Geomorphology 222 (2014) 143–150

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Sediment transport and mixing depth on a coral reef sand apron

Ana Vila-Concejo *, Daniel L. Harris, Hannah E. Power, Amelia M. Shannon, Jody M. Webster

Geocoastal Research Group, School of Geosciences F09, The University of Sydney, NSW, Australia

ARTICLE INFO

Article history:
Received 21 September 2012
Received in revised form 19 September 2013
Accepted 19 September 2013
Available online 18 October 2013

Keywords:
Carbonate sand
Depth of disturbance
Coral reef morphodynamics
Coral sand
Sand sheet

ABSTRACT

This paper investigates the mechanics of sediment transport on a subtidal sand apron located on a coral reef environment. In this environment 100% of the sediment is carbonate bioclasts generated in situ. The sand apron is located on the back reef and only affected by waves during high tides. It is commonly accepted in the literature that sand aprons are features that prograde lagoonwards and that most of the progradation occurs during high-energy events. Measurements of water depths, waves, currents and near bed suspended sediment concentrations (all at 10 Hz) on the sand apron were undertaken over a nine day intensive field campaign over both spring and neap tides; waves and tides were also measured in the lagoon. The topography and bathymetry of the sand apron were measured and mixing depth was obtained on three transects using depth of disturbance rods. We found that sediment transport on sand aprons is not solely restricted to high-energy events but occurs on a daily basis during spring tides. The main factor controlling the sediment transport was the water depth above the bed, with depths of 2–2.3 m allowing waves to promote the most sediment transport. This corresponds to a depth over the reef crest of 1.6–1.9 m. The second most important control was waves; transport was observed when H_s on the apron was 0.1 m or greater. In contrast, current magnitude was not a controlling mechanism for sediment entrainment but did affect sediment transport. The morphology of the sand apron was shown to affect the direction of currents with the currents also expected to influence the morphology of the sand apron. The currents measured during this field campaign were aligned with a shallow channel in the sand apron. Mixing depths were small (<2.5 cm) yet they were larger than the values predicted by empirical formulae for gentle siliciclastic ocean beaches.

1. Introduction

The study of marine sediment transport has fascinated scientists and engineers since the second half of the 20th century. There have been numerous attempts to develop empirical formulae that can predict sediment transport (e.g., Komar and Inman, 1970; Bayram et al., 2007; Van Rijn, 2007a,b). One of the problems associated with the study of sediment transport is the difficulty in undertaking direct field measurements. Field methods include, amongst others, sand tracers (e.g., Ciavola et al., 1998; Vila-Concejo et al., 2004; Silva et al., 2007; Matias et al., 2010), streamer traps (Kraus and Rosati, 1987) and optical backscatter sensors (OBSs) (e.g. Aagaard et al., 2002; Tonk and Masselink, 2005). The sediment mixing depth is the vertical thickness of the layer of active sediment exchange, below which lies an immobile bed (Sherman et al., 1993). It is generally accepted that the sediment mixing depth, or depth of activation of sediment, represents the thickness of the sediment-transport layer (Sunamura and Kraus, 1984; Sherman et al., 1994; Ferreira et al., 2000). Several studies have measured sediment mixing depths and used these to develop empirical formulae to predict mixing depth in different settings including beaches with steep ($\tan\beta > 0.08$) and gentle slopes ($\tan\beta < 0.08$). These studies primarily aimed to establish an empirical relationship between significant breaking wave height (H_{bs}) and the measured average mixing depth (Z_m). According to Ferreira et al. (2000) the mixing depth on steep beaches is about an order of magnitude larger than that of gently sloped beaches.

