Quaternary shorelines of Kaibu Island, southwest Pacific Ocean:
implications for Last Interglacial sea-level history and uplift of the Lau-Colville Ridge

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Abstract
The island Kaibu in north-east Fiji exhibits a series of three limestone terraces (5.0–5.5 m, 8.0–9.2 m and 12–14 m) arranged around a volcanic core. Each terrace comprises a fossil coral reef along its seaward side and an erosional platform and notch along its landward side. Where the lowest terrace is locally absent, it is marked by an emerged notch (5.1–5.2 m above the modern notch) cut into the cliff.

Ages of fossil corals from the forereef zone of the lowest emerged reef all indicate that it was living during the Last Interglacial (oxygen-isotope Stage 5e). A plausible interpretation is that the ages represent a double sea-level maximum with peaks around 133–130 kyr and 123–120 kyr. The earlier maximum was some 2 m lower than the later and marked by the growth of a surface reef. The later maximum appears to have involved only cutting of erosional shorelines at the 5.0–5.5 m level.

Since there are no ages for the two higher terraces, various scenarios can be envisaged. The one favoured is that both terraces formed during Stage 7 sea-level maxima.

Key Words
coral reef, limestone, uplift, sea-level,
Last Interglacial, Pacific Islands.

Introduction

The island Kaibu is located in the north-east Fiji group, south-west Pacific and is enclosed within the same barrier reef as the larger nearby island Yacata (Figure 1). The islands represent the emerged reef cover of a largely-submerged volcanic edifice similar to others rising from the north–south trending Lau-Colville Ridge (Nunn, 1996, 1998a); volcanic rocks are exposed only in the interior of Kaibu (see Figure 2).

Kaibu and Yacata were two targets of a research team investigating both environmental and human history in this part of the Pacific. The present account is confined to Kaibu as this was the only island in the study area from which fossil corals were successfully dated. The study aimed to understand the late Quaternary interaction between tectonic and sea-level changes.

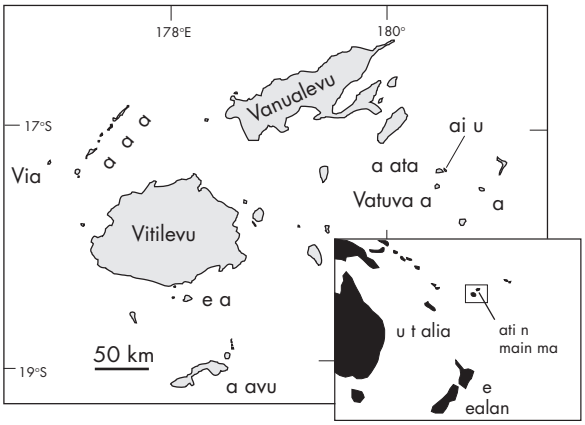

Figure 1. Location of Kaibu within the Fiji Islands. Inset locates the main map within the Southwest Pacific.

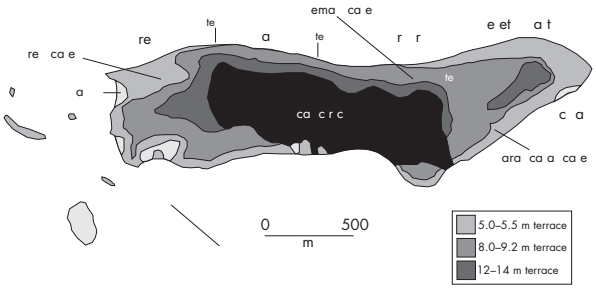

Figure 2. Geology of Kaibu Island (after Fiji Mineral Resources Department, 1984) showing the three reef-shoreline complexes mapped and the location of study sites.

