Title: Coastal Landslide Mapping of the Black Ven Spittles Complex, Charmouth, UK

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Abstract:

Landslides are not generally perceived as natural hazards that significantly affect the UK. However, slope instability significantly affects many parts of Britain including the Dorset and Devon Coastline. Black Ven Spittles is a classic landslide complex along this coastline, exhibiting some of the largest and most dynamic landslips in Europe. It has a long history of instability with significant event occurring as recent as 2008 when a succession of rockfalls occurred towards the western side of the complex, uncovering waste material from the old town tip. With the beach adjacent to the landslide regularly used by tourist, fossil hunters and locals for recreational activities, it is of paramount importance that landslides be mapped to determine the active areas. Such mapping may be used for effectively managing the risk posed for this landslide complex. Through field and geospatial mapping techniques utilising remote sensed imagery and Geographical Information System (GIS), this paper produced the most updated geomorphic map of the Landslide complex. The maps produced as a result of this research identify how the 'system' has changed since 1996 (most comprehensive geomorphic map prior to this research). The most active section of the landslide complex is near to the village of Charmouth which is popular with tourists and fossil-hunters. By identifying this increasing risk, management can be better informed and the public made more accurately aware of this natural hazard.

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1 Introduction

Landslides are not generally perceived as natural hazards that significantly affect the UK. However, one of the most comprehensive reviews to date, The *Review of Research on Landsliding in Great Britain* (Jones and Lee 1994), demonstrated that slope instability is a significant natural hazard in many parts of Britain, including the Dorset and Devon Coastline. As highlighted by McGuire (2003), landslides are one of the most underestimated of geological hazards and an increasing number of the UK's population, critical infrastructure and the built environment are at risk as a result of slope instability. Recent events such as the Holbeck Hall landslide in 1994 (BGS, 2013a) and the deadly rockfall in Burton Bradstock in 2012 (Bol, 2012) has brought this to the forefront of national attention. With the UK climate predicted to become more varied with wetter winters and summers, the problem may be exacerbated and increase the risk that slope instability poses to our population (Stavrou, Lawrence, Mortimore & Murphy, 2011). Coinciding with the wettest year on record, the British Geological Survey (BGS) released figures indicating a four- to five-fold increase in landslide activity during July and December 2012 compared to previous years (BGS, 2013b).

Coastal landsliding threatens approximately 53% (3,327km) of coastline around England and Wales. In recent years noteworthy activity has occurred along the Jurassic Coast which comprises 96miles of Dorset and East Devon's shoreline (Brunsden & Chandler, 1996; EA, 2010; Jurassic Coast Partnership, 2012). Located between Lyme Regis and Charmouth is Black Ven and The Spittles (from hereon referred to as Black Ven Spittles), a classic landslide complex with recorded movement dating back to the 18th century (Koh, 1992). Events include the 1908 mudslide and 'Lyme Volcano' formation (Gallois, 2009), the succession of major and minor activity throughout 1957-8 (Koh, 1992) and the 2008 avalanche-like failure which intersected the old town tip (Gallois, 2009).

2 Setting

Black Ven Spittles encompasses 2.5-3km of coastline between Lyme Regis and Charmouth and elevates approximately 145m above sea level (Koh, 1992). It is one of the most profusely studied sites across Europe due to its long history of instability and landslide activity, but also for the paleontological, geological and geomorphological interest its slopes exhibit (Flux, 2009; Jurassic Coast Partnership, 2012; Koh, 1992; Panizza, 1996; Pitty, 1971).

