Marine Geology 359 (2015) 50–60

Contents lists available at ScienceDirect

Marine Geology

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

Holocene coral reef growth and sea level in a macrotidal, high turbidity setting: Cockatoo Island, Kimberley Bioregion, northwest Australia

Tubagus Solihuddin [a,d,*], Lindsay.B. Collins [a,d], David Blakeway [b], Michael J. O' Leary [c,d]

[a] Department of Applied Geology, Curtin University, Bentley, WA 6102, Australia
[b] Fathom 5 Marine Research, 17 Staines Street, Lathlain, WA 6100, Australia
[c] Department of Environment and Agriculture, Curtin University, Bentley, WA 6102, Australia
[d] The Western Australian Marine Science Institution, Floreat 6014, Australia

ARTICLE INFO

Article history:
Received 9 September 2014
Received in revised form 6 November 2014
Accepted 18 November 2014
Available online 25 November 2014

Keywords:
Acropora
Porites
Reef geomorphology
Holocene reef growth
Sea-level change
Accretion rate

ABSTRACT

The inshore Kimberley Bioregion of northwest Australia is a macrotidal, low wave energy, frequent cyclones, and high turbidity setting with abundant fringing coral reefs. Here we describe the Holocene development of a sheltered fringing reef at Cockatoo Island in the Kimberley, using data from reef cross-sections subaerially exposed in an iron ore mining pit, seismic profiles across the adjacent contemporary reef, and GIS and ground truth mapping of contemporary reef habitats. Subsidence since the Last Interglacial has provided accommodation for ~13–20 m of Holocene reef accretion upon an older, probably Last Interglacial, reef. In the pit cross-sections, the reef initiated at ~9000 cal y BP and accreted in a catch-up mode, reaching sea level at ~3000 cal y BP, and reef accretion rates varied from 26.8 mm/year to 0.8 mm/year, averaging ~2 mm/year. The catch-up interpretation is supported by the predominance of branching *Acropora* throughout the Holocene section and the absence of contemporary intertidal indicators such as *Porites cylindrica* and *Millepora intricata*. This pattern differs from the otherwise similar mud-rich but mostly microtidal inshore fringing reefs of the Great Barrier Reef, which initiated in the late Holocene on shallow substrates under a stable sea level. The study provides the first Holocene reef growth history for an inshore Kimberley reef within a biodiversity "hotspot".

1. Introduction

The Kimberley coast is a remote sparsely populated and poorly studied region located in the NW of Western Australia. However, the discovery of a major hydrocarbon province in the offshore Browse Basin, and an increase in petroleum exploration in the region, has led to a heightened awareness of the region's rich biodiversity (Collins, 2002; Chin et al., 2008; Collins et al., 2011). While the presence of coral reefs have been broadly documented, occurring as fringing reefs in coastal settings, platform reefs in mid-ramp settings and atoll-like reefs along the shelf margin (Wilson et al., 2011), there have been few investigations into their biogeography, diversity and developmental history.

Coral reefs are particularly ubiquitous to the complex drowned landscape of the Kimberley coast, which provides abundant Proterozoic deformed rocky substrate for fringing reef development. These inshore fringing reefs occur in sheltered and exposed settings and endure in seemingly extreme environment conditions including: high turbidity and sediment input, elevated water temperatures (av. 28.5 °C), a 10 m macrotidal range, significant subaerial exposure during low tides, and frequent cyclones. Despite these extreme conditions, the coral biodiversity in the Kimberley is far richer than that of the inner GBR fringing reefs and a little richer than those of the Pilbara to the south (Wilson, 2013).

Critically, our understanding of the development of the Kimberley reefs still remains a gap in our knowledge. For example it is not known whether reefs are thin veneers over rock platforms or significant long-lived accretionary structures. Additionally, the linkages between present reef geomorphology, Holocene sea level rise, reef growth history, and coastal processes have been recognized (e.g. Wilson, 2013) but are yet to be explored in any detail. Despite this lack of knowledge, Kimberley reefs have been identified as having international significance and are in need of comprehensive study (Chin et al., 2008; Wilson, 2013).

