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Beach development on an uplifted coral atoll: Niue, south west Pacific

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ABSTRACT

Niue is an uplifted coral atoll in the south western Pacific characterised by erosional terraces on its coastal margin. Beaches are found around the island located in pockets at the rear of erosional shore platforms. The beaches in Niue are <100 m long, <25 m wide and generally less than 0.5 m thick. The beaches sit on top of an abrasion ramp that dips seaward at a similar angle to the beach. The morphology, stability and sedimentology of these beaches are investigated through laser surveying, aerial photo analysis and petrographic techniques. Surveying was undertaken in 2008 and 2010 with data compared to previous work conducted in the 1990s in order to assess the controls on sediment deposition on uplifted coral atolls. There is a high potential for sediment transport on the island. The beaches are entirely removed during tropical cyclone events and even under calm conditions sediment is mobile. The restriction of beaches to pockets along the rocky coast suggests that these areas temporally interrupt sediment transport allowing beaches to form. All the beaches are composed of a typical chlorozoan assemblage of carbonate grains dominated by coral (20–50%), coralline algae (18%) and foraminifera (up to 81%). These sediments are produced on the platforms in the immediate vicinity of the beaches with little longshore transport between embayments being evident. The close relationship between source and depositional zones, combined with the high transport potential across the platforms indicates that the beaches are highly vulnerable to any change in either energy conditions or sediment supply.

1. Introduction

Low-lying reef islands are considered to be some of the most vulnerable landforms in the world to sea-level rise (McLean and Tsyban, 2001; Mimura et al., 2007) with their low elevation often cited as the primary reason for this vulnerability (Mimura, 1999). In part this vulnerability is related to the dynamic nature of the shoreline. The position of the shoreline can shift on an annual basis in response to seasonal changes in wind direction (Kench and Brander, 2006a) and on a decadal scale islands pivot on their reef flat by a few degrees (Flood, 1986; Webb and Kench, 2010). Waves crossing the reef flat drive this dynamism with sediment generally formed in greatest abundance in the higher energy zones and deposited in areas of energy minima (termed nodal points) (Gourlay, 1988).

For an island to form sediment must also be available to be deposited. The sensitivity of a beach to climate change is therefore dependent on the relationship between the sediment producing areas and the islands on which they are deposited (McKoy et al., 2010). Sediment transport to an island is generally unidirectional across the reef (Woodroffe, 2008) with longshore movement dominating once material is deposited on the shore (Kench and Brander, 2006b). Such a relatively simple sediment system can be easily interrupted by human activity, such as by dredging or groyne construction, further compounding island vulnerability. As a result significant attention has been focussed on predicting the response of beaches on low-lying reef islands to projected sea-level rise (Cowell and Kench, 2000; Yamano et al., 2007). Predicting the response of beaches perched on coral reefs is, however, difficult as the hard reefal substrate on which they sit contravenes the assumptions of commonly used beach response models such as the Bruun Rule (Cooper and Pilkey, 2004).

However, beaches are not restricted to low-lying reef islands (Scott and Rotondo, 1983). In areas of uplift, coral reefs may be raised many tens of metres above current sea level as a result of tectonic plate collision (e.g. Tonga; Nunn and Finau, 1995), or differential loading of oceanic crust by the emplacement of volcanoes (e.g. Cook Island; Dickinson, 1998). The shorelines of uplifted atolls are often dominated by vertical cliffs and terraces with beaches found in the intertidal zone. Beaches on uplifted coral atolls form in a setting that is often inhospitable for sediment accumulation. This means that they are likely to be highly sensitive to changes in boundary conditions such as sediment supply or wave energy. Understanding their dynamics may therefore provide evidence on relative importance of these boundary conditions to sediment accumulation in coral reef environments.

Uplifted coral atolls are generally considered to be more resilient to climate change than their low-lying counterparts (Barnett and Adger, 2003), yet the vulnerability of the beaches developed on them is less

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well understood. These beaches are important because on rocky coasts sediments can protect cliffs from the erosive nature of marine and biological processes (Trenhaile, 2004) as well as being the main areas of recreation. Predicting how such landforms may respond to sea-level rise is difficult as there is little knowledge on the short-term dynamics of these features or the relationship between the beach and the areas of sediment production. This paper sets out to examine the sedimentology and morphology of the beaches of the uplifted coral atoll of Niue and assess their stability over decadal scales in order to understand the boundary conditions that allow for beach accumulation.

2. Regional setting

Niue (19.03°S, 169.85°W) is an uplifted coral atoll, 259 km^2 in area, which rises to a maximum elevation of 70 m (Fig. 1). Uplift is estimated to be occurring at rates of 0.13–0.16 mm/yr related to the subduction of the Pacific Plate in the Tonga Trench (Dickinson, 2001) (Fig. 2). The oldest exposed limestones on the island are of late Miocene age, the majority of which have been dolomotised (Schofield, 1959). A series of seven Pleistocene terraces composed of partially-recrystallised aragonitic and calcitic reef framework (Schofield and Nelson, 1978; Wheeler et al., 1999) occur around the edge of the island and date back to 700 ka (Nunn and Britton, 2004). The widest terrace (termed the Alofi Terrace) is primarily erosional in origin and the most continuous around the island (Kennedy et al., 2012). The seaward edge of the Alofi terrace is characterised by prominent vertical cliffs over 20 m high which fall to elevations close to sea level or plunge into deep water. Erosional shore platforms and plunging cliffs cut into reef limestone of Tertiary and Quaternary age characterise the contemporary shoreline at mean sea level (Kennedy et al., 2012).

