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In situ exhumation from bedrock of large rounded boulders at the Giant's Causeway, Northern Ireland: An alternative genesis for large shore boulders (mega-clasts)

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ABSTRACT

Very large boulders (mega-clasts) are found on some coasts. The size and position of the boulders has been used to suggest that contemporary marine processes, acting within their normal spatial and energy range, are unlikely to have moved them. Explanations for the presence of such boulders include transport by infrequent very high-energy marine processes (storms or tsunamis), mass movement from backing cliffs, transport by ice, or exhumation from glacial deposits. This paper advances an alternative explanation which does not involve transport by any of the marine or glacial processes, or gravity. It is proposed that, in a very specific geological and topographic setting, large boulders are exhumed *in situ* by storm waves acting on heavily weathered jointed basalts. Eventually wave action liberates residual blocks from the deeply weathered matrix. These liberated boulders will be mobile only if they lie within wave competence, and the larger ones will remain as stationary residuals. The same *in situ* weathering processes, followed by removal of the friable matrix material debris by wave action, also progressively round the boulders. Consequently, despite their appearance of being transport-rounded, the larger boulders have not transported at all. In specific locations, the assumption that the presence, and rounding, of such large clasts in the shore zone can be attributed to marine transport can lead to erroneous interpretations of very high-energy storm wave (or tsunami) activity.

1. Introduction

Very large bedrock boulders (mega-clasts) have been described on shorelines in a variety of settings. The size of the boulders plus, in some cases, their vertical elevation above sea level and/or distance landward of the high water mark makes it seem unlikely that they were transported by contemporary marine processes acting within their "normal" spatial and energy range. Five primary mechanisms have been described to account for the presence of such large clasts in the shore zone. The first three of these explanations are marine, while the latter two invoke non-marine processes. They are:

(1) Exceptional storm waves
(2) Tsunami
(3) Sea level change (emergence), i.e. large marine boulders originally emplaced by marine processes but left stranded by RSL fall
(4) Slope movements, particularly rockfall from bedrock cliffs
(5) Glacial and para glacial processes: These include cases where (a) boulders have been transported as erratics (b) boulders have been emplaced by polar shore processes such as ice-push and ice abrasion, and (c) boulders have been exhumed *in situ* from an eroding Quaternary deposit.

Much of the debate about the origin of very large shore boulders focuses on processes associated with extreme storms (for example Hansom et al., 2008) and tsunami (for example Paris et al., 2010), with continuing search for a hydrodynamic or sedimentological signature that might distinguish between these agents of transport and deposition (for example Nott, 1997; Williams and Hall, 2004; Morton et al., 2006; Dawson and Stewart, 2007; Kortekaas and Dawson, 2007; Switzer and Burston, 2010). However, in this paper we describe an additional mechanism (*in situ* exhumation from bedrock) to account for the presence of rounded shore mega-clasts, one in which wave action has played a significant but subordinate role in forming the boulders, but where it has played no role in transporting the larger examples.

2. Study area

The study area is at the Giant's Causeway on the north coast of Ireland (Fig. 1). This coast is an Atlantic storm wave environment (Cooper et al., 2004; Jackson et al., 2005) and experiences a wave climate with long-term median significant wave heights of 2–3 m and periods of 8–9 s. The field site itself is relatively sheltered, particularly on the landward sections of the shore platform. Refraction of swell waves results in a broadly shore normal approach. However, in extreme conditions maximum wave heights of >12 m and periods of 18 s have been recorded in Portrush West Bay, 10 km to the west. Tides are semi-diurnal with a mean spring range of 1.5 m. In the winter of 1982–83

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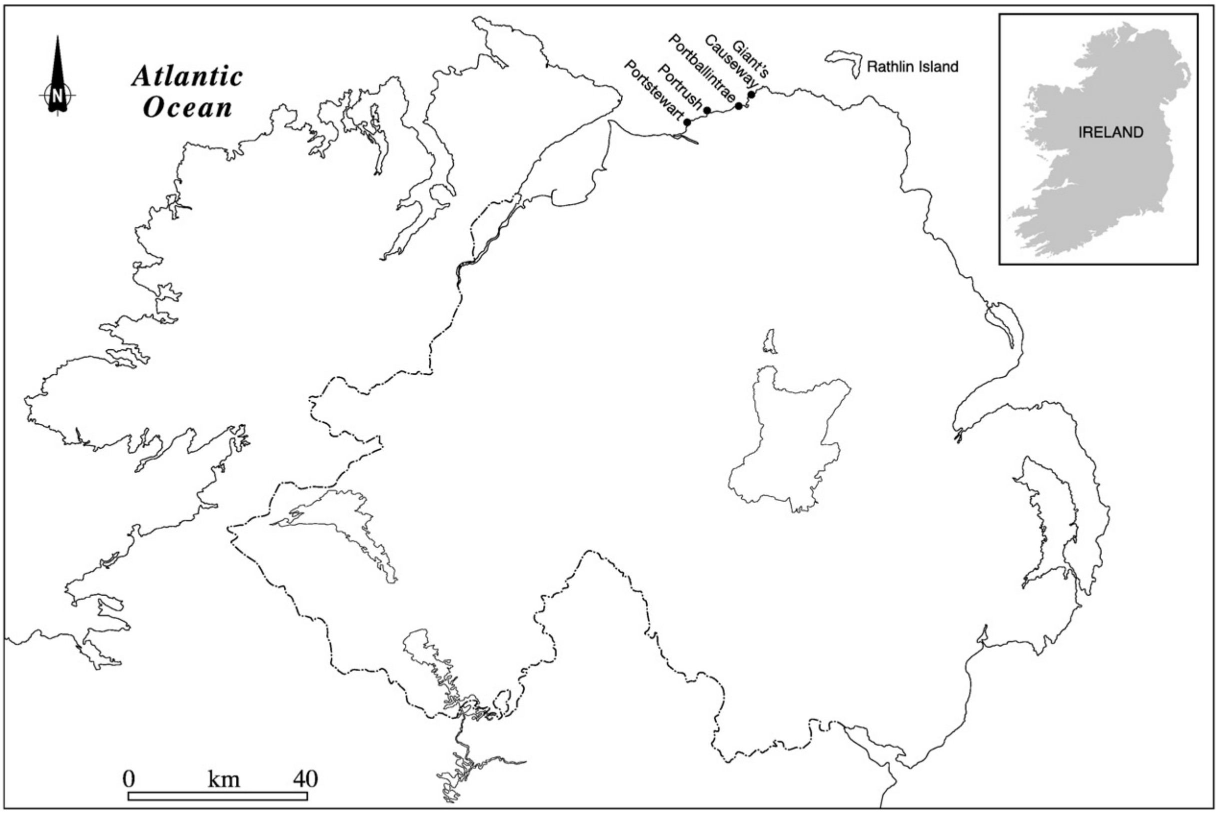

