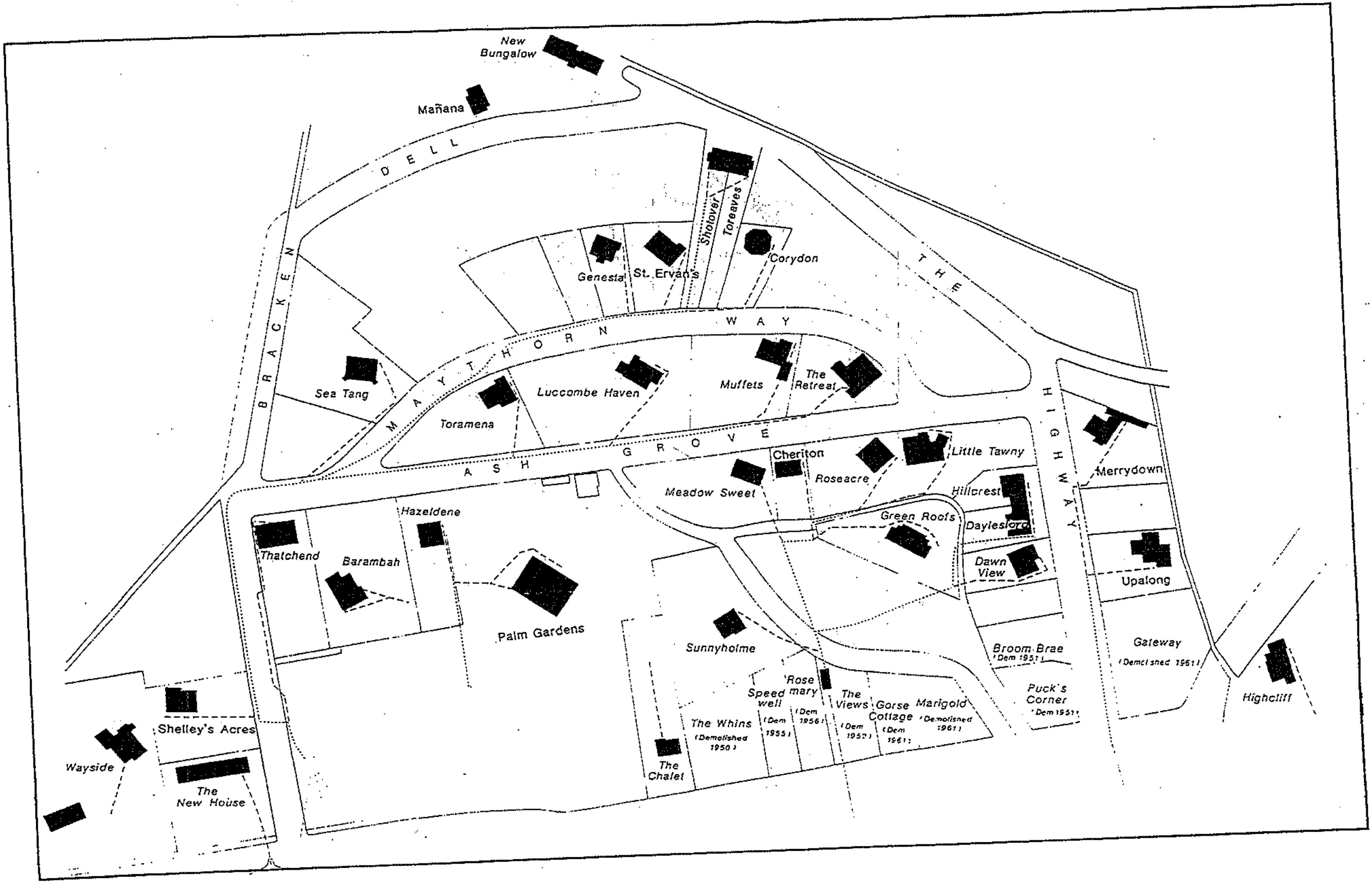


Figure 1.2 Location of Luccombe Coombe.



1.2 Luccombe Village.

1.7 THE METHODS

The work undertaken for this investigation (Task 13) was carried out between November 1988 and January 1989, and is based on:

(i) a desk study of existing data;
(ii) examination and interpretation of air photo cover;
(iii) comprehensive geomorphological mapping of the coombe;
(iv) an assessment of building damage;
(v) interpretation of the information and observations in terms of landslide mechanisms and risk.

1.7.1 The desk study

A review of relevant information contained in extant published sources has been carried out, enabling the study area to be placed in a regional geological and geomorphological context. In addition, the following specific material was collected and compiled as important background information:

(i) oblique aerial photography of Luccombe Village and the sea-cliffs between Luccombe Chine and Shanklin, over a period of approximately 60 years;

(ii) post cards of Luccombe Coombe and the sea-cliffs, over a period of approximately 90 years;

(iii) photographic records of damage caused by previous landslide events in and around Luccombe Village;

(iv) records of previous landslide events reported in local newspapers. A search of local newspapers (especially the Ventnor Mercury and the Isle of Wight Observer), from 1850 to present-day, was carried out at the British Library Newspaper Library, Colindale;

(v) 25 inch to 1 mile and 1:2,500 scale Ordnance Survey maps of the study area, published in 1862, 1939 and 1977. These maps were compared with the most recent 1:2,500 scale topographic maps produced by Huntings Surveys Ltd for N.E.R.C. in 1980, to determine an average rate of cliff retreat over the last 100 years;

(vi) relevant minutes of meetings held by the Sandown/Shanklin Urban District Council (Works Committee, 1949-1961) and South Wight Borough Council (Environmental Health and Control Committee, 1988);

(vii) reports of previous ground investigations in and around Luccombe Village, most notably Gower Pimm Structural Soils Ltd (1973) at New Bungalow and the work carried out by Malcolm Woodruff in relation to the 1988 slippage (Woodruff, 1988a, b, c);

(viii) groundwater and water supply records provided by the Southern Water Authority Divisional Office, Newport;

(ix) rainfall data for Shanklin and the Undercliff, supplied by the Meteorological Office.

1.7.2 Air photograph interpretation

A geomorphological interpretation was made of the following stereo, vertical black and white aerial photography:

(i) Flight OS/68/026 flown by the Ordnance Survey at approximately 1:7,000 scale on 8/4/68 (Photo Nos. 556-568);

(ii) Flight HSL/UK/80/7 flown by Huntings Surveys Ltd on 3/3/80 (c. 1:10,000 scale, Photo Nos. 8008-8014);

(iii) Flight 87/42 flown by Aerofilms on 11/6/87 (c. 1:3,000 scale, Photo Nos. 3246-3249);

(iv) Flight RC8-DS from the Cambridge University Collection (c. 1:4,000 scale Photo Nos. 128-131).

This interpretation was essentially a two-stage process, comprising:

(a) identification of morphological units, by dividing the ground into segments bounded by abrupt breaks of slope or more gentle changes of slope angle, known as inflections. This was carried out by the stereoscopic study of pairs of aerial photographs. Transparent overlays were annotated using the standard symbols presented in Cooke and Doornkamp (1974);

(b) a geomorphological interpretation was made regarding the units identified and the processes likely to have created them. This interpretation was subsequently expanded and clarified by field verification (see 1.5.3 below), concentrating on the extent of evidence for slope instability.

1.7.3 Geomorphological mapping

The initial stage of this mapping exercise involved the production of a morphological map using a tape and compass; slope angles were measured with a Suunto clinometer. This morphological map formed the basis for the subsequent geomorphological interpretation which involved the identification of landforms, earth surface processes and materials present within the area. Further details of the technique are presented in Cooke and Doornkamp (1974), Geological Society Working Party (1982) and Griffiths and Marsh (1983).

The results of the geomorphological interpretation have been presented on two separate maps:

(i) a 1:5,000 scale summary map of Luccombe Coombe, derived from air-photograph interpretation and field verification (Figure 4.1);

(ii) a 1:2,500 scale geomorphological map of the area in the immediate vicinity of Luccombe Village, indicating the relative position and extent of landslide units, derived from a detailed mapping programme which included the measurement of joint orientations along the sea-cliffs (Figure 4.2)

1.7.4 Assessment of building damage

A general assessment of the nature and extent of visible building damage within Luccombe Village was carried out by N

H Noton and Associates. The incidence and extent of cracking and tilt was assessed only in general terms, and precise measurements were not made. Nevertheless, given the nature of the movement, the evaluation is considered to be representative of conditions on site. A photographic record was made of the observed damage.

1.7.5 Landslide mechanisms and risk

The assessment of landslide mechanisms and risk to property within Luccombe Coombe are only preliminary observations based solely on geomorphological evidence, supplemented by background information and eye-witness accounts.

1.8 CONTENTS OF THIS REPORT

This report comprises a written report (this volume) and a series of Annexes containing supporting information. The written volume consists of two main elements:

(i) Part I, comprising a general review of the geology, hydrogeology, geomorphology and history of landsliding within Luccombe Coombe and the coastal cliffs. A preliminary explanation model of the landsliding processes within the study area is presented, and the key controlled influences identified (Chapters 2-5);

(ii) Part II, comprising a detailed presentation of the nature and causes of the 1987-1988 landslide movements within Luccombe Village (Chapter 6), and a discussion of the landslip potential within Luccombe Village, together with possible future landslide management strategies (Chapter 7).

The Annexes contain:

(i) a photographic record of historical and recent landslide movements within Luccombe Coombe (Annex A);

(ii) a photographic record of building damage within Luccombe Village (Annex B);

(iii) details of previous landslide events within Luccombe Coombe (Annex C);

(iv) detailed meteorological data for Shanklin Big Meade and St Catherine's Point (Annex D);

(v) borehole logs for the site investigation caried out within Luccombe Village by Malcolm Woodruff in 1988 (Annex E).

These can be consulted at:

(a) Dep. of the Environment
2 Marsham Street
London
SW1

(b) Borough Surveyor's Dep.
South Wight Borough Council
Salisbury Gardens
Ventnor
Isle of Wight
PO38 1EJ

CHAPTER 2
GEOLOGY

2.1 STRATIGRAPHY

The area around Luccombe Village lies on the eastern margin of the Southern Downs outlier and is developed in Lower and Upper Cretaceous sedimentary rocks (Figure 2.1). The Lower Greensand units are well exposed along the coastal cliffs between Luccombe Chine and Shanklin Chine, with the top of Knock Cliff east of Luccombe Village formed in the lower units of the Gault Clay (Figure 2.2). The only inland exposures are at the following sites:

(i) the Upper Greensand Chert Beds are exposed in the road cutting by "The Lynch" on the A3055 (Figure 1.2), and also on a small spur c.200m SW of Luccombe Farm Cottage;

(ii) the Lower Chalk is visible in the disused quarries by "Glenavon" on the A3055 (Figure 1.2).

There are no inland exposures of the _in situ_ Gault Clay within the study area.

Details of each of the Cretaceous formations which crop out within the area are outlined in the following sections 2.1.1 - 2.1.6 and also shown in Table 2.1 and Figure 2.3.

2.1.1 The Ferruginous Sands

The lower portion of the cliffs between Knock Cliff and Shanklin Chine are developed in the uppermost part of the Ferruginous Sands. White (1921) described the following sequence of beds (Figure 2.4):

(i) a persistent band of ironsand (the _Exogyra_ Beds) which has been eroded to form the shore platform of Horse Ledge; passing up into:

(ii) a 6m thick bed of argillaceous and pyritous greensand containing fossiliferous concretionary ironstone. This bed rises above sea level at Yellow Ledge;

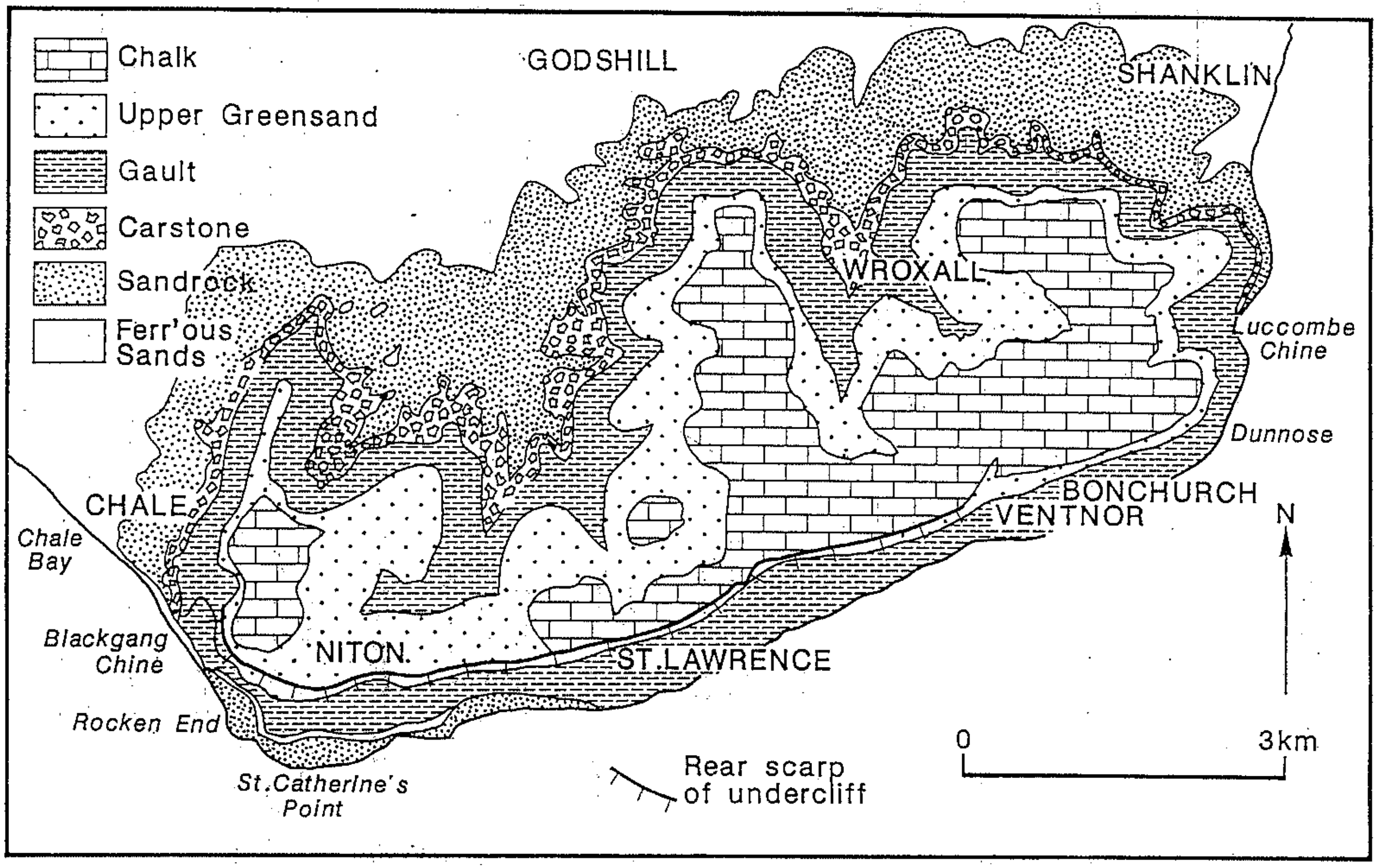


Figure 2.1 Regional geology (after Hutchinson, 1987a).

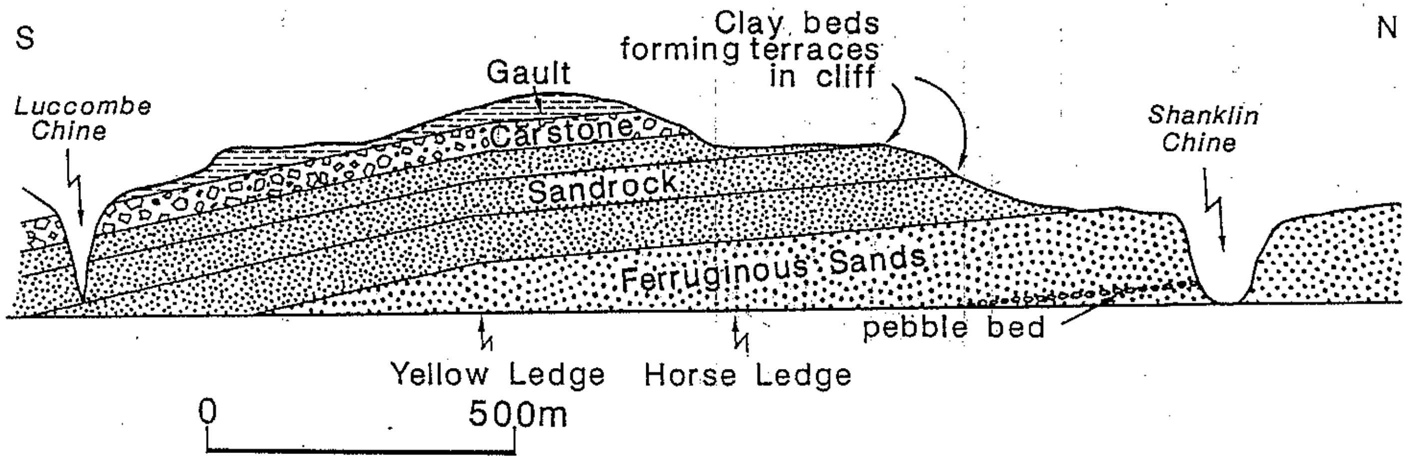
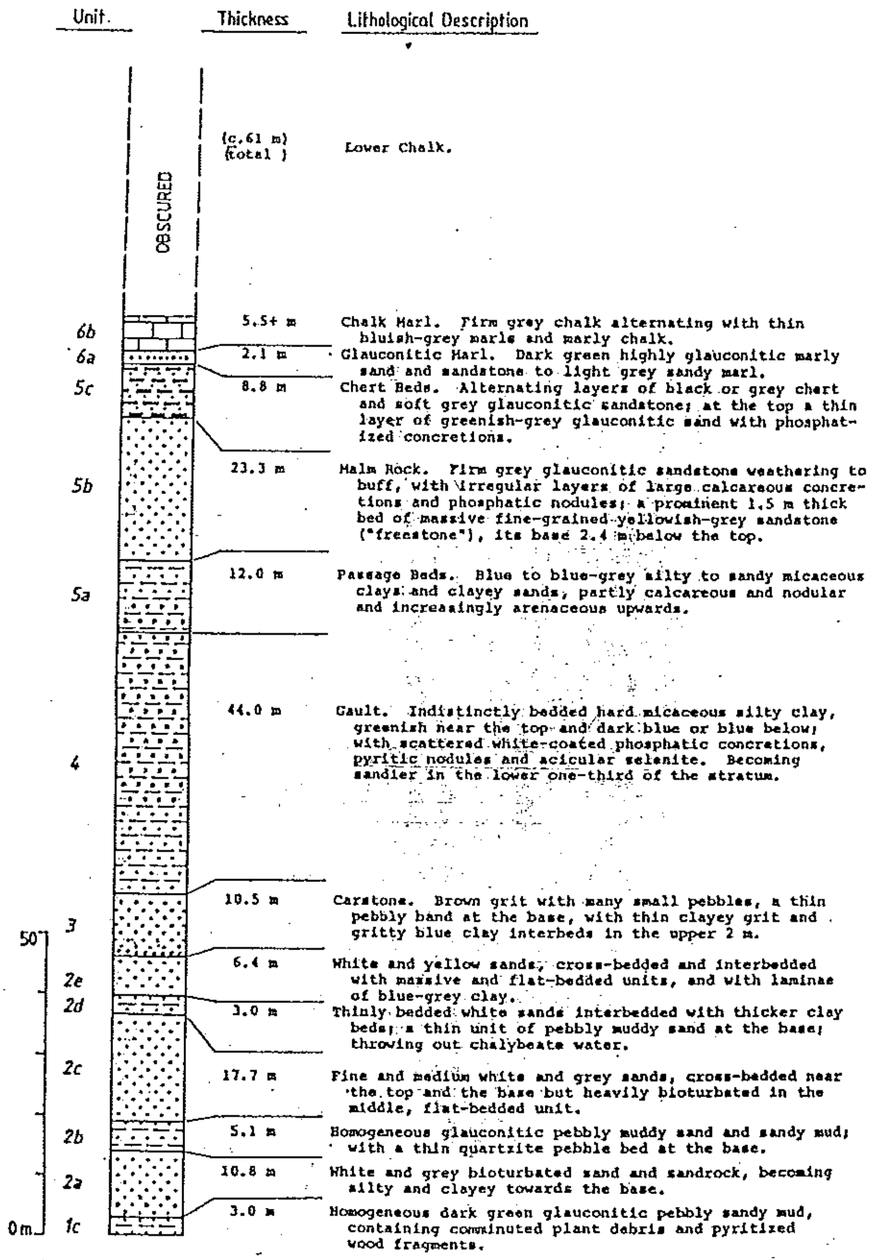


Figure 2.2 Geological section of Knock Cliff (after Daley and Insole, 1984).

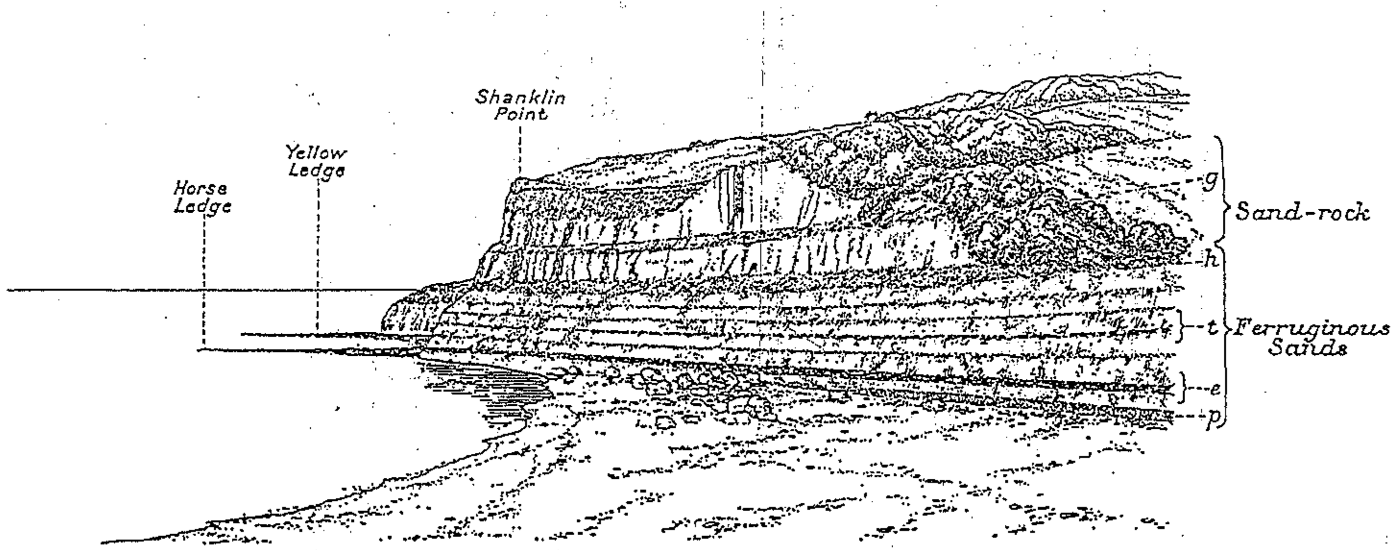
CENOMANIAN	CHALK	CHALK MARL	5.5 m of firm grey chalk alternating with thin bluish grey marls and marly chalk.
		GLAUCONITIC MARL	2.1 m of dark green highly glauconitic marly sand and sandstone to light grey sandy marl.
UPPER ALBIAN	UPPER GREENSAND	CHERT BEDS	8.8 m of alternating layers of black/grey chert and soft grey glauconitic sandstone.
		MALM ROCK	23.3 m of firm grey glauconitic sandstone weathering to buff, with irregular layers of calcareous concretions and phosphatic nodules.
		PASSAGE BEDS	12 m of blue-grey silty to sandy micaceous clays and clayey sands.
	GAULT CLAY		44 m of blue-grey overconsolidated silty clay. Lower 15-18 m are more silty and less plastic than layers above.
LOWER ALBIAN	LOWER GREENSAND	CARSTONE	10 m sequence comprising basal pebble bed passing up into brown grits, sandy clays and brown ferruginous rock.
UPPER APTIAN		SANDROCK	44 m; alternating sequence of 3 pale sandstone units and 2 bands of dark clay, the latter forming the sea cliff ledges.
LOWER APTIAN		FERRUGINOUS SANDS	Brown, green and yellow sands with some coarse pebble horizons. Top of unit is marked by a conspicuous unit of grey sandy clay.

Table 2.1 Stratigraphy of the Cretaceous rocks of the southern Isle of Wight.



Unit.	Thickness	Lithological Description
	(c.61 m) (total)	Lower Chalk.
6b	5.5+ m	Chalk Marl. Firm grey chalk alternating with thin bluish-grey marls and marly chalk.
6a	2.1 m	Glauconitic Marl. Dark green highly glauconitic marly sand and sandstone to light grey sandy marl.
5c	8.8 m	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.
5b	23.3 m	Malm Rock. Firm grey glauconitic sandstone weathering to buff, with irregular layers of large calcareous concretions and phosphatic nodules; a prominent 1.5 m thick bed of massive fine-grained yellowish-grey sandstone ("freestone"), its base 2.4 m below the top.
5a	12.0 m	Passage Beds. Blue to blue-grey silty to sandy micaceous clays and clayey sands, partly calcareous and nodular and increasingly arenaceous upwards.
4	44.0 m	Gault. Indistinctly bedded hard micaceous silty clay, greenish near the top and dark blue or blue below; with scattered white-coated phosphatic concretions, pyritic nodules and acicular selenite. Becoming sandier in the lower one-third of the stratum.
3	10.5 m	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 2 m.
2e	6.4 m	White and yellow sands, cross-bedded and interbedded with massive and flat-bedded units, and with laminae of blue-grey clay.
2d	3.0 m	Thinly bedded white sands interbedded with thicker clay beds; a thin unit of pebbly muddy sand at the base; throwing out chalybeate water.
2c	17.7 m	Fine and medium white and grey sands, cross-bedded near the top and the base but heavily bioturbated in the middle, flat-bedded unit.
2b	5.1 m	Homogeneous glauconitic pebbly muddy sand and sandy mud; with a thin quartzite pebble bed at the base.
2a	10.8 m	White and grey bioturbated sand and sandrock, becoming silty and clayey towards the base.
1c	3.0 m	Homogeneous dark green glauconitic pebbly sandy mud, containing comminuted plant debris and pyritized wood fragments.

Figure 2.3 Composite section at Luccombe (after Chandler, 1984).



g. Dark clayey grit (brick-clay of Gatten). *h*. Dark sandy clay (brick-clay of Lower Hide). *t*. Bed with concretions containing moulds of *Trigonia*, *Thetironia*, &c. *e*. Bands of *Exogyra sinuata*. *p*. Pebble-beds.

Figure 2.4 Section in Knock Cliff, Shanklin (after White, 1921).

(iii) 6m of greyish greensand;

(iv) 2.5m of grey sandy clay which rises above sea level around 350m south of Yellow Ledge. The outcrop of this unit is marked by a distinct ledge in the cliff.

2.1.2 Sandrock

The sea cliffs between Knock Cliff and Luccombe Chine are composed almost entirely of the Sandrock. This series comprises (after White, 1921):

(i) 6.3m of white and ashy grey sand and sandrock, passing up into;
(ii) 2.5m of very green clayey grit;
(iii) 15.9m of white and grey sand;
(iv) 11.1m of bright yellow and white sand with laminae of blue clay in planes of current bedding.

This sequence for Knock Cliff suggests that the total thickness of the Sandrock is 35.8m, which contrasts with the more recent estimate by Chandler (1984) who indicates that the unit is approximately 43m thick in the vicinity of Luccombe and Dunnose (Figure 2.3). The latter value has been adopted by this study.

Daley and Insole (1984) summarised this sequence as consisting of three thick units of pale sandstone (units 2a, 2c, 2e; Figure 2.3) separated by bands of dark clay (units 2b and 2d), the latter forming the cliff ledges (Figure 2.2). The lower sandstone bed contains considerable quantities of shipworm-bored fossil wood, mainly of coniferous type.

Matthews (1977) provides geotechnical data for beds 2c and 2e at Luccombe Chine, which indicate that the materials are uniformly graded fine sands (effective size $D_{10}^{*} = 0.04 - 0.16$mm) with porosities between 25-36%.

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* D_{10} - diameter at which 10% of the material is finer.

The drained shear strength* of undisturbed samples of bed 2a tested in a shear box by Matthews (1977) was found to be:

(a) dry : $c' = 7kN/m^2$ $\phi' = 48^o$;

(b) saturated: $c' = 10kN/m^2$ $\phi' = 42^o$.

2.1.3 Carstone

The unconformable junction of the Carstone and the underlying Sandrock is uneven, suggesting an erosive contact between the two units. Between Luccombe Chine and Knock Cliff the Carstone is obscured by vegetation and is inaccessible. However, White (1921) describes the Carstone section in Monk's Bay, Bonchurch:

GAULT		
	- blue micaceous clay with lines of grit	1m
	- brown ferruginous rock with derived phosphatic concretions containing oolitic grains of iron oxide	0.3m
CARSTONE		
	- sandy and gritty blue clay, passing down	0.3m
	- clayey brown grit and nodules as above	1m
	- brown grit	2m
	- brown grit with many small pebbles	6m
	- pebbly band with quartzites up to half an inch in length	0.07-0.15m
SANDROCK		

No geotechnical data is available for the Carstone in this area.

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* Shear strength - the resistance to deformation provided by the chemical and physical forces of interaction in addition to the gravitational force associated with the weight of the soil mass. Defined by the following equation in terms of effective stress:

$$t' = c' + \sigma' \tan \phi'$$

where t' is the shear strength, c' is the cohesion, σ' is the normal stress and ϕ' is the friction angle.

2.1.4 Gault Clay

This unit is a dark blue-grey overconsolidated silty clay, around 44m in thickness. The lowest beds are exposed at the top of the cliffs between Luccombe Chine and Knock Cliff (Figure 2.2). Geotechnical data (Table 2.2) from Blackgang (Chandler, 1984) and Dunnose (Mathews, 1977; Street, 1981; Chandler, 1984) indicate that the Gault Clay can be sub-divided into two main zones:

(a) a lower, less plastic, silty (Clay Fraction (CF) = 35%) layer from the base of the stratum to c.15-18m height corresponding to a series of twelve thin beds, mainly of micaceous silty clays (Owen, 1971). Residual shear strength values recorded by Matthews (1977) and Chandler (1984) range from 18°-27.3° (Table 2.2);

(b) an upper, plastic, layer (LL* = 65%) with a Clay Fraction (CF) = 50-60%, comprising two beds of clay (Owen, 1971). Residual shear strength values of 8.9°-14.5° were recorded by Street (1981) in this unit (Table 2.2).

2.1.5 Upper Greensand

This formation is commonly sub-divided into three main units:

(i) the Passage Beds, comprising around 12m of blue-grey silty to sandy micaceous clays and clayey sands, partly calcareous and nodular, becoming increasingly arenaceous upwards, passing up into;

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

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* LL = liquid limit; the moisture content at which soil starts acting as a liquid.
PL = plastic limit; the moisture content at which soil begins to exhibit plastic deformation.
PI = plasticity index; the range of moisture context in which a soil exhibits plastic deformation: PI% = LL-PL

(iii) the Chert Beds, 8.8m of alternating layers of black or grey chert and soft grey glauconitic sandstone.

