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Submerged coral reefs in the Gulf of Carpentaria, Australia

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Abstract

We report the discovery of three submerged, living patch coral reefs covering 80 km^2 in the southern Gulf of Carpentaria, Australia, an area previously thought not to contain coral bioherms. The patch reefs have their upper surfaces at a mean water depth of 28.6 ± 0.5 m, and were consequently not detected by satellites or aerial photographs. The reefs were only recognised in our survey using multibeam swath sonar supplemented with seabed sampling and under water video. Their existence points to an earlier, late Quaternary phase of framework reef growth, probably under cooler climate and lower sea level conditions than today. Submerged reefs with surfaces between 20 and 30 m water depth occur in other regions of the Earth and existing bathymetry indicates they could be widespread in the Gulf. Many tropical regions that today do not support patch or barrier reefs for reasons similar to the modern Gulf, may have done so in the past, when environmental conditions were more suitable. Submerged reefs may provide an important refuge for corals during the next few decades when near-surface reefs are threatened by widespread coral bleaching due to warmer global sea surface temperatures.

Keywords: submerged coral reefs; sea level; Quaternary; multibeam sonar; geomorphology

1. Introduction

The total area of coral reefs in the world's oceans is estimated to be about 255,000 km^2 (Spalding and Greenfell, 1997; Spalding et al., 2001), comprised of shallow reef crests and reef flats close to the sea surface. But there exists also an unknown number of submerged coral reefs, below the sea surface and often invisible to satellite imagery or air photography. Such submerged reefs were difficult to detect prior to the advent of multibeam sonar systems and consequently they have been documented in only a few studies from the Gulf of Papua, Great Barrier Reef (GBR), Indian Ocean, Gulf of Mexico, and the Bahamas (Macintyre, 1972; Hine and Steinmetz, 1984; Carter and Johnson, 1986; Harris and Davies, 1989; Vora and Almeida, 1990; Gardner et al., 2001; Harris et al., 2002). Here, we report the unexpected discovery of submerged reefs in the Gulf of Carpentaria, Australia (Fig. 1), in similar (~ 30 m) water depths to those reported from other areas. The Gulf is known to contain fringing reefs and isolated coral colonies (Veron, 1993; 2000) but not patch or barrier reef bioherms like those found in the GBR. Our discovery points to the possibility of the occurrence of further submerged reefs in the Gulf and other

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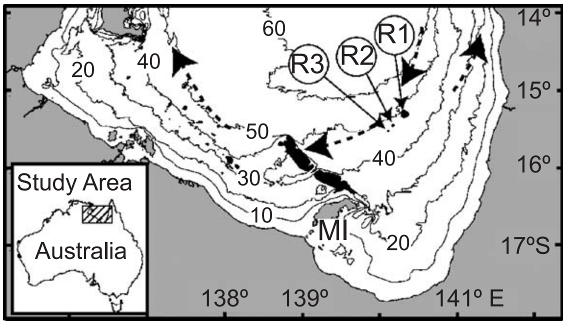

Fig. 1. Location map showing bathymetry of the Gulf of Carpentaria and the location of submerged reefs R1, R2 and R3. Arrows indicate the direction of residual water circulation during SE trade winds (Wolanski, 1993). Other submerged platforms, which may also be coral reefs, are shown in black. The largest potential coral reef province in the Gulf extends >100 km NW of Mornington Island (MI). Future proposed swath surveys should resolve its true nature.

parts of northern Australia, where near-surface reefs are rare or absent.

2. Methods

A Reson™ 240 kHz swath system (model no. 8101) was used to map selected areas of seafloor in depths of 10–50 m in the southern Gulf of Carpentaria (Fig. 1). An Applied Microsystems SV PLUS acoustic velocity profiler was used to measure the acoustic velocity range, which was from 1542 to 1546 m/s in the study area. Data were corrected for tidal elevation and cleaned on board ship using Caris™ software, to remove spurious data and other artefacts. A Datasonics™ 3.5 kHz Chirp Sub-bottom profiler, and an EG&G Sparker system were deployed to image the underlying sedimentary strata.

A Seabird™ SBE911 CTD was deployed along with a Seatech transmissometer at nine locations. The transmissometer was calibrated to measure suspended sediment concentration using water samples filtered through pre-weighed 0.45-μm filter papers. The filter papers were oven dried at 60 °C and re-weighed in the laboratory to the nearest ± 0.0001 g.