Alongside coastal erosion processes, it is understood that geological structure and hydrogeology are the greatest influences to landsliding in this area. The geological conditions at Black Ven Spittles are characteristic of the 'Reservoir' principle of mass movement (Figure 1) (Denness, 1972). Water permeates through the Chert and Foxmould in the Upper Greensand Formation, allowing it to accumulate on the Gault Formation, eventually saturating it and forming a slippery interface between the underlying Belemnite Marl (Brunsden & Chandler, 1996; Flux, 2009; Koh, 1992). As pressure and weight increases, the Upper Greensand layer slides across the Gault in a single or multiple rotational movement onto the underlying terrace (Denness, Conway, McCann & Grainger, 1975; Flux, 2009; Koh, 1992). Falling material and water seepage from these slides erodes and forms gullies in the Belemnite Marl resulting in rock falls, mudflows and mudslides as material from each layer coalesces (Brunsden, 1996; Flux, 2009; Koh, 1992). Displaced material accumulates and loads the underlying terrace above the Black Ven Marl, encouraging water accretion and the formation of ‘secondary’ reservoirs. Consequently, material continues to slide down the cliff-face, occasionally removing its surface layer and steepening the cliff to its failure threshold (Brunsden & Chandler, 1996; Denness, Conway, McCann & Grainger, 1975; Koh, 1992). This material loads the terrace comprising the Shales-with-Beef geology, similarly encouraging water accretion, the formation of ‘Secondary’ reservoirs and the transportation of material. Debris deposited at the cliff-toe forms fans and lobes across the beach, which during wet periods spread out into the sea (Brunsden & Chandler, 1996; Denness, Conway, McCann & Grainger, 1975; Flux, 2009; Koh, 1992).

(Figure 1 Reservoir principle of mass movement applied to the geological structure of Black Ven Spittles)

Monitoring of water levels during 1988-9 revealed that high pore-water pressure also contributes to instability across Black Ven Spittles. This behaviour is associated with the ‘undrained loading’ hypothesis which suggests that high precipitation induces excess water pressure at the head of a slide, causing material displacement (Hutchinson & Bhandari, 1971).

Scholars propose activity is increasing across Black Ven Spittles, with Gallois (2008) suggesting areal expansion of approximately 40% throughout the second half of the 20th century. Statistics indicate over 81,700 people (Charmouth Heritage Coast Centre - 2010) visit this area each year for recreational and academic purposes and consequently it is important to identify the risk Black Ven Spittles poses to the public. The most recent and comprehensive mapping of this system was in 1996 (Brunsden & Chandler, 1996) and therefore needs updating.

Hence, this paper aims to produce the most updated geomorphic mapping of Black Ven Spittles landslide complex, utilising both field and geospatial mapping techniques. This will be used to identify how this complex has changed since 1996.

3 Methodology

The technique used for landslide assessments is dictated by the aims and objectives of the investigation, the scale of study and precision required. Methods are further constrained by resource availability, including time, finance, historical data and prior knowledge (Miller, 2007). Complex, data-intensive methodologies, including geotechnical and geophysical instrumentation and geomorphic mapping, are often confined to small areas due to their impracticableness at regional and national scales consequent of discussed constraints. For this large-scale study, geomorphic mapping was adopted alongside site investigations to record areas of current landslide activity at Black Ven Spittles.

Geographical Information Systems (GIS) offer the capability to quickly and efficiently process geographical data including inputting, manipulating, storing, updating, analysing and outputting information for a given purpose (Burrough and McDonnell, 1998). It “boasts tremendous potential for the analysis and modelling of spatial data” (Crosbie, 1996, p.383) and consequently has proven to be a valuable tool for landslide assessments at a variety of scales (Carrara et al., 1995; Huabin et al., 2005). ArcGIS (v.10) software was used for this study since it was readily available, free of cost and a familiar suite of programs. It was used to map geomorphic features of the landslide, analyse changes in activity since 1996 (when the most recent, comprehensive mapping was created (Brunsden & Chandler, 1996)) and to produce output maps for evidential purposes.

Boasting similar advantages, aerial photography, satellite and airborne imagery has successfully been used for landslide mapping in the UK and worldwide (Browitt et al, 2007; Wilson, 2006; Whitworth et al., 2005). These resources familiarise researchers with the study area, enable subtle, small or inaccessible features to be identified and facilitate quicker, more efficient mapping particularly of large geographic areas (Coe, 2011; Kearey, 2009). The use of online aerial photographs was favoured for this research since they were freely available, of high spatial resolution and the most up-to-date imagery available during data collection.

Aerial photographs, dating 2010, were sourced from the layer package ‘Bing Maps Aerial’ in ArcGIS (v.10); this imagery was also used as a base-map. Google Earth was frequently used for clarity of features since it provided more recent imagery (2012) but of lower resolution, particularly at larger scales. Landslides were initially mapped at a 1:50,000 scale, corresponding with previous maps (Brunsden & Chandler, 1996), with larger scale imagery used to view a greater level of detail. Aerial photointerpretation was use to map the location, spatial extent and type of landslides and indicative features of activity including gullies and tension cracks.