Geology and geomorphology of Kaibu

Kaibu is 1.5 km^2 in area and reaches a little over 40 m above sea-level in its south–central part. Middle Miocene andesite lavas and breccias belonging to the Yacata Andesite group (Fiji Mineral Resources Department, 1984) are exposed in the centre of the island and are surrounded by a series of three reef-limestone terraces of variable width (Figure 2). The seaward parts of these terraces are interpreted as former fringing reefs which grew out from the ocean-facing (rather than the lagoon-facing) shores of Kaibu at various times in the past. In places at the back of the two lower terraces is found a conspicuous erosional notch, regarded as analogous in origin to that forming along the modern shoreline. The terraces therefore represent reef–shoreline complexes which have emerged since they formed at sea-level.

The highest terrace (12–14 m above the modern shoreline) is least continuous and least well-exposed. It onlaps the volcanic rocks in the centre of the island and, because of the variable elevation of this onlap, is thought to have covered them once. The middle terrace (8.0–9.2 m above the modern shoreline) is more widely exposed and actually comprises the coastline along the island's central north-eastern coast. The lowest terrace along this coast occurs as a veneer of younger reef on the cliff face beneath an emerged notch 5.1–5.2 m above the modern notch. The 5.0–5.5 m terrace is best exposed around the extremities of the island where it forms a broad level surface in which various divisions, corresponding to ecotones on modern reefs in this area, could be recognized.

The surfaces of the reef terraces usually exhibit around 0.5 m of relative relief although sinkholes occur occasionally — such as at Dreli and Nukusemani caves (see Figure 2). The boundary between adjacent terraces is generally marked by steep cliffs along the base of which are found emerged erosional notches and caves such as that at Qaranicava.

The first report of the Kaibu Island terraces was made by Derek Woodhall as part of his survey of Lau Island geology which has as yet been reported only in a series of geological maps by the Fiji Mineral Resources Department (1984). The Department granted the authors access to

Woodhall's unpublished notes and reports and these provided significant insights. For this study, detailed investigations of emerged reef terraces on Kaibu were made along the entire north-east coast of the island where they were well-exposed and most conspicuously fossiliferous.

Detailed investigations

The bedrock limestone at the northern end of Dakui Beach can be clearly distinguished from a younger fossil reef by the large numbers of visible fossils, mostly corals in their growth positions, crowded into the latter at this location (Figure 3). Farther south, the younger reef is less prominent but can be recognised as a veneer on the cliff face. Two samples taken from this reef at Dakui (samples D4 and D5) imply that this younger reef is of Last Interglacial age (Table 1).

The younger reef is regarded as contemporaneous in age with the 5.1–5.2 m emerged notch, which forms a conspicuous feature along this cliffed coast (Figure 4). Although well beyond the reach of modern coastal erosion, this notch is smooth-walled and smooth-floored and has well-developed speleothem pillars at one place. At this site, two higher emerged notches were surveyed, one emerged 8.9 m above the modern notch, the other (which was inaccessible) emerged about 11.3 m.

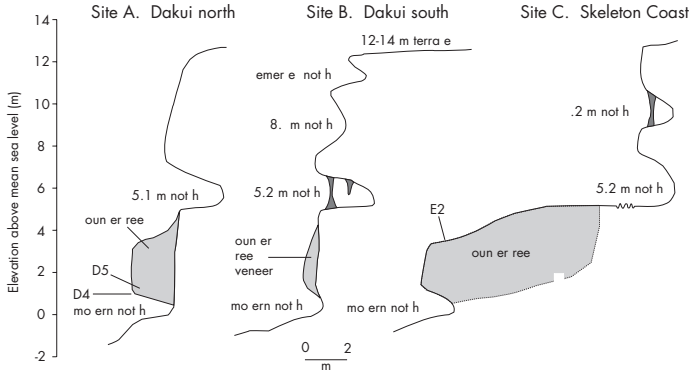

Figure 3. Coastal sections showing locations of samples D4, D5 and E2.

The 12–14 m terrace forms the flat surface at the top of the cliffs all along Dakui Beach.

The younger reef is better preserved to the south at Sirosironiqoli and what we named Skeleton Coast. At the latter, the younger reef and the associated shore platform and notch are 30–40 m broad in places. Fossil corals were abundant throughout the seaward 10–15 m of this feature but were exposed best along the coast where they were sampled. A single date from this location gave a Last Interglacial age for the coral sample E2 (Figure 5).

