NEW EVIDENCE FOR THE HOLOCENE SEA-LEVEL HIGH FROM THE INNER SHELF, CENTRAL GREAT BARRIER REEF, AUSTRALIA

R. BEAMAN, P. LARCOMBE, AND R.M. CARTER
Marine Geophysical Laboratory, Geology Department, James Cook University, Townsville 4811, Australia

ABSTRACT: **Radiocarbon dates from fossil oyster beds of intertidal origin on Magnetic Island, north Queensland indicate that the local Holocene maximum of relative sea level was attained no later than 5660 ± 50 B.P. (conventional uncorrected age) and remained at 1.6-1.7 m above modern levels until 4040 ± 50 B.P. Given the tectonic stability of the area, this implies that eustatic sea level remained at its Holocene peak for at least ca. 1600 yr. The new high-precision sea-level data indicate sea levels 1-5 m higher than those of the same age inferred from buried mangrove deposits on the inner shelf in north Queensland. Uncertainties in deriving relative sea level from such mangrove deposits may be a significant source of error in worldwide attempts to distinguish the eustatic and crustal warping components of relative sea-level change, especially in the tropics.**

INTRODUCTION

There is wide interest in the nature of sea-level change since the late Pleistocene sea-level minimum. One important aspect of the problem is the timing, elevation, and duration of the Holocene sea-level high (e.g., Devoy 1987; National Research Council 1990). The Great Barrier Reef (GBR) continental margin of northeast Australia is an important region for such sea-level studies, because of its tectonic stability and because of the presence of a wide variety of indicators of relative sea level. Most interest has been directed upon the last 8–10 ky B.P., i.e., since the shelf was inundated. The existence of a sea-level high along the central coast of the Great Barrier Reef shelf in mid-Holocene times (ca. 7–6 ky B.P.) has been argued by several workers, although the timing, duration, and magnitude of peak sea level remains under debate (Hopley 1983b; Flood 1984).

It has been suggested that there is regional variation in the magnitude of the proposed high in relative sea level (Hopley 1978, 1983b) with, near Townsville, evidence for Holocene sea levels of up to +4.9 m (Hopley 1975, 1978). These high levels were based on cemented deposits, and were criticized by Belperio (1979), who noted that the elevated intertidal sedimentary deposits that would be consistent with this interpretation are absent from the Townsville coastal plain. Later, it was recognized that the cemented deposits were more closely related to the highest tidal levels rather than mean sea level (Hopley 1983b), and the interpreted sea levels were at least 1 m too high. More recent studies of fossil micro-atolls, which indicate a precise paleo-intertidal level, support a peak postglacial sea level of less than 2 m above present levels (Chappell et al. 1982, 1983; Hopley 1983b). Modeling studies have also predicted a similar peak elevation for the northern GBR and Townsville area (Nakiboglu et al. 1983; Lambeck and Nakada 1990). The central GBR has been tectonically quiet since at least 13 ky B.P. (Day et al. 1983). There is no evidence for local tectonic movements since 5.5 ky B.P. between areas from Princess Charlotte Bay and Bowen, although there may have been minor hydro-isostatic warping and subsidence (< 3 m) normal to the coastline across the shelf since 6 ky B.P. (Chappell et al. 1982, 1983). Differential flexing along the inner shelf has been probably less than 1 m.

We present evidence consistent with a peak Holocene sea level of less than 2 m above the present level, and conclude that this peak at Magnetic Island was 1.65 m above modern mean sea level. We also show that this peak sea level was maintained for at least ca. 1600 years, rather than gradually falling immediately after reaching the peak, as has previously been assumed. Following this extended stillstand, relative sea level apparently fell rapidly to the modern levels, probably as a result of some combination of hydro-isostatic and eustatic control.

SITE DESCRIPTION

Balding Bay is a north-facing bay on the northeastern side of Magnetic Island, off Townsville (19°6.7'S, 146°52.2'E) (Fig. 1). On its eastern side are large weathered granite boulders, ca. 15 m high and formed by erosion along crosscutting vertical joints, some of which have been eroded to form fissures and caves. A well-formed fossil oyster bed, 1-2 m high and 20 m long, is present on the vertical walls of one fissure (left fissure in Figure 2, and also see Figure 3). Beds of this nature were first noted by Smith (1978). The oyster bed is also present at a similar elevation on both walls of an adjacent cave (right of Figure 2), the base of which is not a discrete block and is almost certainly *in situ.* Therefore we are confident that the blocks have not moved since deposition of the oyster bed.

