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Boulder dynamics on an Atlantic-facing rock coastline, northwest Ireland

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ABSTRACT

The rock coast of northwest Ireland comprises steep cliffed headlands and more open coastal sections where bedrock shore platforms are developed. Many shore platforms are overlain by boulders; the locations on the platform from which boulders are derived are marked by 'holes' of fresh and unweathered rock surfaces that are not, or are poorly, covered by lichen. These areas of boulder detachment are termed sockets. This paper examines the mapped distributions and physical properties of boulders, sockets and shore platform context of an Atlantic-facing granite shore in County Donegal, northwest Ireland. Results from Schmidt hammer rebound tests show statistically-significant differences in rebound values between areas inside and outside of sockets and between sockets and boulders. Based on their distributions and physical properties, relationships between sockets and boulders are explored. We calculate that sockets are formed rapidly by winter storms but are also rapidly weathered over c. 5 years, becoming indistinguishable from the surrounding bedrock platform. We argue that, in contrast to some studies, boulders here were formed during recent winter storms (episodically during the last 150–200 years) rather than by more ancient waves or by tsunamis. However, a significant proportion of boulders (c. 20%) are morphometrically dissimilar to sockets; we argue that these were formed by infrequent and unusually-powerful waves that stripped whole bedrock sheets off the platform surface and which detached boulders from the lower shoreface.

1. Introduction

Bedrock-derived boulders litter many bedrock platforms along Atlantic-facing European coasts (e.g. Trenhaile, 2002, 2005; Blanco-Chao et al., 2007; Hall et al., 2008). Large and isolated boulders (~3–8 m dimensions) can be found scattered at high elevations (<50 m above mean high water springs [MHWS]) either at the landward edge of bedrock platforms or on top of bedrock cliffs of varying heights (e.g. Hansom et al., 2008; Hansom and Hall, 2009). These large boulders are often interpreted as having been transported inland by and deposited from high-magnitude storm or tsunami waves (e.g. Hall et al., 2006, 2008; Hansom et al., 2008; Pignatelli et al., 2009; Suanez et al., 2009). Smaller boulders (~1–3 m dimensions) are more commonly found clustered within the upper intertidal zone of bedrock shore platforms, and organised into distinctive ridges, mounds, cusps and other mesoscale structures indicative of wave transport and sorting (e.g. Trenhaile, 2005; Scicchitano et al., 2007; Goto et al., 2009; Etienne and Paris, 2010). Many of the largest boulders cannot in themselves be used as synoptic wave climate proxies because they may reflect deposition by infrequent and non-climatic events (including tsunamis). The smaller boulders, however, can be used in this context because they reflect more commonly-occurring (winter) wave climate conditions, and can be measured and monitored over temporal and spatial scales that are relevant to both numerical modelling and coastal management (Goto et al., 2009; Knight et al., 2009; Etienne and Paris, 2010).

Much research has focused on the dynamic behaviour of these smaller boulders, including their trajectories across storm-influenced bedrock platforms and their response to forcing by storms and waves over short (episodic to seasonal) timescales (e.g. Etienne and Paris, 2010). Little research, however, has considered issues of where and how boulders are detached from rockhead along these coasts (Naylor et al., 2010). Consideration of these implications, however, is useful for two main reasons. First, rock coasts in the paraglacial mid-latitudes have likely been reoccupied during several glacial–interglacial cycles and so may be both polygenetic and formed over long time periods (Trenhaile, 2002; Blanco-Chao et al., 2007). Second, changes in nearshore wind and wave climates and sea-level rise will increase the frequency and magnitude of future storms that are responsible for rock coast erosion, including boulder formation, boulder transport and rock cliff collapse (Pirazzoli et al., 2004; Regnauld et al., 2004; Hansom and Hall, 2009).

The high-energy, Atlantic-facing coasts of western Europe are particularly well placed to record the dynamic behaviour of rock coasts in response to rapid climate change, because coastal changes are largely coeval with climate variability including the North Atlantic Oscillation (Cooper et al., 2004; Regnauld et al., 2004) and also because its coastlines are very variable, from rock to mud, so that boulder coast responses can be compared to the morphodynamics of

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other adjacent coastal types under similar forcing. This paper describes the boulder dynamics of the rocky and high-energy Atlantic coastline of northwest Ireland. We focus on geotechnical data from the bedrock shore platform surface, detached boulders, and locations where boulders have been detached from rockhead, termed sockets. These data are supported by morphological and biological evidence. Together, these data are used to evaluate the relative age structure of boulders and bedrock surfaces and implications for boulder dynamics, including their detachment processes. In detail the paper has two main aims: (1) to describe the geotechnical properties of sockets, boulders and adjacent rock surfaces; and (2) to consider the relative time periods of socket and boulder formation and implications for the role of climate forcing on rock coast dynamics.

2. Location of the study area

The morphology of the mesotidal coast of northwest Ireland is strongly affected by onshore Atlantic winds and waves (Delaney and Devoy, 1995; Duffy and Devoy, 1999; Cooper et al., 2004; Burningham, 2008). The coastline is characterised by rocky inlets, headlands and embayments developed in the underlying Devonian granites and metasediments, and is strongly controlled by geologic structure, including rock type and fault orientation (Long and McConnell, 1999). During the late Quaternary, successive glacial cycles weathered and eroded these rocks, and erosional products were transported to ice margins located offshore on the adjacent Atlantic shelf (McCabe, 2008). Present-day coastline geography and coastal structures reflect this mixed geologic and glacial inheritance. The region around Gweebarra Bay comprises bedrock headlands separated by sandy beaches and embayments (Burningham and Cooper, 2004). A granite shore platform is developed on the seaward margin of the bedrock-defined entrance to the sandy estuary of Trawenagh Bay (around 54°53.5′N, 08°24′W; Fig. 1).