No geotechnical data is available for undisturbed Upper Greensand units, although in 1973 Structural Soils Ltd carried out an investigation at New Bungalow, Luccombe Village, on what is likely to be an old landslide bench. This investigation involved two shell and auger boreholes to a depth of 7.6m, standard penetration tests and the collection of undisturbed samples for laboratory analysis. An undrained triaxial compression test gave values of $\phi = 23.5^{\circ}$, $c = 34$ kN/m^2 (see section 4.2.4.2).

2.1.6 Lower Chalk

The slopes of Luccombe Down, above the A3055, are developed in the Lower Chalk, comprising:

(i) Glauconitic Marl, 2.1m of dark green highly glauconitic marly sand and sandstone to light grey sandy marl, passing up into;

(ii) Chalk Marl, 5.5m of firm grey chalk alternating with thin bluish-grey marls and marly chalk;

(iii) Grey Chalk;

(iv) A. plenus Marls.

2.2 STRUCTURE

The gross geological structure of the area is quite simple, with the Lower Cretaceous beds dipping gently to the south at 1-2°. Studies made by Hutchinson (1965) and Chandler (1984) have suggested that the area may lie on the eastern limb of a shallow syncline, the Ventnor Syncline, whose axes plunges gently to the SSE.

In this study measurements of joint orientation and dip were taken at various sites along the cliff section between Luccombe Chine and Shanklin Chine. Data were collected principally from the Sandrock, where powerful joints are frequently defined by a coating of brown iron oxide. It was observed that the dip of some of the powerful joints is highly variable, ranging between 60° and vertical, and in some cases high angle structures appear to root into shallow

Residual shear strength data for Gault at Blackgang

Height in stratum (m)	LL (%)	c'_r (kN/m^2)	ϕ'_r	Range of σ'_n (kN/m^2)	Remarks
43.7	47	4.4	10.9°	50-390	
43.0	79	4.7	12.9°	50-390	
31.6	69	2.6	9.0°	50-390	Slip surface
31.0	79	2.7	7.0°	50-390	
18.1	61	2.7	8.8°	50-390	Slip surface
c.18.0	-	5.3	8.2°	110-450	Slip surface
15.7	64	4.0	14.3°	50-390	
c.15.2	56	0	19°	-	Denness (1969)*
12.5	48	1.7	25.1°	50-390	
8.4	41	0	19.4°	220-450	
c. 6.1	43	0.	27°	-	Denness (1969)*
-	75	2.0	6.8°	-	Humphris (1979)
-	58	7.0	14.6°	-	Humphris (1979)
-	54	5.0	22.7°	-	Humphris (1979)
-	42	2.0	23.3°	-	Humphris (1979)

* These shear strength data derived from multiple reversal shear box test.

Residual shear strength data for Gault at Dunnose

Height in stratum (m)	LL (%)	c'_r (kN/m^2)	ϕ'_r	Range of σ'_n (kN/m^2)	Remarks
>15	48	1.2	14.5°	50-250	Street (1981)
15.2	57	5.8	8.9°	50-390	Slip surface
c.15	55	0	18°	200-780	Matthews (1977)*
0	32	1.6	27.3°	50-390	

*Total displacement of 75 mm in shear box, ultimate residual strength may not have been reached.

Selected geotechnical properties for Gault at Dunnose

Approx. height in stratum	LL (%)	PL (%)	PI (%)	CF (%)	Reference
Slip plane in landslide, above 15 m	48	21	27	53	Street (1981)
Top of sea cliff, approx. 15 m	55	23	32	28	Matthews (1977)
" " " " " " "	50	21	29	23	Matthews (1977)
Near the base	43.5	19	24.5	26	Hutchinson (Reconn. in prep)

Table 2.2 Geotechnical properties of the Gault Clay from the Isle of Wight Undercliff (after Chandler, 1984).

dipping joints. Jointing is not well developed in the Ferruginous Sands, and for reasons of accessibility no data were obtained from the Carstone.

Measurements of the dip and strike of the joint surfaces were made using a standard Silva compass clinometer and the data are presented on a lower hemisphere, Lambert equal area polar stereographic projection.

The results of 30 joint measurements made along this section are presented in Figure 2.5. The data can be resolved into two distinct groups. One joint set strikes at 180° ± 10° and dip at 60-70° E. The second set strikes at 024° ± 10 ° and dips steeply to the east. These data reveal a close correlation between the trend of the coastline and the orientation of the joints. It is clear that the geometry of the large loose blocks within the Sandrock is controlled by systems of steep, easterly dipping joints oriented N-S and at 024°. The close correlation between the strike of these structures and the orientation of the coastline in this area highlights the primary morphological control exerted by local joint patterns. This joint pattern is similar to the structures identified elsewhere in the Lower Greensand units, highlighting the absence of a well developed orthogonal joint set in contrast to the Upper Greensand units (Figure 2.6). Hence, the rear faces of the large blocks observed in the Sandrock cliff face are well defined planar structures whilst the sidewalls are frequently irregular.

The absence of any clear, continuous exposure of either the Gault Clay or Upper Greensand in the study area prevented the collection of data for this work. However, on the basis of fieldwork elsewhere in the Undercliff, including Gore Cliff and Ventnor Station (Figure 2.6), the following points can be made:

(i) the Upper Greensand is characterised by large, almost vertical fissures with interfacial separation of around 50cm. Some of the fissures identified at Gore Cliff and Ventnor Station are partially infilled with brecciated material;

(ii) the degree of jointing markedly decreases from the Chert Beds into the Malm Rock, which may be a

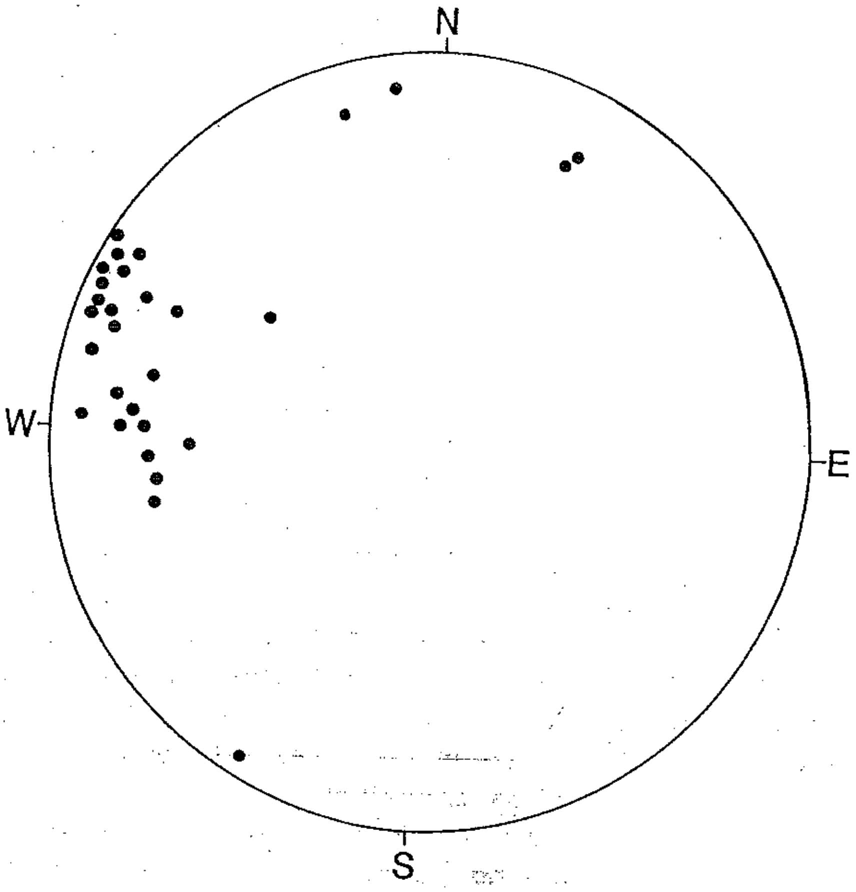

Figure 2.5 Stereographic projection of joint data collected from the Lower Greensand rocks between Luccombe Chine and Shanklin Chine.

function of the high competency of the Chert Beds relative to the lower units;

(iii) in the underlying Passage Beds the joints are defined by iron-coated planes which, as in the Gault beneath, are shallower dipping than the joints identified in the 'Malm' and Chert Beds, possibly reflecting the less competent nature of this unit;

(iv) the dominant trends of the joint sets in the Upper Greensand and Gault are as follows (see Figure 2.6):

- striking 130°
- striking 034° ± 10°
- striking 090° ± 15° (Ventnor Station)

(v) the steeply dipping orthogonal joint sets probably exert a primary control on the morphology of the rock masses involved in landsliding. Lower angle joints in the Gault Clay are considered to be of great importance as they may assist the dip-slip and forward movement of failed blocks. This situation has been observed at Gore Cliff, where high-angle structures in the Chert Beds pass down into shallow dipping joints within the Passage Beds and Gault.

2.3 THE GEOLOGICAL CONTROL ON LANDSLIDING

The lithologically variable Cretaceous rocks which occur in the study area have been identified elsewhere as being particularly prone to landsliding, especially in the coastal environment. The combination of hard, competent sandstones and chert beds overlying thick overconsolidated clays has given rise to many large coastal landslides on the south coast of England. Examples of landslides in this type of geological setting include Folkestone Warren, Kent (Hutchinson et al., 1980), the abandoned sea cliff behind Romney Marsh (Hutchinson et al., 1985), Fairlight Glen (Moore, 1986), Fairy Dell, Dorset (Brunsden and Jones, 1976), the Bindon landslide, Devon (Pitts and Brunsden, 1987) and the Isle of Wight Undercliff (e.g. Hutchinson, 1965; Chandler, 1984; Hutchinson, 1987a).

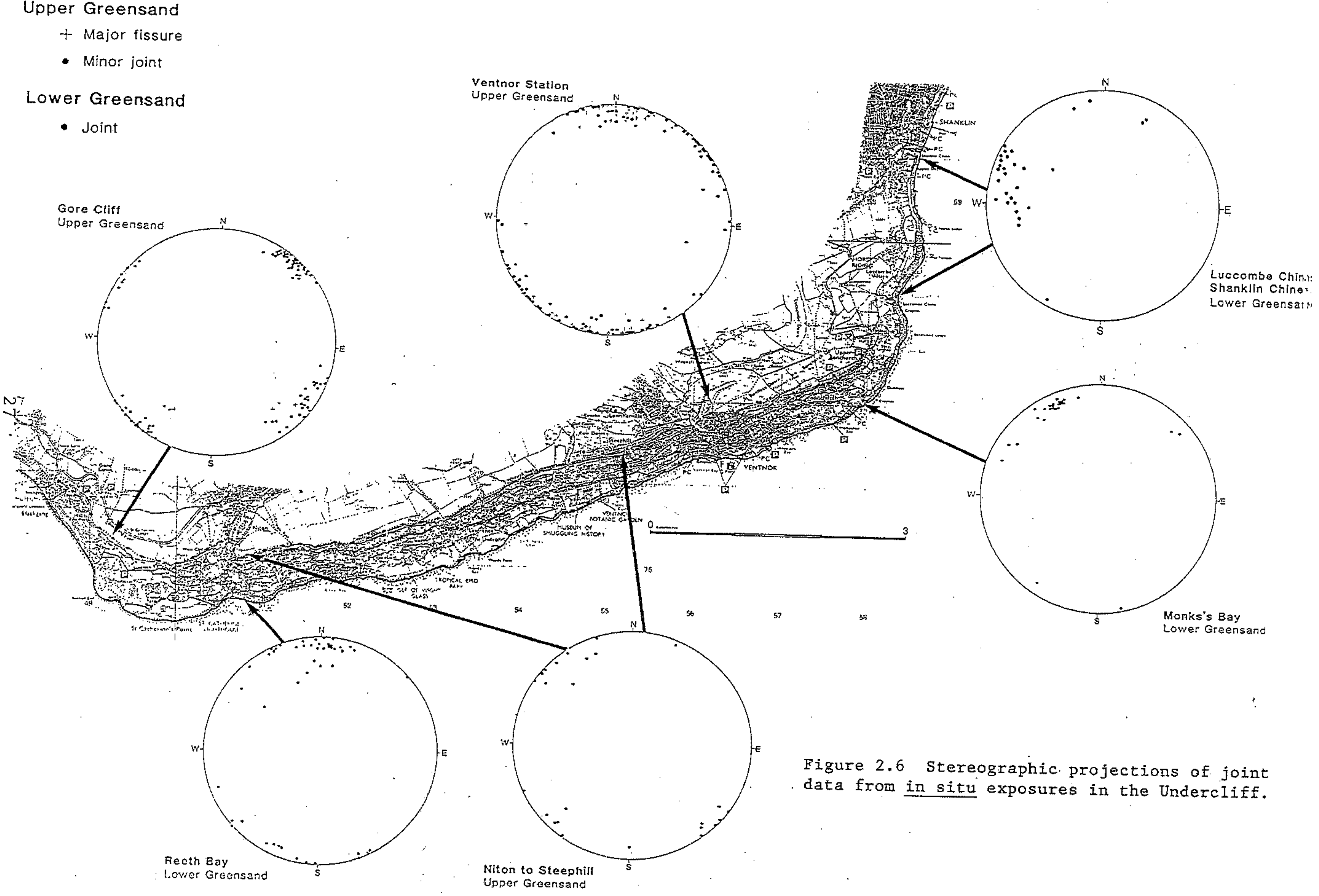

Figure 2.6 Stereographic projections of joint data from in situ exposures in the Undercliff.

Within the study area the overconsolidated Gault Clay is underlain by alternating sandstones and clays of the Lower Greensand formations. These strata are particularly susceptible to erosion, through a combination of marine undercutting and seepage at the interface of a clay layer with the overlying sandstone. A dramatic example of such erosion of Lower Greensand strata occurs at Chale Bay, Isle of Wight (Hutchinson et al., 1981).

These relationships between geology and landsliding are discussed in further detail in Chapters 4 and 5.

CHAPTER 3
HYDROGEOLOGY AND HYDROLOGY

3.1 REGIONAL HYDROGEOLOGY

The water-bearing aquifers of the Southern Downs of the Isle of Wight consist of two main units:

(a) the unconfined Chalk and Upper Greensand (UG aquifer)
(b) the Lower Greensand (LG aquifer)

These two aquifers are separated by the Gault Clay, forming an aquiclude, thus two main independent groundwater regimes can be identified (Figure 3.1).

The groundwater capacity and transmissivity of the Chalk and Upper Greensand is related to the joint and bedding structure of the strata. Whitaker (1910) and Fairley (1932) identified a predominance of vertical joints and vertical water transmission, although lateral flow would occur along bedding planes and above clay layers, as are encountered around the top of the Lower Chalk. Within the Upper Greensand Chandler (1984) identified a spring line at Blackgang in the upper part of the Passage Beds, c.3.5m below the base of the Malm Rock. Investigation by Southern Water (Packman pers.comm.) have indicated that much of the Chalk is unsaturated while the Upper Greensand is mostly saturated, which would explain the occurrence of the Passage Bed springs. The model is summarised in Figure 3.1 (after Chandler, 1984), although it should be noted that this model is not directly applicable to the Luccombe Coombe situation.

Below the Upper Greensand lies the Gault Clay aquiclude, although described in some of the literature as an aquitard (e.g. Chandler, 1984). The impermeable nature of the Gault Clay leads to the development of the spring line within the overlying Passage Beds. Bristow (1862), de Rance (1882) and Reid and Strahan (1889) have attributed the formation of landslides in the Upper Greensand to the occurrence of this spring line.

The Lower Greensand aquifer as described by Whitaker (1910) comprises a substantial thickness of generally permeable materials, although variations in jointing, bedding and particularly lithology, lead to locally complex

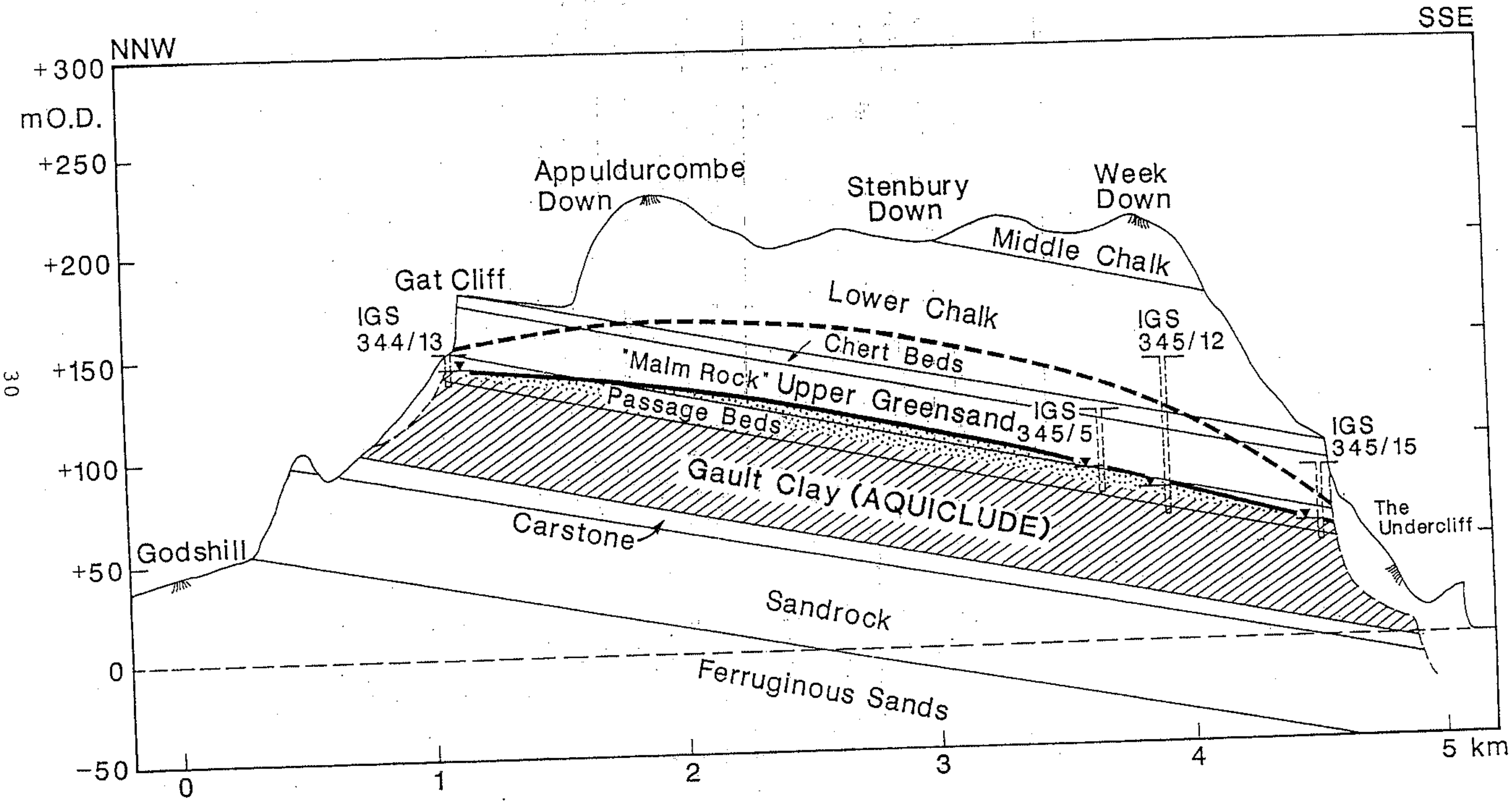

Figure 3.1 Hydrogeological model of the Southern Downs. Solid line : inferred level of water table. Dashed line : level shown by IGS and SWA (1979).

hydrogeological conditions. Clay lenses form minor aquitards in the overall sequence allowing the development of localised springs or seepages which have been largely responsible for the formation of the stepped cliff profile, at Blackgang, through the process of seepage erosion (Hutchinson et al., 1981).

3.2 SURFACE STREAMS

Within Luccombe Coombe, several perennial streams issue from a line of springs, probably in the Passage Beds. All but one of these are situated away from the ancient landslide area close to Luccombe Village (Figure 3.6). Two streams have their confluence at Dunnose Cottage and flow to the sea through Luccombe Chine. The main source of these streams originates from lateral flow above the Gault Clay aquiclude, at grid reference SZ 577791 (Luccombe Farm Cottages) and SZ 457794 (Luccombe Farm), at approximately 104m OD. A third tributary of the stream outflowing through Luccombe Chine issues from below Thatch Cottage at 79m OD. The true source of this stream is unknown, but it is likely that the spring and upper reaches of the stream have been disturbed and obscured by landslide debris or that the stream originated entirely as drainage from the landslide mass.

3.3 RAINFALL

3.3.1 Introduction

Rainfall data have been obtained from two nearby meteorological stations:

1. Shanklin Big Meade (SBM) (SZ 581808) 1947-1988 1km from Luccombe Village
2. St Catherine's Point (SCP) (SZ 498754) 1951-1988 10km from Luccombe Village

Monthly rainfall totals for both these stations are presented in Annex D (Tables F and G).

Further weather data have been recorded in the Undercliff (less than 10km from Luccombe) at the Royal National Hospital (RNH) (SZ 546767), Ventnor Park (VP) (SZ 546773), Ventnor Cemetery (VC) (SZ 556778) and Ventnor Radar Station (VRS) (SZ 570786). Apart from Ventnor Park and the Royal

National Hospital these data are of little additional benefit because the records are often discontinuous.

3.3.2 Analysis

Records of rainfall and climatic data for the area are very limited prior to the late 19th century. Reference is made by Martin (1849) and de Rance (1882) to mean, maximum and minimum annual rainfall totals for the Undercliff (Tables 3.1 to 3.3). More recently Chandler (1984) analysed weather data for three stations (St Catherine's Point, Royal National Hospital and Ventnor Park), over the period 1902-1983. These data, together with that from Shanklin Big Meade, are presented in a series of three tables; Table 3.1 summarises the mean annual rainfall; Table 3.2 summarises high magnitude annual and monthly rainfall and Table 3.3 summarises low magnitude annual and monthly rainfall.

Inspection of the data presented in Tables 3.1 to 3.3 and Tables F and G in Annex D reveals:

(i) Shanklin Big Meade, and by inference Luccombe, with an annual mean of 888.4mm receives, on average, more rainfall than St Catherine's Point (752.3mm). This trend is highlighted in Figure 3.2 which clearly shows an eastward increase in annual rainfall along the Undercliff and into Luccombe Bay;

(ii) since 1902 the wettest years have been:

1368.9mm	1960	SBM
1233.1mm	1951	SBM
1111.5mm	1974	SBM
1083.3mm	1966	SBM
1056.7mm	1954	SBM
1026.0mm	1967	SBM
1007.0mm	1986	SBM

High magnitude monthly rainfall totals have occurred in the following years:

1987 (Oct)	258.3mm	SBM
1974 (Sep)	250.3mm	SBM

Rainfall Total (mm)	Period	Station/location	Author/source
658.9	1838 - 1848	Undercliff	Martin (1849)
852.8	1876 - 1879	Royal National Hospital	De Rance (1882)
762.3	1924 - 1983	St. Catherine's Point	Chandler (1984)
783.7	1902 - 1951	Royal National Hospital	Chandler (1984)
840.3	1926 - 1983	Ventnor Park	Chandler (1984)
752.4	1951 - 1987	St. Catherine's Point	Table G
888.4	1947 - 1987	Shanklin Big Meade	Table F

Table 3.1 Mean annual rainfall totals recorded within the Undercliff and at Shanklin (Tables F and G included in Annex D).

1 ANNUAL RAINFALL

Rainfall Total (mm)	Year order	Station/location	Author/source
1000.3	1848	Undercliff	Martin (1849)
1003.6	1951	St. Catherine's Point	Table G
1233.1	1951	Shanklin Big Meade	Table F
878.1	1954	St. Catherine's Point	Table G
1056.7	1954	Shanklin Big Meade	Table F
891.8	1958	St. Catherine's Point	Table G
1224.5	1960	St. Catherine's Point	Table G.
1354.9	1960	Ventnor Park	Chandler (1984)
1368.9	1960	Shanklin Big Meade	Table F
914.3	1961	St. Catherine's Point	Table G
880.7	1963	St. Catherine's Point	Table G
909.6	1966	St. Catherine's Point	Table G
1083.3	1966	Shanklin Big Meade	Table F
1026.0	1967	Shanklin Big Meade	Table F
1111.5	1974	Shanklin Big Meade	Table F
1007.0	1986	Shanklin Big Meade	Table F

2 MONTHLY RAINFALL

Rainfall Total (mm)	Year order	Station/location	Author/source
239.3	1914 Dec.	Royal National Hospital	Chandler (1984)
227.5	1928 Oct.	Royal National Hospital	Chandler (1984)
225.5	1928 Oct.	St. Catherine's Point	Chandler (1984)
235.5	1934 Dec.	Ventnor Park	Chandler (1984)
228.1	1939 Oct.	Ventnor Park	Chandler (1984)
229.1	1940 Nov.	Royal National Hospital	Chandler (1984)
241.3	1949 Oct.	Shanklin Big Meade	Table F
179.6	1951 Nov.	St. Catherine's Point	Table G
225.3	1951 Nov.	Shanklin Big Meade	Table F
189.5	1959 Dec.	St. Catherine's Point	Table G
227.8	1959 Dec.	Shanklin Big Meade	Table F
188.7	1960 Oct.	St. Catherine's Point	Table G
222.8	1960 Oct.	Shanklin Big Meade	Table F
199.0	1963 Aug.	St. Catherine's Point	Table G
221.8	1970 Nov.	St. Catherine's Point	Table G
231.4	1979 Nov.	Ventnor Park	Chandler (1984)
241.1	1970 Nov	Shanklin Big Meade	Table F
176.8	1974 Sep.	St. Catherine's Point	Table G
250.3	1974 Sep.	Shanklin Big Meade	Table F
211.5	1987 Oct.	St. Catherine's Point	Table G
258.3	1987 Oct.	Shanklin Big Meade	Table F

Table 3.2 High magnitude annual and monthly rainfall totals recorded within the Undercliff and at Shanklin (Tables F and G included in Annex D).

1 ANNUAL RAINFALL

Rainfall Total (mm)	Year	Station/location	Author/source
481.8	1842	Undercliff	Martin (1849)
445.8	1921	Royal National Hospital	Chandler (1984)
626.9	1953	Shanklin Big Meade	Table F
437.4	1973	St. Catherine's Point	Chandler (1984)
557.1	1973	Ventnor Park	Chandler (1984)
557.3	1973	Shanklin Big Meade	Table F
539.9	1983	St. Catherine's Point	Table G
674.2	1983	Shanklin Big Meade	Table F
575.4	1985	St. Catherine's Point	Table G
726.1	1985	Shanklin Big Meade	Table F

2 MONTHLY RAINFALL

5.3	1910 Sep.	Royal National Hospital	Chandler (1984)
0	1925 June	St. Catheine's Point	Chandler (1984)
0.3	1938 Apr.	Ventnor Park	Chandler (1984)
0	1940 Aug.	St. Catherine's Point	Chandler (1984)
4.1	1956 Feb.	St. Catherine's Point	Table G
6.1	1956 Feb.	Shanklin Big Meade	Table F
4.3	1959 Sep.	St. Catherine's Point	Table G
5.3	1959 Sep.	Shanklin Big Meade	Table F
4.0	1961 Mar.	St. Catherine's Point	Table G
1.8	1961 Mar.	Shanklin Big Meade	Table F
3.7	1969 Oct.	St. Catherine's Point	Table G
3.7	1969 Oct.	Shanklin Big Meade	Table F
3.1	1975 June	St. Catherine's Point	Table G
3.2	1975 June	Shanklin Big Meade	Table F
4.7	1976 June	St. Catherine's Point	Table G
6.6	1976 June	Shanklin Big Meade	Table F
3.8	1978 Oct.	St. Catherine's Point	Table G
6.8	1978 Oct.	Shanklin Big Meade	Table F
0.5	1984 Apr.	St. Catherine's Point	Table G
0.6	1984 Apr.	Shanklin Big Meade	Table F

Table 3.3 Low magnitude annual and monthly rainfall totals recorded within the Undercliff and at Shanklin (Tables F and G included in Annex D).

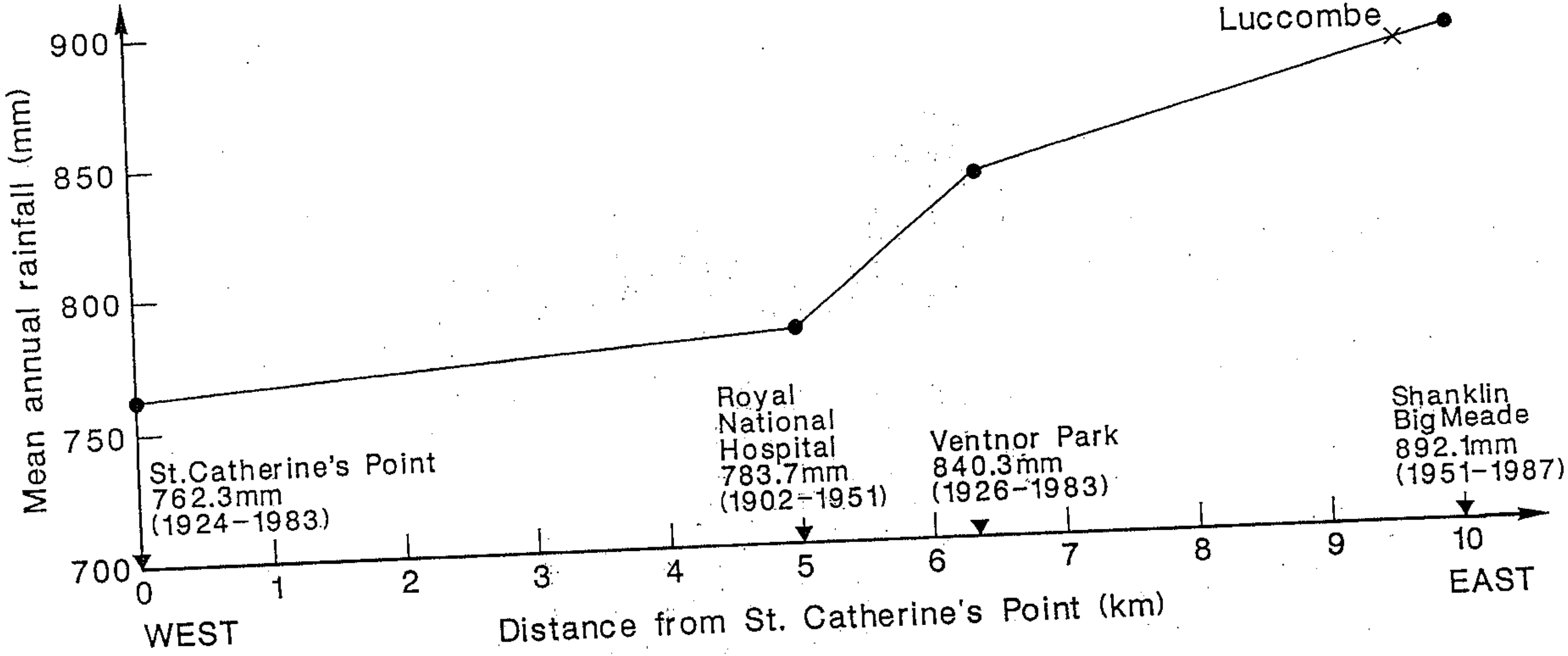

Figure 3.2 Mean annual rainfall trend within the Undercliff.

