Geomorphic and Archaeological Landscapes of the Sigatoka Dune Site, Viti Levu, Fiji: Interdisciplinary Investigations

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RECENT ARCHAEOLOGICAL STUDIES in Oceania have highlighted the importance of Holocene changes in island landscapes for understanding prehistoric settlement and the cultural adaptations of ancestral Pacific peoples (Anderson 1994, 1995; Dickinson et al. 1994; Gosden and Webb 1994; Hope 1996; Kirch 1996; Kirch and Ellison 1994; Lepofsky et al. 1996; Nunn, 1994*a*). Some geomorphic changes can be regarded as natural background, unaffected by human culture, others are solely anthropogenic in origin, while still others represent a subtle interplay of both natural and human agency. The complexity of relevant archaeological and geological data dictates an interdisciplinary approach to research. In many Oceanian settings, a full interpretation of landscape and human history is otherwise impossible.

A case in point is the Sigatoka Dune archaeological site on the south coast of the island Viti Levu in Fiji (Fig. 1). The site lies at the eastern end of a parabolic dune field built on deltaic deposits of the Sigatoka River. The dynamic local sedimentary environment, both fluvial and eolian, has resulted in a series of well-stratified, ceramic-rich archaeological deposits that represent the key phases of Fijian prehistory, from first settlement some three millenia ago up to recent times. Over several decades, this important site has attracted a number of archaeological investigations (Anderson et al. 1996; Best 1988; Birks 1973; Birks and Birks 1968; Burley 1997; Crosby 1991; Gifford 1951; Green, 1963*b*; Hudson 1994; Palmer 1966, 1968). There remain, nevertheless, several questions about site function,

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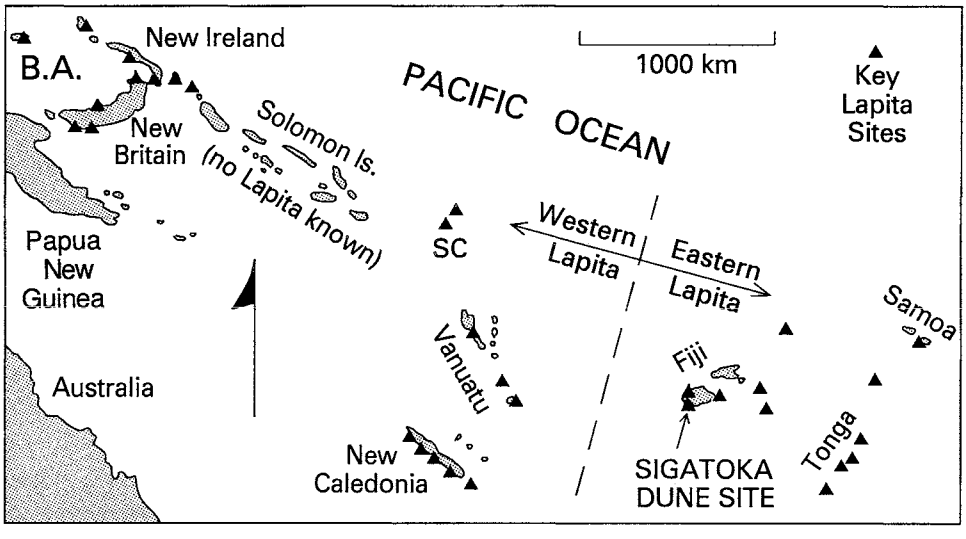


Fig. 1. Location of Sigatoka Dune site in southwest Pacific region showing distribution of key Lapita sites (triangles) from Bismarck Archipelago (B.A.) on northwest to Tonga and Samoa on southeast (modified after Dickinson et al. 1996). SC denotes the Santa Cruz Group of eastern Solomon Islands outliers at northern end of the New Hebrides island arc.

periodic abandonment, and subsequent reoccupation that cannot be resolved without a firmer understanding of the surrounding landscape and its evolution.

The focus of our paper is on the geomorphic evolution of the Sigatoka dune field and its implications for understanding human occupations at the mouth of the Sigatoka River. In offering fresh insights for the Sigatoka Dune site, we emphasize the importance of a combined geological and archaeological approach to Pacific prehistory, and for reconstructions of paleogeography.

SIGATOKA DUNE SITE IN FIJIAN PREHISTORY

Earthenware pottery has been an important portable artifact throughout the Fijian past, and it continues to be made today in selected villages near Sigatoka and elsewhere. Surface exposures of pottery fragments were recorded near the eastern end of the Sigatoka dune field as early as 1944 by anthropologist B. Biggs (Green 1963*b*). In 1947, E. W. Gifford (1951) undertook archaeological surveys and excavations on Viti Levu, again reporting surface pottery and other materials at two different locations on the seaward slope of the Sigatoka dune field. In the early 1960s, R. C. Green (Green 1963*a*; Green and Palmer 1963) reconsidered Gifford's material and, analyzing additional ceramic collections recovered in the interim, including one from Sigatoka, developed a chronological framework for Fijian prehistory based on stylistic changes in pottery decoration.

With modification and refinement (Best 1984; Frost 1979; Hunt 1986; Shaw 1967), Green's framework continues to be employed. It includes a four-fold sequence: (1) Sigatoka phase (dentate-stamped and notched ceramics), 1200–100 B.C.; (2) Navatu phase (paddle-impressed relief and leaf-impressed ceramics), 100 B.C. to A.D. 1100; (3) Vuda phase (incised/applique ceramics), A.D. 1100–

c. 1800; (4) Ra phase (greater proportion of incised/applique ceramics), c. A.D. 1800–1900. Hunt (1986) has proposed a fifth, transitional phase, Yanuca, between the Sigatoka and Navatu phases. Although we thus summarize the different phases as being defined by relatively discrete diagnostic ceramic types, such is the actual case only for the dentate-stamped ceramics of the Sigatoka phase and the incised ceramics of the later periods. Paddle-impressed relief pottery, first appearing in the Navatu (or Yanuca) phase, continues forward thereafter, albeit with much less frequency in later periods, and there are other ceramic types that transcend chronological boundaries (Best 1984: Fig. 3.55; Crosby 1988). Moreover, varying proportions of plain undecorated pottery were made during each phase.

Apart from Gifford's collections at Sigatoka and Green's use of Sigatoka ceramics to help define Fijian chronology, many past projects have investigated aspects of the Sigatoka Dune site, including eight during which excavations were undertaken (Burley 1997). By far the most comprehensive and informative of these studies was conducted by L. Birks in 1965–1966 (Birks 1973). Based on 2700 m^2 of excavation, he was able to document multiple and stratigraphically separated site occupations. Subsequent programs have focused largely on salvage work, especially the excavation of burials (Best 1988), or on related considerations of resource management. Salvage concerns were amplified in 1993 as a result of damage to the site by Hurricane Kina (Hudson 1994).

The successive projects at the Sigatoka Dune site have led to a satisfactory understanding of its overall archaeological content. Eolian and other processes active on the site landscape have led to cultural components that are stratigraphically separated by large volumes of sterile sand. These same processes have preserved large fragments of ceramics, or in some cases reconstructable vessels, that offer insights into manufacturing technology and vessel forms uncommon in the usual context of Pacific archaeological studies. The constant erosion of archaeological remains from the dune field has also led to the recovery of a large skeletal collection providing potential insight into early demography, diet, and disease (Best 1988; Visser 1994).