This study will for the first time investigate the Holocene development and evolution of an inshore Kimberley coral reef located at Cockatoo Island (Fig. 1). Cockatoo is unique in that iron ore mining on the Island has exposed a complete vertical section of the inner part of a Holocene fringing reef. This has allowed for detailed stratigraphic, palaeoecological and geochronological analysis spanning the entire reef growth history, thus enabling an investigation into how these reefs were able to persist under extreme environmental conditions as well as respond to Holocene sea level change. The addition of seismic reconnaissance data has allowed for the broader reef architecture and structure to be assessed. Lastly this study develops a Holocene reef

* Corresponding author at: Department of Applied Geology, Curtin University, Bentley, WA 6102, Australia. Tel.: +61 8 9266 3710.
E-mail address: tubagus.solihuddin@postgrad.curtin.edu.au (T. Solihuddin).

http://dx.doi.org/10.1016/j.margeo.2014.11.011
0025-3227/

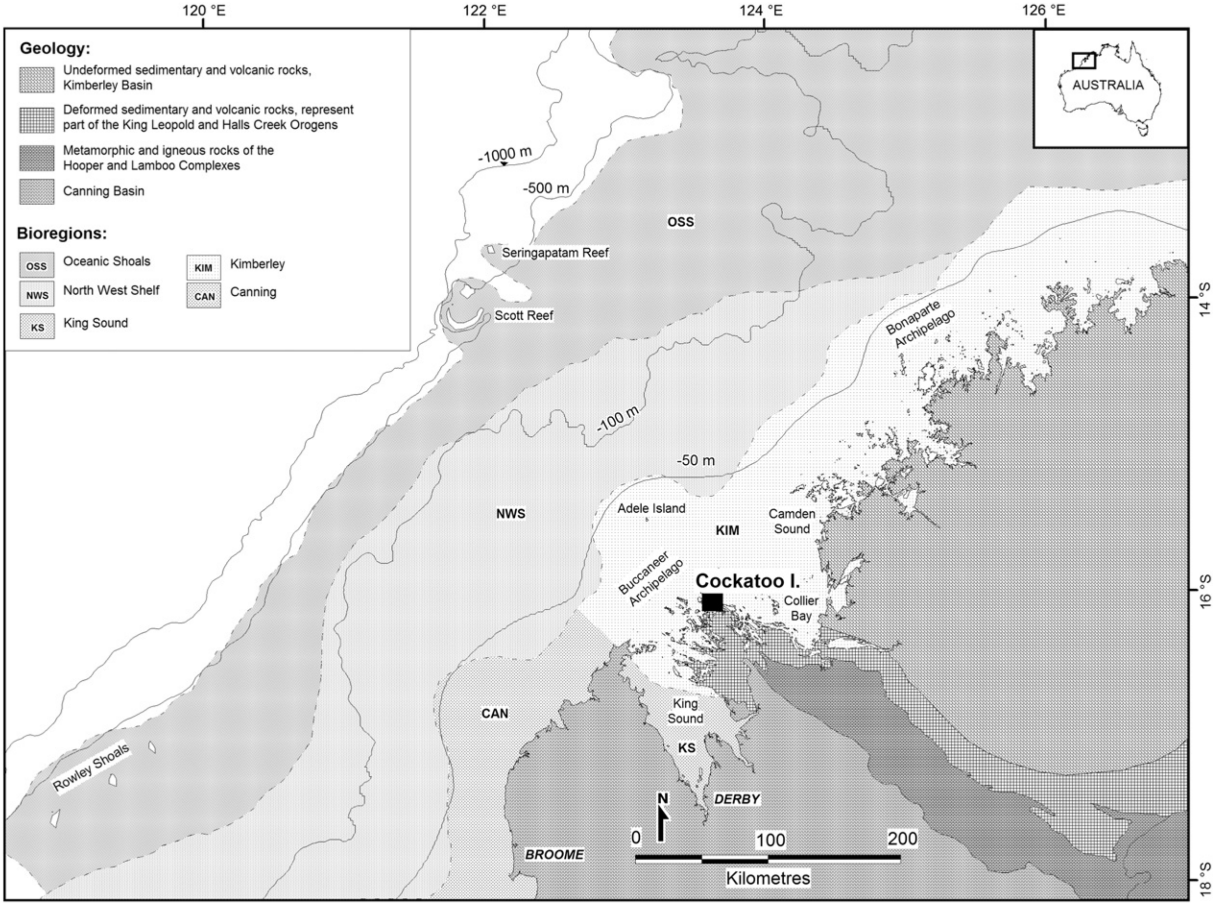

Fig. 1. Map showing Bioregions modified from the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) and geology of the Kimberley Region. (Reproduced with permission from Griffin and Grey, 1990).

growth rate curve for the Kimberley, so that the shelf drowning history can be reconstructed. The initiative to protect these marine areas through the Kimberley Science and Conservation Strategy (Government of Western Australia, 2011) also requires a fundamental baseline understanding of how the environment formed for effective long term protection.

1.1. Oceanography of the Kimberley Region

The region is tidally dominated, with coastal mean spring range of 9.2 m in King Sound (see Fig. 1; Harris et al., 1991), the highest tide range in Australia (Short, 2011) and the second highest tide in the world after the Bay of Fundy in Canada (Purcell, 2002; Wolanski and Spagnol, 2003). This macro-tidal system generates an extensive intertidal zone and strong tidal currents, which in turn cause high turbidity in coastal waters (Brooke, 1997). The region lies in the monsoonal belt with prevailing westerly or northwesterly rain-bearing winds from November-March, and dry southeasterly or easterly trade winds from May to September. It is cyclone-influenced (average 3 per year, Lough, 1998) and has southwest prevailing swell.

