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Coastal Processes and Landforms of Fiji: Their Bearing on Holocene Sea-Level Changes in the South and West Pacific*

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ABSTRACT

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In Fiji, the legacy of past sea-level changes, notably those of Holocene age, cannot be deciphered on modern coastlines without reference to the contemporary local tectonic regime. The structure and the dominant tectonic tendency for each constituent element of the Fiji islands during the late Quaternary include: (a) areas of predominant uplift and perhaps vertical creep, such as Cikobia and Taveuni; (b) areas where subsidence dominated between intermittent bursts of uplift, such as the Cakaudrove coast of Vanua Levu and parts of Viti Levu's south coast; areas where subsidence was dominant, such as the Yasawa and Mamanuca island groups and the Yasayasa Moala; and (d) areas which were (effectively) stable, such as the islands of the Lau Ridge and Lomaiviti.

Evidence for low-level/Holocene shoreline displacement from Fiji's coasts can be interpreted in the context of local tectonics. Average shoreline displacement increases from areas where subsidence has been dominant through those which have been (effectively) stable to those where uplift has been dominant. The likeliest explanation for this pattern of shoreline displacement is one involving a uniform Holocene emergence, probably a sea-level fall and not a regional hydro-isostatic effect, being imposed on local tectonics. Dates from emerged Holocene shorelines in Fiji suggest that the Holocene transgressive maximum reached 1–2 m above present mean sea level some 3,000–2,000 years ago.

Selected aspects of Holocene coastline development are described in the context of the sea-level history established earlier. These include river-mouth and coastal progradation, which seems to have been most marked on stable or slowly subsiding coasts; coastal dune accumulation, which may have been more closely linked to Holocene eustatic and tectonic changes than hitherto suspected; beachrock and related deposits; lagoon infilling and coral-reef emergence; and the effects of catastrophic events, particularly storm surges, on Fiji's coasts.

An account is also given of the explanations which the deduced Holocene sea-level history provides for aspects of contemporary settlement history which have long puzzled prehistorians. Some discussion of shoreline movements in the last fifty years and in the future in Fiji concludes the paper.

ADDITIONAL INDEX WORDS: *Mid-ocean islands, Fiji, sea-level changes, Holocene coastline development, tectonics, uplift, subsidence, coral reefs.*

INTRODUCTION

For a variety of purposes, calls have been made over the last few years for increased studies of the evidence for sea-level change around mid-ocean islands (*e.g.* BLOOM, 1967; CLARK, 1980; NUNN, 1984) but these calls have gone largely unheeded. This appears symptomatic of a reluctance on the part of many Earth scientists to conduct investigations of small islands, particularly those in the middle of oceans, although there are abundant reasons for them to do so (NUNN, 1987a).

The present paper summarizes the current state of knowledge about Holocene sea-level changes in Fiji, a physiographically and geologically diverse group of islands (RODDA, 1975; 1986) occupying an area of 18,376 km^2, for which the regional tectonic framework is not well known (COLLEY and HINDLE, 1984; KROENKE, 1984; NUNN, 1988a). Knowledge of the pattern of Holocene sea-level change within the archipelago allows this framework to become more sharply focused and aids the solution of certain Holocene sea-level problems of wider geographical applicability.

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HOLOCENE SEA-LEVEL PROBLEMS IN THE SOUTHWEST PACIFIC

Many early geological investigations of Pacific island coasts (*e.g.* WENTWORTH and PALMER, 1925; DALY, 1934) concluded that widespread relative emergence had occurred. The later inference that many emerged strandline features were of Holocene age (RUSSELL, 1961; SCHOFIELD, 1964) led to the belief that there had been a Holocene high sea level in the Pacific Basin. This was challenged and, for many, effectively dismissed by the findings of the 1967 CARMARSEL expedition, which found a conclusive absence of 'emerged' Holocene shoreline indicators in part of the northwest Pacific (BLOOM, 1970a, 1970b; CURRAY *et al.*, 1970), a result also obtained by EASTON and OLSON (1976) for Hawaii.

The 'Micronesia' sea level curve (Figure 1), which derived from the work of the CARMARSEL expedition, was considered by BLOOM (1980: 505) to be a "reference standard" which could be extended across much of the Pacific, including the part with which this paper is concerned. Displaced Holocene shoreline indicators in the southwest Pacific which deviate from the Micronesia curve were explained by BLOOM (1980) as having been affected by tectonic activity, an indisputable condition for most examples cited.

Although the model involving no Holocene sea level higher than the present in the western Pacific has gathered support, as has a similar model elsewhere in the world (*e.g.* BELPERIO, 1979; JELGERSMA, 1980), SCHOFIELD has presented evidence favoring a contrary view for the southwest Pacific (SCHOFIELD, 1970, 1977a, 1980; SCHOFIELD and SUGGATE, 1971). This has received empirical support from within the region (GUILCHER, 1970; BUDDEMEIER *et al.*, 1975; EASTON and KU, 1980; ROY and RICHMOND, 1987) but, perhaps more importantly, theoretical support from the global models of CLARK *et al.* (1978) and CLARK (1980). Much of the western and central Pacific, and all the south Pacific, lie within CLARK's (1980) Zone V where he calculated that up to 2 m of Holocene coastal 'emergence' had taken place. In support of this, he cited SCHOFIELD's (1964) study (Figure 2).

PIRAZZOLI's (1978) synthesis of Holocene sea-level changes in the northwest Pacific led him to conclude tentatively that there has probably been no contemporary sea level higher than the present in the region, but he has since reported clear evidence to the contrary (PIRAZZOLI and DELIBRIAS, 1983; PIRAZZOLI *et al.*, 1984, 1985, 1988). The effects of a late Holocene regression were also reported by workers on the Great Barrier Reef in eastern Australia (*e.g.* GILL and HOPLEY, 1972; HOPLEY, 1978)

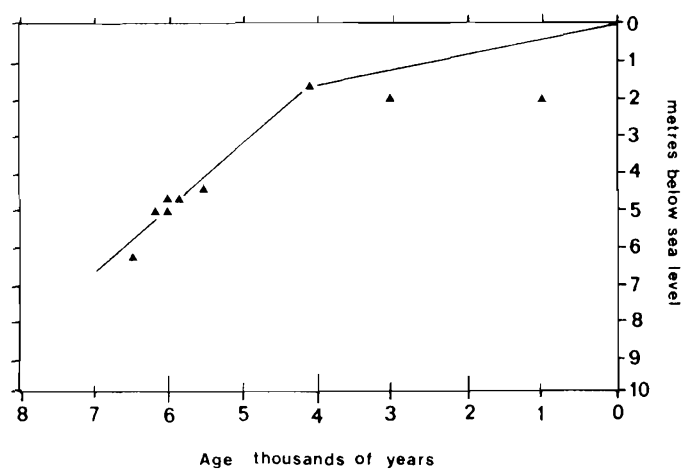


Figure 1. The Micronesia sea-level curve considered as a standard for much of the Pacific (after Bloom, 1970a). Triangles represent radiocarbon-dated samples.

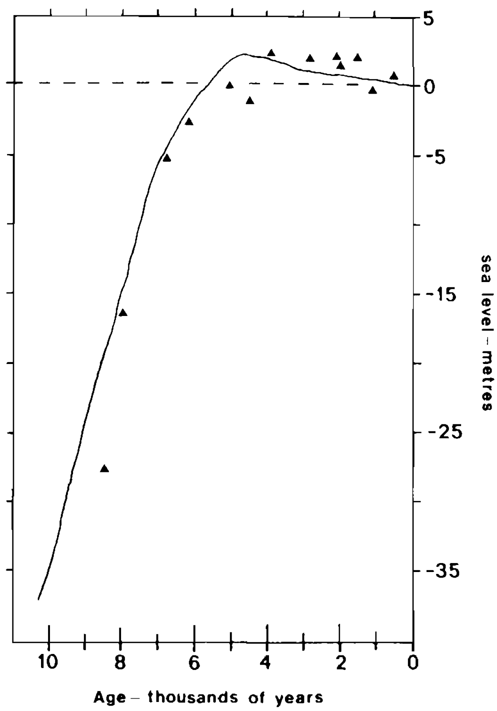


Figure 2. Comparison of predicted Holocene sea-level change with Schofield's (1964) observations for Clark's Zone V in the southwest Pacific (after Clark, 1980). Triangles represent radiocarbon-dated samples.

though their interpretation was questioned by BELPERIO (1979). In a synthesis of New Zealand data, GIBB (1986) concluded that the transgressive maximum in the last 6,500 years was about 0.5 m above present sea level some 3,500 years ago.

Important questions in the south and west Pacific are whether the sea exceeded its present level during the Holocene, as SCHOFIELD (1980) claimed, or whether it did not, as BLOOM (1980) averred, and whether this was a regional phenomenon, as most writers have implied, or one which varied from place to place, as CHAPPELL *et al.* (1983) and HOPLEY (1987) argued. The answers to these questions have implications for the past, for the understanding of Pacific prehistory (GIBBONS and CLUNIE, 1986; NUNN, 1987b, 1988b) for example, and for the future, especially as regards the relative stability of many Pacific island coastlines (*e.g.* NUNN, 1987c) and the future behaviour of sea level within the region (NUNN, 1987d). Likewise they can illuminate such diverse phenomena as upper Earth rheology (WALCOTT, 1972), deglaciation regimes (NAKIBOGLU *et al.*, 1983) and geoidal eustasy (NUNN, 1986) in the region.

COASTAL GEOMORPHOLOGICAL WORK IN FIJI—AN OVERVIEW

The earliest work in Fiji (see Figure 3) was that of DANA (1872) and AGASSIZ (1899; 1903) who emerged on different sides of the debate about whether or not Fiji was part of DARWIN's (1838; 1842) zone of Pacific Basin subsidence, Dana following Darwin, Agassiz opposing, primarily as the result of his (Agassiz's) work among the high limestone islands of Lau in eastern Fiji. The resulting controversy inevitably influenced those who followed (ANDREWS, 1900, 1916; FOYE, 1917, 1918; DAVIS, 1916, 1920, 1927).

DANA (1872) noticed a difference in signs of recent relative emergence in various places within the Fiji archipelago and this was

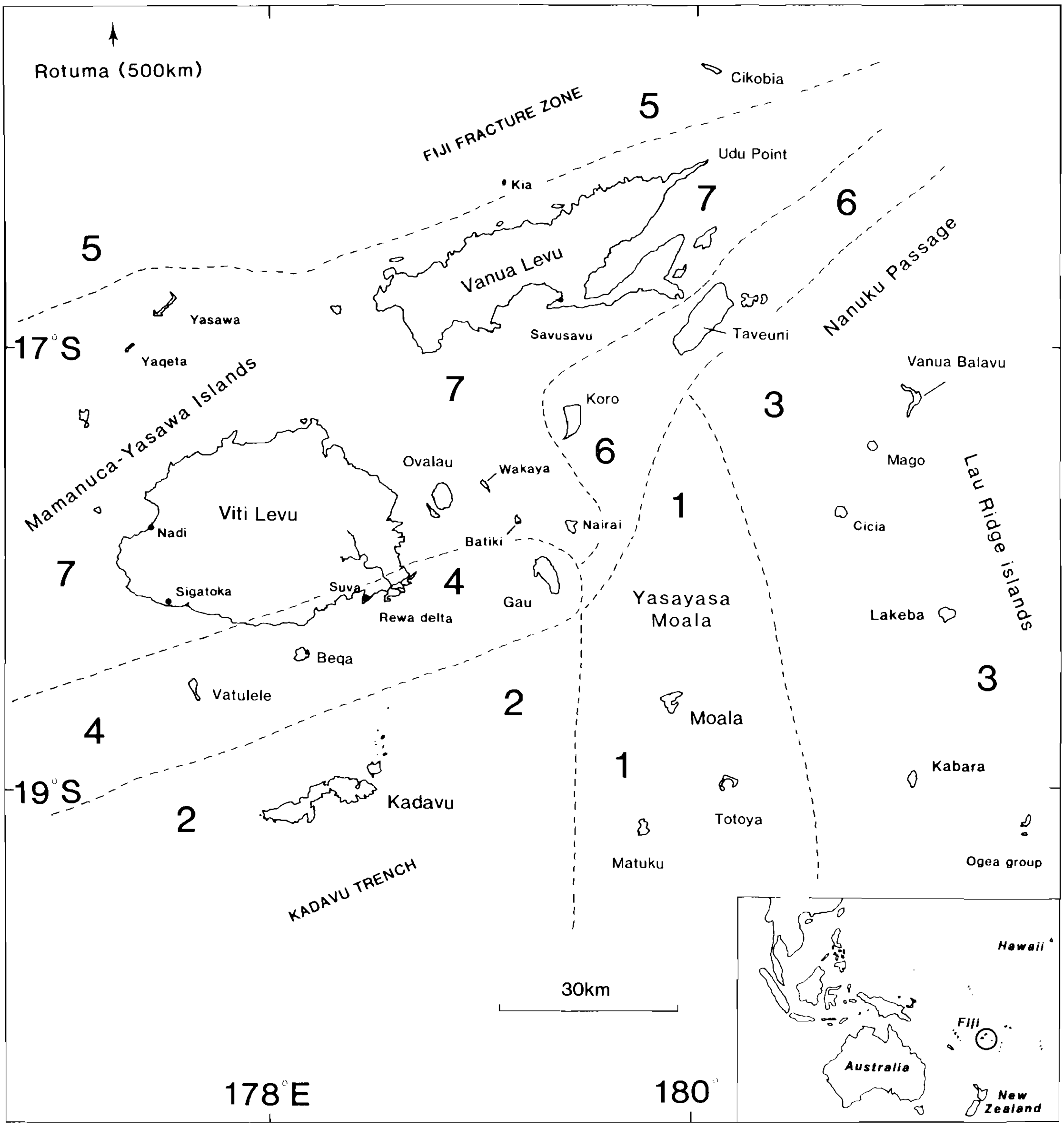


Figure 3. Tectonic divisions (1–7) of Fiji, see text for details. Rotuma (177°E, 12.5°S) and the southernmost islands of the Lau group are not shown.

detailed by DAVIS (1927, 1928), who explained the tectonic development of the small islands in central and eastern Fiji by the migration of an anticline from west to east[1]. DAVIS equated asingle barrier or fringing reef with a single phase of subsidence inferring, where both

1. Davis' (1927) perspicacity was remarkable. The idea of a migrating anticline, rather an obscure and abstract notion at the time, with the amplitude and moving at the rate Davis envisaged is compatible with that of a (positive) migrating geoid anomaly. The importance of the migration of these in causing the apparent uplift of many Pacific island reefs was discussed by Nunn (1986): specific

occurred around a single island, that 'second-generation subsidence' was in progress (DAVIS, 1920, 1927, 1928).

