ELSEVIER

Marine Geology 187 (2002) 299–311

MARINE GEOLOGY
INTERNATIONAL JOURNAL OF MARINE GEOLOGY, GEOCHEMISTRY AND GEOPHYSICS

www.elsevier.com/locate/margeo

Late Quaternary sea-level and tectonic changes in northeast Fiji

Patrick D. Nunn [a,*], Cliff Ollier [b], Geoffrey Hope [c], Peter Rodda [d], Akio Omura [e], W. Richard Peltier [f]

[a] Department of Geography, The University of the South Pacific, Suva, Fiji
[b] Department of Geography, The University of Western Australia, Hackett Drive, Crawley, WA 6009, Australia
[c] Research School of Pacific and Asian Studies, The Australian National University, Canberra, ACT 0200, Australia
[d] Mineral Resources Department, Private Mail Bag, Suva, Fiji
[e] Department of Earth Sciences, Kanazawa University, Kakuma, Kanazawa, Ishikawa 920-11, Japan
[f] Department of Physics, University of Toronto, Toronto, ON, Canada M5S-1A7

Received 4 September 2001; accepted 5 April 2002

Abstract

The islands of northeast Fiji studied are all the emergent parts of the northern end of the Lau–Colville Ridge, a remnant island arc which has been rising for most of the Quaternary. Within the study area, investigations of coastal landforms (primarily emerged notches and shore platforms) and emerged coral reefs allow rates of tectonic movements to be calculated. The Vanuabalavu Island group is shown to have subsided during the late Quaternary while the area around is shown to have risen over the same time period. This disparity may be a result of tensional rifting associated with the continuing rotation of the Fiji Platform.

Keywords: Pacific islands; tectonics; sea-level change; Quaternary; Holocene

1. Introduction

Low-latitude oceanic island coasts are excellent places to unravel Quaternary sea-level and tectonic history, yet comparatively little work has been carried out on the islands of the southwest Pacific. This study reports and interprets the results of fieldwork and sample analysis from four (groups of) islands in northeast Fiji (Fig. 1): the Vanuabalavu group (Vanuabalavu, Namalata, Susui, Munia, Cikobia-i-Lau and Avea), Mago, Yacata and Kaibu, and Vatuvara, with a focus on late Quaternary tectonics and sea-level changes.

2. Tectonic context

All the islands shown in Fig. 1 rise from the northern end of the Lau (–Colville) Ridge, a remnant arc separated from the presently active island arc in Tonga by the back-arc Lau (–Havre) Basin. Comparison between the geology of the Lau Islands and that of Tonga shows that the Tonga arc was once joined to the Lau arc and

* Corresponding author.
E-mail address: nunn_p@usp.ac.fj (P.D. Nunn).

0025-3227/02/$ – see front matter
PII: S0025-3227(02)00296-7

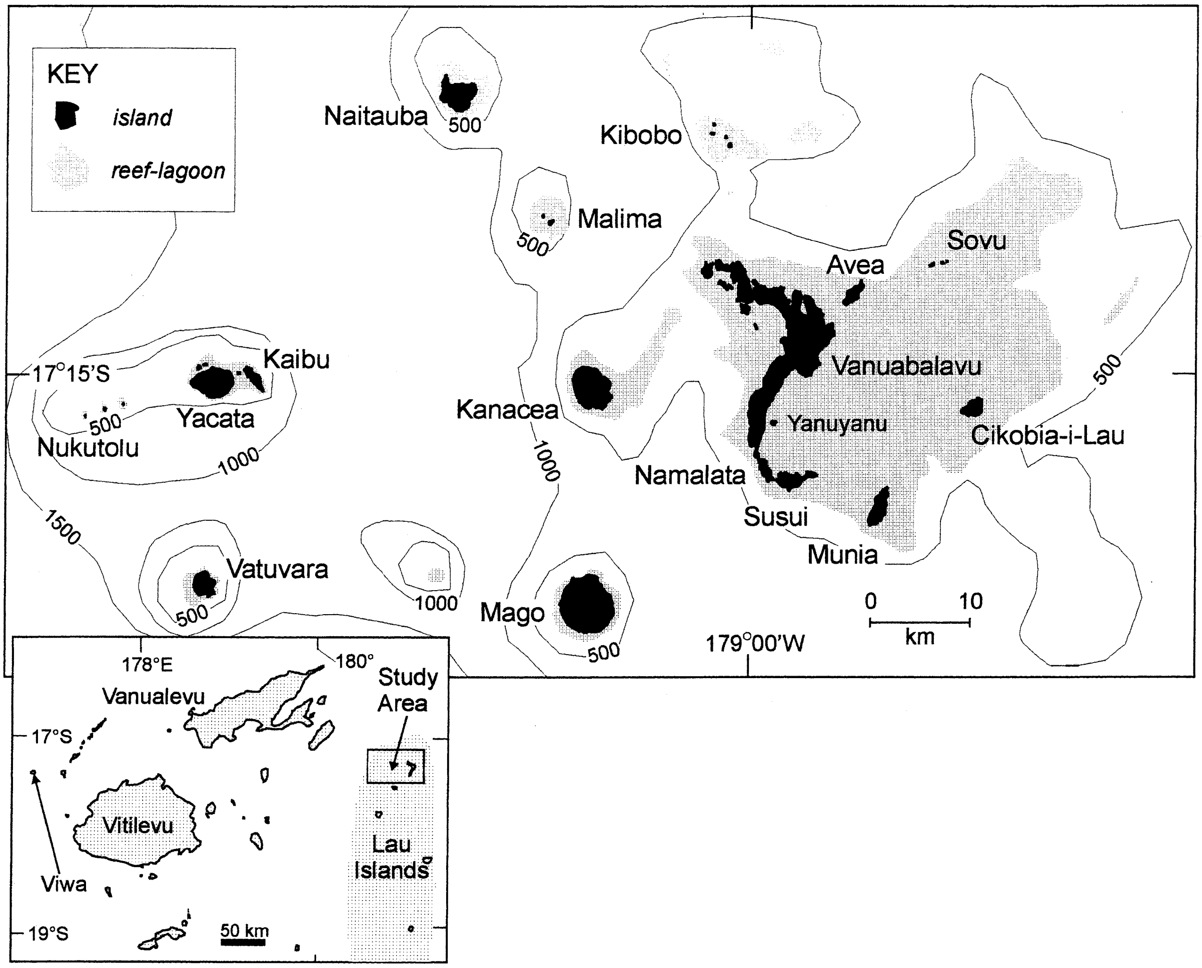

Fig. 1. Northeast Fiji showing the locations of the islands studied and reef–lagoon systems. The bathymetry of the study area, after Fiji Mineral Resources Department (1994), is also shown with isobaths in metres. Inset shows location of the study area within Fiji, and relative to the rest of the Lau Islands.

that they split longitudinally, probably around 5.5 Ma (Coleman, 1980, Kroenke, 1984). For the next 2–3 Myr, the Lau Ridge subsided and the volcanoes that were built when it was an active island arc became covered/flanked by shallow-water reef limestone. Then, probably during the late Pliocene, the northern part of the ridge (on which all the modern Lau Islands are located) began rising. This uplift has continued throughout most of the Quaternary and emerged shorelines on most high islands have been linked on the basis of elevation, age and morphostratigraphic character (Nunn, 1987, 1996, 1998).

