Coral Microatolls and a Low-resolution Record of Sea-level Changes

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Corals are particularly useful indicators of sea level over a range of time scales. Most corals grow in shallow water and radiometric dates, even if they are on corals that are in their growth position, are indicative, rather than definitive, of sea-level position. Coral microatolls are disc-shaped corals that have grown into the intertidal zone and whose lateral growth has been limited by exposure at low tide. Microatolls are living on their outer margin but are predominantly dead on their upper surface. Microatolls in their growth position are fixed biological sea-level indicators and can be used to indicate previous limits to coral growth. The upper surface of these individual coral colonies track sea level and provide low-resolution records of interannual sea-level variations at decadal to millennial scale that have been used for detailed reconstructions of Holocene sea level in those parts of the Indo-Pacific region which experienced a mid-Holocene sea-level highstand.

Microatolls were first described from the Cocos (Keeling) Islands by Guppy (1889), who initially termed them minature atolls. The geographical variation in microatolls around the Cocos (Keeling) Islands has been mapped in detail by Smithers and Woodroffe (2000), and it has been shown that fields of microatolls occur in three different habitats: on reef flats, in inter-island passages, and in the lagoon. Microatolls have played an important role in deciphering the pattern of mid- and late Holocene sea-level change, and a comparison of the elevation of radiocarbon-dated fossil microatolls with their living counterparts indicates that the sea was higher relative to Cocos around 3000 years ago (Figure 1).

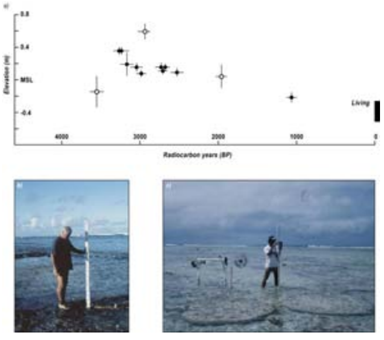

Figure 1. a) Age-height relationship based on radiocarbon dating of fossil microatolls (b), from the Cocos (Keeling) Islands and their relationship to modern microatolls (c), (after Woodroffe, 2005).

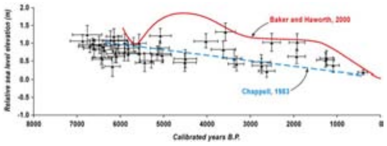

Figure 2. Sea-level interpretations from northern Queensland based on microatolls (Lewis et al., in prep.).

Microatoll morphology has been described from the northern Great Barrier Reef (Scoffin and Stoddart, 1978) where microatolls have been used to constrain former sea levels (Figure 2). Whereas Chappell (1983) inferred a gradual fall in sea level over the past 6000 years, more recently Holocene oscillations have been inferred (Larcombe et al., 1995), based on fixed biological indicators, primarily worm tubes, from along the NSW coast (Baker and Haworth, 2000).

Individual living microatoll colonies can be up to several metres in diameter. Microatolls grow up to a level close to mean low tide and are constrained by water level during their growth, so that a low-resolution water-level history is contained within the upper surface of the coral. Annual growth bands can be detected using X-radiography or fluorescence. The banding within microatolls confirms that growth has been primarily lateral and also indicates periods during which the limit to coral growth has been temporarily raised or lowered, as undulations on the upper surface of the colony. Two of the larger living specimens, F2 (Figure 1c) and PP30, have been sampled from Cocos, containing a low-resolution sea-level history for most of the 20th century (Smithers and Woodroffe, 2001). The two corals show good synchronous correlation indicating undulations of sea-level (a, b, c and d), and a pronounced hiatus occurring around 1982 (e), that appears related to El Niño in that year. Average rate of sea-level rise of ~0.35 mm a^{-1} is indicated over the past century, with broad fluctuations of sea level of about 20 years length and of 5-10 cm amplitude (Figure 3).

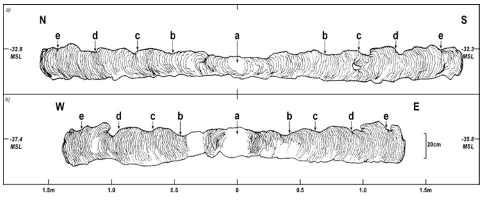

Figure 3. Schematic sclerochronology of F2 and PP30 Porites microatolls from Cocos for most of the 20th century.

