Geological controls on the failure mechanisms within the Black Ven-Spittles landslip complex, Lyme Regis, Dorset

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The Black Ven-Spittles landslip complex is one of largest active landslip systems on the south coast of England. It was probably initiated in the Pleistocene in a periglacial climate, but then remained inactive for most of the Holocene. There is map and photographic evidence to show that it has been especially active in the last 100 years and that it is expanding westwards towards the Lyme Regis urban area. The landslip can be divided into two distinct parts; an upper Cretaceous-based part that behaves independently, and an underlying Jurassic-based part that is greatly influenced by movements in the Cretaceous part. The upper landslip is composed of collapsed Gault Formation clay (up to 5 m thick), overlain by a *c.* 75 m-thick succession of decalcified calcareous sandstones and calcarenites of the Upper Greensand Formation. Below this and extending to the sea, the 100 m-thick Jurassic Charmouth Mudstone Formation crops out in a series of low cliffs, each of which is capped by a thin bed of limestone. During the past 60 years, large-scale failures have occurred in the 'Cretaceous' landslip at less than 10-year intervals, usually after prolonged periods of rain. Each of these has generated large sand-rich debris flows that have poured onto the Charmouth Mudstone Formation outcrop and initiated failures in the more clay-mineral-rich parts of the succession. The more calcareous parts of the Charmouth Mudstone Formation are not prone to failure and form stable ribs within the landslip complex. Large bedding-plane-initiated failures occur infrequently in the Charmouth Mudstone Formation at the seaward end of the complex, beneath The Spittles, where there is a low downslope dip. Two such events have been recorded, in 1908 and 2008.

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Introduction

The largest landslips[1] on the south coast of England are those associated with failure surfaces in montmorillonite-rich mudstones close to the base of the Gault Formation (mid Cretaceous). Those at Folkestone Warren, Sussex (Trenter and Warren, 1996), Ventnor, Isle of Wight (Hutchinson, 1969) and Black Ven-Spittles, west Dorset (Brunsden, 2002) are among the largest active landslip systems in the UK. All three are close to urban areas and have been the subject of extensive geological and geomorphological studies.