The work of LADD (1930, 1934) and LADD and HOFFMEISTER (1927, 1945) was concentrated in southern and eastern Fiji and is still the most recent comprehensive geomorphic work available today for some parts. Contrary to DAVIS' (1927, 1928) generalization that there was no low-level 'eustatic' shoreline in Fiji, Ladd and Hoffmeister found a 'postglacial' shoreline in many places. LADD and HOFFMEISTER (1945) also dismissed many of Davis' ideas about Lau islands being 'raised atolls', atolls which had undergone uplift before second-generation subsidence had begun (see NUNN, 1987c for discussion).

More recent work on Fiji's coastline has, with the exception of incidental observations recorded in Geological Survey publications, broadly reflected the disparate views outlined above. Japanese workers (MATSUSHIMA *et al.*, 1984; MAEDA *et al.*, 1986; MIYATA *et al.*, 1988; SUGIMURA *et al.*, 1988) have reported evidence for a Holocene high sea level in places: other workers have found evidence for a low-level shoreline (*e.g.* BROWN, 1986; NUNN, 1987b, 1988a) but have lacked dates to demonstrate its apparent Holocene age. BERRYMAN (1979) inclined to the idea that there had been no sea level higher than the present during the Holocene in Fiji.

CONTEMPORARY TECTONIC ENVIRONMENTS OF FIJI

Evidence for Quaternary shoreline displacement cannot be evaluated properly without reference to contemporary tectonics. Attempts to classify tectonic environments within the structurally complex archipelagos of the south and west Pacific frequently encounter problems arising from the lack of agreement over details of the regional geotectonic (plate-tectonic) framework. In Fiji, there is no consensus as to the location of the major boundary or boundaries between the Indo-Australian and Pacific lithospheric plates, for example. Any tectonic classification must necessarily therefore be tentative and subject to change until such time as data are available throughout the region to enable a more precise picture to emerge.

At present, however, the most fruitful approach has been through a study of seismicity, both contemporary from patterns of historical earthquakes (ISACKS *et al.*, 1967; EVERINGHAM, 1986) and over the late Quaternary through analysis of likely shoreline displacements, both in Fiji (TAYLOR, 1978; BERRYMAN, 1979; NUNN, 1988a) and elsewhere in the Pacific (OTA, 1986; PILLANS, 1987). The classification below is based on these together with inferences from the likely structural pattern within the region.

The tectonic divisions of Fiji are shown in Figure 3 and the character of each summarized below. It is stressed that this is intended to be a contemporary picture, thought to be applicable to the late Holocene, of tectonics within a region which has evidently been actively evolving throughout the late Cenozoic. With reference to Figure 3, tectonic divisions are as follows.

Yasayasa Moala[2] (Figure 3, Division 1)

Insufficient is known to characterize present tectonics but unpublished data from Moala, collected by the present writer (NUNN, 1988a), and Totoya (FARNELL, 1987; ROOK, 1987) show that (late) Quaternary shoreline emergence and rifting has occurred. Earthquakes have been felt in Moala and Matuku during the last fifty years (EVERINGHAM, 1984, and *personal communications* from islanders). COULSON (1976) suggested that the Hunter Fracture Zone, as the Kadavu Trench complex (see below) was then known, might extend eastwards through the prominent Uciwai Bay rift on Moala. KROENKE (1984) and others doubted this, extending the Kadavu subduction zone along an arc to the northwest of the Moala group. This interpretation suggests that the islands' recent tectonic history could be the result of lithospheric flexure. Intermittent uplift during the late Quaternary has undoubtedly been separated by periods of subsidence as would be expected as the result of lithospheric cooling. The last volcanic activity on Moala was

reference to geoid changes in the Lau islands of eastern Fiji was made by Nunn (1987c).

2. In Fijian this means 'Moala island group' and comprises the islands of Moala, Matuku and Totoya and the sea-level reef of Navatu. (Facing page).

about 3–4 Ma (COULSON, 1976; NUNN, 1988a).

Kadavu Trench Complex (Figure 3, Division 2)

From south to north, this comprises the Denham Trough, the Denham Ridge, the Astrolabe Trough and the Kadavu Ridge which correspond to a late Quaternary arc-trench couple related to broadly northwards subduction of the Indo-Australian plate in the South Fiji Basin (MALAHOFF *et al.*, 1982; GILL *et al.*, 1984; NUNN, 1988a). Kadavu was the only part of Fiji where calc-alkaline volcanism persisted after the Pliocene (HAMBURGER, 1986): volcanic activity at Delainabukelevu occurred 0.48 ± 0.92 Ma (WHELAN *et al.*, 1985). Numerous seismic events up to 6.5 MM (Modified Mercalli intensity scale), perhaps higher in the last 130 years (EVERINGHAM, 1986), along the Kadavu trench support the interpretation of the area as an arc-trench complex although its present condition is unclear. HAMBURGER (1986: 8) argued that "the absence of an inclined seismic zone and shallow thrust-type focal mechanisms favor the interpretation that the Hunter Fracture Zone [Kadavu Trench] is not accommodating plate convergence at present." This area is unlikely to have been stable during the late Quaternary and reef configuration suggested to WOODROW (1980) that the main island of Kadavu may be tilting southwards along a west-east axis.

Lau Ridge (Figure 3, Division 3)

This is an abandoned volcanic arc (PACKHAM, 1978; KROENKE, 1984) with a Pliocene to (early?) Quaternary history of relative uplift (NUNN, 1987c). The tectonic component of this uplift may have been caused by heating of a detached lithospheric slab left beneath the ridge since the opening of the Lau Basin (NUNN, 1988c). Isolated volcanic activity occurred on Mago island 0.28 ± 0.12 Ma (WHELAN *et al.*, 1985). Late Quaternary seismicity is thought to have been negligible (BERRYMAN, 1979; EVERINGHAM, 1984; 1986) but this may be a false picture resulting from lack of data. From consideration of regional geotectonics, various writers consider the late Quaternary Lau Ridge to have been stable (MILSOM, 1970) or slowly subsiding (PACKHAM, 1978).

Vatulele-Beqa Ridge (Figure 3, Division 4)

This was thought by BERRYMAN (1979) and KROENKE (1984) to have been affected by right-lateral slip along a northeast striking fault. Contemporary seismicity occurs to 6.75 MM (EVERINGHAM, 1986). Contemporaneous volcanism along the ridge occurred between 4.72 ± 0.19 and 3.07 ± 0.08 Ma (WHELAN *et al.*, 1985). Quaternary uplift on Vatulele and Beqa has been linked to contemporary underplating along the Kadavu trench (NUNN, 1988a; in press, a). Parallelism with the Kadavu Trench complex suggests that the Vatulele-Beqa Ridge may represent an island arc, possibly extending east to Gau island, which was abandoned as the trench migrated southwards and/or the gradient of the Benioff zone increased (BROCHER and HOLMES, 1985). Slow differential subsidence, at least in the Beqa area and along Vatulele's east coast, appears to have characterized this area during the Holocene (NUNN, 1988a).

Fiji Fracture Zone (Figure 3, Division 5)

This is the most seismically active area of Fiji at present, with numerous events up to 6.5 MM north and northwest of Vanua Levu and others to 7.0 MM around Udu Point and to the northeast (EVERINGHAM, 1986). Cikobia island in this area is reportedly rising at 0.5 mm/yr (BERRYMAN, 1979). This zone has been interpreted as a transform fault, along which left-lateral movement is occurring, linking a spreading ridge in the North Fiji Basin with one in the Lau Basin and the Tonga Trench complex to the east (FALVEY, 1975; EGUCHI, 1984).

Koro-Taveuni Line (Figure 3, Division 6)

This is a zone of comparatively recent volcanic activity from 1.8 ± 0.3 Ma on Koro (COULSON, 1976) to 2050 ± 150 years BP on Taveuni (FROST, 1974) and perhaps more recently (WOODHALL, 1980). An interpretation of the Koro-Taveuni line as a leaky transform fault is compatible with the ideas of CHASE (1971), and BROCHER and HOLMES

(1985) that a plate boundary, perhaps defining a microplate, runs along the Nanuku Passage, which separates the western end of the Lau Ridge from the Vanua Levu platform. This would lend some credence to the idea that shoreline uplift on Lau islands was abetted by collision along the Nanuku Passage, an explanation discussed along with others by NUNN (1987c; 1988c). Holocene volcanism on Taveuni has probably caused slight emergence of the island as the result of thermal dilation of the lithosphere but the recorded signs of this are few.

Yasawa-Viti Levu (except southeast)—Vanua Levu (Figure 3, Division 7)

Historical records of seismicity in Vanua Levu and northeast Viti Levu (EVERINGHAM, 1983a) probably reflect available data sources. This division undoubtedly has inherent tectonic variability which additional data will allow to be subdivided. The general trend appears to have been intermittent late Quaternary uplift resulting from compression between the Fiji Fracture Zone and the Kadavu trench complex with subsidence dominating between periods of uplift. Updoming of central Viti Levu was proposed by DICKINSON (1972), RODDA (1980) and HAMBURGER (1986) and is supported by seismic records (EVERINGHAM, 1983b). Northwards tilting of the island involving emergence of the south coast and submergence of the north coast was an explanation favoured by MIYATA (1984).

EVIDENCE FOR RECENT SHORELINE DISPLACEMENT

The data presented below include all unambiguous indicators of shoreline displacement in Fiji which are known to be or are potentially of Holocene age. The majority of the data are directional, indicators of sea-level change which form at various heights above or below mean sea level, rather than finite, which include organisms and sediments having a definite relationship with a sea-level datum, in nature (CHAPPELL *et al.*, 1983). Therefore, any conclusions, especially drawn from data distributed across a large area, should be considered preliminary. This section largely excludes sedimentary indicators of relative sea-level changes which, in Fiji, are generally more ambiguous. These are discussed in a later section.

In this account, the raw data are presented by area within Fiji (Figure 3) and followed by a synthesis for the group as a whole. All data in the following account are relative to present mean sea level, many having been converted using tidal corrections for 1988 reported from the closest tidal station (*Anon.,* 1988). Fiji's coastline experiences semi-diurnal tides with a mean tidal range of around 1.1 m, ranging from 0.9 m at Naroi on Moala, to 1.4 m at Galoa Harbour on Kadavu (*Anon.*, 1988).

Yasawa—Mamanuca—Viti Levu

Although no relatively emerged features of certain Holocene age are known from the Yasawa and Mamanuca islands (Figure 4), several low-level indicators of shoreline displacement have been reported, most notably fossil reefs in association with emerged notches, at *c* 0.8 m and *c* 1.5 m at Yaqeta village on Yaqeta island and Nabukeru village on Yasawa island respectively (BERRYMAN, 1979). HOUTZ (1959) found exposed, probably low-tide, shore platforms at 1.3 m on Malolo island.