The island groups studied (Fig. 1) exhibit a variety of lithologies and ages. Most have volcanic basements dating from the main phase of arc volcanism >5.5 Ma. Younger volcanics outcrop out on Kanacea, Malima, Kibibo and Vanuabalavu (the Korobasaga Volcanic Group, 4.01–2.46 Ma), and on Mago and Yanuyanu (the Mago Volcanic Group, 2.53–0.28 Ma) (Woodhall, 1985). The volcanic rocks are covered by reef limestone which reaches a minimum thickness of 315 m on Vatuvara. The limestone topography is typically a series of surfaces separated by steep cliffs. These surfaces were divided by Nunn

(1996) into *terraces* (flat, primarily aggradational surfaces, emerged ≥10 m) and *shorelines* (sub-horizontal surfaces and notches of primarily erosional origin, emerged <10 m).

3. The study area

The islands investigated are shown, along with nearby islands, in Fig. 1. The time spent on particular islands varied and thus the amount of data collected also varied. In-depth surveys were made of the main island of Vanuabalavu, Mago, Yacata and Kaibu, while shorter surveys were carried out on Vatuvara and the outliers of the Vanuabalavu group.

Previous surveys of the evidence for emergence in these islands and others in the Lau Group include those by Agassiz (1899), Foye (1917) and Davis (1920) and have been largely superseded. The study by Ladd and Hoffmeister (1945) was a benchmark in that it provided the most detailed account of many locations and attempted the first well-founded synthesis of the evidence for Quaternary emergence throughout Lau. The geological survey by Woodhall (1985) and Woodhall (in press) reported such evidence for particular islands but this was a subordinate aim of his work. The lead author's own work has advanced as the number of islands visited has increased (Nunn, 1987, 1996, 1998).

4. Research questions

There has been considerable interest in whether the northern part of the Lau Ridge continues to rise, as it has manifestly done for most of the Quaternary (Woodhall, 1985; Nunn, 1998), or whether it has stabilised. Also it is unclear whether uplift affected the entire Lau Ridge as a single unit or whether it is divisible into tectonically discrete sub-units (Milsom, 1970; Woodhall, 1985; Rodda, 1994; Nunn, 1998). Answers to these questions have implications for understanding the geotectonic condition of a wider region, and have the potential to help calibrate the rates of the processes involved. In addition, information about the present tectonic condition of the region is of considerable interest to those charged with managing its future development (Nunn et al., 1999).

5. Methods

This paper employs measurements of the relative upward vertical displacement (emergence) of former shorelines. These are typically marked by shore platforms, notches, marine caves and, less commonly, fossil corals and beach deposits. Emergence was calculated by measuring the vertical height between the same part of emerged and modern shoreline indicators, such as notch retreat (innermost) points or cave lips. Emergence magnitude is thus usually calculated without reference to any sea-level position. Where there are no modern counterparts to the emerged shoreline indicators, the level at which they formed relative to a palaeosea-level position was estimated, and emergence magnitudes calculated.

6. Results

Results are presented separately below for each of the four (groups of) islands studied.

6.1. Vanuabalavu group

The main islands of the Vanuabalavu group are shown in Fig. 2, together with the five key field sites. Emerged shorelines in this group are far fewer than expected given their comparative abundance around the other islands studied and those elsewhere in the Lau Group (Nunn, 1996). The only clear evidence of a ∼5.2-m level is the solution-eroded notch along the west side of Cavaura Pond on Namalata Island (Fig. 3). Cavaura is a 130-m-diameter sinkhole, 80–110 m deep and swamp-floored, with a water surface close to sea level. There is a modern notch around all sides of the sinkhole at water level and the 5.2-m level is believed to represent a time when water level was persistently this much higher. By analogy with dated emerged shorelines on Kaibu Island (see

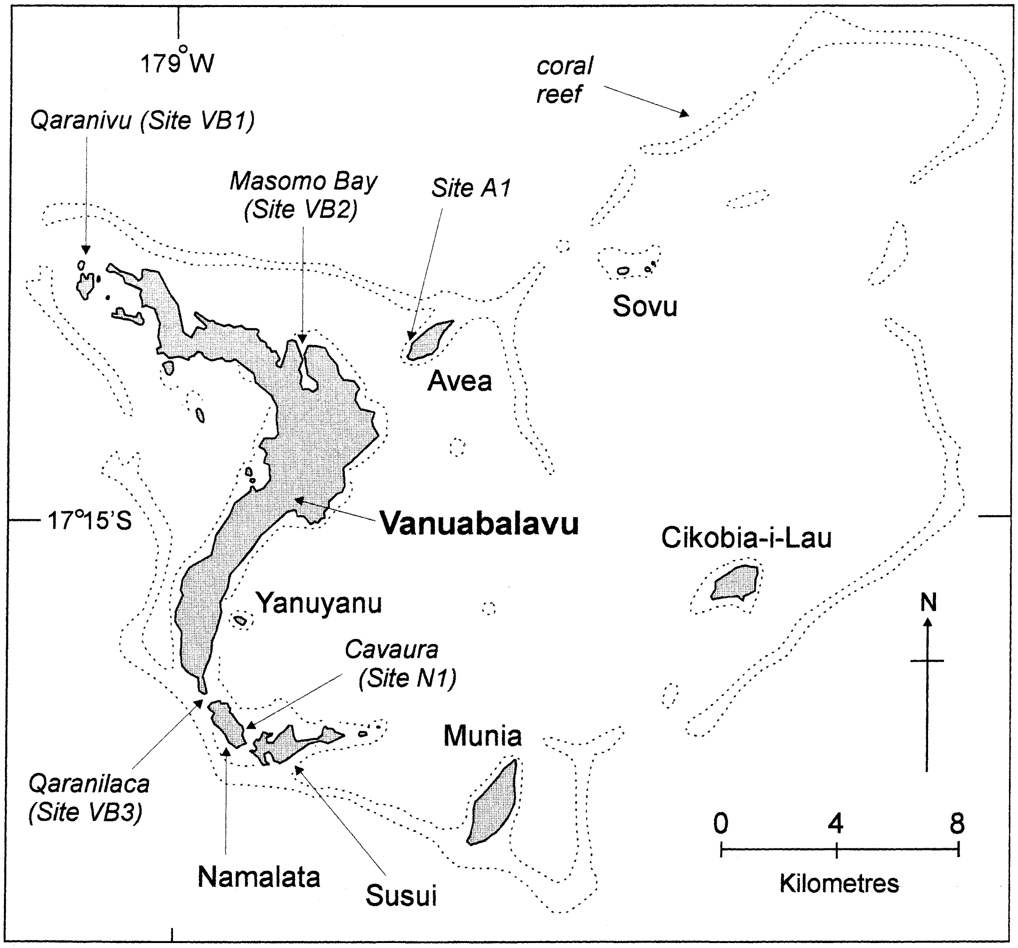

Fig. 2. The Vanuabalavu Island group.

below), it is plausible to suppose that this notch formed during the Last Interglacial and indicates that sea level is the principal control of water level in Cavaura.

