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# Late Pleistocene and Holocene Sea-Level Highstands in Northern Australia

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**ABSTRACT**

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Late Pleistocene and Holocene sea-levels along sections of the northern Australian coastline were significantly higher than present. An *in situ*, raised coral reef on the western shore of the Gulf of Carpentaria returned $^{14}C$ ages of 26 ka BP. and 30 ka BP. The results of independent studies of Late Quaternary environments, both here and near-by and the fact that these corals have undergone extensive calcite recrystallisation suggest that this raised fossil reef is of Last Interglacial age or older. Several raised beach deposits sitting up to 2.5 m above high tide level near Darwin returned $^{14}C$ ages ranging between 2.05–3.39 ka BP. The relative heights of these deposits and the raised *in situ* coral reef suggest: firstly, that sea-levels may not have fallen progressively from the mid-Holocene everywhere in this region, and secondly that the northern margin of the Australian continent may not be subsiding as rapidly as previously thought.

**ADDITIONAL INDEX WORDS:** *Darwin, raised beaches, coral reef, Gulf of Carpentaria.*

## INTRODUCTION

In contrast to other shores of the Australian continent, relatively little is known of late Quaternary sea-level oscillations against the 12,000 km long northern Australian coast. Until now, there has been no published description of higher than present Pleistocene sea-levels in this region. The only previously recognised evidence of Pleistocene sea-levels, from Cobourg Peninsula, was taken to suggest that sea-level here during the Last Interglacial stood at approximately the same height as present (WOODROFFE *et al.*, 1992). Descriptions of Holocene sea-levels, compared to the remainder of the Australian continent, are also comparatively sparse. WOODROFFE *et al.* (1987), concluded from their detailed study of the South Alligator estuary (Figure 1) that Holocene sea-levels have remained relatively stationary since the termination of the transgression, approximately 6 ka. However, a raised beach deposit at Cobourg Peninsula suggested to WOODROFFE *et al.* (1992) that Holocene sea-level may have been up to 1 m higher than present between 5–6 ka. Elsewhere along the northern Australian margin, only three other sites have been recognised as preserving information on Holocene sea-levels. Using the heights of cheniers and beach ridges along the southern and south-eastern shores of the Gulf of Carpentaria, RHODES *et al.* (1980) and CHAPPELL *et al.* (1982) suggested that Holocene sea-level ranged from 1–3 m above present between 6,000–5,000 yr B.P.

Two conclusions have been drawn from these relatively few descriptions of paleosea-level data. The first, that the northern margin of the Australian continent is subsiding in response to continental flexure (MURRAY-WALLACE and BELPERIO, 1991; BRYANT, 1992), is based on the apparent lack of higher than present Pleistocene sea-level data in this region and the assumptions that Last Interglacial eustatic sea-levels were uniformly higher than present. The second conclusion states that relative sea-level has either fallen or remained stationary since the mid-Holocene (CHAPPELL *et al.*, 1982; WOODROFFE *et al.*, 1987). These interpretations, however, along with those focusing on the north Queensland Coast (CHAPPELL *et al.*, 1982), contrast with paleosea-level data from southeast Australia which suggests that relative sea-level remained higher than present well into the late Holocene (FLOOD and FRANKEL, 1989; BRYANT *et al.*, 1992).

This paper discusses evidence which suggests that late Pleistocene and late Holocene sea-levels along parts of the north Australian coast were significantly higher than present. Descriptions and chronologies are presented of a recently discovered *in situ* raised Pleistocene coral reef in the western Gulf of Carpentaria, as well as two well preserved, raised late Holocene beach deposits southwest of Darwin. These features provide important information for the recent tectonic history of the north Australian margin and contribute to the conundrum of variable sea-level maxima and their Holocene chronologies around the Australian Coast.

## LATE PLEISTOCENE SEA-LEVEL

Rosie Reef (named here), a raised *in situ* coral reef, lies on the western shore of the Gulf of Carpentaria, approximately 50 km north of the mouth of the Macarthur River, near Borroloola (Figure 1). This reef lies approximately 150 m offshore and is joined to the mainland by a sand spit. A ferricrete reef

