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Postglacial sediment deposition along a mixed carbonate-siliciclastic margin: New constraints from the drowned shelf-edge reefs of the Great Barrier Reef, Australia

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ABSTRACT

A seismic stratigraphy analysis was conducted at two sites, Hydrographers and Noggin passages, separated by about 540 km on the shelf-edge of the central Great Barrier Reef (GBR), Australia. We used recently available seismic and bathymetry data and a new synthesis of downhole logs and lithological, petrophysical and radiometric data from cores recovered by the Integrated Ocean Drilling Program Expedition 325 (Great Barrier Reef Environmental Changes). We compared the stratigraphy of both sites, identifying a full depositional sequence with deposits from at least 28 ka BP to ~7 ka BP, bounded by two marine flooding surfaces. Within this sequence, each systems tract is represented by unique depositional features characteristic of the shelf-edge systems. Despite the broad environmental and geomorphic similarities between the two sites, differences in postglacial reef development were remarkable. These contrasts can be explained as a result of: (1) local antecedent substrate variations and (2) the interplay of shelf physiography with Late Quaternary sea level fluctuations, which favoured changes in biological production and sediment flux as the palaeo-shoreline evolved from linear to complex during intermediate sea levels. During these intermediate sea levels, the northern estuarine coast and its steep substrate at shelf-edge locations contrasted strongly with the protected palaeo-lagoons and the extensive, gentle marginal terraces found at the southern central GBR. This setting enhanced the regional differences in sediment transport and reef development through the last transgression. The conceptual model presented here provides a broader depositional framework and improves the understanding of the main processes controlling the spatial and temporal depositional patterns on the shelf-edge of mixed siliciclastic-carbonate margins.

1. Introduction

Recent works have shown extensive drowned, or submerged, reef features on the shelf-edge of the northeastern Australian margin. These features extend for more than 1000 km, in water depths that correspond to past Last Glacial Maximum (LGM) and postglacial sea levels (~125 to 40 m) (Abbey et al., 2011a; Beaman et al., 2008; Gischler et al., 2013; Webster et al., 2011). The deposition of these reefs is consistent with similar findings worldwide (Montaggioni, 2000), suggesting that early-postglacial reef development is more widespread than previously thought.

In the Great Barrier Reef (GBR), these shelf-edge features have revealed a complex history of growth and erosion during lower sea levels (Abbey et al., 2011a; Beaman et al., 2008; Gischler et al., 2013; Webster et al., 2011). Abbey et al. (2011a) conducted the first detailed geomorphic interpretation of the external architecture of the shelf-edge reefs (SERs) of the GBR, showing the presence of terraces, pinnacles and ridges, which were interpreted as fringing, patch and barrier reefs respectively, coexisting with channels of possible tidal origin. Their work linked the development of the SERs to the low-amplitude (~20 m) sea level fluctuations common during the overall MIS-5 to MIS-2 regression (Lambeck et al., 2014) and proposed a reef accretion model consistent with this idea.

In 2010, the Integrated Ocean Drilling Program (IODP) Exp. 325 was the first to investigate the internal characteristics of these reefs (Webster et al., 2011). Core samples from 17 locations of the SERs (between 2.5 and 46.4 m of length cored, 26% average recovery) confirmed their reefal nature and the LGM to postglacial ages (pre-30 to 10 ka BP) of these structures. The geochemical, palaeo-ecological, sedimentological, and petrophysical data derived from these boreholes are providing unprecedented detail about the variations in palaeo-ecological, palaeo-environmental, palaeo-oceanographic and depositional patterns (Abbey et al., 2011a, 2013; Felis et al., 2014; Gischler et al., 2013; Harper et al., 2015; Hinestrosa et al., 2014) since the last glaciation.

These cores have also provided firm constraints for a recent stratigraphic interpretation of a seismic survey carried out in one of the drilled sites in the southern central GBR, Hydrographers Passage

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(Hinestrosa et al., 2014). Following a seismic-stratigraphy approach (Mitchum et al., 1977), they recognized two prominent reflectors responding to major lithologic and diagenetic changes, and corresponding to a lower marine flooding surface and to an upper, more recent unconformity. Similar to past geomorphic studies (Abbey et al., 2011a), they recognized the influence of channels in the postglacial geomorphology and confirmed the strong geomorphic subsurface differentiation between shallower and deeper areas at the shelf-edge, dominated by both fringing and barrier reefs. Hinestrosa et al. (2014) also demonstrated the persistence of reefal and lagoonal formations at similar geomorphic locations for at least the last eustatic cycle.