OVERVIEW OF SIGATOKA DELTA AND DUNES

The Sigatoka dune field lies along the seaward fringe of the delta of the Sigatoka River, which rises in the central highlands of Viti Levu and flows to the sea along a course lying along and just west of the boundary between the windward (wet) and leeward (dry) climatic zones of the island (Fig. 2). The Sigatoka drainage basin includes extensive exposures of a mid-Tertiary orogenic terrain overlain unconformably by younger sedimentary and volcanic strata (Rodda 1993). The mineralogically complex sand delivered to the coast by the Sigatoka River is consequently derived from a varied bedrock assemblage of Tertiary sedimentary, metamorphic, and igneous rocks, with the latter contributing both volcanic and plutonic detritus (Dickinson 1968). Deltaic sedimentation and freshwater flow have caused a break in the otherwise near-continuous fringing reef along the southwest coast of Viti Levu (Nunn 1990*b*).

The Sigatoka dune field has formed where the prevailing trade winds blow sand obliquely inland from the beach face along the margin of the subaerial delta

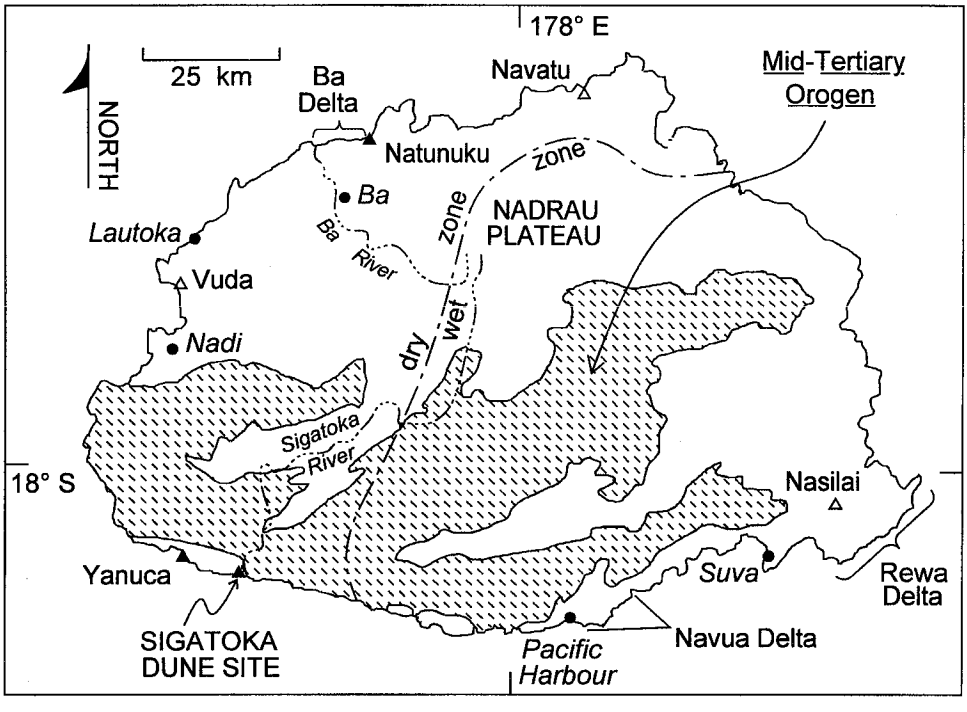


Fig. 2. Location of Sigatoka Dune site on Viti Levu in Fiji. Exposures of mid-Tertiary orogen after Rodda (1993) and wet/dry zone boundary after Cochrane (1969) and Parry (1987). Triangles denote key archaeological sites (Davidson et al. 1990; Gifford 1951; Hunt 1986; Rosenthal 1995), shown solid where Lapita pottery is known and open where only post-Lapita wares occur.

plain. The characteristic dune forms are elongate parabolic dunes oriented parallel to the trade winds at angles of 25°–45° to the curving shoreline (Fig. 3). Approximately 50% of the dune field is stabilized by vegetation (Cabaniuk et al. 1986), but blowouts of windblown sand occur sporadically within its vegetated portions. The inland edge of the dune system is marked by steep slip-off slopes that have advanced recently over a delta plain of low relief.

In plan view, the dune field is wedge-shaped, broadening westward to a maximum width of nearly 1 km. Its eastward termination is at a point where low dunes merge with the surface of a sand bar, which has formed as a beach ridge blocking most of the width of the river mouth (Fig. 3). The river-mouth bar is at intervals overtopped or washed out by major river floods. Maximum elevations of dune crests rise systematically westward, from perhaps 20 m near the river mouth to as much as 60 m farther west. The morphology of the dune field indicates that the ultimate source of the dune sand is the river, with sand moving first longshore along the beach face within the surf zone, and then inland as windblown sand climbing the upwind slopes of the parabolic dunes. The broad washover backslope of the river-mouth barrier bar, inland from the beach berm forming the crest of the bar, also represents a voluminous source of potential dune sand lying immediately upwind from the dune field.

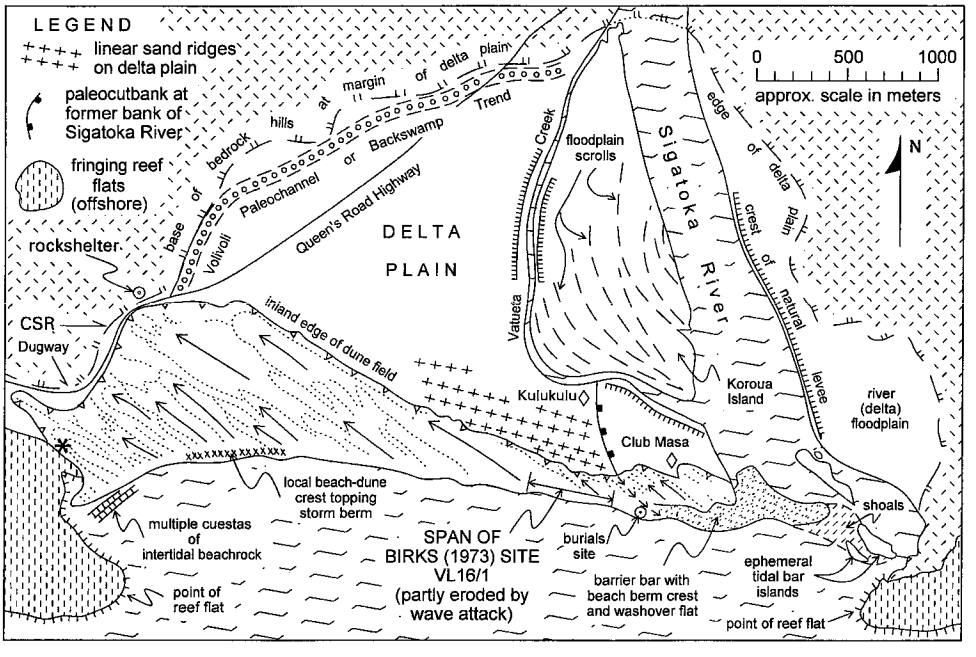


Fig. 3. Geomorphic sketch map of Sigatoka delta and dune field traced from an aerial photograph provided by the Fiji Museum, Suva, Fiji. Dotted lines within the dune field denote longitudinal crests and curved closures of parabolic dune forms, with arrows indicating principal blowout depressions (arrowheads downwind). Dashed lines on Koroua Island denote the axes of chute troughs of an array of floodplain scrolls (chutes being the arcuate topographic lows between successive multiple crests of compound point bars). Dashed line with arrows passing near archaeological site VL 16/1 (Birks 1973) and associated burial site (Best 1987, 1988) is a projection (at constant curvature) of paleo-cutbank scar (line with filled squares on slope face) marking former position of Sigatoka River bank. Bold asterisk near western limit of dune field denotes approximate location of site VL 16/22 (Naqarai). See map legend and annotations for other symbols and text for discussion.