Coral reef platforms are mostly composed of sedimentary deposits: coral sand and rubble. These deposits are highly mobile and their changing morphologies can influence the geomorphology of living coral and other biota. One example of these deposits are the ubiquitous sedimentary features called sand aprons (or sand sheets) that prograde into back reef areas, smothering living corals and altering the configuration of the associated lagoons. Coral reefs have been investigated extensively, with studies focusing on Quaternary reef platform development in relation to sea level (e.g. Davies and Kinsey, 1977; Davies and Marshall, 1980; Woodroffe et al., 2004; Hopley et al., 2007), island formation (Stoddart et al., 1978; Woodroffe et al., 1999; Mandlier and Kench, 2012) and also physical oceanography (Frith, 1983; Gourlay, 1994; Wolanski, 2001; Callaghan et al., 2006). Lagoonal infill is the major constructional process for coral reefs once they attain a stable elevation with respect to sea level (Marshall and Davies, 1982). Sand is produced on the reef crest and transported into the back reef area or lagoon by waves and currents. This sediment often forms sand aprons which on average cover 20% of the reef platform (Rankey and Garza-Pérez, 2012). Even though there is an understanding of the

* Corresponding author. Tel.: +61 2 9351 5190; fax: +61 2 9351 2442.
E-mail address: ana.vilaconcejo@sydney.edu.au (A. Vila-Concejo).

0169-555X/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geomorph.2013.09.034

forcing mechanisms that drive sand apron formation, attempts to predict sand apron dimensions using parameters such as wave characteristics have proven unsuccessful (Rankey and Garza-Pérez, 2012). Coral reef response to sea level rise depends on how the rates of coral growth compare with the rate of sea-level rise. Traditional qualitative and descriptive studies have led to development of the "leaky bucket" theory (Purdy and Gischler, 2005) by which reef platforms are expected to infill continuously with small percentages of sediment leaking out of the reef system, i.e., it is lost to the deeper sea floor surrounding the reef.

Most studies on sediment transport have been undertaken in siliciclastic environments where the sediment has a variable percentage of carbonates, which typically consist of shell fragments. Few studies have examined sediment transport in coral reef environments (e.g., Hine et al., 1981; Ogston et al., 2004; Storlazzi et al., 2009, 2011). Morphodynamics and the contemporary processes occurring in coral environments have been the subject of few studies; those studies that have been undertaken have investigated topics such as morphodynamic growth of reef islands (Barry et al., 2007, 2008), wave transformation on coral reefs (e.g., Gourlay, 1994; Nelson, 1994; Gourlay, 1996a,b; Gourlay and Colleter, 2005), the geomorphology of reef islands (e.g., Woodroffe et al., 1999; Kench et al., 2006, 2008, 2009; Perry et al., 2011), and the physical processes (e.g., Frith and Mason, 1986; Kench, 1998a,b; Wolanski, 2001; Ogston et al., 2004; Hoeke et al., 2011). An extensive literature search on the geomorphology of sand aprons (or sand sheets) yields some studies (e.g., Kench, 1998b,c; Ryan et al., 2001; Purdy and Gischler, 2005; Harris et al., 2011; Rankey and Garza-Pérez, 2012) but highlights that there has not been any work done on the mixing depth on sand aprons of coral reefs. This paper presents field measurements of sediment transport under typical conditions on a sand apron located on a coral reef during both spring and neap tides. It includes measurements of waves and currents as well as suspended sediment and mixing depth. Using these data, this paper highlights which conditions maximise the potential for sediment transport under modal conditions.

1.1. Regional setting

The Great Barrier Reef (GBR) Marine Park is the largest underwater reserve in the world. Covering 350,000 km^2, the GBR stretches over 2500 km of the NE Australia coastline and consists of 2900 individual reefs including examples of all major reef types (Hughes et al., 1999). One Tree Reef (OTR) is a mature reef platform (Davies and Marshall, 1980) located in the southern GBR. It is located at approximately 100 km off the Australian coast and only 20 km west of the edge of the continental shelf (Davies et al., 1976). It is therefore considered a high-energy reef as it is exposed to the southeast trade winds and modal swell regime for most of the year (Frith and Mason, 1986). It is located at 23°30′S 152°06′E (Fig. 1). One Tree Reef has an asymmetrical triangular shape, is 5.5 km long and 3 km wide, and has one larger (approximately 4 km diameter) and two smaller lagoons (Wilson, 1985). It is surrounded by water depths between 25 and 60 m. OTR is the only whole reef system that is a designated Scientific Research Zone under the GBR Marine Park Authority's zoning plan from 2010. As such, it is a pristine reef in which scientific research can occur without the influence of local human activity.