1949 (Oct)	241.3mm	SBM
1970 (Nov)	241.3mm	SBM
1914 (Dec)	239.3mm	RNH
1934 (Dec)	235.5mm	VP
1940 (Nov)	229.1mm	RNH
1939 (Oct)	228.1mm	VP
1959 (Dec)	227.8mm	SBM
1928 (Oct)	227.5mm	RNH
1951 (Nov)	225.3mm	SBN
1960 (Oct)	222.8mm	SBM

(iii) the long-term annual rainfall trend for Shanklin Big Meade is shown by a five year running mean (Figure 3.3) which highlights 1950-1952, 1958-1962 and 1965-1968 as significant wet periods. It is important to note that this trend shows there has been a general reduction in annual rainfall since 1969 with mean totals as low as 800mm and there has accordingly been less rainfall between 1969-1987 than in previous decades (1947-1968).

(iv) Figure 3.4 clearly shows a seasonal variation in rainfall at Shanklin Big Meade, with two marked phases:

(a) dry phase between February and September, with 50-70mm rainfall per month;

(b) a wet phase between September -January, (with over 80mm rainfall per month).

Since 1947, the average September - January (wet phase) rainfall for Shanklin Big Meade is 437.8mm, with the largest totals occurring in the following years:

1960-1961	884.8mm
1976-1977	749.5mm
1974-1975	727.2mm
1987-1988	638.1mm
1961-1962	595.1mm
1959-1960	585.6mm
1949-1950	577.4mm
1954-1955	572.3mm
1952-1953	560.6mm
1950-1951	540.5mm

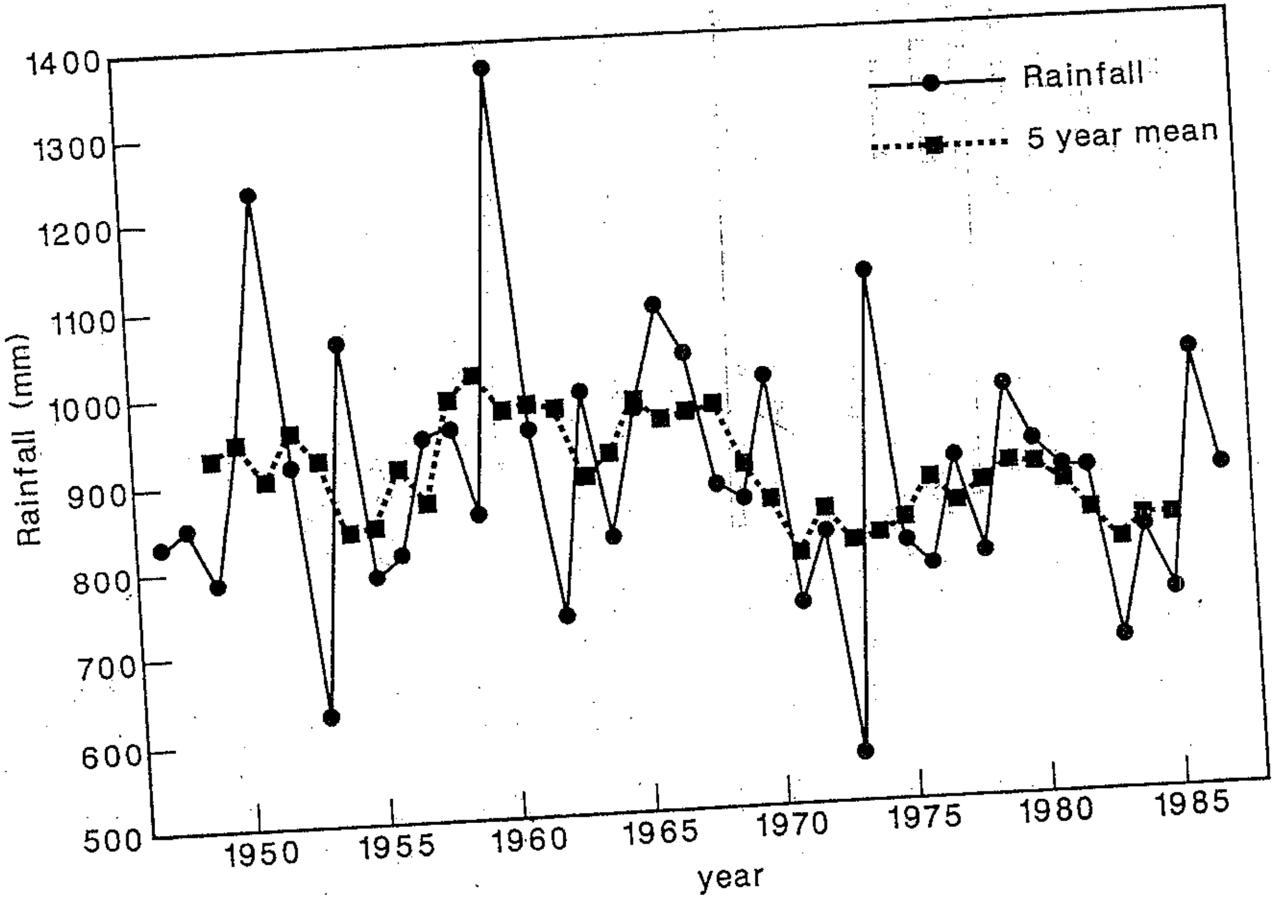

Figure 3.3 .Annual rainfall at Shanklin Big Meade.

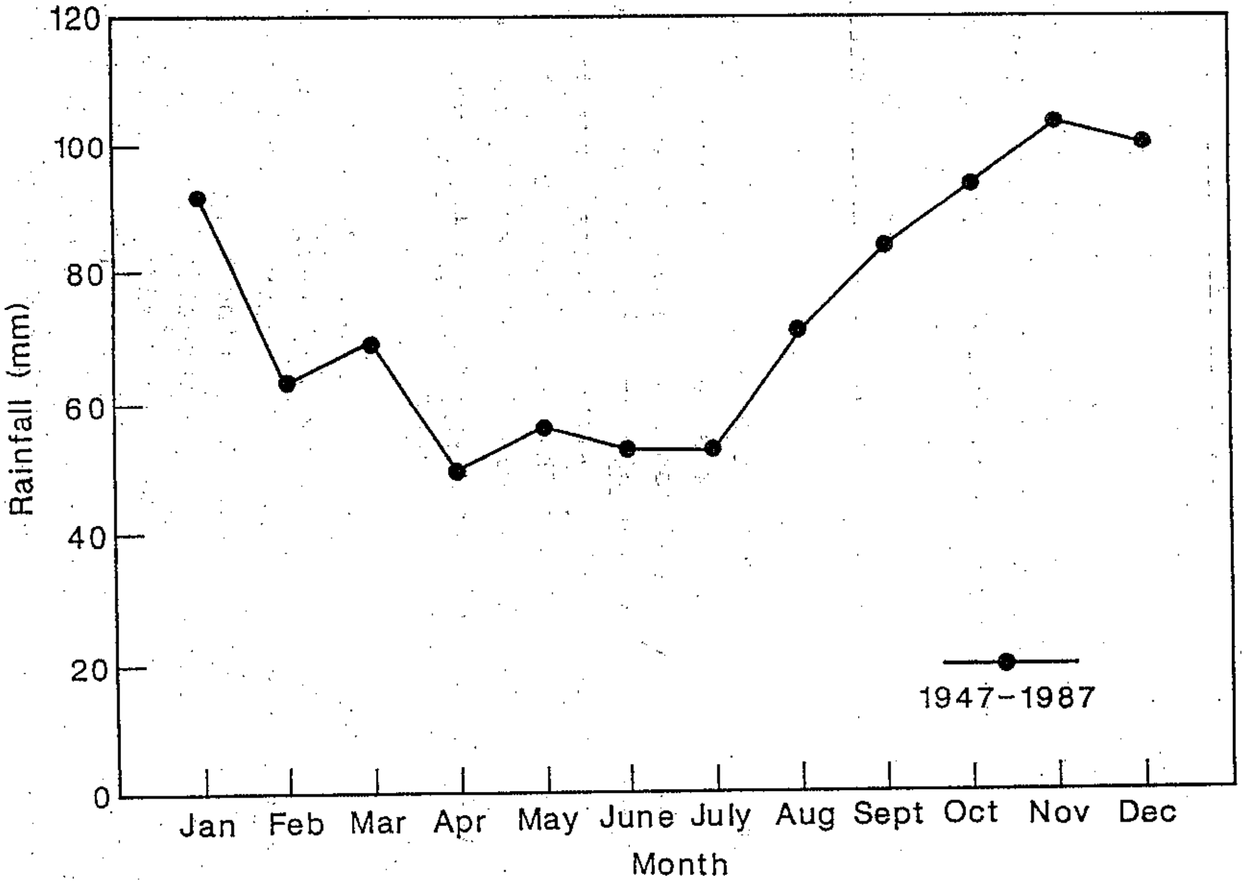

Figure 3.4 Mean monthly rainfall at Shanklin Big Meade (1947-1987).

3.4 GROUNDWATER

3.4.1 Phreatic levels

It is clear that the predominant groundwater source of both the UG and LG aquifers is rainfall and, therefore, fluctuations in groundwater, phreatic or rest-water levels may be expected to coincide with antecedent rainfall events. The seasonal and long-term changes in rainfall within the Undercliff and Luccombe area were considered in section 3.3. There are very limited records available for analysing the regional and temporal variations in groundwater levels. Consequently, it is not possible to reliably estimate the response times of the UG and LG aquifers to seasonal or long-term variations in recharge by precipitation. Limited groundwater data has been provided by the Southern Water Authority (Table 3.4).

(a) LG aquifer; Chandler (1984) presented phreatic surface levels for this aquifer from a well at Itchill and a borehole at Whitell, and concluded that there was a clear seasonal cycle reflecting the importance of rainfall on water levels. Although these monitored observations are at least 7km from Luccombe, it is likely that groundwater levels within the LG aquifer below Luccombe Coombe experiences similar seasonal fluctuations in phreatic surface;

(b) UG aquifer: Table 3.4 summarises groundwater levels for six Southern Water Authority observation boreholes in the Upper Greensand aquifer (Figure 3.5). The Luccombe Down borehole was discontinued in 1986 and replaced by Luccombe Copse observation borehole in 1987. Each borehole has been read periodically (approximately once a month) since installation in 1986-1987. Although the data record is too short to assess any long-term trends in groundwater levels, an attempt has been made to establish the antecedent lag-times between rainfall events and changes in the phreatic surface.

Figure 3.5 presents plots for the groundwater records at Lowtherville (Ventnor), Luccombe Copse, Week Farm and St Lawrence Shute in relation to monthly rainfall

Borehole	Datum (m)	Date	Level (m)
Littleton Down (SZ 5630 7840)	223.89	23.10.87	132.93
		22. 3.88	132.89
		21. 4.88	128.41
		19. 5.88	133.02
Lowtherville (SZ 5500 7820)	115.93	6. 1.86	92.44
		28. 2.86	92.12
		1. 4.86	92.33
		30. 4.86	92.68
		30. 8.86	91.97
		30. 9.86	91.81
		30.10.86	91.75
		30.11.86	92.23
		31.12.86	92.78
		16. 1.87	93.13
		23. 2.87	92.93
		16. 3.87	93.03
		24. 4.87	93.93
		18. 5.87	93.55
		15. 6.87	93.12
		16. 7.87	92.73
		18. 8.87	92.38
		17. 9.87	92.12
		23.10.87	92.30
		23.11.87	93.05
		28. 1.88	93.11
		18. 2.88	94.57
		22. 3.88	93.61
		21. 4.88	92.87
Luccombe Copse (SZ 5760 7890)	137.54	16. 7.87	103.69
		18. 8.87	103.21
		17. 9.87	102.99
		23.10.87	109.22
		23.11.87	110.82
		16.12.87	106.84
		28. 1.88	111.18
		18. 2.88	111.30
		22. 3.88	108.84
		21. 4.88	108.71
		19. 5.88	106.52
Luccombe Down	231.08	5.86	136.43
		6.86	136.01
		7.86	135.62
		8.86	138.07
St. Lawrence Shute (SZ 5340 7720)	109.3	16. 7.87	84.5
		18. 8.87	84.5
		17. 9.87	84.53
		23.10.87	84.58
		23.11.87	84.67
		16.12.87	84.69
		28. 1.88	84.87
		18. 2.88	84.80
Week Farm (SZ 5370 7790)	133.81	16. 7.87	93.43
		18. 8.87	93.05
		17. 9.87	92.77
		23.10.87	107.54
		16.12.87	106.00
		28. 1.88	109.31
		18. 2.88	98.91
		22. 3.88	109.46
		21. 4.88	110.07

Table 3.4 Southern Water Authority observation boreholes in the Upper Greensand aquifer.

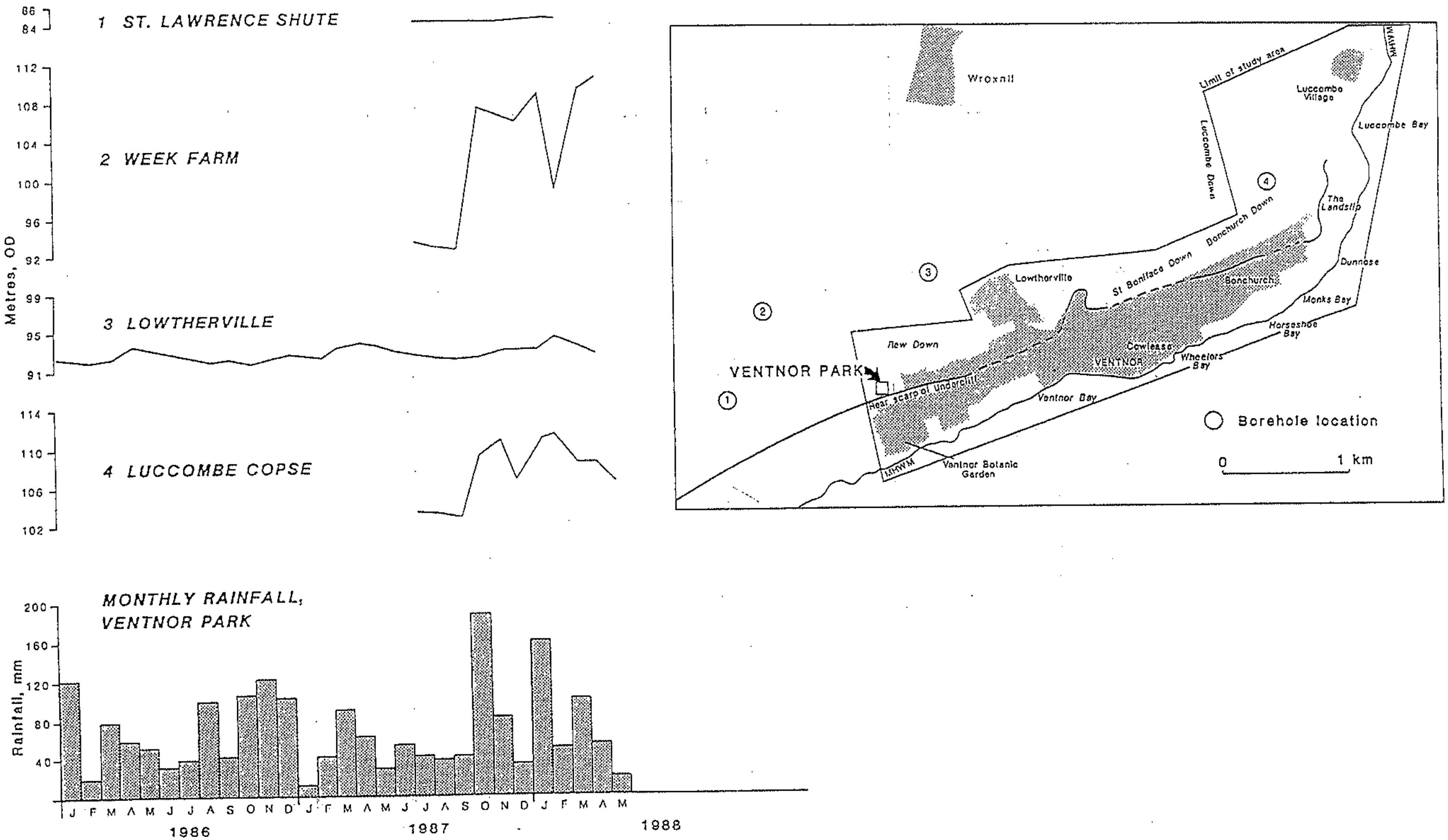

Figure 3.5 Fluctuations in ground water levels and monthly rainfalls.

totals recorded at Ventnor Park (the most representative site for the four selected boreholes).

The results demonstrate the following points:

(i) the sensitivity of groundwater levels in the UG aquifer to fluctuations in rainfall;

(ii) groundwater levels show variable responses depending on the intensity and duration of rainfall events.

(iii) a variable but relatively long-term antecedent response time for the Lowtherville borehole;

(iv) relatively short-term antecedent response times for the Week Farm and Luccombe Copse boreholes.

Although these observations are necessarily provisional, until further data is available, the results indicate seasonal and short-term fluctuations in groundwater levels with rainfall events which have important implications for slope instability. This relationship is discussed in further detail in section 6.5 with respect to the 1987-1988 movements in Luccombe Village.

3.4.2 Water suply

Luccombe Village obtains its water supply from three sources (Figure 3.6):

(i) <u>Ventnor railway tunnel</u>; according to the Southern Water supply statistics, Luccombe Village is supplied 0.14 mega litres per day from this source. This is an estimated value (SWA, 1988) which has remained consistent throughout available records (January, 1986 - 1988);

(ii) <u>Luccombe Farm Cottage spring</u>; this spring yields up to 2.63 l/sec. Water from Luccombe Farm Cottage is gravity fed into small storage tanks, treated and pumped to a high level reservoir or direct to the supply tank near to the Luccombe Riding School;

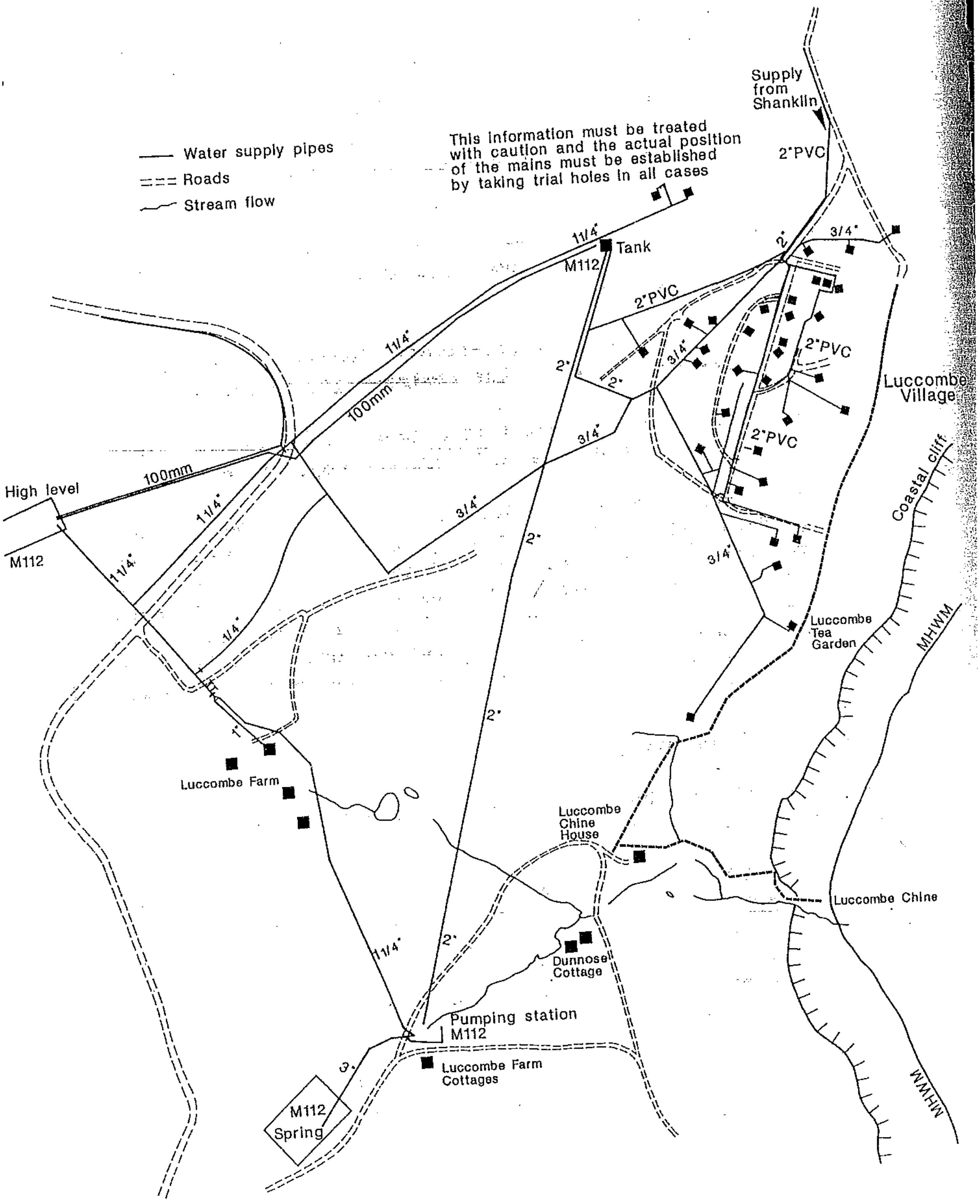
This information must be treated with caution and the actual position of the mains must be established by taking trial holes in all cases

Figure 3.6 Water supply network at Luccombe (from information supplied by Southern Water Authority).

(iii) Shanklin; water from sources in Shanklin is pumped into Luccombe Village, in 2 inch PVC pipes along Luccombe Road. No supply statistics for this source have been made available.

3.5 SUMMARY

The hydrogeology of the area is dominated by two rainfall-sensitive aquifers (the Upper and Lower Greensand aquifers) separated by the Gault Clay aquiclude. There is a clear local trend of annual rainfall totals rising eastward along the Undercliff (Figure 3.2), and this probably contributes to the higher groundwater levels recorded in the Upper Greensand aquifer at Luccombe Copse compared with Lowtherville and St Lawrence Shute (Table 3.4). Within Luccombe Coombe groundwater levels are likely to be slightly more complicated as a result of the disturbed nature of the ground in the vicinity of the ancient landslide systems (see section 4). however, it is likely that the distinct seasonal trend in rainfall that occurs at Shanklin Big Meade (Figure 3.4) is matched by seasonal variations in groundwater levels within Luccombe Coombe, although following a certain lag-time.

Thus, prolonged periods of heavy rainfall during the autumn and winter will be followed by high groundwater levels and increased pore-water pressures which will probably result in seasonal variations in slope stability. It is important to note, therefore, that rainfall totals may be used as an indicator of groundwater levels and indirectly landslide potential (this is discussed in further detail in section 6, with reference to the 1987/1988 movements in Luccombe village).

Within the Lower Greensand aquifer the occurrence of alternating bands of sandstone and clay has led to the development of a series of perched water tables above the clays. It is possible that seepage erosion may occur at the interface of the clays and the overlying sandstone, and could have contributed to formation of the characteristic bench form "undercliff" of the sea cliffs between Luccombe Chine and Knock Cliff.

CHAPTER 4
GEOMORPHOLOGY

4.1 INTRODUCTION

Luccombe Coombe is a broad west-east trending stream valley excavated between two elongate Chalk ridges, Bonchurch Down (c.240m) and Cowleaze Hill (between 150-180m). The coombe was formed as a result of considerable stream incision during the last two million years of the Quaternary, although the valley system of the Southern Downs may have been initiated during the Tertiary period (Hutchinson, 1982). Streams flowing out of the eastern slopes of Luccombe Down have cut down through the Upper Greensand strata, exposing the Gault Clay in the valley bottom, at around 80-100m OD.

Valleys such as Luccombe Coombe are clearly relict features not related to present day catchments, or groundwater tables (indeed, a number of the valleys south of Luccombe Farm are now dry). The considerable depth of relief would have been created by surface run-off during cold, periglacial phases of the Pleistocene when groundwater levels would have been significantly higher owing to the presence of perma-frost, and sea-levels considerably lower than present day. It is possible that the orientation of the valleys could be related to the mesofracture pattern in the Upper Greensand and Chalk, as found elsewhere in southern England (Bevan, 1984, 1985). The village of Luccombe is located on the eastern flank of the Cowleaze Hill ridge, above the valley floor, at between 100-200m OD, and approximately 200-300m inland of the 80m high Lower Greensand sea-cliffs.

The occurrence of landslide features in Luccombe Coombe reflects a combination of the geological setting, together with the evolutionary history of the landscape and patterns of environmental change experienced throughout the Pleistocene. The main influences on landscape development during this period can be attributed to three main factors:

(i) periglaciation: it is generally accepted that the Isle of Wight remained ice free during the Pleistocene. However, the fluctuations in climatic conditions resulted in the periodic establishment of periglacial conditions. Some of the estimated

17-23 cool/cold phases in the last 2 million years were of sufficient severity to cause the production of broad belts of tundra with frozen ground (permafrost). 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. Besides occurring as fans in front of coombes, these deposits would have infilled the floors of the valleys within the Chalk uplands. The main phases of mass movement activity are likely to have been associated with the change from harsh arctic conditions to a warmer, moist climate. During these periods, some of which were as short as a thousand years, the ground was particularly susceptible to slope failure, as snow melt, increased rainfall and gradual thawing of the permafrost would have resulted in the development of saturated surface layers over permanently frozen subsoils. Landslide activity would have been widespread until a forest cover had developed;

(ii) sea-level changes: one of the most important consequences of the repeated accumulation and degradation of the ice sheets during the Pleistocene were the major oscillations in sea-level (within the Northern Hemisphere). These fluctuations were especially characterised by major reductions in world-wide sea-level during periods of ice advance, possibly to in excess of -100m, and also higher levels than recorded at present during interglacial times. Local evidence for higher sea-levels in the past is provided by the occurrence of high-level estuarine deposits at +38-40m OD at Bembridge (Holyoak and Preece, 1983), and the raised beach between Bembridge Point and Howgate Farm (White, 1921);

(iii) uplift: in recent years it has become clear that the whole of southern England experienced significant warping during the Quaternary. It is likely that warping was accompanied by tilting towards the south-east, producing differential uplift rates and stimulating considerable drainage incision. As a result, relative relief would have progressively increased throughout the Pleistocene. Once valley excavation had reached sufficient depth to expose the Gault Clay, landsliding became a significant mechanism of valley slope remodelling. Evidence for widespread landslide activity, probably initiated in the late Devensian and late glacial periods (c.18,000-10,000 years ago), is widespread both in Luccombe Coombe and on the northern margin of the Southern Downs (Hutchinson, 1965; BGS, 1976).

Pleistocene cold climatic conditions ceased around 10,250 BP (before present) since when generally warmer conditions have prevailed providing a widespread vegetation cover. Sea-levels rose rapidly in the post-glacial period, from -100m at 14,000 BP to around -20m by 8,000 BP, after which the rate of change lessened (Jones, 1981). As a consequence the sea advanced quickly up the South Western Approaches, re-occupying former shoreline features and giving rise to rapid coastal cliff retreat through landsliding. It is likely that the pattern of contemporary coastal landslide activity was initiated around 7,000-5,000 BP as sea-levels approached present-day levels (Chandler, 1984; Hutchinson, 1987).

On the basis of current estimates of cliff retreat of 0.3m pa (Barrett, 1985), it is likely that the former, post-glacial, shoreline would have been at least 2km seaward of its present position. Steers (1981) has suggested that the Luccombe and Shanklin Chine streams previously extended further seaward, and were probably left-bank tributaries of the Eastern Yar.

4.2 GEOMORPHOLOGICAL UNITS

The geomorphology of Luccombe Village and the surrounding area is presented on two separate maps:

(i) a 1:5,000 scale summary map showing the village in its local context, derived from the interpretation of aerial photographs and field verification (Figure 4.1);

(ii) a 1:2,500 scale geomorphological map of the village and its immediate surroundings, indicating the

Figure 4.1

GEOMORPHOLOGICAL MAP

Please see enclosure pocket

relative position and extent of the landslide units, produced after a detailed field mapping programme (Figure 4.2). In view of the seasonal movements which occur in the landslide, particularly below the path, this map portrays transient features and must be seen as "a picture in time".

These maps, together with the series of cross-sections (Figures 4.3 to 4.6), indicate that the study area can be divided into six main geomorphological units:

(i) the Chalk Downs;
(ii) the valley slopes developed in Upper Greensand;
(iii) the Gault Clay vale;
(iv) landslide systems;
(v) the sea-cliffs;
(vi) the beach/near-shore zone.

Each of these units is briefly described in the following sections 4.2.1 to 4.2.6, and their extent shown on the accompanying geomorphological maps (Figures 4.1 and 4.2).

4.2.1 The Chalk Downs

The slopes of Luccombe Down, Bonchurch Down and Cowleaze Hill are developed in the Glauconitic Marl, Grey Chalk and <u>A. plenus</u> Marl of the Lower Chalk. The summit elevation of these Chalk Downs is around 240m at Luccombe Down, gradually declining eastwards along the elongate ridges of Bonchurch Down and Cowleaze Hill.

The upper slopes of the Downs are convex in form, with slopes ranging from 12-17° close to the crest, to 26-31° above the A3055. In general, these slopes are smooth, with only slightly irregular microtopography, with no evidence of major mass movement activity. Above the lane to Luccombe Chine and Corner Cottage the slopes are indented by large, broad relict stream channels associated with former high-level spring lines.

The mid-slopes are characterised by a gently sloping narrow bench at between 150m (Cowleaze Hill) and 130m (south of Luccombe Farm Cottage). This bench is up to 100m in width and, with slopes of 6-14°, it contrasts sharply with the

Figure 4.2

GEOMORPHOLOGICAL MAP

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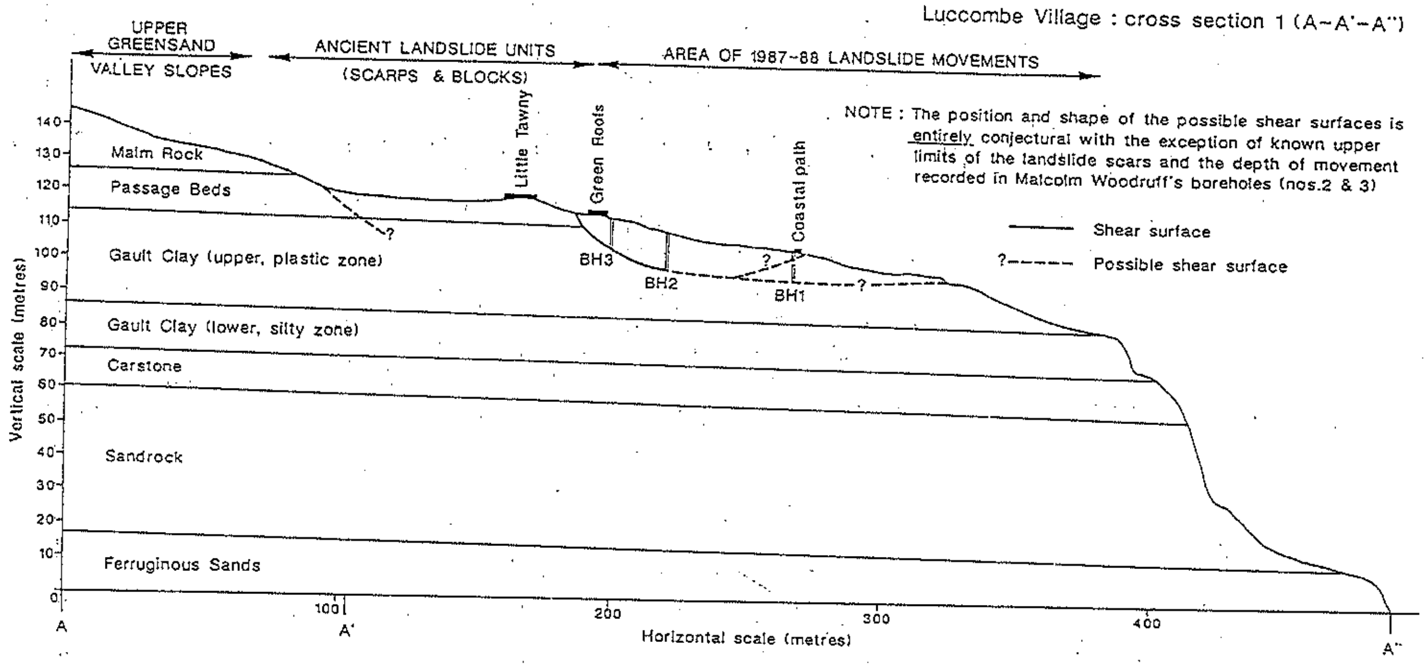


NOTE : The position and shape of the possible shear surfaces is entirely conjectural with the exception of known upper limits of the landslide scars and the depth of movement recorded in Malcolm Woodruff's boreholes (nos.2 & 3)

Figure 4.3 Cross-section through the study area $(A - A^{I} - A^{II})$.