From Viti Levu (Figure 5), the largest island in Fiji, BLOOM (1980) reported a date of 5,500 ± 110 years BP for a peat 4.3 − 4.9 m below sea level, collected beneath estuarine muds in the Rewa delta, which he believed dated the Holocene transgression prior to later delta progradation. This interpretation is doubted since this area has probably undergone appreciable subsidence during the late Holocene, as the study of historical settlement pattern suggests (PARRY, 1984). The effect of compaction, to which mangrove peats are especially susceptible (GILL and LANG, 1977), was not discussed by BLOOM (1980). Data from the east coast of Viti Levu are summarized in Table 1.

Few clear indicators of Holocene shoreline emergence are known from Viti Levu's north coast, and it may be that Holocene coastal progradation and development of extensive mangrove swamps has been influenced by subsidence, perhaps brought about by south-north (emergence-submergence) tilting of Viti Levu (MIYATA, 1984). An interesting case study is that of Natunuku, the earliest known settlement in Fiji dating from 3,240 ± 100 years BP.

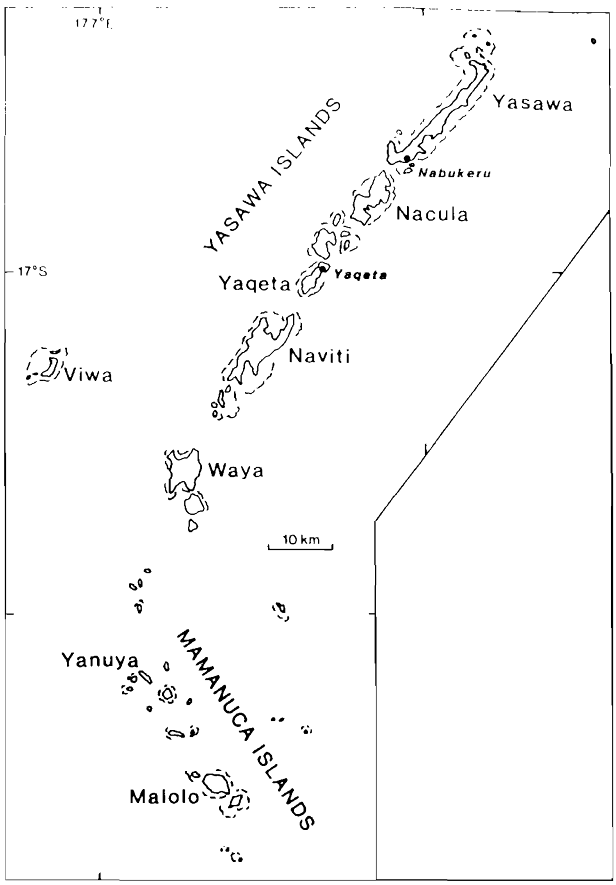


Figure 4. The Mamanuca and Yasawa islands; fluted lines represent the seaward edges of modern reefs.

The site is on consolidated beachrock, suggesting the sea had fallen prior to the time of settlement (GREEN, 1979).

Radiocarbon dates from corals lying just above Lowest Astronomical Tide (LAT) level at three sites along Viti Levu's north coast suggested to ASH (1987) that late Holocene emergence of up to 0.45 m had taken place in the last *c* 5,000 years. Since the amount of apparent emergence is so small, it is doubted whether this caused their death. Instead, since all corals sampled by ASH were buried by sediment, this seems the most likely cause of coral death.

On the west coast of Viti Levu, low-level shorelines displaced with respect to mean sea level are also known (Table 2a). One notable site is Lomolomo Cave, on the floor of which canoes were beached *c* 4,000 years ago, since which time it has apparently 'emerged' by 1.3 m (BERRYMAN, 1979). Observations of spit development at the mouths of the nearby Sabeto and Nadi rivers suggested to BARTHOLOMEW (1960) that late Holocene emergence was continuing in this area.

Exposed shoreline features along Viti Levu's southwest coast (Table 2b) include a Lapita site dated to 2,980 ± 90 years BP resting on a 2.1 m beach at Yanuca Island (GREEN, 1979). The most extensive features are the dunes at Sigatoka, thought to have accumulated "within the last 2,500 years during a marine transgression upon a delta margin" (DICKINSON, 1968: 115), and the fossil reefs around and east of the Sigatoka river mouth, the lower of which, at 1.5 m,

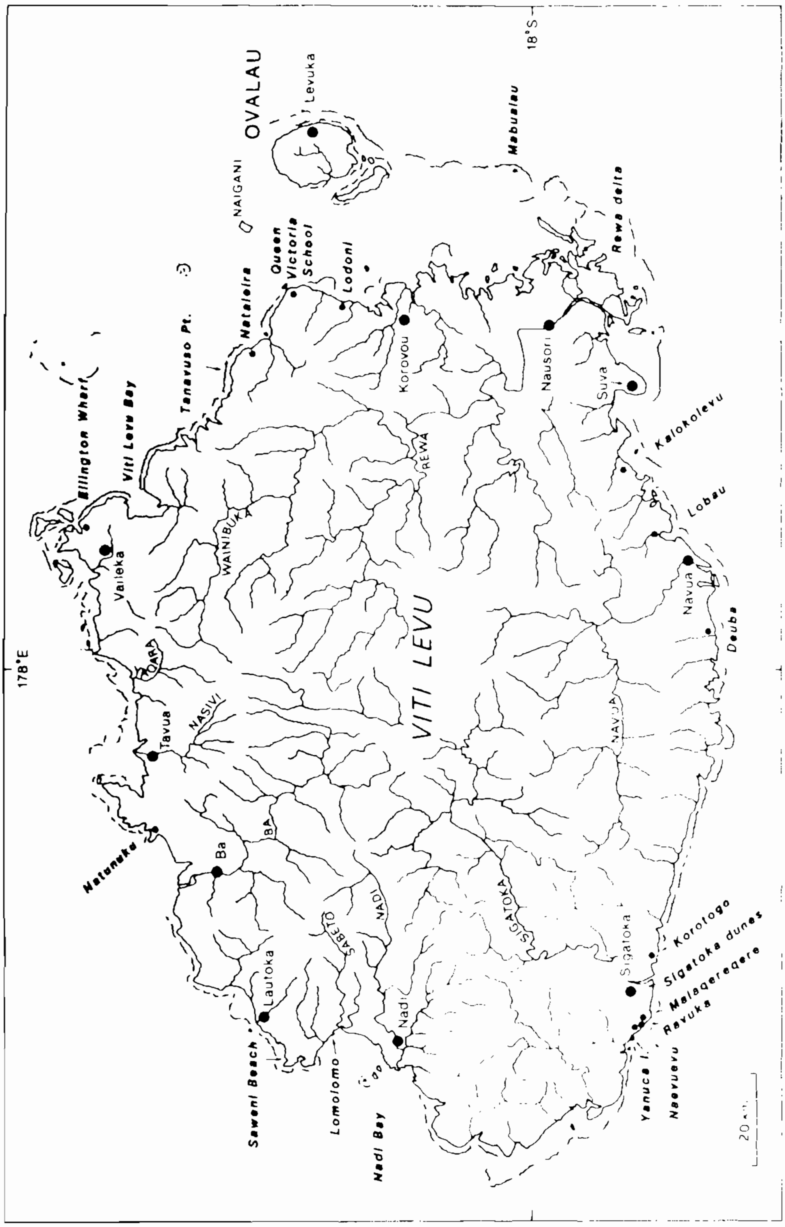


Figure 5. Viti Levu; fluted lines represent the seaward edges of modern reefs.

BERRYMAN (1979) thought was probably of mid-Holocene age. The Sigatoka dunes are discussed in more detail in a later section.

Low-level emerged shoreline features along the eastern part of the south coast of Viti Levu were described in general terms by FOYE (1918) and BERRYMAN (1979). SCHOFIELD (1970) found evidence for a late Holocene high sea level at 0.92 m at Deuba. The reality of a Holocene high sea level of 1.6 m around 2,500 years BP presented by MATSUSHIMA *et al.* (1984) was disputed by ASH and ASH (1985)

Table 1. *Low-level shoreline indicators between Korovou and Vaileka, Viti Levu. Heights are in metres above mean sea level.*

Location	Type	Height (m)	Source of data
Lodoni	terrace	1-4.5	Berryman 1979
Queen Victoria School	terrace	1.5-2.5	Berryman 1979
Nataleira	terrace	c3.0	Berryman 1979
Tanavuso Point	bench/ notch	2.25	Nunn 1954
Viti Levu Bay	notch	c3.0	Ladd 1934
Ellington Wharf	notch	1.0	Berryman, 1979

who re-surveyed the dated sites at Lobau and Kalokolevu, between Navua and Suva. Later work at Lobau by MAEDA *et al.* (1986) and SUGIMURA *et al.* (1988) placed the date of the Holocene high sea level about 1,000 years earlier (Figure 6), which is compatible with the results of recent work carried out at Deuba and Navua showing a *c* 1 m emergence since (late) Holocene coastal progradation commenced (see below).

Vatulele—Beqa—Kadavu—Moala—Lomaiviti[3]

From Vatulele island (Figure 7), MATSUSHIMA *et al.* (1984) dated beach gravels referable to a Holocene sea level a little higher (*c* 0.8 m) than the present to 1,375 ± 65 years BP. The gravels are overlain by extensive coastal dunes at Ekubu village on the east coast of the island, which may be sinking relative to the west coast. The prominent 2.27 m shoreline (Figure 8A), the lowest of a series of four, on Vatulele was regarded as of Last Interglacial age by NUNN (in press, a).

Data from Beqa (Figure 7) were collected by BERRYMAN (1979) and NUNN (preliminary report and analysis—1988a). The latter recognized six relatively emerged shorelines on Beqa and nearby Yanuca[4]; the two lowest at mean elevations of 0.96 m (named MUA1) and 1.93 m (BUL1). Shoreline MUA1 is believed to represent a Holocene shoreline and BUL1 to be the Last Interglacial shoreline, coeval respectively with the two lowest emerged shoreline levels on Vatulele. Relative vertical displacement of as much as 0.25 m has occurred along ridge-normal faults in the Beqa and Yanuca area since shoreline MUA1 was abandoned, perhaps only around 1,300 years ago (*cf.* Vatulele date).

Off the western tip of Kadavu (Figure 7), the 3 m high emerged reef island of Nagigia was described by WOODROW (1980) and, although possibly of Holocene age, especially given the contemporary seismicity of the area (EVERINGHAM, 1986), the coral has not been dated. Low-level shorelines at 1.5 m were reported from the small islands of Ono and Dravuni off northeast Kadavu by BERRYMAN (1979).

Moala, the principal island in the Yasayasa Moala (Figure 9), has been studied in detail by the present writer. A preliminary report is given in NUNN (1988a). A 1.22 m shoreline

3. In Fijian, this means 'center of Fiji', and includes the islands of Batiki, Gau, Koro, Makogai, Moturiki, Nairai, Ovalau and Wakaya.

4. Note that this is the Yanuca island within the Beqa lagoon not that just off the south coast of Viti Levu on which an early archaeological site is found.

Table 2. *Low-level shoreline indicators on the west and southwest coasts of Viti Levu. Heights are in metres above mean sea level.*

Location	Type	Height (m)	Source of data
(a) *West coast*			
Saweni Beach	beachrock[1]	1.0	Berryman 1979
Saweni Beach	notch	2.5	Berryman 1979
north Nadi Bay	beachrock platform	2.5	Berryman 1979
north Nadi Bay	notch	1.6	Ladd 1934
Lomolomo Cave	cave floor	1.3	Berryman 1979
(b) *Southwest coast*			
Malaqereqere	reef platform	0.95-2.15	Ladd and Hoffmeister 1927
Ravuka	cave lip	1.85	Ladd and Hoffmeister 1927
Naevuevu	notch	0.95	Taylor 1978
Yanuca island	notch	1.0	Berryman 1979
Yanuca island	raised beach	2.1	Green 1979

[1] possibly modern

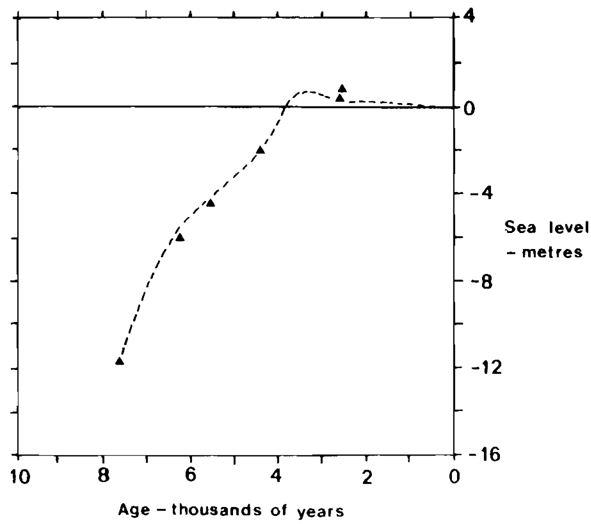


Figure 6. Holocene sea-level curve for Lobau, southern Viti Levu (after Maeda *et al.*, 1986). Triangles represent radiocarbon-dated samples.