There is a higher-than-present Holocene shoreline in only a few places in the Vanuabalavu group (Fig. 3). In the interior of the cave Qaranivu, described first by Sawyer and Andrews (1901), there is a zone of fossil oysters (*Ostrea* sp.) dated to the late Holocene (Table 1), emerged 0.9 m above the zone in which they currently live. An emerged notch, cut back by erosion of the modern notch below, is recognisable along the sheltered cliffed sides of Masomo Bay (Fig. 4) and is interpreted as a Holocene shoreline 1.3 m above its modern analogue (Fig. 3); a cemented shell-rich beach conglomerate, interpreted as an emerged notch fill, was dated here (Table 1). An emerged coral microatoll (*Porites* sp.) in growth position from the northwest coast of Avea was also dated to the late Holocene (Table 1). Ladd and Hoffmeister (1945) measured the conspicuous, probably coeval, level at 1.2–2.6 m throughout this group comprising emerged sea-caves and shore platforms; Berryman (1979) also reported 'terraces' within this height range from Vanuabalavu and Namalata islands.

Evidence for sea-level fall around 300 BP was obtained from Qaranilaca (cave) at the southernmost tip of Vanuabalavu, described previously by Nunn et al. (2000).

All sites in the Vanuabalavu group where

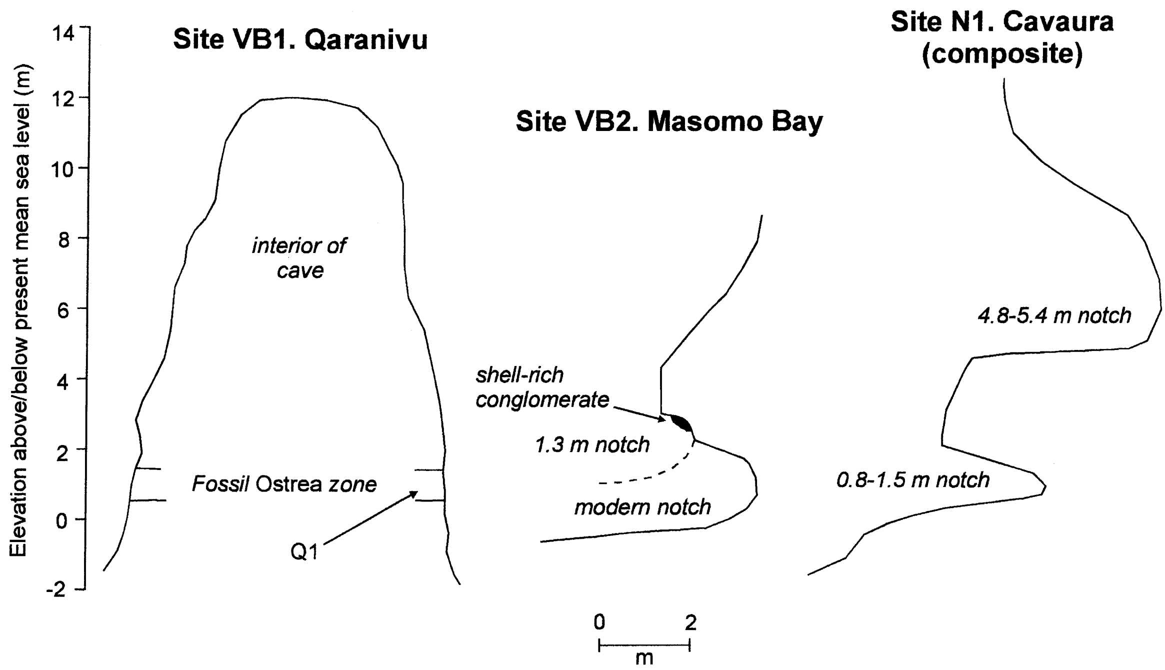

Fig. 3. Coastal sections at Qaranivu and Masomo Bay on Vanuabalavu Island and at Cavaura on Namalata Island.

emerged shorelines are found are uncommonly sheltered; two (VB1 and VB3) occur in caves, two (VB2 and N1) along the sides of deep karstic depressions, the other (A1) on a leeward reef flat. This suggests that the effectiveness of coastal erosion in obliterating evidence is much greater here than elsewhere in the study area. This is unlikely to have anything to do with the relative efficacy of coastal processes but rather the comparative ease with which the Vanuabalavu limestones are eroded. Many of these are rubble limestones, formed from erosion and transport of massive limestones, and many have high levels of porosity and impurity. Their general cohesiveness is less than elsewhere in the Lau Islands, as evinced by the almost total lack of large caves in the islands of the Vanuabalavu group compared to those elsewhere in Lau (Nunn et al., 1991). It is reasonable to suppose both that the processes of notch formation are less effective in such lithologies and that the obliteration of erosional forms is more effective.

Table 1
^{14}C ages for Holocene sea-level indicators from the Vanuabalavu Island group

Site	Laboratory number[a]	Location	Material dated	Elevation (m LAT[b])	Displacement and net error	Conventional age (^{14}C yr BP)	Calibrated age[c] (cal yr BP)
VB1	WK-7590	Qaranivu	*Ostrea* sp.	2.00	0.90 ± 0.20	3640 ± 60	3671–3337
VB2	WK-9150	Masomo Bay	marine shell	2.25	1.30 ± 0.20	3950 ± 60	4083–3683
VB3	WK-9149	Qaranilaca	marine shell	0.34	0.34 ± 0.20?	600 ± 50	≤ 298
A1	WK-7589	Avea Island	coral (*Porites* sp.)	0.20	0.20 ± 0.20	4110 ± 60	4320–3890

[a] WK – University of Waikato Radiocarbon Laboratory.
[b] Lowest Astronomical Tide level, also known as Fiji Datum in Fiji.
[c] Age calibrated online (http://depts.washington.edu/qil/calib/calib.html) using CALIB 4.3 marine curve with the Fiji δR value of 38 yr from Toggweiler et al. (1991), 2σ range given.