Table 1. Ages of emerged corals from Kaibu

The sole ^{14}C age was determined at the University of Waikato, New Zealand, and is considered to be a minimum age for what is likely to be a Last Interglacial coral. The $^{230}Th/^{234}U$ ages were determined by Akio Omura, Kanazawa University, Japan. Only the three acceptable ages are given; to be acceptable, the $^{234}U/^{238}U$ activity ratio should be between 1.13 and 1.16.

Laboratory number	Location	Coral genus	Elevation above modern reef (m)	Conventional ^{14}C age (BP)
WK-5418	Sample D4 from notch overhang, northern end of Dakui Beach	*Favites* sp.	1.40	33,150 ± 350

Laboratory number	Location	Coral genus	Elevation above modern reef (m)	Age (kyr)	$(^{234}U/^{238}U)_0$ (activity ratio)
443	Sample E6 from emerged reef platform at edge of 5-m terrace, northern end of Ucuna Beach	*Platygyra* sp.	3.85	131.1±2.4	1.149±0.011
AO454	Sample E2 from platform at front of 5-m terrace, Skeleton Coast	*Platygyra lamellina*	3.60	132.8±2.3	1.159±0.010
AO455	Sample D5 from cliff at front of young reef outcrop, northern end of Dakui Beach	*Porites* sp.	1.45	126.8±2.1	1.155±0.010

Figure 4. View north-west along the coast at Dakui from inside the 5.2 m emerged notch. The line of this notch is visible along the cliff face as far as Dakui north, where it was measured at 5.1 m above the modern notch.

Figure 5. The 9.2 m notch about 80 m inland of the modern shoreline at Skeleton Coast. The staff is 5 m long.

At the back of the Last Interglacial shoreline along the Skeleton Coast, there is commonly a cliff in which what we regard as the Last Interglacial notch (emerged 5.2 m) is preserved. There is a higher notch (Figure 5), with considerable speleothem development locally, emerged 9.2 m above the modern notch. This notch, in which were found numerous human burials, appears older than the 5.2 m notch on account of the degree of weathering of the exposed surface. This was true especially of the notch floor in which fossil corals (*Porites* sp) were upstanding relative to their weathered matrix. No ages could be obtained for samples within this notch because they were recrystallised.

A sample from the front of a 5.0–5.2 m platform at Ucuna (not shown in Figure 3) was also dated to the Last Interglacial and confirms the age of the 5.0–5.5 m shoreline.

Chronology

Four ages (Table 1) suggest that the 5.0–5.5 reef–shoreline is of Last Interglacial age. Assuming that the three securely-dated corals all grew close to the mean low-tide level (MLT), as is plausible if not demonstrable, then two scenarios can be envisaged (Figure 6).

The first and simplest is one involving a single sea-level maximum perhaps about 124 kyr as Chappell and Shackleton (1986) proposed, although AO455 would then have to have been growing more than 3.5 m below MLT (Figure 6)

The second scenario is one involving a double sea-level maximum, as inferred originally by Chappell (1974) from his recognition of a disconformity between emerged Reef VIIa and Reef VIIb on the Huon Peninsula in Papua New Guinea. Evidence for a Last Interglacial double sea-level maximum has since been found elsewhere (Ku et al., 1974, Sherman et al., 1993, Montaggioni and Hoang, 1988). As shown in Figure 6, either scenario is possible; the critical factor is whether the Porites coral dated by sample AO455 grew at the ocean surface or 3.5 m or so below the ocean surface (MLT). If this coral grew at MLT, then we envisage a scenario, shown in Figure 6, in which Last Interglacial sea-level rose to a maximum around 133–130,000 years ago. This transgression must have been sufficiently slow for coral reef to 'keep up' or at least 'catch up' with sea-level rise (to use the terms of Neumann and MacIntyre, 1985). Following this maximum, the sea level fell by around 2 m before rising again to a maximum around 123–120,000 years ago. We infer this sea-level rise to have been comparatively rapid, sufficiently so that coral reefs 'gave up' trying to grow upwards at the same rate. The result was that when the sea-level maximum was reached, a largely erosional shoreline (that at 5.0–5.5 m) was cut. This scenario explains the observed form of the Last Interglacial shoreline on Kaibu marginally better than one involving a single sea-level maximum.