The incrustation in the main fissure comprises *Saccostrea cucculata* and is 15 cm thick at its top, tapering downwards to < 1 cm thick at its base (enhanced in Figure 2 for clarity). *Saccostrea* also dominates the nearby modern oyster zone, the topmost living individuals of which are at the base of the fissure, some 2 m below the top of the fossil oyster zone. Cemented within or completely covering the fossil oysters are several species of barnacles. The fossil barnacles are dominantly *Octomeris brunnea* and *Tetraclitela* sp., which live in sheltered locations such as fissures, whereas the dominant nearby modern species is *Chthamalus malayensis,* which prefers exposed positions.

In northern Queensland, *Saccostrea* form distinctive shell beds in the intertidal zone between mean high-water neaps and mean sea level (Endean et al. 1956). According to the frequency emersion curve for Townsville (Kenny 1979), *Saccostrea* would be submerged 34–50% of the year. *Tetraclitella* belongs to an intertidal family, for which there are also a few known examples of very shallow sublittoral occurrence (Foster 1987). At Balding Bay, the upper limit of the modern oyster bed (which also approximates the level of the highest living oyster) lies at +0.4 m AHD (Australian Height Datum, which in the Townsville area is equivalent to mean sea level). The modern and ancient oyster beds are thus preserved directly adjacent to each other in a vertical sense, with only slight overlap. There is therefore no doubt that the beds are equivalent sea-level indicators. Intertidal zonation of some barnacles and other organisms is dependent upon exposure to waves (Moore 1966), and because fossil organisms at levels intermediate between the ancient and modern oyster bed occupy relatively gently sloping positions, their elevation is less directly comparable to the modern zonation.

Elevation data were measured using a standard level, leveling the oyster beds to sea level during calm conditions when sea level could be established accurately. Data were then reduced to AHD using the sea-level record from a permanent tide gauge near Cape Cleveland (Fig. 1), which has a maximum difference in sea level compared to the study site of less than 2–5 cm (Mason et al. 1991). We estimate that the error in determining sample elevation is ± 0.05 m and the error in indicating ancient sea level is less than ± 0.15 m.

Radiocarbon Dates

Five samples of the incrustation have been radiocarbon dated at the Radiocarbon Dating Laboratory, University of Waikato (Table 1). The

JOURNAL OF SEDIMENTARY RESEARCH, VOL. A64, NO. 4, OCTOBER, 1994, P. 881–885
1073-130X/94/0A64-881/$03.00

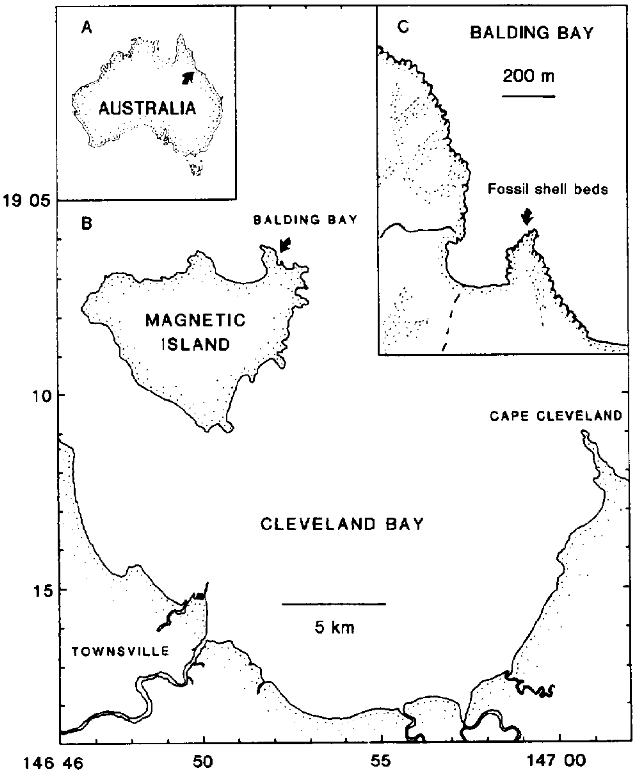

Fig. 1.—Location of A) Cleveland Bay, Townsville, northeastern Australia; B) Balding Bay, Magnetic Island; C) fossil shell beds in Balding Bay. Tide-gauge data were obtained from a gauge 10 km SSE of Cape Cleveland.