Tides on the mid-west coast of County Donegal are mesotidal, with a tide range of 1.6 m at neaps to 3.5 m at springs. The mean annual offshore wave height is 2.9 m (Marine Institute buoy M4/62093 located at 54.67°N, 9.067°W), but is strongly seasonal, with a summer mean wave height of 2.2 m and winter mean of 3.7 m, one third of winter waves are greater than 4 m in height. The wind climate is dominated by southwesterlies, and wind records from Malin Head (north County Donegal, 1956–2006) and offshore (buoy 62093, for year 2007) exhibit an annual mean hourly wind speed of 8 m s^{-1}.

The broad distribution of boulders along this coastline was described in a previous paper (Knight et al., 2009). These boulders are located mainly along a 800 m-long stretch of a southwest-facing shore platform (Fig. 1). This bedrock platform is developed in rudaceous and massive biotite granite (Long and McConnell, 1999) through which there are multiple sets of intersecting contraction joints that have a vertical and a surface-parallel alignment. These joints define weaknesses in the granite that have been later exploited by weathering. Overall, the platform surface has a consistent and laterally-extensive seaward dip of 8–10° to the southwest, and a low local relief (Fig. 2A). Bedrock-derived boulders are located around the uppermost intertidal and lower supratidal zone of the platform. These boulders form a number of distinctive shore-normal ridges that have a consistent geometry and spacing (Knight et al., 2009) (Fig. 2B). The rock platform also shows a number of sockets, where the boulders have been detached from rockhead.

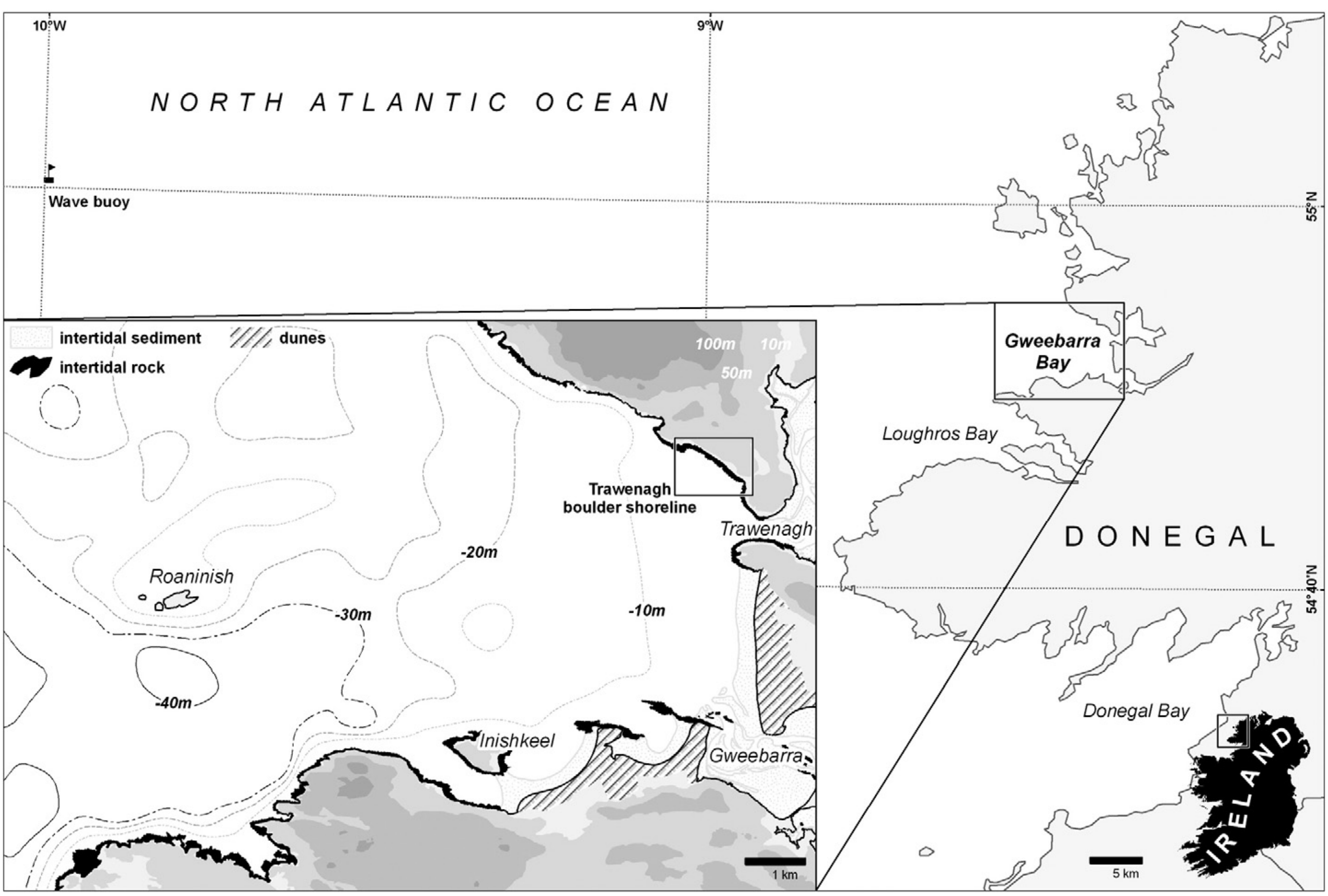

Fig. 1. Location of the Trawenagh Bay rocky shoreline in County Donegal, NW Ireland.