Palaeogeography, Palaeoclimatology, Palaeoecology 392 (2013) 473–494

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Deglacial mesophotic reef demise on the Great Barrier Reef

E. Abbey [a], J.M. Webster [a,*], J.C. Braga [b], G.E. Jacobsen [c], G. Thorogood [d], A.L. Thomas [e,f], G. Camoin [g], P.J. Reimer [h], D.C. Potts [i]

[a] Geocoastal Research Group, School of Geosciences, University of Sydney, NSW 2006, Australia
[b] Departamento de Estratigrafia y Paleontologia, Universidad de Granada, Granada, Spain
[c] Institute for Environmental Research, Australian Nuclear Science and Technology Organisation, Locked Bag 2001, Kirrawee DC, NSW 2232, Australia
[d] Institute of Materials Engineering, Australian Nuclear Science and Technology Organisation, Locked Bag 2001, Kirrawee DC, NSW 2232, Australia
[e] University of Oxford, Department of Earth Sciences, Parks Road, Oxford OX1 3PR, UK
[f] School of Geosciences, University of Edinburgh, West Mains Road, Edinburgh EH9 3JW, UK
[g] Aix-Marseille Université, CNRS, IRD, CEREGE UM34, Europôle Méditerranéen de l'Arbois, B.P. 80, F-13545 Aix-en-Provence CEDEX 4, France
[h] School of Geography, Archaeology and Palaeoecology (GAP), Queen's University Belfast, Belfast, BT7 1NN Northern Ireland, UK
[i] Department of Earth and Evolutionary Biology, University of California, Santa Cruz, CA 95604, USA

ARTICLE INFO

Article history:
Received 5 June 2013
Received in revised form 27 September 2013
Accepted 30 September 2013
Available online 9 October 2013

Keywords:
Mesophotic reef
Submerged reef
Coralgal assemblages
Radiocarbon dating

ABSTRACT

Submerged reefs are important recorders of palaeo-environments and sea-level change, and provide a substrate for modern mesophotic (deep-water, light-dependent) coral communities. Mesophotic reefs are rarely, if ever, described from the fossil record and nothing is known of their long-term record on Great Barrier Reef (GBR). Sedimentological and palaeo-ecological analyses coupled with 67 ^{14}C AMS and U–Th radiometric dates from dredged coral, algae and bryozoan specimens, recovered from depths of 45 to 130 m, reveal two distinct generations of fossil mesophotic coral community development on the submerged shelf edge reefs of the GBR. They occurred from 13 to 10 ka and 8 ka to present. We identified eleven sedimentary facies representing both autochthonous (in situ) and allochthonous (detrital) genesis, and their palaeo-environmental settings have been interpreted based on their sedimentological characteristics, biological assemblages, and the distribution of similar modern biota within the dredges. Facies on the shelf edge represent deep sedimentary environments, primarily forereef slope and open platform settings in palaeo-water depths of 45–95 m. Two coral–algal assemblages and one non-coral encruster assemblage were identified: 1) Massive and tabular corals including *Porites*, *Montipora* and faviids associated with Lithophylloids and minor Mastophoroids, 2) platy and encrusting corals including *Porites*, *Montipora* and *Pachyseris* associated with melobesioids and *Sporolithon*, and 3) Melobesiods and *Sporolithon* with acervulinids (foraminifera) and bryozoans. Based on their modern occurrence on the GBR and Coral Sea and modern specimens collected in dredges, these are interpreted as representing palaeo-water depths of <60 m, <80–100 m and >100 m respectively. The first mesophotic generation developed at modern depths of 85–130 m from 13 to 10.2 ka and exhibit a deepening succession of <60 to >100 m palaeo-water depth through time. The second generation developed at depths of 45–70 m on the shelf edge from 7.8 ka to present and exhibit stable environmental conditions through time. The apparent hiatus that interrupted the mesophotic coral communities coincided with the timing of modern reef initiation on the GBR as well as a wide-spread flux of siliciclastic sediments from the shelf to the basin. For the first time we have observed the response of mesophotic reef communities to millennial scale environmental perturbations, within the context of global sea-level rise and environmental changes.