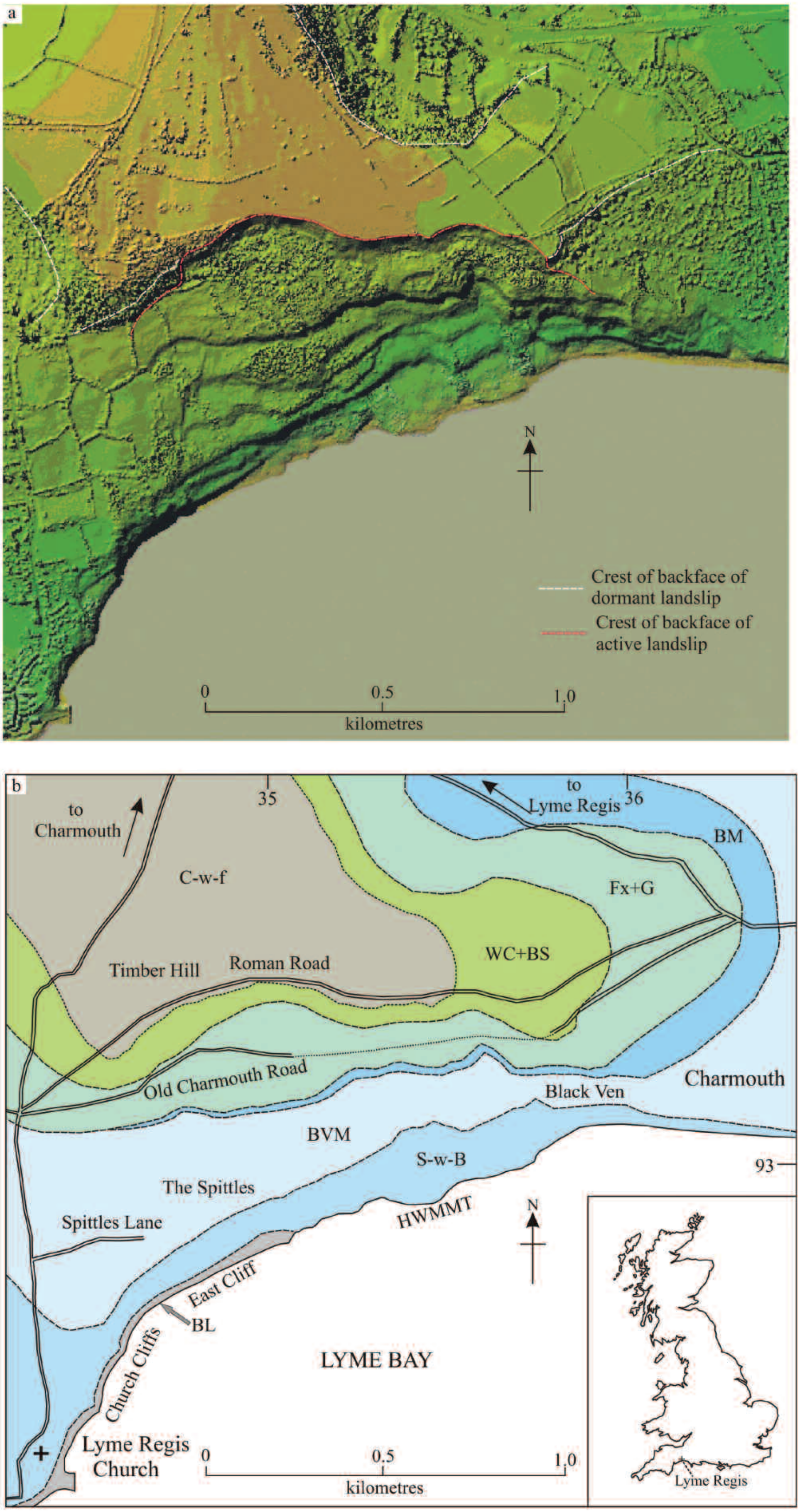
Much of the area adjacent to the outcrop of the Gault in south-west Dorset is occupied by large landslips. As with large dormant landslides elsewhere in southern Britain (Lee and Jones, 2004), many of these were probably initiated in periglacial climates in the late Pleistocene when the region was subjected to successive periods of freezing and thawing of a deep permafrost layer. The inland landslips are mostly afforested or have been drained for agricultural purposes and are dormant. A few have become remobilised due to man-made works. In contrast, all those in the coastal zone that are subject to marine erosion have been remobilised on a large scale. The currently active part of the Black Ven-Spittles complex lies within a larger landslip that stretches from Charmouth to the eastern slopes of the Lim Valley (Figure 1).

There is historical evidence to show that the rate of reactivation of the Black Ven-Spittles Landslip has increased in the past 100 years, and photographic evidence to show that the central and western parts have been especially active in the last 60 years. The region has experienced a variable temperate climate for the past 10,000 years, but the reactivation of the 'fossil' landslip appears to have begun within historical times. Deforestation, man-made drainage works and road building seem likely to have been important contributing factors to the reactivation of the upper part of the complex. Holocene sea-level rise, which has caused a progressive increase in the rate of erosion at the toe of the landslip complex, has also clearly played an important role.

The first metalled road between what are now the towns of Charmouth and Lyme Regis was built by the Romans to link Dorchester and Exeter. It followed high ground on the Upper Greensand outcrop and Clay-with-flints plateau immediately inland from the unstable slopes of the coastal zone (Figure 1). Roberts (1834) noted that the medieval lane to Charmouth, which avoided a long detour and uphill walk to the Roman road, ran eastwards from Spittles Lane at Lyme Regis across what are now the lower slopes of the active part of the landslip. Following a series of failures that breached this route, a new road was opened in 1825 on the lower part of the Upper Greensand outcrop some distance below the Roman road. This failed at its eastern end within 3 years and after several more collapses was replaced by the modern road in 1880 (Woodward and Ussher, 1911). The 1825 road (now referred to as the Old Charmouth Road) remained open to pedestrians until 1935 and much of it was still in use as a footpath in 1947 (Figure 1).

As a result of post WW2 urban expansion, housing at Charmouth now abuts onto part of the active landslip, and at Lyme Regis the modern Charmouth Road is locally only 100 m distant from it. Concern about the possible future expansion of the landslip complex and its economic consequences have

[1]Most of the large, complex mass-movement structures in Britain have traditionally been referred to as landslips (e.g. on BGS maps). In recent years, landslide has become the preferred generic term for most mass-movement deposits and their landforms.