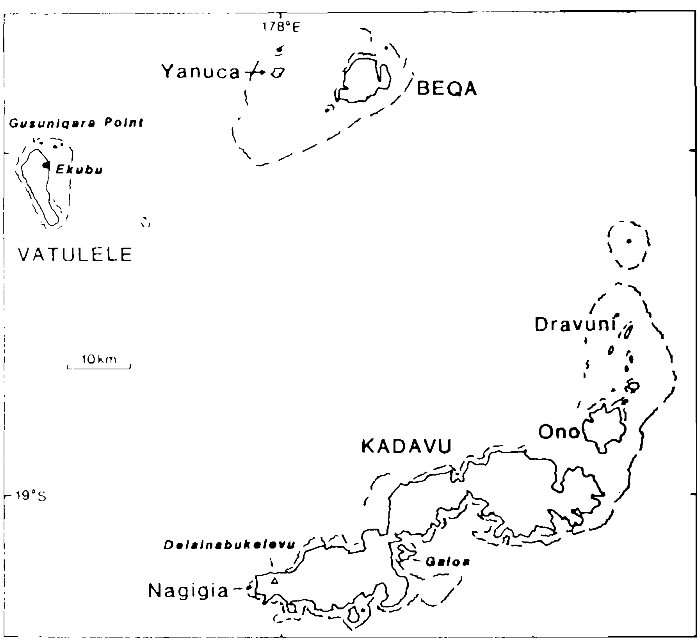


Figure 7. The islands of Vatulele, Beqa and Kadavu; fluted lines represent the seaward edges of modern reefs.

(named MOA1) is present and thought to be of late Holocene age on account of its preservation across areas of contrasting late Quaternary tectonic activity (Figure 8B) *and* because of its altitudinal correlation with a raised beach at Naroi Wharf (Figure 10) dated to between 1,750

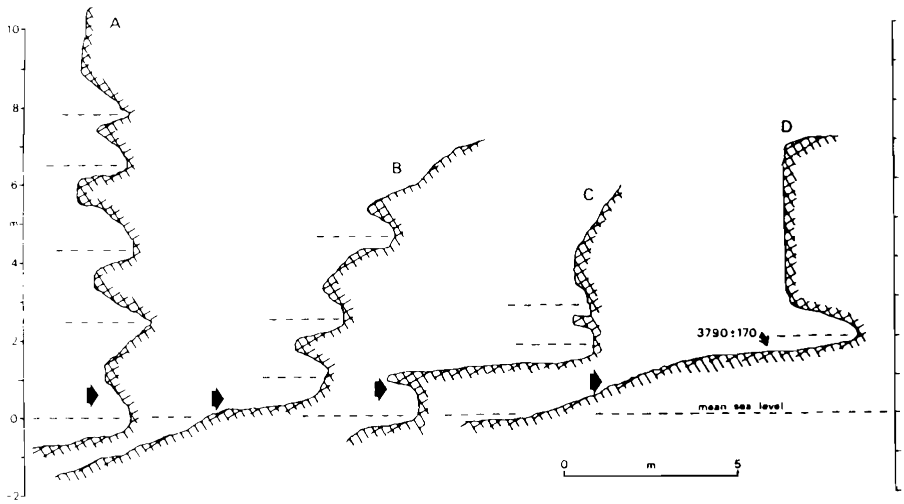


Figure 8. Notch profiles from selected locations in Fiji (Nunn, 1987b). Thick arrows represent approximate mean high-tide levels, higher broken lines are former mean sea levels. Key: (A) Gusuniqara Point, Vatulele (Nunn, in press, a); (B) Nuku, Moala (Nunn, 1988a); (C) beneath Delailagi, Nairai (after Brown, 1986); (D) Maravu Point, Vanua Levu (after Maeda *et al.*, 1986).

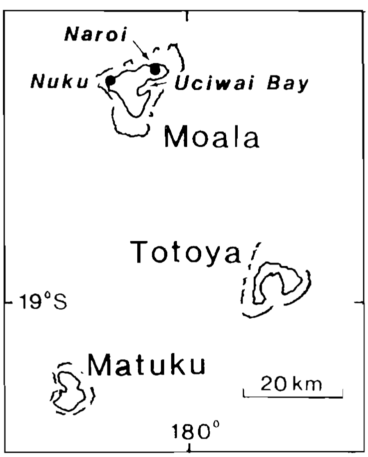


Figure 9. The Yasayasa Moala; fluted lines represent the seaward edges of modern reefs.

± 145 (1.50 m) and 1,180 ± 95 years BP (1.30 m)[5]. Data collected on nearby Totoya (ROOK, 1986; FARNELL, 1987) indicate that a 0.94 m shoreline exists, thought to be Holocene in age because of its preservation intact across areas of assumed late Quaternary rifting. These writers also noted a higher emerged shoreline on Totoya at 1.49 m.

In Lomaiviti (Figure 11), DAVIS (1920: 381) found a *c* 1.3 m "corniced shoreline" along the east coast of Ovalau. A low-level shoreline (Figure 8C) has been recognized on Wakaya, Batiki and Nairai at *c* 2.0 m (BROWN, 1986). Disparities in level of the shoreline between these islands are thought to manifest the rate of subsidence each is currently experiencing. On Wakaya, the lowest emerged shoreline averages 2.26 m but is thought to be pre-Holocene in age. On the east coast of Gau island, the fill of the lowest emerged notch (5.35 m) at Muaigau Point was dated to >40,000 years BP (WK-1368). The amount of emergence here may be partly the result of uplift. Yaciwa, off the southern tip of Gau, is of emergent reef limestone, as are parts of Naigani, northwest of Ovalau (IBBOTSON, 1961; COULSON, 1976); neither formation has been dated.

Vanua Levu—Taveuni—Cikobia—Lau—Rotuma

On Vanua Levu (Figure 12), one of the most fruitful areas for study of late Quaternary

5. The original dates, based on the Libby half-life, were 2,200 ± 110 (WK-1189) and 1,630 ± 60 (WK-1190) years BP. Corrected ages, as given in the text, were derived using a marine correction factor for Tonga of −450 ± 35 years provided by the Radiocarbon Dating Laboratory at the Australian National University.

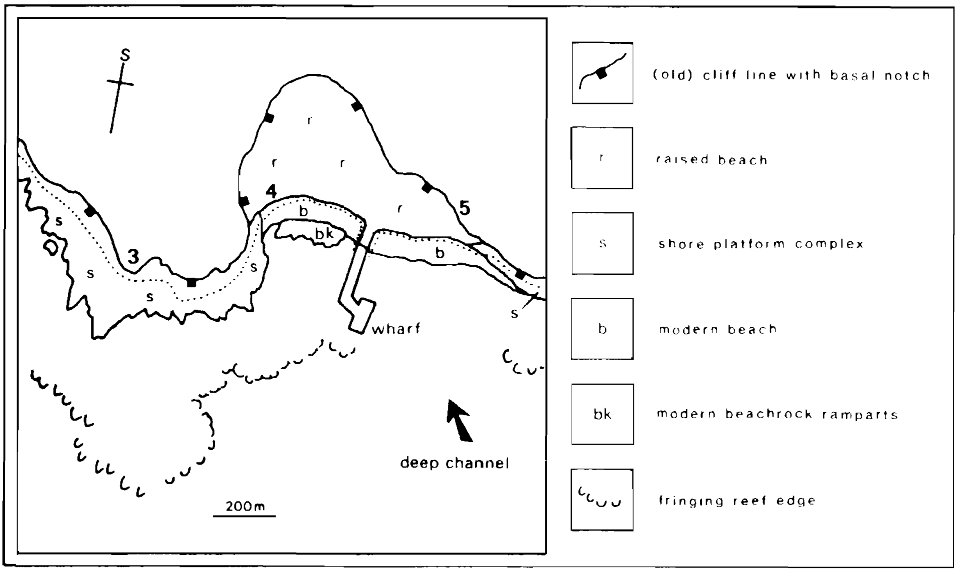


Figure 10. Geomorphological map of Naroi Wharf bayhead (Nunn, 1988a).

shoreline displacements has been the south coast east from Lesiaceva (Savusavu) Point (Table 3). Fossil corals in growth position on the floor of a 2.05—2.25 m (level of innermost point) notch at Maravu Point (Figure 8D) were dated to 3,790 ± 170 years BP (MAEDA *et al.*, 1986). It was claimed that this age represents the 'period of formation' of the notch which has been uplifted in excess of 2 m since this time (MAEDA *et al.*, 1986; MIYATA *et al.*, 1988) but this is not demonstrable. The same authors suggest that the accordance in height of other notches in the vicinity at 0.6 m and 2.3 m may be significant in terms of a Holocene high sea level.

Although, during the Holocene, the sides of Natewa Bay have probably been affected by differential movements, especially subsidence associated with continuing development of the Natewa Bay graben, emerged dead corals in growth position were found near Drekeniwai village (RICKARD, 1966), an emerged reef also occurring at 1 m near Lakeba and Vuniwai villages on the eastern Vanua Levu coast (BERRYMAN, 1979).

The north coast of Vanua Levu borders the band of recent high seismicity, associated with the Fiji Fracture Zone (Figure 3), and a complex history of vertical tectonics probably occurred here. The most recent general movement appears to have been relative emergence, attested to by the dissection of most valley fills along this coast (IBBOTSON, 1966). BERRYMAN (1979) recognized a 1.0 m shoreline in places on the main island and offshore on Kia.

The coast of Vanua Levu between Bua and Daria is that of Seatura volcano and no shoreline displacements are known even though volcanic activity ceased over 2 Ma (HINDLE and COLLEY, 1981). One explanation for this is that the area has been subsiding but this is uncertain without additional investigation. Further to the east, towards Savusavu, BARTHOLOMEW (1959) found a 1.8 m raised beach at the mouth of the Yanawai[6]: levels at 0.75–0.95 m were recently dated to between 2,010 ± 95 and 2,270 ± 95 years BP (WK-1387 and WK-1386)[7].

On Taveuni (Figure 12), BERRYMAN (1979) found the lowest-level shoreline between 1.0 m and 3.5 m and this occurs in association with

6. The colloquial Fijian for 'river' is 'wai', literally 'water'; thus 'Yanawai' is the 'Yana River', and to say 'Yanawai River' is tautological.

7. Corrected ages are given. A marine correction factor of −450 ± 35 years was used (*cf.* Note 5).

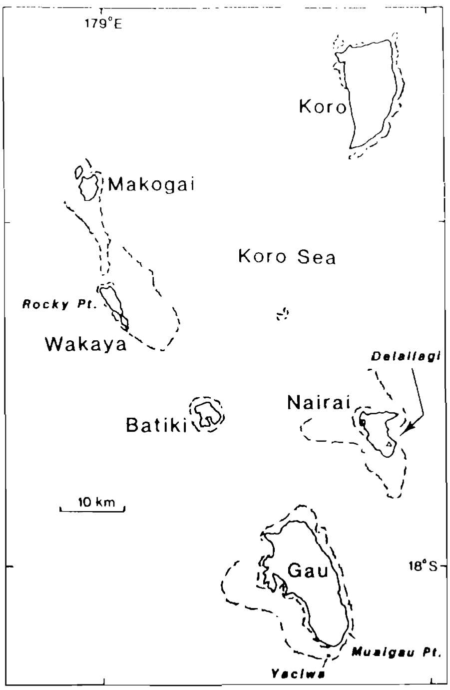


Figure 11. The Lomaiviti island group; fluted lines represent the seaward edges of modern reefs.

coastal flats backed by old sea cliffs (UNESCO/UNFPA, 1977). On Cikobia, undoubtedly one of the most seismically-active islands in Fiji during the Quaternary, a 3 m emerged reef marks the lowest-level major shoreline displacement though uplift is continuing at a rate of about 0.5 mm/yr (BERRYMAN, 1979).

The Lau islands (Figure 13) rise from the meridianal Lau Ridge, the late Cenozoic history of which has been interpreted in the context of shoreline displacements (NUNN, 1987c, 1988c). From the Vanua Balavu group in the north, LADD and HOFFMEISTER (1945: 16) reported "a low elevated platform fronted by a sand beach and backed by steep slopes" widespread on the main island, which they interpreted as a relatively recent emerged shoreline between 1.15 m and 2.65 m. Also in the Vanua Balavu group, a well-developed notch line is found at 0.75–0.95 m on Cikobia-i-Lau (LADD and HOFFMEISTER, 1945).

Elsewhere in Lau, low-level shorelines have been reported at 3 m on Vatuvara (WOODHALL, in press) and *c* 2 m on Lakeba (BERRYMAN, 1979). Also on Lakeba, McLEAN (1979) dated an 'emerged' microatoll to 4,560 ± 170 years BP (assumed to be at around +0.75 m) and concluded that there had been a slight fall in sea level since this time, a conclusion backed by a study of fringing reef productivity on Lakeba, which was echoed for the island of Kabara by GALZIN *et al.* (1979). LADD and HOFFMEISTER (1945) recorded a 0.5–1.2 m shoreline on Komo and a 2 m notch on Fulaga and in the Ogea group.