SITE STRATIGRAPHY AND CHRONOLOGY

The excavation program of Birks (1973) was centered upon three darkened paleosols eroded from the seaward flank of the eastern end of the Sigatoka dune field (Fig. 3). Occurring at different elevations on a dune face, the paleosols appeared to represent three discrete culture levels, separated by paler intervals of sterile sand (Fig. 4). The paleosols were labeled by Birks (1973) as Levels 1, 2, and 3, from earliest to most recent.

Dentate-stamped, undecorated, and other types of ceramic vessels of the Sigatoka phase are characteristic of Level 1 (Birks 1973; Petchey 1995). Dentate-stamped ceramics represent the initial settlement of Fiji, and they are part of the far-flung Lapita cultural complex extending from the Bismarck Archipelago to the northwest as far as Tonga and Samoa to the southeast (Fig. 1). Radiocarbon dates for Level 1 fall within the approximate interval 900–400 B.C. (Table 1). Based on comparable vessel forms and ceramic motifs from elsewhere, we suspect that some of the Level 1 dentate-stamped sherds (Hudson 1994: Table 3; Petchey

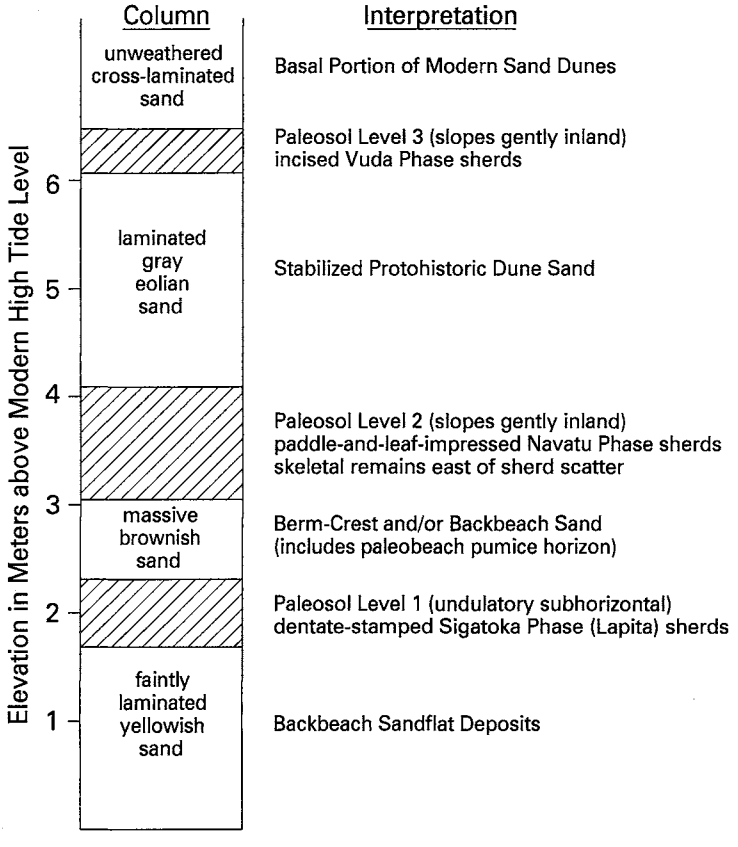


Fig. 4. General stratigraphy of the Sigatoka Dune site (VL 16/1) after Birks (1973). Actual elevations of artifact-bearing paleosol Levels 1–2–3 fluctuate along trend of beach face. Diagonal rules denote darkened humus-rich A horizons of paleosols (includes underlying oxide-rich B soil horizon of Level 2).

1995 : 107–109) may prove to be somewhat older, dating to perhaps as early as 1200 B.C. (Kirch and Hunt 1988).

Level 2 is typified by leaf-impressed trays and paddle-impressed relief pots and bowls. Erosionally exhumed Level 2 ceramics are scattered over a distance of 750 m or more along dune slopes, and the eastern part of the level contains numerous human burials (Best 1988). Radiocarbon dates for Level 2 fall within the approximate interval A.D. 100–400 (Table 1), within the span of the Navatu phase.

Coring at 50 m intervals in 1996 to depths of 1.5 m below modern mean-tide level and to distances of 20 m inland from the present high-tide line on the beach face failed to detect the presence of Level 1 below erosional exposures of Level 2. As Level 1 was last recorded as an exposure beneath a low foredune, which was eroding rapidly in 1993 (Hudson 1994) and is no longer in existence, we conclude provisionally that Level 1 cultural remains have been largely if not entirely removed by shoreline erosion since the Birks excavation of the Sigatoka Dune site three decades ago.

TABLE 1. RADIOCARBON DATES ASSOCIATED WITH ARCHAEOLOGICAL DEPOSITS AT THE SIGATOKA DUNE SITE, VITI LEVU, FIJI

LAB. NO.	DATE B.P.[a]	CALIBRATED DATE[b]	LOCATION	PHASE	REFERENCE
NZ 4789	2630 ± 80	910–550 B.C.	Level 1	Sigatoka	Petchey 1995
Gak 946	2460 ± 90	760–410 B.C.	Level 1	Sigatoka	Birks 1973 : 57
Wk 996b	1870 ± 70	A.D. 80–240	Level 2	Navatu	Best 1988 : 48
Gak 1206	1720 ± 80	A.D. 240–420	Level 2	Navatu	Birks 1973 : 57
NZ 7599	1680 ± 60	A.D. 250–440	Level 2	Navatu	Best 1988 : 48
Wk 5333[c]	590 ± 60	A.D. 1300–1420	Level 3	Vuda	this paper
CAMS 32252	510 ± 60	A.D. 1330–1480	Open field	Vuda	Burley 1997
CAMS 32251	230 ± 40	A.D. 1650–1810	West dunes	Vuda	Burley 1997

Note: All samples charcoal except human bone for Wk 996b. Data for CAMS samples provided by Lawrence Livermore National Laboratory (USA), and for Wk samples by Waikato University Radiocarbon Dating Laboratory (New Zealand). Known $\delta^{13}C$ values (others unknown): NZ 4789, −25.8; Wk 5333, −26.3; CAMS 32252, −25.9; CAMS 32251, −27.8.