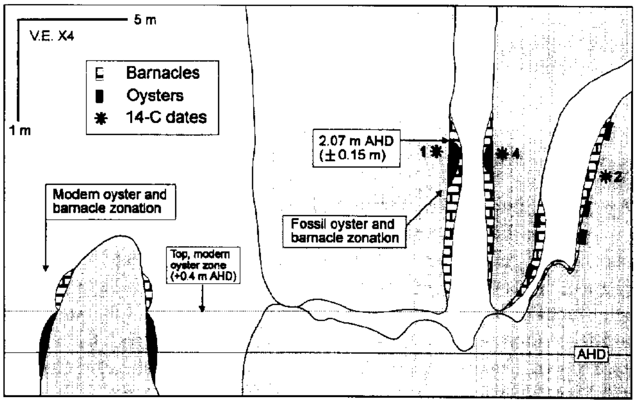

Fig. 2.—Cross section through granite blocks and fissures at Balding Bay, showing distribution of modern and fossil biological zones, sample locations, and their relationship to sea level (AHD). The thickness of the oyster beds has been enhanced for clarity. "Top, modern oyster zone" marks the sharply defined top of the living oyster bed, which also approximates the level of the highest living oyster.

location and nature of the dated samples are given in Figure 2 and Table 1. Samples BBAY1a–1c are 25 mm lengths from a horizontal core of 60 mm diameter taken through the upper part of the fossil oyster zone, and represent the outer (younger), central, and inner parts, respectively of the fossil oyster bed. Sample BBAY4 was collected from the facing wall from a smaller fossil oyster bed. Sample BBAY2 comprised fossil barnacles from an adjacent undercut cave.

All samples were in excellent condition, lacking marine boring and with no evidence of dissolution or of recrystallization of calcite. Some interstitial aluminosilicate alteration products were present in the incrustation, but these were excluded during acid digestion of the carbonate and would therefore have not influenced the date obtained. Samples BBAY1a, 2, and 4 had a light surface stain of green lichen, which was removed before analysis. Contamination of the samples is thus unlikely, and we have a high degree of confidence in the radiocarbon dates presented. In the text, we quote conventional uncorrected dates unless otherwise stated. Table 1 gives uncorrected data and data corrected using the marine correction of −450 ± 35 yr for northeastern Australia (Gillespie and Polach 1979).

DISCUSSION

The Peak Sea Level Attained

Various sea-level curves for eastern and northeastern Australia suggest that sea level reached and passed upwards through its modern level between 6.5 and 6 ky B.P. (Thom and Chappell 1975; Belperio 1979; Hopley et al. 1983; Thom and Roy 1983; Grindrod and Rhodes 1984; Carter et al. 1986; Crowley et al. 1990) rising rapidly to the Holocene highstand. For the northern Great Barrier Reef (GBR) shelf, Chappell et al. (1983) assumed that sea level then fell gradually and linearly after ca. 6 ky B.P. towards modern levels, and that there were no secondary oscillations in sea level during that period. Minor regional variation in Holocene sea levels has been attributed to hydro-isostatic movement (Chappell et al. 1982, 1983), except for the Halifax Basin (the mid- and outer shelf off Townsville), where additional tectonic subsidence may have occurred (Hopley 1983a).

Despite these earlier data, there remains uncertainty about the elevation and timing of the peak Holocene sea level attained in the Townsville area. Hopley and Thom (1983) summarized the evidence for mid-Holocene sea levels higher than present near Townsville, suggesting that sea level peaked at 1.0–3.9 m above modern mean sea level at 6000–4500 C^{14} yr B.P. (Belperio 1979; Hopley 1971, 1978, 1983a; Chappell et al. 1983). The strongest local evidence to date is that of Chappell et al. (1983), who sampled dead micro-atolls on the modern reef flats of Magnetic Island and presented data extending back to 6375 B.P. However, there is a lack of data that allow the exact timing of peak sea level to be pinpointed, because few studies have addressed this issue with high-resolution data.

Populations of living micro-atolls generally have a range of vertical

Fig. 3.—Photograph showing the extent of the fossil oyster bed along the fissure wall. The top of the oyster bed is clearly delineated (O). Shelly material above this line consists entirely of fossil barnacles (B). The hammer is 32 cm long.