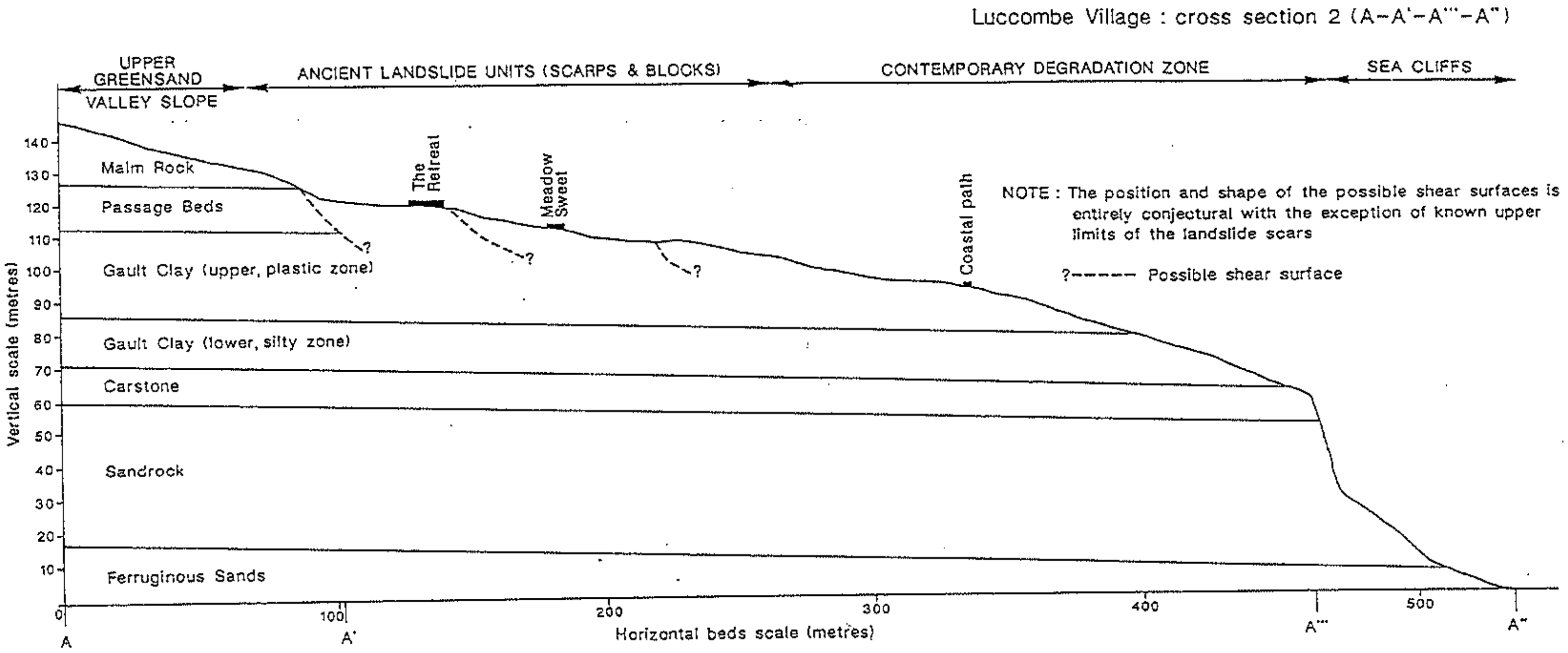


Figure 4.4 Cross-section through the study area $(A - A^{I} - A^{III} - A^{IV})$.

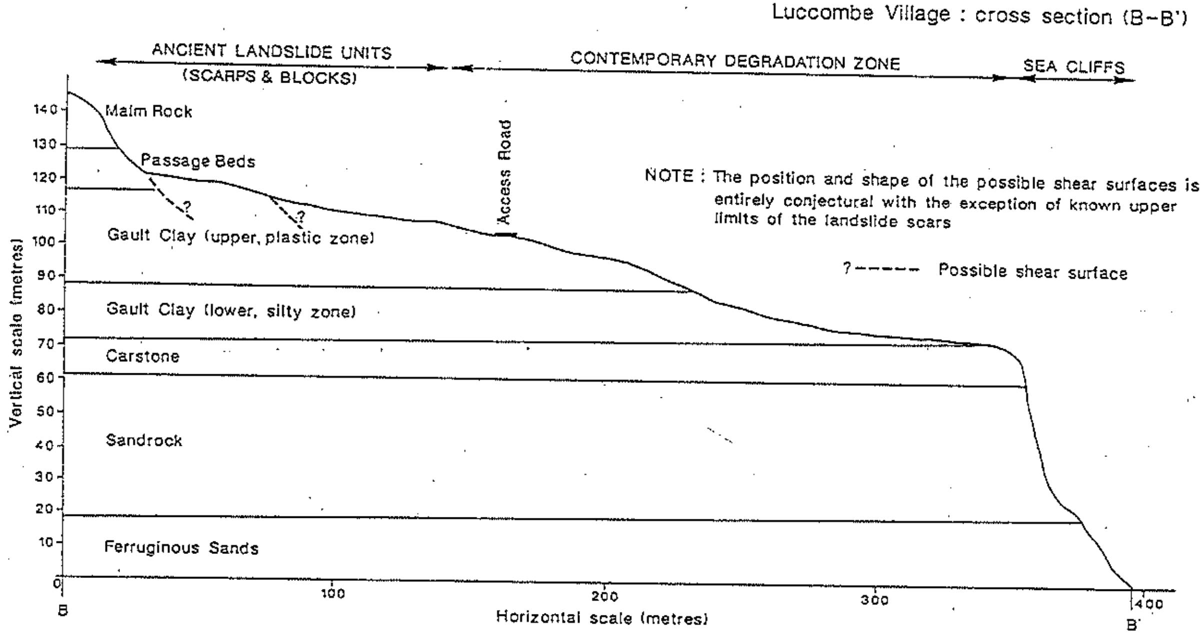


Figure 4.5 Cross-section through the study area (B - B^{I}).

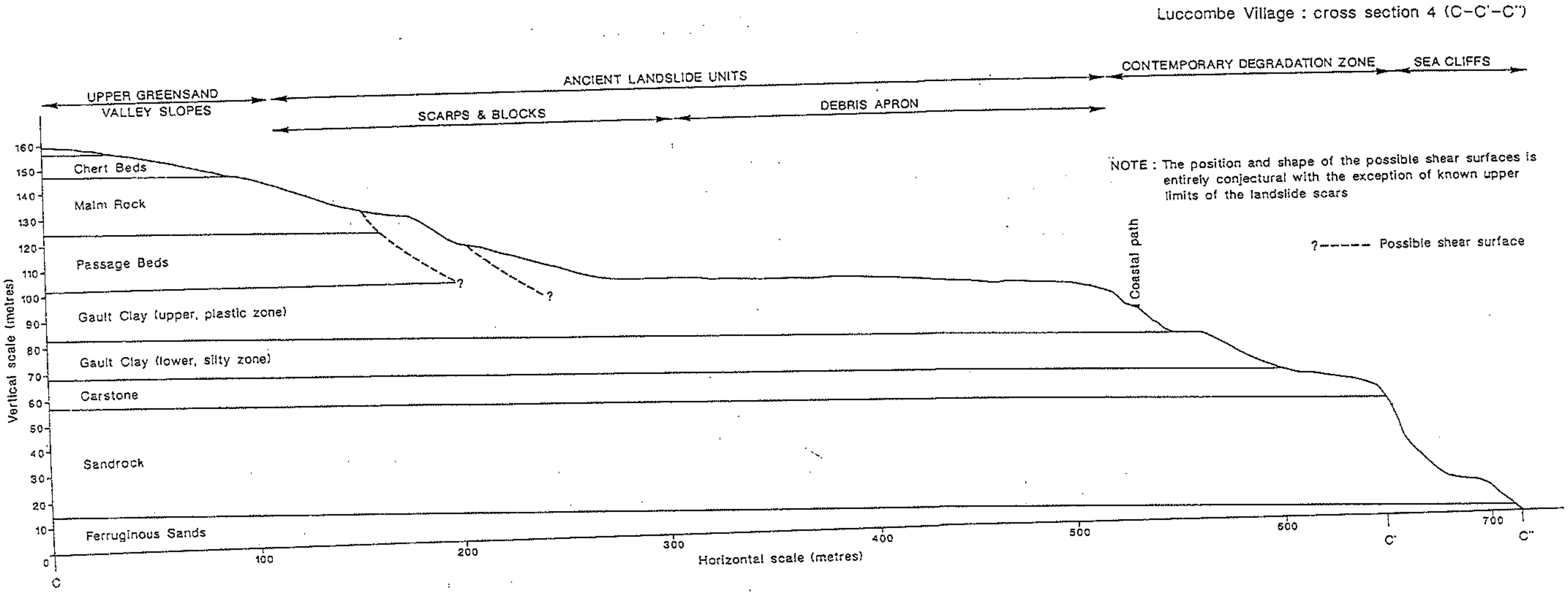


Figure 4.6 Cross-section through the study area $(C - C^{I} - C^{II})$.

steep upper slopes of the Chalk Downs. It is likely that this bench is lithologically controlled, probably developed in the Glauconitic Marl and Chalk Marl at the base of the Lower Chalk, with a superficial cover of colluvial material from upslope. Of note is the presence of three additional relict stream gullies, associated with former springs issuing towards the base of the Lower Chalk, which have created a serrated front to the bench between Luccombe Farm and Luccombe Farm Cottage.

Two small chalk pits were worked, just to the north of Glenavon (Figure 1.2), but are now disused.

4.2.2 The valley slopes developed in Upper Greensand

The Upper Greensand Chert Beds, Malm Rock and Passage Beds form the valley mid-slopes of Luccombe Coombe. This unit can be further sub-divided into two main areas:

(i) between Luccombe Farm Cottage and Luccombe Farm; this area is characterised by a series of long linear, west-east oriented, ridges and narrow dry valleys. The ridges are steep-sided with between 15-25m of relative relief close to the top of the Upper Greensand, where the valleys cut through the Chert Beds, with slopes of 17-22°. Terracettes, associated with contemporary soil creep, are common on slopes above 20°. As the ridges extend downslope through the Malm Rock and Passage Beds into the Gault Clay vale, the relief is more subdued and slope angles decline to around 6-9°.

The narrow dry valleys are associated with former high-level springs in the Lower Chalk, and are generally gently sloping in long profile (6-8°). The valley floors are likely to have been infilled with soft unconsolidated colluvial deposits;

(ii) flanks of the Cowleaze Hill ridge; this long, south-west to north-east oriented narrow ridge extends downslope from Luccombe Down. Below an elevation of around 156m the ridge is developed in Upper Greensand strata. The slopes on the south-east flank of the ridge are convex in form ranging from 6-13° close to the ridge crest, and below

130-140m OD have been affected by large-scale landslide activity. There is no evidence of springs issuing from the in-situ slopes.

The seaward extent of the ridge has been truncated by landsliding to the north-east of Luccombe Riding School.

It is interesting to note that similar Upper Greensand mid-slopes are absent on the eastern flank of Bonchurch Down, where there has been considerable landslide activity with major movements of the landslip area recorded in 1810, 1818 and 1910 (Englefield, 1816; Colenutt, 1938).

4.2.3 The Gault Clay vale

The streams flowing out of Luccombe Coombe have cut down through the Lower Chalk and Upper Greensand strata, exposing the Gault Clay which forms a gently sloping ($5-6^{o}$) vale. This vale has been infilled with soft unconsolidated layers of alluvial materials and possibly peats. Two streams flow across the vale, both of which are fed by springs issuing above the top of the Gault Clay and the overlying Passage Beds. The edges of the contemporary stream valleys are marked by low, continuous terraces which cut through the landslide features, probably associated with stream incision since the late Pleistocene phase of landsliding.

4.2.4 Landslide systems

Within Luccombe Coombe four areas of ancient landsliding have been identified by this study; **west of Luccombe Road, between Luccombe Farm and Luccombe Village, west of Dunnose Cottage** and **east of Luccombe Farm Cottage** (Figures 4.1 and 4.2). The present form of these slides represents the degraded remnants of a series of major rotational failures of Upper Greensand strata on shear surfaces probably seated within the Gault Clay. The distribution of these extensive landslide systems is a reflection of former environmental conditions towards the end of the later Pleistocene phases of cold climate between 18,000-10,000 years ago (see section 4.1).

The landslide systems in Luccombe Coombe have been subdivided into four interrelated zones:

(i) landslide backscars;
(ii) zone of landslide blocks;
(iii) debris aprons;
(iv) contemporary degradation zone.

4.2.4.1 Landslide backscars

The steep faces upslope of the main landslide blocks represent the degrading backscars of the ancient rotational failures. These features are developed in Upper Greensand strata, especially the Malm Rock. The morphology of these features varies between the four areas of landsliding:

(i) Luccombe Road; the upslope limit of this landslide is defined by an arcuate backscar extending northwards from the new access road. The slopes are consistently in the order of 40° and approximately 20m high. South of the access road the feature is remarkably subdued, although it may be traced between Merrydown and Upalong (Figure 1.3);

(ii) Luccombe Farm - Luccombe Village; two distinct and one possible continuous scar features, 500-700m in length, have been identified in this landslide unit. These features are clearest in Luccombe Village, becoming more subdued towards Luccombe Farm. Within Luccombe Village the backscars can be easily traced as a stepped series of steep, up to 20°, scarps:

- at the top of the steep bank above the Highway;
- running close to Dawn View, Little Tawny, the Retreat, Muffets, Corydon, Shotover and New Building (Figure 1.3);
- passing in front of Meadow Sweet, Luccombe Haven, Genesta and Manana (Figure 1.3);

(iii) Dunnose Cottage (W); the backscar of this slide is a low (c.3m high) bank, around 100m in length, at the seaward end of the long Upper Greensand ridge below Luccombe Copse;

(iv) Luccombe Farm Cottage (E); the main backscar of this slide is linear in form, with slopes of 17-24°. This distinct feature is approximately 40m below the A3055 and has developed in the Upper Greensand Chert Beds. A secondary backscar, downslope of the main scar, is arcuate in form and more subdued, with slopes of 11-21°.

4.2.4.2 Zone of landslide blocks

This zone occurs immediately downslope of the landslide backscars and comprises a sequence of linear benches separated by steep scarp slopes. This unit has probably been formed by a series of retrogressive rotational, and possibly translational, failures involving the Upper Greensand strata, with a basal shear surface in the Gault Clay. The linear nature and orientation of the landslide blocks clearly reflects the controlling influence of the mesofracture pattern in the Upper Greensand strata (oriented at c.034°; section 2.2), with failure in these rocks occurring preferentially along open fissures (see section 2.3).

On the basis of the surface morphology the following points can be made concerning each of the landslide units:

(i) Luccombe Road; immediately below the 20m high backscar there is a narrow (25m wide) elongate bench which, in places, is back-tilted indicating the rotational nature of the initial failure mechanism. This bench is fronted by a subdued scarp with slopes of 6° to 19°. Further downslope High Cliff lies on a similar landslide bench, below Luccombe Road;

(ii) Luccombe Farm - Luccombe Village; eight landslide benches have been identified within this unit, the most significant in terms of the stability of Luccombe Village are:

(a) the Shotover bench; this feature is a possible landslide bench up to 700m in length, below the highest backscar. This bench varies in form from 50m wide and sloping at 5^{o} by Shotover to over 170m wide, with slopes of $8-11^{o}$, close to Luccombe Farm. In 1973 a site investigation was carried out by Structural Soils Ltd to establish the ground conditions around the, then proposed, New Bungalow. This investigation involved two shell and auger boreholes to a depth of 7.6m, which revealed an uninterrupted sequence of weathered siltstones with thin clay layers;

(b) a 75m wide almost flat-topped bench in Luccombe Village. The following houses have been built on this feature; Corydon, Muffets, the Retreat, Little Tawny, Dawn View, Daylesford and Merrydown. Of particular significance is the presence of a small graben-like feature in front of Corydon, wich continues into the adjacent allotments;

(c) the Genesta bench; this is a 225m long, 25m wide bench which lies below the front scarp of the Highway bench. Genesta, Manana and Luccombe Haven have been built on this feature;

(d) Sea Tang bench; Sea Tang has been built on a 50m wide bench with $4-6^{o}$ slopes;

(e) Sunnyholme bench; Sunnyholme has been constructed on a narrow, 50m wide, bench. The north and east margins of this bench have been considerably modified by recent landslide activity. It is probable that Sunnyholme and Sea Tang benches are parts of an originally continuous bench which was subsequently degraded, particularly in the Palm Gardens area;

The variation in present-day form of the blocks in the Luccombe Farm-Luccombe Village landslide should not be viewed as reflecting different modes of formation, rather as due to the extent of subsequent degradation. It is important to note that the degree of block disruption increases towards the west i.e. closer to the streams;

(iii) Dunnose Cottage (W); immediately downslope of the backscar there is a gently sloping (4-10°) bench fronted by a 12° scarp. This block has been partially eroded by the two streams which flow into Luccombe Chine;

(iv) Luccombe Farm Cottage (E); this landslide unit is characterised by a series of small linear benches and scarps which become increasingly subdued downslope, towards the toe area of the slide. It should be noted that both this slide and Dunnose Cottage (W) are likely to be in a condition of marginal stability due to the removal of landslide debris from the toe areas by the streams.

4.2.4.3 Debris aprons

The lower parts of the two fields south of Luccombe Village are generally low-lying and gently sloping (0-5°), but with distinct local variations in relief, which often result in the ponding of surface water during the winter. It is probable that the ridges and troughs in this zone are the subdued remnants of a range of landslide features, including:

(i) toe features of the major rotational slides;

(ii) lobes of debris from shallow translational failures and mudslides off the front of the rotational blocks;

(iii) pressure ridges formed by translational failure of the landslide debris and the underlying Gault Clay;

(iv) small-scale horsts and grabens formed by spreading failure of the debris.

This apron of landslide debris represents the former accumulation zone for both fans of coombe rock from Luccombe Coombe and the degrading ancient rotational landslides. There is likely to be considerable variation in the depth of material above the in-situ Gault Clay. This zone was previously more widespread and would have probably extended in front of Luccombe Village itself. However, subsequent to the formation of these aprons there has been significant erosion as a result of contemporary landslide activity stimulated by the recession of the coastal cliffs.

A clear parallel can be drawn between these aprons and the similar, albeit younger, features found close to sea-level along the Undercliff, for example, at St Catherine's Point, Ventnor and Bonchurch (Hutchinson, 1965; Chandler, 1984; Hutchinson, 1987a). At these sites the presence of such aprons has been recognised as having a major influence on the present-day stability of the Undercliff landslides by providing toe support and reducing the overall steepness of the profile (Hutchinson et al., 1985).

4.2.4.4 Contemporary degradation zone

This zone represents the upslope extent of contemporary landslide activity, and is characterised by a series of part-translational, part-succesive rotational failures in both landslide debris and the underlying in-situ Gault Clay, in response to continuing sea-cliff retreat caused by marine erosion.

In general, the zone can be sub-divided as follows:

(i) areas of low-angle failures (slope angles: $1-12^{o}$) involving landslide debris from earlier failures and, possibly, the upper, plastic zone of the Gault Clay. The main areas of this type of failure are:

- the grounds of Palm Gardens;
- around the coastal path, east of Greenroofs and Sunnyholme;
- east of Luccombe Road;
- north of Luccombe Chine House;

(ii) areas of higher angle failures (slope angles: $19-28^{o}$), probably involving the silty lower unit of the Gault Clay. This zone has a higher angle of shearing resistance than the more plastic, upper part of the Gault. This type of failure is common close to the cliff edge, especially south of New House.

This degradation zone acts as a debris transport slope, moving landslide material away from the block zone and debris apron towards the Lower Greensand cliffs. The debris then falls over the cliff edge and forms temporary accumulations on the undercliff benches.

At present this zone is actively unstable in the following locations:

- in a broad zone, approximately 150m wide between The Chalet and Luccombe Road turning point (the nature of the recent landslide activity in this area is discussed in more detail in section 6);
- movement has taken place on Luccombe Road, and between Merrydown and Upalong;
- in front of Luccombe Tea Gardens, where there has been a recent series of retrogressive movements within a high-angle (c. 20°) mudslide system (cracks have appeared within the lawn area in front of the tea shop);
- there is a small active mudslide unit on the cliff edge, approximately 50m north of Luccombe Chine.

It is important to note that, with the exception of the mudslide north of Luccombe Chine, active movement appears to be concentrated around built up areas, and that the active zone in Luccombe Village extends inland further than at any other point.

It is probable that much of the contemporary degradation zone has experienced landslide movements over the last 100 years or so, although it appears that many former slide units have now stabilised and are under a dense vegetation cover.

4.2.5 The sea-cliffs

The sea-cliffs are developed in the alternating sequence of sandstones and clays of the Lower Greensand Carstone, Sandrock and Ferruginous Sands. However, over much of the section between Luccombe Chine and Luccombe Village the cliff top is developed in the lower, silty unit of the Gault Clay. The cliffs vary in height from around 60m at Luccombe Chine to 85m east of Luccombe Village, declining again towards Shanklin. It is likely that the trend of the cliff line is controlled by the orientation of powerful, easterly dipping, joints which strike at $024^{o} \pm 5^{o}$ (section 2.2).

The cliffs comprise a series of lithologically controlled benches or 'undercliffs' which are covered by spreads of landslide debris that has spilled over the cliffs above:

(i) the lowest bench marks the boundary of the Ferruginous Sands and the overlying Sandrock. This feature is around 25m wide and has been developed on the bed of grey sandy clay at the top of the Ferruginous Sands, rising above sea-level around 300m north of Luccombe Chine;

(ii) the lowest clay unit within the Sandrock (Bed 2b, section 2.12) forms a distinct (20-30m wide) bench which rises from around 12m at Luccombe Chine to 30m above Yellow Ledge;

(iii) a third bench coincides with the upper clay unit of the Sandrock (Bed 2d, section 2.1.2). This is a discontinuous, narrow (10-15m wide) feature which is absent below Luccombe Village.

The alternations of weakly cemented sands and clays has led to the development of perched water tables as indicated by seepage lines at the back of each of the benches. It is possible that this seepage may result in back-sapping within the sands followed by the undermining and subsequent collapse of the strata above. This process of seepage erosion has been a major influence on the development of the characteristic 'undercliff' form of the Chale cliffs west of Blackgang (Hutchinson et al., 1981).

The main types of undercliff failure are:

(i) **rock falls and topples** off the Sandrock, which detach from the cliff probably as a result of weathering of joints and stress relief;

(ii) **large block failures** of the Sandrock that are high-angle ($60-70^{o}$) rock slides in which the blocks slowly subside due to the gradual loss of support at the base, possibly in response to seepage erosion;

(iii) **shallow mudslides;** these transport debris across each of the undercliff benches, which then spills over onto the lower bench or, finally, the shore;

(iv) **rotational failures;** a large rotational failure has disrupted the Ferruginous Sands bench and also partially affected the seaward margin of the lower Sandrock bench. This failure is approximately 300m in width and stretches from where the Ferruginous Sands rise above sea-level to 50m south of Yellow Ledge. It is probable that this landslide has been caused by basal failure of the Clay bed at the top of this formation, in response to a combination of marine undercutting and high pore-water pressures. Much of the morphology of this landslide has been obscured by the spreads of debris that have spilled over the cliffs in recent years.

4.2.6 The beach/near-shore zone

The beach below the Lower Greensand cliffs slopes gently seaward, with an intertidal zone width of between 40-80m. A 5-10m wide strip of shingle and small boulders forms a storm beach above the high water mark, and provides a degree of protection to the cliffs. However, marine undercutting remains a significant cause of the cliff retreat, as indicated by the almost continuous wave-cut notch at the base of the cliff and the trimming of the debris lobes in front of the basal slip (see section 4.2.5).

From Luccombe Chine to approximately 400m south of Yellow Ledge, the intertidal zone comprises small boulders and shingle, whereas north of this point the beach is sandy with only occasional patches of boulders. Horse Ledge and Yellow Ledge are shore platforms cut by wave action on the *Exogyra* Beds and argillaceous greensand bed of the Ferruginous Sands, respectively (see section 2.1.1).

The direction of littoral drift is eastwards along the Undercliff and northwards into Sandown Bay. However, only small quantities of shingle from the cliffs between Ventnor and Bonchurch are present in Luccombe Bay, with the source of this material now protected (Barrett, 1985). Large quantities of beach material are produced by the Lower Greensand cliffs between Dunnose and Shanklin which erode at an average rate of 0.3m p.a. (Barrett, 1985). Between Luccombe Chine and Horse Ledge, three steel groynes have been constructed to restrict the northwards littoral drift.

CHAPTER 5
HISTORY OF LANDSLIDING

5.1 REPORTED LANDSLIDE ACTIVITY

The recent history of landsliding within the Luccombe Coombe area has been established from a number of sources:

(i) a systematic search of local newspapers from 1900-1988, including the Isle of Wight Chronicle and Mercury (Ventnor);

(ii) analysis of engravings, postcards and photographs from 1839-1988;

(iii) additional sources such as council minutes and damage plans, consultants reports, Ordnance Survey 25 inch to 1 mile topographic maps and information provided by Luccombe Residents Association.

The general development of the area between Luccombe Chine and Luccombe Village is presented in Table A (see Annex C). A small fishing community existed on the foreshore below Luccombe Chine. This settlement was destroyed by the 'Great Landslip' of 1910 (see below and Plates 1-4, Annex A). The ground seaward of the coastal path was known as Luccombe Common and in the 1920's this area was open grassland, with clear views over the sea-cliffs (Plate 8, Annex A). Luccombe Village itself was developed mainly between 1927-1936 on open grassland above Knock Cliff (Plates 7 and 8, Annex A).

Photographic and newspaper evidence of recorded landslide activity this century, within Luccombe Coombe, is presented in Tables B and C respectively (see Annex C) and is summarised in Table 5.1 which highlights a number of important points:

(a) landslide movements have been recorded in four main areas:

  (i) The Landslip;
  (ii) Luccombe Chine;

DATE	LOCATION	TYPES	EXTENT	COMMENTS	SOURCES	PLATE
1839	Luccombe Chine	R/TS	S	Unstable cliffs and Undercliff affecting small fishing community.	Brannon Engraving	1
c.1890's	Luccombe Chine	R	S	Minor instability affecting small fishing community - 5 houses.	Early photograph	2
c.1900's	Luccombe Chine	R, TR	M	Two cottages at risk from failure of Undercliff north of Chine.	Photograph	3
1904	The Landslip	TR	M	Active mudsliding at coastal margin of the Landslip	Postcard	4
1910	Luccombe Chine	TR	E	Associated with reactivation of the Landslip the community at Luccombe Chine was affected by movements at Bordwood Ledge.	Postcards	5
1910	Luccombe Chine	R	M	Fall of cliff damaged several cottages and exposed a smuggler's cave which was thought to have caused the landslide.	Local press	
c.1920	Luccombe Common	TR	M	Serious landslide near Luccombe Tea Rooms with prominent tension shears, broken ground and trees.	Postcards	6
1923	Luccombe Chine	TR, R	S	A midden was cut into by a slide in 1923 and finally destroyed by a landslide in 1931.	Poole and Dunning (1937)	
1925	Luccombe Chine	R	S	A small rockfall occurred in the Chine.	Local press	
1932	Luccombe Village	TR	M, N	Following development of new village at Luccombe pre-existing tension scars exposed near Little Tawny and Dawn View.	Photograph	7
c.1940	Luccombe Village	TR	S	Evidence of landslide damage to vegetation between access road and the cliff edge fronting the village.	Photograph	8
1950	Luccombe Common	TR	M	Landslide damage near Luccombe Tea Rooms similar to event in 1920. Tension scars and very broken ground and trees evident.	Postcard	
1950	Luccombe Village	TR	M	"A landslide took place in the Luccombe village area".	Local press	

TYPES R= Rockfall/slide TR = Translational/rotational TS = Talus/scree
EXTENT S = Small(localised rockfall) M = Major landslide, discrete boundaries E = Extensive landslide N = Non-active

Table 5.1 Summary of recorded landslide events within the study area.

(iii) Luccombe Common;
(iv) Luccombe Village.

It should be noted that although there are no **reported** failures of the sea-cliffs between Luccombe Chine and Knock Cliff, it is clear that there has been significant cliff retreat over the period (see section 5.2);

(b) there is evidence of possible ground movement within Luccombe Village as early as around 1932 (Plate 7, Annex A), with tension scars exposed below Little Tawny, The Retreat and Dawn View;

(c) the types of recorded landslide activity range from rockfalls off the sea-cliffs, which in 1910 destroyed the settlement below Luccombe Chine (Plate 4, annex A) to part translational, part rotational slides below Luccombe Village and the coastal path;

(d) movements appear to occur mainly during the winter months, particularly January and February e.g. 1910, 1925, 1950, 1951.