No comparable data have been reported from Rotuma, the northernmost island in Fiji (177°E, 12°30′S), and it is possible that evidence for emergence here has been obscured by late Holocene volcanic activity (RODDA, 1986).

Synthesis

The description of (probable) Holocene sea-level indicators above can be meaningfully interpreted only within the context of the recent and contemporary tectonic framework. The areas of Fiji within which it can be assumed that a single tectonic regime persisted during the late Quaternary have been defined above. Data referring to the elevations of former mean sea levels relative to the present mean sea level have been averaged for each of these areas; for those areas, such as Viti Levu, where different tectonic processes dominated in different parts, each constituent part is treated separately (Table 4).

The relationship between mean elevations of Holocene/low-level shorelines and tectonics is shown in Figure 14. This indicates a correlation between elevation and dominant tectonic regime: those areas which experienced uplift during the Holocene exhibit the greatest contemporary shoreline displacement; those areas which have been predominantly stable occupy the middle range; and those areas which experienced dominant subsidence show the lowest shoreline displacements. This pattern is consistent with an apparently uniform Holocene emergence superimposed on local tectonic regime throughout the archipelago. The question still remains as to whether this was the result of a contemporary sea-level rise or the effect of hydro-isostatic compensation within the region, as HOPLEY (1987) suggested.

Figure 12 (*facing page*). Vanua Levu and Taveuni; fluted lines represent the seaward edges of modern reefs.

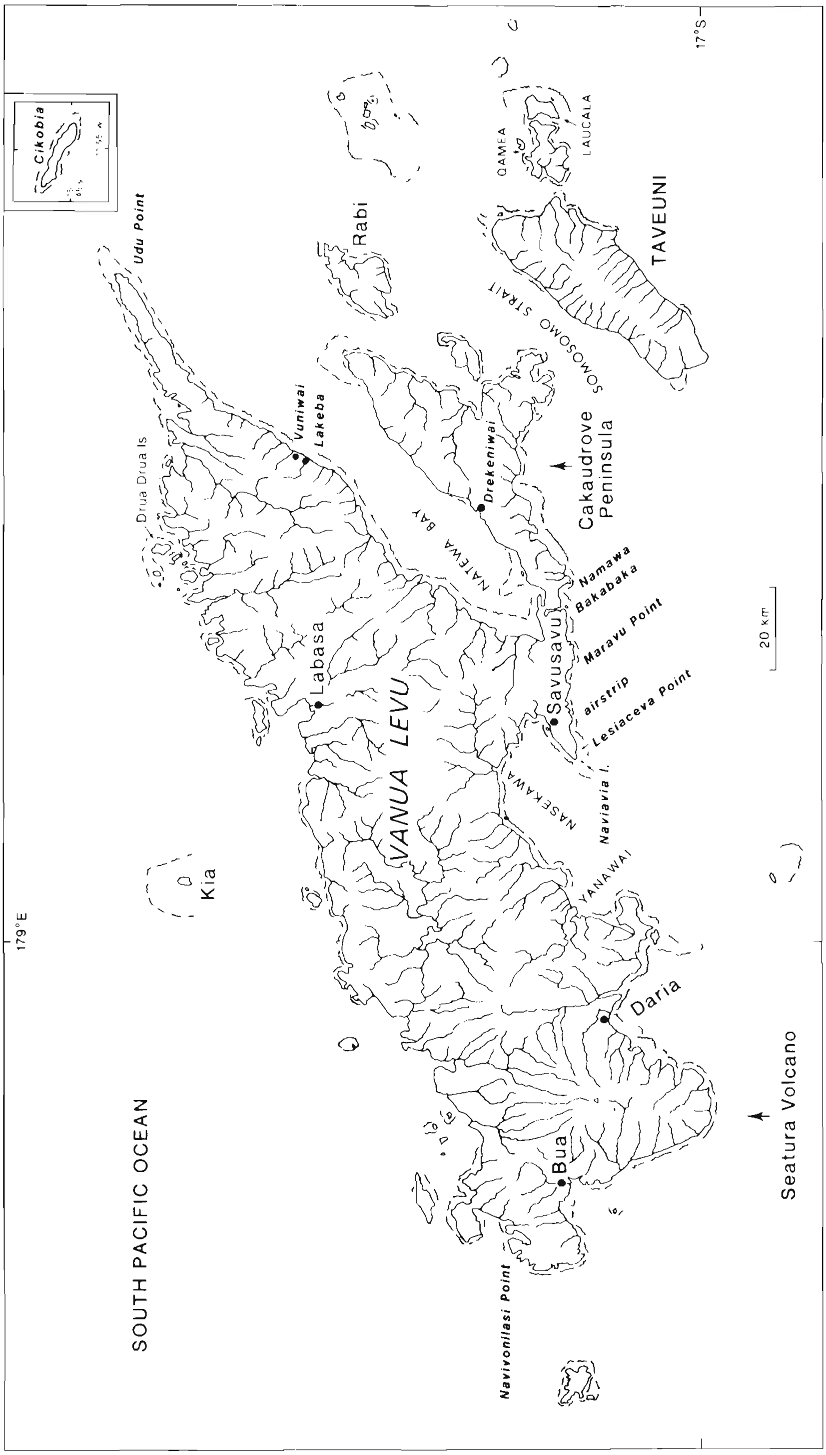

SOUTH PACIFIC OCEAN
VANUA LEVU
Cikobia
Udu Point
Drua Drua Is
Vuniwai
Lakeba
Labasa
Kia
179°E
17°S
Rabi
QAMEA
LAUCALA
TAVEUNI
SOMOSOMO STRAIT
Cakaudrove Peninsula
Drekeniwai
NATEWA BAY
Namawa
Bakabaka
Maravu Point
Savusavu
airstrip
Lesiaceva Point
NASEKAWA
Naviavia I.
YANAWAI
20 km
Daria
Bua
Seatura Volcano
Navivonilasi Point

Table 3. *Low-level shoreline indicators between Savusavu and the Cakaudrove peninsula, Vanua Levu. Heights are in metres above mean sea level.*

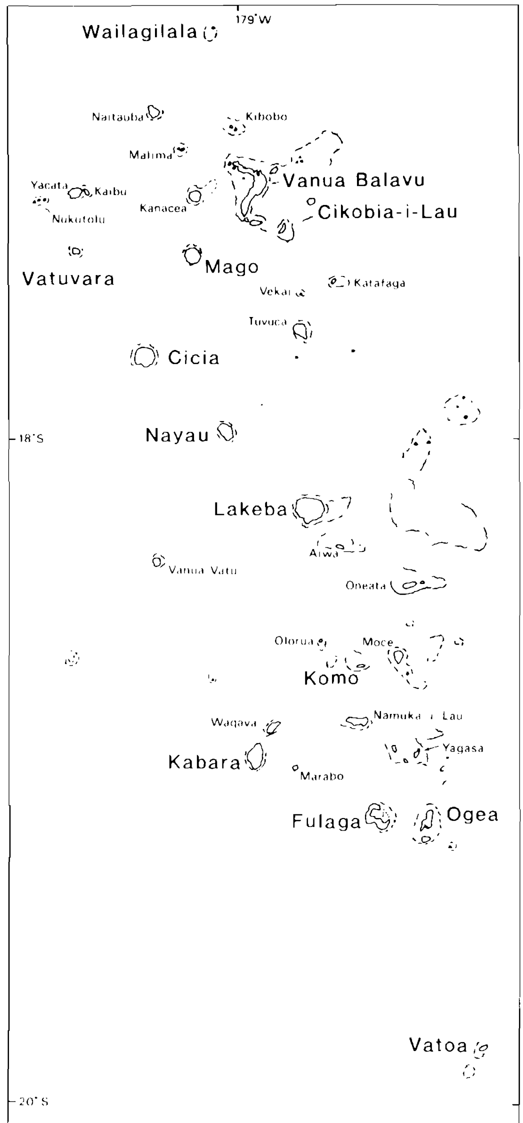
Location	Type	Height (m)	Source of data
Savusavu	terrace	1.5	Berryman 1979
Lesiaceva Point	terrace	1.0	Berryman 1979
Naviavia island	reef	3.2-3.9	Guppy 1903
Savusavu airstrip	platform	2.0	Woodrow 1976
Bakabaka	reef	1.5	Rodda 1986a
Namawa	notch	1.0	Berryman 1979

Given the variable quality and uneven scatter of data, the only feasible way to test whether or not Holocene emergence in Fiji was the consequence of regional hydro-isostasy is to see if there is a relationship between insular shelf widths[8] and mean emergence. This proposition rests on the assumption that wide shelves would be expected to have subsided more as the result of Holocene hydro-isostasy than narrow shelves, excluding the effects of local tectonic movements. The highest emerged shorelines would therefore be expected to face narrow rather than wide shelves. Data to test this proposition are listed in Table 5.

A correlation coefficient of −0.085 was calculated for all data (mean shelf width against mean emergence); this was +0.293 when data from the least stable areas (Vatulele/Beqa, Kadavu, Taveuni and Cikobia) were excluded. From these results, it is concluded that, if a regional hydro-isostatic signature is present, then it is not readily detectable and that the best explanation for the data in Figure 14 is that sea level exceeded its present level in Fiji during the Holocene.

The timing of this higher-than-present sea level can be deduced from the eleven dates available (Table 6); dates defining the early Holocene transgression are not given here but were presented by MATSUSHIMA *et al.* (1984), MAEDA *et al.* (1986) and SUGIMURA *et al.* (1988). Dates allegedly defining a late Holocene regression in northern Viti Levu were given by ASH (1987) but are not considered to come from a stable coastline (see above).

In the plot of the data listed in Table 6 (Fig-



8. It would also have been desirable to use depth to test the idea of regional hydro-isostasy but sufficiently high-resolution data are not available for all areas.

Figure 13 (*facing column*). The Lau islands; fluted lines represent the seaward edges of modern reefs.

Table 4. *Calculation of mean elevations of low-level emerged shorelines by area in Fiji showing the Holocene tectonic condition of each area (see also Figure 14). All data in metres above present mean sea level.*

Area	Data	Mean elevation	Holocene tectonics[1]
Yasawa-Mamanuca	0.8, 1.3, 1.5	1.20	s, i
Viti Levu–east coast	1, 2, 2.25, 2.75, 3	2.33	st
—west coast	1, 1.3, 1.6, 2.5, 2.5	1.78	st
—southwest coast	0.95, 1, 1.55, 1.85, 2.1	1.49	s, i
—south/southeast coast	0.92, 1, 1, 1.5	1.11	s, i
Vatulele/Beqa	0.8, 0.96	0.88	s
Kadavu	1.5, 3	2.25	t
Yasayasa Moala	0.94, 1.22	1.08	s, i
Lomaiviti[2]	1.3, 2	1.65	s, i
Vanua Levu–east and southeast coasts	1, 1, 1, 1.5, 1.5, 2, 2.15, 3.55	1.71	s, i
Taveuni	2.25	2.25	u
Cikobia	3	3.00	u
Lau	0.75, 0.85, 0.85, 1.9, 2, 2, 2, 2, 3	1.71	st, s?

[1] s–subsidence; u–uplift (vertical creep); i–intermittent uplift; st–stable; t–tilting (differential tectonics).
[2] Comprising the islands of Batiki, Nairai, Ovalau and Wakaya in the Koro Sea for the purposes of this table.

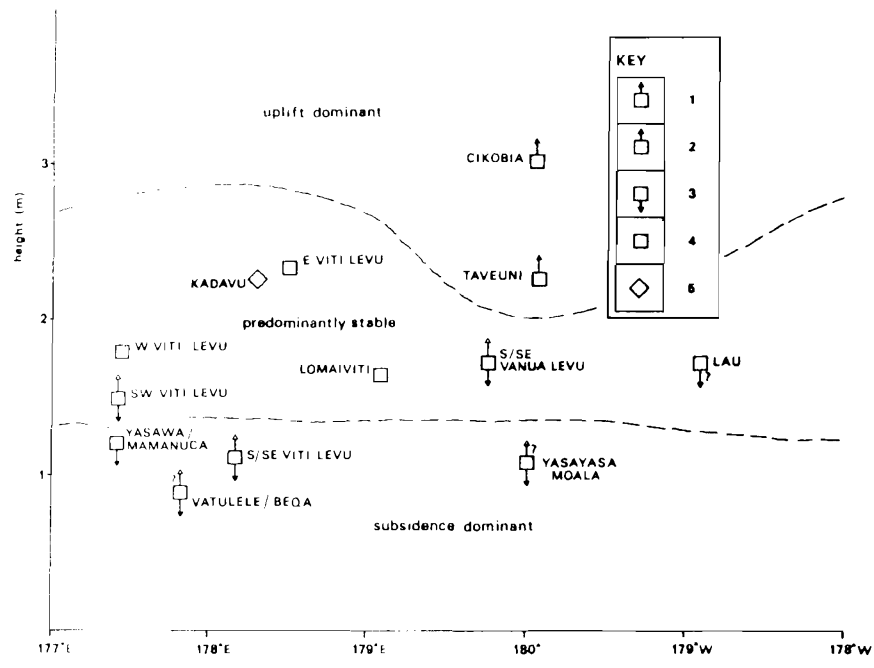


Figure 14. Graph showing the relationship between mean elevations of probable Holocene emerged shorelines and contemporary tectonic regime (from data in Table 4). Locations defined by longitude. Key: (1) area of uplift (vertical creep?); (2) area of intermittent uplift; (3) area of subsidence; (4) stable area; (5) tilted area.

ure 15), the sea-level envelope shows the course of the transgressive maximum in Fiji: its highest level was roughly 1–2 m some 2,000–3,000 years BP.