[a]Dates B.P. are conventional rediocarbon ages (Stuiver and Polach 1977).

[b]Calibrations derived from standard calibration curves (Stuiver and Pearson 1993, Pearson and Stuiver 1993). Calibrated age ranges derived using cumulative probability as calculated by the calibration program Oxcal version 2.8. For text discussions, the limits of the calibrated intervals are rounded off to the nearest century. Additional off-site radiocarbon ages cited in text are uncalibrated.

[c]Date for Level 3 (Wk 5333) from paleosol in western part of dune field not demonstrably contiguous with excavated Level 3.

Level 3 is partly enigmatic, for the pottery vessels recovered from it are mostly undecorated *kuro* (flared-rim cooking pots), and no radiocarbon dates for Level 3 were obtained from the Birks excavation. The *kuro* pot form has greater frequency, however, in later prehistory (Best 1984: Fig. 2.55), and occasional finds of surface sherds with incised decoration associate Level 3 with the Vuda phase. A radiocarbon date (Table 1) for a similar Vuda-related ceramic assemblage from an excavation into a field on the low-lying surface of the delta plain just inland from the eastern end of the dune field provides an inferred temporal interval of approximately A.D. 1300–1500 for Level 3. An eroding paleosol in the western part of the dune field that is morphologically similar to the Level 3 paleosol, and occurs at an analogous elevation c. 6 m above sea level, has yielded a comparable radiocarbon date of A.D. 1300–1600 (Table 1). An additional radiocarbon date of A.D. 1600–1800 (Table 1) from an eroding hearth feature in the western part of the dune complex extends human use of the dune field to the onset of the protohistoric Ra phase.

Petrographic studies of sand tempers in selected sherds from the Sigatoka Dune site indicate that the various pottery assemblages were largely manufactured locally, in the general vicinity of the Sigatoka delta if not within the dune field itself (Dickinson 1971; Petchey 1995). The composition and texture of the indigenous sand tempers closely resemble those of the dune sands (Dickinson 1968). The grain types of sand tempers in typical sherds are without exception the same as those of the dune sands, and their proportions are comparable as well. In detail, however, relative proportions of ferromagnesian mineral grains of high specific gravity, as opposed to less dense quartz and feldspar mineral grains and polyminerallic rock fragments, vary widely among the sherd tempers, which form a

spectrum of closely related but not identical sands (Dickinson 1973). The range in temper composition indicates that ancient potters selected as tempers a range of local sands that had undergone different degrees of placering, either within the dune field, on the adjacent beach, or on nearby river banks, bars, and channels of the delta plain.

Identification of the sherd tempers as indigenous to the Sigatoka delta is an important indication that the bulk of the ceramics excavated at the site were not left there by temporary visitors from afar. Leaf and mat impressions on pottery recovered from the site have been identified as large leaves of native plants now living near the site, or as woven matting of native pandanus and sedge (Palmer 1965; Lambert 1971). These floristic observations are fully compatible with indigenous manufacture of the Sigatoka pottery assemblages.

Few other archaeological sites in Fiji display superposition of the different ceramic traditions of Fijian prehistory as clearly as the Sigatoka Dune site (Palmer 1968), which has played a significant role for determining the chronologic framework of Fijian archaeology (Frost 1979; Green 1963*a*). Available radiocarbon dates establish that there were three discrete periods during which the site was intensively used. Because Sigatoka pottery was evidently made on site or nearby, we assume that use was related to local occupations, despite the absence of architectural remains or other habitation features. The barren nature of the thick sand layers that intervene between the paleosol culture levels (Fig. 4) suggest sustained absences or periods of severely limited site use during two temporal intervals prior to the modern period. These intervals of abandonment correspond approximately to the periods from 400 B.C. to A.D. 100, and from A.D. 400 to A.D. 1300, although future radiocarbon dates may further constrain their timings. We address the questions of why the site was initially settled, and why it was later abandoned and reoccupied twice more, by inquiring into the geomorphic evolution of the site and its surroundings.

GEOMORPHIC EVOLUTION

Understanding the geomorphic evolution of the Sigatoka delta is an indispensable background for interpreting the archaeological record of the Sigatoka Dune site, for interpretations of site use and the nature of human occupations cannot be made without paleogeographic reconstructions. Key aspects of local geography include the history of delta construction, evolution of the dune field along the seaward margin of the delta, the pattern of past and present distributary channels on the delta plain, and changes in relative Holocene sea level along the adjacent coast.

Delta Growth

The modern Sigatoka delta could not have begun to form prior to the postglacial rise in global eustatic sea level. Study of deltas worldwide suggests that delta-building on all or most coasts began c. 7500 years ago when the rate of postglacial sea-level rise slowed enough to allow fluvial delivery of terrestrial sediment along shorelines to overcome the tendency for marine transgression as sea levels rose (Stanley and Warne 1994). Provided this insight is valid for the Sigatoka delta,

delta-building processes had been underway for approximately 4500 years before the earliest human presence at the site c. 3000 years ago.

As sea level 7500 years ago was approximately 10 m below its modern position (Bard et al. 1996), initiation of the Holocene Sigatoka delta may have occurred at a locus offshore from the present delta plain. With time, aggradation of delta sediment led to development of the present triangular delta with its apex onlapping bedrock exposed along the flanks of the Sigatoka River valley, which was deeply incised into bedrock during sea-level lowstands associated with Pleistocene glaciation. Associated backfilling of the upstream valley by fluvial aggradation has resulted in sediment fill more than 68 m thick, with its base more than 57 m below modern sea level, for at least 10 km inland from the present river mouth (Parry 1987). For the 4500 years of delta history preceding human occupation of the delta, we lack any information about potential phases of delta progradation or outbuilding, as opposed to phases of destructive retreat of the delta front owing to wave attack. It seems most likely, however, that the margin of the subaerial delta never extended beyond the edges of the fringing reef flats lying east and west of the delta front. A line connecting the two points of reef flat adjacent to the delta front lies only 500–750 m off the modern beach (Fig. 3).

Information about the deep subsurface stratigraphy of the delta sediment pile is scanty. Exploratory coring of the dune sands established that they overlie an unknown thickness of beach or other littoral marine sand containing a much lower percentage of heavy iron-bearing minerals than the dune sands (Hirst and Kennedy 1962). Shallow seismic reflection profiling across the submerged delta front within a belt lying 125–1250 m from the shoreline detected a prominent reflector interpreted as the upper surface of subdelta bedrock at a depth of 75–95 m below sea level (Holmes et al. 1983:8). Such a thickness of Holocene deltaic sediment beneath the coastal dune field is fully compatible with the known thickness of presumably Holocene fill present up the Sigatoka River valley when fluvial erosion induced by the drawdown of sea level during the last glaciation is taken into account.