TABLE 1.—*Radiocarbon data, Balding Bay, Magnetic Island, Inner Shelf, Great Barrier Reef shelf**

Sample Name		Location	C^{14} age (conv.)	C^{14} age (corr.)	Elevation (m AHD)
Fossil Oysters—*Saccostrea cucculata*:					
Wk-2917	BBAY1a	Outermost oyster bed	4040 ± 50	3590 ± 61	+2.07
Wk-2918	BBAY1b	Central oyster bed	4600 ± 60	4150 ± 69	+2.07
Wk-2919	BBAY1c	Innermost oyster bed	5660 ± 50	5210 ± 61	+2.07
Wk-2921	BBAY4	Facing wall	5010 ± 50	4560 ± 61	+2.07
Fossil Barnacles—*Octomeris brunnea* & *Tetraclitela* sp.:					
Wk-2920	BBAY2	Adjacent cave	5000 ± 60	4550 ± 69	+1.8

* Notes: 1) The marine correction for N.E. Australia is −450 ± 35 years (Gillespie and Polach 1979); 2) The top of the modern oyster bed lies at +0.4 m AHD, thus mean Holocene sea level was ~0.4 m below sample elevation. Elevation errors are ± 0.05 m.

elevations of ca. 0.1 m (Chappell et al. 1983), limited in elevation above the local low-water spring tide. Thus ancient micro-atolls represent a minimum elevation of low-water spring tide (LWST). There are two further reasons why micro-atoll data represent a minimum tidal level. The oldest micro-atolls dated by Chappell et al.(1983) were located very close to the landward edge of the modern reef flats, near the highest point of the reef flat (Chappell et al. 1983, their fig. 3). It follows that for the peak in sea level, the micro-atoll data indicate a minimum elevation of LWST because:

(1) Formation of higher micro-atolls may not have been prevented by a tidal level, but by a lack of suitable sites for coral growth close to the coastal sediments behind each reef flat, and/or

(2) Higher micro-atolls may have developed, but are now buried under adjacent coastal sediments, which, in the case of the Magnetic Island reef flats sampled by Chappell et al. (1983), are alluvial and beach/beach-ridge sands. Emerged microatolls have been found beneath beach rock (Hopley et al. 1983), and there are other examples of Holocene reef burial by coastal sediments, including burial under organic mangrove muds (Spenceley 1977) and beach/beach-ridge sands (Johnson and Carter 1987). The overlying sediments are of late Holocene and modern age, and at Cape Tribulation, the highest parts of the buried reef-top unit are nearly 1 m above AHD (Johnson and Carter 1987).

Figure 4 presents sea-level data derived from radiocarbon-dated sea-level indicators from the inner shelf near Townsville. Data points indicate ancient mean sea level as derived from the present relationships of living oyster beds (this paper) and mangrove facies (Spenceley 1977, 1980; Belperio 1978, 1979) to sea level. The microatoll data (Chappell et al. 1983) indicate minimum elevation of LWST. In addition to the new data reported herein, Figure 4 incorporates the micro-atoll data of Chappell et al. (1983) and sea levels derived from buried mangrove muds (or wood fragments within mangrove muds) near Townsville, including unpublished data, and published data of Spenceley (1980) and Belperio (1978). The data point at 1.1 m at 700 B.P. is derived from an exposed *in situ Ceriops* root (Spenceley 1980) on the west coast of Magnetic Island, where modern *Ceriops* trees live at an elevation of + 1.5 ± 0.2 m AHD (Spenceley 1980).

When converted to mean sea level, the data reported by Chappell et al. (1983) are consistent with a Holocene sea-level peak of at least 1–1.4 m AHD (Fig. 4). The oyster-bed data reported herein indicate unequivocally that mid-Holocene mean sea level at Magnetic Island peaked at 1.65 m above AHD. There are no fossil oysters and only scattered fossil barnacles for a few decimeters above this level, which suggests that the top of the fossil oyster bed accurately marks the maximum sea level attained. The shape of the oyster bed (i.e., increased thickness at its top) is similar to its modern counterpart, and is therefore presumably consistent with sea level having remained at its peak for a significant period of time. The dated age difference of ca. 1600 yr between the inner and outer layers of the uppermost fossil oyster zone indicates that peak sea level was maintained for that interval.

