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A combined geomorphological and geophysical approach to characterising relict landslide hazard on the Jurassic Escarpments of Great Britain

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ABSTRACT

The Jurassic Escarpment in the North York Moors in Northern Britain has a high density of deep-seated relict landslides but their regional hazard is poorly understood due to a lack of detailed case studies. Investigation of a typical relict landslide at Great Fryup Dale suggests that the crop of the Whitby Mudstone Formation is highly susceptible to landslide hazards. The mudstone lithologies along the Escarpment form large multiple rotational failures which break down at an accelerated rate during wetter climates and degrade into extensive frontal mudflows.

Geomorphological mapping, high resolution LiDAR imagery, boreholes, and geophysical ERT surveys are deployed in a combined approach to delimit internal architecture of the landslide. Cross-sections developed from these data indicate that the main movement displaced a bedrock volume of c. 1×10^7 m^3 with a maximum depth of rupture of c. 50 m. The mode of failure is strongly controlled by lithology, bedding, joint pattern, and rate of lateral unloading. Dating of buried peats using the AMS method suggests that the 10 m thick frontal mudflow complex was last active in the Late Holocene, after c. 2270 ± 30 calendar years BP.

Geomorphic mapping and dating work indicates that the landslide is dormant, but slope stability modelling suggests that the slope is less stable than previously assumed; implying that this and other similar landslides in Britain may become more susceptible to reactivation or extension during future wetter climatic phases. This study shows the value of a multi-technique approach for landslide hazard assessment and to enhance national landslide inventories.

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1. Introduction

Landslide hazards pose a threat to people and infrastructure worldwide. They are a constraint on land use and can impact on the economy of an affected community (e.g. Jones and Lee, 1994; Schuster and Highland, 2001). However, our ability to assess hazard and risk in slide prone terrain, such as the North York Moors (NYM) region of the UK, and in Polar Regions currently undergoing de-glaciation, is hindered by a lack of knowledge about the magnitude and frequency of events and hillslope processes operating in these settings more generally. This paper provides a baseline reference study for landslide hazards in mudrocks that can be used to calibrate magnitude/frequency estimations for landslide hazard assessments in the region and in similar geological terrain elsewhere.

Jurassic mudrocks underlie much of the UK including the North Yorkshire Moors area. These rocks are exposed in coastal slopes which are prone to instability (Jones and Lee, 1994; Fish et al., 2006; Cooper, 2007; Johnson and Fish, 2012) but landslide problems on inland escapement slopes in the NYM region are under-represented in the literature (Senior and Rose, 1994; Waltham and Forster, 1999; Marsay, 2010; Merritt et al., 2013). Previous geomorphological studies in the region (Fox-Strangways et al., 1885; Gregory, 1962a) did not describe the landslide geology or geomorphology in any great detail. This paper aims to address this knowledge gap.

The study focuses on the Mark Nab landslide in Great Fryup Dale, Upper Eskdale (Fig. 1), which is the largest in a cluster of bedrock landslides distributed throughout several of the deep valleys in the north of the region. We combine newly acquired remote-sensing data (LiDAR), ground-based geomorphological mapping, electrical resistivity tomography (ERT), and geotechnical data into a ground model in order to conceptualise the 3D landslide architecture. We also use Accelerator Mass Spectrometry (AMS) dating methods to further develop the movement history. This ground model was then used to develop a deterministic slope stability model to test theories about trigger and preparatory factors that led to the initial failure; including changes in stress and

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Fig. 1. The Mark Nab landslide on the Jurassic escarpment, showing complex landslide morphology. Looking south-west. Photo taken by A. H. Cooper. Copyright BGS/NERC P769517.

porewater pressure brought about by glacial erosion, glacial debuttressing, changes in regional groundwater levels and glacial lake development. An assessment of the present stability state of the dormant slope is also presented to provide an indication of the current and future regional hazard posed by relict landslide systems.