ASPECTS OF HOLOCENE COASTLINE DEVELOPMENT

Besides looking for directional evidence of

Table 5. *Average offshore shelf widths for those areas of Fiji for which emergence data were reported (Table 4). Bathymetric data from SMITH and RAICEBE (1984).*

Area	Mean width[1]	Mean emergence[2]
Yasawa-Mamanuca	17.7	1.20
Viti Levu–east coast	15.5	2.33
Viti Levu–west coast	43.1	1.78
Viti Levu–southwest coast	1.2	1.49
Viti Levu–south/southeast coast	4.8	1.11
Vatulele/Beqa	10.9	0.88
Kadavu	3.7	2.25
Yasayasa Moala	3.1	1.08
Lomaiviti	5.2	1.65
Vanua Levu–east/southeast coasts	3.1	1.71
Taveuni	2.8	2.25
Cikobia	1.6	3.00
Lau	3.3	1.71

[1] in kilometres to nearest 100 m isobath
[2] data from Table 4

Table 6. *Radiometric and archaeological dates from emerged Holocene shorelines in Fiji (see Figure 15). All elevations in metres relative to present mean sea level, all dates in years BP.*

Location	Elevation	Date	Tectonic behavior during late Holocene[1]	Source of data[2]
Lomolomo Cave, Viti Levu	1.3	c4000	st	Berryman 1979
Yanuca island, near Sigatoka, Viti Levu	2.1	2980 ± 90	u?	Green 1979
Lobau, Viti Levu	1.0	c4000	st	Sugimura *et al.* 1988
Ekubu, Vatulele	0.8	1375 ± 65	s	Matsushima *et al.* 1984
Naroi Wharf, Moala	1.3	1180 ± 95[3]	st	Nunn 1988a
	2.2	1750 ± 145[3]	st	Nunn 1988a
Maravu Point, Vanua Levu	2.2	3790 ± 175	u	Maeda *et al.* 1986
Yanawai mouth, Vanua Levu	0.8	2010 ± 95[3]	s	this paper
	0.8	2270 ± 95[3]	s	this paper
	1.0	2250 ± 95[3]	s	this paper
Lakeba, Lau	c0.8	4560 ± 170	st	McLean 1979

[1] Using nomenclature in Table 4.
[2] In columns 2 and 3.
[3] Dates incorporating a correction factor of − 450 ± 35 years.

recent high sea levels, several lines of inferential evidence may be profitably discussed for Fiji. These are considered below under various subheadings.

River-Mouth and Deltaic Coastal Progradation

The most widespread type of coastal extension in Fiji during the Holocene was undoubtedly that associated with the mouths of rivers, perhaps associated with large deltas, which gave rise to the coastal flats on which most small island settlements within Fiji are situated today.

Around the mouth of the Nasekawa river in Savusavu Bay, Vanua Levu, coastal extension of 640 m, representing a sea-level fall of 0.12 m, has occurred during the last 3,760 ± 80 years through the development of a succession of low-relief beach ridges, composed of both river sediments and material transported alongshore (ROY, 1986). A survey of beach ridges just east of Deuba on Viti Levu's south coast suggested that at least 1 km of coastal progradation here occurred in association with a sea-level fall of

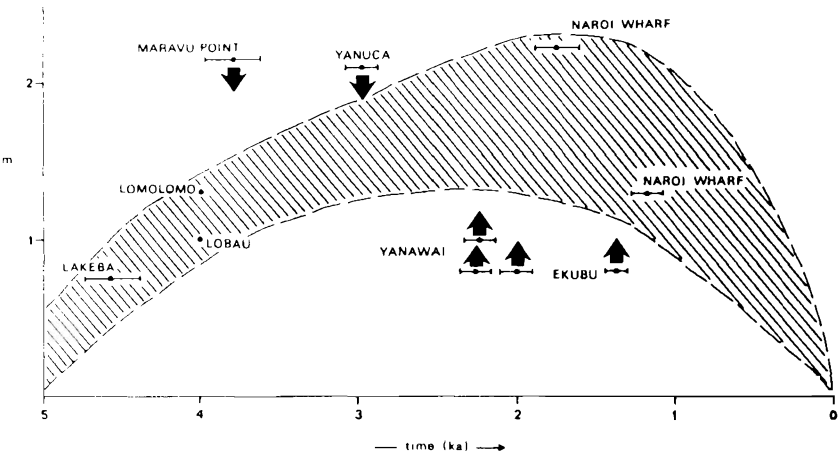


Figure 15. Sea-level envelope for the Holocene transgressive maximum within the Fiji archipelago. Dates from sites listed in Table 6. Late Holocene tectonics of unstable sites are shown by down arrows (uplift) and up arrows (subsidence).

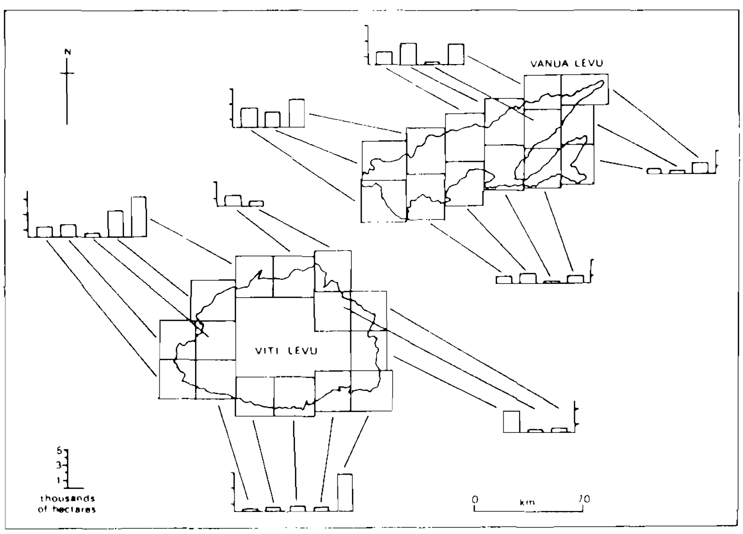


Figure 16. Mangrove distribution around Viti Levu and Vanua Levu, calculated from appropriate 1:50,000 sheets (data from Watling, 1985).

just under 1 m (M. Shepherd, *personal communication,* 1987). This figure agrees with the conclusion of SUGIMURA *et al.* (1988) drawn from dates obtained from the uppermost marine series beneath the Lobau flats, east of Deuba, that a high stand of sea level about 1 m above the present occurred some 4,000 years ago (see above). The earlier survey of SCHOFIELD (1970) in the area reached a similar conclusion.

Coastal changes, largely attributable to progradation, at the mouth of the Rewa delta in southeastern Viti Levu have been documented for the last 150 years (GUPPY, 1903; PARRY, 1984). The series of beach ridges in the western part of the delta also suggests that a late Holocene regression accompanied contemporary progradation (ROY and RICHMOND, 1986; M. Shepherd, *personal communication*, 1987). Similar observations have been made elsewhere in Fiji. For example, from Rotuma, HINDLE (1974: 4) described "coastal sand flats [which] represent . . . raised beaches . . . left behind by the falling [late Holocene] sea level."

On many (parts) of the smaller Fiji islands during the late Holocene, where sediment supply from either the land or offshore was insufficient to allow coastal flats to prograde, as on many (parts of) larger islands, the effect of the contemporary sea-level fall was to cause the formation and/or emergence of a barrier beach. The shallow lagoon behind the beach became gradually infilled and still sometimes contains standing water, as along the west coast of Beqa, or is occupied by lowland swamps, as on many Lau islands especially in limestone areas. Buried beach deposits along the inland margins of Levuka swamp on Lakeba have been dated to 3,500 years BP (LATHAM, 1979).

The role of mangroves in coastal progradation is debated (CARLTON, 1974). In Fiji, the effect of the prevailing southeast trade winds may explain the large-scale distribution of mangroves on the largest islands (Figure 16). About 47% of the mangroves around the coast of Viti Levu are found on north-facing coasts, compared to only about 21% on south-facing coasts; approximately 67% of the total mangrove acreage on Vanua Levu is found along the northernmost coast between Navivonilasi Point and Udu Point.

At a more local level, the broadest areas of mangroves in a coast-parallel sense appear to be associated with stable or slowly subsiding coasts, such as those in northern Viti Levu. Mangrove acreage is noticeably less along less stable coasts, such as in south and southeast Vanua Levu. Although aspect, particularly in an area such as Fiji where southeast trade winds are dominant throughout the year, is probably the most important control of mangrove development, there are many reasons for supposing that a causal relationship also exists between tectonic regime and mangrove development through the medium of sediment supply. Stable or subsiding coasts may provide optimum conditions for mangrove development in Fiji.

Coastal Dune Accumulation

The largest dune field in Fiji lies just west of the mouth of the Sigatoka river in southern Viti Levu. Smaller areas of dunes are found on Yasawa (RODDA, 1986) and Vatulele (NUNN, in press, a) islands.

The Sigatoka dune field (Figure 17) comprises an area of (artificially) stable dunes (KIRKPATRICK and HASSALL, 1981) and active dunes (active between 1964 and 1974) that fringe the present beach (PARRY, 1987). It has been conclusively demonstrated that the provenance of the dune sand is the upper Sigatoka valley (DICKINSON, 1968). The system of dune accumulation would therefore seem to be Sigatoka river load deposited on the beach and offshore shoals near and to the west of the river mouth being moved alongshore westwards and onshore by wind and waves, the energy of which is higher than normal for this coast owing to the gap in the reef here (Figure 17). DICKINSON (1968) also demonstrated that the earliest dunes had accumulated during a (early to middle Holocene?) transgression on an aeolian flat, probably a delta margin. What is unusual about their subsequent development is that extensive dunes are not common in tropical areas (JENNINGS, 1964), especially those where tides are semi-diurnal and have a small vertical range as at Sigatoka.

One clue to the development of these dunes is their stratigraphy, as recorded by BIRKS (1973) during his excavation of early settlements along the seaward margin of the eastern dunes. BIRKS identified three occupation strata, the two youngest dated to 2,460 ± 90 and 1,720 ± 80 years BP respectively, separated by artifact-sterile strata. The occupation strata were linked with periods of stabilization of the dunes; the sterile strata with their destabilization and an acceleration in sand accumulation. Birks favored an explanation for the latter involving accelerated erosion resulting from forest burning within the Sigatoka catchment which would have greatly increased the sand fraction of the river load. In contrast, PARRY (1987) believed that there was a link between movements of the Sigatoka river mouth from east to west across its alluvial delta and sand supply to the dune front, and that large flood events had caused abrupt shifts in the location of the main river channel mouth which in turn caused changes in the rate of sand accumulation on the dunes. Both theories are feasible but insufficient data have been gathered to test them adequately.

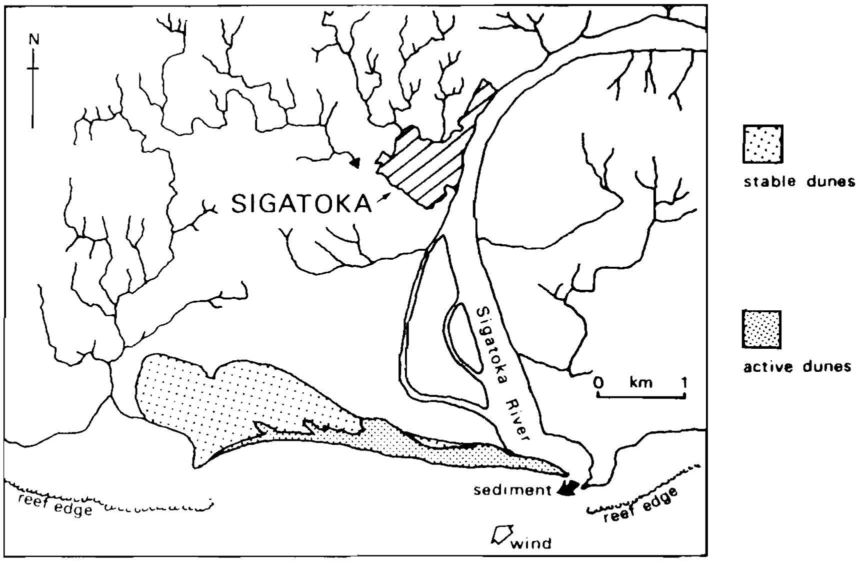


Figure 17. The Sigatoka area, showing the dune field and its sediment supply system. Fluvial sediment from the Sigatoka valley is moved onto the dunes by longshore drift; note the break in the fringing reef. The area of active dunes (1964–1974) was mapped by PARRY (1987).