Fig. 1. The Giant's Causeway, County Antrim, Northern Ireland and other locations mentioned in the text.

extreme water levels up to 2.5 m O.D. were recorded at Portrush during a north-westerly storm surge (Mc Kenna, 1990).

2.1. Geology

The area is well known for its basalt geology and landforms, particularly the columnar basalt of the Causeway itself. Despite its landscape and tourism importance, the Causeway, a World Heritage Site, has been relatively neglected from a geomorphological standpoint. The limited amount of work carried out has focused on slope processes because of their management significance (Smith, 2008).

The geology of the Causeway Coast has been described in detail by Wilson and Manning (1978), Lyle and Preston (1993) and Lyle (1996, 2000). The broad pattern is that sub-horizontal beds of Tertiary (Palaeocene) basalts rest non-conformably on Cretaceous White Limestone (chalk). At the Causeway the basalts have a basic two-fold chronological division into the Lower Basalt Formation (LBF) and the Interbasaltic Formation (IBF). The latter includes both the laterites of the Port na Spaniagh Member (commonly referred to as the Interbasaltic Bed) and the Causeway Tholeiitic Member.

In the olivine-rich Lower Basalts individual lava flows average 6 to 8 m in thickness and are discontinuous. However, some massive flows reach thicknesses of up to 23 m. Thin, reddened horizons are visible in the cliff sections. Some of these are weathered and laterised flow tops, but many are weathered ash layers from the succeeding flow eruption. The outpouring of the Lower Basalts was followed by a long period of quiescence, perhaps lasting c. 100 kyr. During this period, the upper two or three flows were subjected to deep weathering in a warm temperate humid climate. This produced a thick red layer of laterite, often up to 10–15 m thick, termed the Interbasaltic Bed (Port na Spaniagh Member). A renewed phase of volcanic activity then produced the basalts of the Causeway Tholeiitic Member. Slow cooling of this ponded lava in a pre-existing steep-sided valley produced the basalt columns of the contemporary Giant's Causeway.

During and after the period of igneous activity the basalts suffered considerable flexing and warping as the crust adjusted to the excess loading. These movements generated discontinuities such as faults and joints which, along with the sub-horizontal weathered flow tops, provide zones of weakness that are preferentially attacked by processes of degradation and erosion. The spacing of these discontinuities exerts a strong control on the size and shape of blocks produced by weathering and erosion.

Fig. 2 (after Lyle, 1996 page 27) shows the detailed geology of the field site in both plan and profile views. The significant detail here is that east to west across the site the shore platform is cut, firstly in the Interbasaltic Bed where it descends to the shoreline for a short stretch immediately west of the Causeway promontories, and then into the Lower Basalts which form the shoreline further west.

2.2. Contemporary coastal geomorphology

The field site is shown in Fig. 3. It lies on the shore platform in Port Ganny, and is bounded immediately to the east by the three distinctive promontories of the Giant's Causeway (essentially seaward-dipping shore platforms cut into the columnar Causeway Basalts), and to the west by the Great Stookan headland.

The foreshore in Port Ganny consists of an irregular shore platform approximately 70 m wide, backed in turn by a cobble/boulder ramp, the Causeway access road, talus slopes and high Causeway Basalt cliffs. The western part of the platform is formed in the Lower Basalts. It is irregular and chaotic and is dominated by high relief ridges and ribs of bedrock rising to 2 m above the lower parts of the platform surface and extending across the intertidal area. These bedrock ridges have deeply dissected surfaces caused by the concentration of weathering and marine erosion along polygonal joints. The eastern section is largely formed of the friable lateritic material of the Interbasaltic Bed. It is much more regular and uniform with only low relief ridges. The seaward platform margin is poorly defined with no