Mapping the landslide complex at St Catherine’s Point, Isle of Wight

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ABSTRACT: The system of landslides at St Catherine’s Point, Isle of Wight have been shown by a series of subsurface investigations and surface mapping exercises to take the form of a large, deep-seated compound landslide, with a bedding-controlled sub-planar basal shear following a clay bed. This landslide occurred while the terrain was already the scene of a system of shallower, but also bedding-controlled, landslides associated with other clay beds higher in the sequence. Today, the situation is complicated by active marine erosion, and a series of shallow mudslides that respond to rainfall. The paper describes how the sequence of events at the site have been unravelled by a combination of subsurface geotechnical investigations, detailed topographic and geomorphological maps, observations of movement through geodetic and GPS surveys, and stability analyses. There remain a number of uncertainties regarding the evolution of the site morphology, and these are in the process of being addressed through, for example, 3-D modeling.

1 INTRODUCTION

The Isle of Wight is a small island situated close to the south coast of the English mainland. In its southern part, outcropping rocks of Cretaceous age take the form of a gentle SSW-plunging syncline, which marine erosion has affected in such a way as to leave a broadly linear swathe of coastal landslides approximately 11km in length and around 500m in width. This coastal landslide system is bounded for much of its extent on its landward side by an inland cliff, giving rise to its name “the Undercliff”. The town of Ventnor and numerous smaller settlements have grown up on the Undercliff, attracted by its marine aspect and favourable microclimate. These settlements are commonly affected directly by movements of the underlying landslides, or indirectly through movements in highways or other infrastructure. Figure 1 shows a general location plan. St Catherine’s Point is the southernmost point on the island, marking one end of a bay in which sailing vessels could often be shipwrecked as they were unable to escape against the prevailing south-westerly winds. It is therefore the location of a lighthouse critical to navigation on this coast, as well as being close to the western end of the Undercliff.

The Undercliff landslides have been investigated by means of boreholes at a number of sections, but nowhere better than at St Catherine’s Point.

2 GEOLOGY

The Undercliff is developed in a sequence of rocks including the top of the Aptian, all of the Albian (Lower Cretaceous) and some of the Cenomanian (Upper Cretaceous), although in the westernmost part of the Undercliff, there is very little Cenomanian material left in place at the cliff top, and the Aptian is mostly below sea level. Figure 2 shows a cross section, based on subsurface investigations, that shows on the left, in the unslipped part of the section, the basic stratigraphic sequence (see also Fig. 3). In essence, the landslide is a compound landslide with a major part of its basal slip surface developed along a clay bed in the Sandrock (Hutchinson et al. 1991).

In this diagram, the lithostratigraphic units are named as they appeared in most historical records (although they have been reclassified comparatively recently by the British Geological Survey) as follows: 1 – Ferruginous Beds (reddish-brown iron-cemented sands, Aptian); 2 – Sandrock, which is a white “locked sand” containing two major clay beds (hence 2b and 2d), and numerous unnumbered thinner beds and seams of clay that are all black in colour; 3 – Carstone (another iron-cemented sandstone); 4 – Gault, a major deposit of very dark grey to black silty clay; 5- Upper Greensand and 6 – Lower Chalk. The Upper Greensand comprises a lower part which is a buff coloured weak sandstone,
and an upper part that is a readily identifiable sequence of cherts.

Investigations elsewhere in the Undercliff have revealed that the landslide complex slides preferentially along one (or more) of three principal “slide-prone horizons” in the Albian (Hutchinson & Bromhead, 2002), of which two are in the thick clay beds in the Sandrock (there are numerous thin clay beds which have not been observed to exhibit this behaviour), or within the more plastic upper part of the Gault, most noticeably at a particular level some 5 to 8m above the base of this unit (Bromhead et al. 1991).

3 LANDSLIDE INTERNAL STRUCTURE AND GEOMORPHOLOGY

It was discovered in the investigations that the landslide complex at St Catherine’s Point comprised three major units and a number of subsidiary ones. The first two of these form irregular but prominent ridges sub-parallel to the coast, described by Hutchinson et al. (1991) as ridge “L” (landward) and ridge “S” (seaward). Ridge L is formed from subsided and rotated blocks of Chalk, Upper Greensand, Gault, Carstone and Sandrock, and ridge S preserves the stratigraphic sequence in the Sandrock, Carstone and lower Gault as it has slid along a thin clay layer (stratum 2b) towards the base of the Sandrock. A low-lying “apron” of debris, up to 36 m thick and comprising material sourced from the Chalk, Upper Greensand and Gault, forms a third unit seawards of ridge S (Fig. 4). This also slides along a surface in unit 2b of the Sandrock (Fig. 2).