1. Introduction

Mesophotic reefs are light-dependent coralgal communities found on deep forereef slopes (ca. 40–100 m) along continental margins and oceanic islands (Lesser et al., 2009; Kahng et al., 2010). Their distribution is becoming increasingly well-known as they are the topic of much interest, thought to be refuges during past environmental disturbances (summarised in Bongaerts et al., 2010). These communities are commonly composed of depth generalists found in shallow-water reefs (Bongaerts et al., 2010) and are thought to be the source for shallow-water reef regeneration following disturbances. However, the genetic and ecological link between mesophotic communities and shallow-water reefs remains unclear (Van Oppen et al., 2011) and mesophotic reef presence in the fossil record is poorly documented compared with their shallow counterparts.

Sea-levels dropped to a maximum level of about −125 m during the Last Glacial Maximum (LGM) (Yokoyama et al., 2001; Peltier, 2002;

* Corresponding author at: Geocoastal Research Group, School of Geosciences, The University of Sydney, NSW 2006, Australia. Tel.: +61 2 9036 6538; fax: +61 2 9351 0184.
E-mail address: jody.webster@sydney.edu.au (J.M. Webster).

0031-0182/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.palaeo.2013.09.032

Peltier and Fairbanks, 2006), and evidence for shallow-water reef colonisation on deep island flanks and continental shelf edges during the deglacial sea-level rise can be found in the South Pacific (Camoin et al., 2006; Cabioch et al., 2008; Flamand et al., 2008), Hawaii (Webster et al., 2004; Faichney et al., 2009), the Caribbean Sea (Macintyre et al., 1991; Toscano and Lundberg, 1999; Blanchon et al., 2002), the Indian Ocean (Wagle et al., 1994; Vora et al., 1996; Dullo et al., 1998; Rao et al., 2003; Camoin et al., 2004; Fürstenau et al., 2010) and Australia (Harris and Davies, 1989; Harris et al., 2004; Beaman et al., 2008; Woodroffe et al., 2010; Abbey et al., 2011a). Indications of rapid pulses in sea-level rise during the last deglaciation (meltwater pulses) have been identified in the submerged reef and coastal sequences in the Caribbean and the Indo-Pacific (Fairbanks, 1989; Hanebuth et al., 2000; Webster et al., 2004; Fairbanks et al., 2005; Camoin et al., 2012), with coral reefs responding to rapidly changing environmental conditions via a combination of community transitions, and/or complete demise and backstepping.

The causes of shallow-water reef demise have increasingly been studied in both the modern (e.g., Eakin et al., 2010) and the fossil records (e.g., Montaggioni, 2005; Blanchon, 2011). However, the causes and occurrence of modern mesophotic reef demise are relatively unknown compared to their shallow-water counterparts (Smith et al., 2010). Mesophotic coral communities are similar in composition to shallow-water reefs (Bongaerts et al., 2010; Bridge et al., 2012), and as such are difficult to differentiate in fossil coral cores without the aid of multi-taxa reconstructions and precise radiometric dating. Mesophotic reefs also tend to have slow accretion rates (Grigg, 2006) and produce only a thin veneer of coral growth (e.g., Jarrett et al., 2005; Abbey et al., 2011b) and as such, there is limited potential to investigate fossil mesophotic reef death in vertically drilled sequences alone. Despite these limitations, fossil mesophotic reefs have the potential to provide valuable information about conditions during sea-level rise, as well as better constraining mesophotic tolerances.

Due to its wide (50–150 km), mostly gently-sloping continental shelf reaching depths of >100 m (Hopley et al., 2007), the Great Barrier Reef (GBR) offers an excellent opportunity to study fossil mesophotic communities and their response to sea-level rise and palaeo-environmental changes. Modern mesophotic communities are found on submerged banks and Pleistocene reefs to depths of 75 m (Bridge et al., 2010, 2011a, 2011b; Harris et al., 2012), and provide a robust foundation for environmental reconstruction through direct comparisons of the fossil communities to the modern.