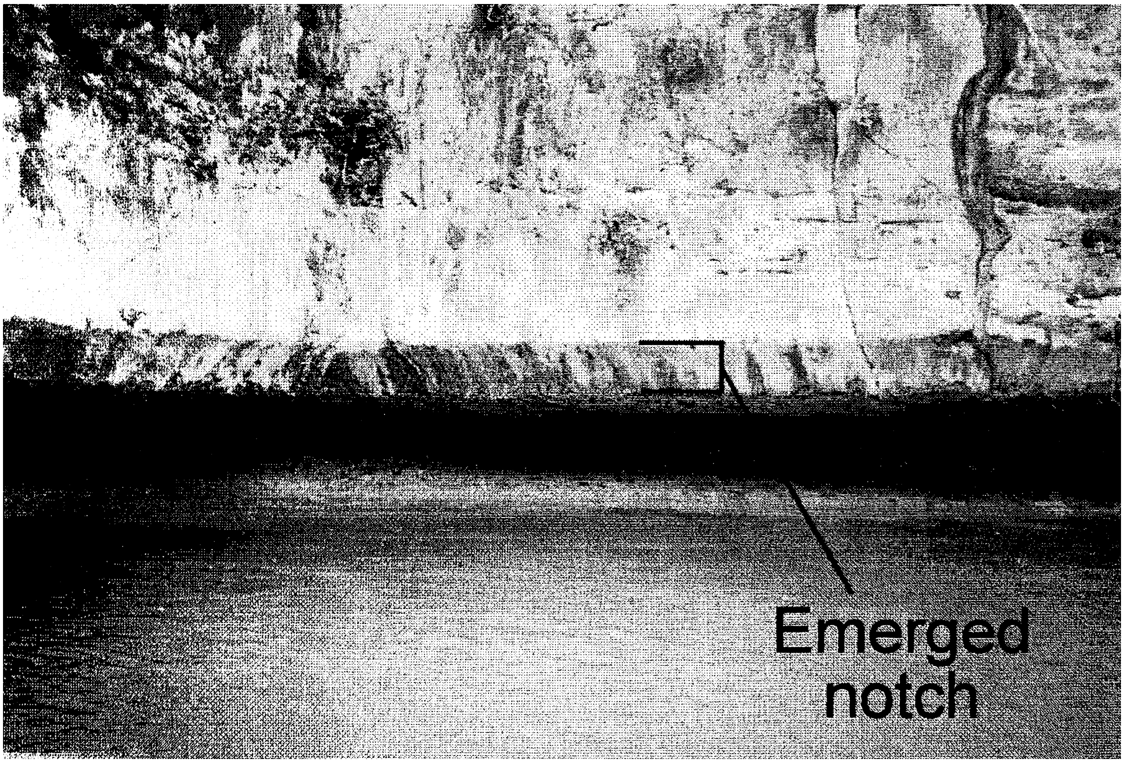

Fig. 4. The emerged notch along the western side of Masomo Bay, northern Vanuabalavu Island, is interpreted as representing a +1.3-m sea-level highstand (Site VB2 in Fig. 3).

6.2. *Mago*

Sites in the Yacata–Mago group are shown in Fig. 5. The volcanic foundation of Mago Island is draped with reef limestone which now forms high *makatea* (limestone plateaux) around most of the island's fringe. Pleistocene volcanic activity occurred on Mago ~0.33–0.28 Ma (Whelan et al.,

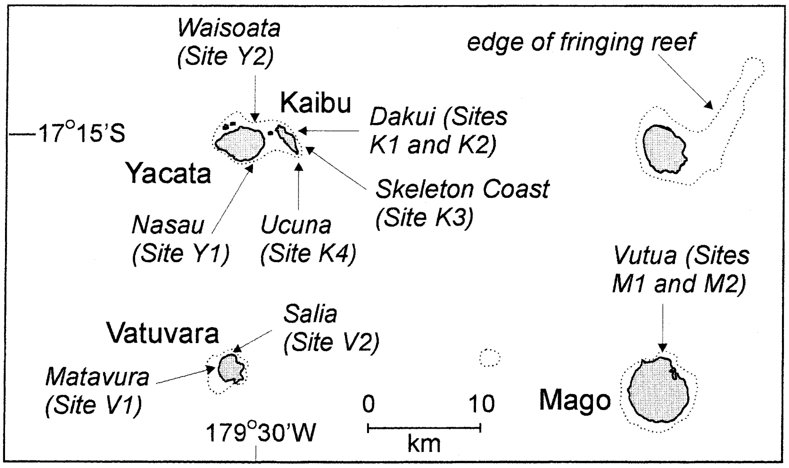

Fig. 5. The Mago–Yacata island group.

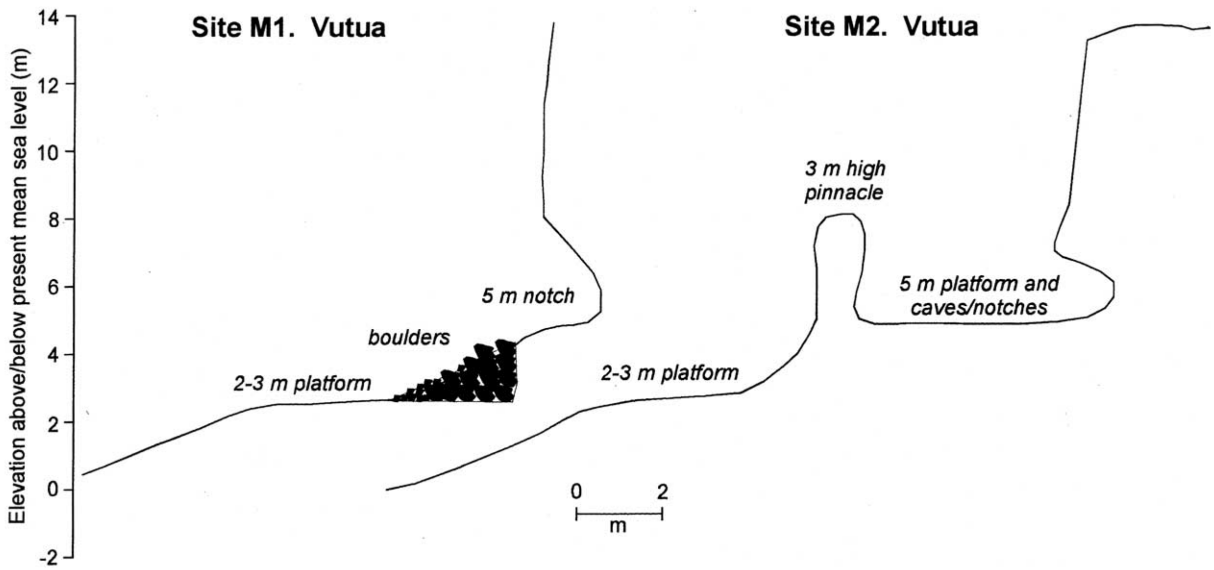

Fig. 6. Coastal sections at Vutua on Mago Island.