To map landslides using aerial photointerpretation, an understanding of the main forms of mass movement (Table 1) and how their characteristic features appear on photographs had to be acquired. Landslides were identified by the following characteristics:

1. Geomorphic features
2. Drainage and hydrological features
3. Soil/vegetation characteristics

Recognising these features on aerial photographs with regard to different movement types is explained in Table 2.

(Table 1 Main types of mass movements)

(Table 2 How to recognise characteristic landslide features from aerial photographs (Miller, 2007))

3.1 Geomorphic Features

Traditionally, slope geomorphology has been used to identify landslides on aerial photographs (Singhroy & Mattar, 2000). Landslide features, particularly when recent, are very distinct and easily interpreted on aerial photographs, including; block slide, debris slide, slide scarp, steep back scarps, tilting or detached blocks, transverse and radial cracks, faults and debris deposits (Figure 2). Less discernible features such as tension cracks, hillslope bulging and displaced material blocks can also be recognised on aerial photographs (Figure 2) (Walstra, 2006). The morphological characteristics of a slip face or displaced block indicates the type of movement that has occurred, as explained in Table 2.

(Figure 2 Identifying geomorphic landslide features on aerial photographs)

3.2 Drainage and Hydrological Features

Landslide related drainage and hydrological features are usually easy to discern on aerial photographs. When displaced debris blocks and impounds a flow of water, an often visible ‘landslide dam pool’ forms (Clements, 2009). This can lead to flash flooding if the dam is breached (Clements, 2009; Sassa & Canuti, 2008). Debris deposited in steams can also redirect the flow of water causing sharp deviations from the water course (Clements, 2009).

These features provide visible evidence on aerial photographs of landslide activity, whether by the presence of water, including pools, disrupted flows or springs and/or the growth of aquatic or water-loving plants. Furthermore, landslide areas typically have higher water contents primarily since high pore water pressure significantly influences and triggers instability. Difference in moisture content may be detected on aerial photographs since areas of high water content often appear a darker tone on monochrome images.

3.3 Soil/Vegetation Characteristics

Detecting anomalies in vegetation cover can be used to infer the presence of landslides. Where significant movement has occurred in vegetated areas, disturbance of foliage patterns indicate landslide activity (Figure 3) (Coates, 1977). An absence, or scarcity of vegetation compared to the surrounding area or the growth of much younger or different vegetation can indicate ground instability (Glade, Anderson & Crozier, 2006; Walker & Shiels, 2012). In densely forested areas, an outline of the landslide can often be discerned on aerial photographs by the distinct gap created between trees at the head of the slide and their differing elevation and angle (Figure 3). The distinction between vegetation within and outside of landslide zones can indicate their relative ages (Glade, Anderson & Crozier, 2006). Recent landslides typically appear a lighter tone on monochrome images compared to the surrounding area, but as darker patches in polychrome images; this however is dependent on the underlying geology.

(Figure 3 Identifying landslides on aerial photographs through anomalies in soil and vegetation characteristics)

3.4 Field-Work

Typically, a combination of the three elements discussed indicates the possible presence of a landslide. However, field verification is required to confirm, guide and enhance the quality of aerial photointerpretation, particularly in this study where imagery dated 2010. A field-study was undertaken following initial aerial photointerpretation, involving field mapping onto an aerial photo print, sketches and photographs.

3.5 Geomorphic Mapping

The information from photointerpretation and field verification was collated in ArcGIS (v.10), involving the adding of spatial data, the creation of bespoke symobology and digitization. So as to analyse spatial and temporal changes across this system, the 1996 geomorphic map of Black Ven Spittles (Brunsden & Chandler, 1996) was geo-referenced and overlaid onto the current map. Visual and geospatial analysis was conducted to identify similarities and differences between morphological features mapped in 1996 and 2012.