Tides are semidiurnal and mesotidal with an average spring tidal range of 3 m. Wave direction is mostly south-easterly with average offshore significant wave heights (H_{so}) of 1.15 m (Hopley et al., 2007).

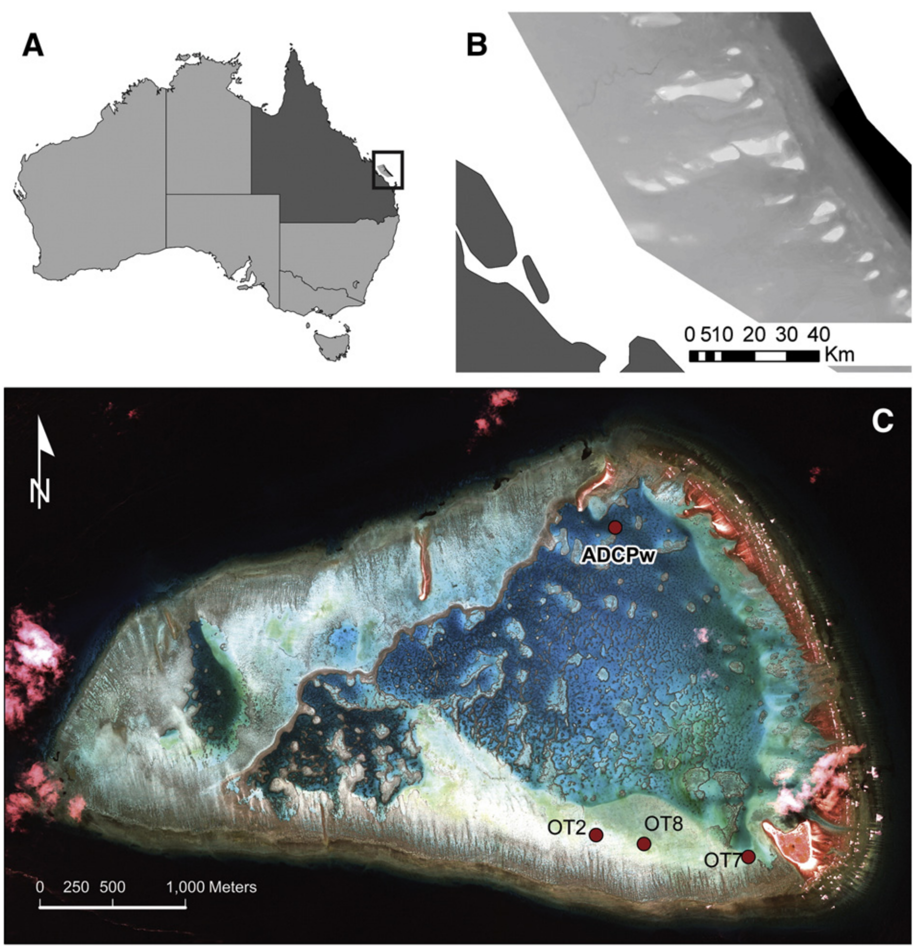

Fig. 1. The study area is located off the NE coast of Australia (A). One Tree Reef is a platform reef located in the Capricorn Bunker Group in the southern Great Barrier Reef (B). One Tree Reef has a large sand apron on its southern side where stations OT2, OT8 and OT7 are located (C). This figure also shows the location of the ADCPw.