1985) and, at Maruna on the northwest coast, lavas covered the 20-m terrace and this has become an important chronostratigraphic marker in Lau (Nunn, 1996, 1998). Detailed investigations of low-level emerged shorelines on Mago were confined to the Vutua (Votua) area, where an archaeological site was found, and are shown in Fig. 6.

A 5-m emerged shoreline is visible here, and in many other places along the Mago coast. The marine origin of this shoreline is clear from its morphological similarity to modern erosional

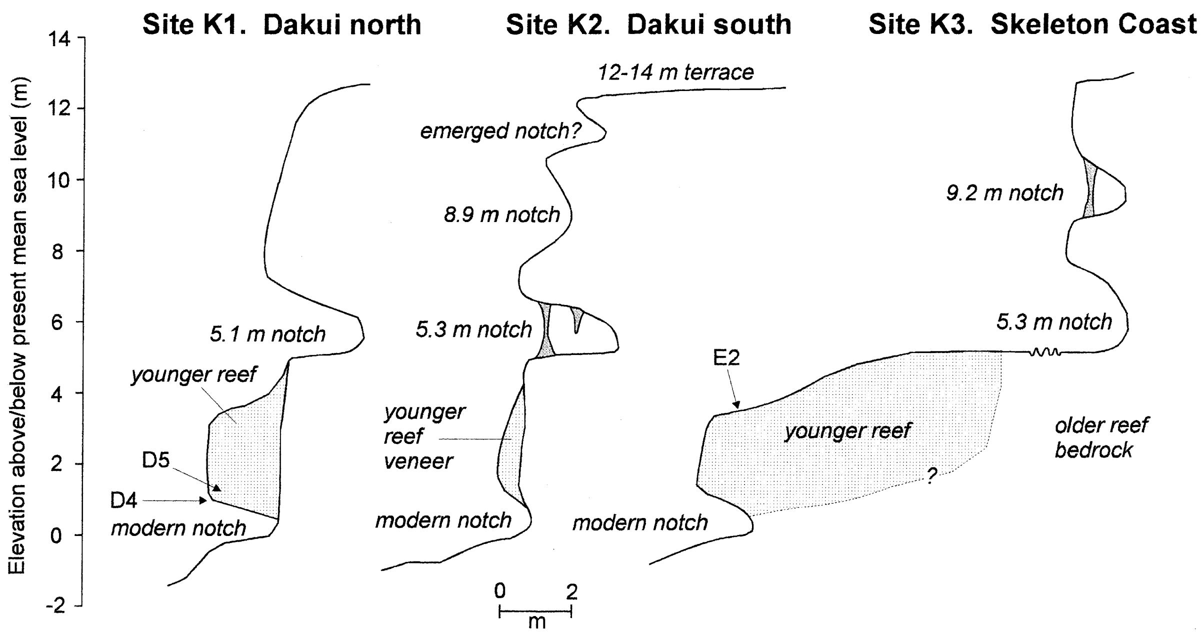

Fig. 7. Coastal sections at Dakui and Skeleton Coast on Kaibu Island.

Table 2
^{230}Th/^{234}U dates of emerged corals from the northeast and east coast of Kaibu

Site	Laboratory number[a]	Sample location	Coral type	Elevation above modern reef (m)	Date (kyr)	^{230}Th/^{232}Th (activity ratio)	^{230}Th/^{234}U (activity ratio)	(^{234}U/^{238}U)$_0$ (activity ratio)
K1	AO455	Sample D5 from cliff at front of young reef outcrop, northern end of Dakui Beach	*Porites* sp.	1.45	126.8 ± 2.1	> 320	0.7000 ± 0.0062	1.155 ± 0.010
K3	AO454	Sample E2 from platform at front of 5-m terrace, Skeleton Coast	*Platygyra lamellina*	3.60	132.8 ± 2.3	> 370	0.7174 ± 0.0063	1.159 ± 0.010
K4	AO443	Sample E6 on emerged reef platform at edge of 5-m terrace, northern end of Ucuna Beach	*Platygyra* sp.	3.85	131.1 ± 2.4	> 430	0.7121 ± 0.0068	1.149 ± 0.011

Sites are located on Fig. 5.
[a] All determinations were made by alpha counting at the Radiometric Dating Laboratory, Kanazawa University.

shorelines, including sea stacks, caves and shore platforms, but unfortunately none of the diagnostic samples collected were suitable for dating. A 2–3-m platform and cave line, noted by Andrews (1900), is another persistent feature of the Mago shoreline.

6.3. Yacata–Kaibu group

The islands Yacata and Kaibu (Fig. 5) are the remains of a single andesite volcano of Miocene age (Woodhall, in press) which was at one time covered almost entirely by reef limestone. This limestone has been eroded to expose the volcanics in southeast and central Yacata and central Kaibu.

Emerged shorelines (< 10 m) occur in all parts of Yacata and Kaibu. The most persistent is that around 5.3 m which occurs as notches in cliffs, particularly along the south coast of Yacata and the northeast coast of Kaibu. It also occurs as aggradational reef platforms in northern Yacata, notably at Waisoata, and along the Skeleton Coast of southern Kaibu. Details of Kaibu sites are shown in Fig. 7. A series of ^{230}Th/^{234}U dates from fossil corals on the floor of the emerged shore platform which runs into the 5.1–5.2-m notch in northeast Kaibu (Table 2) suggests it is of Last Interglacial age.

The lowest widespread emerged shoreline on Yacata is around 2.5 m and is believed to be entirely erosional in origin (Fig. 8). It is likely to mark erosion at a higher-than-present late Holocene sea level while a high-energy window was open. This situation resulted from the inability of reef surfaces to grow upwards at the same rate as sea level rose during the later part of the postglacial transgression. Similar situations have been reported along the Great Barrier Reef (Hopley, 1984) and elsewhere in Fiji (Nunn, 1990).

6.4. Vatuvara

No volcanic rocks are exposed on Vatuvara island (Fig. 5), where the highest emerged reef limestones in the Lau Islands occur at 315 m (Nunn, 1996). Emerged shorelines were recorded at two places on the islands' west and north coast

(Fig. 9). The sequence is comparable to that on Yacata and Kaibu with a conspicuous 5.2-m notch and a variety of erosional shoreline indicators around 2 m above their modern equivalents.