A Last Interglacial shoreline at 5.0–5.5 m is close to the +6 m palaeosea-level occurring at

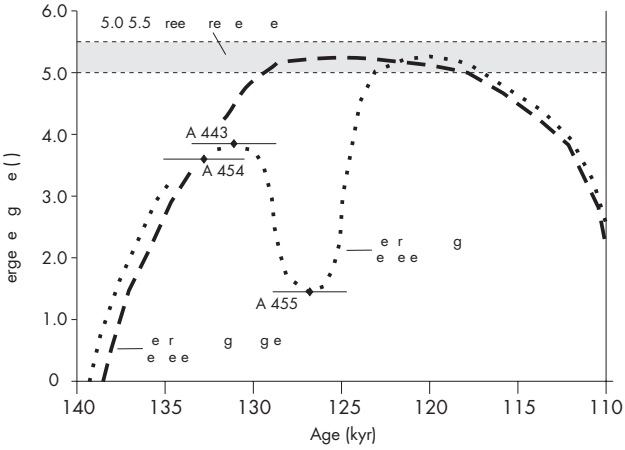

Figure 6. Plot of $^{230}Th/^{234}U$ ages against sample elevation showing the various possible Last Interglacial sea-level reconstructions.

approximately 124 kyr. This is derived from comparison of the record from the emerged reef staircase on the Huon Peninsula in Papua New Guinea with the deep-sea oxygen-isotope record (Chappell and Shackleton, 1986). Analogues from elsewhere in the region include the Last Interglacial reefs dated on Viwa Island in the Yasawa Group of western Fiji (see Figure 1) and those on the islands 'Eua and Tongatapu in Tonga by Taylor (1978).

The higher terraces on Kaibu have not been dated directly and, from what is now known about pre-Last Interglacial sea-levels, it is not a simple matter of assigning them to successive earlier interglacial stages. That said, there is evidence from throughout the islands of the Lau Ridge that uplift was the norm for much of the Quaternary but that, at least in parts of the group, this uplift effectively ceased during the late Quaternary around 150 kyr (Nunn, 1996, 1998a, Nunn et al., 2002). Unless a scenario involving intermittent uplift is invoked, the most plausible explanation is that both higher terraces formed during Stage 7 (Penultimate Interglacial) sea-level highstands and were uplifted at rates of between 0.30 mm a^{-1} and 0.43 mm a^{-1} before uplift ceased around 150 kyr.

Conclusions

This study is significant because it provides a detailed chronology of late Quaternary reefs in north-east Fiji where no comparable studies have been carried out. As such it has implications not only for the various chronologies of (reef-) terraces mapped on nearby islands (Nunn, 1996, 1998a) but also for an understanding of the age of the low-lying Ucuna Limestone which is ubiquitous in the Fiji archipelago (Rodda, 1994).

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References

Chappell, J. and Shackleton, N.J. 1986. Oxygen isotopes and sea level. *Nature*, 324: 137–40.

Chappell, J. and Veeh, H.H. 1978. Late Quaternary tectonic movements and sea-level changes at Timor and Atauro Island. *Geological Society of America, Bulletin*, 89: 356–68.

Fiji Mineral Resources Department. 1984. *Geology of Nukutolu, Vatuvara, Yacata and Kaibu, Naitauba, Kibibo, Malima, Wailagilala, Katafaga, Vekai, Cicia, Mago, Kanacea, Tuvuca, Tavanuku-i-vanua and Yaroua*. 1:25,000 geological map (MRD 785).

