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Reconstructing the recent failure chronology of a multistage landslide complex using cosmogenic isotope concentrations: St Catherine's Point, UK

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ABSTRACT

The pre-existing multistage landslide complex at St Catherine's Point comprises a series of large rotational and translational failures that form the western section of the Isle of Wight Undercliff, UK. Cosmogenic beryllium and aluminum concentrations extracted from chert samples of the Upper Greensand are used to date the most recent sequential failure events. We use our understanding of the failure mechanics and landslide geomorphology to produce a cosmogenic exposure model that incorporates pre-failure topography into our shielding calculations. This method allowed us to date two successive landslides at the site using ^{10}Be, the most recent of which occurred ~1064 ± 348 (±1 σ) ^{10}Be years ago, much more recently than was previously thought. An earlier failure event is dated at ~3471 ± 348 ^{10}Be years, supporting the hypothesis that the St Catherine's Point landslide complex was reactivated by relative sea-level rise at the end of the Holocene Climatic Optimum period.

1. Introduction

Deep-seated landslide complexes are found throughout the world (e.g. Crozier et al., 1995; Hutchinson and Bromhead, 2002; Kasai et al., 2009; Della Seta et al., 2013; Young, 2015). Removal of mass through erosional processes, seismic shaking, and fluctuations in ground water hydrology alter the stress environment to which geological materials are exposed, which can lead to rotational or translational failure across shear surfaces (Petley and Allison, 1997). In coastal environments, the continual removal of material through marine erosion can often result in multiple stages of failure through time (e.g. Hutchinson, 1988; Rudkin, 1990; Della Seta et al., 2013). An example of this from the UK is St Catherine's Point landslide complex which forms the westernmost part of the Isle of Wight Undercliff, a pre-existing landslide complex on the south coast of the Isle of Wight (Fig. 1). Measuring approximately 12 km in length and reaching up to 0.6 km from crest to toe, the Undercliff represents one of the largest urbanized landslide complexes in western Europe. The small towns of Ventnor, Bonchurch, St Lawrence and Niton with a total resident population of 6000 are located along the Undercliff (Lee and Moore, 1991; Moore et al., 1995, 2010; McInnes, 2007; Gillarduzzi et al., 2007).

The litho-stratigraphy of the Undercliff is composed of a sequence of sandstones and clays overlain by the Lower Chalk formation as shown in Table 1 (Palmer et al., 2007). The regional dip is to seaward at 1.5° to 2° (White, 1921). However, both the dip and the height of the strata relative to sea-level are influenced by the St Lawrence syncline, the axis of which runs through the centre of the Undercliff between St Lawrence and Ventnor (Chandler, 1984; Hutchinson and Bromhead, 2002). Slope stability along the Undercliff is controlled by shear surfaces in the weaker stratigraphic layers, most importantly in units 4a and 4b of the Gault Formation and units 2b and 2d of the Sandrock Formation (Hutchinson and Bromhead, 2002; Moore et al., 2007, 2010). Currently, the landslides within the complex exist in a state of dynamic metastable equilibrium with winter groundwater levels resulting in higher ground motions following periods of high effective stress (Gillarduzzi et al., 2007; Moore et al., 2010). The landslide complex is thought to have been activated by the erosion of the St Catherine's Deep, a submerged palaeovalley running parallel to the Undercliff approximately 2.8 km offshore, in conjunction with changes in base level and marine erosion associated with sea-level rise during interglacial periods (Chandler, 1984; Moore et al., 2007).

The geomorphology of St Catherine's Point has been thoroughly investigated (e.g. Hutchinson et al., 1991, 2002; Hutchinson and Bromhead, 2002; McInnes, 2007) and is summarized here. Due to its location on the western limb of the St Lawrence syncline, the base of the Gault Formation is roughly 53 m above sea-level and the Sandrock is roughly at sea-level (Fig. 2A). Shear surfaces within these strata control instability at the site (Hutchinson et al., 1991). The ground model (Hutchinson et al., 1991) indicates a rapid multistage failure resulting