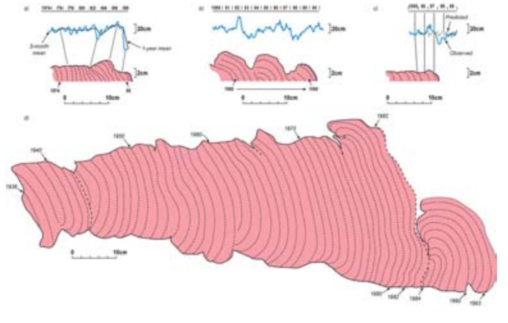

Figure 4. Examples of coral banding patterns that record water-level fluctuations associated with ENSO in the Pacific; (a) Abemama, (b) Christmas Island, (c) Abaiang, and (d) Tongareva.

El Niño is a major control on the ocean surface in the central Pacific Ocean. Undulations on the top of microatolls from the central Pacific Ocean have been shown to track, but lag behind, sea-level fluctuations that are related to the El Niño-Southern Oscillation phenomenon (ENSO). Several examples are shown in Figure 4. A distinct fall in sea level associated with the 1982 El Niño was shown to have been captured in the surface morphology of a field of *Porites* microatolls (Figure 4a) from the reef flat of Abemama in Kiribati (Woodroffe and McLean, 1990); and similar variations occur in other unpublished records of corals from Christmas Island, Kiribati (Figure 4b). Record of the 1997 El Niño, together with annual annuli (Figure 4c) have been described from corals on Abaiang, Kiribati (Flora and Ely, 2003); and microatolls from Tongareva, in the northern Cook Islands show longer records (Figure 4d), including distinct response to the 1982 and at least one earlier event (Spencer et al., 1997).

Microatoll growth pattern and morphology in response to a series of different sea-level scenarios is shown schematically in Figure 5. *Porites* microatolls grow upward until constrained by a water level close to mean low tide level, after which they continue lateral growth and become disc-shaped corals (Figure 5a), contrasting with dome-shaped colonies that are in water deep enough not to be constrained by sea level (Figure 5b). On coasts that experience seismic uplift, a coral previously not limited by sea level may be elevated above the water level, and the exposed upper surface will die, but with continued lateral growth at a lower elevation (Figure 5c). Where a microatoll, previously limited by water level, experiences an increase in water level it can resume vertical growth and begin to overgrow the formerly dead upper surface (Figure 5d). Successive falls in water level result in exposure of the living rim, and a series of terracettes develop, recording the water level falls (Figures 5e and 5g). Fluctuations of water level with a periodicity of several years are recorded on the upper surface of a microatoll as a series of concentric undulations (Figure 5f and 5h, also Figure 4).

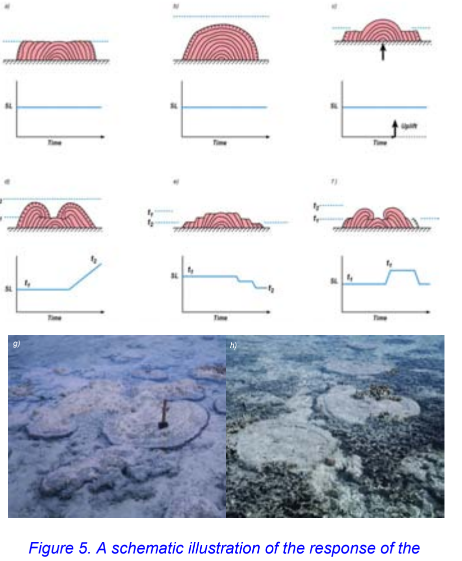

Figure 5. A schematic illustration of the response of the upper surface of microatolls to changes of sea level or uplift of the land, and examples of e) and f) from Cocos.

Microatolls offer important supplementary information to extend tide gauge records back in time particularly for remote reef settings, with the prospect of linking living and fossil colonies using techniques such as isotope-based wiggle-matching, resolving the extent to which there have been oscillations of sea level during the Holocene. However, several cautions need to be exercised: i) storms can moat or re-align corals; ii) microatolls are related not to mean sea level but to some poorly determined low water related to exposure of the polyps; iii) there is a time lag in the coral's response to water level rise because of the time required for the coral to grow vertically; and, iv) the dead upper surface of microatolls can undergo erosion so the record deteriorates. Nevertheless, microatolls are an important source of additional data on sea level.

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