7. Interpretation

Comparison between levels of emerged shorelines on the islands studied show that a Last Interglacial shoreline has emerged in northeast Fiji by around 5.0–5.2 m (range 4.8–5.5 m). A largely erosional shoreline around 2.0 m (range 0.2–3.5 m) dates from the middle Holocene. Table 3 shows the breakdown of emergence data by island together with various estimates of the Holocene maximum sea level in Fiji.

7.1. Last Interglacial sea level

Last Interglacial corals on Viwa Island in western Fiji (see inset in Fig. 1) were dated by Taylor (1978) and Nunn and Omura (1999). Minimum emergence magnitudes, based on the elevations of the dated samples above the modern reef surface are 2.1–3.1 m. However, if the cliff-top surfaces above the dated samples are taken as marking the associated Last Interglacial sea-level maximum and these are assumed to have then been growing below this level, emergence magnitudes become 4.6–7.1 m. This figure is similar to most estimates of Last Interglacial sea-level maximum (e.g. Chappell, 1974, 1983; Israelson and Wohlfarth, 1999). Since there is no sign of tectonic disruption of the Viwa limestones, it is concluded that Last Interglacial sea level in the Fijian region reached 4.6–7.1 m above its present mean level.

Since Last Interglacial palaeoshorelines within the study area all fall within this range, this suggests that no net uplift has occurred here within the latest Quaternary. This interpretation conflicts with the evidence that this part of the Lau Ridge has been rising for the past 1.4 Myr or so which is why such great thicknesses of shallow-water reefal limestones are exposed. A position which encompasses both views is to suppose that Pleistocene uplift of the Lau Ridge was faster than hitherto supposed and that it effectively ceased before the Last Interglacial.

Resolution of this issue might be achieved by dating the higher-level shorelines and low terraces

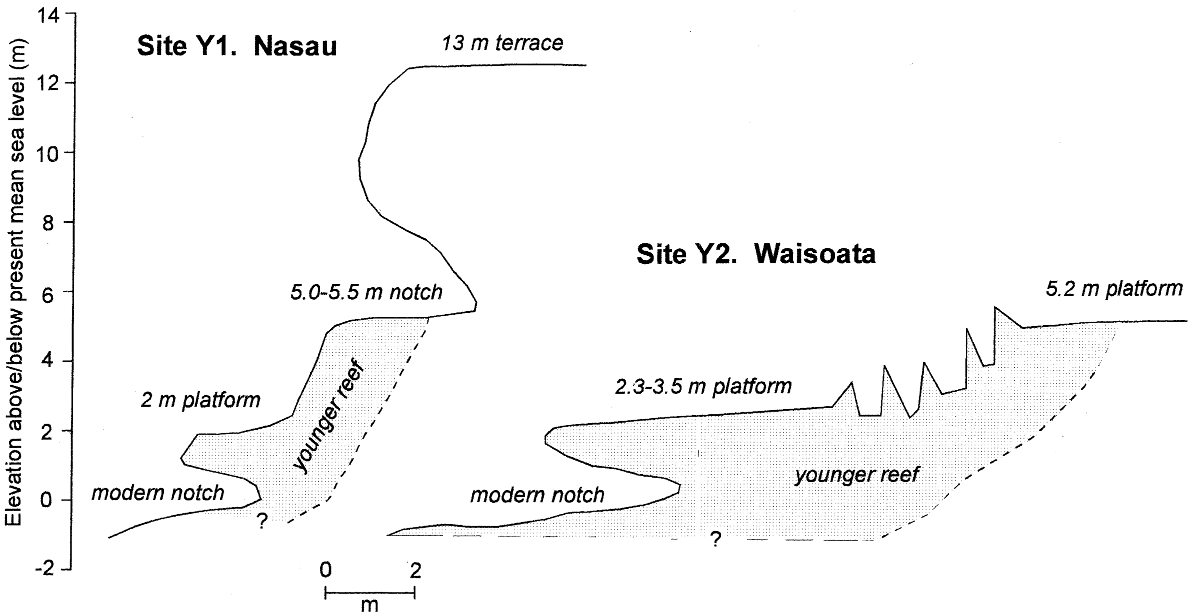

Fig. 8. Coastal sections at Nasau and Waisoata on Yacata Island.

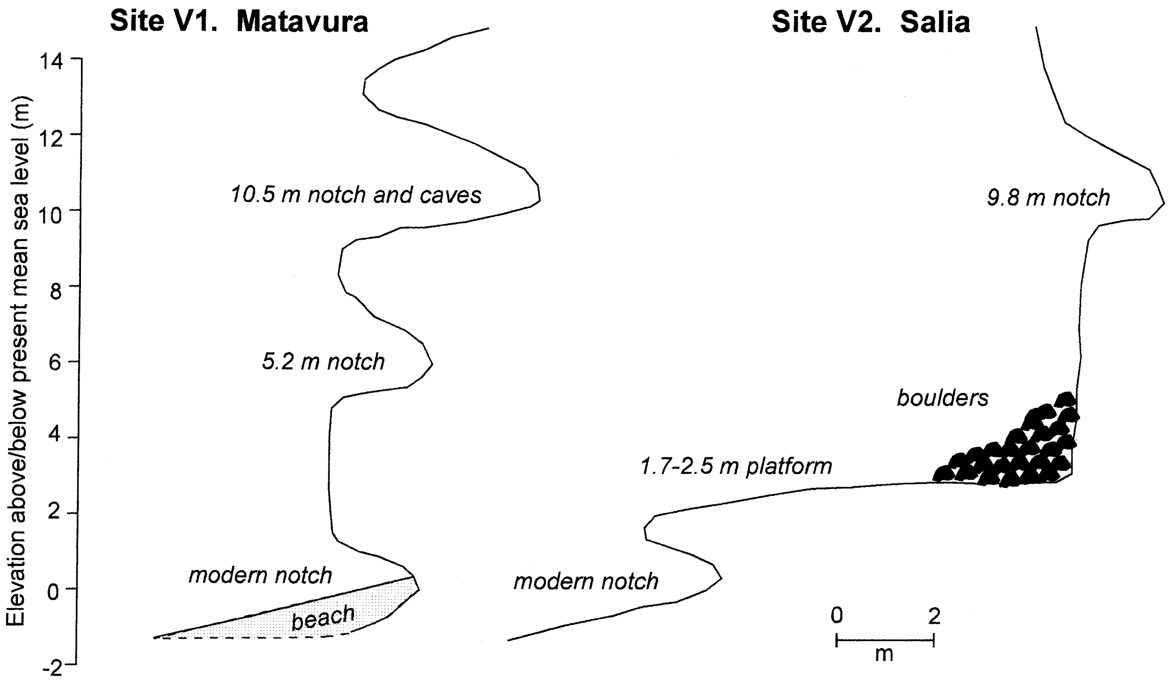

Fig. 9. Coastal sections at Matavura and Salia on Vatuvara Island.