2. Mark Nab study area

2.1. Topography

The study area, located at British National Grid reference 471350, 502840 (54.42, −0.90 WGS84), covers a north facing slope on the Jurassic escarpment at the head of Great Fryup Dale (Fig. 2). The foot of the slope lies at c. 150 m above Ordnance Datum (aOD) and rises up over hummocky ground by c. 200 m over a distance of c. 600 m. At the top of the slope, Middle Jurassic bedrock is exposed in the near-vertical cliff that forms the main Jurassic escarpment, above which is an upland moorland plateau which reaches a high point of 432 m aOD on Danby High Moor. The plateau sits at the northern edge of the North York Moors which are fragmented by a series of deep valleys generally orientated south-west north-east. The heads of these valleys are commonly incised by streams fed by runoff from peat covered moorland catchments. Numerous springs issue groundwater along the foot of the escarpment. The streams, such as Great Fryup Beck in 'Dale Head' and Slidney Beck (Fig. 2) then flow north-eastwards into the River Esk which discharges into the North Sea at Whitby. At Great Fryup Dale the lower valley slopes are U-shaped and are typically inclined at c. 20°, but towards the head of the valley (Dale Head) the profile becomes increasingly V-shaped and irregular, due to Holocene fluvial incision and slippage.

2.2. Bedrock geology

The Great Fryup valley is cut into a bedrock succession of Lower to Middle Jurassic sedimentary rocks comprising units of mudstone, siltstone and sandstone, with subsidiary ironstone bands and limestone beds that together represent subsidence and eventual infilling of the Cleveland Basin (Kent et al., 1980; Holliday et al., 1992; Cox et al., 1999). The valley is positioned on the northern limb of the east–west trending Cleveland Anticline structure. The bedding in the valley is typically near-horizontal but locally dips 1° to 2° to the north, dipping gently out of the slope below Nark Nab.

The succession comprises formations of the Lower Jurassic Lias Group, overlain by those of the Middle Jurassic Ravenscar Group. The typical lithologies of this succession are summarised in Table 1.

The overview geological map in Fig. 3 shows that landslide deposits are extensive in Great Fryup Dale and are largely coincident with the Whitby Mudstone Formation (WHB) and Dogger and Blea Wyke Formations. The Whitby Mudstone Formation is predominantly argillaceous

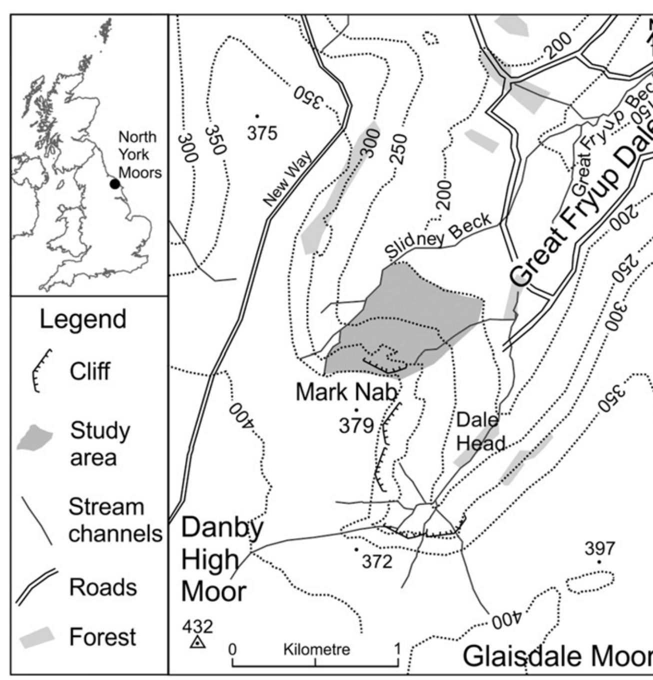

Fig. 2. Location map of the Mark Nab landslide study site at Great Fryup Dale, North York Moors. Contours and spot heights are in metres above Ordnance Datum. Contains Ordnance Survey data © Crown copyright and database right 2014.

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