Surf on the beach at the delta margin is strong because freshwater flow and a sediment plume from the river mouth sustain the break in the fringing reef along the delta front. This allows waves from the open ocean to impinge directly on the edge of the delta. The effect of the river-derived sediment is readily apparent after heavy rains when muddy floodwater discolors the seawater for long distances offshore and downwind from the river mouth. Swells driven by the trade winds generate breaking waves with sufficient energy to drive coarse sediment longshore across the entire width of the delta front within the surf zone. Although the exposed beach itself is composed exclusively of sand, transported pebbles occur along the foot of the forebeach slope, and bedrock pebbles derived from the river load are encased in cemented intertidal beachrock of submodern age fronting the beach at the far western end of the dune field (Fig. 3).

Vibrocoring to a maximum of 2 m along the submerged delta front, in support of the seismic profiling study, has shown that near-surface offshore delta sediments are heterogeneous gravelly, sandy, and silty deposits underlying a veneer of fine sand up to 1 m thick (Holmes et al. 1983). Clinoform reflectors indicative of prograding deltaic strata occur below the seabed in water depths of 25–30 m. Approximately 1.75 km southwest of the present Sigatoka River mouth, and

1.25 km nearly due west from the tip of the present fringing reef east of the delta, an uncored submerged reflector of limited extent (350 m × 150 m) lies approximately 10 m below the seabed or 30 m below sea level (Gauss 1983). Although this feature has been interpreted as a local patch reef buried by delta growth, it might instead represent a beachrock horizon dating from early in deltaic history, but otherwise similar to the patch of submodern beachrock present immediately offshore somewhat farther west. In either case, the subbottom reflector is not continuous along the delta front (Holmes et al. 1983 : 8).

The surface of the delta plain immediately inland from the coastal dune field in the vicinity of the archaeological site is scored by a series of low parallel sand ridges (Fig. 3), spaced 50–100 m apart with intervening swales, covered by thin soil and scanty vegetation. Archaeological test excavations among the ridges and swales near the dune field have recovered ceramic rim sherds of types related to the Sigatoka phase ceramics of Level 1 (Burley 1997). The ridges stand 2–4 m above the general surface of the delta plain and lie subparallel to the present shoreline in distinct contrast to the trend of the much higher nearby ridges of the parabolic dune complex closer to the present beach face (Fig. 3). The sand beneath the crests of the delta-plain ridges is depleted in heavy minerals, suggesting that the features are accretionary beach ridges related to successive phases of delta growth. Several holes bored into the delta plain by soil and sand augers revealed progressively thicker accumulations of organic matter and weathered (discolored) soil horizons inland, a pattern that presumably reflects increasing age of deposition of delta sediment with increasing distance from the modern shoreline. We conclude that the delta plain gradually developed seaward as the Sigatoka River infilled an estuary formed by postglacial eustatic rise in sea level, but that delta growth predated human occupation.

Dune Field

Critical information about the evolution of the dune field on the delta margin comes from archaeological excavations within and near the Sigatoka Dune site. Each of the three artifact-bearing layers is a humus-rich paleosol (Birks 1973; Dickinson 1968) that must have formed at a time when the sand substratum was stabilized to an extent that allowed vegetation to persist. Although human cultural activities doubtless contributed organic debris to the paleosols, they are not merely midden accumulations, for each of the lower two is a clearcut soil horizon with oxide-stained B horizons of illuviation and precipitation present below the dark A horizons of leaching and eluviation rich in organic material. Since their burial beneath dune sands, all the paleosols have been modified to some extent by subsoil weathering within the vadose zone of the dune field between the ground surface and the local water table, and leaching of organic material from buried A horizons has caused the coloration of the humus-rich horizons to become successively paler with depth (Birks 1973).

The youngest of the paleosols (Level 3) is both the thinnest (c. 0.4 m) and the most irregular in its elevation, which varies longitudinally along the trend of the beach face by at least 5 m. Both texturally and compositionally, the subjacent sand (between Levels 2 and 3) closely resembles the modern dune sands above Level 3 (Dickinson 1968). From its morphology, Level 3 can be interpreted as an

ephemeral surface on stabilized dunes similar to the present dunes, though neither as high nor as large 500–700 years ago because Level 3 is buried beneath at least 15 m of younger dune sand (Birks 1973). The temporary dune stability recorded by Level 3 may have been limited in extent, with the original continuity of the paleosol broken at intervals by sand blowouts similar to those seen today separating vegetated portions of the existing dune field. Level 3 has not been traced continuously longshore within the dune field, but analogous paleosol exposures on erosional dune slopes westward from the excavated site appear approximately equivalent to Level 3 because associated ceramic assemblages are characteristic of the late prehistoric Vuda phase. These isolated paleosol exposures also underlie thick accumulations of modern dune sand.

The evolving dunes originally advanced obliquely inland until blocked by bluffs of limestone and marl of the Pliocene Cuvu Formation (Houtz 1960), against which dune sand was banked as a rampart at the foot of steep slopes. At present, the artificial Colonial Sugar Refining Company (CSR) dugway (Fig. 3), cut initially during the interval 1913–1915 for a railroad to transport sugar cane and now occupied by the paved Queen's Road highway, separates dunes from bluffs. Inland dune faces at the western end of the dune field were artificially oversteepened by this excavation. Wind-blown sand has also moved around the southern end of the bluffs to form low dunes and undulating eolian sand flats near the coast west of the Sigatoka dune field (Houtz 1960).

The older two paleosols of Levels 1 and 2 differ in important respects from the younger one of Level 3. Each has a well-developed B soil horizon, stained by iron oxides, approximately 1 m thick beneath a humus-rich A horizon. Moreover, the sand between and immediately below them contains a distinctly lower percentage of dark ferromagnesian oxide minerals, concentrated by placer action, than the overlying dune sands lying both below and above Level 3 (Dickinson 1968). On average, the latter contain 2.5 times as much ferromagnetic material by weight (15 vs. 6 percent). An environment of deposition different in important respects from the modern dune field is postulated for the older sands and paleosols, for no feasible change in provenance conditions within the Sigatoka drainage basin could account for such a dramatic increase in the proportion of ferromagnetic oxides in derivative detritus.

Dickinson (1968) originally suggested that the two older paleosols accumulated on the surface of an eolian flat that occupied a part of the delta plain behind a dune field similar to the present one. The implication was that the two older occupation sites were buried as the dune field advanced inland during a destructive phase of delta history. This hypothesis accounted well for the marked compositional difference between the older sands and the modern dune sands, because deflation of sand from dune crests would tend to concentrate grains of higher specific gravity within the dune field and leave the sands deposited on the eolian flat relatively impoverished in heavy ferromagnesian minerals.

Several relationships make this hypothesis now unattractive. On the one hand, the direction of modern dune advance is strongly oblique to the shoreline, with the inland slipfaces of the dunes merely side slopes of longitudinal arms of parabolic dune forms (Rubin 1984). Sedimentation on an eolian flat might also be expected to mask the linear ridges and swales that are still preserved on the delta plain behind the modern dune field. Most directly contradictory, however, is the

presence of a layer of paleo-beach pumice within sand deposited between the two older paleosols (Levels 1 and 2). Porous gray pebble-sized lapilli of floating pumice from eruptions in the active Tonga and Vanuatu island arcs commonly lodge on beaches in Fiji (Bryan 1968), and are washed by wave action over beach berm crests to form discrete layers on backbeach flats, but are not blown inland into either the dune field or elsewhere. The pumice clasts in the pumice layer between Levels 1 and 2 are 2.5–25 mm in mean diameter, form a thin horizon only one clast thick, are not associated with a scour surface, and resemble modern beach pumice clasts in all respects except for surface pitting and discoloration to yellowish hues by weathering.