The subsidence of ridge L left a steep scar in Lower Chalk and Upper Greensand that has subsequently degraded into a chalky scree, mantling the slopes at the head of the slide. It also caused internal dislocation at the junction of the two main slide blocks. This was revealed during drilling in the valley between the blocks by extreme variability in the depth to the Carstone marker, represented diagrammatically in the section.

A further minor unit found during the subsurface investigation was the capping of debris found on top of ridge S. This is identical with the debris found in the debris apron. At its base there is a basal slip surface developed in the slide-prone horizon in the Gault. The existence of this unit, and the debris apron, are central to any understanding of the sequence of events at the site. The paper-thin contact surface was relocated in fieldwork in summer 2007 where it had been exposed by shallow sliding in the seaward face of ridge S.

The aerial photographs in Google Earth are particularly good at St Catherine’s Point, where the lighthouse is situated at coordinates shown on Figure 1 caption.

4 A BLIND ALLEY

Investigations of the Undercliff landslides progressed slowly, although the area has been recognised as a coastal landslide belt for over 200 years (vide Hutchinson, 1991). Up until the 1960’s, the prevailing view was that sliding took place on
the “unctious” upper surface of the Gault (e.g. Osborne White, 1921), “lubricated” by water from the overlying Chalk and Upper Greensand. Indeed, there is some truth in this, as there are numerous places in the Undercliff where compound slides have developed on the low-strength slide prone horizon in the Gault. This was recognised from boreholes and visual examination of outcrops (Chandler, 1984). In connection with this, it was recognised that the thicknesses recorded for some of the lithostratigraphical units were incorrect, and the details of the plunging syncline were not known quantitatively to the requisite degree of accuracy. Accordingly, a programme of engineering surveying was carried out to locate a number of prominent marker horizons. The summary map was published by Chandler (1984). One of the marker beds was a thin layer of fine quartz pebbles at the base of the Carstone Unit.

At that time, the internal structure of the St Catherine’s Point landslide system was unknown. However, the fine quartz pebble marker at the base of the Carstone was found in the seaward face of ridge S at a level that was conformable with observations of the pebble bed immediately to the west, under Gore Cliff (Bromhead et al., 1991) as well as elsewhere in the Undercliff, and with the general structural form indicated by other markers.

Furthermore, although the slide prone horizon was not found in the face of ridge S at that time, as it was still obscured by vegetation and scree, its position was known in broad terms, and this too was conformable with the findings at Gore Cliff. Accordingly, Chandler (1984) proceeded on the assumption that the entire Undercliff landslide system had developed on this single slide prone horizon in the Gault. Given its apparent ubiquity, for a time it became known colloquially as “the magic horizon”. The justification for the approach was that it had been found to be so at Gore Cliff, at Monk’s Bay and Luccombe towards the Eastern end of the Undercliff – indeed, everywhere that had been investigated.

Evidence to the contrary was not long in coming. It came first from Ventnor town where some boreholes in connection with a proposed coastal marina showed a basal slip surface in Sandrock Bed 2d, followed by the subsurface investigations at St Catherine’s Point, where the basal shear lay in Sandrock 2b, and further investigations in Ventnor, where Sandrock 2d was again discovered to be the critical bed (although Moore et al. 2007 place it somewhat higher, at the improbable Gault-Carstone junction).

However, in support of the “magic horizon” hypothesis, sliding at or on this location in the Gault has subsequently been identified in boreholes at several other locations along the Undercliff, including at the numerous sites where shallow mudslide activity severed or damaged the A3055 coast road (Hutchinson & Bromhead, 2002) during the particularly wet winter of 2000-2001.

5 MOVEMENTS OF THE LANDSLIDE COMPLEX

Movements of the lighthouse were considered by Hutchinson et al. (2002). Lighthouses are insensitive to translation, but are hypersensitive to tilt, due to the fact that the lens and lamp system floats in an annular bath of mercury with small clearance and tilt could jam it. The tilt of the lighthouse has been monitored since 1873. Inclinometer casings were installed in several boreholes and a geodetic network was set up. It was initially believed that these would show no significant movement and that they would need to be monitored long-term, but the geodetic observations showed movements much larger than anticipated (approx 75-100mm pa in the debris apron and 25mm per annum in ridge S, Bromhead et al., 1988) which sheared the inclinometers before useful results were obtained.

The UK’s national mapping organisation, the Ordnance Survey, chose lighthouses - including St Catherine’s - as secure sites to install base stations for GPS. The station at St Catherine’s Point exhibited gross movement, especially during the wet winter of 2000-1 (Hutchinson et al. 2002), broadly confirming the earlier geodetic survey in both magnitude and direction, (SSW). The GPS readings showed also that movement was seasonal (Fig. 4).