Seabed and subsurface sediment samples were collected using a Smith Macintyre grab at 27 locations and a vibro-core was taken at 11 locations. A benthic sled was deployed at 10 stations to collect a representative sample of benthic biota and a dredge was used at 6 stations to recover cemented limestone and fragments of corals. Video footage (minimum of 5 min bottom time) of the seabed was also collected at 31 stations to characterise the seabed type and record associated benthic fauna.

3. Results and discussion

Geophysical mapping and sampling took place in May–June 2003, over three large patch reefs (R1, R2 and R3; Fig. 1) 72.5, 5.5 and 1.6 km^2 in area, respectively. Multibeam sonar mapping in this study generated more than 1 million depth soundings over the 80 km^2 of reefs, which not only clearly reveals the reef morphology but also permits highly accurate estimates of the depths of different features (Table 1; Fig. 3). The submerged reefs exhibit classic patch reef geomorphology including an oval shape in plan view, steep, spur-and-groove, fore-reef slopes at depths of 30–45 m, and reef crests that rise locally to within 18 m of the water surface (Fig. 2). All three reefs contain a talus slope on their southern margins, suggesting

Table 1
Water depth of reef tops, platforms and terraces measured for the submerged reefs from multibeam sonar data

Feature	Minimum (m)	Maximum (m)	Mean (m)	S.D. (m)	No. data points	Area (km^2)
Total R1	20.8	(35)*	28.20	0.70	724,848	72.48
R1 reef top	20.8	22.4	21.92	1.78	349	0.04
R1 platform	26.6	28.2	27.33	1.37	481,505	48.15
R1 terrace	28.8	29.8	29.24	0.89	75,261	7.53
R1 terrace	30.4	31.2	30.80	0.22	38,724	3.87
Total R2	20.2	(35)*	29.39	0.42	221,656	5.54
R2 reef top	20.2	21.4	20.75	0.61	5376	0.13
R2 terrace	24.2	25.4	24.89	1.20	1881	0.22
R2 terrace	26.8	27.6	27.20	2.14	23,945	0.60
R2 platform	29.4	31.6	30.42	0.99	101,294	2.53
Total R3	20.2	(35)*	30.24	0.62	62,326	1.56
R3 reef top	20.4	21.4	20.90	0.92	3183	0.08
R3 platform	30.2	31.4	30.83	0.07	27,552	0.69
R3 terrace	31.6	32.0	31.79	2.01	7455	0.19
Grand total	20.2	(35)*	28.59	0.54	1,008,830	79.59

*Outer reef edge defined as 35 m depth (see Fig. 2).