The layer of paleo-beach pumice indicates that the paleosols of Levels 1 and 2 developed on the beach side of any coastal dune field that may have existed 3000–1500 years ago. The most likely setting for the associated occupation sites was a backbeach flat, perhaps protected from the open shore by low eolian dunes capping a beach berm to form a beach-dune ridge of modest relief that could be overtopped by storm waves transporting the pumice clasts during the interval of time between occupation of the two levels. Longshore changes in the elevations of Levels 1 and 2 reflect undulatory relief of only 1–5 m on the stabilized surfaces where the paleosols formed. Deflation of the beach-dune ridge by wind, coupled with intermittent erosion of the ridge by storm waves, could account for the deposition of sand relatively impoverished in heavy minerals on the backbeach flat, leaving placer concentrates on the beach-dune ridge.

Plate I shows a modern backbeach flat, protected by a low beach-dune ridge, on the seaward flank of the modern dune field, and represents the type of setting inferred for the cultural horizons of Levels 1 and 2. There is no need to suppose, however, that a dune field comparable to the present one existed at the time. The low beach-dune ridge may have been the only topographic feature marking a delta margin of low relief, and the backbeach occupation sites may well have lain tens or even hundreds of meters inland from the ancient shoreline. Development of a prominent dune field is not indicated by available evidence until after human occupation of Layers 1 and 2. Our archaeological survey in the western half of the dune field failed to find paleosols or deflationary features on the high dune slopes exposing diagnostic ceramics dating to earlier than 900 years ago. Their absence supports the argument for late prehistoric development of the dune field in its present massive form.

Delta Distributaries

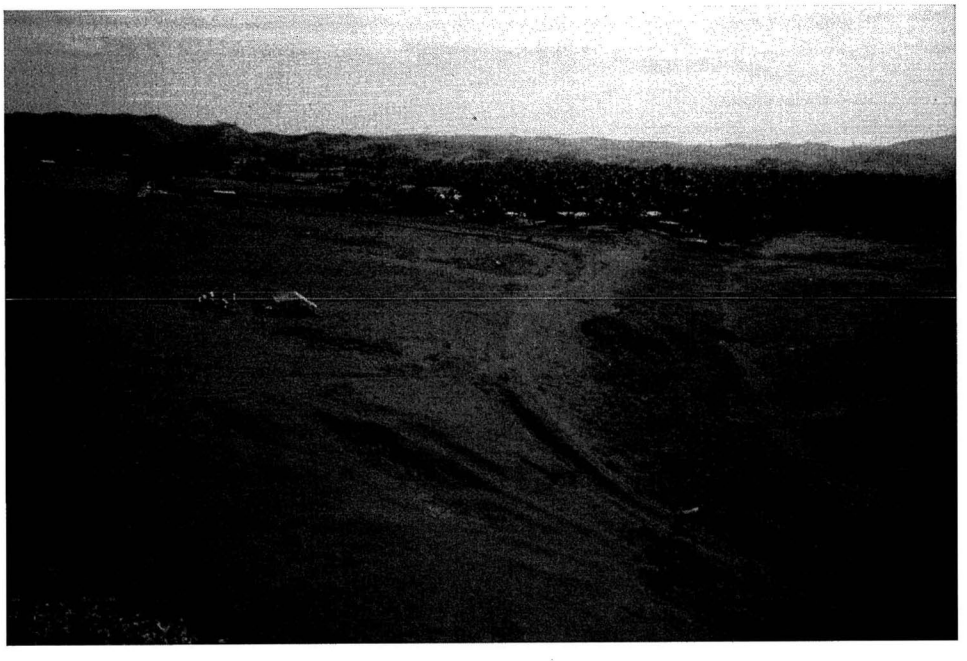
As a stream depositing deltaic sediment flows across a delta plain, its channel commonly either bifurcates into multiple distributaries, or flows alternately down different distributary channels as sedimentation incrementally builds up first one and then another part of the delta plain. The course of the present Sigatoka River, which flows across the delta plain as a single distributary, is apparently constrained to flow along the eastern edge of the delta by the buildup of high dunes downwind from the river mouth. The presence of the dunes blocks any attempt by the river to shift its course toward a different mouth farther west. Multiple chute troughs and floodplain scroll bars on Koroua Island between the Sigatoka River and the branch channel of Vatueta Creek graphically record the

Pl. I. View west along the shoreline fronting the Sigatoka dune field showing a modern backbeach flat seaward of high dunes lying to the right. Note that a low beach-dune ridge developed near the modern berm crest provides partial protection for the backbeach flat (location of same beach-dune berm-crest ridge shown by special symbol on Fig. 3). Beach pumice clasts are strewn across the backbeach flat.

manner in which attempts by the river to shift its course westward are defeated by dune blockage of any more westward path to the seashore (Fig. 3). Meander loops built episodically to the west in the past have evidently been stranded repeatedly by meander cutoffs that reflect resumption of river flow along the eastern margin of the delta in a position forced by inability of the river to forge any other course through the topographic barrier of the dune field.

A slightly different past configuration of the Sigatoka River mouth is indicated by topographic features on the delta plain immediately south of Koroua Island (Fig. 3). West of the present natural levee flanking the modern river channel, an arcuate paleo-cutbank approximately 2–3 m high separates the backswamp of the modern floodplain from the older surface preserving linear sand ridges and swales inland from the modern dune field (Pl. II). The paleo-cutbank is interpreted as a former margin of the Sigatoka River channel, and indicates that the river mouth once lay slightly farther west, or was wider, prior to the development of dunes across the seaward projection of the paleo-cutbank.

Along the western edge of the delta, a belt of marshes and ponds occupies a curvilinear topographic hollow interpreted by Parry (1987) to mark an abandoned paleo-channel (Fig. 3) of the Sigatoka River. Alternately, the low ground might represent the deepest part of a residual backswamp ponded beween natural levees and crevasse-splay fans of the Sigatoka River and the bedrock hills bordering the delta. The topographic low is ponded near its southern end by a barrier of dunes



Pl. II. View north from the crest of the dunes standing above the Sigatoka Dune site (behind the observer to the south) along the trend of a paleo-cutbank (just to the right of the center of view) marking the former western bank of the Sigatoka River (see Fig. 3). The paleo-cutbank, with ~2–3 m of relief, is the arcuate declivity trending toward the cluster of houses (Kulukulu Village) in the middle ground, and lies between the residual surface of the delta plain (on the left), as scored by linear sand ridges and swales (see Fig. 3) upon which exploratory excavations are underway, and the modern river floodplain (on the right), with a marshy backswamp at the foot of the paleo-cutbank separated from the modern river channel by a natural levee (crest out of view to the right).