These movement readings posed two conundrums: why should the movements be so westerly, when the dip is east of south, and secondly why should the debris apron move so much more than ridge S (movements of ridge L remain unknown, but cannot logically be more than those of ridge S). The answer to the differential magnitude of movements comes from two factors. Firstly, although it was very
obvious that the seawards face of ridge S contained a series of similarly-sized embayments from which in the past mudslides or debris slides had issued to feed the debris apron, it was not particularly evident that they could, and did, operate in the present, notwithstanding some records of one of them being active in an earlier wet winter of 1960. However, a series of wet years towards the end of the 20th century led to no less than 3 of the mudslides being reactivated at various times, although only one reached the coast. It was therefore obvious that loading at the head of the debris apron was ongoing. Secondly, comparative stability analyses showed that the debris apron was more sensitive to coastal erosion than the landslide complex as a whole.

6 LANDSLIDE MECHANICS

The vector direction of movement conundrum was resolved (at least to the satisfaction of the Authors) by means of a 3D analysis of the slide system (Olliffe, 2008). This showed that the topographic form of the slide as well as the dip of its bedding-controlled basal shear, had a bearing on the direction of least stability. In effect, ridge L is composed of at least 2 sub-units, the westerly one of which has descended further than the easterly one. Presumably, this indicates that the western block was earlier. The eastern block represents an increased unbalanced force that is propelling the slide system as a whole in a more westerly direction than it would choose if the topography was more uniform (i.e. more perfectly parallel to the coast).

Stability analyses using 2D methods on the sections with boreholes showed the landslide system to be in equilibrium with a residual shear strength acting on the slip surface averaging about 10°, concordant with several phases of remeasurement on small samples of clays from the Gault and Sandrock in a ring shear machine, most recently by Clarke (2005) and Moore (2008). Three dimensional analysis (Olliffe, 2008) did not improve on this finding (i.e. 2D analysis was accurate enough), although it did offer a rationale for the movement direction. The analyses showed that the landslide system was sufficiently large not to be hugely sensitive to the present day drivers for instability of small amounts of coastal erosion and wet weather, and the movements observed are compatible with a large system currently in equilibrium being acted upon by only small magnitude influences.

7 AGE AND EVOLUTION OF THE LANDSLIDE SYSTEM

A discussion of the evolution of the landslide is given by Hutchinson et al. (1991). The critical observation is that ridge L is not capped by debris, and that the rear scarp of the system is not sufficiently landward to have provided the source for the debris capping ridge A and forming the debris apron. A radiocarbon date of 4490 ± 40 years B.P. was determined on a yew log found in the debris at the sea cliff. This, with an associated soil horizon and tufa layer, divides the debris of the apron into a lower spread, around 13m thick, and an upper, between 10 and 20m thick. The extent of the debris apron represents a huge volume of Chalk and Upper Greensand. The reconstruction is given in Figure 5.

It may therefore be stated with some confidence that the debris apron was derived from a former cliff line in the Upper Greensand/Lower Chalk considerably to seawards of the present scarp, and probably represented by the now subsided cliff in ridge L. The mechanism for transport of the debris was sliding along the “magic horizon” in the Gault, with a compound debris landslide as seen in action in the present day at Gore Cliff.

Figure 5. Possible stages in the evolution of the system at St Catherine’s Point (Hutchinson et al. 1991). “Stage 6a” is typical of the slopes at Gore Cliff, and is not thought to represent conditions ever experienced at St Catherine’s Point.

As to whether this transport mechanism dumped debris on the beach to form an apron (Stage 6a, 6b), or whether it built up behind an earlier deep seated landslide (Stages 2 to 5 inclusive), it is still unclear which could have occurred. The former is evidenced by what is actually happening today at Rocken End,
immediately to the west of the St Catherine’s Point landslides, although the latter is more convincing, as it presents fewer difficulties explaining why the deeper mechanism under shot at some later date.

On reflection, it seems that Stages 2 to 5 also account for the soil and logs found in the sea cliff. These could have accumulated in a hollow in the landslide system far from the coast, but when the sea broke through a ridge, it could have rejuvenated the supply of debris by reactivating sliding along the “magic horizon”.

In addition, the scenario for formation of the upper spread of debris (discussed above) suggests that the deep seated landslide had not occurred as long ago as 4.5 ka bp.