Haddad, G.A. 1994. *Calcium carbonate dissolution patterns at intermediate water depths of the tropical oceans during the Quaternary*. Unpublished PhD Thesis, Rice University, Houston, Texas.

Ku, T.-L., Kimmel, M.A., Easton, W.H. and O'Neill, T.J. 1974. Eustatic sea level 120,000 years ago on Oahu, Hawaii. *Science*, 183: 959–62.

Montaggioni, L.F. and Hoang, C.T. 1988. The last interglacial high sea level in the granitic Seychelles, Indian Ocean. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 64: 79–91.

Murray-Wallace, C.V. and Belperio, A.P. 1991. The last interglacial shoreline in Australia — a review. *Quaternary Science Reviews*, 10: 441–61.

Neumann, A.C. and MacIntyre, I. 1985. Reef response to sea-level rise: keep-up, catch-up or give-up. *Proceedings of the 5th International Coral Reef Congress*, 3: 105–10.

Nunn, P.D. 1995. Holocene tectonic histories for five islands in the south-central Lau group, South Pacific. *The Holocene*, 5: 160–71.

Nunn, P.D. 1996. Emerged shorelines of the Lau Islands. *Fiji Mineral Resources Department, Memoir* 4, 99.

Nunn, P.D. 1998a. Late Quaternary tectonic change on the islands of the northern Lau-Colville Ridge, southwest Pacific. In, Stewart, I.S. and Vita-Finzi, C. (eds). *Coastal Tectonics*, 269–8. Geological Society, London, Special Publication 146.

Nunn, P.D. 1998b. *Pacific Island Landscapes*. Institute of Pacific Studies, The University of the South Pacific, 318 pp.

Nunn, P.D. and Omura, A. 1999. Penultimate Interglacial emerged reef around Kadavu Island, Southwest Pacific: implications for late Quaternary island-arc tectonics and sea-level history. *New Zealand Journal of Geology and Geophysics*, 42: 219–27.

Nunn, P.D., Ollier, C.D., Hope, G.S., Rodda, P., Omura, A. and Peltier, W.R. 2002. Late Quaternary sea-level and tectonic changes in northeast Fiji. *Marine Geology*, 187: 299–311.

Rodda, P. 1994. Geology of Fiji. In, A.J. Stevenson, R.H. Herzer and P.F. Ballance, (eds) *Geology and Submarine Resources of the Tonga-Lau-Fiji Region*. SOPAC Secretariat (SOPAC Technical Bulletin 8), Suva, Fiji, 131–51.

Sherman, C.E., Glenn, C.R., Jones, A.T., Burnett, W.C. and Schwarcz, H.P. 1993. New evidence for two highstands of the sea during the last interglacial, oxygen isotope stage 5e. *Geology*, 21: 1079–82.

Taylor, F.W. 1978. Quaternary tectonic and sea-level history, Tonga and Fiji, Southwest Pacific. Unpublished PhD thesis, Cornell University, Ithaca, New York.

Buck, C.E., Higham, T.F.G. and Lowe, D.J. 2003. Bayesian tools for tephrochronology. *The Holocene* 13: 639–47.

Gale, S.J. 2003. Making the European landscape: early contact environmental impact in Australia. In, 'Geography's New Frontiers'. *Geographical Society of New South Wales Conference Papers* 17: 7–16.

Hesse, P.P. and McTainsh, G.H. 2003. Australian dust deposits: modern processes and the Quaternary record. *Quaternary Science Reviews*, 22: 2007–35.

Hesse, P.P., Humphreys, G.S., Smith, B.L., Campbell, J. and Peterson, E.K. 2003. Age of loess deposits in the Central Tablelands of New South Wales. *Australian Journal of Soil Research*, 41:1115–31.

Reid, M., Fluin, J., Ogden, R., Tibby, J. and Kershaw, P. 2002. Long-term perspectives on human impacts on floodplain-river ecosystems, Murray-Darling Basin, Australia. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie*, 28: 710–16.