The Timing of Sea-Level Fall

The Magnetic Island fossil oyster evidence suggests that sea level did not begin to fall from its peak until after 4040 ± 50 B.P. The data also suggest that significant post-4040 B.P. sea-level stillstands did not occur, because—had they occurred—they should have produced a thicker growth of oysters at other levels. The tapering thickness of the oyster bed down the fissure walls is consistent with a gradual fall (rather than an episodic one) towards the modern level, which was too fast to allow significant colonization of the fissure wall by oysters; the higher barnacle zone successively overgrew stranded oysters. The continuous nature of the barnacles also argues against a tectonic event having produced abrupt crustal uplift. Gradual fall is consistent with the assumption of Chappell et al. (1983) of gradual and smooth sea-level fall, and consequently, we have drawn a sea-level envelope that falls smoothly to modern levels after 4040 B.P. (Fig. 4). It cannot be ruled out, however, that the rate of fall in sea level may have been faster than shown, or that small (< 0.5 m) variations in sea level have occurred in the last 3000 years. The *Ceriops* data point at ca. 700 B.P. may imply a slightly higher sea level then than at present, but the sea-level curve indicated is not inconsistent with this data point given its large elevation error bar.

That sea level was maintained at its peak for ca. 1600 years contrasts with the conclusion of Chappell et al. (1983) who suggested that sea level began to fall at ca. 6000 B.P. However, their data, based on fossil microatolls, represent minimum tidal elevations and are thus consistent with our results. Further, the inferred larger fall of 1.65 m is still in agreement with the theoretical map of hydro-isostatic downwarping since 5500 B.P. presented by Chappell et al. (1982) if extended southwards. Our data indicate that the predicted sea-level curve of Lambeck and Nakada (1990) overestimates the Holocene peak sea level at Townsville by ca. 0.6 m, but otherwise appears a reasonable approximation to sea-level change for the mid- and late Holocene. It is also noteworthy that in northern New South Wales sea level was ca. 1 m above present levels as recently as 3420 B.P. (Flood and Frankel 1989), and more recent work puts sea level > 1 m above modern levels up until 1520 ± 120 B.P. for the central New South Wales coast (Bryant et al. 1992). The precise nature of the late Holocene sea-level fall needs further study.

The Suitability of Mangrove Muds for Derivation of Ancient Sea Levels

The interpreted sea levels from mangrove muds are consistently lower than those derived from oyster and micro-atoll data (Fig. 4). The presence of significant compaction or subsidence beneath Holocene strata has previously been rejected by Belperio (1979) because stratal elevations were similar, irrespective of whether their basement was deltaic or granitic. In contrast, our data suggest a need to correct buried mangrove material by between 1 m and 5 m upwards, as discussed in more detail below.

Compaction and Preferential Preservation.—The above difference might be explained by compaction within the Holocene sequence and/or by a tendency for muds deposited on mid-tide mangrove mudflats to be preferentially preserved in the geological record (and thus sampled) compared to mangrove muds deposited on high-tide mangrove flats. The Holocene coastal succession at Townsville is generally less than 5 m thick (Carter et al. 1993) and is unlikely to have caused compaction of more than 1 m. Further, the vertical range of modern mangrove muds in the Townsville area is 1.5 m (between 0 m and + 1.5 m AHD; Belperio 1979), so in the worst case of all mangrove samples having been derived from the base of the mangrove mud sequence, the error in sea level derived from core material would reach only 1.5 ± 1.5 m.

Contamination and Reworking.—A further possibility that might contribute to the observed discrepancies is the potential for a systematic difference in radiocarbon dates obtained from mangroves compared to coexistent corals or carbonate shells. If rootlets have penetrated the sample from above, the date may become too young. For the data presented here, if the dates are too young, the requirement would be that the mangrove dates are up to 1500 yr too young, which would help explain the older mangrove data (in the left of Figure 4). However, no intrusion of rootlets was observed in the dated material, and further, this would not explain those mangrove sediments, which date younger than 2 ky B.P. Mangrove deposits also have the potential to be reworked, so that a final deposit may contain a mixture of contemporary and older organic material (Bloom 1980), which may cause dates to be too old. This explanation does not fit our data. Finally, reworking within a mangrove environment may also reduce the elevation of material. However, assuming that final deposition happened within the elevation range normally occupied by mangrove facies, this possibility is accounted for in the error bars.

Coring Effects.—Core shortening caused by the vibracoring process used to collect the mangrove samples cannot explain the discrepancy, because all elevations were corrected to the sea-bed elevation, and compacted sediments would thus be shifted upwards, reducing the discrepancy rather than increasing it. James Cook University vibracores are at most 5 m long, and shortening of up to 20% would produce a maximum error of only 1 m in reduced elevation. Expansion of a core upon retrieval beyond its buried length would produce a downward shift of data, but expansion effects have been found to be negligible or absent.