At Gore Cliff, ploughing extends right to the present cliff edge, suggesting that there has been some retreat of the cliff in the time that cultivation has been practised. The finding of a Romano-British brooch in this plough wash suggests a later date for the landslide, perhaps as recently as within the past 2 millennia. However, the approximately 70m displacement and current movement rates of ridge S could imply an older date.

8 SEA LEVEL CHANGES

Global sea level rose from a low around 22ka bp (see the CLIMEX maps in Antonioli et al., 2004, as an example) which was certainly more than 120m lower than at present, to reach more or less present levels around 6ka bp, and although sea levels have risen a little since then, the effect is not particularly marked at the scale on which the section, Figure 2, is drawn.

Map evidence reviewed by Hutchinson et al., 2002 suggests that erosion in the past 150 years has been from 10 to 20 metres, and extrapolated over 6000 years, this could easily have seen a huge width of Undercliff removed, even if the erosion had been progressively concentrated at the end of the period. Indeed, the possible amount of erosion in the timescale postulated could have seen the erosion of a whole landslide system of the type now present, and the formation of a new one (as sketched in Fig. 5). This is particularly the case as the seaward dips would place the toe of such a precursor system at a lower elevation than the present toe, with the possibility of erosion at a lower sea level. It is therefore unlikely that the landslide system now present at the site predates the attainment of modern sea levels.

To compound the problem, the tidal range at St Catherine’s Point is rather small by UK standards, and this keeps the sea in close proximity to the foot of the coastal cliff throughout the tidal cycle. Although the coastal cliff is somewhat “armoured” in places by the presence of boulders derived from the cherty part of the Upper Greensand and washed out of the debris, the matrix surrounding them is weak and erodible. The foreshore is also cut into the same debris, and shore lowering as well as retreat of the coastal cliffs, has a detrimental effect on stability, although a small one at current rates of erosion. Sea level has been shown to have risen during the 20th century, and although the rise has been small (c. 0.2m), projections are for further rises, and in combination with climatic predictions of increased storminess, the prognosis is for erosion of the low coastal cliffs of the debris apron to continue to increase, with a corresponding small, but systematically detrimental, effect on overall stability.

9 CLIMATE CHANGE

Recent landsliding (over the past few hundred years) in the Undercliff generally has largely been triggered by rainfall. The rainfall records for the Isle of Wight show an underlying increasing trend since the middle of the 19th century when accurate records began (Ibsen, 2002). At the present time, projections to mid-century are for decreases in summer rainfall accompanied by increases in winter rainfall, with an overall annual precipitation that continues to increase. As the deep-seated movements have been shown to correlate to wet winters by the GPS data, and the activity of the mudslides similarly relate to wet years, it is likely that the generally activity of the landslide system at St Catherine’s Point as well as the remainder of the Undercliff will increase.

10 REMAINING UNCERTAINTIES

On the geomorphological plan (Fig. 4), ridge L is shown broken into 3 parts. The westernmost and smallest part is clearly tilted to the west, into the channel of a major debris slide that formed as a result of collapses of Gore Cliff in 1799 and 1928. Inspection of the outcrop of Upper Greensand Cherts in the southern face of ridge L shows that there are a set of dip and fault structures that imply a general tendency for movement of this type, and the mechanics of this remain to be explored.

The role of the eastern part of ridge L in a 3-D sense driving the landslide generally in a SSW direction against the dip in the underlying strata (in which the basal slip surface is developed) is understood in general terms from the 3-D analysis. However, the valley between ridges L and S is much deeper in the eastern part of the slide than in the west, as well as the ridge itself being at a generally higher elevation in the eastern part of the slide compared to the central and western fragments. Inspection of the cross section shows that to displace
the Carstone into the position shown requires “loss of ground” in both the underlying Sandrock and the overlying Gault in the subsiding block. The volumes are approximately matched by the wedge of debris (shown pale coloured in the section, Fig. 2) forming the valley floor between ridges L and S. It is probable that the “missing” part of the Gault is from the upper and more plastic zone of this stratum. The mechanisms for this are unusual, and again, remain poorly understood. However, it now appears clear that this extrusion has not taken place in the eastern part of the slide system, thus accounting for the lesser displacement of the eastern part of ridge L and the greater depth of inter-ridge valley, the latter not being caused by erosion.

Three-dimensional aspects of the groundwater behaviour are not understood at this time. Readings of the piezometers have been intermittent in the 20 plus years since they were installed, but they never revealed significant (if any) seasonal level changes. Although it is clear that the mudslides (or debris slides) feeding the head of the debris apron are liable to reactivation even today during wet years, it is not known if there is a systematic reactivation as coastal erosion of the debris apron continues, or if the system responds solely to rain.

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