During the period 1950-1988, Luccombe Village experienced three major phases of landsliding (in 1950/1951, 1961 and 1988). The extent of the 1951 and 1961 phases of landsliding was recorded by the Local Authority (Figure 5.1). Postcards and photographs show the nature of movements and damage in 1950/1951 (Plates 9 to 16, Annex A). These movements, especially the 1950/1951 sliding were reported in the local newspapers which give an indication of the nature and extent of the resulting damage (Table 5.2). The following points are noted:

(i) **1950/1951 slippage;** the local surveyor's plan (Figure 5.1) indicates that the major movements and subsidence occurred along the coastal access road to the village. The main tension scar extended from the 'Whine' to 'Broom Brae', delimiting the area of most active landsliding. In addition, a secondary tension scar opened further inland extending from Luccombe road to 'Dawn View' and 'Roseacre'. This scarp is possibly an extension of

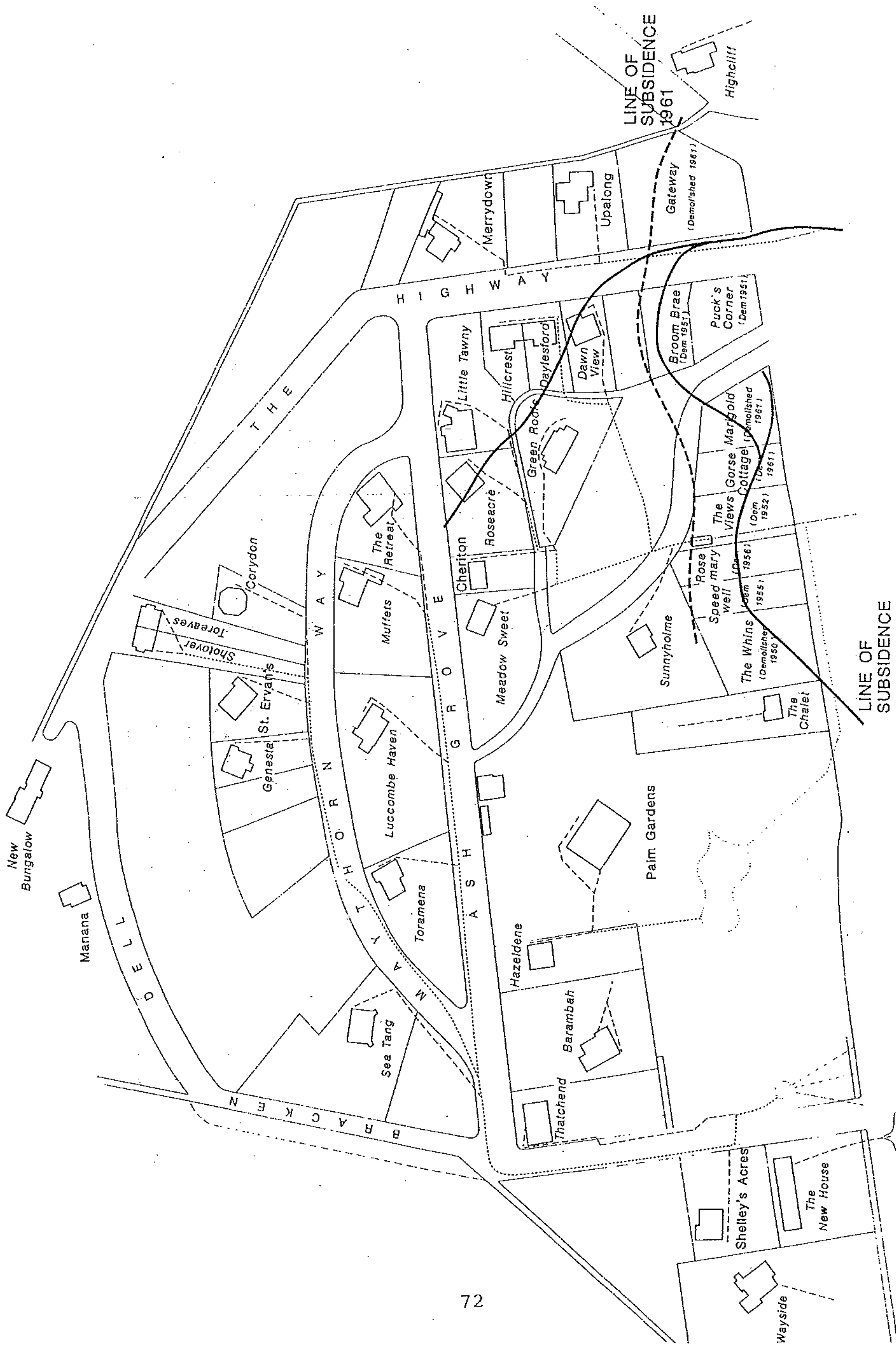


Figure 5.1 Surveyor's plan of landslide extent in 1950 and 1961.

Date	Comments	Source
16. 2.1950	A landslide took place in the Luccombe village area.	I.W. Guardian
11. 1.1951	A further landslide at Luccombe village. Local residents considered Luccombe had been on the move for a number of years. Major damage caused to roads and pathways on Sunday and Monday last.	
11. 1.1951	Surveyor to report on suitable methods for marking footpath limits. Contributions invited for the cost of a light and necessary maintenance work to the roadway between The Priory and Highcliff.	I.W. Chronicle
13. 1.1951	Luccombe subsidences. Width of access road reduced to 4 yards in places, and nearby cracks suggest that more land is likely to slip. Council seeking legal advice.	I.W. County Press
15. 1.1951	Threat to island village.	Portsmouth Eve. News
18. 1.1951	Luccombe village isolated. During the past week widening fissures have appeared, accompanied by deep subsidence.	I.W. Guardian
15. 2.1951	Further subsidence at Isle of Wight village. Aggravated by recent heavy rainfall the entire section of land fronting Luccombe village has slipped considerably nearer the sea in the last few days. Mrs Chappel of The Chalet was the second resident of the village in 1924.	Portsmouth News.
1. 3.1951	Luccombe village appeal. The Local Planning Authority considered that further building should be barred and existing consents revoked. The route of the new access road will be placed higher up than originally planned, in order to avoid further subsidences.	I.W. Chronicle
3. 3.1951	New access road for Luccombe.	I.W. County Press
17. 3.1951	Twenty four residents in the village have signed an undertaking to contribute to the cost of the proposed new access road. Tenders are being considered.	I.W. County Press
12. 4.1951	Houses in Luccombe affected by land subsidences may have to be demolished and re-erected elsewhere in the district.	I.W. Chronicle
12. 5.1951	Luccombe village housing. Twelve additional building licences granted by the Council to enable owners of damaged houses in Luccombe to build elsewhere in the district.	
15. 7.1951	Further serious landslides at Luccombe. Aggravated by heavy rainfalls which took place towards the end of last week, the whole section of land fronting the village moved several feet nearer the sea. Pipes leading to cess-pools also broke with the movement. About one hundred property owners and occupiers met members of Sandown and Shanklin U.D.C.	I.W. Guardian
15. 7.1951	Former development consents for 1935-49 to be revoked.	I.W. Chronicle
22. 7.1951	Villagers vacate homes after further land subsidences. Local Authority will contribute 2/3 of the cost of the new access road to be constructed in the near future. Heavy rainfalls last week have caused further slips and crack widening. Several residents have been advised to vacate their homes; two homes 'Speedwell' and 'Rosemary' were "in the front line".	I.W. Guardian
22. 9.1951	Three applications to erect bungalows at Luccombe were unanimously revoked by the County Planning Committee.	I.W. County Press
22. 9.1951	Building banned owing to landslides. Development at Luccombe has been brought to an abrupt halt.	I.W. Guardian
10. 5.1952	Subsidences at Luccombe. The development of building at Luccombe began 30 years ago, and about 50 houses have since been built. The destruction of the road at Luccombe was considerably more gradual than its appearance suggests. There has been no sensational slides, the fastest rate of subsidence being seven inches in one week. The first indication of trouble occurred in the severe winter of 1947-48. The Chalet was the first to be built on the site in 1927.	I.W. County Press
14. 1.1954	Luccombe residents seek landslide compensation. 38 residents signed petition presented to Island M.P. It points out that six people have lost their homes owing to land subsidence.	I.W. Guardian
19. 1.1954	Luccombe appeal to Island M.P.	Portsmouth Eve. News
19. 1.1954	Compensation sought for homes lost in Luccombe subsidence.	Southern Daily Echo
20. 2.1954	Land subsidence compensation.	I.W. County Press
4. 3.1954	Cowes and Ventnor Urban District Council have supported Luccombe residents in their petition requesting support and compensation to victims of land subsidence.	I.W. Guardian
11. 3.1954	Luccombe - No action. Ryde Borough Council have not supported Luccombe residents in their representations to the Government for compensation.	I.W. Guardian
21. 3.1968	Residents may have to face locker system. Owing to the very rough state of the unadopted roads, South Coast Dairies says it is almost impossible to continue a door to door delivery. A suggestion of a bank of individual milk lockers has been submitted for approval.	I.W. Guardian
11. 4.1968	Luccombe milk deliveries.	I.W. Guardian

Table 5.2 Records of landslides and related events in and around Luccombe Village 1950-1987.

the feature identified on photographs in 1932 (see Plate 7, Annex A and (b) above).

A report in the Isle of Wight County Press (10.5.1952) stated that "the first indication of trouble occurred in the severe winter of 1947-1948"; however, no further details were given. It is apparent from many reports that the major landslide damage was caused in the first week of January 1951, although this was preceded by movements in 1950. Ground movements continued into February 1951, "aggravated by heavy rainfall". It is reported (10.5.1952) that there were no "sensational" slides during this phase of landsliding, the fastest rate of subsidence being seven inches in one week. Further serious landslide activity was reported on 15.7.1951 which involved crack widening and 'several feet' of displacement. Heavy rainfall the previous week was considered responsible for the ground movements.

The nature of the ground movements is clearly shown on Plates 9 to 16 (Annex A). The coastal road was badly damaged with tension cracks, subsidence and seaward movements severing access to the village (Plates 9 and 10, Annex A). Some photographs appear to show greater vertical displacement than seaward movement (e.g. Plate 12, Annex A). The principal form of movements appears part rotational and part translational in nature. The ground to the seaward side of the road suffered deep subsidence (greater than 1m) and considerable disruption (Plates 14 and 16, Annex A).

The damage sustained in this phase of landsliding resulted in the demolition of three properties (Broom Brae, Puck's Corner and The Whine). The coastal road was severely disrupted, necessitating the construction of a new access road to the west of the village. In addition, it is likely that considerable damage was caused to pipes connecting properties to septic tanks and domestic services;

(ii) **between 1952-1956** three further properties were demolished (The Views, Rosemary and Speedwell;

Figure 5.1) indicating a continuation of ground movements during this period, although it is likely that the damage to Rosemary and Speedwell mainly occurred in 1951 (Isle of Wight Guardian 22.7.1951);

(iii) **1961;** the local surveyor's plan (Figure 5.1) indicates that the scar feature delimiting the area of most active landsliding extended inland by as much as 22m in 1961. The alignment of this scarp is similar in form to the line of subsidence in 1951, except for a slight extension northwards through the grounds of 'Gateway'. Few reports of value have been found that describe the nature of these movements although they are unlikely to vary from those already described. Hutchinson (1965) notes that movements also took place in December 1960;

(iv) it should be noted that Woodruff (1988a) states that in 1980 a major slide took place in the village which "virtually followed the same line as that of the recent (1988) slip".

Whilst there is a clear relationship between the 1950/1951 and 1961 movements with periods of high rainfall (and hence high groundwater levels), it is clear that significant movements do not appear to happen in every wet year (see section 3.3). Most notably there appears to have been no reported movements in 1976-1977 or 1974-1975, despite having the second and third highest September-January (wet phase) rainfall totals since 1947.

5.2 CLIFF RECESSION EAST OF LUCCOMBE VILLAGE

In addition to periods of high rainfall another major control on landslide movement is the erosion of the sea cliffs which has resulted in the reactivation of the ancient landslide systems on the cliff top (see section 4.2).

The form, rate and nature of recession of this section of sea cliffs has been established from two sources:

(a) a comparison of twenty five inch to 1 mile Ordnance Survey and 1:2,500 scale Huntings Surveys Ltd plans of the area

(b) an analysis of oblique, vertical and ground-based photography.

Figure 5.2 shows the mean high water mark (MHWM) and position of the cliff edge as surveyed by the Ordnance Survey in 1862, 1939 and 1977, and by Huntings Surveys Ltd in 1980. The following points are noted:

(a) there has been around 50m cliff top recession over the period 1862-1980;

(b) this cliff top retreat has been accompanied by a smaller retreat of the MHWM (c. 35m);

(c) the rate of recession appears fairly uniform along the length of sea cliffs, as indicated by the almost parallel retreat. This suggests that the retreat is controlled by high-frequency, small magnitude events which affect the entire length of cliffline;

(d) bearing in mind the variable accuracies of different surveys it appears that there may have been an increase in the mean rate of cliff top and MHWM recession over the last 40 years (Table 5.3). Indeed, cliff top retreat has apparently increased from 15.6cm/yr (1862-1939) to 31.6cm/yr (1939-1977) and 233.3cm/yr (1977-1980). This latter rate should be treated with caution as the 1980 Huntings Survey Ltd map represents a complete resurvey of the area, based on photogrammetry, whereas the 1977 Ordnance Survey maps are likely to have only been revisions of earlier editions;

(e) the average rate of cliff retreat over the period 1862-1980 is 26cm/yr, which is in broad agreement with the figure of 30cm/yr suggested by Barrett (1985).

Table D in Appendix C presents an analysis of photographs of the coastal cliff section for the period 1900-1988. The

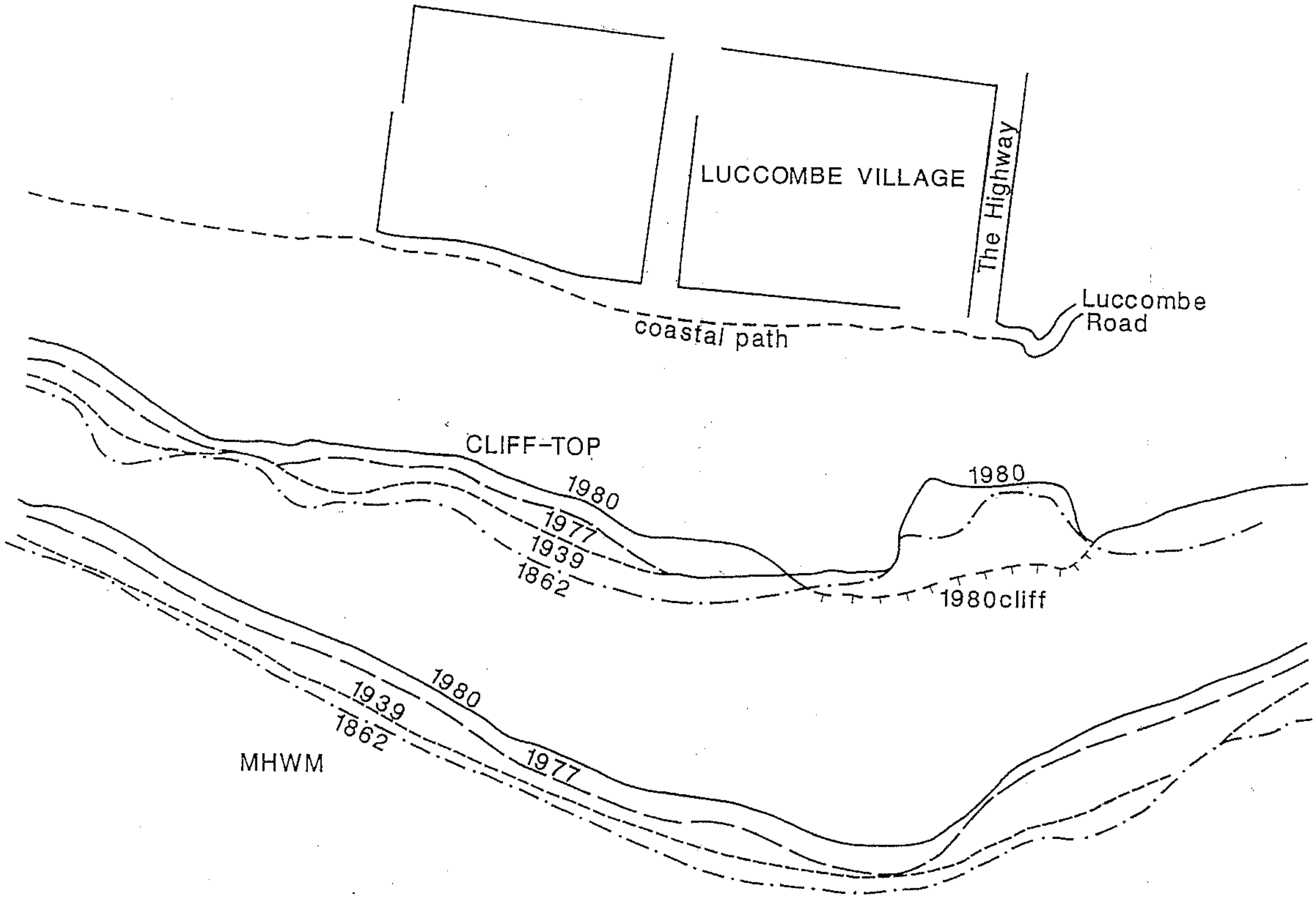


Figure 5.2 Coastal cliff retreat; 1862-1980 (based on Ordnance Survey 25 inch to 1 mile maps, 1862, 1939 and 1977; Huntings Surveys Ltd .1:2,500 scale maps 1980).

Number of Years	Period		Cliff top recession	MHWM recession
77	1862-1939	max	15 m	8 m
	" "	min	0.5 m	1 m
	" "	mean	12 m	6 m
Mean annual recession			**15.6 cm**	**7.8 cm**
38	1939-1977	max	16 m	14 m
	" "	min	0 m	1 m
	" "	mean	12 m	9 m
Mean annual recession			**31.6 cm**	**23.7 cm**
3	1977-1980	max	16 m	12 m
	" "	min	4 m	6 m
	" "	mean	7 m	8 m
Mean annual recession			**233.3 cm**	**266.6 cm**

Table 5.3 Rates of recession of the coastal cliffs east of Luccombe Village.

following points are noted on the nature of cliff erosion beneath Luccombe Village:

(i) throughout the period 1900-1988 the sea cliffs appear to have maintained an overall consistent form, with only minor variations (see section 4.2.5). There appears to have been little disruption to the characteristic 'undercliff' form of lithologically controlled benches and near-vertical faces. The nature of landslide activity also appears consistent, with clear evidence of rock-slides and rockfalls off the Sandrock in most photographs. The large basal failure of the clay bed at the top of the Ferruginous Sands appears to be a long-term form, and not the result of a recent isolated event;

(ii) there appears to have been a marked increase in seepage below Luccombe Village following its development between 1927-1931 (as indicated on the photographs in Annex A). By 1935-1940 several prominent lines of seepage may be identified (Plate 17, Annex A). Over the same period there was an apparent increase in seepage erosion above the lowest Sandrock bench. A photograph taken around 1940 shows major subsidence of the Sandrock and a series of debris lobes on the beach being eroded (Plate 18, Annex A). The dominant type of failure mechanism within the Sandrock appears to be high-angle rock slides rather than rockfalls. Debris movements across the undercliff benches appear to be translational in nature;

(iii) an oblique photograph in 1948 (Plate 19, Annex A) shows an increase in landslide activity on the cliff top east of Luccombe Village. Seepage lines may be seen overflowing most of the section in view;

(iv) in 1951 a major landslide affected all of the ground from the cliff edge to Luccombe Village (Plate 20, Annex A). Many scars are clearly visible (see section 5.1), and the landslide appears retrogressive and translational in character. However, the sea-cliff form shows surprisingly little change, except for the slight extension of debris/talus cones;

(v) vertical photographs taken in 1968 and 1980 by the Ordnance Survey and Huntings Survey Ltd respectively show no significant changes within the Luccombe area;

(vi) a vertical photograph taken on 11.6.1987 clearly shows the extent of earlier landslide activity (Plate 21, Annex A; Figure 6.4) including a scar feature extending from the 'Chalet' to 'Greenroofs' and 'Dawn View'. The Undercliff at this time shows that a lithological bench in the upper section of the Sandrock cliffs had failed forming a rectangular embayment not apparent on earlier photographs. (A section of cliff below the Carstone approximately 14m wide and 100m long appears to have been removed between 1980 and 1987.) A much greater amount of debris mantles the Undercliff and beach below;

(vii) further landslide activity is seen in an oblique photograph taken around July 1987 (Plate 22, Annex A). The amount of debris on the Undercliff and beach appears to have increased. The rearmost tension scar has recessed slightly but the extent of landsliding is not that much greater than in 1951.

The results of this analysis suggest that the characteristic form of the sea-cliff is one of lithologically controlled benches and near-vertical cliff faces. It is likely, therefore, that formative events i.e. those which effectively shape the cliffs, are generally high-frequency small-scale rock slides and rockfalls resulting from weathering, seepage erosion and marine undercutting. These persistent forms, together with the fact that there appears to have been uniform, almost parallel, retreat of the cliffs, suggests that there is little variation in the rate of weathering and landslide activity along the cliff-line, and that over a period of 120 years the cliff system appears to be approaching a state of dynamic equilibrium. The contrast between rates of recession for cliff top and MHWM does suggest that the system may be out of balance. However, in the long-term it is likely that the rates of cliff top and MHWM retreat are similar, and hence, the benches represent a balance between erosion and removal of debris. Such a balance between process and form will only be maintained as long as conditions are constant, and thus, the increase in water seepage through the cliffs below Luccombe Village, since its development, may have initiated an increase in mass movement activity.

In this respect comparisons can be made with the Lower Greensand (Sandrock and Ferruginous Sands) sea-cliffs between Chale and Blackgang Chine where recession rates have increased by around three times over the last 120 years, and the rear scarp and sea cliff generally retreat at different rates (Hutchinson et al., 1981).

5.3 GENERAL MODEL OF LANDSLIDE DEVELOPMENT

On the basis of the geomorphological mapping and the review of historical sources, and by drawing analogies with areas of the Undercliff, it is possible to identify a general model to explain the development of the landslide systems within Luccombe Coombe, and their relationship with the retreat of the Lower Greensand cliffs:

(i) the presence of extensive areas of ancient landsliding within Luccombe Coombe is a reflection of former environmental conditions towards the end of the later cold phases of the Pleistocene, between 18,000-10,000 years ago. Failure of the Upper Greensand strata was probably initiated by a combination of high groundwater levels and the undercutting and steepening of the valley sides by streams flowing out of the coombe. As the streams cut further down through the Upper Greensand strata, longer steeper slopes would have been produced, increasingly susceptible to landslide activity. However, major failure probably only occurred where the Gault Clay was exposed;

(ii) the gradual climatic amelioration at the beginning of the present interglacial phase was accompanied by the cessation of both active stream undercutting and removal of debris from the foot of the slopes, factors which had previously controlled the rate and nature of slope failure. Once the importance of stream action had diminished the landslides would have gradually degraded towards an angle of long-term stability corresponding to the steady-state groundwater conditions and the residual shear strength of the materials (Hutchinson, 1986).

This degradation would have resulted in the accumulation of debris in broad spreads or aprons towards the base of the main landslide system;

(iii) the rapid rise in sea-level during the Flandrian Trangression would have initiated the present phase of rapid retreat of the Lower Greensand sea-cliffs. These cliffs appear to retreat through a combination of rockfalls, rock slides (Plate 23, Annex A) and rotational slides, in response to a combination of two main processes:

(a) marine undercutting at the base of the cliffs

(b) weathering and landslide activity at the back of each undercliff bench. It is possible that seepage erosion may contribute to the failure of the sandstone above each bench.

Debris is transported across each successive bench by a series of shallow translational landslides, and then spills over the front onto the bench below, and ultimately the beach, where it is removed by the sea.

Inspection of photographs of Knock Cliff over the last 100 years suggests that overall cliff retreat may approach a state of dynamic equilibrium. However, the failure of the uppermost bench, below Luccombe Village, in recent years indicates that short-term trends may be more complex;

(iv) as the cliffs have retreated they have removed support to the slopes above and thereby activated a zone of degradation upslope, resulting in the gradual erosion of the debris aprons in front of the ancient landslides. Degradation of these areas has been achieved through a series of retrogressive failures, including:

(a) the development of high-angle "first-time" failures in the lower silty beds of the Gault Clay. These failures generally take the form of mudslides and occur close to the cliff edge;

(b) the reactivation of older failures, along pre-existing shear planes and in remoulded materials. This type of failure tends to occur further inland than the high-angle slides, as movements can be initiated at lower slope angles. Considerable movement of this nature has taken place in and around Luccombe Village where there has been a series of major movements since 1950.

It is clear from the geomorphological mapping that much of this degradation zone has probably experienced landslide activity over the last 100 years or so, as indicated by the freshness of many scarp features below the coastal path. However, recent movements have been confined to a limited number of locations, with much of the area now apparently inactive under dense vegetation cover;

(v) this erosion of the in-situ Gault Clay and the landslide debris aprons has led to the continued unloading of the areas of the main landslide blocks upslope, and has thereby reduced the stability of the whole landslide system. As a result there has been limited renewal of movements, along pre-existing shear surfaces, well away from the degradation zone e.g. in front of Corydon;

(vi) the debris from the recent movements in the degradation zone spills over the cliff top onto the Undercliff benches (Plate 24, Annex A), where it can cause shallow translational failure through undrained loading (Hutchinson, 1987). It is clear that this continual removal of debris over the cliff edge perpetuates the instability in the ancient landslide systems on the cliff top by preventing the build up of a protective debris apron.

It is clear therefore that landslide activity is a common feature within the study area, with the main factors controlling the occurrence of landslides being:

(i) the presence of overconsolidated clays below hard competent rocks (the Gault Clay and Upper Greensand respectively), has led to a landslide prone geological setting;

(ii) the environmental changes which occurred at the end of the Pleistocene period created conditions whereby slopes were more vulnerable to mass movements. Within Luccombe Coombe four main areas of landsliding occurred at this time. These landslides would have gradually degraded to a more stable form;

(iii) following the recovery of sea-levels around 7,000-5,000 years ago rapid erosion of the sea cliffs brought about by a combination of marine erosion and weathering has led to the reactivation of the ancient landslides within Luccombe Coombe.

Over the last 100 years landslide activity within Luccombe Coombe has involved:

(i) rock slides and falls of the sea cliffs e.g. the 1910 landslip at Luccombe Chine;

(ii) degradation of the ancient landslide units on the cliff top through a series of shallow part translational and part rotational landslides e.g. below Luccombe Village where major movements have been reported in 1950/1951, 1961 and 1987/1988,

The likely causes and mechanisms involved in the recent 1987/1988 movements at Luccombe Village are discussed in Part II of this report.

CHAPTER 6
THE 1987-1988 LANDSLIDE MOVEMENTS IN LUCCOMBE VILLAGE

6.1 INTRODUCTION

Between early November 1987 and the end of January 1988 a major phase of landslide activity took place in and around Luccombe Village, which resulted in considerable damage to property. The area affected by these movements is broadly similar to that affected by the 1950/1951 and 1961 phases of landsliding (see Figure 5.1). The nature of damage was recorded by Malcolm Woodruff (Consulting Civil and Structural Engineer) in February 1988 and included:

(i) the coastal path was destroyed, and subsequently replaced;

(ii) the ground adjacent to Dawn View subsided approximately 2-3m, undermining this property which subsequently had to be demolished (Plate 25, Annex A);

(iii) Green Roofs was subject to rotational movement, with the ground subsiding by 0.5m. This property has now been demolished (Plate 26, Annex A);

(iv) The Chalet was undermined, and has been condemned as a dangerous structure (Plate 27, Annex A);

(v) extensive cracking and subsidence occurred in the lower parts of the garden to Sunnyholme (Plate 28, Annex A);

(vi) minor cracking occurred in the gardens of Roseacre and Cheriton.

Damage was also caused by a second area of landslide movement, on the northern side of the village. This slip resulted in cracking to Merrydown and Upalong, the latter being subsequently condemned and demolished.

The sequence of events leading up to and covering the period of ground movements was recorded by Mrs F Longman and Mrs P Roberts of the Luccombe Residents Association and can be summarised as follows:

- November 11 1987; slippage on coastal path and in Sunnyholme's garden;
- January 5 1988; slippage noted in Sunnyholme's garden;
- January 13 1988; slippage below Sunnyholme;
- January 16 1988; water main burst at Cheriton;
- January 20 1988; Sunnyholme's garage affected by subsidence;
- January 23 1988; 'massive' landslip noted, with Dawn View badly affected;
- January 29 1988; further slippage affecting Sunnyholme's garage;
- February 10 1988; cracks noted in gardens at Meadowsweet, Cheriton and Corydon;
- February 12 1988; cracks noted in garden at Roseacre;
- February 13 1988; cracks in garden at Merrydown.

The damage associated with the movements, together with the efforts of the Local Authority and the Residents Association to find a solution to the problem has received considerable newspaper attention, as outlined in Table E in Annex C

In February 1988 South Wight Borough Council commissioned Malcolm Woodruff to carry out a preliminary investigation of the landslide area. This work was followed up by a limited site investigation involving the drilling of five boreholes, of which two were outside the main landslide area. The results of these investigations are discussed in section 6.2.

As part of the present investigation into the nature and extent of landsliding in Luccombe Coombe, an assessment has been made of the visible building damage as a result of landsliding within the village (section 6.3). On the basis of the geomorphological appraisal of the site (see section 4) it has been possible to make a preliminary assessment of the mechanism and cause of the recent movements (sections 6.4 and 6.5).

6.2 PREVIOUS INVESTIGATIONS

In February 1988 Malcolm Woodruff (Consulting Civil and Structural Engineer) was commissioned by South Wight Borough Council to carry out a preliminary investigation of the landslide movements in Luccombe Village. This work was carried out between February 4-11, and involved:

- (i) a walkover survey;
- (ii) inspection of aerial photographs;
- (iii) inspection of previous editions of Ordnance Survey maps;
- (iv) ground survey of a cross-section through the landslide area;
- (v) one hand augered borehole to 5m depth, adjacent to Sunnyholme.

On the basis of this work Woodruff (1988a) reported that:

- (a) the landscape had "been formed by a series of landslips occurring in the Gault Clay carrying away blocks of the overlying Greensand leaving the small 'headland' behind Luccombe defined by the rear scarp of the slips. Most of the Greensand blocks have long since disappeared but it is thought possible that Luccombe Village is itself built on the remains of a number of Greensand blocks";

- (b) the recent continuing activity is superimposed on top of these ancient slips;

- (c) the recent movements followed a similar pattern to those in 1950, 1961 and 1980;

- (d) the failure mechanism was considered to involve:

  - (i) rotational failure in front of a scarp 40m back from the cliff edge;
  - (ii) translational failure further upslope.

Using results from ring shear tests carried out on the Gault Clay at Ventnor, Woodruff (1988a) stated that a residual shearing angle ($\phi'r$) of 11° gives a slope at an angle of 8.5° a Factor of Safety of 1.0, with the water table 5.5m below the ground surface. Potential for more widespread movement exists should the water table rise. All the time that the 'average angle of the slope from a line drawn through the toe of the Gault exceeds 5.5° i.e. a residual angle of phi of 11° with water table near the surface, the potential for movement exists' (Woodruff, 1988a). On the basis of these criteria Woodruff identified two categories of properties at risk from further movements (Figure 6.1):

(a) **houses at less risk from the present slip,** defined as properties 'above a line drawn at 5.5° through the toe of the slope on the cliff' which 1could be affected if the water table is raised high enough for a sufficiently long period due to heavy rainfall' (Woodruff, 1988a);

(b) **houses at most risk from an extension of the present slip;** these properties lie above a line drawn at 8.5° through the toe of the slope.

Woodruff recommended the implementation of a site investigation to determine the depth of the slip, to measure pore water pressures and to allow a stabilisation scheme to be designed and costed. As a result a borehole investigation was commissioned by South Wight Borough Council and carried out by West Wight Drilling under the supervision of Malcolm Woodruff. This investigation involved (Woodruff, 1988c):

(i) shell and auger borings, with continuous U100 sampling at three locations in the landslip area (Figure 6.1):

- on the coastal footpaths (BH1);
- adjacent to the garage at Sunnyholme (BH2);
- adjacent to the entrance of Green Roofs (BH3).