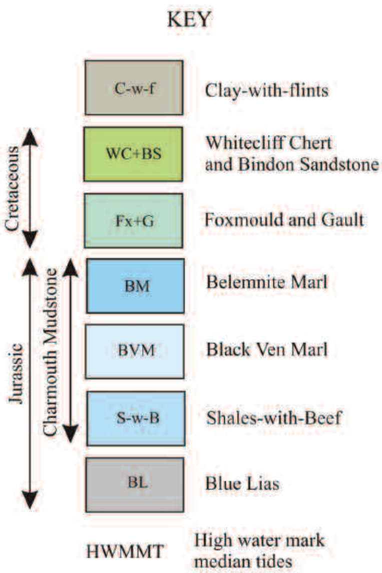


Figure 1. *(a) LIDAR image of the Black Ven-Spittles landslip complex and adjacent areas, May 1998. Copyright Geomatics Group 2008. (b) Geological sketch map of the same area. Drift deposits, including landslip debris, omitted for clarity.*

prompted studies of the geology (Arber, 1973; Conway, 1974), mechanism (Brunsden and Jones, 1976; Brunsden and Chandler, 1996; Chandler and Brunsden, 1995) and engineering geomorphology (Brunsden, 2002). The site was visited by the Ussher Society as part of the 2001 meeting at Sidmouth, most propitiously during a period of particularly wet weather when a steady stream of mud and debris flows was observed (Gallois, 2001).

Geological setting

The Black Ven-Spittles Landslip can be divided into two distinct parts: an upper, Cretaceous-based active complex that behaves independently, and a Jurassic-based complex that is in part affected by movements in the Cretaceous-based complex. The upper landslip, *c.* 0.2 km^2 in area, is composed of collapsed Cretaceous rocks consisting of up to 5 m of Gault clay overlain by a *c.* 75 m-thick succession of Upper Greensand. Below this and extending to the sea, about 0.4 km^2 of collapse-debris derived from the *c.* 100 m-thick Jurassic Charmouth Mudstone and from the Cretaceous rocks forms a lower landslip. The debris rests on a series of benches within the Charmouth Mudstone Formation outcrop (Conway, 1974) that are separated by low cliffs of calcareous mudstone that are not prone to failure. The most prominent of these is the outcrop of the Belemnite Marl which forms a permanent steep slope *c.* 25 m-high that separates the lower and upper parts of the landslip complex. Two large mudflow/debris-flows currently traverse the lower landslip.

Jurassic rocks

The stratigraphy of the Jurassic rocks that underlie the landslip is well known from the adjacent cliff and foreshore exposures, and from an extensive drilling programme carried out by West Dorset District Council as part of the site investigation for recently completed and proposed landslip stabilisation and sea-defence works (Gallois and Davis, 2001; Brunsden, 2002). These data have been supplemented by field surveys within the landslip area to determine the relationship of the lithostratigraphy to the landslip mechanisms. The Jurassic succession consists almost entirely of mudstones. At the base, the Blue Lias Formation forms a stable foundation composed of thinly interbedded mudstone and limestone. Above this, the Charmouth Mudstone Formation is divided into members partly on the basis of gross lithology and partly arbitrarily at thin (mostly < 0.4 m thick) muddy limestone marker beds that can be traced at outcrop throughout the lower landslip.

The Jurassic succession that underlies the landslip is summarised in Figure 2, together with the positions of the principal failure surfaces. The division into 'major', 'widespread' and 'minor' is arbitrary and varies from locality to locality due to lateral variations in the stratigraphy and, most importantly, the local structure. For example, the failure surfaces in the Shales-with-Beef Member in Langmoor and Lister gardens in Lyme Regis (Brunsden, 2002), where there is a seaward dip, are absent to the west of Lyme Regis below Devonshire Head where the Shales-with-Beef Member forms a near-vertical cliff.

The mudstones can be divided into two broad types for geotechnical purposes: thinly interbedded and interlaminated clay-mineral-rich and organic-rich mudstones that weather to weak fissile mudstones ('paper shales') and listric clays, and calcareous mudstones with widely spaced nodules and beds of muddy limestone. The principal failure surfaces occur in fissile-weathering mudstones a little above each of the more laterally persistent limestone beds in the Shales-with-Beef and Black Ven Marl, with the result that the limestones cap terraces in a stepped profile (Figure 3). At the top of the succession the calcareous Belemnite Marl forms an unbroken cliff (Figure 4). Minor landslips within the Jurassic outcrop are connected by mudflows and debris flows that cross the intervening ridges at times of high activity. At the present time these flows are concentrated in, but not confined to, two principal belts, one at Black Ven and one at The Spittles.

