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Extracting a record of Holocene storm erosion and deposition preserved in the morphostratigraphy of a prograded coastal barrier ☆

Amy J. Dougherty *

Institute of Earth Science and Engineering, University of Auckland, Auckland, New Zealand

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ABSTRACT

Prograded barriers preserve palaeoenvironmental records within their varied morphologies and buried stratigraphy. In order to extract historical records of particular events, such as storms, the morphostratigraphy of these barriers must be detailed and the evolution deciphered. This study examines the progradation of Omaha barrier, New Zealand, using an integrated high-resolution geophysical and sedimentological approach. The barrier evolution appears complex, both spatially and temporally, with two different linear morphologies forming simultaneously alongshore, which both transition into a third type of ridge morphology across-shore. To determine what influenced the formation of these different morphologies, within the barrier and through time, various geological controls are investigated. The results are threefold: (1) a fall of sea level from a +2 m highstand drove barrier progradation, (2) differences in sediment supply driven by an exposure related longshore energy gradient dictated ridge morphology, and (3) storms punctuating barrier progradation formed the swales that define all morphologic ridges.

High-energy events are recorded throughout the formation of Omaha barrier. Storm signatures are the most prominent features identified along the active beach and throughout the barrier morphostratigraphy. Observations of a high-energy event in 2007 document a unique depositional ridge emplaced landward of the characteristic erosional dune scarp and flattened beachface composed of course-grained/heavy mineral lag. A total of 25 paleo-beachfaces with the same post-storm geometry are identified within ground penetrating radar records of the barrier stratigraphy, including one associated with a known event in 1978 that has since been buried. Using limited ages available and the variable preservation of storm events in the morphostratigraphy, a speculative record of storm frequency and intensity is hypothesized. Future work aims to test this hypothesis by acquiring a comprehensive chronology.

1. Introduction

Sandy coastal barriers act as buffers to the hinterland by dissipating the increased energy of storms (Pethick, 1984). These coastal landforms are comprised of unconsolidated sediments, which make them highly susceptible to erosion. During storms, many of the sediments that form low-lying transgressive barriers are driven onshore in washover fans (Penland and Boyd, 1981). In the case of stationary or prograding barriers with large foredunes, high-energy events are unable to overtop them or break through, instead eroding distinct scarps in these dune complexes. During the storm these eroded sediments are transported in an offshore direction forming inshore bars, which later are reworked back onshore by lower-energy swell waves (Shepherd, 1950; Bascom, 1953; Strahler, 1966; Gorsline, 1966). Along transgressive or stationary barriers, depositional evidence of a storm is obliterated by the next high-energy event, but progradational systems have the potential to preserve these storm signatures within their accreting layers (Scheffers et al., 2012; Tamura, 2012).

Storms can produce dramatic changes along beaches that front sandy barriers. Large storms leave behind signatures such as washovers, dune scarps and flattened beach profiles with concentrations of coarse-grained sediment and heavy-minerals (Smith and Jackson, 1990; Sommerville et al., 2003; Buynevich et al., 2007; Tamura, 2012). Dune scarps are one of the most prominent surficial expressions along present-day beaches; even with time and vegetation growth, their existence can be clearly marked within the foredune morphology (Fig. 1). Beachfaces associated with these eroded dune scarps typically consist of coarse-grained lag or heavy-mineral deposits concentrated along a flattened topographic profile, which remain as pronounced horizons within barrier stratigraphy preserved by

☆ This paper is dedicated to the memory of a dear friend and colleague, Dr. Hiroki Ogawa. The research contained within this manuscript was part of the many wonderful coastal conversations we had during our PhD days.

* Present address: School of Earth and Environmental Science, University of Wollongong, Wollongong, NSW, Australia.
E-mail addresses: adougher@uow.edu.au, amydoc13@hotmail.com

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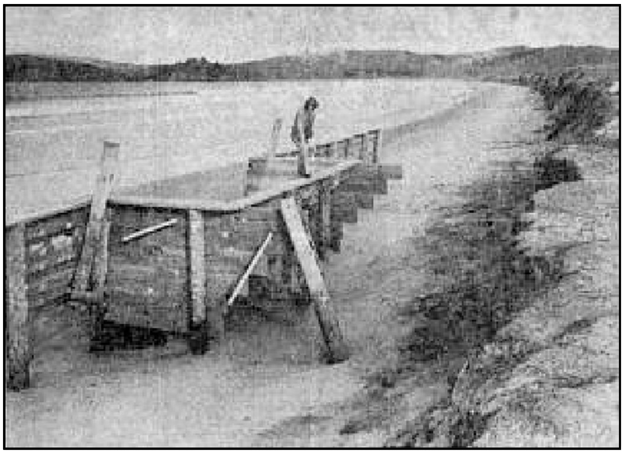