Detailed logs of each of these boreholes are provided in Annex E;

(ii) two piezometers were installed in each borehole; one at the base of the hole and one at the junction of the Gault Clay with the overlying Greensand debris. The results of the monitoring of these piezometers are presented in Table 6.1;

(iii) slip indicators were placed in the deepest piezometer tubes to determine the depths of movement;

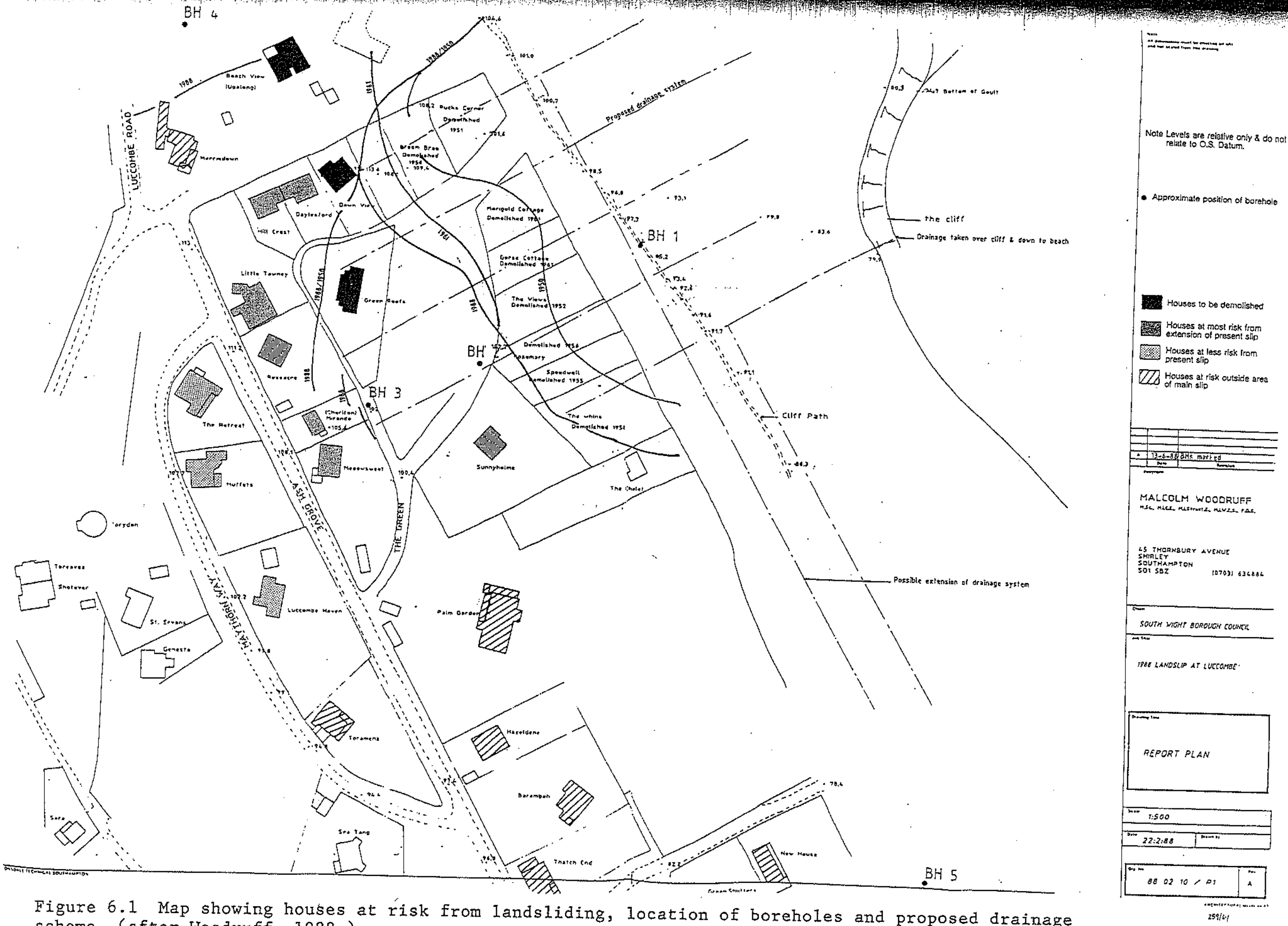


Figure 6.1 Map showing houses at risk from landsliding, location of boreholes and proposed drainage scheme (after Woodruff, 1988c).

	BH 1		BH 2		BH 3	
Depth of piezometer	3.3 m	2.2 m	3.9 m	12.02 m	1.5 m	12.0 m
Date						
24 March 1988	1.40	Dry	2.20	2.40	1.10	10.00
5 April 1988	1.46	Dipper stuck at 5.46 m	1.75	2.18 Dipper sticks at 6.6 m & 10 m	1.40	3.40
19 April 1988	1.53	Abandoned	1.35	2.4	Dry	2.3
25 April 1988	1.79	-	1.80	2.35	1.15 BH contaminated with sewage	2.35

Table 6.1 Piezometer readings (from Woodruff, 1988c).

(iv) ring shear tests were carried out on samples from the slip planes identified in BH1 and BH3 (Table 6.2);

(v) two additional boreholes were put down, north of Merrydown and adjacent to the entrance of Wayside (Figure 6.1);

(vi) an investigation of the foul drainage of those houses affected by the slip (Woodruff, 1988b).

The U100 samples from the boreholes revealed a series of possible slip zones:

(a) BH1 at 11.9m, 14.3m and 16.m (base of the hole at 21.8m
(b) BH2 greater than or equal to 9.8m (base of hole);
(c) BH3 greater than or equal to 11.5m (base of hole).

Slip indicators suggested that movement in BH2 was occurring between 6-10m below ground level. No movement was recorded in BH3 although later results indicate that movement was occurring at 10m depth (Woodruff, pers. comm.). The piezometer in BH1 sheared before the slip indicator was installed.

Stability analyses carried out using the site investigation results indicated that the slide was probably more rotational than previously thought (Figure 6.2) and that the Factor of Safety was particularly sensitive to changes in water table. Drainage of the slide was considered to be relatively straight forward, and Woodruff (1988a) states that lowering the water table by one metre would increase the Factor of Safety by about 10%. A scheme comprising 9m deep drains at 25m spacings, was costed at some £230,000-£310,000 (Woodruff, 1988c). Woodruff (1988c) considered that such a drainage scheme 'would be succesful in stabilising the area reducing the likely movement of the rear of the slip most years to a negligible amount and preventing the further rearward spread of the slip'.

With regard to the reports produced by Woodruff (1988a, c) the following points should be borne in mind:

Normal stress	Stress ratio	$\phi r'$ Degrees
BH 2 DEPTH 16.40 METRES		
100	0.275	15.4
200	0.236	13.3
300	0.227	12.8
400	0.222	12.5
500	0.217	12.2
BH 3 DEPTH 11 METRES		
100	0.221	12.5
200	0.184	10.4
300	0.172	9.77
400	0.162	9.21
500	0.159	9.04

Table 6.2 Ring shear test results, Luccombe (after Woodruff, 1988c).

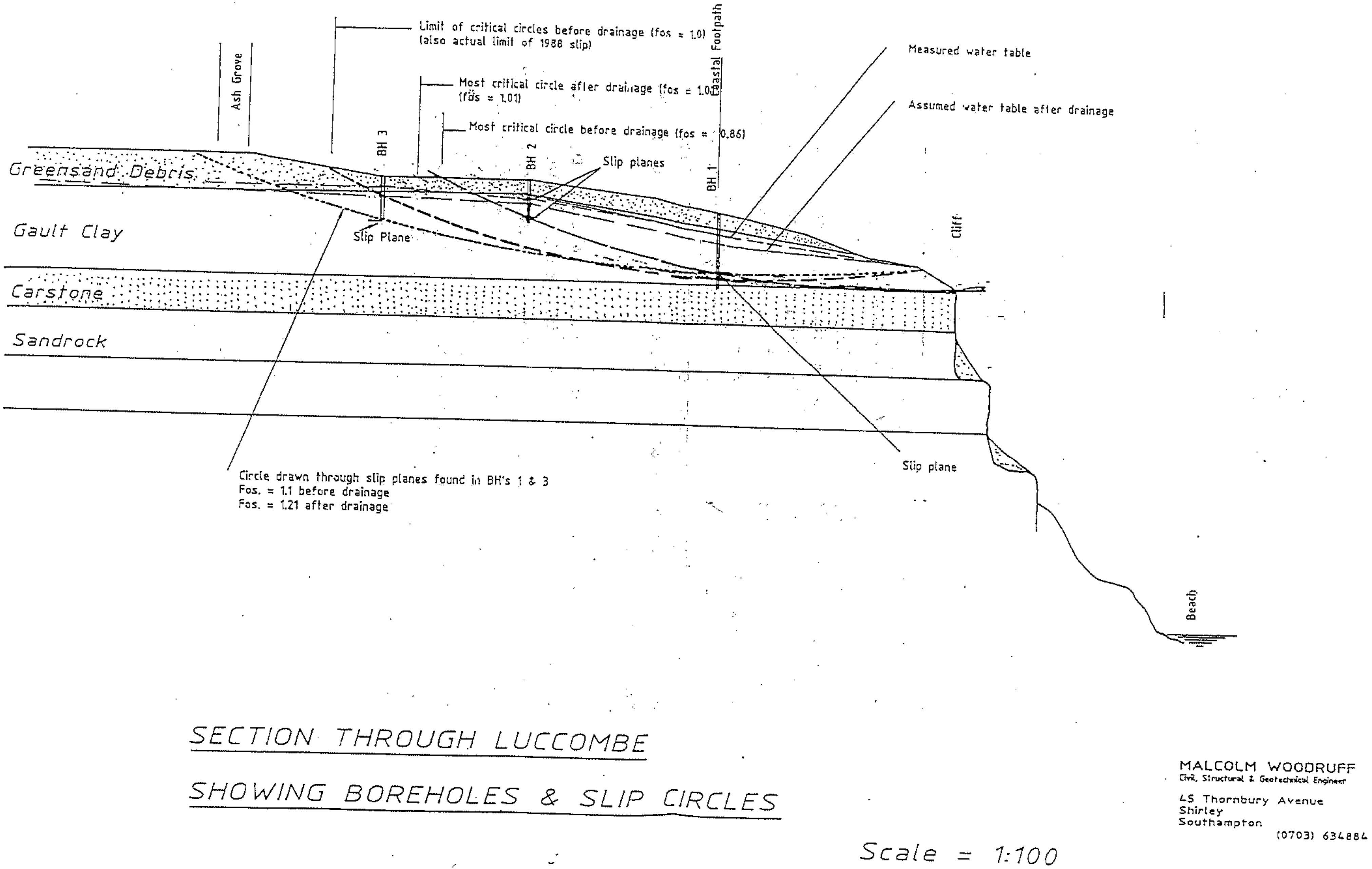


Figure 6.2 Section through Luccombe showing boreholes and possible shear surfaces (after Woodruff, 1988c).

(i) **stratigraphy;** there appears to be a discrepancy concerning the thickness of the Sandrock. As noted in section 2.1.1 White (1921) reported a thickness of 35.8m at Knock Cliff, whereas Chandler (1984) reported a sequence of 43m. However Woodruff (1988a) states that the Sandrock is 28m thick.

Of greater significance is the problem concerning the boundary between the Gault Clay and the Carstone. Woodruff (1988a) states that the boundary of the Gault Clay and Upper Greensand lies at about 110m OD in Luccombe Village, and that the Gault Clay is 44m thick. This would give an expected Gault/Carstone boundary at **66m OD.** However, tachymetric survey measurements carried out by Woodruff indicate that this boundary is at 74.7m (Woodruff, 1988a, Drg. No. 88 02 10/RI). However, Woodruff's measurements are 'relative only and do not relate to the OS datum'. Comparison of spot height values on Woodruff's plan with those on the available 1:2,500 scale plans suggest that Woodruff's heights are consistently 8.3m below OS datum. This correction would produce a Gault/Carstone boundary at **83m OD** i.e. **17m higher than expected.**

The situation is further complicated by the evidence of the site investigation (Woodruff, 1988c). Shell and auger Borehole 1 was located by the coastal path at approximately 104.3m OD (96m on Woodruff's drawing), and recorded the presence of a 'broken sample of crumbly hard dark green grey coarse sandstone' which was identified as Carstone at the base of the hole (21.8m depth) i.e. **at 82.5m OD.**

On the basis of observations made during the course of the present study it is clear that:

(a) the top of the Upper Greensand Chert Beds is approximately 156m OD at the Lynch (Figure 1.2). This would indicate that, taking into consideration the accepted thicknesses of strata and a 1.5^{o}

southerly dip the Gault/Upper Greensand boundary should be at 109m OD and the Gault/Carstone boundary at **65m OD**;

(b) the top of the Ferruginous Sands, by Yellow Ledge, is at approximately 11m OD. Taking the thickness of the Sandrock to be 43m and the Carstone to be 10.5m, this would suggest that the base of the Gault Clay should be anticipated at **approximately 65m OD.** Using the thicknesses of Sandrock suggested by White (1921) and Woodruff (1988a) **would put the boundary even lower.**

It is clear that these discrepancies cannot be explained by a thinning of the Gault Clay by 17m, as this would necessitate an equivalent increase in thickness of either the Upper or Lower Greensand strata. However, as outlined in points (a) and (b) above, this would not conform with the field observations;

(ii) **risk assessment;** the plans produced by Woodruff (1988a) do not conform with accepted definitions of risk (Varnes, 1984), namely that:

Risk = Intensity of Natural Hazard
x concentration of elements at risk
x vulnerability of elements at risk

Risk can therefore be seen as the expected level of damage to property, people injured etc. (Varnes, 1984). In producing his risk map Woodruff takes no consideration of the likely nature and intensity of future movements, nor of the ability of individual buildings to withstand them.

The approach adopted by Woodruff (described earlier) relies on a very simplistic relationship between future slope stability and a limited amount of geotechnical data (not verified in the study area). The approach has not been based on an understanding of the causes and mechanisms of the 1988 movements, nor the nature and extent of relict landslide features which have a considerable bearing on the overall stability of the slopes;

It must be concluded that such a map must be treated as provisional and used with utmost caution.

6.3 ASSESSMENT OF BUILDING DAMAGE

As part of the present study of landsliding within Luccombe Coombe a general assessment was made of building damage within Luccombe Village. This survey was carried out in December 1988 and involved the recording of the visible incidence of cracking and tilt within the village; precise measurements were not made and this survey did not constitute a full structural survey. A photographic record of the characteristic types of recorded damage was made and is presented in Annex B.

The owners of property within Luccombe Village have a natural concern to preserve the capital value of their property. Although damage was noted to every property, albeit to varying degrees, the majority of owners denied that they had any damage, in spite of the fact that repairs could be seen in most cases.

The purpose of this study was to:

(i) determine the extent of contemporary ground movements within the village i.e. since c.1930, based on the structural damage pattern;

(ii) assess the nature of ground movements within this period i.e. rotation (contra-tilt), translational, subsidence and creep movements.

On the basis of the work carried out in this survey, a broad classification of building damage has been established (Figure 6.3):

(i) **properties with no observable damage;** no buildings in Luccombe Village appear to have remained free of damage;

(ii) **properties with damage from ground movement,** as a result of creep and/or differential settlement: The New House, Sea Tang, New Bungalow, Genesta,

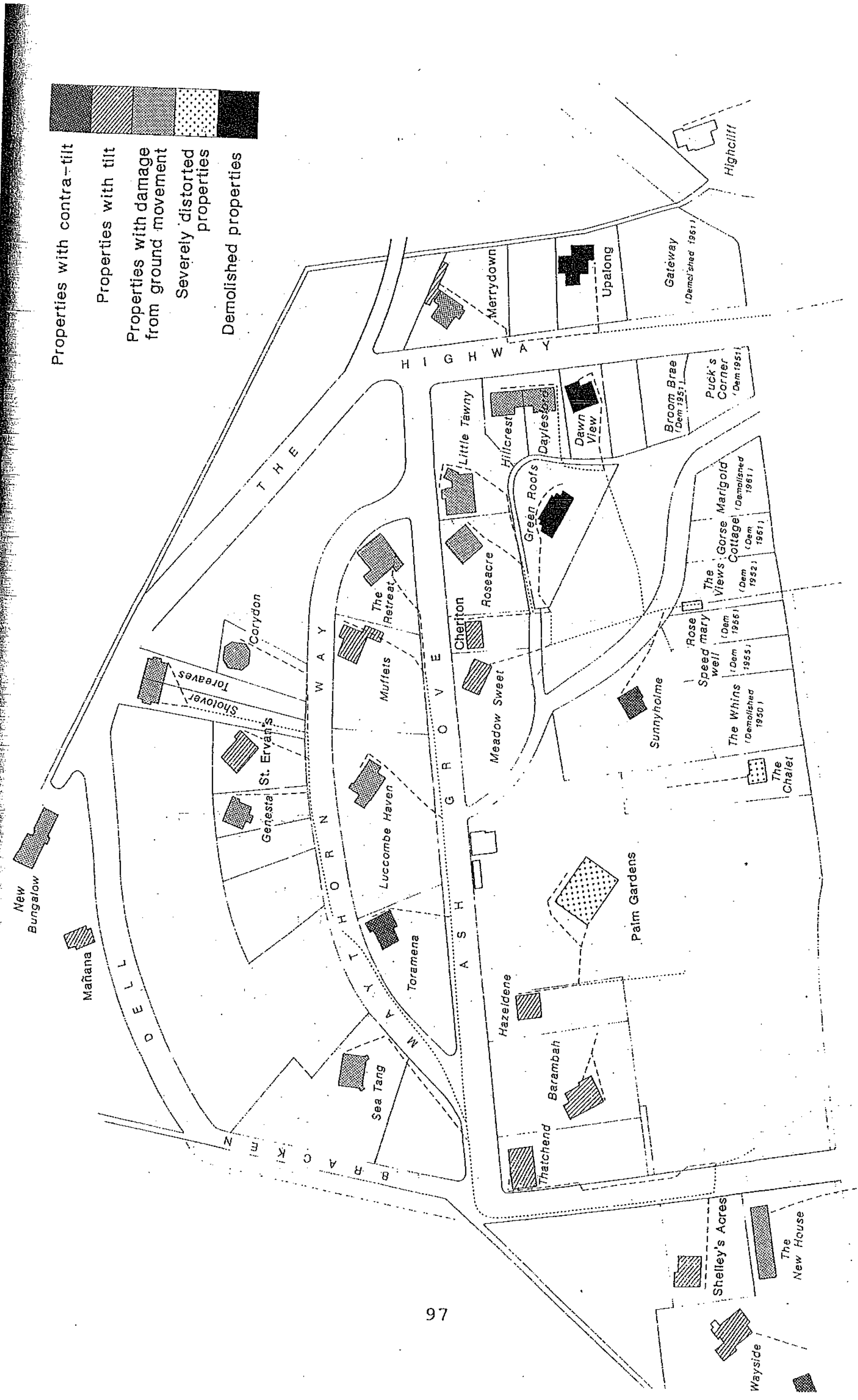


Figure 6.3 Building damage within Luccombe Village.

Shotover, Toreaves, Corydon, Luccombe Haven, The Retreat, Roseacre, Little Tawny, Hillcrest, Daylesford and Merrydown;

(iii) **properties with downslope tilt, and damage from ground movement;** Manana, Thera, Muffets, Meadow Sweet, Cheriton, Hazeldene, Barambah, Thatch End, Shelley's Acres, Wayside and the extension at Merrydown;

(iv) **properties with contra-tilt** i.e. affected by rotational movements; Sunnyholme, Wight House and Luccombe Tea Gardens;

(v) **Severely disorted properties;** Palm Gardens, and Sunnyholme garage;

(vi) **demolished properties;** a total of 13 properties have suffered major damage, have collapsed or have been demolished:

1950 - The Whine
1951 - Broom Brae, Pucks Corner
1952 - The Views
1955 - Speedwell
1956 - Rosemary
1961 - Marigold Cottage, Gorge Cottage, Gateway
1988 - Upalong, Dawn View, Green Roofs, The Chalet.

It is clear that the whole of Luccombe Village has been affected, to a greater or lesser extent, by ground movements. The degree of damage tends to increase downslope from slight ground movements around Shotover, to severe distortions and collapse as at Palm Gardens and Green Roofs respectively. Whilst much of the more visible damage is probably related to periods of significant movement (see section 5.1), it is likely that there have been slow, insidious movements ever since the site was developed in the 1930's. **It is important to note that the amount of movement cannot be readily judged from nature of damage, as some buildings can accommodate much distortion without showing clear signs of damage.**

From the building damage map it is possible to divide the village into four main zones, in terms of the nature of movements:

(i) a zone of severe distortion, coinciding with the area affected by the 1950/1951, 1961 and 1988 major movements;

(ii) a zone of tilt which affects properties built on the Genesta bench (see section 4.2) or on the steep slope immediately upslope i.e. Cheriton, Meadow Sweet, Muffets, Thera and Manana;

(iii) a zone of tilt which affects properties on the southern side of the village i.e. Hazeldene, Barambah, Thatch End, Shelley's Acres and Wayside;

(iv) a zone of minor ground movement and possibly subsidence, which affects properties built on the Highway and Shotover benches (see section 4.2).

There are exceptions to this pattern, most notably the absence of major damage in Sunnyholme, the lack of evidence for tilt at Luccombe Haven and Genesta, and the contra-tilt at the Wight House. However, the survey does clearly indicate that the whole village has been affected by movements, and that there appears to be a clear relationship between the geomorphological setting and the nature of damage.

6.4 NATURE OF FAILURE

It is clear from the geomorphological appraisal of the site, photographic records and eye-witness accounts that the 1987-1988 landslide at Luccombe Village was a reactivation and upslope extension of earlier movements which occurred in 1950/1951 and 1961. This is highlighted in Figure 6.1, which indicates the relative positions of the landslide boundary, as the system has evolved between 1950-1988. The reported pattern of contemporary landslide activity has been described in sections 5.1 and 6.1, but can be summarised as follows:

(a) major movements and subsidence occurred along the coastal access road in 1950/1951. Damage was caused to the buildings immediately above the coastal road, a number of which had to be demolished. A secondary tension scar opened up along a line between the coastal road to Dawn View and Roseacre. This feature is believed to have been a reactivation of a similar scar present on early photographs of the village, taken around 1932 (see Table 5.1, Plate 7, Annex A);

(b) continuing minor movements are believed to have occurred between 1951 and 1960, resulting in further building damage;

(c) in 1960 there was major reactivation of the landslide system, with the boundary of main movement advancing upslope by around 20m. Three houses, built above the former coastal road, were severely damaged by these movements;

(d) Woodruff (1988a) notes that in 1980 a major slip took place in the village. This failure 'virtually followed the same line as that of the recent slip';

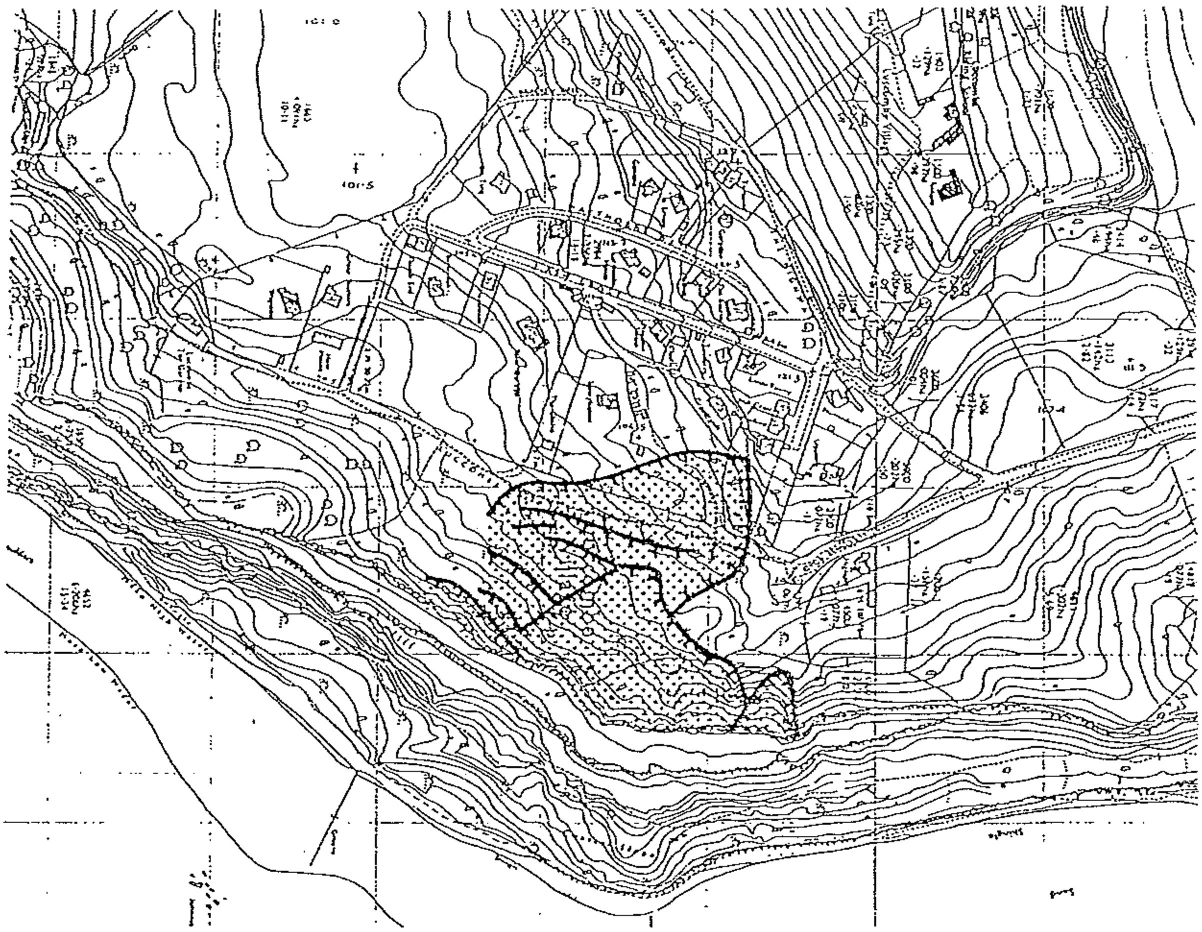
(e) on November 11 1987 slippage was reported both on the coastal path and in the garden below Sunnyholme (Plate 28, Annex A);

(f) minor movements have been reported between January 5-20 1988, mainly below Sunnyholme, with a water main bursting at Cheriton on January 16;

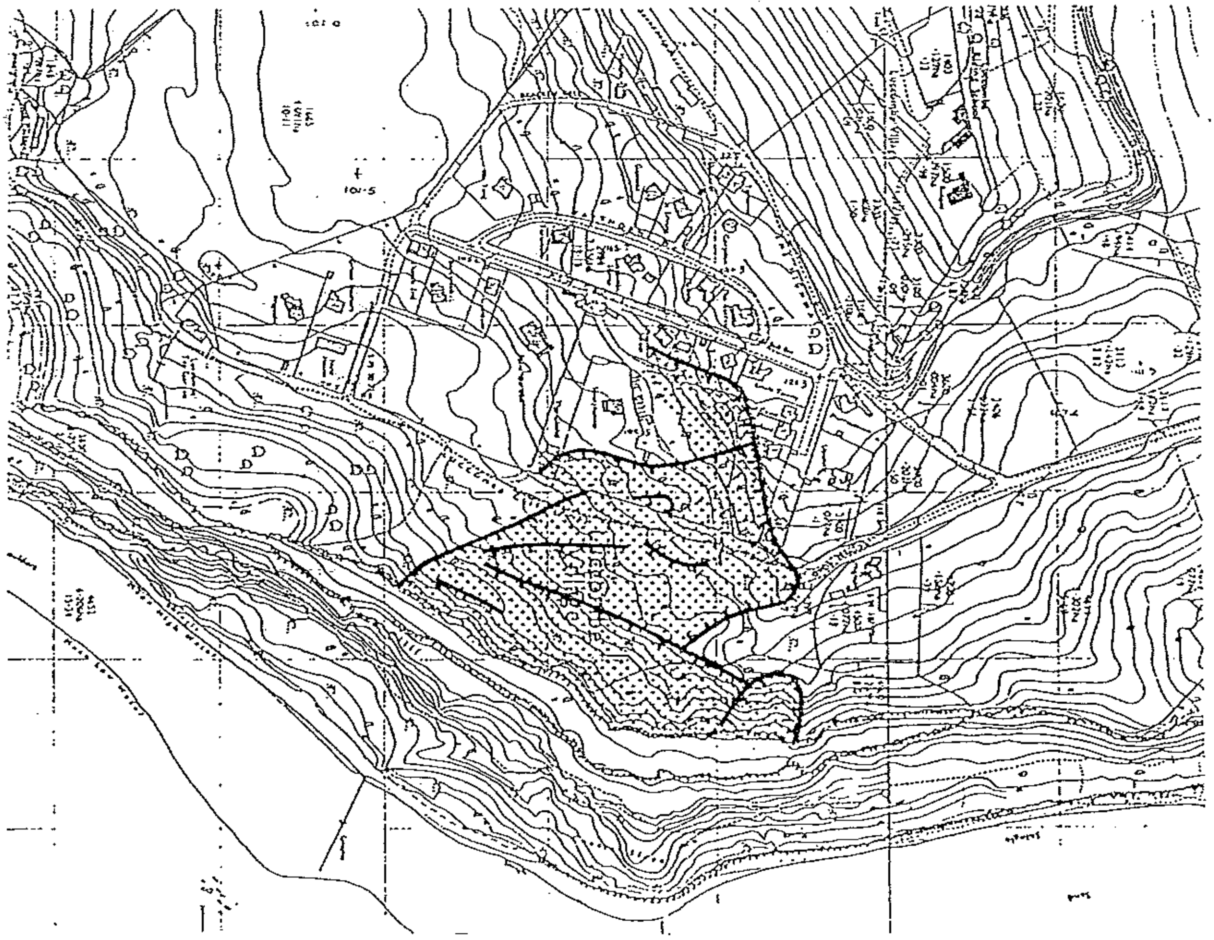
(g) a major movement occurred on January 23 1988 which badly affected Dawn View, and possibly Green Roofs (Plates 25 and 26, Annex A);

(h) further slippage and the opening of tension cracks was noted between January 19 and February 13 1988.

The overall pattern of movement appears to suggest periodic upslope retrogression of the head of the landslide area, and possibly seasonal movements within the centre portions (Wellam, pers. comm.). This is clearly demonstrated in Figure 6.4 which compares the main elements of the 1987-1988 slippage with the pre-existing features as determined from



a) 1987 Extent of landslide



b) 1988 Extent of landslide

Figure 6.4 Comparison of the extent of landsliding in (a) June 1987 and (b) November 1988.

an interpretation of stereo vertical aerial photography taken in June 1987.

Whilst firm statements concerning the failure mechanism cannot be made because of the very limited sub-surface information, it is possible to make a number of general observations:

(i) the materials involved in the landslide are Greensand debris and Gault Clay. The borehole investigation carried out by Woodruff (1988c) showed between 1.3-8.8m of soft green clayey sand and sandy clay (Greensand debris) over structureless stiff grey micaceous clay (Gault Clay).