Drowned SERs are not exclusive to the GBR margin, but they have not been studied as extensively everywhere. Late Quaternary SERs of comparable dimensions to those on the GBR have been recognized in Florida and in India (Rao et al., 2003; Vora et al., 1996). Lidz et al. (1991) described the architecture of the Florida SERs and proposed mechanisms for margin progradation based on the new seaward accretion of reefs and their successive backfilling. Lidz et al. (1997) conducted a comparative study in two locations separated ca. 150 km. Interestingly, they concluded that the interplay of energy regimes and sea level fluctuation was the key driver of geomorphic differentiation along the Florida shelf-edge.

Studies on other settings such as the drowned reef terraces of the Hawaiian chain (Faichney et al., 2011; Webster et al., 2010), or the Tahiti postglacial drowned reefs (Abbey et al., 2011b; Camoin et al., 2012) have improved the understanding of accretion and demise patterns, and of the ecological responses to sea level and environmental changes (e.g. water quality, currents, temperature, siliciclastic influx). By using seismic stratigraphy, studies in New Caledonia (Le Roy et al., 2008), Mayotte (Zinke et al., 2001), Hawaii (Grossman et al., 2006) and in the Gulf of Elat (Hartman et al., 2015) have shed light on the internal architecture of the shelf-edge systems, including drowned reefs, and the factors (e.g. sediment input, antecedent substrate, proximity of source, relative sea level) driving their development. The strong relationship between the postglacial reef surface and the topography of the antecedent Pleistocene substrate has been highlighted, by these and other authors, as a key component in shelf-edge reef architecture (Harvey and Hopley, 1982, GBR; Gischler and Hudson, 2004; Purdy et al., 2003, Belize; Kayanne et al., 2002, Palau; Zinke et al., 2001, Mayotte; Lidz et al., 1997, Florida).

The GBR shelf-edge represents an exceptional location to investigate the factors controlling past Quaternary reef development. Since the LGM, the contrasts in physical conditions along the shelf-edge of the central GBR have probably been minimal (Table 1). Moreover, the GBR shelf-edge exhibits some common characteristics along its central margin: to landward, small gradients in the present-day lagoon; to seaward, drowned reefs that change to a featureless, deepening upper continental slope. These factors serve as control variables in this large natural experiment on the internal and external geomorphic contrasts at the two study sites, Hydrographers and Noggin passages, separated by about 540 km.

Here, we followed a sequence stratigraphy approach to interpret the seismic data of the two sites constrained by local and regional bathymetry data (Abbey et al., 2011a; Beaman, 2010), and by lithologic, radiometric and downhole log data related to IODP Exp. 325 boreholes (Felis et al., 2014; Gischler et al., 2013; Webster et al., 2011). Our objectives were to: (1) characterize the seismic architecture of Noggin Passage (northern central GBR); (2) compare the internal and external morphology of Noggin Passage and Hydrographers Passage (southern central GBR; Hinestrosa et al., 2014); and (3) establish depositional models to explain the differences between the two sites, based on our

Table 1
Comparison of climatic and geomorphic parameters between the two study sites.

	Hydrographers Passage (18–20° S)	Noggin Passage (16–18° S)
Climate and oceanography		
Air temperature[A] (min/max, 1958–1987; °C)	22.6/28.3	23.2/28.7
Rainfall[A] (mean summer/winter, 1958–1987; mm/year)	687/214 (Central Queensland coast)	924/210 (NE Queensland coast)
Monthly sea surface temperature[A] (maximum/minimum, 1958–1987; °C)	28.3 Feb/22.6 Aug (18–20 °S)	28.7 Feb/23.2 Jul (16–18 °S)
Wind[B] (mean speed/mean direction, 1989–2013; $m.s^{-1}$)	24.1/111° (Hardy reef)	24.8/128° (Agincourt reef)
Cyclones [A] (1958–1987, % of cyclone days)	14.6	18.1
Coastal river runoff [C] (annual average; km^3)	19.75 (Shoalwater to Haughton catchments)	22.76 (Ross to Endeavour catchments)
Fine sediment export[C] (annual average; $10^6 t$)	6.85 (Ross to Endeavour catchments)	3.58 (Ross to Endeavour catchments)
Maximum alongshore current velocity[D] ($m.s^{-1}$)	~0.15	~ 0.21
Tidal range[E] (m)	~3	~ 3
Margin physiography and shelf morphology		
Shelf width (0 to 130 mbsl, E–W axis; km)	275	72
Shelf-edge width (50 to 130 mbsl, E–W axis; km)	~24	~9
Continental slope gradient (upper-slope; degrees)	~1	~2.3
Terraces/platforms width (m)	150–3000	50–1000
Shallowest point surveyed (mbsl)	13	15

[A] Lough, 1994.
[B] Australian Institute of Marine Sciences, Historic data.
[C] Furnas, 2003.
[D] Ridgway and Dunn, 2003.
[E] Wolanski, 1994.