Niue lies at the margin of the Indo-Pacific Warm Pool and is influenced by the Intertropical Convergence Zone. The island has a monthly mean air temperature range of 23.3–25.8 °C (annual mean 24.9 (±0.4 s.d.) °C) with a mean annual rainfall of 2036 (±538 s.d.) mm/yr (Rasbury and Aharon, 2006). The mean annual significant wave height for Niue is 2.4 m (Kreft, 1986; Barstow and Haug, 1994) and there is a distinct windward and leeward wind regime with southeast and easterly winds occurring for over 60% of the time (Kreft, 1986) (Fig. 3). Tropical cyclones impact the island on average once every 4 years (Kreft, 1986), the most recent being Tropical Cyclone (TC) Heta in 2004. Observations by local residents indicate that all the sandy beaches surveyed during this study were completely eroded during this tropical cyclone. The island is microtidal with an average spring tide range of 0.7 m and sea surface temperature range from 24 °C in winter to 28 °C in summer (Kreft, 1986).

3. Methods

Topographic surveys of the beaches and shore platforms on Niue were conducted in May 2008 and February 2010 using a Sokkia 3030R total station. Surveys were conducted at nine locations around the island with 19 individual beaches surveyed. These sites represent all those beaches which are accessible by foot. Five sites (Tautu, Hio, Pofitu and Utuko), which typify the island's beach morphology, were surveyed in both 2008 and 2010, with three beaches also being previously surveyed by Forbes (1996). All surveys were reduced to the height of

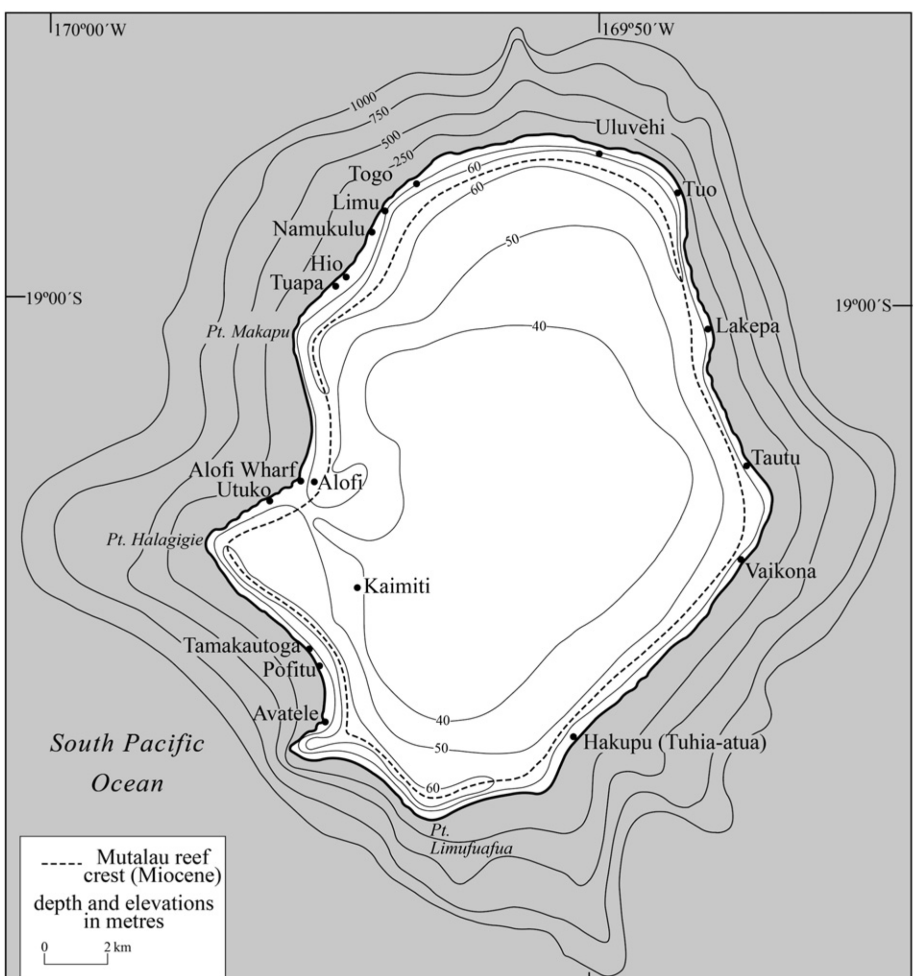

Fig. 1. Bathymetric and topographic map of Niue.