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Holocene reef growth over irregular Pleistocene karst confirms major influence of hydrodynamic factors on Holocene reef development

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ABSTRACT

Many factors govern reef growth through time, but their relative contributions are commonly poorly known. A prime example is the degree to which modern reef morphology is controlled by contemporary hydrodynamic settings or antecedent topography. Fortunately, reefs record essential information for interpreting palaeoclimate and palaeoenvironment within their structure as they accrete in response to environmental change. Five new cores recovered from the margin of Heron Reef, southern Great Barrier Reef (GBR), provide new insights into Holocene reef development and relationships between Holocene reefs and Pleistocene antecedent topography, suggesting much more irregular underlying topography than expected based on the configuration of the overlying modern reef margin. Cores were recovered to depths of 30 m and 94 new ^{230}Th ages document growth between 8408 ± 24 and 2222 ± 16 yrs. BP. One core penetrated Pleistocene basement at ~15.3 m with Holocene reef growth initiated by ~8.4 ka BP. However, 1.83 km west along the same smooth margin, four cores failed to penetrate Pleistocene basement at depths between 20 and 30 m, suggesting that the margin at this location overlies a karst valley, or alternatively, the antecedent platform does not extend there. A 48 m-long margin-perpendicular transect of three cores documents the filling of this topographic low, at least 30 m beneath the current reef top, with seaward lateral accretion at a rate of 34.3 m/ka. Cores indicate steady vertical and lateral accretion between 3.2 and 1.8 ka BP with no evidence of the hiatus in reef flat progradation seen in most other offshore reefs of the GBR at that time. These cores suggest that the relative protection afforded by the valley allowed for unconsolidated sediment to accumulate, enabling continuous progradation even when other areas of the reef flat appear to have 'turned off'. Additionally, the cores suggest that although reefs in the southern GBR clearly owe their location to Pleistocene antecedent topography, modern reef morphology at sea level primarily reflects the interaction of Holocene reef communities with contemporary hydrodynamics.

1. Introduction

The record of Holocene reef development is generally obscured beneath living reefs such that many of the controls of longer term reef development remain poorly understood. The Holocene reef growth model developed for the Great Barrier Reef (GBR) in the 1980s implies that sea level is a key factor controlling modern reef growth geometries (Davies et al., 1985; Davies and Marshall, 1980; Davies and Montaggioni, 1985; Marshall and Davies, 1982), as rising sea level provides accommodation for reef growth and stillstand limits accretion to lateral progradation (Cabioch et al., 1999a; Montaggioni and Faure, 1997). In both the Pacific (Davies et al., 1985) and the Caribbean (Neumann and Macintyre, 1985) the standard Holocene reef growth model includes two phases that follow initiation on a topographic high: 1) dynamic vertical accretion, either keeping up, or more commonly catching up, with sea

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level, primarily on the windward side; and 2) lateral accretion (progradation) primarily directed towards the lee owing to limited vertical accommodation as the reef grows at a stabilised sea level. However, the degree to which modern reef morphology reflects contemporary hydrodynamic regime versus morphology of antecedent topography remains poorly known (Cabioch et al., 1999a; Camoin et al., 2012; Camoin and Webster, 2015; Gischler et al., 2016; Montaggioni and Faure, 1997; Woodroffe and Webster, 2014).

Fairbridge (1950) acknowledged that modern coral reefs were localised on topographic highs, but considered the shapes of reefs to be controlled primarily by modern wind, wave and current regimes. He suggested that prevailing wind direction was the most important controlling factor in the GBR and devised a five-stage evolutionary sequence for reefs on that basis. Purdy (1974a,b) on the other hand, working mainly on atolls and building on the work of MacNeil (1954), suggested that reef morphology is controlled predominantly by antecedent karst topography. He attributed overall reef shape, location of reef passes-channels and even spur and groove structures to Pleistocene karst and noted that although Holocene reef growth could accentuate the underlying karst features, the 'reef growth *per se* has little to do with the basic [reef] configuration' (Purdy, 1974b, p. 9). Halley et al. (1977) attributed the position of lagoonal patch reefs in Belize directly to antecedent karst pinnacles. Harvey et al. (1979) and Harvey and Hopley (1981) suggested that lagoons in the GBR were largely inherited from antecedent topography on the basis of seismic refraction data and Marshall and Davies (1982) reached a similar conclusion based on cores collected from One Tree Reef. Gischler and Hudson (1998) documented sequential Holocene reef initiation and growth on Pleistocene basements of differing elevation offshore of Belize and found that Pleistocene basement was increasingly obscured by thicker Holocene growth. Subsequently, Purdy et al. (2003) and Gischler and Hudson (2004) also showed that faulting and subsidence are significant factors influencing the variable elevation of the Pleistocene basement in Belize reefs but reiterated that relative exposure to waves and currents was an important driver of modern reef geomorphology.