The abruptness of the breaks between occupation and sterile strata may have resulted from uplift events associated with large magnitude earthquakes. Such occurrences have been called upon to explain shoreline emergence on offshore Vatulele, Beqa and Yanuca islands nearby (NUNN, 1988a) and may also have been responsible for the emergence of the lowest fossil reef, thought to be Holocene in age, at Korotogo and other places to the east of the Sigatoka river mouth. These considerations suggest that the effects of seismotectonics on dune development at Sigatoka should not be ignored.

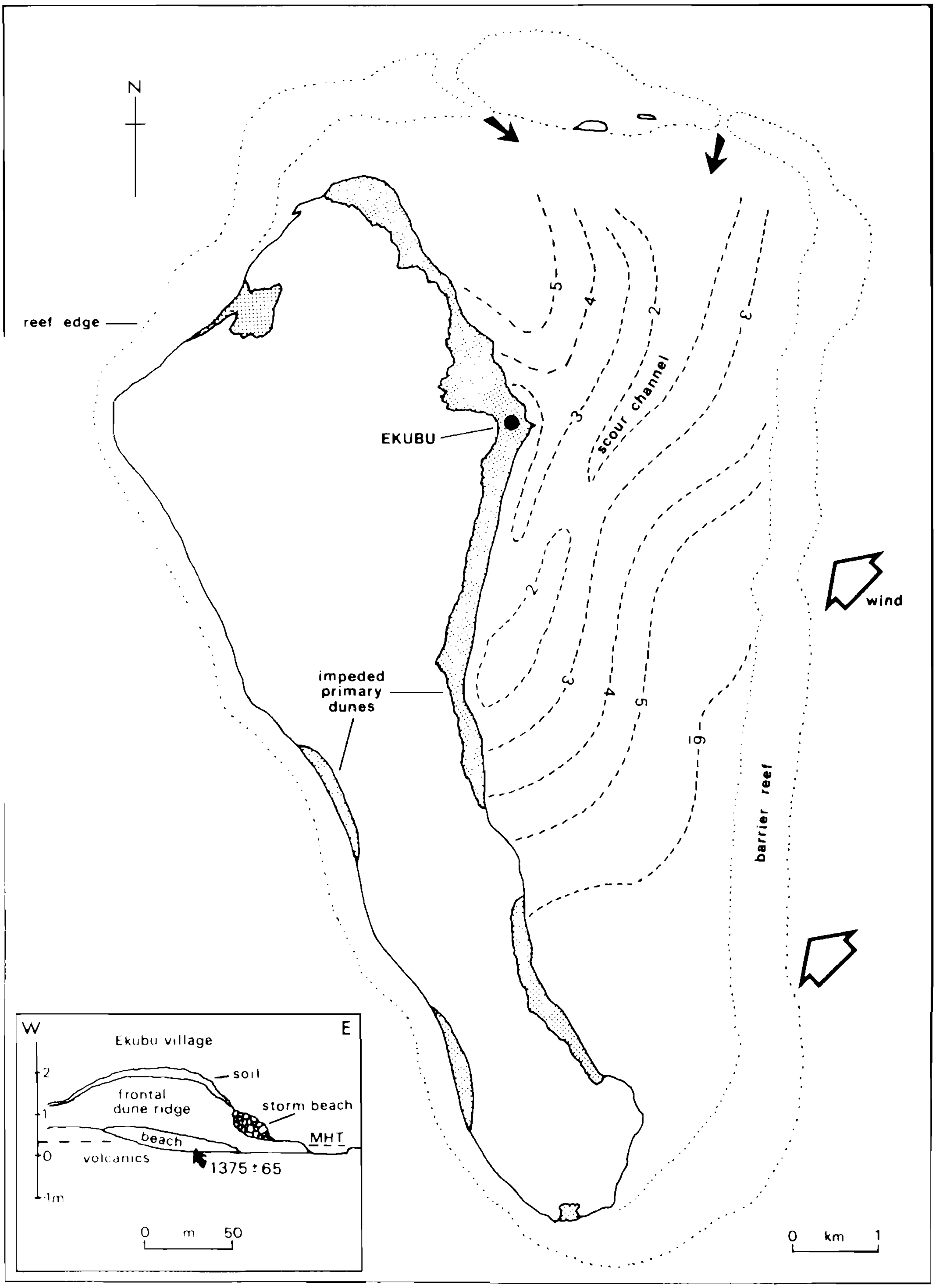
The dunes on Vatulele island, some 35 km south of Sigatoka, are mostly impeded primary dunes, comprising areas of frontal dune ridge and dune platform, but with a few areas of contemporary activity on the eastern side of the island's northern tip (Figure 18). Accumulation in the latter area can be explained by the shallowness of that immediately offshore which is abundantly supplied with sediment (*cf.* sediment thicknesses in Figure 18), a condition attributable, at least in part, to the area's proximity to the reef passages in the north and northeast of the lagoon.

Most of the Vatulele dunes are believed to be relict features, formed as the result of wind acting on lagoon-floor sediment exposed during the late Holocene regression (NUNN, in press, a), as the section from Ekubu suggests (inset—Figure 18).

No specific studies of dune genesis have been carried out in Fiji but these clearly have the potential to resolve questions such as dune age (range), and environmental controls on dune accumulation, which are of wider relevance to Holocene coastal development. Critical questions about changes in Holocene coastal and nearshore sedimentation, particularly any record of a "high-energy window", which occurred on the Great Barrier Reef during the later part of the Holocene transgression when reef growth lagged behind sea-level rise (HOPLEY, 1984), could be answered by comprehensive dune studies in Fiji.

Beachrock and Related Deposits

Most beachrock in Fiji, known locally as *devo*, occurs within the tidal range and much is probably forming today. The forms of most beachrock observed by the writer in Fiji duplicate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Ekubu village
soil
frontal
dune ridge
storm beach
beach
MHT
volcanics
1375 ± 65
2
1
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-1m
0 m 50

those of associated sand beaches. Most beachrock is bedded and shows signs of marine abrasion such as ridges and furrows. No systematic variations in beachrock character within Fiji are known, although it does seem to occur more commonly on windward rather than leeward coasts. Beachrock plays an important role in the preservation of sand cays, such as Nanuku in the Beqa lagoon (BAND, 1968), and other surficial features, such as the spit connecting the islands of Wailagilala and nearby Cakaudrove in northern Lau (AGASSIZ, 1899), but is also the bane of many tourist resort managers, especially along Viti Levu's south coast (NUNN, 1988d).

FRENCH (1986) studied beachrock on Batiki, Nairai and Wakaya islands in Lomaiviti and found all of it occurred within the tidal range except for one exposure at Rocky Point on Wakaya, which was about 1.7 m above mean sea level, at least 0.7 m above the local splash zone.

It is possible that some of the beachrock that occurs in Fiji is better classified as coral conglomerate, the genesis of which was discussed by MONTAGGIONI and PIRAZZOLI (1984) for islands in French Polynesia. Old water-table levels, equivalent to low-tide levels, are represented in these conglomerates by the boundary between mostly marine phreatic and marine vadose cementation and can be used to determine the magnitude of relative emergence, especially in areas of low tidal range (MONTAGGIONI and PIRAZZOLI, 1984). A coral conglomerate of this kind was identified along the north and west coasts of the Totoya lagoon in the Yasayasa Moala by FARNELL (1987).

Lagoon Infilling and Coral-Reef Emergence

Sedimentation leading to the gradual infilling of shallow enclosed lagoons is the expected consequence of the mid-Holocene stabilization of sea level and its subsequent fall, events which would have respectively initiated lagoonal sedimentation and caused a reduction in lagoon area and volume.

Although reef-derived materials are usually regarded as the major contributor to lagoonal sediment, increases in the volume of terrigenous sediment input would also have come about as the result of late Holocene forest clearance in Fiji. The record of anthropogenic sedimentation is best known in Fiji from swamp cores on Lakeba in the Lau group: between 1,900 and 1,750 years BP, sediment was deposited at a rate of 2,600 t/km^2/year in Waitabu swamp (HUGHES *et al.*, 1979). In southern Viti Levu, landsliding associated with Cyclone Wally in 1980 caused nearby beaches and reefs to become cloaked with sediment (HOWORTH *et al.*, 1981). From such studies, it is clear that terrigenous sediments contribute significantly to most beach, lagoon and even offshore reef environments in Fiji, but no studies have been carried out to quantify the relative importance of reef-derived and terrigenous sediment input.

Lagoon-sediment thicknesses on the floor of the Vatulele lagoon (Figure 18) suggest that it has been gradually infilled during the late Holocene. This is especially noticeable in its southern part to which most sediment brought in through the two passages (arrows in Figure 18) is directed and from where it cannot escape under normal conditions. Many small patch reefs in the area south of the 6 m isopach in Figure 18 have been almost completely smothered by sediment (NUNN, in press, a). This situation seems analogous to the study PENN (1983) made of Holocene sedimentation on Nukubuco Reef, just southeast of the Suva peninsula, on which sediment, much of it from the Rewa, accumulated at a rate oaf between 1.9–2.9 m/ 1,000 years during the Holocene.

Corals within the lagoon and on the barrier reef of Kabara island in Lau have been killed off owing to late Holocene relative emergence (GALZIN *et al.*, 1979), one of the principal effects of which would have been a reduction in lagoon volume and a proportionate increase in sedimentation. Structural damage to coral reefs, consistent with uplift during large-magnitude earthquakes (STODDART, 1972), is observable in some places but this cannot be easily attributed to such a cause in the absence of direct knowledge of the time of the earthquake and the magnitude of the uplift involved.

On many smaller islands, the outgrowth of fringing coral reefs may have reduced the supply of non-terrigenous sediment to beaches since the sea level stabilized around its present

Figure 18 (*facing page*). Impeded primary dunes and lagoon-sediment thickness on Vatulele island (from Nunn, 1988b). Lagoon coring by Warner and Rossfelder (1982). Inset shows composite section through coastal sequence at Ekubu village (from data collected by writer and Matsushima *et al.*, 1984), vertical scale relative to mean sea level.

level. For Kabara and Lakeba, McLEAN (1980) suggested that this was responsible for contemporary beach erosion.

Effects of Catastrophic Events

Among the catastrophic events which have produced long-lasting changes on Pacific island coastlines are tropical cyclones, particularly those accompanied by hurricane-force winds (STODDART, 1970), and storm surges. Case studies of hurricane effects in Tonga (WOODROFFE, 1983) and Tuvalu (FITCHETT, 1987) are applicable to similar island types in Fiji, although no detailed work has been carried out here.

Some effects of 'Hurricane' Val in 1975 on island coasts in northern Lau were described by PHIPPS and PREOBRAZHENSKY (1977). Among these was the breaking-up of beachrock, also seen by the present writer on Cicia island following Tropical Cyclone Raja in January 1987. Removal of beachrock from many coasts increases their vulnerability to wave attack.

Examination of several coastal sites in Fiji following Tropical Revolving Storm MELI in 1979 suggested to WINGFIELD (1982) that associated storm surges up to +6 m have been responsible for cutting steps 2–3 m above mean sea level along aggradational (sandy beach) coasts.

A coastal notch with a retreat point 4 m above mean sea level and a mouth 0.9 m high at the back of the high-energy Likunawai beach on Vatulele island observed in April 1985 had been completely buried in June 1986 (NUNN, in press, a), a time during which no hurricane-force winds were felt in the area. Changes to beaches of this magnitude are therefore perhaps attributable to medium-strength winds and perhaps unrelated to storm surges.

ENVIRONMENT AND SETTLEMENT DURING THE LATE HOLOCENE

People inhabited the Papua New Guinea mainland at least 26,000 years ago (WHITE *et al.*, 1970), probably closer to 40,000 years ago. Why the earliest settlements on the Pacific islands to the east are so much more recent (Table 7) has long puzzled prehistorians.

A recent attempt by GIBBONS and CLUNIE (1984) to resolve this question suggested that coastal settlements had indeed been established during the early Holocene in the island Pacific but that these had been inundated subsequently in the Holocene transgression: those settlements dated in the region (Table 7), argued GIBBONS and CLUNIE, were only those which had been established **after** the sea level had stabilized close to its present level around the middle Holocene. Although this idea is intriguing, it as yet remains without empirical support and cannot adequately explain the marked succession in both space and time of the apparent colonization of the south and west Pacific which has long been interpreted as indicating the region's progressive settlement from a homeland in the west.