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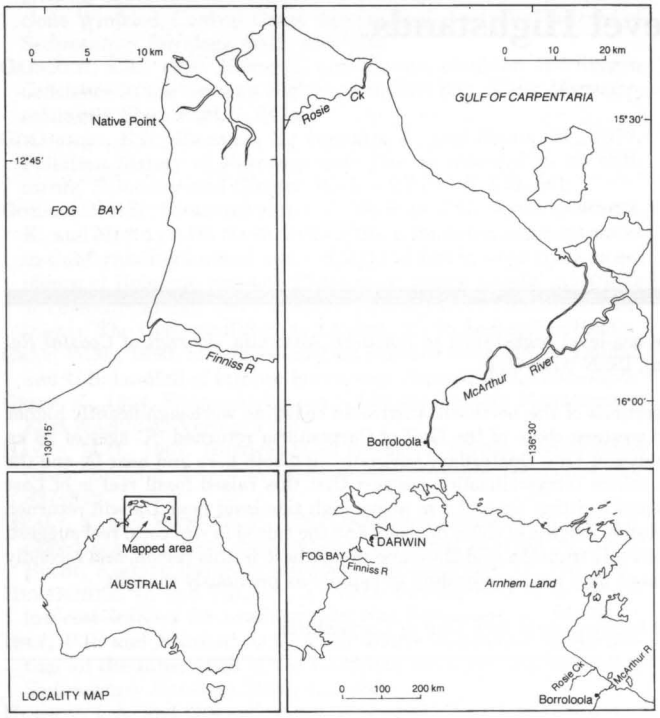


Figure 1. Location of study sites.

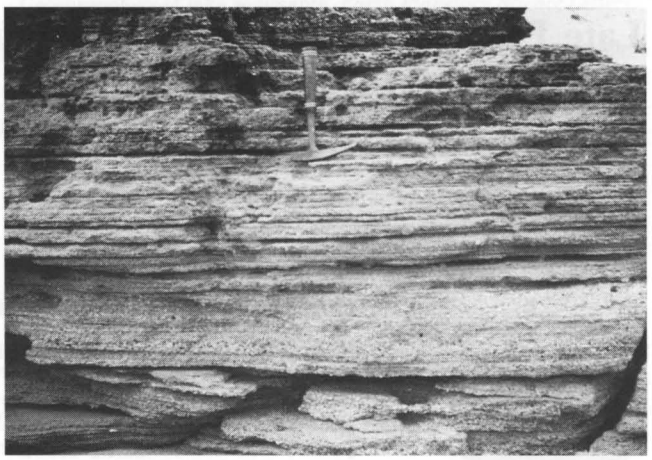

Figure 2. Sand laminae and shell beds within raised beach deposit, Fog Bay.

surrounds the base of Rosie Reef and extends seaward another 150 m. Only a relatively small area of Rosie Reef (~10 $m^2$) stands approximately 3 m above the level of spring low tides, while the remainder of the reef (~200 $m^2$) lies 1–1.5 m lower in elevation. This lower level of Rosie Reef has been planed by waves and is contiguous with the ferricrete reef with the two at this level forming an intertidal platform. The crest of the 10 $m^2$ raised portion of Rosie Reef has also been truncated by waves. This raised section is capped by a 10–20 cm thick layer of detritus composed of poorly sorted sand, ferricrete pisoliths and coral fragments set within a matrix of carbonate cement. Rosie Reef itself is composed of dead corals in their original growth position. The matrix material between individual coral heads within the reef is composed largely of medium to coarse sands cemented by carbonates. The dominant species of coral within the reef is *Favites chinensis*.

X-ray diffraction analyses of samples of exposed *in situ* fossil corals from Rosie Reef revealed these materials to be composed of 98% calcite. Reliable radiometric dating of these materials therefore has been difficult. In order to obtain a broad estimate of the age of this reef, two samples were submitted for $^{14}C$ analyses at the Quaternary Dating Centre A.N.U. Ages of 26.15 ± 0.46 ka (ANU 8453) and 30.32 ± 0.74 ka (ANU 8453) were obtained from *in situ* corals 0.5 m and 1.5 m below the crest of the raised section of Rosie Reef, respectively.

TORGERSEN *et al.* (1988), using extensive geochemical, geophysical, microfossil and sedimentological data, demonstrated that the Gulf of Carpentaria was a fresh water lake from approximately 12 ka to at least 40 ka. The characteristics of their sedimentological Unit IV (35 ka–26 ka), which correlates with the $^{14}C$ ages presented here for Rosie Reef, suggest that at this time the Gulf of Carpentaria was a fresh to brackish water lake (Lake Carpentaria). TORGERSEN *et al.* (1988) argued that Lake Carpentaria had no connection to the open sea across either the Arafura or Torres Strait sills. On the basis of this evidence, and the extensive recrystallisation of the sampled corals, the $^{14}C$ ages from Rosie Reef are best regarded as minimum values.