In the late 1960s Maxwell (1968) differentiated oceanic atoll reefs from continental shelf reefs and attributed reef shapes in the GBR to wave and current intensity associated with dominant wind directions and tidal regime. He constructed a more complicated reef evolution classification system than Fairbridge's (1950) scheme, also attributing reef shape to hydrodynamic orientation. Although it is clear that many Holocene reefs are localised on Pleistocene reef substrates (Hopley et al., 2007; Montaggioni and Braithwaite, 2009), data from many modern Indo-Pacific reefs suggest that Holocene reef geomorphology, accretion rates and, to a lesser extent, size reflect modern processes more than pre-existing topography (Duce et al., 2016; Hopley, 1982; Montaggioni, 2000, 2005; Smith et al., 2009).

Mid-outer shelf platform reefs in the GBR are thought to occur mostly on relatively flat antecedent Pleistocene platforms based on scattered cores and limited seismic profiles (Davies, 1974; Dechnik et al., 2015; Harvey et al., 1979; Harvey and Hopley, 1981; Hopley et al., 2007; Marshall and Davies, 1982; Smith et al., 2009; Walbran, 1994). Harvey et al. (1979) identified the Pleistocene basement at depths from 8 to 23 m beneath reefs in the Capricorn/Bunker groups of the southern GBR with localised relief (within tens to hundreds of meters) of 2–8 m on a given reef. Although modern platform reefs in the southern GBR appear to have developed mostly on underlying Pleistocene basement (Hopley et al., 2007), some areas of Pleistocene basement do not support modern reef growth on their tops, such as the area of submerged platform interpreted as Pleistocene basement between Heron and Sykes reefs (Jell and Flood, 1978) (Fig. 1A). Hence, the shapes of modern reefs do not necessarily reflect the shapes of the antecedent topography. Furthermore, investigations of the Pleistocene basement have been hampered by the rarity of deeper reef cores and seismic data. Only one previous core reached the antecedent platform of Heron Reef (Richards and Hill, 1942) with the shallowest solution unconformity encountered in the bore interpreted as the Holocene-Pleistocene unconformity (Davies, 1974). That core, and limited seismic data, indicate that the Pleistocene basement beneath Heron Reef occurs at ~12–15 m (Harvey et al., 1979; Jell and Flood, 1978; Smith et al., 2009). Subsequent coring documented variable lateral accretion on Heron Reef (Dechnik et al., 2016; Webb et al., 2016) but none of those cores penetrated Pleistocene basement. Hence, the expectation was that a relatively flat Pleistocene basement extended uniformly beneath Heron Reef at a depth between 10 and 15 m consistent with seismic data (Harvey et al., 1979; Smith et al., 2009) and the depth of the platform between Heron and Sykes reefs (Jell and Flood, 1978).

Recent shallow reef coring in the southern GBR suggests that seaward progradation is controlled by modern hydrodynamic regimes with very limited progradation seawards on windward margins with strong wave energy (Dechnik et al., 2016). However, closely spaced core transects on Heron Reef also identified varying temporal patterns in progradation with significant early (e.g., ~6–4 ka BP) progradation in some leeward positions ceasing abruptly after ~4 ka BP (Webb et al., 2016). A broader analysis of lateral reef accretion patterns throughout the GBR found a general hiatus in reef progradation between ~3.6 and 1.6 ka BP, attributed to a small fall in relative sea level, which decreased carbonate production (Dechnik et al., 2017b). Few previous cores from the southern GBR have penetrated to the Pleistocene basement (Dechnik et al., 2017a) and many uncertainties remain about the exact relationship between underlying antecedent platforms and modern reef morphology.

This paper presents data from five new rotary cores recovered from the southern margin of Heron Reef, including ninety-two new Holocene ^{230}Th ages and two Pleistocene open system model ^{230}Th ages (Thompson et al., 2003) that constrain the Holocene-Pleistocene unconformity (Table 4). The data allow for the reconstruction of a robust chronostratigraphy for a Holocene section that varies in thickness between <15 and >30 m, providing new insight into the relationship between Holocene reef development and underlying karst topography.

2. Materials and methods

2.1. Reef cores

Heron Reef (23°27′S, 151°55′E) is part of the Capricorn Group of reefs, a group of seventeen reefs from North Reef to Llewellyn Reef that, with the Bunker Group, Lady Elliott Reef and four northerly shoals, make up the southernmost part of the GBR (Jell and Webb, 2012). The reefs occur on topographic highs located on the mid-to outer shelf ~70 km from the mainland. Heron Reef is a platform reef that, together with Sykes Reef, occupies a submerged platform (~10–15 m deep) interpreted as the remains of the last Pleistocene reef rising from 30 to 40 m depth on the continental shelf (Jell and Flood, 1978). New dates from other reefs in the Capricorn Group (Dechnik et al., 2017a) confirmed for the first time that antecedent platforms in the region are last interglacial (LIG) in age (marine isotope stage –MIS 5e).

Five rotary cores (HLC 1 to HLC 5) were recovered in 2014 from the protected south western Heron Reef margin on the edge of the channel across from nearby Wistari Reef (Fig. 1) using a purpose-built, environmentally sensitive, jack-up platform/deployment vessel combination, the R.V. *D. Hill* (Fig. 2). Cores were recovered to