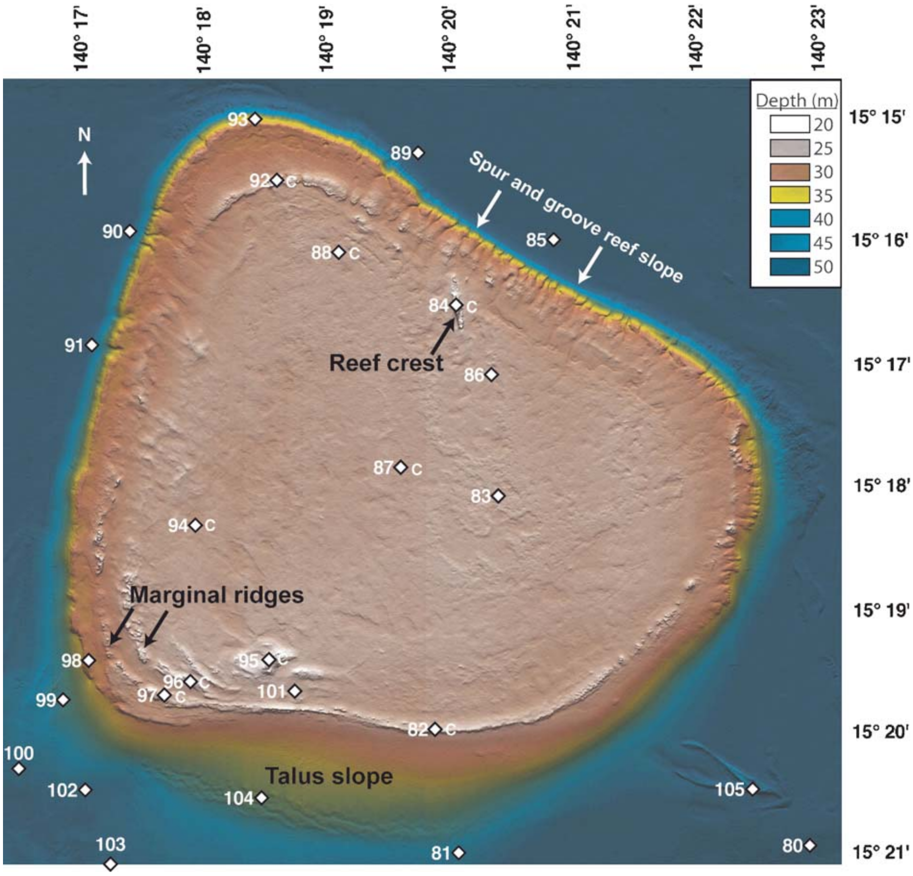

Fig. 2. Detailed colour bathymetry map of reef R1, showing typical patch reef geomorphology. Mapping was carried out using a Reson™ 240 kHz multibeam sonar system and data gridded at 10 m horizontal resolution. Survey lines were spaced at 100–150 m and adjusted according to water depth to provide 100% coverage at a ~ 3 m horizontal resolution. "C" indicates stations where live corals were seen in video footage of the seabed.

wave and current transport of sediment from the north.

The reef's morphology comprises six prominent surfaces (Table 1), two of which (A and B; Fig. 3) we believe are palaeo sea-level indicators because they occur on more than one reef. The most extensive surface is a central reef platform at 27.3 ± 1.4 m (48.8 km^2) that is well developed on reefs R1 and R2. The second surface at 30.6 ± 0.58 m (7.1 km^2) correlates with terraces on R1 and R2 and the central platform of R3. These broad submerged surfaces (A and B; Fig. 3) represent regionally significant phases of carbonate deposition during a prolonged Quaternary sea level still-stand (Macintyre, 1972; Searle and Harvey, 1982). Reef growth over several sea level cycles is evident in seismic profiles which reveal horizontal, sub-surface reflectors that unconformably overlie an undulating acoustic basement reflector having positive relief (Fig. 4). A series of 3–4 m high marginal ridges on reef R1 (Fig. 2) also indicates that it has developed by multiple phases of lateral reef growth. The Carpentaria reefs thus appear similar in their growth history and geomorphic expression to those of the GBR and Caribbean reef provinces (Macintyre, 1972; Searle and Harvey, 1982).

Although appearing relict, the Gulf of Carpentaria reefs are mantled by a thin and patchy veneer of live corals. Dredges yielded a live specimen of the plate coral *Turbinaria* sp. (Station 82; Fig. 2) and abundant

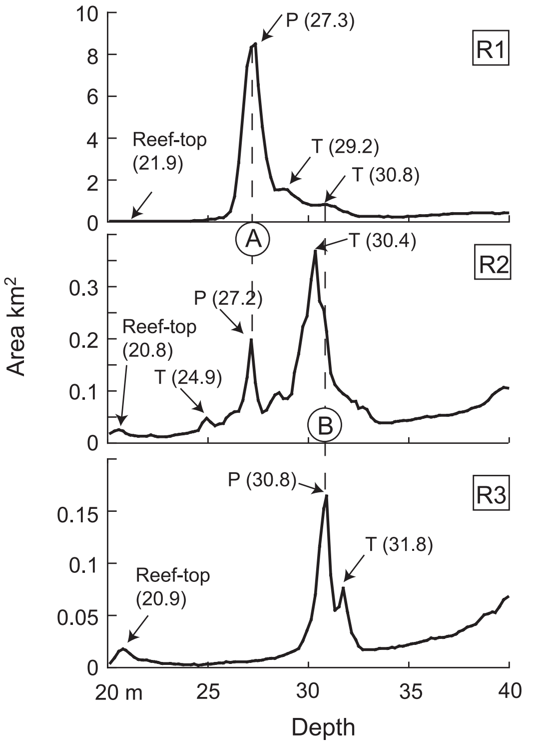

Fig. 3. Hypsometric curves for reefs R1, R2 and R3 based on 1,008,830 multibeam sonar data points (Table 1). The largest peaks, A and B, correspond with horizontal surfaces of extended area (depths in meters shown in brackets) that can be correlated between the reefs. These two surfaces are interpreted to reflect palaeo sea-level still stands and periods favourable to coral reef growth. Small peaks represent other surfaces of <1 km^2 in area specific to individual reefs, and are inferred to reflect carbonate deposition during palaeo sea-level still stands followed by subaerial erosion processes.

hard corals (*Leptoseris* sp.) were observed in video of the seabed on all three reefs. Underwater video from the reef top of R1 showed live hard corals were present at 9 out of 14 stations (Fig. 2). Also contained in the dredges were seven species of gorgonians, one species of soft coral, four species of sponge including two species of fan sponge (*Ianthella basta*; *Ianthella flabelliformis*) and one species of barrel sponge (*Xestospongia* sp.), and a starfish species (*Linkia* sp.). These species are typical of the inner-shelf coral reef association encountered in northern Australia (Veron, 1993, 2000).