4 Geomorphic Changes in the Black Ven Spittles Landslide Complex: Results and Analysis

Using written documentation of Black Ven Spittles areal extent in 1992, it is apparent from geospatial analysis that an approximate 90m landward recession has occurred since this date (Figure 4) (Koh, 1992). The system has retained an average 2.5-3km width since 1996, regardless of a reduction in activity where the 'old dormant system' was situated, west of the system (Figure 4) (Brunsden & Chandler, 1996). These observations suggest that Black Ven Spittles continues to be active, but that activity is diminishing to the west of the system.

Synonymous with Brunsden & Chandler's (1996) findings three broadly defined active units are discernible across the system, amidst which Gallois (2008) upper and lower geological divisions are identifiable (Figure 4). Brusden & Chandler's (1996) spatial divisions are utilised for analytic comparison purposes throughout this paper, segregating the landslide complex into Black Ven Spittles East, West and Central (Figure 4).

Within these active units and along five main cliff terraces, a total of thirty-three flows, twenty-six areas of creep, six rotational failures, 200+ gullies and 600+ tension cracks are mapped in 2012 (Figure 5) (Brunsden & Chandler, 1996). There were comparatively less movements mapped in 1996 and although major terraces align relatively well, differentiations suggest morphological change has occurred and the system remains active. In order to substantiate this theory, movements within each active unit – Black Ven Spittles East, West and Central – are explored in more detail.

(Figure 4 2012 geomorphological map of Black Ven Spittles, annotated with spatial and geological divisions)

(Figure 5 2012 geomorphological map of Black Ven Spittles, annotated with terraces mapped in 2012 and 1996)

4.1 Black Ven Spittles East

Black Ven Spittles East (BVS-E) predominantly comprises seven flows, nine areas of creeps and one small rotational slide, originating along three main terraces (Figure 6). Features indicative of instability were identified in this zone in 1996, including graben, tension cracks and erosional heads (Brunsden & Chandler, 1996). However, a greater magnitude and diversity of failures are noted in 2012 suggesting activity has increased.

(Figure 6 2012 geomorphological map of Black Ven Spittles East)

Five flow failures are located in BVS-E, labelled A, B, C, D and E (Figure 7). Movement A initiates along the uppermost terrace, with displaced material extending through the middle and loading the lower bench where Movement B initiates (Figure 8). The interaction of movements influences B's failure by increasing sediment input and causing Black Ven Marl to accumulate at its head; this encourages reservoir accretion and pressure loading (Koh, 1992). The active status of these slides is evidenced by scarring above the head-scarps, lack of vegetation growth and extensive gully networks across each site (Figure 8). Both failures demonstrate a greater level of activity than that exhibited in 1996 when these zones were mapped as structural and debris slopes surrounded by graben. It can be hypothesised that this increase in activity is influenced by increasing precipitation, evidenced by widespread gullying (Figure 8) and the known impact material saturation has on failures across Black Ven Spittles.

(Figure 7 2012 geomophological map of Black Ven Spittles East, annotated with five major mass movements)

(Figure 8 2012 geomorphological map of Movements A and B in BVS-E)

Initial development of Movement C, initiating west of B along the uppermost terrace, was identified in 1996 with historical features, such as structural slopes, outlining the curvature and position of the current head-scarp. Current mapping shows little vegetation exists in the bowl-shaped cavity at the head of this flow; however, this is most likely owed to the incline being too steep for flora habitation rather than instability, particular since abundant vegetation exists at the slope-base (Figure 9). An area of soil creep is identified directly above the main scarp, indicating the initiation of relatively recent but minimal activity (Figure 9).

(Figure 9 2012 geomorphological map of movement C in BVS-E)

Movement D was identifiable in 1996 with historical features following the current head-scarps curvature and position. This movement originates along the middle terrace and flows to the cliff-toe where hummock formation is evidenced (Figure 10). A small rotational failure exists within the hummock debris, evidenced by back-tilting material at the cliff-base. This movement appears relatively active due to the abundance of hummocky debris, the existence of creep above the head-scarp, and the lack of vegetation across the slope; this could be attributed to the slope's steep incline (Figure 10). Nevertheless, the limited cliff-line recession suggests movement is minimal or occurring at a relatively slow rate at this site.