The local oceanography of the inshore Kimberley Bioregion is influenced by the Holloway current, which is driven by the Indonesian Throughflow waters through a southward flow over the shallow Timor Shelf (DEWHA, 2008). This current flows seasonally from March to July and is closely associated with the northwest monsoon by which a south-westerly flow of surface water mass is released along the shelf margin. During the summer months (December to March), the Throughflow is deflected eastward, releasing a weak Holloway current along the inner shelf of the Kimberley. The upwelling generated by the Holloway current along with *in situ* planktonic production are believed to be contributing to the reef development in this region due to their roles in delivering nutrients where measures of N (0.05/12.8 μM), P (0.11/0.85 μM) and carrying planktic biota including planktotrophic larvae and reef animals (Wilson, 2013). Nutrient concentrations in the nearshore coastal Kimberley waters are relatively high here, influenced by riverine inputs from the adjacent terrestrial, high runoff environment (Wilson, 2013).

2. Location and methodology

Cockatoo Island (Fig. 1) is located in the Buccaneer Archipelago (123.6°E; −16.1°S), approximately 7 km north of Yampi Peninsula. The geomorphology of the Buccaneer Archipelago and Yampi Peninsula are structurally controlled, reflecting the deformation geometry of the King Leopold Orogen (Wright, 1964). Cockatoo is an elongate island approximately 6 km long and 1.5 km wide and oriented along a NW/SE axis; with the NE side exposed to higher wave energies while the SW side is largely sheltered.

2.1. Geophysical surveys

Sub-bottom profiling was performed using an Applied Acoustics Boomer SBP system CSP-P300; with SBP Sound Source, AA201 Boomer Plate, mounted on a CAT100 surface tow catamaran. The receiver streamer had 8 element hydrophones, and A/D Interface Box from NI (National Instruments) Device Monitor V5.3.1. Data acquisition was made using Chesapeake Technology Inc SonarWiz 5 software. Position acquisition was made using a Fugro Seastar 8200XP/HP DGPS receiver. Survey lines were run across the modern reef flat up to a retaining seawall, which runs the length of the mining pit. Two survey lines were also