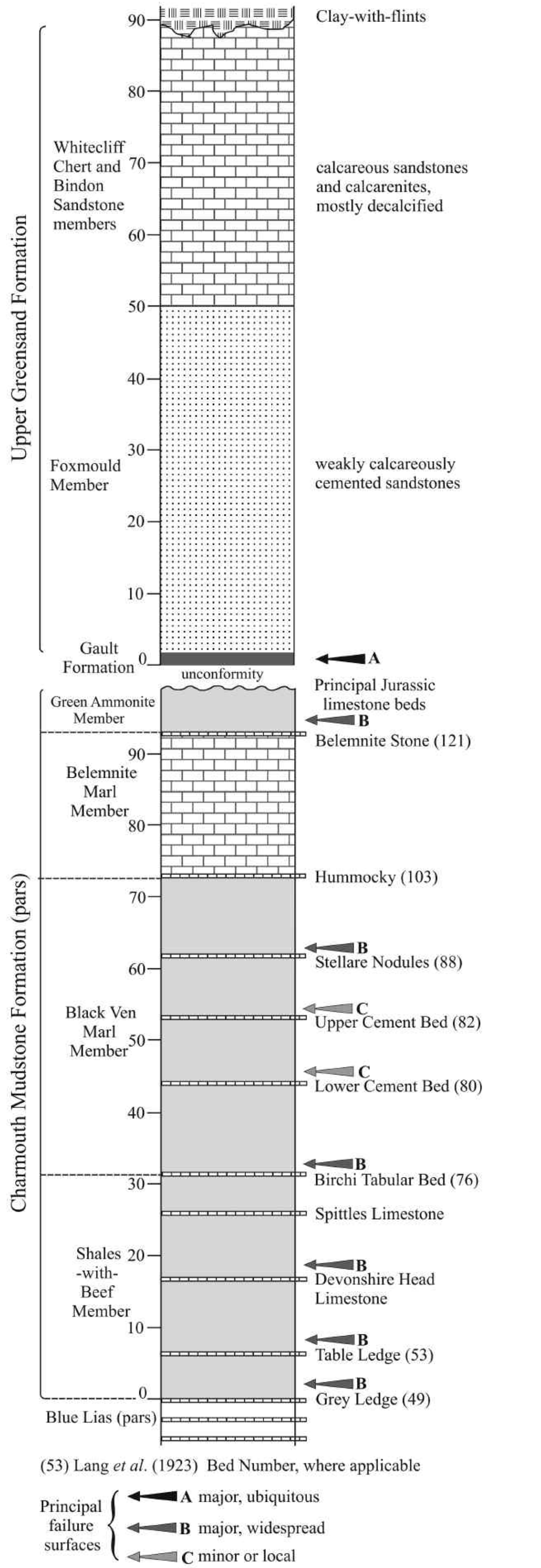


Figure 2. *Generalised vertical stratigraphical section for the Charmouth Mudstone Formation exposed in the Black Ven-Spittles landslip complex.*

