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Boulder transport by waterspouts: An example from Aorangi Island, New Zealand

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Abstract

In 1996 the vegetation on Aorangi Island within the Poor Knights Island Nature Reserve, New Zealand, was found to be severely damaged. The damaged zone consisted of a distinct trail of stripped soil and broken vegetation starting at sea level and travelling in an arc across the northeastern flank of the island. Cobbles encrusted with marine life, sea urchins and seaweeds, were deposited at elevations up to 45 m above sea level along and beside the damaged zone. Boulders up to 2 m in size were transported horizontally at elevations of 5–15 m above sea level, and larger boulders were destabilised at 25 m above sea level causing them to slide and roll downslope.

Application of threshold entrainment relationships for tsunamis, storm waves and waterspouts indicates that a waterspout is the most probable mechanism for the observed damage and transport of large clasts. The addition of 2.5–5% of atomised water to the waterspout vortex significantly increases the flow competence. Hence, intensity T3–T5 (TORRO Tornado Intensity Scale) or F2 (Fujita Tornado Intensity Scale) waterspouts commonly observed around the New Zealand coast are capable of moving boulders up to 2 m in size.

Keywords: sediment transport; tornado; waterspout; boulder deposits

1. Introduction

Aorangi Island is part of the Poor Knights Island Nature Reserve located some 24 km offshore from the east coast of Northland, New Zealand (Fig. 1). The Poor Knights Islands consist of two main islands, Tawhiti Rahi (163 ha) and Aorangi (110 ha), and a scattering of smaller islands and islets (de Lange and Cameron, 1999). Both main islands rise steeply from the sea to ~200 m above sea level, with Aorangi being the highest (216 m) and more accessible via sloping shore platforms in Crater Bay and at Fraser's Landing.

The Poor Knights Islands represent the eroded remnants of a late Miocene rhyolite dome volcano, and consist mostly of rhyolitic breccia and tuff that have undergone intense hydrothermal alteration (Hayward, 1991). Slow tectonic uplift over the last million years and changes in sea level have resulted in the development of eight marine terraces preserved between 30 and 185 m above sea level on Aorangi Island.

The lower terraces contain rounded rhyolite pebbles that may represent beach deposits. However, archaeologists suggest that these may have been introduced by

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Maori to improve the soils for the cultivation of kumara (Hayward, 1993). Further, all the terraces have been extensively modified by the Maori and it is probable that most, if not all, are artificial constructs and not marine in origin. One feature of relevance to this paper is the relative absence of boulders on the terraces due to the development of gardens.

Despite evidence of repeated and prolonged human habitation, the Poor Knights Islands have remained rodent free resulting in a remarkable diversity of endemic and nationally scarce invertebrates and reptiles (de Lange and Cameron, 1999). This resulted in the creation of the Poor Knights Islands Nature Reserve, with access strictly controlled by the Department of Conservation (DOC).

2. Aorangi Island

To facilitate monitoring of flora and fauna within the Nature Reserve, the Department of Conservation established a campsite in Puweto Valley above Crater Bay (Figs. 1 and 2). An intertidal rocky shore platform is located on the eastern side of Arid Point, rising almost vertically some ~40 m to a coastal platform. This platform is a slab-like unit of rhyolitic breccia that slopes downwards northwest to The Landing, where it is ~1 m above high tide level (Fig. 2A). The surface of the slab is covered in numerous small ponds fed by seepages and ephemeral streams draining Puweto Valley, and boulders up to 2 m in diameter (Fig. 2B). The slab forms a steep cliff that drops into the waters of Crater Bay.

On the 5th August 1996, a small party from DOC and Auckland Museum (including one the authors, P de Lange) arrived at Aorangi Island to undertake a weeklong botanical survey. They found that a stretch of the shoreline several hundred metres long at Arid Point had been stripped of all encrusting marine life; the coast appeared as if it had been steam or water-blasted. The stripped zone continued inland across the coastal platform and up a cliff towards the Puweto Valley (Fig. 2C).

On the coastal platform at an elevation of 5–15 m above sea level boulders up to 2 m in diameter were displaced inland up to 10 m from their original positions as determined from depressions in peat and/or absence of ground cover in rocky areas. In some areas the original cover of peat and vegetation was removed, but the original locations of boulders were evident as differences in the staining of the underlying rock. There were no evident tracks between the inferred original locations of the boulders and their final resting places. The deposited boulders overlay broken vegetation, remnant peat, or sat directly on the underlying rock. The deposit was chaotic and there was no obvious imbrication, orientation or sorting. However, the survey party comprised only botanists and a sedimentological survey was not undertaken.

At the top of the coastal platform a formerly dense belt of flax (*Phormium tenax*) and oioi (*Apodasmia similis*) was completely removed. The underlying oioi peat, which had been ~30 cm thick, was completely stripped down to the underlying rhyolite rock (Fig. 3A). The damaged zone narrowed away from the coast, becoming a swath ~20 m wide and extending to ~50 m above sea level in the Puweto Valley near the DOC campsite (Fig. 3B and C), before running northwards to The Landing where it terminated at the coast (Fig. 2). Various species of seaweed (*Carpophyllum* sp., *Ecklonia* sp. and *Cystophora* sp.) were found in treetops, and both seaweed and sea urchins (*Evechinus chloroticus*) were mixed in with debris throughout the damaged zone. Shears and Babcock (2004) surveyed sub-tidal flora and fauna near The Landing, Aorangi Island. From their data, *Carpophyllum* are strong strap-like seaweeds that are found in the lower littoral zone at depths <2 m. *Ecklonia* are large fragile brown algae that are easily damaged by waves and occur in dense beds in the sub-littoral zone to depths of 20 m, with the densest beds at depths >6 m. *Evechinus* normally feed on *Ecklonia* sp. with the highest concentrations occurring between 4–10 m depth on the eastern coast of Aorangi Island, but they can be found from the littoral zone to depths of 50 m (Doak, 1979).

The DOC campsite at ~25 m above sea level was found to be strewn with boulders with long axes up to ~5 m. This site had previously been free of large boulders. A boulder bank above the campsite had collapsed, and this may have contributed some of the boulders found within the damaged zone. However, the smaller boulders (cobble-sized) were still encrusted with marine organisms, including barnacles and coralline algae, typical of the shallow waters and shore platforms of the Poor Knights Islands (Shears and Babcock, 2004), including the shore platform at Arid Point. Much of the broken off foliage in the damaged zone was still green, while young seedlings were found on freshly exposed soil. The seaweed had shriveled and blackened however, and the urchins were largely decayed. It was estimated therefore, that the damage occurred some 2–6 weeks prior to the arrival of the survey team.

3. Mechanisms

In the literature, there has been considerable debate about the formation of coastal boulder deposits by extreme events. Proposed mechanisms include tsunamis and storm waves (Nott, 2004; Stone and Orford, 2004; Williams and Hall, 2004). There are no known tsunamis