to form Volivoli Lagoon, a local marshy lake at the edge of the delta plain, but influent streams farther north are drained eastward by a channel leading to the Sigatoka River. Conventional radiocarbon ages from a pit cut into the floor of Volivoli Lagoon include one for submodern marine shell (1010 ± 70 B.P.; Australian National University #9925), recovered from dark lagoonal sediment only 35 cm below the top of the pit, and one for mid-Holocene peat (4640 ± 80 B.P.; Australian National University #9926), recovered at a level 1.1–1.2 m below the surface under a layer of brown clay c. 0.5 m thick. Underlying gray sand identical to modern beach sand, with an abundant component of dark ferromagensian minerals, was encountered in the bottom of the pit at depths below 1.6 m from the surface. The pit stratigraphy indicates that Volivoli Lagoon was probably an estuary separated by beach ridges from the open sea until near 5000 years ago, but became fresh shortly thereafter and supported a swamp forest during a period of uncertain duration in mid-Holocene time. Sediment data from the pit indicates that no active Sigatoka River paleo-channel has existed along the trend of the Volivoli hollow at any time since initial human occupation of the Sigatoka delta. The shallow stratigraphy of Volivoli Lagoon further implies that any such channel was blocked by beach ridges well before growth of the dune field.

Holocene Sea Level

Hydroisostatic theory, as currently understood, predicts a distinct mid-Holocene highstand of 1.5–2.5 m in regional sea level for South Pacific islands, peaking at c. 4000 years ago and declining monotonically since that time (Mitrovica and Peltier 1991). The effect is complex to understand in detail but stems fundamentally from slow deformation of the Earth's mantle in response to the shift of superimposed crustal loads from Pleistocene ice fields concentrated near the poles to ocean water distributed widely over the globe. The inferred timing and magnitude of the mid-Holocene highstand are subject to revision as information about the melting budget of Pleistocene ice and the rheology of the mantle improves. Although the regional hydroisostatic influence on local relative sea level was almost an order of magnitude less than the postglacial eustatic rise of perhaps 125 m in global sea level (Dickinson 1995), its magnitude was nevertheless significant for coastal environments sensitive to slight changes in relative sea level.

Retrodicting mid-Holocene sea levels in Fiji is complicated by the influence of variable rates of tectonic uplift and subsidence at different places within the island group (Nunn 1990*c*). Compilation of empirical evidence for Holocene sea-level change in Fiji suggests a Holocene maximum of 1–2 m above modern sea level approximately 2000–3000 years ago, or somewhat later than theoretical global analysis implies (Nunn 1990b, 1995).

Emergent paleo-shoreline features are preserved along the south coast of Viti Levu both east and west of the Sigatoka Dune site along coastlines fronted by continuations of the fringing reefs built into the sea on both sides of the Sigatoka delta (Fig. 3). The flat surfaces of the fringing reefs are fundamentally wavecut platforms incised into emergent Quaternary limestone but covered by a thin veneer of modern coral growth. Coastal benches cut into uplifted Quaternary reef-flat limestone at elevations of 1.8–2.2 m above the shoreline notch marking the modern high-tide level appear to record the mid-Holocene highstand: 1.8 m near Korotogo 3 km east of the Sigatoka River mouth, 2.2 m on the eastern side of the peninsular headland flanking the river mouth on the east, and 1.9–2.1 m along the coastline between Yadua and Naevuevu 8 km west of the river mouth. A coral sample collected from Quaternary reef limestone exposed 1.7 m above the modern fringing reef surface at the Tambua Sands Resort, located 12 km east of the Sigatoka River mouth, has yielded a conventional radiocarbon age of 3230 ± 50 B.P. (Waikato University #Wk-3448), a date that confirms pronounced late Holocene emergence of the locale. The variability in observed elevations of the emergent wavecut benches and associated paleo-shoreline notches need not reflect any tectonic influence, for the exact positions of such features formed by solution and bioerosion depend upon vagaries of exposure to wave attack and wind-driven currents. Alternatively, their local differences in elevation may reflect a component of differential tectonic uplift, which has variously affected the nearby offshore islands of Vatulele and Beqa (Nunn 1990*c*, 1997).

Delta Shoreline

The excavated portion of Level 1 at the Sigatoka Dune site lies only 1.7–2.3 m above modern high-tide line (Birks 1973), at an elevation comparable to the

emergent paleo-shoreline notches on the reefed coastlines to the east and west. The observed elevation of Level 1 apparently precludes a local relative highstand of sea level, along the front of the Sigatoka delta at the time of human occupation, comparable to the mid-Holocene highstand documented to the east and west along the Viti Levu coast. Whereas people can live safely just above the high-tide line along sheltered coasts protected by fringing reefs, wave runup surges well above high-tide level on surf-washed beaches, and would subject coastal settlements built at a comparable elevation to frequent flooding. There are two possible explanations for the lack of residual effects of a relative mid-Holocene highstand of sea level along the Sigatoka delta front, with neither necessarily exclusive of the other.

First, the mid-Holocene highstand may have declined to a level only 1.0–1.5 m above modern sea level by the time of initial occupation of the site c. 3000 years ago (Mitrovica and Peltier 1991). Stratigraphic relations at the Lapita site in the Yanuca rockshelter 10 km west of the Sigatoka River mouth are compatible with this inference (Birks and Birks 1967, 1978; Hunt 1980). The modern ground surface in the rockshelter stood 3.3–3.5 m above modern high-tide level before excavation, with the preoccupation floor of the cultural horizon only 1.3–1.6 m above modern high tide. The Yanuca rockshelter fronts sheltered waters confined by an offshore islet, and could have been occupied near high-tide line, but local relative sea level at a comparable elevation along the Sigatoka delta margin would expose the Sigatoka Dune site to wave attack during storms that struck the beach at high tide.

Second, progressive subsidence of the delta platform owing to time-delayed compaction and dewatering of buried delta sediments is also likely throughout Holocene time. At Pacific Harbour (Fig. 2) on the south coast of Viti Levu 65 km east of Sigatoka, Shepherd (1990) cored sediments beneath an accretionary chenier plain on the western flank of the Navua River delta, and concluded that local relative sea level has never stood more than 0.6 m above modern sea level at any time since 4000 years ago. The crest of the innermost of multiple accretionary beach ridges at Pacific Harbour dates to c. 4000 years ago but stands only c. 2.5 m above modern high-tide level. As storm wave runup can probably build beach berms to that height under modern wave conditions, there is no requirement for significantly higher relative sea level when the paleo-beach ridge was at the shoreline.

If the theoretical hydroisostatic inference of a regional mid-Holocene highstand and the supportive evidence provided by emergent paleo-shoreline features near Sigatoka are taken as indicative of relative mid-Holocene sea level along the south coast of Viti Levu, then the relations at Pacific Harbour imply subsidence of the Navua delta by approximately 2 m since mid-Holocene time (c. 0.5 mm/year). Continuing subsidence of the Navua delta and its environs is seemingly confirmed by the occurrence of an excavated pottery-bearing horizon near Pacific Harbour at an elevation near present mean sea level but well below modern high-tide level (Palmer 1965).