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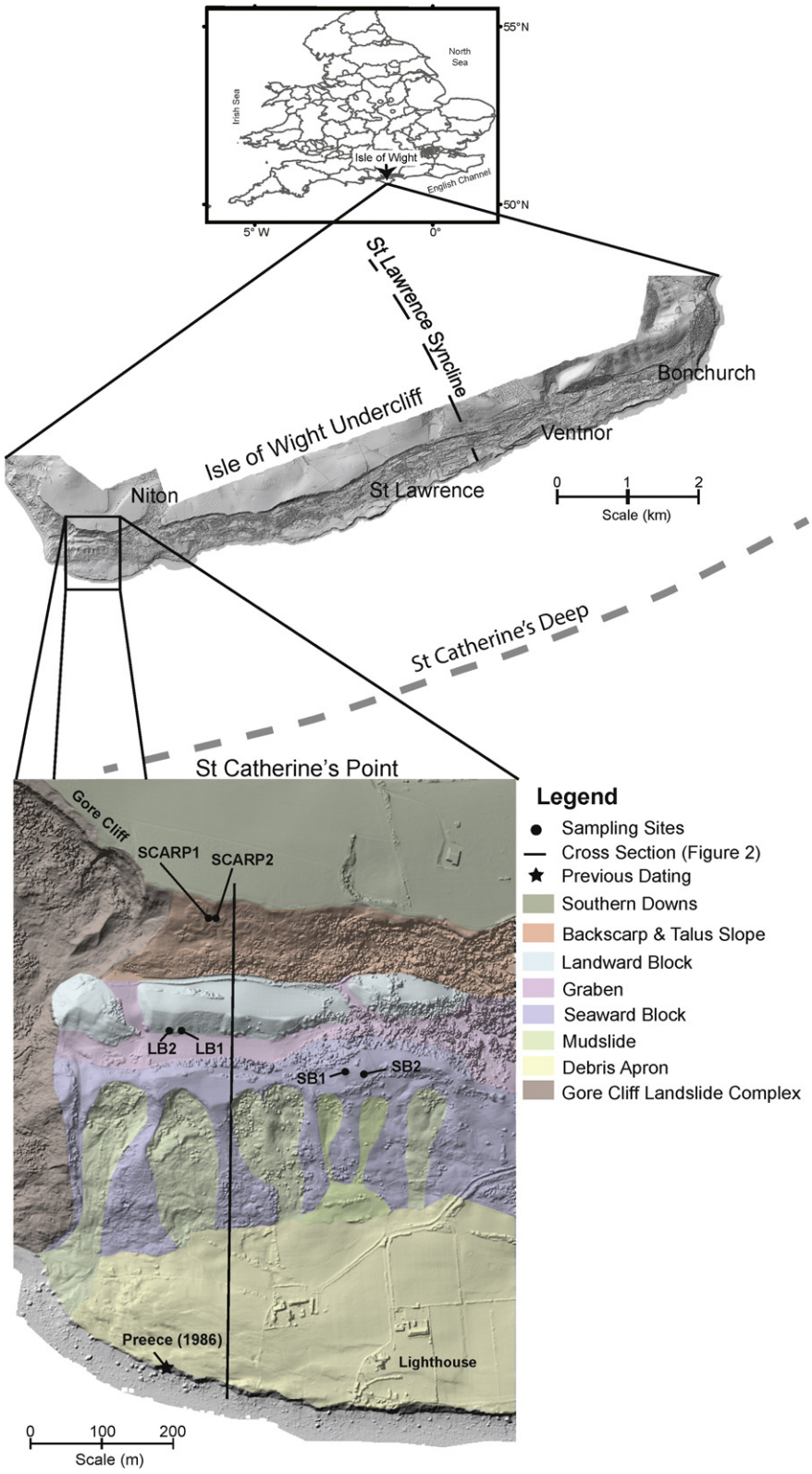

Fig. 1. Site location. Shaded relief map of the Isle of Wight Undercliff and St Catherine's Point provided at larger scales with main geomorphological features and sampling sites indicated. Black line indicates cross sectional transect (Fig. 2). Topographic data courtesy of the Channel Coastal Observatory.

from marine erosion. The failure mechanics have created three major morphological features illustrated in Figs. 1 and 2A; a seaward block composed of a sequence of sandstones and Gault Formation that has been displaced southwards by ~100 m, a landward block formed by rotational failure of the Upper Greensand and Lower Chalk formations, and a rear scarp of Upper Greensand and Lower Chalk. To the south, a large debris apron protects the landslide blocks from marine erosion. The borehole data used to construct the ground model is also shown in Fig. 2A. These boreholes did not penetrate the entire stratigraphic sequence such that there is some subjectivity in the model (Hutchinson