Table 3
Comparison of mean emergence magnitudes (m) for the (groups of) islands studied with other key sites in the Fiji–Tonga region

	Holocene shoreline	Last Interglacial shoreline	Higher-level shoreline[a]
Vanuabalavu group			
Vanuabalavu	1.1 (0.9–1.3)	–	–
Avea	0.2	–	–
Namalata	1.1 (0.8–1.5)	5.1	–
Mago	2.5 (2.0–3.0)	5.0	–
Yacata and Kaibu group			
Kaibu	–	5.2	9.05 (8.9–9.2)
Yacata	2.8 (2.0–3.5)	5.3 (5.0–5.5)	–
Vatuvara	2.1 (1.7–2.5)	5.2	10.15 (9.8–10.5)
ICE-4G model predictions[b]	2.0		
Fiji – general[c]			
most likely	1.4 (1.35–1.50)[d]	2.68 (2.1–3.1)[e]	
possibly	2.1[e]		

Note that an absence of data is not an indication that an emerged shoreline at the particular elevation is absent on the particular island only that its emergence magnitude was not precisely measured.

[a] Note that the term 'shoreline' in this context refers only to features < 10 m above the modern shoreline.
[b] Specific to the Vanuabalavu–Mago area.
[c] Tectonic effects removed.
[d] Nunn and Peltier (2001).
[e] Mean of three dates from Viwa Island: Taylor (1978) and table 2 in Nunn and Omura (1999).

on the islands concerned with a view to determining precise uplift rates but so far all samples have proved unsuitable for dating because of recrystallisation.

7.2. Middle Holocene sea level

The presence of an emerged shoreline marking the culmination of Holocene (postglacial) sea-level rise is consistent with the picture from elsewhere in this region (Nunn, 1995). In addition, infilled karstic hollows near modern sea level were cored on Yacata and Kaibu, Mago and Namalata islands to depths of at least 5 m below sea level. The basal dates are all derived from leaf and algal organics formed in shallow lakes during this period of sea-level rise. The sites show a transition to shallow water or swamp at 4–3000 BP. This may reflect a fall in groundwater level which is controlled largely by sea level (Clark and Hope, 2001).

There is a disparity of around 1 m between elevations of the highest emerged Holocene shoreline in the Vanuabalavu group and that in the rest of the study area suggesting that the latter has risen *relative* to the former at a rate of perhaps 0.25 mm/a^{-1}. If it is assumed that uplift did not affect any part of the study area during the latest Quaternary (see above) then this disparity has to be explained by subsidence of the Vanuabalavu group at the same rate. This helps explain the comparative absence of erosional and aggradational evidence for a middle Holocene highstand of sea level in the Vanuabalavu group.

7.3. Discussion and conclusions

There is a disparity between late Quaternary tectonics in the two constituent areas of northeast Fiji studied, and the first question to be answered is whether this is an expression of block faulting of the entire Lau Ridge, or an indicator of lithospheric flexure associated with Plio–Pleistocene volcanic loading.

The case for block faulting of the northern part of the Lau Ridge derives largely from mapping of structural lineations (Woodhall, 1985), but most of these must have been inactive for most of the Quaternary since they have not faulted the levels of various emerged shorelines across the group (Nunn, 1996). If the Vanuabalavu structural block has been subsiding throughout the late Quaternary, then this could be part of the tensional rifting which during the same period affected eastern Vanualevu and Taveuni, an island 90 km northwest of Vanuabalavu which has been volcanically active during the Holocene. The postrifting volcanism on Vanuabalavu and surrounding islands could be explained in the same way. Woodhall (1985) concluded that late Quaternary rifting in this area was a result of the continuing anticlockwise rotation of the Fiji Platform.

Alternatively it is possible that the Vanuabalavu Island group represents a discrete load on the lithosphere in the region and that part of the resulting tectonic response has been to cause subsidence in the centre and to elevate the surrounding area. Similar situations are known to have occurred in other Pacific Island groups (McNutt and Menard, 1978; Dickinson, 1998; Dickinson and Green, 1998), although are unlikely to be occurring at present in the study area because flexural compensation is generally complete within 100 000 years of the imposition of a volcanic load. A characteristic moat-and-arch bathymetry is not readily observable in the available bathymetry (see Fig. 1).

It is unclear how the anomalously young volcanism (Mago Volcanic Group: 2.53–0.28 Ma) on two islands (Mago and Yanuyanu) in the study area might be linked to either of these explanations of the tectonic disparity. It is possible that tensional rifting of the study area allowed magma access to the surface locally in the study area. It is also possible that collapse of voided magma chambers beneath the Vanuabalavu group may have contributed to its subsidence.

Studies of coastal geomorphology and emerged reefs in the islands of northeast Fiji have shown that there are two distinct areas: the Vanuabalavu Island group which has been subsiding during the late Quaternary and the surrounding area which has been uplifted. Although no one explanation is favoured, answers to the kinds of questions which are raised by this study could help an understanding of the present geotectonic complexity in the tropical Pacific.

Acknowledgements

We are grateful to Ratu Sir Kamisese Mara for his permission to work in these islands. For their hospitality, assistance and interest in this study we are also grateful to the people of Yacata, especially Etuate Vulakoro; the then-owners of Kaibu, Scott Johnson and family, and to the Manager at the time of fieldwork, Kolinio Bavatu; to the owners of Mago, Tokyu Corporation (Japan), and to Davi and Mani Prasad and the people of Mago; to the people of Vanuabalavu especially Tevita Fotofili of Sawana; and to Sepeti Matararaba of the Fiji Museum. For assistance in the field we thank Francis Areki, Stephen Bay, Lepani Cavu, Carl Corby, Bill and Jackie Dickinson, Kristine Korsgaard, Roselyn Kumar, Sina Lui, Alifereti Naikatini, Rachel Nunn, Warwick Nunn, Tamara Osborne, Peni Puamau, Nirupa Ram, Finau Ratuvili, Monika Swamy, Epeli Tawake, Bren Weatherstone, and the crew of the *Sere-ni-Wai*. Most of this research was funded by the University of the South Pacific. Thanks are also due to William R. Dickinson and Joyce Lundberg for their incisive comments on an early draft of the manuscript.

References

Agassiz, A., 1899. The Islands and Coral Reefs of Fiji. Bull. Mus. Comp. Zool., Harvard, 33.