(Figure 10 2012 geomorphological map of movement D in BVS-E)

Eastwards, Movement E is located along the middle terrace in a historically (1996) unclassified area. This movement initiates in two adjacent bowl-shaped cavities and transports debris to the cliff-toe where a hummock has accreted. The presence of this large, ununiformed hummock, existence of soil creep above the crown scarp, the deep incision of gullies and lack of vegetation across the site suggests this movement is recent and relatively active (Figure 11).

(Figure 11 2012 geomorphological map of movement E in BVS-E)

Landward recession of the cliff-line is also identified in BVS-E, particularly south of ‘Higher Sea Lane’ (Figure 12). Surrounding this, additional tension cracks, four areas of soil creep, one flow and one deeply incised gully are identified, indicating the current ‘active’ status of the area and likelihood of future retreat and failure (Figure 12). This movement is of particular interest due to its close proximity to Charmouth, threatening people and property.

(Figure 12 2012 geomorphological map of eastern BVS-E, highlighting geomorphological features)

4.2 Black Ven Spittles West

Geomorphological characteristics of Black Ven Spittles West (BVS-W) suggest two rotational-slides envelop this active unit. Evidence for this is more perceptible on the western side which exhibits a concave and convex, stepped morphology and curved head-scarp. Historical mapping indicates the existence of these rotational slides in 1996 and it cannot be deduced whether activity has increased or decreased significantly. However, the density of vegetation across this active unit suggests limited activity has occurred since 1996. Individual movements are explored in more detail subsequently for further analysis.

A total of 16 flows and 11 areas of creep are identified across this active unit, predominantly on the eastern side within the lower Jurassic geology. The majority of zones encompassed by these failures were historically mapped as structural terraces, slumped blocks or pronounced lateral shear surfaces. This provides evidence that BVS-W was unstable in 1996. However, since current mass movement types (flows and creep) are characteristically more active, evidence suggests that activity has increased.

Furthermore, terraces mapped in 2012 align relatively inaccurately with those identified in 1996 with discontinuations and breaks found in terraces, particularly along the middle terraces within the lower Jurassic geology (Figure 13). This is postulated to have been caused by post-1996 mass movement activity, including perhaps the reactivation of the 1994 sand flow. In order to induce such morphological changes, activity must have been relatively deep-seated or large-scale, indicating an increase in activity since 1996. However, the abundance of vegetation across this site suggests that surface movements have stabilised and the complex could be moving as a larger mass.

(Figure 13 2012 geomorphological map of BVS-W, annotated with terraces mapped in 1996)

At a relatively smaller scale, an excess of approximately 75 tension cracks are mapped across BVS-W; abundantly more than 1996 estimates, indicating increasing slope instability (Figure 14). Several gullies are also mapped in 2012, predominantly within the 1994 sand flow scar (Figure 14). Due to water accumulation contributing significantly to slope failure along these cliffs, the existence of these gullies suggest instability. Furthermore, this supports the previous theory that the 1994 sand flow reactivated post-1996.

(Figure 14 2012 geomorphological map of BVS-W, annotated with gullies and tension cracks)

4.3 Black Ven Spittles Central

Three main rotational failures are discernible within Black Ven Spittles Central (BVS-C), labelled F, G and H (Figure 15). Movement F is a large, deep-seated, multi-rotational failure which initiated along the uppermost terrace in the upper Cretaceous geology (Figure 16). To some extent this failure was perceptible in 1996 with evidence of an active, curved head-scarp underlain by slumped blocks and tension cracks (Brunsden & Chandler, 1996). Since this slide was not recorded in detail comparative to mapping in 2012, there is little evidence to suggest whether activity has increased or decreased. However, this provides evidence that movement F continues to be active.

(Figure 15 2012 geomorphological map of Black Ven Spittles Central, annotated movements F – H)

(Figure 16 2012 geomorphological map of movement F in BVS-C)

Movement G intercepts the south western side of F, initiating along the boundary between the upper Cretaceous and lower Jurassic geology (Figure 17). This movement appears to have progressed relatively slowly, since vegetation is dense but gaps in the foliage are evident (Figure 17). Mapping from 1996 provides little evidence of this movement existing prior to this date, with features such as tension cracks and slumped blocks sparsely mapped across the site. Therefore, although movement is limited, an increase in activity since 1996 is noted.