From the above, it is evident that none of the effects discussed can alone explain the 1–5 m discrepancy between the mangrove and the oyster-bed data. Therefore a combination of these factors, and perhaps other effects, is probably responsible. It is pertinent to note that the sea level indicated by the *in situ* and unburied *Ceriops* root (Fig. 4), which is consistent with microatoll and oyster-bed data, does not need correction, because compaction would be negligible.

Resolution of Sea Level

The apparently inaccurate nature of sea-level information derived from mangrove muds has significant implications for the conclusions reached by past workers who have used such material to examine the nature of Holocene coastal development in relation to sea-level rise along the central GBR shelf coastline (e.g., Crowley et al. 1990; Grindrod and Rhodes 1984; Carter et al. 1993) and elsewhere (Woodroffe 1988, 1990; Ellison 1993). Our present understanding of eustatic sea-level changes and crustal warping derives from integrated use of hydro-isostatic modeling of the northeast Australian continental margin together with a wide range of Holocene sea-level information (Chappell et al. 1982; Nakiboglu et al. 1983; Lambeck and Nakada 1990). Off Townsville, sea-level rise caused the shoreline to retreat rapidly during the early Holocene, leading to drowning of coastal sediments, including extensive mangrove facies (Carter et al. 1993). With subsequent shoreline progradation and the onset of marine sedimentation, these facies were buried beneath inner-shelf deposits up to 4 m thick. We have concluded above that these processes probably produced erosion of the higher parts of the mangrove muds, and compaction, which together result in a significant underestimate of sea level. However, the extent of this discrepancy varies depending upon how much erosion occurred, the geotechnical nature of the deposit, and the overburden of the sediment column since deposition. Further, it is pertinent to note an additional source of uncertainty. Bunt et al. (1985) found that erosion, accretion, or other disturbance may cause variation of the order of 1 m in the elevation of a living mangrove species or community.

The magnitude of the factors described above varies greatly according to the particular set of coastal processes that have operated in an area, and unless these can be determined, there will be significant uncertainty in determining relative sea level from intertidal mangrove sediments. These uncertainties will persist during attempts to distinguish eustatic sea-level fluctuations from crustal warping.

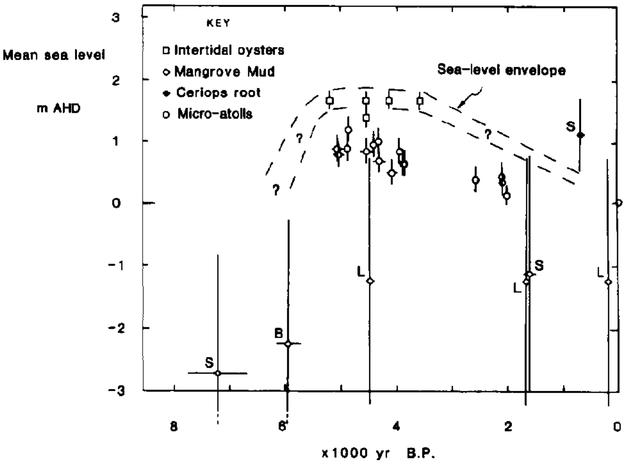

FIG. 4.—Interpreted sea-level envelope for Magnetic Island, inner shelf of the central Great Barrier Reef shelf, using: Balding Bay oyster data (squares); Chappell et al. (1983) micro-atoll data from Magnetic, Great Palm, Orpheus, and Fantome Islands (circles); data of Spenceley (1980) (S), Belperio (1978) (B), and Larcombe et al. (unpublished) (L) (diamonds). Data points represent corrected conventional radiocarbon age and derived mean sea level, except for the data of Chappell et al., which represent *minimum* mean sea level. Horizontal error bars represent quoted errors in radiocarbon dates. The size of the vertical error bars includes surveying errors, the vertical spread of equivalent modern sea-level indicators, and tidal corrections. Compaction is not included.

CONCLUSIONS

(1) Radiocarbon dating of a fossil oyster bed indicates that relative sea level in the Townsville area peaked at 1.65 m above present mean sea level at 5660 ± 50 B.P. (conventional uncorrected age). This sea level was maintained until 4040 ± 50 B.P., when either tectonic or eustatic effects reduced relative sea level rapidly towards modern levels.

(2) Ancient sea levels derived from buried Holocene mangrove muds in north Queensland may require between 1 m and 5 m of upward correction. Similar corrections may be necessary for other areas where muddy Holocene facies have been deposited under similar conditions of sea-level change and sediment supply.