Despite intensive study of the Holocene growth history of the modern GBR (see Hopley et al., 2007 for a comprehensive review), little is known of the submerged reefs found at the shelf edge. Submerged geomorphological features at depths of 50–130 m are interpreted to be the result of widespread reef growth during the deglaciation and previous periods (Harris and Davies, 1989; Beaman et al., 2008; Abbey et al., 2011a), but ecological and chronological information is sparse (Veeh and Veevers, 1970; Yokoyama et al., 2000; Davies et al., 2004). Prior to this study, only two corals have been recovered from these deep slopes, both in the southern GBR; a *Galaxea clavus* was recovered from 175 m depth and dated to 17.0 ka (Veeh and Veevers, 1970; Yokoyama et al., 2000), and an encrusting Acroporid was recovered from 90 to 110 m and dated to 9.1 ka (Davies et al., 2004). However, a recent program of offshore drilling on the shelf edge has targeted these submerged geomorphological features, and preliminary results confirm the underlying structure is composed of a combination of mainly shallow water coralgal-microbial framework and detrital facies that developed since the LGM (Webster et al., 2011).

The deeper regions of the GBR shelf edge may provide new insights into the fossil mesophotic communities, their palaeo-environments and the timing and causes of their demise. Our study is based on samples and data collected on a 2007 cruise on the RV *Southern Surveyor* that investigated the geomorphology, fossil coral communities and modern benthic habitats preserved on the outer shelf of the GBR (Webster et al., 2008). The specific objectives of our study are; (1) to describe the ecological and sedimentological characteristics of the fossil mesophotic communities and their palaeo-environmental significance; (2) constrain the timing of mesophotic reef demise and assess the cause of death during the last deglaciation; and (3) discuss the implications of these findings for understanding the environmental thresholds of these deep-water communities.

2. Location and methods

The GBR extends from ca. 10° to 24°S along Australia's eastern continental shelf. Conditions are oligotrophic on the shelf edge where reefs grade from a nearly continuous barrier in the north to isolated platforms in the central region (Hopley et al., 2007). Shelf edge reefs are buffered from terrestrial influences due to their great distance from the shore (King et al., 2001; Brinkman et al., 2002). Four widely-spaced shelf edge sites on the GBR were selected for this study, including near Ribbon Reef 5, near Noggin Pass, near Viper Reef and near Hydrographers Passage (Figs. 1 and 2). Abbey et al. (2011a) conducted a detailed study of shelf geomorphology at these four sites, and identified drowned reef features including fringing reefs, patch reefs, an outer barrier reef and an inner barrier reef. Many of these features were dredged, including the following:

1. *Continental slope*: the slope seaward of the shelf break.
2. *Shelf break*: the inflection point demarking the continental slope from the continental shelf.
3. *Terraces*: flat, horizontal or sub-horizontal features bound on their landward and seaward margins by more steeply dipping sea bed.
4. *Pinnacles*: high relief, steep sided outcrops, generally circular to oval in shape and less than 100 m in diameter.
5. *Barrier reefs*: high relief outcrops with extensive linear continuity. They may be flat-topped or formed by closely-spaced or joined pinnacles.

2.1. Dredging

Samples were recovered using a benthic sled, designed to recover the top layer of the substrate as it was towed over a distance of 50–250 m at each sampling site. Twenty-two dredges were recovered from between 46 m and 173 m (Table 1) with depth ranges estimated using a combination of shipboard GPS and 5 m pixel cell size bathymetric models (Bridge et al., 2010, 2011a; Abbey et al., 2011a). Depth errors were minimized (5–10 m) by dredging parallel to the isobath in most cases (Fig. 2).

2.2. Biota, facies and environmental characterisation

Samples larger than ca. 50 mm in diameter were halved along their long axis and used for analyses and those smaller than 50 mm were not included. The cut surfaces of more than 900 selected samples were used to assess the facies, fossil assemblages and internal bioerosion.

Modern biota were identified by the presence of live tissue and recent biota by preservation of fine-scale surface ornamentation but lacking tissue and/or a modern (<500 years) radiometric age. The degree of bioerosion was estimated visually (Flügel, 2009) as a percentage of the cut surface area affected by voids created by boring organisms. Each sample was classified using Wright's (1992) revised version of Dunham's (1962) and Klovan and Embry's (1971) classifications. Samples were considered in situ on the basis of a freshly broken basal surface lacking any encrusting biota. Additional factors taken into account include the orientation of geopetals and the location of staining relative to the upper surface indicated by the biota (e.g. corallites). Those samples exhibiting rounding, no freshly broken basal surface or