(Figure 17 2012 geomorphological map of movement G in BVS-C)

Movement H intercepts the south-west of G, located solely within the lower Jurassic geology (Figure 18). This rotational slide occurred in 2008, as documented by many geomorphologists and still exhibits signs of instability. Substantial soil creep is visible above the head-scarp, vegetation is sparse and a large, ununiformed hummock exists at the toe suggesting recent replenishment (Figure 18). This landslide is situated on a site which is particularly susceptible to failure, historically being host to the 1908 slide and ‘Lyme Volcano’ formation. The lands instability is perhaps owed to a fault-line which runs directly through it or the unconsolidated nature of material resultant of this areas historic usage as a landfill site and unlicensed dumping ground (BBC, 2008; Gallois, 2009). Since Gallois (2008) noted that the 2008 slide was larger than the 1908, it can be deduced that mass movement activity has increased. This is of particularly concern since the 2008 failure cause landfill material and hazardous waste to spill onto the beach. If activity increases there is concern that further waste will become exposed.

(Figure 18 2012 geomorphological map of movement H in BVS-C)

Within the rotational movements discussed are eight significant flow failures and three main areas of creep. The head-scarps of each of these failures have retreated landwards since previous mapping in 1996, vegetation appears sparse and there are in excess of 75 tension cracks. These factors indicate that activity has increased in this area.

However, a decrease in activity is observed west of BVS-C in the location Brunsden & Chandler (1996) labelled the ‘Old Dormant System’. Although this status suggests that this zone was dormant in 1996, few tension cracks and slumped blocks were mapped. Since these are imperceptible on the 2012 map is can be deduced that this zone has stabilised further. This stabilisation could be owed to engineering techniques implemented at the base of this slope as part of the ‘Lyme Regis Coastal Protection Works’. This has included the installation of a seawall, promenade, slope stabilisation and drainage techniques since the 1990’s; Phase One was completed in 1995.

5 Discussion

Through analysing the geomorphological map, a general increase in activity is noted across Black Ven Spittles since 1996 when the most recent, comprehensive mapping of this system was produced (Brunsden & Chandler, 1996). A greater number of mass movements are identified, with numerous areas hosting more active landslips than previously mapped and an abundant amount of features indicative of instability are visible across the system, including gullying and tension cracking.

The greatest increase in landslide activity is noted in Black Ven Spittles East (see Figure 6). A greater amount of mass movements were mapped in 2012 and significant cliff-line recession was identified, particularly below Higher Sea Lane (see Figure 12). It is notable that 2012 was the second wettest year on record and an unprecedented amount of landslide occurred throughout the UK (EA, 2013). Increased landslide activity at Black Ven Spittles may be owed to the greater levels of precipitation, which encourage reservoir accretion and undrained loading (Denness, 1972; Hutchinson & Bhandari, 1971). An increase in activity at this location is of particular concern due to its proximity to Charmouth; if mass movement continue to intensify it could threaten people and property in this coastal village.

Evidence from the 2012 geomorphic map suggests significant morphological changes have occurred within Black Ven Spittles West. Major terraces do not align well with those previously mapped and additional mass movements exist, particularly on the eastern side within the lower Jurassic geology (see Figure 13). However, due to the density of vegetation cover across the site, it is postulated that surface movements have stabilised and the active unit is moving as a larger mass.

The dense vegetation across Black Ven Spittles Central indicates that the surface material is relatively stable. This is perhaps related to stabilisation techniques implemented by the 'Lyme Regis Coastal Protection Works'. Nevertheless, three large rotational movements are located within this active unit, most notably movement H which occurred in 2008 (see Figure 18). The characteristics of each of these rotational movements suggest that the area is more active than previously observed (see Figure 15). Taking into account the vegetation cover however, it is suggested that these movements are sporadic and occur following triggering events such as prolonged periods of rainfall.

6 Conclusion

Utilising both field and geospatial mapping techniques, this research has identified an increase in mass movement activity across the Black Ven Spittles landslide complex since previous mapping in 1996 (Brunsden & Chandler, 1996). The greatest risk area is located in Black Ven Spittles East, near to the village of Charmouth which is popular with tourists and fossil-hunters. By identifying this increasing risk, management can be better informed and the public made more accurately aware of this natural hazard. In doing so people's vulnerability will be reduced.

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