The absence of reefs near the sea surface in the southern Gulf cannot be attributed to high levels of turbidity. Measurements taken 2 m above the bed in the central Gulf during May–June 2003 indicate that turbidity levels reached 6.5 mg/l ($n=2$) below 50 m water depth, due to local resuspension of muddy bottom sediments by waves. In contrast, turbidity levels of only 2.9 ± 1.9 mg/l ($n=9$) were measured in shallower water near the reefs. Seabed samples revealed that these regions of low turbidity lacked mud and contained hard substrates of corals or coarse carbonate sediments. This is an example of the positive feed back of reef growth armouring the seabed and removing the source of fine sediments, limiting resuspension and reducing turbidity even at shallow water depths (i.e., <30 m). We conclude that the "catch-up" (Neumann and Macintyre, 1985) Gulf reefs have not reached the sea surface because of insufficient Holocene coral framework deposition and/or their recolonisation was delayed until relatively recently.

In the SE corner of the Gulf, sea grass beds are well developed in depths of less than 20 m (Poiner et al., 1987), nourished during the wet-season outwelling of nutrients and saline waters from coastal salt flats (Ridd et al., 1988). Local sea surface temperatures near the coast range from 15 to 32 °C and salinity ranges from 0 to 39‰ (Hilliard et al., 1997), which are outside the range of temperatures and salinities best suited for reef growth (James and Bourque, 1992). In such environments, corals are unable to compete with fleshy algae for habitat, which explains their absence in these shallow coastal waters. Coastal waters are confined to the SE corner of the Gulf by a strong clockwise residual current during SE trade wind conditions (Wolanski, 1993; Fig. 1), which also brings central Gulf surface water over the coral reefs located in deeper water. This current could also transport coral larvae from Torres Strait and be responsible for seeding the modern coral communities (Veron, 1993).

The morphology and depth of the reef surfaces (Table 1) indicate that they formed mainly when sea level was 25–27 m below its present position. In the late Quaternary, such low sea level periods (Fig. 5) coincide with cooler and drier climatic conditions than present (Chivas et al., 2001; Kershaw et al., 2001), when the Gulf of Carpentaria was a large embayment with only one entrance via the Arafura Sea (Torres Strait was an emergent land bridge). It appears that

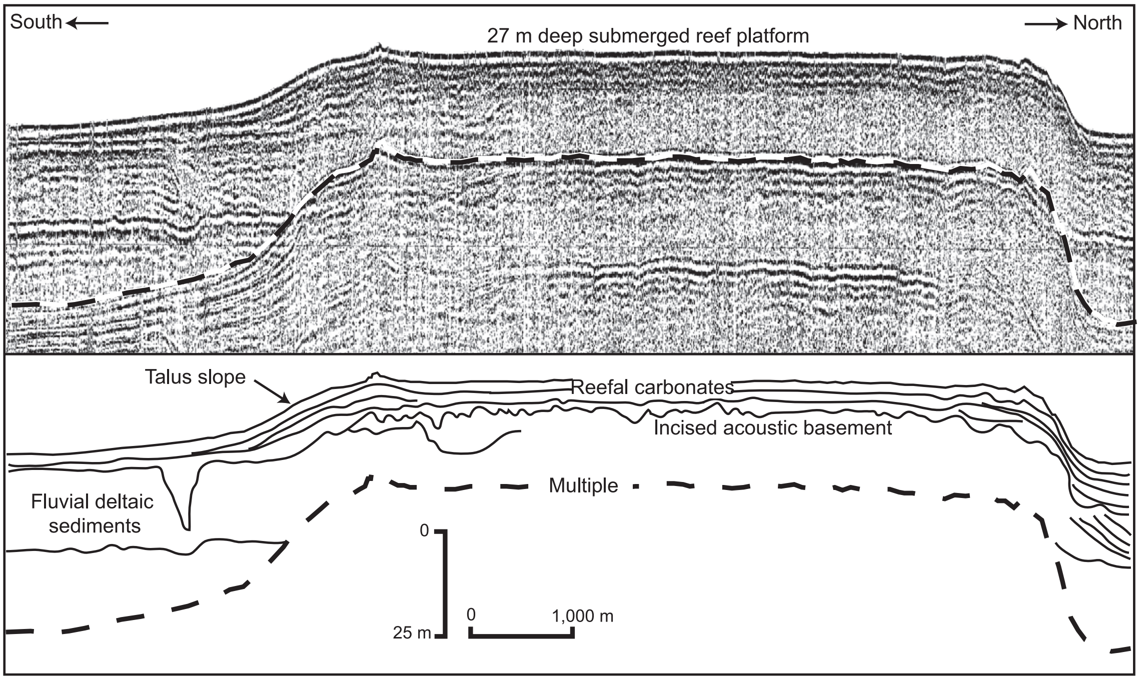

Fig. 4. Sparker shallow seismic reflection profile of reef R1 showing reefal carbonates overlying incised acoustic basement having positive relief. Holocene lithology of a talus slope was verified by a 5 m vibrocore recovered from Station 104 (Fig. 2). The horizontal reflectors and talus deposits indicate that reef growth has taken place over numerous sea level cycles.