Fig. 1. (A) Photograph of a dune scarp at Omaha Beach, New Zealand, that resulted from a series of storms in 1978 (http://www.seafriends.org.nz). The purpose of the wood structure is unknown; however, it does not seem to have reduced landward erosion compared to the rest of the coast and actually demonstrates the ~12 m cut back recorded in the area. (B) Picture of Omaha Beach in 2007. The photo was taken from the crest of the vegetated 1978 scarp. While the steep-gradient of the erosional scarp is evident, the associated post-storm beachface is obscured by subsequent incipient dune formation.

post-storm recovery (Komar and Wang, 1984; Hayes and Boothroyd, 1969; Brenninkmeyer, 1978). The distinct morphology and contrasting sediment characteristics of these buried erosional features produce distinctive reflections in ground penetrating radar (GPR) records, thereby enabling them to be mapped within the subsurface stratigraphy and comparisons made with the geometry of a known storm profile (Buynevich et al., 2004; Dougherty et al., 2004).

Omaha is a prograded barrier (also known as Mangatawhiri Spit) located 75 km north of Auckland, New Zealand (Fig. 2). In 1978 a series of three sequential storms resulted in severe beach erosion and a large dune scarp (Fig. 1A). While the dune scarp is still evident, the eroded beachface has been obscured by subsequent accretion (Fig. 1B). This study uses GPR collected over the incipient dune formations and underlying berm construction to image the known storm deposit. The results are then used to identify similar geophysical signatures recorded throughout the entire barrier stratigraphy. The stratigraphic evidence of paleo-storms is then examined with respect to the overlying morphology.

Five different relict morphologies exist within the topography of Omaha barrier (Fig. 2). In the south, the spit is anchored to the mainland by a flat-lying featureless area that transitions into a series of low-lying shore parallel ridges. The central portion of the barrier consists of a series of larger shore parallel ridges. North near the tidal inlet, a field of large chaotic dunes dominates the updrift end of the barrier. All of these four different morphologies are fronted by a large foredune complex that consists of two ridges running the length of the active beach. This range of distinct topographic regions contained in one barrier allows for the isolation of certain processes that control similarities and differences within the morphology.

The majority of this study focuses on the different parallel ridges. Confusion and debate exist with respect to the nomenclature of parallel ridges along sandy prograded barriers (Taylor and Stone, 1996; Otvos, 2000; Hesp et al., 2005; Scheffers et al., 2012; Tamura, 2012). The two main classifications are: (1) all ridges are classified as beach ridges regardless of formative processes or origin (Otvos, 2000) or (2) only ridges formed by waves are beach ridges while those with the slightest eolian component are deemed foredune ridges (Hesp et al., 2005). The focus of this paper is more on the variation in evolution of these different ridge formations, rather than classifying them, but it is necessary to name them in order to differentiate between the morphologic units. Using either of the main classifications would label all of these features either foredune ridges (Hesp et al., 2005) or beach ridges (Otvos, 2000), therefore, to avoid confusion neither of these definitions is used. The nomenclature used to distinguish different types of ridges throughout the text is based on obvious increases in eolian content and location with respect to the present-day beach. Therefore, the low-lying ridges in the south are labeled beach ridges and the larger ridges north of them are deemed dune ridges while the two large ridges that run the length of the active beach are called foredune ridges (Fig. 2).

While all of the ridges are shore parallel there are distinct transitions in the type of ridges both along and across the barrier. Initially the low-lying beach ridges in the south formed simultaneously with the larger hummocky dune ridges to the north, assuming that the barrier prograded seaward uniformly. Later a change occurred in which the linear variation ceased and two uniform foredunes were constructed along the length of the entire barrier. These preserved spatial and temporal contrasts in the morphology offer the opportunity to decipher the factors causing these changes. To best interpret the past, observations of the active beach and incipient dunes that front the foredune ridge are analyzed. This analysis includes documentation of the effects of storms in 1978 and one in 2007. The resulting data set provides a unique opportunity to use signatures of known storm events to identify evidence of paleo-storms within the barrier stratigraphy. The results will not only determine the role high-energy events play in the formation of topographic ridges, but also distinguish the controls that led to the evolution of these various morphologies within the same barrier. Ultimately, understanding the role of sea level, sediment supply, accommodation space and wind/wave energy on barrier evolution will allow for the influence of storms to be isolated and extracted over time providing a record of high-energy events.

2. Regional setting

Omaha is a 3.5 km long north/south trending barrier spit that is attached to Karamuroa Point in the south and bordered to the north by the inlet to Whangateau Harbour and Ti Point (Fig. 2). Dating analysis on shelly mud deposits underlying the sandy barrier sequence give an age of 6460 ± 60 years BP, indicating a mid-Holocene time of initial progradation (Schofield, 1973). Grain-size and sediment transport studies indicate that offshore and inner shelf deposits are the primary source for barrier construction