Landslide mechanisms in the Axmouth to Lyme Regis Undercliffs National Nature Reserve, Devon, UK

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The Axmouth to Lyme Regis Undercliffs National Nature Reserve (NNR) on the east Devon coast contains one of the largest active complexes of overlapping and coalescing landslides in Europe. Taken together they include examples of all the more common type of landslide ranging from rock falls in sandstones and limestones to mud flows in deeply weathered clays. The most spectacular landslides during the past 200 years have been translational failures in which detached blocks of Cretaceous rocks of up to millions of tonnes have been displaced seawards by up to 500 m. There are few published detailed descriptions of most of the landslides in the reserve, the notable exception being the Bindon Landslide of Christmas Day 1839. When regarded as an evolutionary whole, the various types of mass-movement deposit in the NNR can be divided into three broad categories (primary, secondary and tertiary) based on the state of the materials involved immediately prior to failure. The present account describes how the historical and genetic inter-relationships of these categories have combined to produce the present-day complex. The major primary landslides in the eastern part of the NNR involve shear failures in montmorillonite-rich mudstones in the Cretaceous Gault Formation. Those in the western part involve failures in thin beds of similar mudstone in the lowest part of the Upper Greensand Formation. The larger secondary landslides involved the collapses in the Cretaceous rocks and bedding-plane failures in Jurassic mudstones.

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Introduction

Between the outfall of the River Axe and Lyme Regis, a distance of 10 km, the coastal zone is a complex of coalescing landslides 100 to 600 m wide that collectively form the Axmouth to Lyme Regis Undercliffs National Nature Reserve (NNR). Throughout most of its length the boundaries of the NNR are defined by sea cliffs composed of *in situ* rocks and rocks and debris displaced by landslides, and inland by the back scarps of landslides. In total, *c.* 16 km of rock cliffs. The Undercliffs NNR is the largest active landslide complex in Britain and includes examples of all the principal types of mass movement including rotational failures, mudflows, slab (translational) slides, rock falls, debris slides, and liquefied sand flows.

The NNR can be divided into six landslide areas based on the most recent large-scale failures (Figure 1): these are closely similar to the divisions used by earlier authors (e.g. Arber, 1940; Pitts, 1981a). Each complex comprises overlapping and superimposed landslides that extend back for hundreds of years, as a result of which the boundaries between them are to some extent arbitrary. A few of the larger individual events of the past 200 years have been well documented, but most of the medium and smaller failures in that period are only known from a passing reference to their occurrence (e.g. 'a landslide occurred at…') even though, taken together, they have produced an unusual topography that has attracted numerous authors and artists. Reviews of the historical accounts of the landslides in the NNR include those of Arber (1940, 1973) and Pitts (1981a, b). These accounts were reviewed in the Geological Conservation Review volume *Mass Movements in Great Britain* (Cooper, 2007) which incorrectly classified the Undercliffs as a mass-movement site in Jurassic strata.

A range of late Triassic to late Cretaceous rocks is exposed *in situ* in sea cliffs and the back scarps of the landslides in the NNR (Figure 2). Large parts of the Cretaceous succession are repeated in relatively undisturbed detached masses within the landslides. The stratigraphy and geological structure vary across the NNR: their effects on the failure mechanisms are discussed below, landslide complex by landslide complex. The principal landslides in the eastern part of the NNR involved shear failures in Cretaceous Gault mudstones and liquefaction of the overlying Foxmould sands. Those in the western part failed along thin (mostly <0.1 m thick) beds of mudstone in the lowest part of the Upper Greensand. The mechanisms of these landslides have been much described and discussed from 1840 onwards from the time of the first detailed description and analysis of a major landslide, the 1839 Bindon Landslide (Conybeare *et al.*, 1840). However, few of the subsequent descriptions took sufficient account of the detailed stratigraphy and the geological structure.

The principal factors that influence the formation of landslides are the geotechnical properties of the unweathered and weathered rocks, their stratigraphical relationships,