such periods were more conducive to reef growth than today and that most reefal carbonates are deposited in the Gulf when sea level was about 25 m lower than present (Fig. 5). This interpretation of the history of reef growth in the Gulf leads to several interesting insights about reef growth around Australia. Whereas coral reefs in Australia today are found mainly in the Great Barrier Reef and Ningaloo regions, the distribution of coral reefs around Australia for much of the late Quaternary might have been quite different. While the Carpentaria reefs were flourishing, were other regions of Australia, such as the Timor or Arafura Seas, similarly home to abundant coral reef complexes? Clearly, reef growth is not unique to interglacial periods since the seed stock must have come from somewhere.

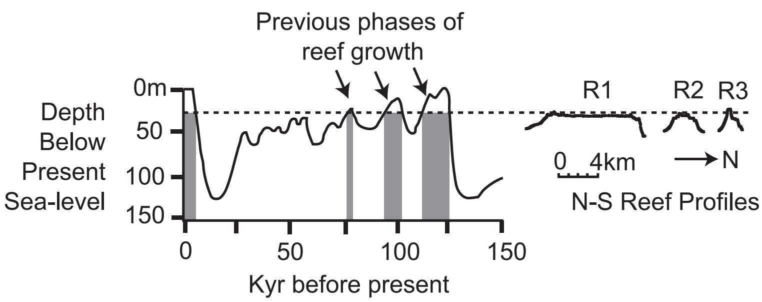

Fig. 5. Sea level curve for the past 150,000 years (after Chappell et al., 1996) showing the phases when the Carpentaria reefs were submerged. Reef growth and main deposition of the reefs probably occurred during the three high stands around 50–120 thousand years BP.

Dating of fossil samples from several submerged reefs could help to constrain palaeo sea level curves derived from uplifted coral terraces (Bard et al., 1990; Gvirtzman et al., 1992; Chappell et al., 1996). The Gulf reefs are located on a comparatively stable continental plate margin, and the extensive horizontal reef surfaces (Fig. 3) provide vertical reference points that appear to be tied to prolonged phases of lower sea level. Testing of this hypothesis awaits the collection of suitable material for radiometric dating.

Submerged reefs may be important for regenerating coral assemblages in regions where surface-dwelling corals are subject to bleaching by SST exceeding 30 °C. The thicker water column above submerged reefs filters out harmful solar radiation and ameliorates diurnal over-heating of the uppermost surface waters. The submerged reefs in the Gulf of Carpentaria are within the latitudinal belt (10–15°) predicted to be most affected by SST warming and coral bleaching (Sheppard, 2003). Sea surface temperatures in the central Gulf range from 28 to 30 °C annually (Wolanski, 1993), and our data indicate that surface water temperatures over the reefs in May–June 2003 were 28 °C. In areas that have suffered substantial bleaching, unaffected submerged reefs like those we have discovered in the Gulf could provide a refuge for corals and larvae for reseeding. Consequently, mapping of submerged reefs should be a priority for government agencies responsible for the management and protection of these important living marine resources (Hughes et al., 2003).

4. Conclusions

Multibeam sonar mapping has revealed the presence of 80 km^2 of submerged coral reefs in the southern Gulf of Carpentaria, an area not previously thought to contain coral bioherms. Although water temperature and salinity ranges in the coastal region of the Gulf are outside the limits normally associated with reef growth, the absence of near-surface reefs further offshore is not explained by the available temperature, salinity or turbidity data. Indeed, living corals were found on the submerged reef-tops, but their growth rate has been too slow in the Holocene for the reefs to reach the sea surface. Consequently, much of the reef morphology appears to be relict, inherited from previous phases of reef growth in the Quaternary that probably correspond with sea levels positioned around 25–37 m below present-day elevations. Existing bathymetric data indicates that there may be numerous submerged reefs in the southern Gulf of Carpentaria. Future multibeam surveys proposed by Geoscience Australia will reveal their true nature.

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