The late Quaternary sea-level curve of CHAPPELL and SHACKLETON (1986) for the Huon Peninsula indicates that there were several marine transgressions into the Gulf of Carpentaria over the last 100,000 years; but none, since approximately 120 ka, would have equaled or exceeded present day sea-level. Since no published evidence exists for localised tectonics in this region throughout the late Quaternary and as Rosie Reef stands approximately 3 m above the level of the spring low tide (present upper limit of coral growth), relative sea-level must have been at least this much higher than present sea-level during formation of Rosie Reef. On the basis of the Huon Peninsula sea-level curve, the detailed environmental reconstructions of TORGERSEN *et al.* (1988) and the fact that the ages thus far obtained can only be regarded as minimum values, it is reasonable to conclude that Rosie Reef is of Last Interglacial age or older.

## HOLOCENE SEA-LEVEL

Raised beaches occur at two separate locations within Fog Bay, approximately 50 km southwest of Darwin. The first beach deposit lies above and adjacent to a raised shore platform which stands approximately 1–1.5 m above the present intertidal shore platform at Native Point (Figure 1). The other beach deposit lies adjacent to a small creek approximately 1 km north of the Native Point deposit. Both of the deposits are composed of medium to coarse sands, horizontal to low

angle planar cross-beds between 4 mm–6 cm thick that dip (1–4°) towards the present beach and well defined beds of shell within medium to coarse sand matrices (Figure 2). Each deposit extends from the level of the modern beach (and from below in the case of the deposit north of Native Point) to 2–2.5 m above the level of the highest astronomical tide (H.A.T.). Both raised beach deposits grade vertically into overlying dune sands which in some locations display trough cross-beds.

Relatively small patches of ferricrete reef lie immediately offshore of both deposits. The preservation potential of these two raised beaches is likely to have been enhanced by these offshore reefs through the dissipation of wave energy during storms. Elsewhere along this coast, raised beaches are absent and coastal dunes lie at the high tide mark behind present-day beaches.

Shell samples were dated from both the basal and upper sections of each of the raised beach deposits. The Native Point deposit returned uncorrected ages of 3.39 ± 0.22 ka B.P. (ANU 8054) and 2.09 ± 0.07 ka B.P. (ANU 8845), 1 m and 2 m above the high tide level, respectively. The deposit 1 km to the north returned uncorrected ages of 3.12 ± 0.07 ka B.P. (ANU 8842), 2.88 ± 0.09 ka B.P. (ANU 8053) and 2.05 ± 0.07 ka B.P. (ANU 8844), 1 m, 1.5 m and 2 m above the high tide level, respectively.

It is unlikely that these beach sands were deposited under elevated sea-levels during storms. The region is prone to tropical cyclones producing surges capable of exceeding the height of these raised deposits. However, such storms and the resulting waves and surge are more likely to erode sand from the beach. The relatively frequent 'wet season' storms during which strong onshore winds generate waves 1–2 m in height have been observed by the author to erode rather than deposit sand on the modern beaches along this section of coast. The well defined laminae, many of which are normally graded, and distinct beds of shell suggest that these raised beach deposits were laid down under fair weather conditions. And, as shown by the chronostratigraphy, these deposits were not laid down in a single event, but rather accumulated gradually over a period of at least 1,000 yr at or close to the berm of the fossil beach.

## DISCUSSION

Relative heights of Holocene sea-level maxima and their chronologies show considerable variability around the Australian continent (see reviews by HOPLEY, 1987; HOPLEY and THOM, 1983; BRYANT *et al.*, 1992). Apart from the effects of localised tectonics, two main issues dominate the debate (see THOM *et al.*, 1969, 1972; GILL and HOPLEY, 1972; BELPERIO, 1979; HOPLEY, 1980) which has ensued as a result of this variability: the accuracy and validity of different types of paleodatum, and the timing of sea-level maxima during the Holocene. Both of these issues are relevant to the Fog Bay deposits.

The validity of raised marine deposits as accurate paleodatum appears to be site specific and is often dependent upon being able to correlate the deposit both altitudinally and chronologically with other forms of evidence. For instance, HOPLEY (1982) interpreted sand, shelly sand, and sandy shingle deposits on islands of the Great Barrier Reef, Queensland as evidence for mid to late Holocene sea-level up to +3 m above present. These data, however, were shown to be inconsistent with the fringing-reef micro-atoll sequences reported from the same islands by CHAPPELL *et al.* (1983) who argued that sea-levels had fallen smoothly from approximately 1 m above present since the mid-Holocene. Elsewhere, however, raised beach deposits have been shown to be consistent with other forms of paleosea-level evidence. On the Illawarra Coast of south-east Australia, for example, BRYANT *et al.* (1992) correlated raised marine deposits with estuarine deposits, fossil tree stumps and microfossil evidence within estuarine sediments and were able to demonstrate consistent results between each of the different forms of paleodatum.