It is clear that Holocene environmental changes played a critical and probably underestimated role in the initial settlement of the southwest Pacific, not only those changes resulting from the effects of the early to middle Holocene transgression (GIBBONS and CLUNIE, 1984) but also those caused by the late Holocene regression. The latter event created comparatively attractive environments for settlement along southwest Pacific island coastlines, most of which had been quite unattractive to potential settlers hitherto. This probably explains, albeit only in part, the apparent sudden peopling of the region during the late Holocene (SCHOFIELD, 1977b; WHITE, 1979; NUNN, 1988b). Among the environmental changes wrought by the late Holocene regression would have been the exposure of wide, well-drained coastal plains, on which soil rapidly developed/accumulated and vegetation soon colonized. Since the earliest settlements in the island Pacific are almost all coastal, it seems that the attraction of these sites was appreciated as much by potential settlers then as now although, in the interregnum, increasing population pressure led to settlements being established inland, especially in defensive positions.

The most detailed study of early settlement development in Fiji is that of BEST (1984) on Lakeba island in Lau. The earliest occupation, dating from the earliest represented ceramic period (2,950–2,500 years BP), was probably seasonal or intermittent, the main contemporary settlements being in rock shelters. Permanent settlements were only established later on coastal flats, perhaps because a sea-level fall

Table 7. *Dates of some early settlements in the southwest Pacific (Best, 1984; Kay, 1984; sources in Green, 1979, and Spriggs, 1984).*

Site, island (group)	Nearest meridian	Date[1]
Misisil, New Britain, Papua New Guinea	150°E	c11,400
Balof, New Ireland, Papua New Guinea	152°E	6800 ± 410
Nanggu, Santa Cruz Islands, Solomon Islands	166°E	3250 ± 70
Fotoruma, Vanuatu[2]	170°E	2920 ± 110
Natunuku, Viti Levu, Fiji	178°E	3240 ± 100
Yanuca, Viti Levu, Fiji	178°E	2980 ± 90
Sigatoka, Viti Levu, Fiji	178°E	2460 ± 90
Naigani, Lomaiviti, Fiji	179°E	2860 ± 50
Lakeba, Lau, Fiji	179°W	c2725
Futuna, Horne Islands	178°W	2120 ± 80
Tongatapu, Tonga	175°W	3090 ± 95
Ferry Berth, Western Samoa	172°W	2890 ± 80

[1] In years BP.
[2] Formerly New Hebrides.

had rendered these more exposed and/or better drained, because of a lower water table, than at the earlier stage.

It appears that the occurrence and timing of a late Holocene regression can be confirmed in certain parts of the southwest Pacific, like Fiji, by the clustering of dates of the earliest coastal settlements. For example, the dates from Fiji (Table 7) are all within or close to the period 3,000–2,000 years BP which, it was concluded above, included the time of the late Holocene transgressive maximum in Fiji and must also have witnessed the commencement of the subsequent regression (see also Figure 15).

SHORELINE MOVEMENTS OVER THE LAST HUNDRED YEARS

Tide gauges and other mean sea-level monitors have not been in operation sufficiently long in Fiji to allow a meaningful picture of secular changes over the last hundred years or so to emerge, although the evidence from New Zealand (HANNAH, 1988— +1 mm/year since 1900) and globally (GORNITZ *et al.*, 1982— +12 cm in the last century) is undoubtedly applicable in general terms to the Fiji situation.

Evidence for recent sea-level rise in Fiji has not been collected systematically, although many beaches exhibit signs of retreat attributable to a rise in high-tide level. Data about shoreline retreat along the tectonically-stable east coast of Viti Levu were obtained through interviews with elderly inhabitants of coastal villages (NUNN, 1988d). For example, a maximum of around 130 m of lateral inundation, estimated to represent a sea-level rise of 10–30 cm, has affected Naloto village in the last 40 years or so (Figure 19). Similar evidence for sea-level rise in the last hundred years has been reported from the islands of Lakeba (UNESCO/UNFPA, 1977), Fulaga and Ogea Levu (THOMPSON, 1940) in Lau, and from Moala (NUNN, 1987b). The preliminary results of a recent regional survey suggest that selected coasts in Fiji have been inundated at an average rate of 15 cm/year in recent decades (NUNN, in press, b).

Scenarios for future sea-level rise have been applied to various coastal environments in Fiji and the surrounding region in order to get some estimate of the impact of this rise (NUNN, 1988e). Major disruption to the socio-economic well-being of the region is likely but this can be minimized by forward planning. Knowledge of the environmental changes attendant upon a rise of similar magnitude and rate about 5,000 years ago can assist this process (NUNN, in press, c).

CONCLUSIONS

It has been shown that sufficient data are now available in Fiji to allow the pattern of Quaternary tectonics to be defined, in outline at least, and to permit a Holocene transgressive signature to be detected and meaningfully interpreted in a regional context. It is hoped that this study, along with others of a similar kind within the Atlantic (NUNN, 1984) and Pacific (PIRAZZOLI, 1985; PIRAZZOLI and MONTAG-

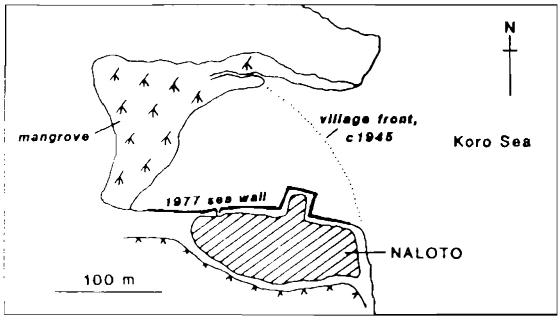

Figure 19. Shoreline retreat over the last c 40 years at Naloto village, east coast of Viti Levu (from Nunn, 1988d).

GIONI, 1985) Ocean Basins, for example, attract the attention of earth scientists to the importance of acquiring data relating to past eustatic and tectonic changes from small islands in the middle of oceans. This is not only because such islands are of considerable interest in their own right (NUNN, 1987a) but also because such data are important complements to and controls on the interpretation of the increasing amount of marine geological information (NUNN, 1988f).

This paper has shown (with little doubt) that Fiji's coasts experienced a middle to late Holocene sea-level maximum some 1–2 m above present mean sea level. It has also shown how the Holocene development of modern coasts in Fiji can be explained by the effects of this regression although no attempt has been made to explore the wider implications of these conclusions.

Future work in Fiji should concentrate on the acquisition of finite data referring to Holocene and earlier sea-level change. Considerable potential lies in the study of microatolls and patch reefs in island lagoons; the emerged reefs of Mabualau, east of the Rewa delta, and Nagigia, off the western tip of Kadavu, are worthy of investigation.

APPENDIX 1. Equivalents of Fijian place names used in the text.

Until a few years ago, most published work concerning Fiji used phonetic spellings of place names. This is also true of most extant maps of the islands. Since the use of phonetic spellings is redundant, only the Fijian spellings of place names are used in the text.

The purpose of this glossary is to allow the reader to identify the equivalents of place names used in the text which appear in phonetic or another form in earlier works or on maps.

Fijian name	*Equivalent*	*Equivalent*
Bakabaka	Mbakambaka	
Batiki	Mbatiki	
Beqa	Mbengga	
Bua	Mbua	
Cakaudrove	Thakaundrove	
Cicia	Thithia	
Cikobia	Thikombia	Farewell Island
Cikobia-i-Lau	Thikombia-i-Lau	
Daria	Ndaria	
Delailagi	Ndelailangi	
Delainabukelevu	Ndelainambukelevu	
Deuba	Ndeumba	
Dravuni	Ndravuni	Colvocoressis
Drekeniwai	Ndrekeniwai	
Ekubu	Ekumbu	Iakumbu
Fulaga	Fulanga	Vulanga
Gau	Ngau	
Gusuniqara	Ngusuninggara	
Kabara	Kambara	
Kadavu	Kandavu	Kantavu
Korotogo	Korotongo	
Lakeba	Lakemba	
Lesiaceva	Lesiatheva	
Lobau	Lombau	
Lodoni	Londoni	
Mago	Mango	
Malaqereqere	Malanggerenggere	
Mamanuca	Mamanutha	Mammanutha
Nabukeru	Nambukeru	
Naceva	Natheva	
Nadi	Nandi	
Nadroga	Nandronga	
Nagigia	Nangingia	Denham Island
Naigani	Naingani	

Fijian name	*Equivalent*	*Equivalent*
Naurabuta	Naurambuta	
Ogea	Ongea	
Rewa	Wailevu	
Sabeto	Sambeto	
Sigatoka	Singatoka	
Tuvuca	Tuvutha	
Uciwai	Uthiwai	
Udu	Undu	
Vanua Balavu	Vanua Mbalavu	
Vatulele	Vatu Lele	Vatu Leile
Vatuvara	Vatu Vara	
Wailagilala	Wailangilala	Wailangi Lala
Yaciwa	Yathiwa	
Yagasa	Yangasa	Yangasa Levu
Yanuca	Yanutha	
Yaqeta	Yanggeta	

Note: Many obscure non-Fijian names for some of the islands in Fiji were listed by Rodda (1981).

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All figures were drawn by the author and all unattributed opinions expressed in the text are the author's responsibility alone.

Note added in press:

Recent work has extended the dates of initial settlement in New Ireland and the Solomon Islands considerably from those dates given in this paper. Data from limestone caves in New Ireland indicate that they were occupied at least 32,000 years ago (ALLEN *et al.*, 1988). Investigations at the Kilu site in the Solomon Islands have shown that people reached there 28,000 years ago (WICKLER and SPRIGGS, 1988).

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□ RÉSUMÉ □

On ne peut déchiffrer l'héritage des variations du niveau de la mer—notamment holocènes—sur les côtes modernes sans ce référer au régime tectonique local actuel. La structure et la tendance dominante de la tectonique de chaque partie des îles Fidji à la fin du Quaternaire inclut: a) des zones où l'exhaussement, voire la reptation verticale prédominent (Cikobia et Tavenni); b) des zones où la subsidence domine, entre des poussées intermittentes d'exhaussements (Cakaudrove, Vanua Levu, côte Sud de Viti Levu); c) des zones où domine la subsidence (Yasawa et Mamanuca, Yasayasa Moala); enfin d) des zones vraiment stables telles que les îles de Lau Ridge et Lomaiviti.

Le déplacement holocène du rivage des îles Fidji peut donc être interprété par rapport au contexte de la tectonique locale. Le déplacement moyen de la ligne de rivage croît depuis les aires de subsidence dominantes vers celles qui sont stables, puis celles où l'exhaussement domine. La meilleure explication de ce phénomène serait celle qui impliquerait une émersion uniforme au cours de l'Holocène, due à la baisse du niveau de la mer, et non à un effet hydro-isostatique régional causé par la tectonique locale. La datation des plages holocènes soulevées des Fidji suggère que la transgression holocène a atteint son maximum à 1 ou 2 m au dessus du niveau actuel, il y a environ 2000 à 3000 ans.—*Catherine Bressolier (Géomorphologie EPHE, Montrouge, France).*

□ ZUSAMMENFASSUNG □

Auf den Fiji-Inseln kann die Aussagefähigkeit der Meeresspiegelschwankungen, insbesondere der holozänen, an der gegenwärtigen Küstenlinie nicht ohne Kenntnis der jungen lokalen Tektonik beurteilt werden. Im Spätquartär werden Struktur und Tendenz der dominanten Tektonikmuster der verschiedenen Fiji-Inseln bestimmt durch: a) Regionen mit dominanter Hebung wie in Cikobia und Taveuni; b) Gegenden mit überwiegender Absenkung zwischen kleinräumigen Hebungsgebieten wie an der Cakaudrove-Küste von Vanau Levu und Teilen der Südküste von Viti Levu; c) Regionen mit vorherrschender Absenkung wie an den Inselgruppen von Yasawa und Mamanuca und auf Yasayasa Moala; und d) stabile Regionen wie die Inseln von Lau Ridge und Lomaiviti.

Belege für relativ geringförmige Veränderungen der Küstenlinie auf den Fiji-Inseln müssen zusammen mit der Lokaltektonik interpretiert werden. Die mittlere Küstenveränderung zeigt Regionen mit vorherrschender Absenkung, solche mit Stabilität und jene mit überwiegender Hebung. Die naheliegenste Klärung für dieses Muster kann durch eine gleichförmige holozäne Auftauchung gegeben werden infolge eines fallenden Meeresspiegels und nicht durch einen regionalen hydroisostatischen Effeckt, und durch eine Überlagerung lokaler Tektonik. Daten von aufgetauchten holozänen Strandlinien in Fiji ergeben, daß das Transgressionsmaximum des Holozäns 1–2 m über dem gegenwärtigen Meeresspiegel vor 2–3000 Jahren gelegen hat.—*Dieter Kelletat, Essen/FRG.*