Index properties for these materials are presented in Table 6.3. Of particular significance is the high plasticity of the Gault Clay from the 2-3m high scarp approximately 40m inland of the sea cliff edge (Plate 30, Annex A; PL = 24%; LL = 61%; PI = 37%). These values suggest that this material is from the upper, plastic zone of the Gault (see Table 2.2; section 2.1);

(ii) different parts of the landslide appear to have moved by different failure mechanisms:

(a) there are clear signs of deep-seated **rotational** movement around the boundary of the landslide, as indicated by the back-tilt of Green Roofs and of blocks in the garden below Sunnyholme (Plate 26, Annex A);

(b) there appears to have been a failure of the scarp feature below Dawn View, with probably up to 5m of ground subsiding in a single event, resulting in an almost vertical face, 4-5m high, in Greensand debris. It is likely that the failure at this point was restricted to the debris, and was in the form of a **slump** of material onto the main landslide unit (Plate 25, Annex A);

(c) **uplift** has probably occurred above the coastal path, in a small area approximately 75-100m south

Material	% MC	LL %	PL %	PI %
1. GAULT CLAY (92m OD from 2-3m high scarp above cliff top)	21.6	61	24	37
2. GAULT CLAY (remoulded landslide debris)	30.3	52	23	29
3. UPPER GREENSAND (landslide debris)	24.3	33	26	7

MC = Moisture content
PL = Plastic limit
LL = Liquid limit
PI = Plasticity index

Table 6.3 Soil test results.

of the turning point (Plate 31, Annex A). Little downslope movement appears to have occurred in this zone;

(d) below the coastal path there is a 50m wide zone of severely distorted ground characterised by minor scars and ridges of debris. It is possible to identify evidence for both **translational** and **spreading** failures in this zone. The downslope extent of this zone is marked by a distinct, almost continuous scarp feature, approximately 2-3m high (Plate 30, Annex A; Figure 6.4 (b));

(e) below the 2-3m high scarp there has been considerable movement of material, mainly through **translational** failures, resulting in the spilling of debris over the cliff top. It is likely that much of the material at present in this zone has slipped over the scarp feature from the translational/spreading failure zone above i.e. the movements below the scarp are related to, but not part of, the main landslide;

(iii) the direction of movement, as ascertained from ground evidence and photographs, is shown in Figure 6.5, which reveals that:

(a) the direction of the rotational failure appears to be towards the SE, with the centre-line passing between Green Roofs and Dawn View;

(b) the slumping off the scarp below Dawn View appears to have been in a SSE direction, normal to the line of the scarp;

(c) there appears to have been very limited lateral movement in the low area above the coastal path. Indeed, there is still rubble from buildings demolished between 1951 and 1961 in this area, emphasising the lack of rapid movement of debris in this zone;

(d) immediately downslope of the area of uplift, the translational/spreading movements appear to have been toward the SSE, away from the turning

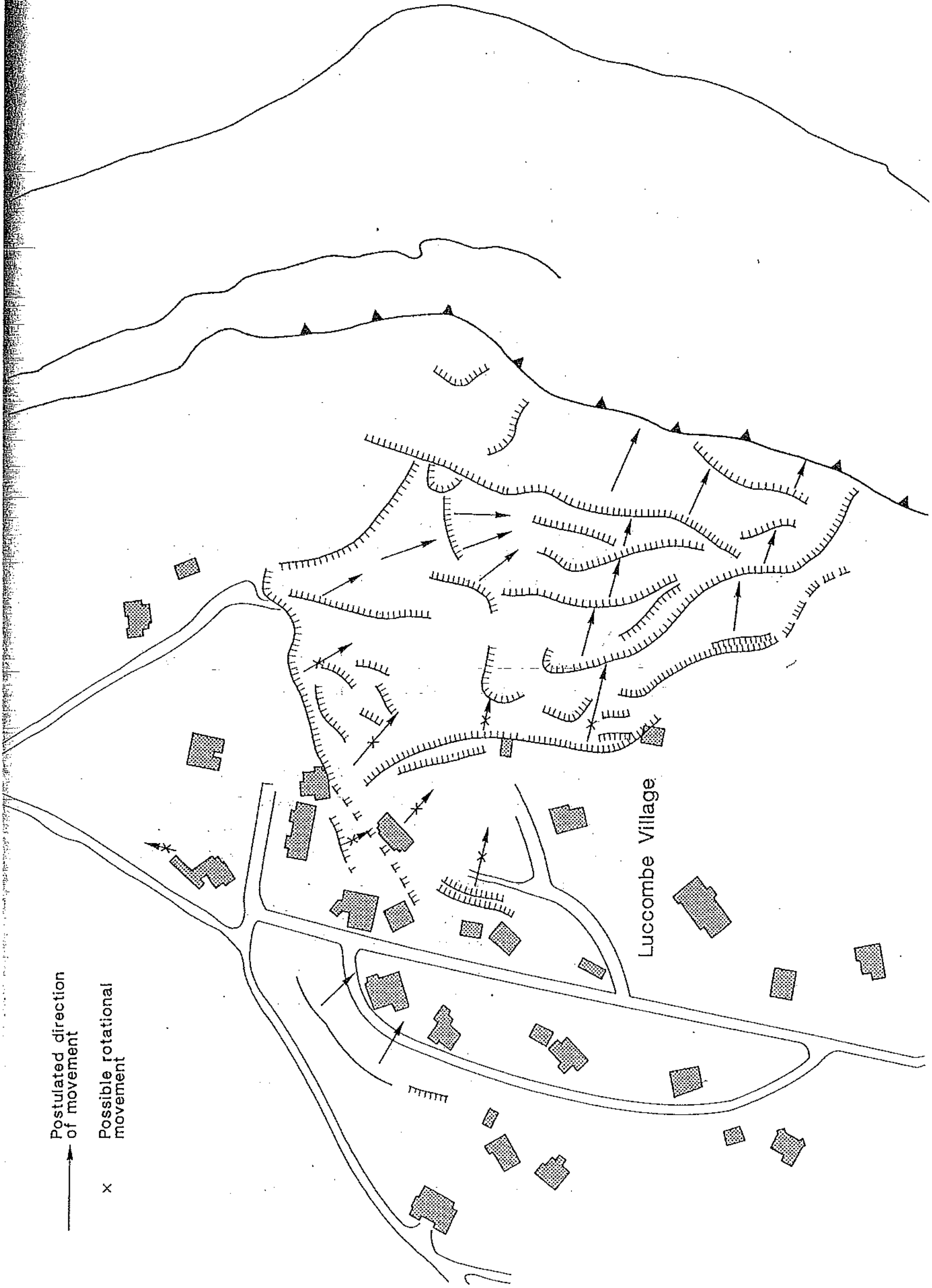


Figure 6.5 Direction of movements, 1988.

point. In places, movement appears to have been sub-parallel with the 2-3m high scarp downslope (Plate 30, Annex A);

(e) immediately downslope of Sunnyholme and The Chalet, the movements above the low scarp were directly towards the cliff top i.e. ESE (Plate 32, Annex A);

(f) all movements below the 2-3m high scarp were directly towards the cliff top i.e. ESE (Plate 32, Annex A);

(iv) the depth of movement i.e. the position of shear planes is known for only three points in the landslide

- borehole 2 near Sunnyholme garage; slip indicators suggested that movement was occurring at between 6-10m below the ground surface i.e. 98-102m OD (Woodruff, 1988c)

- borehole 3, adjacent to Green Roofs; movement was recorded by a slip indicator at 10m depth i.e. 100m OD (Woodruff pers. comm.)

- the landslide material appears to spill over the 2-3m high scarp, 50m east of the coastal path (Plate 30, Annex A). It is therefore assumed that the basal shear surface lies just above this feature, at around 92-98m OD. Assuming that the top of the Gault Clay, in Luccombe Village, is at 110m OD, it is considered likely that the shear surface is located within the upper plastic layer of the Gault, approximately 10m above the lower silty layer (see section 2.1). This suggestion is further supported by the plasticity results from the Gault Clay exposed in the scarp (see (i) above).

However, it should be noted that it is possible that neither BH2 or BH3 reached the basal shear surface of the recent movements.

It is clear that the 1987-1988 movements are complex in form, involving both rotational and translational elements. It is considered likely that the overall form of the landslide is that of a **compound** landslide, defined by Hutchinson (1988) as 'characterised by markedly non-circular slip surfaces formed from a combination of a steep, curved or planar rearward part and a flatter sole'.

A schematic cross-section through the landslide is presented in Figure 6.6, which shows the slide as comprising a rotational failure at the head, and a translational failure downslope. The depth of movement is considered to be at least 10m, with an overall length of c.150m. The resulting d/L ratio of 0.08 is particularly low, although the d/L in the rotational part of the slip is 0.16.

A characteristic of this form of landslide is that the mass cannot fail without prior deformation along internal shear planes to produce a 'kinematically admissible mechanism' (Hutchinson, 1987b, 1988), and it is possible that there would have been a period of deformation under stress, prior to sudden failure. Such a pattern would fit in with the observed landslide activity, with a long period of small movements before the 'massive' failure of January 23 1988.

It is clear that the 1987-1988 movements occurred along a pre-existing shear surface, related to the 1950/1951, 1961 and 1988 movements. This surface may, in fact, be a relict feature related to the ancient landslide system upon which the village has been developed (see section 4.2). Such a relict shear surface would dip towards the former valley floor of Luccombe Coombe and not necessarily directly towards the present-day sea-cliffs. This would possibly explain the dominance of SSE trending movements, as opposed to SE (directly to the coast).

An important consideration in the landslide mechanism is clearly the significance of toe unloading of the slipped mass. As stated by Hutchinson (1977, 1984a) the toe area of a slide is the most sensitive part to mass shifting, and unloading in this area can lead to very strong renewals of movement in slides on pre-existing shears. Such a condition clearly exists at Luccombe Village, where material in the toe area of the slide is seasonally lost over the cliff top, via the translational slides below the 2-3m high scarp. The

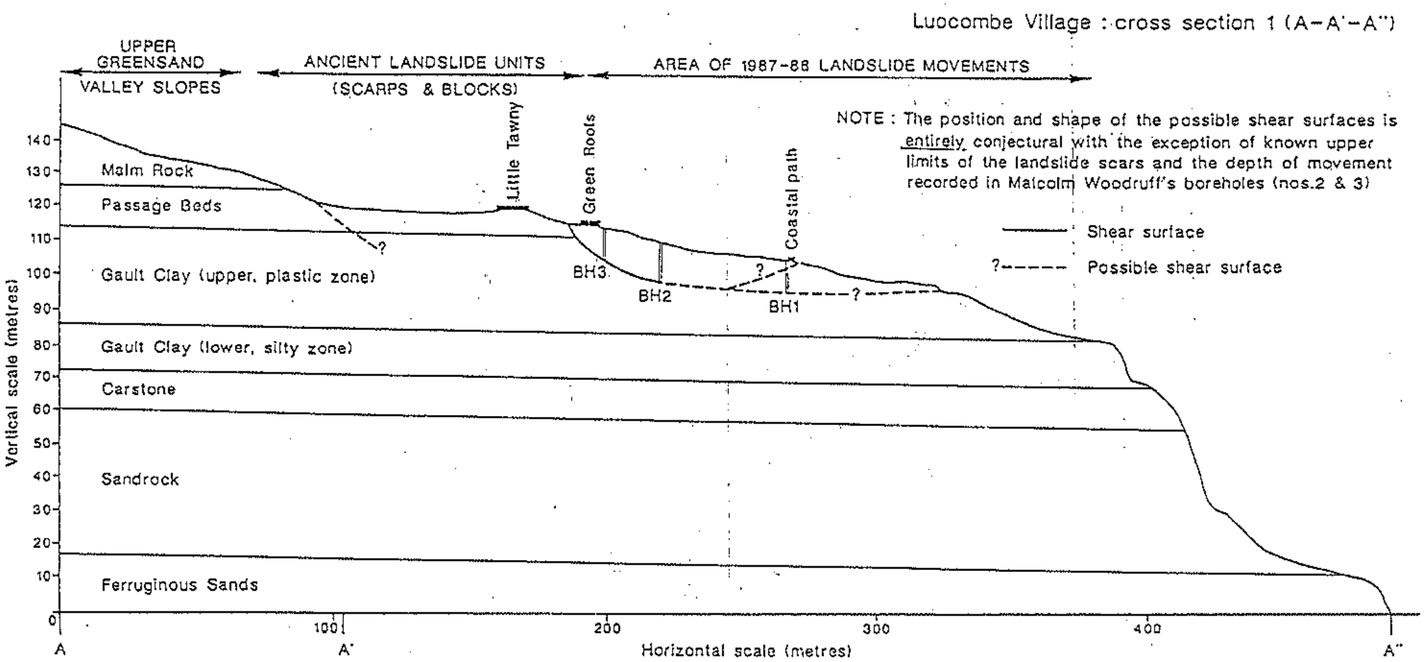


Figure 6.6 Schematic cross-section through the area of recent landsliding.

potential for the unloading is exacerbated by the estimated annual cliff retreat of 0.3m per year, which effectively perpetuates the activity below the coastal path. However, its significance in terms of reactivation of the rotational element of the slide is less clear, especially in the light of the apparently limited lateral movement experienced in this zone since 1961.

As noted in section 6.1 ground movements also occurred outside the landslide area around Corydon and Merrydown. The cracks which appeared in front of Corydon take the form of an upslope-facing small bluff (20-30cm high). This feature, together with the presence of a linear depression between The Highway and The Retreat, is suggestive of an area of extension i.e. The Highway ancient landslide bench is moving slowly downslope, probably in response to the unloading effects of the recent landslide activity below Dawn View and Green Roofs. The cracking between Merrydown and Upalong appears to be associated with relatively deep-seated movements within the Luccombe Road landslide system (see section 4.2.4). As Woodruff (1988a) noted, further movements in this unit could cause serious disruption, not only to the properties but also to Luccombe Road. It is likely that these movements were the result of reactivation of the subdued rotational landslide blocks, again in response to unloading further downslope.

The dramatic nature of ground movements identified within Luccombe Village contrast with those which occur within Ventnor where gradual movements have been widespread (Hutchinson, 1965; Chandler, 1984; Chandler and Hutchinson, 1984). The main form of movement in Ventnor consists of slow intermittent subsidence and seaward movement of parts of the slipped masses forming the Undercliff. Such slow movements have continued intermittently throughout this century causing progressive damage to houses, sewers and the flights of steps connecting the various terraces of the Undercliff (Chandler and Hutchinson, 1984).

6.5 CAUSES

It is important to recognise that Luccombe Village is situated on an ancient landslide system which originated as a result of the environmental changes that occurred at the end of the Pleistocene (around 10,000 years ago). The landslide movements, since 1950 and possibly even earlier, are associated with landsliding along pre-existing shear surfaces within the Gault Clay related to the ancient landslide systems, where the materials are at, or close to, residual strength (see Table 6.2). Hutchinson (1987b) notes that it is a characteristic of landslides on pre-existing shears that movements are usually slow and with relatively limited displacements, as is the case for the slow movements around The Highway. However, in some circumstances large and rapid movements can occur following sudden unloading of the landslide toe as was the case below the coastal path (section 6.4).

The presence of pre-existing shear surfaces must be viewed as central to the whole problem, as it is clear that Luccombe Village has been built on an inherently unstable slope. The factors which have contributed, in varying degrees, to the recent reactivations of the Luccombe Village landslide can be separated into two broad groups: **preparatory factors** that reduce the stability of the slope without actually initiating movement, and **triggering factors** which initiate the movement.

6.5.1 Preparatory factors

Preparatory factors make a slope susceptible to movement without actually initiating it, bringing the slope to a condition of marginal stability whereby a minor change of regular occurrence could precipitate movement. In the case of the Luccombe Village landslide the following three preparatory factors have been identified:

(i) the retreat of the Lower Greensand sea cliffs (c.0.3m pa; Barrett, 1985) has removed support from the ancient landslide systems upslope, thereby initiating a zone of degradation (see sections 4.2 and 5.2). As a result the debris aprons in front of the ancient landslide blocks have been gradually eroded through a series of retrogressive failures. Considerable movement of this nature has taken place in and around Luccombe Village where there have been a series of major reactivations since 1950. The erosion of the debris aprons has led to the unloading of the toe areas of the main ancient landslide blocks upslope, and has progressively reduced the stability of the whole landslide system. As a result there has also been limited renewal of movements, along pre-existing shear planes, well away from the main degradation zone e.g. in front of Corydon.

The seasonal loss of landslide debris over the sea cliffs prevents the accumulation of material in a toe area which would gradually help to stabilise the slope above. Such rapid unloading of the lower parts of the landslide system both perpetuates the activity below the coastal path and provides the necessary conditions for rapid movements along pre-existing shear surfaces (Hutchinson, 1987). Whilst this is a clear control on the development of the lower, translational, element of the landslide, its significance in terms of the reactivation of the upper rotational element of the slide is less clear, especially in light of the apparently limited movement in this zone since 1960.

It is clear, therefore, that slope instability must be seen as a recurring characteristic of the landscape, rather than single isolated events. Sea cliff retreat has reactivated ancient landslide systems on the cliff top and effectively controls the long-term stability of the slopes within Luccombe Coombe;

(ii) building development; the Luccombe Village site has been extensively developed since around 1930. Level plots for houses will have been formed by means of cutting and filling the slopes. Similar works will have been carried out to lay roads. Water, drainage and service pipes have been laid, ponds have been built and gardens terraced. All these operations will have interefered with the natural drainage of the site. Additionally many hardstandings, paths and landscape features will have formed catchment areas for rainfall; all will have concentrated drainage artificially onto a limited number of points in the ground.

It is likely that all these operations will have affected the slope stability. Indeed, there is evidence of ground movement within Luccombe Village as early as around 1932 (Plate 7, Annex A) with tension scars exposed below Little Tawny, The Retreat and Dawn View.

There appears to have been little maintenance of the surface water drainage in the village; rubble drains are infilled with debris, ponds formed in the landslide area remain undrained and, in places, drainage outlet pipes appear to discharge directly onto the landslide.

Experience from work carried out in Ventnor suggests that historically, property owners had full knowledge of the importance of carefully maintained drainage system. However, within Luccombe Village, the mobility of the population may have contributed to the limited maintenance of the drainage;

(iii) water supply leakage; Luccombe Village is supplied with water from a supply tank close to the Riding School. Southern Water Authority have recently monitored the discharge of water from this supply tank over a 24 hour period in November 1988 (Figure 6.7). The flow chart shows a peak demand of 0.55 litres/sec between 8-9 a.m., 0.2-0.3 litres/sec between 9 a.m. to 1 p.m., roughly 0.15-0.2 litres/sec between 1 p.m. and midnight and a residual demand of 0.05 litres/sec between midnight and 7 a.m. The latter figure, the equivalent of 4,320 litres per day, may be considered to be leakage from the supply network within Luccombe Village i.e. 29% of the total water supplied during the day (c.15,000 litres) is lost through leakage.

Water meters have recently been installed for eight properties within the village. These have been read by the residents to allow an assessment to be made of the actual consumption of water by the local community. Table 6.4 summarises the meter readings over eight days in December 1988. The sample size (14 residents) represents the water

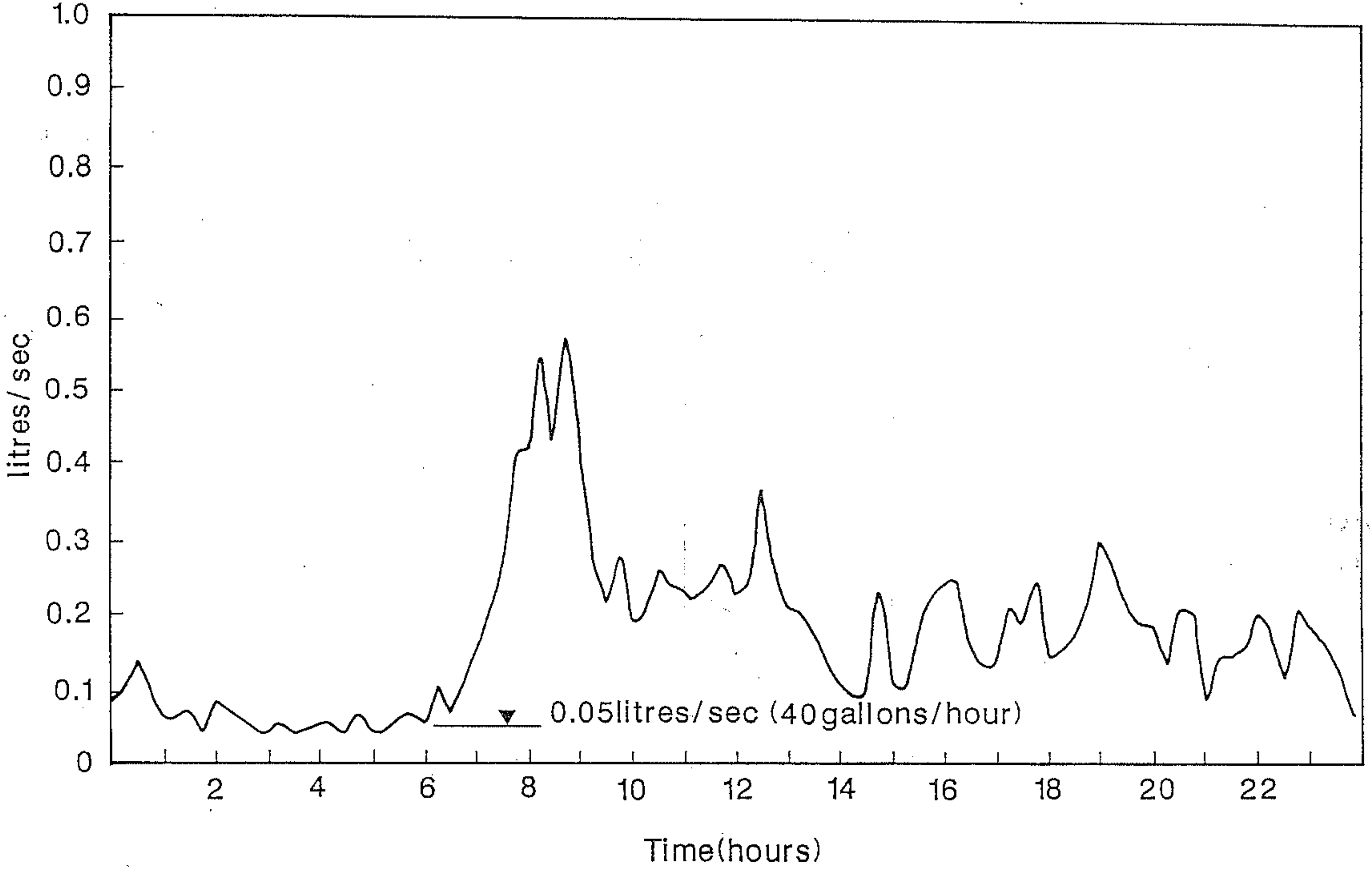


Figure 6.7 24 hour record of discharge from the Luccombe Riding School water supply tank in November 1988.

Daily consumption: (1) Daylesford, (2) Hillcrest, (3) Merrydowm, (4) Upalong, (5) Highcliffe, (6) Roseacre, (7) Cheriton, (8) Meadow Sweet.

Date	(1)	(2)	(3, 4, 5)	(6)	(7)	(8)
7.12.88	471	778	1762	903	1975	1418
8.12.88	486	821	1816	940	1126	1461
9.12.88	515	835	1892	969	1164	1521
10.12.88	532	868	DAMAGED	1002	1207	1574
11.12.88	548	895		1038	1234	1635
12.12.88	564	919		1092	1279	1708
13.12.88	582	942		1120	1328	1740
14.12.88	600	961		1156	1365	1815
15.12.88	619	1000	2364	1191	1405	1858
8 days total	148	222	602	288	331	440
Daily mean	18.5	27.8	75.25	36	41.4	55
Persons per household	1	1	2, 1, 2	2	2	3 ($\bar{x}$ = 1.75)
Mean consumption per person		$\frac{18.1}{100}$ cu. metre/day	= 0.18 cu. metre = 180 litres/day			

Table 6.4 Luccombe water supply.

consumption of 20.1% of the resident population which was found to equal 180 litres per person per day. Extrapolating this sample to include all 65 residents in Luccombe, the amount of water consumed per day would be expected to be approximately 11,700 litres. This is in agreement with the monitored demand from the supply tank of 15,000 litres per day given that 4,320 litres is lost through leakage. A number of points arise out of the water supply statistics made available to this study:

(a) it is not clear whether the leakage of over 4,000 litres a day has been caused by the recent 1987-1988 movements, or whether significant leakage occurred prior to the landslide;

(b) there is a clear discrepancy between the estimated water supply to Luccombe from Ventnor railway tunnel of 140,000 litres a day and the actual consumption of around 12,000 litres a day, suggesting that leakage has occurred from the water supply network prior to the landslide;

(c) Figure 6.8 is a plan compiled by the members of the Luccombe Association which shows the location of known pipe breakages and water leaks, some of which have reportedly remained unrepaired for a number of years i.e. prior to the landslide. It has not been possible to verify the accuracy of this information;

(d) as the village has no sewage system, the majority of the water supplied each day (c.15,000 litres) ultimately enters the landslide system, via leakage or septic tank discharge. The domestic wastes are variously discharged into septic tanks and directly into the ground. Irrespective of the efficiency of the methods (in terms of pollution control), all water discharged will find its way into the ground.

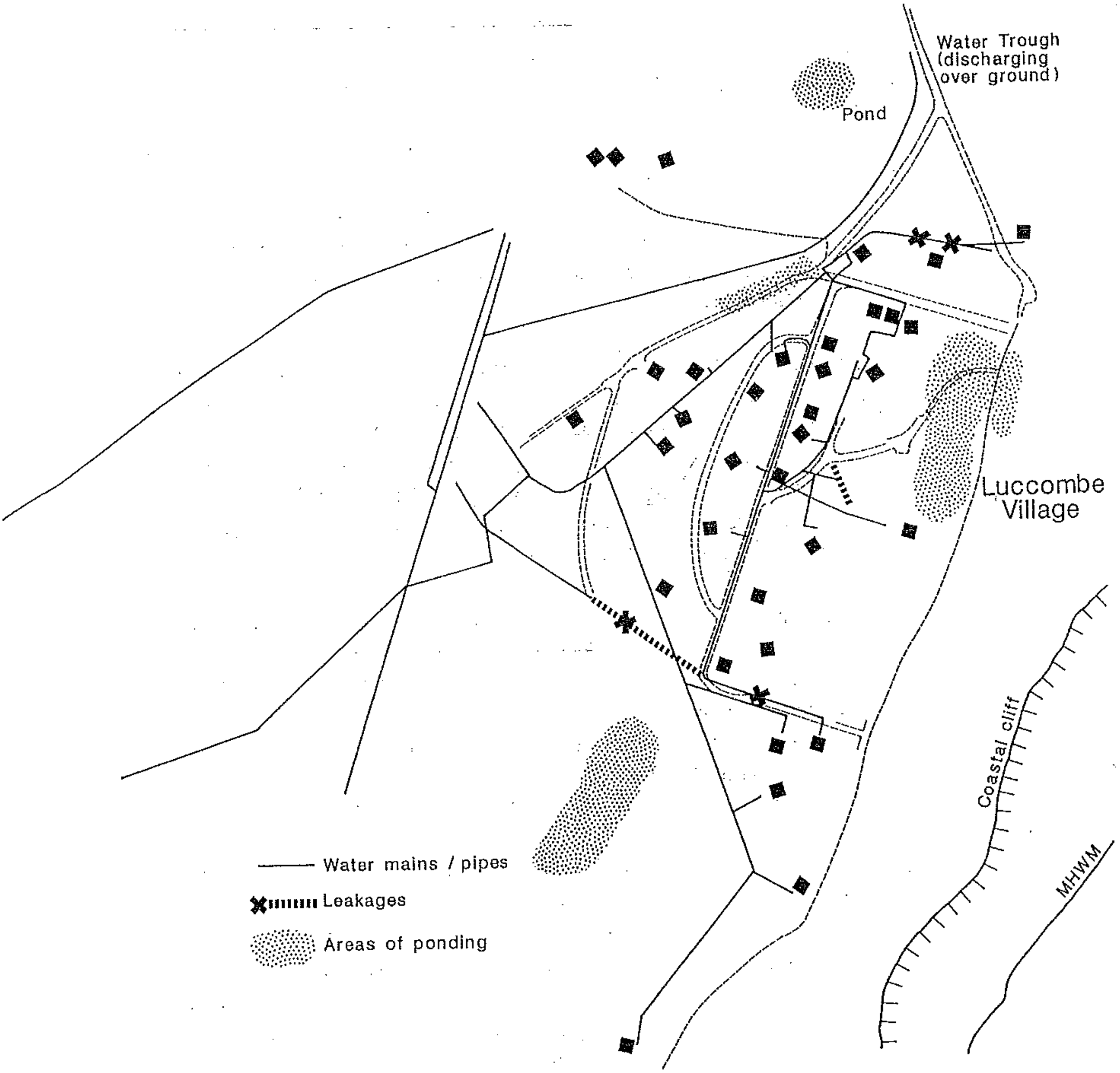


Figure 6.8 Recorded water mains leakages and areas of ponding.

It is clear, therefore, that there has been considerable human interference with the natural drainage of the site, both through the concentration of runoff into a few locations and the artificial groundwater recharge of around 15,000 litres a day, through leakage and septic tanks. As a result, it is likely that since the development of the village the artificially raised groundwater levels will have resulted in a gradual reduction in slope stability. In combination with more long-term geomorphological factors (see (i) above), human activity has clearly produced a situation whereby the ancient landslide system within Luccombe Village has become increasingly susceptible to reactivation.

6.5.2 Triggering factors

Triggering factors initiate landsliding by shifting slope stability conditions from a state of marginal stability to active instability. It is clear that a very significant triggering factor for the 1987-1988 Luccombe Village landslide was a prolonged period of heavy rainfall. The daily records for Shanklin Big Meade (1km from Luccombe 1987 - August 1988* are presented in Figure 6.9 and Tables H and I (Annex D) which reveals:

(i) the September-January rainfall total of 638.2mm was the fourth largest wet phase total since 1947 (see section 3.3);

(ii) the total rainfall in October 1987 (259.3mm) was the highest monthly total recorded since 1947, and was 275% of the mean rainfall for the month (see section 3.3);

(iii) the total rainfall in January 1988 (183.1mm) was the largest January rainfall total since 1947, and was 200% of the mean rainfall for the month;

(iv) as a result, groundwater levels, measured in a borehole at Luccombe Copse rose from c.103m OD in mid-September 1987 to c.111m OD in late January 1988 (see Table 3.4; section 3.4). Within the landslide area it is likely that the groundwater

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FOOTNOTE. No daily rainfall records are available for September 1987.

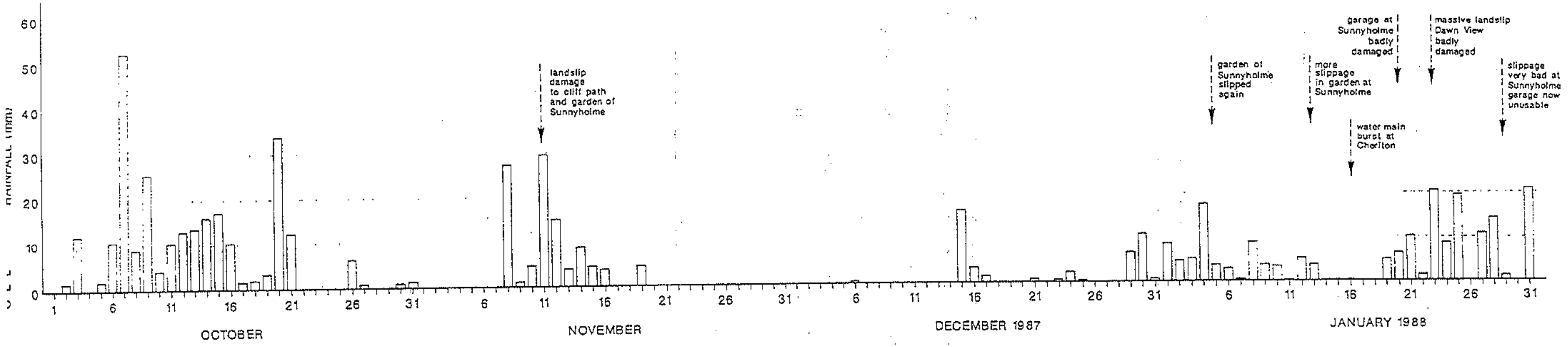

Figure 6.9 Daily rainfall totals for Shanklin Big Meade (October 1987 - January 1988) and sequence of reported landslide events.

levels were close to the surface during the phase of movement, Indeed, the piezometric levels measured by Woodruff (1988c) of between 1.10-2.40m below ground level on March 24 1988 (Table 6.1) are likely to be below the pre-failure levels.