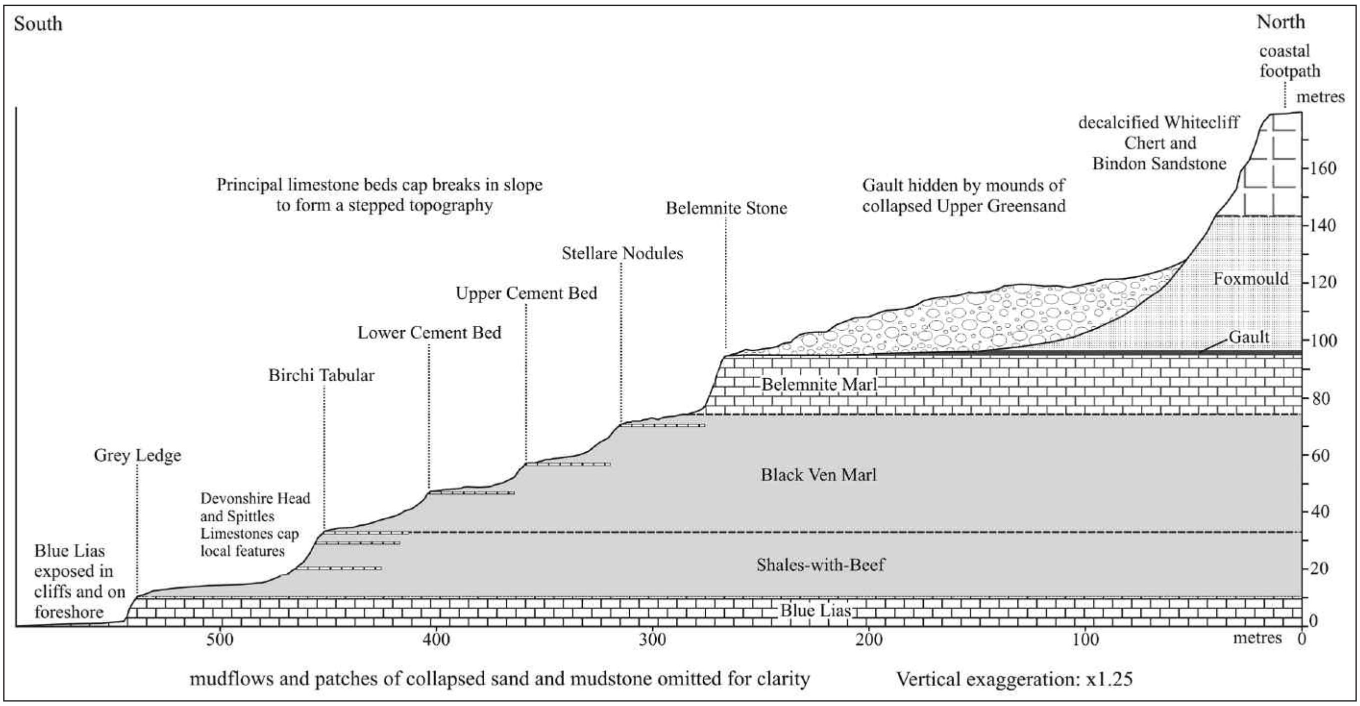


Figure 3 . *Simplified geological section through the central part of the Black Ven landslip showing the relationship of the topography to the underlying geology (after Conway, 1974 and Gallois, 2001).*

Figure 4. *Black Ven (right hand half of the picture) viewed from the sea in July 2004. Photograph courtesy of Richard Edmonds, World Heritage Team.*

Cretaceous rocks

The stratigraphy of the Cretaceous rocks is known in less detail than that of the Jurassic rocks, but there are sufficient data available from past and present exposures in the back faces of the landslip for the failure mechanism to be understood. The succession can be divided into three lithologically distinct parts, in ascending order the Gault Formation, the Foxmould Member of the Upper Greensand Formation and the Whitecliff Chert and Bindon Sandstone members of the Upper Greensand Formation.

The Gault Formation was well exposed at the eastern end of Black Ven [SY 358 932] in Victorian times where Jukes-Browne and Hill (1900, p. 187) recorded up to 5 m of clay and sandy clay that rested unconformably on the Charmouth Mudstone Formation. The Gault Formation thins rapidly westwards until it is about 2 m thick at the western end of the landslip. Where unweathered it comprises relatively strong montmorillonite-rich mudstones and sandy mudstones which at outcrop readily weather to weak swelling clays. The formation gives rise to seepages and springs at the top of the Belemnite Marl outcrop (Figure 4), but it has not been exposed *in situ* in the landslip in recent years, except for a basal 0.5 m of pebbly clay that crops out above Black Ven cliff. Blocks of deeply weathered silty clay can be dug out of the landslip debris about 2 m above the presumed position of the 'basal-Gault' failure surface.

The Foxmould Member consists of weakly calcareously cemented permeable sandstones that are prone to dissolution.

When fresh, the overlying Whitecliff Chert and Bindon Sandstone members consist of strong calcareous sandstones and sandy calcarenites, but above Black Ven these are almost wholly decalcified to produce loose sands and cherts (Gallois, 2004). The age of the dissolution is not known, but it extends to such a great depth and is so pervasive in those parts of east Devon and west Dorset where the Upper Greensand is not protected by a capping of Chalk that it may have begun in the Tertiary, been especially active in the Pleistocene, and continued on a small scale to the present day. When failures occur in the Gault, the decalcified Foxmould Member combines with the overlying beds to produce matrix-supported debris flows that pour over the Belemnite Marl cliff separating the upper and lower parts of the landslip complex. Small streams of sand and chert commonly fall from the Upper Greensand in the landslip backface for months after major failures.