The difference in Holocene sea-level histories indicated by the Fog Bay raised beaches and the mangrove sediments of the South Alligator River (the geographically closest reported paleosea-level datum, approximately 250 km to the east) is not unusual when two different types of sedimentary deposits are compared. For example, CHAPPELL (1987) described a somewhat similar situation at Princes Charlotte Bay on the north Queensland coast where, like the South Alligator River sequence, mangrove facies suggest a Holocene sea-level no higher than present; in this instance micro-atolls located 10 km offshore suggest a 1 m higher Holocene sea-level. CHAPPELL (1987) explains this difference due to compaction of the mangrove sediments during the latter half of the Holocene. Interpretations of Holocene sea-level histories based upon mangrove sediments and beach deposits in Micronesia have also conflicted. Here, BLOOM (1970) suggests that mangrove facies show a rising sea-level since 6 ka; yet SCHOFIELD (1977), using beach deposits, suggests sea-level has fallen over this time.

While differences exist between the interpretations of Holocene sea-level histories based upon the Fog Bay and South Alligator River deposits, raised marine deposits at Cobourg Peninsula (WOODROFFE *et al.*, 1992) and Karumba in the Gulf of Carpentaria (RHODES *et al.*, 1980) do confirm that relative sea-level has been higher than present along the north Australian margin during the Holocene. Here the similarities between the evidence at Fog Bay and these two latter sites ends; Fog Bay is at present the only site along the north Australian coast that suggests that higher sea-levels occurred in this region during the late Holocene. This is not the case, however, along the east coast of Australia. While much debate on this topic has occurred over the last two decades (THOM *et al.*, 1969; GILL and HOPLEY, 1972; THOM *et al.*, 1972; BELPERIO, 1979; HOPLEY, 1980), recent detailed investigations along the southeast Australian margin have uncovered evidence in favour of raised late Holocene sea-levels in this region. FLOOD and FRANKEL (1989) have shown, for example, that based upon the relative elevation and ages of calcareous tube worms and barnacles on the north coast of New South Wales, sea-level here was more than 1 m higher than present between 3.42 ka and 1.8 ka. Likewise, BRYANT *et al.* (1992), in a detailed examination of a variety of forms of evidence along the Illawarra coast of southern New South Wales, concluded that sea-levels were between 1–2 m higher

between 6 ka and 1.5 ka. Nearby, in the Minnamurra estuary, JONES (1990) showed from palynological evidence that sea-level was 0.8–2.3 m above present until 2.5 ka. Furthermore, evidence supportive of higher late Holocene sea-levels has also been reported from the southern Australian margin (GILL and HOPLEY, 1972) and the Pacific region (PIRAZZOLI *et al.,* 1988).

The recognition of evidence indicative of higher Pleistocene and Holocene sea-levels along the northern Australian margin also has implications for recent suggestions that the northern Australian margin has been subsiding due to continental flexure during the late Quaternary (MURRAY-WALLACE and BELPERIO, 1991; BRYANT, 1992). Using trend surface analysis, BRYANT (1992) analysed the available data on Pleistocene and Holocene sea-level maxima from around the Australian continent. Based upon the assumption that there was a ubiquitous Last Interglacial sea-level high of between 4–6 m BRYANT (1992) concluded that northern Australia, and in particular the Gulf of Carpentaria, has been sinking at a maximum rate of 0.032 mm $yr^{-1}$ since approximately 125 ka. This amounts to a maximum of ~3.2 m of subsidence in the 'Gulf' since the last interglacial. If the Last Interglacial sea-levels in this region were 6 m above present, the height of Rosie Reef at +3 m above the limit of present coral growth broadly fits with BRYANT'S conclusions. However, given that the crest of Rosie Reef has clearly been eroded, its present height of +3 m must be taken as a minimum value of its original elevation above modern sea-level. It is likely therefore that this region may not have subsided to the extent that BRYANT predicted based upon the limited information available at the time. It should also be pointed out, however, that BRYANT'S model was designed only to highlight and predict a trend, and the rates of subsidence, and therefore the predicted elevations of paleosea-level datum, are generalised figures.

## CONCLUSION

Late Pleistocene sea-level in the Gulf of Carpentaria can now be shown to have reached elevations significantly higher than present, and equivalent to the level of the Last Interglacial sea-levels throughout wide parts of southern and southeastern Australia. The recognition of this evidence suggests that this section of the north Australian margin may be tectonically stable or at least have subsided less than previously thought. Holocene sea-levels also appear to have been significantly higher in the Darwin region; however, unlike the limited evidence elsewhere along the north Australian coast, the evidence reported here suggests that sea-level in this region did not fall to its present position until after 2 ka.

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