Whilst there is an overall relationship between the period of high rainfall, with correspondingly high groundwater levels, and the recent landslide activity, there appears to be less agreement between recorded movements and rainfall events. The following points highlight these problems:

(i) no reports of landslide activity were made in October, despite the highest rainfall total since 1947;

(ii) the first reports of movement were made on November 11 after over 60mm of rain had fallen in four days;

(iii) no movements were reported between November 11 1987 and January 5 1988, corresponding to a relatively rain-free period (only 117.4mm fell during this period);

(iv) the main phase of movement occurred between January 5 and January 29 1988, although there appears to be little correspondence with large rainfall events (see Figure 6.9).

It is clear, therefore, that antecedent rainfall conditions are likely to be more significant than single rainfall events. The importance of such antecedent conditions has been demonstrated by many authors as a major control of landslide activity (e.g. Crozier, 1986 in New Zealand; Rice, 1982 in California; So, 1971 in Hong Kong). The main effects of a prolonged period of rainfall followed by high groundwater levels are to increase pore water pressures and decrease material strength, leading to slope failure when the material strength falls below a critical value. High groundwater levels and the resultant excess pore-water pressures have been identified by the recently completed review of landsliding in Great Britain (Geomorphological Services Ltd., 1987) as one of the major causes of landslide movements in southern England, particularly on clay slopes.

Although the high September-January rainfall appears to have triggered the 1987-1988 movements, there is little correspondence between previous high rainfall periods and reported landslide activity, which suggests that the patterns of movement are more complex than previously appreciated:

1960-1961	884.9 mm	(movement reported)
1976-1977	749.5 mm	(no movement reported)
1974-1975	727.2 mm	(no movement reported)
1987-1988	638.1 mm	(movement reported)
1961-1962	595.1 mm	(no movement reported)
1959-1960	585.6 mm	(no movement reported)
1949-1950	577.4 mm	(movement reported)
1954-1955	572.3 mm	(no movement reported)
1952-1953	560.6 mm	(no movement reported)
1950-1951	540.5 mm	(movement reported)

It remains a possibility that the burst water main which occurred at Cheriton on January 16 may have contributed to the "massive" landslip of January 23, as well as being the effect of earlier movement.

6.6 FUTURE RISK TO PROPERTY

Statements on the likely future risk to property from landsliding, within Luccombe Village, will only be possible when there is a detailed understanding of both the cause and mechanism of the recent movements. There is a clear need for a detailed geotechnical and engineering geological investigation of the area of landsliding in order to appreciate fully the possible magnitude and frequency of future movements, and their effects on structures within the village. However, on the basis of the work carried out for this report, a number of general comments can be made:

(i) coastal cliff retreat can be expected to continue at a rate of around 30cm a year, through a combination of small-scale rock slides and falls; large landslides are unlikely. It is possible that the rate of retreat may be increasing as a result of the greater discharge of water over the cliffs below Luccombe Village;

(ii) further seasonal movements can be anticipated in the area below the coastal path. Such movements may occur annually, creating considerable problems for maintaining a safe public right of way;

(iii) periodic movements of the scale of the January 23 1988 movements, can be anticipated along the scar feature between the turning point and Roseacre, and in front of Cheriton and Meadow Sweet. These movements are likely to occur after a prolonged period of heavy rain between September and January. Over 500mm of rain between these months may be expected to initiate further movement;

(iv) slow gradual subsidence is likely to occur upslope of the immediate landslide area, as it has since the village was developed. In general, it is likely that the pattern of building damage away from the landslide shown on Figure 6.3, will continue. However, at some sites damage may progressively worsen.

In broader terms the possible risks associated with continuing landslide activity also include:

(a) personal costs; possible injury and prolonged psychological and physical health problems;

(b) economic costs; in addition to building damage these may include:

- costs of house repairs
- costs of road maintenance
- costs of temporary or replacement housing
- depreciating land values
- costs of land actions concerning causes, responsibility and culpability
- coastal path maintenance
- repairs to services.

6.7 SUMMARY

The 1987/1988 landsliding at Luccombe Village is not an isolated event within Luccombe Coombe. Indeed, detailed geomorphological mapping of this area revealed the widespread occurrence of relatively deep-seated landslides, probably related to the environmental changes that took place at the end of the Pleistocene, around 10,000 years ago. The presence of landslide prone strata, especially the Gault Clay, natural slope oversteepening by stream action and high groundwater levels are likely to have been the main factors controlling the distribution of these ancient landslides. After the Pleistocene the climate became warmer and the landslides would have gradually degraded towards an angle of long-term stability corresponding to the residual strength of the materials and groundwater levels. The village of Luccombe was built on the terraced ground asociated with the largest of these ancient landslide systems.

Contemporary landslide activity within the study area involves the gradual reactivation of the ancient landslides. This is a direct consequence of sea cliff retreat associated with the Flandrian recovery of sea-levels to their present levels around 7,000-5,000 years ago (Chandler, 1984; Hutchinson, 1987a), removing the support from the lower parts of the landslides and thereby lowering the overall slope stability. A contemporary degradation zone has been identified in the field which represents the extent of landslide activity over the last few centuries. This zone generally occupies a narrow strip, 100-200m wide, parallel to the sea cliff. At present significant movements within this zone are confined to four main locations:

(i) on the slopes below Luccombe Road
(ii) within Luccombe Village
(iii) in front of the Luccombe Tea Rooms
(iv) north of Luccombe Chine.

It is important to note that, with the exception of the small slide north of Luccombe Chine, active movement in this degradation zone appears to be concentrated around built-up areas.

A review of local newspapers and other sources (e.g. postcards, aerial photographs and Council records) indicates that there has been intermittent landslide activity in the study area this century. The nature of reported landslides ranges from the "great landslip" of 1910 at Luccombe Chine, which destroyed the small fishing community at the base of the cliff, to the recent movements within Luccombe Village. Such large landslide events appear to occur in years when there has been high rainfall during the autumn and winter months, although not all wet years have resulted in landslide activity.

Since Luccombe Village was developed (between 1927-1936) the lower parts of the village have been periodically affected by landsliding. The first evidence of movements within the village date from around 1932, when tension scars were apparent below Little Tawny, The Retreat and Dawn View (Plate 4, Annex A). Between 1950 and the present day there have been three major phases of landsliding within the village, in 1950/1951, 1961 and most recently in 1987/1988. During this period landslide movements have taken the form of intermittent reactivations and upslope extension of earlier features, and thereby have been progressively affecting a larger area of the village. The area affected by these major movements is presented in Figure 6.1. However, it is clear from an assessment of building damage that all the properties outside the recent landslide area have been affected by slow movement of the ancient landslide blocks upon which the village has been built. Thus, the extent of previous landslide damage and hence future risk to property, is more widespread than previously anticipated.

Based on the limited sub-surface investigation carried out by Malcolm Woodruff (1988c) and the detailed geomorphological mapping carried out as part of this study, it is apparent that the 1987/1988 movements are complex in form, involving:

(i) rotational movement towards the head of the slide, with an accompanying area of uplift occurring in the vicinity of the coastal path;

(ii) translational movement below the coastal path including spreading failures which have created a distinctive series of sharp ridges in this zone.

The depth of movement is likely to be around 10m below ground level, as recorded by Woodruff (1988c, pers. comm.), with the basal shear surface occurring within the Gault Clay. The 1987/1988 movements have taken place along a pre-existing shear surface related to the 1950/1951 and 1961 movements. This shear surface is probably located within the upper, plastic zone of the Gault Clay, approximately 10m above its junction with the lower silty zone, at around 92-98. This zone of weakness may be a relict feature associated with the ancient landslide system on which the village was built.

The main factors which appear to influence slope stability are:

(i) the presence of pre-existing shear surfaces within the Gault Clay from previous landslide events. These act as lines of weakness where the materials are at, or close to, residual strength;

(ii) the retreat of the Lower Greensand sea cliff through a combination of marine undercutting and seepage erosion, has progressively removed support from the ancient landslide systems upslope, thereby initiating a zone of degradation. The seasonal loss of landslide debris over the cliff top prevents the build up of a protective toe area to the landslide and thus perpetuates the instability;

(iii) the development of the village on the site of an ancient landslide has resulted in considerable disruption of the natural drainage, with run-off concentrated in a limited number of points. This situation is exacerbated by water supply leakages and the outflow from septic tanks which together probably discharge around 15,000 litres a day into the landslide area. As a result it is likely that since the development of the village, groundwater levels have been artificially raised with a corresponding gradual reduction in slope stability;

(iv) it is considered likely that all the recent main phases of landslide movement (1950/1951, 1961 and 1987/1988) have been triggered by a prolonged period of heavy rainfall and the associated high groundwater levels. The main effect of heavy rainfall will be to increase the soil pore-water pressures and decrease the material strength, leading to failure when the effective shear strength falls below a critical value. However, it is unlikely that there is a simple relationship between high rainfall and movement, as many periods of heavy rainfall are not associated with landslide events.

CHAPTER 7
DISCUSSION

7.1 LANDSLIDE MANAGEMENT STRATEGIES

The present study has identified a continuing potential for landslide activity in and around Luccombe Village, involving:

(i) seasonal movements below the coastal path;

(ii) periodic movements along the rear scar feature between Dawn View and Roseacre, at the head of the landslide. Such movements are likely to occur particularly after a prolonged period of heavy rain;

(iii) slow gradual subsidence upslope of the immediate landslide area.

The future risks associated with further movements range from likely building damage to the possibility of personal injury. In order to alleviate the future impact of continued landsliding within Luccombe Village a number of strategies can be adopted:

(i) monitoring and landslide forecasting;
(ii) planning controls;
(iii) engineering measures;
(iv) acceptance of risk.

Each of these strategies is outlined in the following section 7.1.1 - 7.1.4, and outlined in Figure 7.1.

7.1.1 Monitoring and landslide forecasting

The monitoring of ground movements in and around Luccombe Village could provide valuable information on the landslide potential. Two approaches are of value to the present situation:

(i) monitoring surface movement by means of, for example, **repeated ground survey, surface extensometers or photogrammetry;**

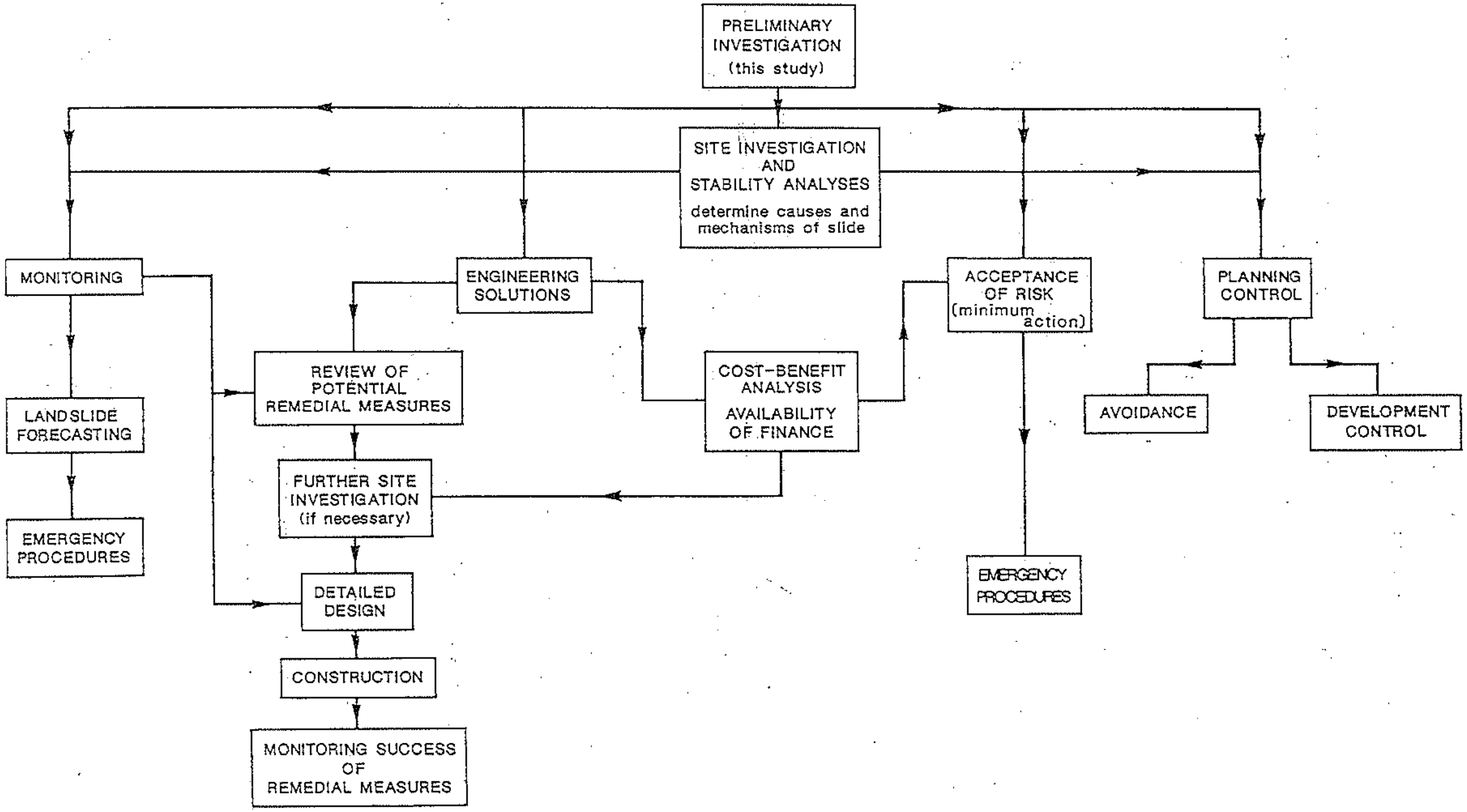

Figure 7.1 Landslide management strategies.

(ii) monitoring sub-surface movement using **inclinometers, slip indicators or sub-surface extensometers.**

The continued monitoring of ground movements, both within and upslope of the immediate landslide area will enable judgements to be made concerning the nature and intensity of continued movement. Such approaches have been used elsewhere as an early warning system to enable avoidance or remedial measures to be undertaken once slope displacement has exceeded a certain threshold (e.g. Kawamura, 1985 in Japan). Within Ventnor Chandler (1984) used a combination of bench-mark surveying and surface extensometer gauge measurements to assess the potential landslide hazard in the town (Chandler and Hutchinson, 1984).

It is clear that the major landslide events within Luccombe Village are related chiefly to prolonged periods of heavy rainfall and hence high groundwater levels (see section 6.5). Consequently rainfall and groundwater monitoring can be valuable in the forecasting of major events. Rainfall can be monitored using **continuous rain gauges** which allow rainfall intensity and storm duration to be determined, or **standard rain gauges** which are usually read every 24 hours. the conventional method of monitoring groundwater levels within landslide systems is by means of **piezometers.** However, it is important to determine the depth of the main shear surfaces prior to installation as pore-water pressures on the slip surface are most crucial to stability (Hutchinson, 1981).

It must be stressed, however, that an essential prerequisite of a reliable early warning system is a clear understanding of the landslide causes and mechanisms. Whilst monitoring could proceed without detailed site investigation it would not be possible to assess the data accurately in terms of the overall significance. The shear surface geometry of the landslide and its sensitivity to changes in external factors (e.g. rainfall) and internal parameters (e.g. material strength) would have to be determined by a detailed sub-surface investigation.

The effective implementation of early warning systems based on landslide forecasting clearly would require the close co-operation and co-ordination of all the relevant bodies and organisations. Also contingency plans would need to be formulated, based on a range of possible scenarios, possibly involving evacuation relief and rehabilitation procedures.

7.1.2 Planning control

A review of overseas practice concerning landslide problems indicates that planning practice and planning responses vary according to the community's perception of the problems (Geomorphological Services Ltd., 1987). Planning controls have a dual effect:

(i) through seeking to protect areas of potential hazard from inappropriate development. This can be achieved by controlling land use within certain areas in order to minimise the adverse effects of landsliding by **avoidance**, the adoption of **buffer zones** and **compulsory purchase of threatened properties**;

(ii) through controlling the methods of development. In California, for example, **building codes** are used to seek control over the manner in which slopes are affected by development and construction, or to require the use of particular types of foundation and structural design which are able to accommodate moderate movements.

The appropriateness of either or both of these approaches, in the present context, needs to be considered by the relevant authorities. However, in the absence of future remedial action, it is important that no further development should be permitted within Luccombe village.

7.1.3 Engineering measures

A wide range of stabilisation methods are available to improve slope stability and prevent further failures (Hutchinson, 1977, 1984b; Rendel Palmer and Tritton, 1986). The most commonly adopted methods in the UK involve one or more of the following:

(i) **excavation and filling;**
(ii) **drainage;**
(iii) **construction of retaining structures.**

In principle the choice of engineering solutions, or indeed the decision as to whether slope stabilisation should be attempted, will depend on factors such as the **availability of finance** and the **risk posed to the community by the landslide.** An assessment of the costs of stabilisation clearly need to be balanced against the costs that would arise if no action is taken (e.g. direct costs, indirect costs, personal loss etc.).

It must be stressed that unless sub-surface investigation and rigorous stability analyses are undertaken to understand the causes and mechanisms of the landslide, it will not be possible to assess the likely success of potential remedial measures and the degree of risk reduction obtained. This is so in the case of the drainage scheme proposed by Woodruff (1988a, c) where the suggested improvement in Factor of Safety cannot be verified unless rigorous stability analysis is carried out based on a clearer understanding of the landslide mechanisms. It is likely that drainage could prove to be the most appropriate solution, however it must be stressed that **the most effective and cost efficient scheme** may involve a broader approach, possibly combining drainage with re-profiling and other measures. It must be stressed that any engineering measures would require both careful design and execution to prevent further deterioration in the situation during the construction period.

Table 7.1 outlines the overall costs of investigation and treatment of different types of landslide problem in the United Kingdom. The figures presented in this table have been derived from previous landslide investigations undertaken by Rendel Geotechnics Ltd and, unless stated otherwise, relate directly to the costs incurred in slope stabilisation. Bearing in mind the preliminary nature of the present report, it is considered likely that long-term engineering measures designed to stabilise the landslide at Luccombe would be in the large to very large scale of operations.

It is important to note that the selection, design and construction of remedial measures at Luccombe could involve a complex programme of operations which may extend over a number of years. Figure 7.2 is a typical example of a work

		PRELIMINARY STUDY		DETAILED DESIGN		CONSTRUCTION	
SCALE OF LANDSLIDE PROBLEM	DESCRIPTION	SITE INVESTIGATION	CONSULTANTS COSTS	SITE INVESTIGATION	CONSULTANTS COSTS	CONSTRUCTION COSTS	SUPERVISION
SMALL SCALE	**Staffordshire**; small failures in Coal Measures strata during road construction (1987).	-	-	£ 1,000	£ 10,000	£ 30,000	£ 2,000
MEDIUM SCALE	**North Yorkshire**; landslide affecting public road, in glacial materials (1989).	£ 1,000	£ 5,000	£ 11,000	£ 15,000	£ 200,000	£ 30,000
LARGE SCALE (includes coast protection)	**North Yorkshire coast**; 40m high cliffs in glacial till overlying mudstones. Coast erosion affecting residential development and a hotel (1985-1989).	£ 12,000	£ 50,000	£ 30,000	£ 200,000	£ 275,000	£ 100,000
VERY LARGE SCALE (includes road earthworks and drainage adit)	**South Wales**; major landslide in South Wales valleys along proposed road alignment (1971-1985).	£ 100,000	£ 75,000	£ 200,000	£ 300,000	£ 2,000,000	£ 100,000

Table 7.1 Summary of costs of various landslide investigations carried out in the United Kingdom.

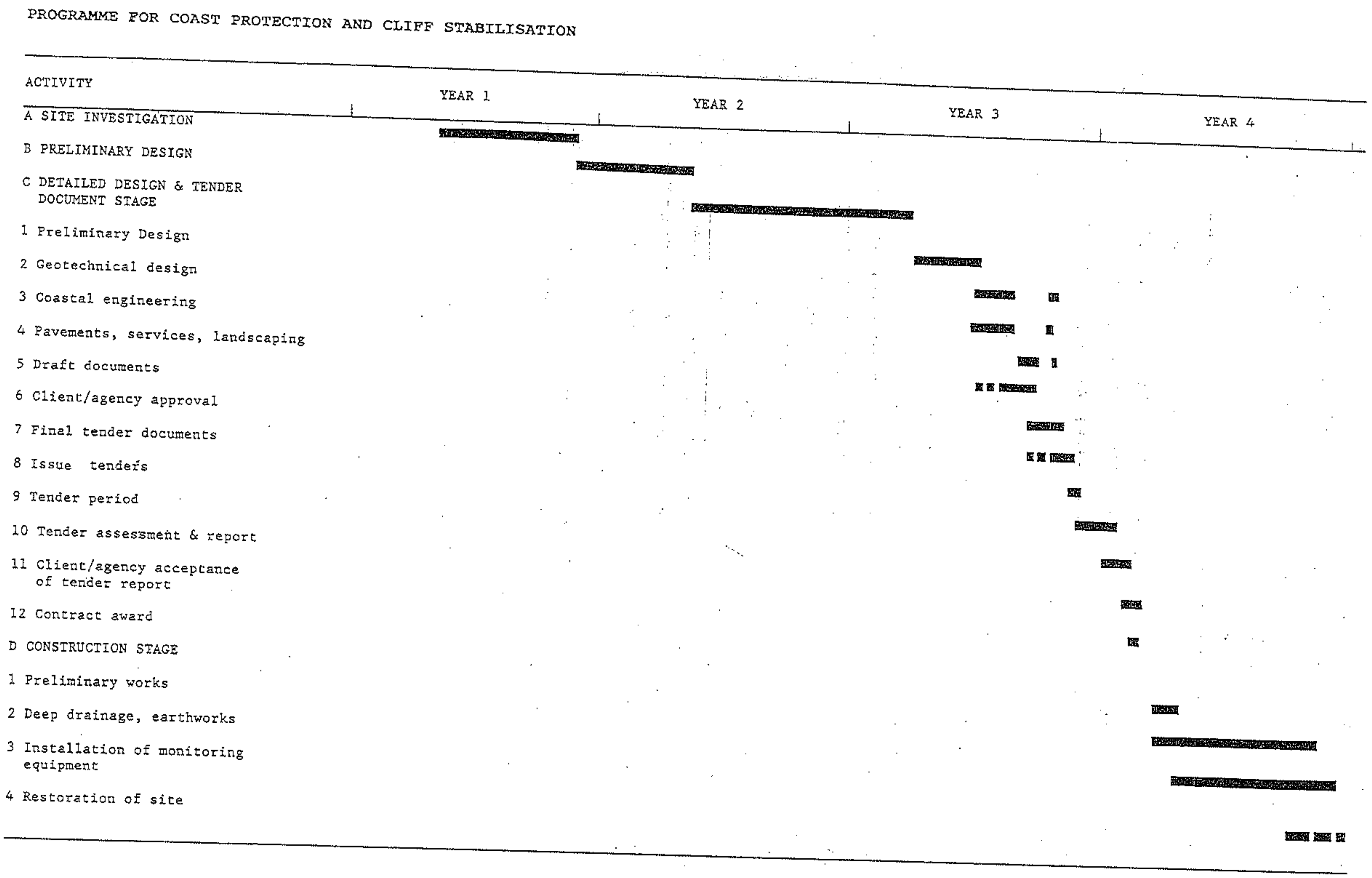

Figure 7.2 Hypothetical programme for coast protection and cliff stabilisation.

programme for coast protection and cliff stabilisation, compiled from a number of recent projects undertaken by Rendel Geotechnics Ltd, and highlights both the range of activities that could be required and that such a scheme may take up to four years to complete.

It must be stressed that it is by no means certain that a financially viable, effective stabilisation scheme can be devised for the whole village and that a limited temporary drainage system at the rear of the slide to reduce both the rate of movement and retrogression may be the only viable option (Hutchinson pers. comm.).

7.1.4 Acceptance of risk

This "minimum action" approach is often taken when economic constraints dictate that the risk posed by slope instability is to be accepted with no avoidance or preventative measures being undertaken. Such an approach can result in high maintenance costs that may prove more costly in the long term than stabilisation. Within the confines of the present understanding of the landslide at Luccombe there are a number of areas where improved maintenance and low-cost remedial measures are considered to be of benefit to the curent situation, although they should not be regarded as a substitute for long-term stabilisation measures:

(i) the water supply system must be adequately maintained in order to prevent further leakage into the landslide area;

(ii) the area below the head of the landslide should be cleared and regraded to prevent the build up of standing water;

(iii) drainage ditches could be dug through the landslide to help carry surface water away from the lower slopes. These ditches must be at a suitable grade and kept clear of blockages;

(iv) it is considered a priority to connect the properties within the village to a sewage scheme, thus preventing further discharge into the landslide area from the septic tanks.

7.2 RECOMMENDATIONS

The 1987/1988 landslide movements within Luccombe Village were not an isolated event in the area. Geomorphological mapping and analysis of historical documents, including newspapers and postcards indicates that the village is built on an ancient landslide system and that there have been intermittent movements this century. Between 1950 and the present day there have been three major phases of landsliding within the village in 1950/1951, 1961 and 1987/1988. During this time the landslide movements have taken the form of periodic reactivations and upslope extension of earlier failures, and have thereby been progressively affecting a larger area of the village. In addition to the obvious landslide damage there has been gradual subsidence which has affected all the properties within the village. The pattern of movement identified during this study is likely to continue in the future and it is possible that the potential for movement may increase.

In the past there has been an ad-hoc response to specific landslide events, primarily related to repairing building damage or condemning properties rather than preventing further movements. However, the nature and scale of the recent movements, accompanied by the continuing potential for further movement indicates that there is a clear need to identify:

(a) the most appropriate strategy to reduce the problems;

(b) to identify who may be responsible for financing and undertaking any future operations.

From our assessment of the site we consider that the following courses of action are necessary to reduce the risk to the local residents and to establish the viability of stabilisation measures:

(i) the development of an efficient monitoring and early warning system whereby rapid on-site assessment of the initial stages of slope failure can be used to predict major movements and instigate preventative measures, thereby reducing the risk of personal injury and damage to property;

(ii) the implementation of a detailed site investigation to determine the causes and mechanisms of the recent movements together with their relationships with the ancient landslide systems and coastal retreat as a basis for defining engineering measures. This investigation should be designed to test the general model of landslide development put forward in this preliminary report. The investigation will probably require a limited number of boreholes and trial pits, plus the installation of instrumentation (inclinometers/slip indicators and piezometers).

The issues that this investigation should address include:

- the thicknesses and relative positions of the various materials involved in the landslide;
- the presence of relict shear surfaces at depth;
- groundwater conditions within the landslide;
- the relationship between rainfall events and groundwater conditions;
- the significance of water supply leakage and discharge from septic tanks.

(iii) a detailed assessment of the financial implications of continued movements should be made, taking into account building damage, insurance, on-going maintenance costs etc.

The results of these investigations would provide clearer information as to whether there could be a cost-effective solution to the problems at Luccombe Village. However, it must be re-emphasised that full stabilisation of the village may prove to be not financially viable.

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APPENDIX

A series of annexes containing supporting information have been produced, and these are held on open file at the following location for general reference:

Department of the Environment
2 Marsham Street
London SW1

These annexes contain:

ANNEX A Photographic record of historical and recent landslide movements within Luccombe Coombe.

Plate 1	Engraving by G Brannon in 1839 showing the fishing community at Luccombe Chine.
Plate 2	The fishing community at Luccombe Chine c. 1890.
Plate 3	Undercliff instability threatening several cottages at Luccombe Chine c. 1900.
Plate 4	Active mudsliding at the coastal margin of The Landslip.
Plate 5	The great landslide at Luccombe in 1910, photographed at Bordwood Ledge after the reactivation of The Landslip.
Plate 6	Major landslide near the Luccombe Tea Rooms, showing prominent tension shears, disturbed ground and broken trees.
Plate 7	The development of the new village of Luccombe with pre-existing scarps apparent beneath Dawn View, Little Tawny and The Retreat.
Plate 8	Early evidence c.1940 of landslide damage on the cliff top fronting Luccombe Village.
Plate 9	Major landslide damage to the Luccombe access road during the 1950/1951 winter months.
Plate 10	1950/1951 landslide; damage to Luccombe Road.
Plate 11	1950/1951 landslide; arcuate scars and subsidence along Luccombe Road.

Plate 12 1950/1951 landslide; lateral shear along Luccombe Road.

Plate 13 1950/1951 landslide; general view of damage to Luccombe Road.

Plate 14 1950/1951 landslide; damage to Luccombe Road.

Plate 15 1950/1951 landslide; damage to Luccombe Road.

Plate 16 1950/1951 landslide; ground movements within the village.

Plate 17 Prominent lines of seepage on the cliffs below Luccombe Village between 1935-1940.

Plate 18 Localised rock falls off the Sandrock cliffs below Luccombe Village c.1940.

Plate 19 Landslide activity below the coastal path c.1948, as indicated by bare ground and scars.

Plate 20 Luccombe Village and cliffs following the major landslide in 1950/1951.

Plate 21 Vertical photograph on 11.6.87 showing the extent of earlier landslide events at Luccombe Village.

Plate 22 A major failure of the Sandrock undercliff below Luccombe Village is apparent on this photograph taken in July 1987.

Plate 23 The Lower Greensand sea cliffs retreat as a consequence of rock slides and falls following joint widening.

Plate 24 1987/1988 landslide; landslide debris and seepage spilling over the cliff top following recent movements in February 1988.

Plate 25 1987/1988 landslide; major subsidence beneath Dawn View, February 1988.

Plate 26 1987/1988 landslide; rotational movements resulted in the evacuation and demolition of Green Roofs, February 1988.

Plate 27 1987/1988 landslide; The Chalet was undermined by a lateral shear surface, February 1988.

Plate 28 1987/1988 landslide; rotational movement and subsidence occurred in the lower parts of the garden at Sunnyholme, February 1988.

Plate 29 Knock Cliff beneath Luccombe Village, showing characteristic undercliff benches developed in the Sandrock.

Plate 30 The 2-3m high scarp developed in the Upper, plastic, Gault Clay, approximately 40m inland from the cliff edge. The main landslide shear surface is believed to be above the top of this scarp feature.

ANNEX B A photographic record of building damage within Luccombe Village.

ANNEX C Details of previous landslide events within Luccombe Coombe.

Table C/A	Luccombe engravings, postcards and photographs; general development.
Table C/B	Luccombe engravings, postcards and photographs; landslide events.
Table C/C	Records of landslides and related events in and around Luccombe Village from a systematic newspaper search (1900-1950).
Table C/D	Luccombe engravings, postcards and photographs; coastal cliff erosion.
Table C/E	Reports of ground instability and related events in and around Luccombe village since 1987.

ANNEX D Detailed meteorological data for Shanklin Big Meade and St. Catherine's Point.

Table D/F	Monthly rainfall totals for Shanklin Big Meade (1947-1987).
Table D/G	Monthly rainfall totals for St Catherine's Point (1951-1987).
Table D/H	Shanklin Big Meade; daily rainfall records 1987.
Table D/I	Shanklin Big Meade; daily rainfall records Jan-Aug 1988.

ANNEX E Borehole logs for the site investigation carried out within Luccombe Village by Malcolm Woodruff in 1988.