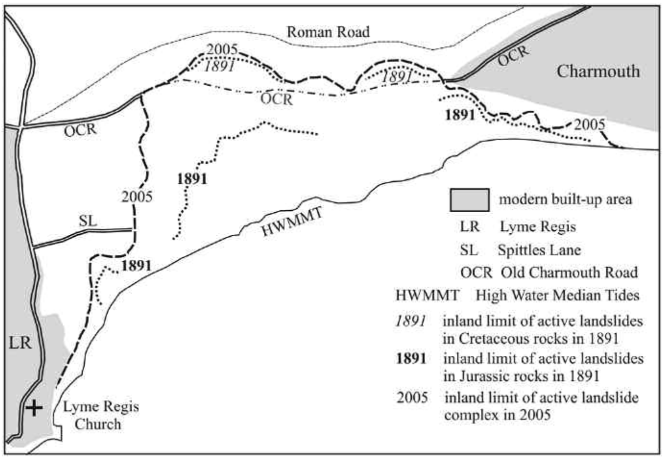


Figure 5. *Sketch map showing the approximate limits of the active landslip areas in 1891 (based on Ordnance Survey maps) and 2005 (based on aerial photographs).*

Changes between 1947 and 2005

Early Ordnance Survey maps, culminating in the first edition of the 1:10560-scale maps of Dorset in 1891, indicate that there was little landslip reactivation up to and including the 19th Century (Figure 5). The construction of the 'old' (1825) Charmouth Road perilously close to the foot of the Upper Greensand scar is likely to have contributed to the renewal of movements along that part of its length. At its eastern end the road passed through a deep cutting, known locally as the Devil's Bellows on account of its funnelling effect on south westerly winds. This was one of the first areas to fail.

The landslip complex expanded rapidly in the second half of the 20th Century, increasing in areal extent by about 40%. A photographic comparison of its extent in 1947 with that in 2005 (Figure 6) shows that the Belemnite Marl cliff was a stable, albeit retreating, feature that separated the upper (Cretaceous) and lower (Jurassic) parts of the complex throughout that time. Between 1947 and 2005, the area occupied by the 'Cretaceous' landslip proportionately increased much faster than that occupied by the 'Jurassic' part (Figures 5 and 6).

Summary and conclusions

Several conclusions can be drawn from the manner in which the landslip complex has developed during the last 60 years. (1) The Cretaceous part of the landslip has doubled in area, almost wholly by a westward expansion in response to a series of failures just above the base of the Gault. The better documented of these have occurred at times of high water-table level in the Upper Greensand. These failures are likely to have been, at least in part, the reactivation of surfaces that initially failed in the Pleistocene. (2) The Jurassic rocks have not played a significant part in the movements in the Cretaceous part of the complex. The Belemnite Marl formed a stable boundary that