ACKNOWLEDGMENTS

Jo Goudie is thanked for the loan of her diamond drill-bit, and Arnstein Prytz assisted in drafting Figure 1. Robert A. Morton, Jeffrey G. Paine, and David Hopley are thanked for their critical reviews.

REFERENCES

BELPERIO, A.P., 1978, An inner-shelf sedimentation model for the Townsville region, Great Barrier Reef province [unpublished Ph.D. thesis]: James Cook University, Townsville, Australia, 210 p.

BELPERIO, A.P., 1979, Negative evidence for a mid-Holocene high sea level along the coastal plain of the Great Barrier Reef province: Marine Geology, v. 32, p. M1–M9.

BLOOM, A.L., 1980, Late-Quaternary sea-level change on South Pacific coasts: a study in tectonic diversity, *in* Morner, N.-A., ed., Earth Rheology, Isostasy and Eustacy: London, Wiley, p. 505–516.

BRYANT, E.A., YOUNG, R.W., PRICE, D.M., AND SHORT, S.A., 1992, Evidence for Pleistocene and Holocene raised marine deposits, Sandon point, New South Wales: Australian Journal of Earth Sciences, v. 39, p. 481–493.

BUNT, J.S., WILLIAMS, W.T., AND BUNT, E.D., 1985, Mangrove species distribution in relation to tide at the seafront and up rivers: Australian Journal of Marine and Freshwater Research, v. 36, p. 481–492.

Carter, R.M., Carter, L., and Johnson, D.P., 1986, Submergent shorelines in the SW Pacific: evidence for an episodic post glacial transgression: Sedimentology, v. 33, p. 629–649.

Carter, R.M., Johnson, D.P., and Hooper, K.G., 1993, Episodic post glacial sea-level rise and the sedimentary evolution of a tropical continental embayment (Cleveland Bay, Great Barrier Reef shelf, Australia): Australian Journal of Earth Sciences, v. 40, p. 229–255.

Chappell, J., Chivas, A., Wallensky, E., Polach, H.A., and Aharon, P., 1983, Holocene palaeoenvironmental changes, central to north Great Barrier Reef inner zone: Australia, Bureau of Mineral Resources, Journal of Australian Geology and Geophysics, v. 8, p. 223–235.

Chappell, J., Rhodes, E.G., Thom, B.G., and Wallensky, E., 1982, Hydro-isostacy and the sea-level isobase of 5500 B.P. in north Queensland, Australia: Marine Geology, v. 49, p. 81–90.

Crowley, G.M., Anderson, P., Kershaw, A.P., and Grindrod, J., 1990, Palynology of a Holocene marine transgressive sequence, lower Mulgrave River valley, north-east Queensland: Australian Journal of Ecology, v. 15, p. 231–240.

Day, R.W., Whitaker, W.G., Murray, C.G., Wilson, I.H., and Grimes, K.G., 1983, Queensland Geology: a companion to the 1:2500,000 scale geological map (1975): Geological Survey of Queensland, Publication 383, 194 p.

Devoy, R.J.N., 1987, ed., Sea Surface Studies: A Global View: Beckenham, Croom-Helm, 649 p.

Ellison, J.C., 1993, Mangrove retreat with rising sea level, Bermuda: Estuarine, Coastal and Shelf Science, v. 37, p. 75–87.

Endean, P., Stephenson, W., and Kenny, R., 1956, The ecology and distribution of intertidal organisms on certain islands off the Queensland coast: Australian Journal of Marine and Freshwater Research., v. 7, p. 317–342.

Flood, P.G., 1984, A geological guide to the northern Great Barrier Reef: Australian Sedimentologists Group Field Guide No. 1, Geological Society of Australia, 100 p.

Flood, P.G., and Frankel, E., 1989, Late Holocene higher sea-level indicators from eastern Australia: Marine Geology, v. 90, p. 193–195.

Foster, B.A., 1987, Barnacle ecology and adaptation, *in* Southward, A.J., ed., Barnacle Biology, Crustacean Issues, 5: Rotterdam, A.A. Balkema, p. 113–133.

Gillespie, R., and Polach, H.A., 1979, The suitability of marine shells for radiocarbon dating of Australian prehistory, *in* Berger, R. and Suess, H., eds., Proceedings of the Ninth International Conference on Radiocarbon Dating, p. 404–421.

Grindrod, J., and Rhodes, E.G., 1984, Holocene sea-level history of a tropical estuary: Missionary Bay, north Queensland, *in* Thom, B.G., ed., Coastal Geomorphology in Australia: North Ryde, Australia, Academic Press, p. 151–178.