Andrews, E.C., 1900. Notes on the Limestones and General Geology of the Fiji Islands, with Special Reference to the Lau Group. Bull. Mus. Comp. Zool., Harvard, 38.

Berryman, K., 1979. Seismotectonic Zoning of the Fiji Islands. N.Z. Geol. Surv. Rep. 70.

Chappell, J., 1974. Geology of coral terraces, Huon Peninsula, New Guinea: a study of Quaternary tectonic movements and sea level changes. Geol. Soc. Am. Bull. 85, 553–570.

Chappell, J., 1983. A revised sea-level curve for the last 300 000 years from Papua New Guinea. Search 14, 99–101.

Clark, G., Hope, G., 2001. Archaeological and palaeoenvironmental investigations on Yacata Island, northern Lau, Fiji. Domodomo 13, 29–47.

Coleman, P.J., 1980. Plate tectonics background to biogeographic development in the southwest Pacific over the past 100 million years. Palaeogeogr. Palaeoclimatol. Palaeoecol. 31, 105–121.

Davis, W.M., 1920. The islands and coral reefs of Fiji. Geogr. J. 55, 34–45, 200–20, 377–88.

Dickinson, W.R., 1998. Geomorphology and geodynamics of the Cook-Austral island-seamount chain in the South Pacific Ocean: implications for hotspots and plumes. Int. Geol. Rev. 40, 1039–1075.

Dickinson, W.R., Green, R.C., 1998. Geoarchaeological context of Holocene subsidence at the Ferry Berth Lapita site, Mulifanua, Upolu, Samoa. Geoarchaeology 13, 239–263.

Fiji Mineral Resources Department, 1994. Lau. 1:250 000 Bathymetric Map Series Sheet 6 (MRD 818).

Foye, W.G., 1917. The geology of the Lau Islands. Am. J. Sci. 43, 343–350.

Hopley, D., 1984. The Holocene 'high energy window' on the central Great Barrier Reef. In: Thom, B.G. (Ed.), Coastal Geomorphology in Australia. Academic Press, London, pp. 135–150.

Israelson, C., Wohlfarth, B., 1999. Timing of the Last Interglacial high sea level on the Seychelles Islands, Indian Ocean. Quat. Res. 51, 306–316.

Kroenke, L.W., 1984. Cenozoic Tectonic Development of the South-West Pacific. United Nations ESCAP, CCOP/SOPAC Tech. Bull. 6, 126 pp.

Ladd, H.S., Hoffmeister, J.E., 1945. Geology of Lau, Fiji. Bernice P. Bishop Mus., Honolulu, Bull. 181.

McNutt, M., Menard, H.W., 1978. Lithospheric flexure and uplifted atolls. J. Geophys. Res. 83, 1206–1212.

Milsom, J.S., 1970. The evolution of the Lau Ridge, Fiji Islands. Earth Planet. Sci. Lett. 8, 258–260.

Nunn, P.D., 1987. Late Cenozoic tectonic history of Lau Ridge, Southwest Pacific, and associated shoreline displacements: review and analysis. N.Z. J. Geol. Geophys. 30, 241–260.

Nunn, P.D., 1990. Coastal geomorphology of Beqa and Yanuca islands, South Pacific Ocean, and its significance for the tectonic history of the Vatulele-Beqa Ridge. Pac. Sci. 44, 348–365.

Nunn, P.D., 1995. Holocene sea-level changes in the South and West Pacific. J. Coast. Res. Spec. Issue 17, 311–319.

Nunn, P.D., 1996. Emerged Shorelines of the Lau Islands. Fiji Miner. Resour. Dep. Mem. 4, 99 pp.

Nunn, P.D., 1998. Late Quaternary tectonic change on the islands of the northern Lau-Colville Ridge, southwest Pacific. In: Stewart, I.S., Vita-Finzi, C. (Eds.), Coastal Tectonics. Geol. Soc. Lond. Spec. Publ. 146, 269–278.

Nunn, P.D., Omura, A., 1999. Penultimate Interglacial emerged reef around Kadavu Island, Southwest Pacific: implications for late Quaternary island-arc tectonics and sea-level history. N.Z. J. Geol. Geophys. 42, 219–227.

Nunn, P.D., Peltier, W.R., 2001. Far-field test of the ICE-4G (VM2) model of global isostatic response to deglaciation: empirical and theoretical Holocene sea-level reconstructions for the Fiji Islands, Southwest Pacific. Quat. Res. 55, 203–214.

Nunn, P.D., Ollier, C.D., Rawaico, N.B., 1991. Caves of eastern Fiji. Helictite 29, 42–47.

Nunn, P.D., Veitayaki, J., Ram-Bidesi, V., Vunisea, A., 1999. Coastal issues for oceanic islands: implications for human futures. Nat. Resour. Forum 23, 195–207.

Nunn, P.D., Matararaba, S., Ramos, J., 2000. Investigations of anthropogenic sediments in Qaranilaca (cave), Vanuabalavu Island, Fiji. Archaeol. N.Z. 43, 125–156.

Rodda, P., 1994. Geology of Fiji. In: Stevenson, A.J., Herzer, R.H., Ballance, P.F. (Eds.), Geology and Submarine Resources of the Tonga-Lau-Fiji Region. SOPAC Secretariat, Suva, SOPAC Tech. Bull. 8, 131–151.

Sawyer, B., Andrews, E.C., 1901. Notes on the caves of Fiji with special reference to Lau. Proc. Linn. Soc. N.S.W. 26, 91–106.

Taylor, F.W., 1978. Quaternary Tectonic and Sea-Level History, Tonga and Fiji, Southwest Pacific. Unpublished Ph.D. Thesis, Cornell University, Ithaca, NY.

Toggweiler, J.R., Dixon, K., Broecker, W.S., 1991. The Peru upwelling and the ventilation of the South Pacific Thermocline. J. Geophys. Res. 96, 20467–20497.

Whelan, P.W., Gill, J.B., Kollman, E., Duncan, R., Drake, R., 1985. Radiometric dating of magmatic stages in Fiji. In: Scholl, D.W., Vallier, T.L. (Eds.), Geology and Offshore Resources of Pacific Island Arcs – Tonga Region. Circum-Pacific Council for Energy and Mineral Resources, Houston, TX, pp. 415–440.

Woodhall, D., 1985. Geology of the Lau Ridge. In: Scholl, D.W., Vallier, T.L. (Eds.), Geology and Offshore Resources of Pacific Island Arcs – Tonga Region. Circum-Pacific Council for Energy and Mineral Resources, Houston, TX, pp. 351–378.

Woodhall, D., in press. Geology of the Lau Islands. Fiji Miner. Resour. Dep. Bull. 9.