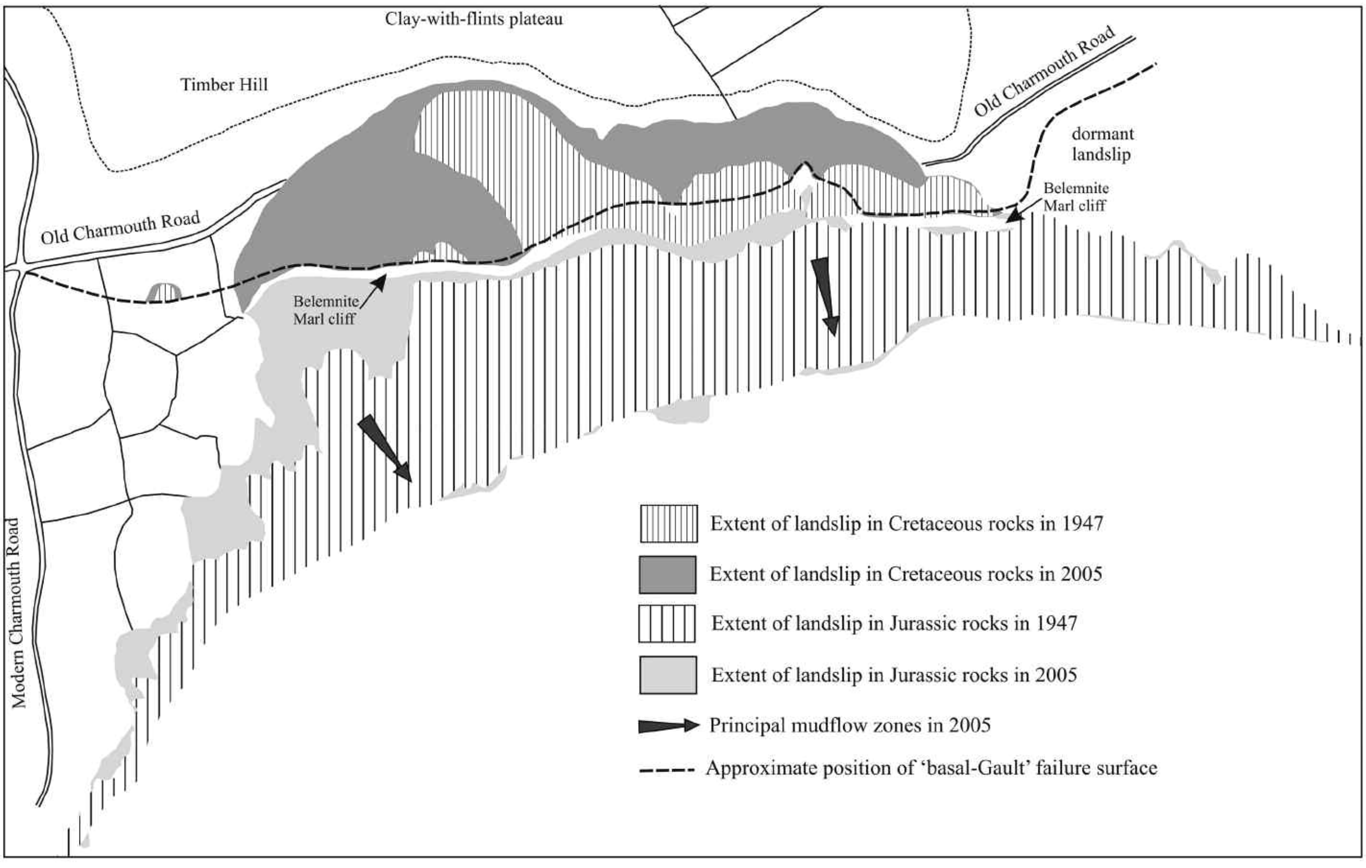


Figure 6. *Comparison of the approximate extents of the 'Jurassic' and 'Cretaceous' parts of the Black Ven-Spittles landslip complex in 1947 (based on RAF Sortie CPE/UK/1947) and 2005 (based on aerial photographs, copyright UK Perspectives).*

separated the failures in the Jurassic and Cretaceous rocks throughout this period. (3) The Jurassic part of the complex has increased in area by about 10%, almost entirely by westward expansion. The western boundary has more or less kept pace with the westerly expansion of the 'Cretaceous' landslip. (4) The *in situ* and collapsed Upper Greensand rocks act as a substantial groundwater reservoir that supplies steady amounts of water to the 'Jurassic' landslip. At times of high activity this material initiates local failures in the Jurassic rocks. The two most active parts of the 'Jurassic' landslip, the mudflow belts, are sited below areas that receive large amounts of runoff from the Cretaceous rocks during periods of wet weather. (5) If the Cretaceous capping was not present, much of the Charmouth Mudstone Formation would crop out in steep cliffs traversed by terraces capped by small amounts of mudstone debris, as seen at Black Ven (Figure 4).

In conclusion, the principal cause of the westward extension of the Black Ven-Spittles landslip complex in recent years has been a succession of failures in the Gault. This has induced secondary failures in the Jurassic mudstones as a result of which the western end of the lower landslip has tended to keep pace with the western boundary of the upper landslip (Figure 6). The eastern edge of the landslip complex has moved little in the last 60 years even though it abuts onto a dormant landslip that is underlain by a similar geological succession to that of the western area. The principal difference between the two areas is that the eastern area was extensively drained in advance of its urban development in the 1950s.

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