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Microfacies and diagenesis of older Pleistocene (pre-last glacial maximum) reef deposits, Great Barrier Reef, Australia (IODP Expedition 325): A quantitative approach

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ABSTRACT

During Integrated Ocean Drilling Program Expedition 325, 34 holes were drilled along five transects in front of the Great Barrier Reef of Australia, penetrating some 700 m of late Pleistocene reef deposits (post-glacial; largely 20 to 10 kyr BP) in water depths of 42 to 127 m. In seven holes, drilled in water depths of 42 to 92 m on three transects, older Pleistocene (older than last glacial maximum, >20 kyr BP) reef deposits were recovered from lower core sections. In this study, facies, diagenetic features, mineralogy and stable isotope geochemistry of 100 samples from six of the latter holes were investigated and quantified. Lithologies are dominated by grain-supported textures, and were to a large part deposited in high-energy, reef or reef slope environments. Quantitative analyses allow 11 microfacies to be defined, including mixed skeletal packstone and grainstone, mudstone-wackestone, coral packstone, coral grainstone, coralline algal grainstone, coral-algal packstone, coralline algal packstone, *Halimeda* grainstone, microbialite and caliche. Microbialites, that are common in cavities of younger, post-glacial deposits, are rare in pre-last glacial maximum core sections, possibly due to a lack of open framework suitable for colonization by microbes. In pre-last glacial maximum deposits of holes M0032A and M0033A (>20 kyr BP), marine diagenetic features are dominant; samples consist largely of aragonite and high-magnesium calcite. Holes M0042A and M0057A, which contain the oldest rocks (>169 kyr BP), are characterized by meteoric diagenesis and samples mostly consist of low-magnesium calcite. Holes M0042A, M0055A and M0056A (>30 kyr BP), and a horizon in the upper part of hole M0057A, contain both marine and meteoric diagenetic features. However, only one change from marine to meteoric pore water is recorded in contrast with the changes in diagenetic environment that might be inferred from the sea-level history. Values of stable isotopes of oxygen and carbon are consistent with these findings. Samples from holes M0032A and M0033A reflect largely positive values (δ^{18}O: −1 to +1‰ and δ^{13}C: +1 to +4‰), whereas those from holes M0042A and M0057A are negative (δ^{18}O: −4 to +2‰ and δ^{13}C: −8 to +2‰). Holes M0055A and M0056A provide intermediate values, with slightly positive δ^{13}C, and negative δ^{18}O values. The type and intensity of meteroric diagenesis appears to have been controlled both by age and depth, i.e. the time available for diagenetic alteration, and reflects the relation between reef deposition and sea-level change.

Keywords Diagenesis, Expedition 325, Great Barrier Reef Environmental Changes, Integrated Ocean Drilling Program, microfacies, Pleistocene, pre-last glacial maximum.

INTRODUCTION

Knowledge of the facies, palaeoecology, diagenesis and age of late Pleistocene reefs is based on studies of classic outcrops in New Guinea (Chappell, 1974; Pandolfi, 1996), Barbados (Mesolella, 1967; Jackson, 1992), the Red Sea (Gvirtzman & Friedman, 1977; Dullo, 1987, 1990; Strasser *et al.*, 1992) and south Florida (Stanley, 1966). Subsurface or borehole studies in Pacific atolls (Quinn, 1991; Camoin *et al.*, 2001; Braithwaite & Camoin, 2011), the Bahamas (Kievman, 1998), south Florida (Multer *et al.*, 2002), the Great Barrier Reef (Braithwaite *et al.*, 2004; Braithwaite & Montaggioni, 2009), Belize (Gischler *et al.*, 2010) and New Caledonia (Montaggioni *et al.*, 2011) have focussed on facies, chronology or diagenesis; however, most studies only acquired qualitative data. The results of diagenetic studies in Pleistocene reefs have been detailed in various articles and textbooks (Bricker, 1971; Longman, 1980; Harris *et al.*, 1985; Schroeder & Purser, 1986; and references therein). Nevertheless, uncertainties remain, including the differentiation of meteoric-phreatic and marine-burial diagenesis that produce similar diagenetic patterns (Melim *et al.*, 1995). Another problem has been the correlation between sea-level variation and petrography, and particularly the possible lack of diagenetic records of high-amplitude sea-level falls (Melim, 1996) and the irregular distribution of cements in Pleistocene sequences (Braithwaite & Montaggioni, 2009). The analyses of climate archives from massive scleractinian corals have provided new insights into the variability of Pleistocene climate at high resolution (Tudhope *et al.*, 2001; Felis *et al.*, 2004; Gischler *et al.*, 2009). These, and chronological investigations providing exact radiometric dating of the past *ca* 500 kyr by U/Th ratios measured by thermal ionization mass spectrometry (TIMS; Edwards *et al.*, 1986) have been hampered by alteration of original aragonite and high-magnesium calcite in the meteoric realm. It is therefore important to have a good understanding of the diagenetic history of the reef material.

Current knowledge of late Quaternary reefs from deeper water or deposited during sea-level lowstands remains limited. Exceptions are studies in Barbados (Fairbanks, 1989), New Guinea (Chappell & Polach, 1991) and Tahiti (Bard *et al.*, 1996; Camoin *et al.*, 2007; Iryu *et al.*, 2010) that cover the time interval back to the last glacial maximum (LGM) and beyond, and have produced almost complete post-glacial sea-level curves (Bard *et al.*, 1996, 2010; Camoin *et al.*, 2012). Interestingly, the post-glacial reefs of both Tahiti and Australia contain substantial proportions of microbialites (Westphal *et al.*, 2010; Seard *et al.*, 2011; Webster *et al.*, 2011) that are hardly represented in older rocks. Possibly, rapid sea-level rise created relatively open coralgal frameworks that offered habitat for microbes while rapidly changing environmental conditions also favoured their growth. With these aspects in mind, the material from Integrated Ocean Drilling Program (IODP) Expedition 325 presents a unique opportunity to quantitatively investigate facies and diagenesis in late Quaternary reefs reflecting low sea-levels (Fig. 1; Webster *et al.*, 2011) that reach beyond the last glacial maximum.

STUDY AREA

The Great Barrier Reef of Australia, the largest modern barrier reef system (Hopley *et al.*, 2007), is over 2000 km long bordering the Queensland shelf that is up to 220 km wide (Fig. 1). Studies on prominent reef settings around the world support the contention that major barrier reefs are geologically young features that were only initiated during the late Pleistocene (mid-Brunhes, *ca* 0·5 Ma). Marshall & Davies (1984) established that in the southern Great Barrier Reef Holocene shallow-water reefs developed on top of reefs formed during the last interglacial marine isotope stage (MIS) 5, some 120 kyr BP. Observations of the International Consortium of Great