Hopley, D., 1971, The origin and significance of North Queensland island spits: Zeitschrift für Geomorphologie, v. 15, p. 371–389.

Hopley, D., 1975, Contrasting evidence for Holocene sea levels with special reference to the Bowen-Whitsunday area, Queensland, *in* Douglas, I., Hobbs, J.E., and Pigram, J.J., eds., Geographical Essays in Honour of Gilbert J. Butland: University of New England, Armidale, Australia, p. 51–84.

Hopley, D., 1978, Sea-level changes on the Great Barrier Reef: an introduction: Royal Society (London) Philosophical Transactions, Series A, v. 291, p. 159–166.

Hopley, D., 1983a, ed., Australian sea-levels in the last 15000 years: a review: James Cook University, Townsville, Australia, Department of Geography, Monograph Series, Occasional Paper No. 3.

Hopley, D., 1983b, Evidence of 15000 years of sea-level change in tropical Queensland, *in* Hopley, D., ed., Australian Sea Levels in the Last 15000 years: A Review: James Cook University, Townsville, Australia, Department of Geography, Monograph Series, Occasional Paper No. 3, p. 93–104.

Hopley, D., and Thom, B.G., 1983, Australian sea levels in the last 15000 years: an introductory review, *in* Hopley, D. and Thom, B.G., eds., Australian Sea Levels in the Last 15000 years: A Review: James Cook University, Townsville, Australia, Department of Geography, Monograph Series, Occasional Paper No. 3, p. 3–26.

Hopley, D., Slocombe, A.M., Muir, F., and Grant, C., 1983, Nearshore fringing reefs in north Queensland: Coral Reefs, v. 1, p. 151-160.

Johnson, D.P., and Carter, R.M., 1987, Sedimentary framework of mainland fringing reef development, Cape Tribulation Area, Great Barrier Reef, Australia: Great Barrier Reef Marine Park Authority, Technical Memorandum 14, 37 p.

Kenny, R., 1979, Predicted, actual and effective tidal emersion at Townsville: Royal Society of Queensland Proceedings, v. 90, p. 113–116.

Lambeck, K., and Nakada, M., 1990, Late Pleistocene and Holocene sea-level change along the Australian coast: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 89, 143–176.

Mason, L.B., Bode, L., and Hardy, T.A., 1991, Numerical modelling of tidal and wind-driven circulation in Cleveland Bay: James Cook University, Townsville, Australia, Marine Modelling Unit, 17 p.

Moore, H.B., 1966, Marine Ecology: New York, Wiley, 420 p.

Nakiboglu, S.M., Lambeck, K., and Aharon, P., 1983, Postglacial sea levels in the Pacific: implications with respect to deglaciation regime and local tectonics: Tectonophysics, v. 91, p. 335–358.

National Research Council, 1990, Sea-level Changes: National Research Council, Geophysics Study Committee, Committee on Physical Sciences, Mathematics and Resources, Washington, D.C., National Academy Press, 227 p.

Smith, A., 1978, Case study: Magnetic Island and its fringing reefs, *in* Hopley, D., ed., Geographical Studies of the Townsville Area: James Cook University, Townsville, Australia, Department of Geography, Monograph Series, Occasional Paper No. 2, p. 59–64.

Spenceley, A.P., 1977, The role of pneumatophores in sedimentary processes: Marine Geology, v. 24, p. M31–M37.

Spenceley, A.P., 1980, The geomorphological and zonational development of mangrove swamps in the Townsville area, north Queensland [unpublished Ph.D. thesis]: James Cook University, Townsville, Australia, 168 p.

Thom, B.G., and Chappell, J., 1975, Holocene sea levels relative to Australia: Search, v. 6, p. 90–93.

Thom, B.G., and Roy, P.S., 1983, Sea-level change in New South Wales over the past 15,000 years, *in* Hopley, D., and Thom, B.G., eds., Australian Sea Levels in the Last 15000 years: A Review: James Cook University, Townsville, Australia, Department of Geography, Monograph Series, Occasional Paper No. 3, p. 64–84.

Woodroffe, C.D., 1988, Mangroves and sedimentation in reef environments: indicators of past sea-level changes, and present sea-level trends? Proceedings of the 6th International Coral Reef Symposium, Australia, Vol. 3, p. 535–539.

Woodroffe, C.D., 1990, The impact of sea-level rise on mangrove shorelines: Progress in Physical Geography, v. 14, p. 483–520.

Received 21 October 1993; accepted 17 March 1994.