If a comparable subsidence rate is assumed for the Sigatoka delta, Level 1 may have subsided by perhaps 1.25 m since its last occupation c. 2500 years ago, or enough to account for the comparable highstand level at that time as inferred from hydroisostatic theory. Given the estimated thickness (85 ± 10 m) of the

underlying pile of deltaic sediment, compaction of the sediment column by only 1.5 ± 0.2 percent would suffice to account for the subsidence.

The hypothesis of post–Level 1 subsidence at the Sigatoka Dune site is compatible with relations at the Natunuku archaeological site (Fig. 2) along the bedrock flank of the Ba River delta on the north coast of Viti Levu (Davidson et al. 1990). The Natunuku site includes dentate-stamped ceramics of the Sigatoka phase at its basal level, and a pooled radiocarbon age for four shell samples suggests a calibrated age of approximately 350 B.C. for a gray paleosol developed on sterile coral sand underlying the cultural horizons (Davidson and Leach 1993). The site lies atop a sandy tombolo spit that ties a small paleo-islet of volcanic bedrock to the mainland of Viti Levu. Along the shore on the seaward flank of the spit, remnants of beachrock formed originally within the intertidal zone now stand up to 1.4 m above the modern high-tide line, near the limit of shoreline emergence expected from hydroisostatic analysis for the time of initial human occupation. A sample of the intertidal beachrock collected 2.1 m above mean sea level (c. 1.4 m above modern high tide) has yielded a conventional radiocarbon age of 3970 ± 50 B.P. (Waikato University #Wk-3445), indicative of mid-Holocene age for the paleo-beachrock. Archaeological remains from the Lapita occupation lie along a topographic level of the spit standing above the mid-Holocene intertidal zone marked by the paleo-beachrock exposures.

Prior to subsidence of the Level 1 horizon at the Sigatoka Dune site owing to compaction of sediment beneath the delta platform, retreat of the sea from a mid-Holocene highstand may have contributed to stabilization of the land surface along the delta margin. If so, the backbeach paleosol of Layer 1 may have formed at a paleo-elevation similar to the elevation of the Natunuku site.

PALEOGEOGRAPHIC IMPLICATIONS

Holocene paleolandscape analysis of the Sigatoka dunes and delta provides a rich tapestry of geomorphic interpretation to use in evaluating the paleogeographic setting of the Sigatoka Dune site. Constraints imposed by the geomorphic evolution of the local landscape set the stage for archaeological interpretations. Figure 5, derived from the map in Figure 3, is a speculative reconstruction of predune morphology of the delta margin. Our conclusions are partly conjectural but point the way toward acquisition of better age control for key landscape features by radiocarbon or optical luminescence dating of delta sediments underpinning them.

River Mouth

A critical feature for the interpretation of early landscapes at the Sigatoka Dune site is the paleo-cutbank, exposed inland from the present dune field and representing a former western limit of the main Sigatoka river channel. Projection of its course through the dune field beneath dune sand emerges on the beach face just east of the excavations into Levels 1 and 2 (Fig. 3), but Level 3 continues eastward toward the modern river mouth (Birks 1973). An abrupt westward rise in the elevation of Level 3 in the vicinity of the projected paleo-cutbank suggests that the dune sand below Level 3 was draped across an abandoned cutbank buried by drifting sand.

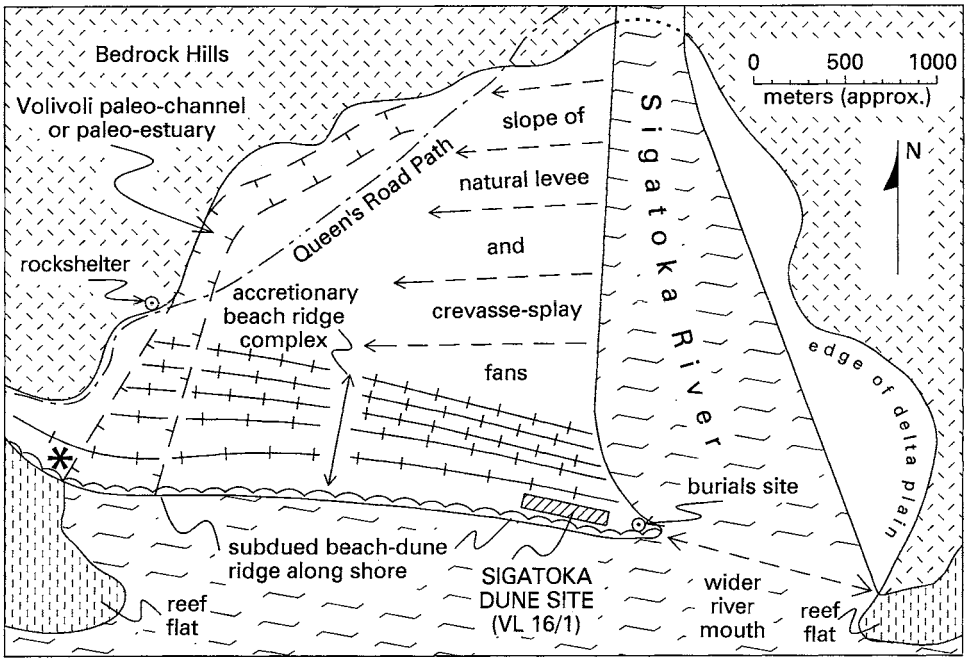


Fig. 5. Reconstruction of Sigatoka delta environments at the time of initial human occupations (c. 3000–2000 B.P.), prior to development of the Sigatoka dune field (compare with Fig. 3, which shows modern conditions). Bold asterisk near left edge denotes Naqarai site (VL 16/22).

These spatial relationships suggest that the archaeological remains in Levels 1 and 2 were deposited when the site lay on a low sandy point where the beach face met the margin of the former river channel (Fig. 5), but that the intradune occupation of Layer 3 occurred after the west bank of the river had retreated toward its present position and a dune field had begun to form at the location of the site. A paleogeographic setting for Levels 1 and 2 on a point at the river mouth would have provided ready canoe access by way of the river, and a protected landing without the risk of surf. It would also have been convenient for the exploitation of both marine and riverine food resources. Without dating the floodplain sediment at the foot of the paleo-cutbank, the alternative that cutbank erosion fortuitously bit into an archaeological site that predated the former river channel cannot be wholly excluded, but seems a less attractive hypothesis. The complex younger array of chute troughs and floodplain scroll bars on Koroua Island east of Vatueta Creek (Fig. 3) must have taken some considerable span of time to evolve. The location of the burial ground of Level 2 (Best 1988) at the tip of a point also accords with common practice among Pacific peoples.

Distributaries and Dunes

Working with the concept that a Volivoli paleo-channel or paleo-estuary was still open to the sea during human occupation of the Sigatoka delta, Parry (1987) suggested that Holocene deltaic history was marked by alternation of the main

delta distributary between the Volivoli paleo-channel along the western flank of the delta and the Sigatoka River along the eastern flank of the delta (Figs. 3 and 5). At times when the western Volivoli paleo-channel was the dominant delta distributary, lack of any voluminous source of sand at the upwind end of the beach would have discouraged dune formation and allowed stabilization of the ground surface to permit the development of paleosols at the Sigatoka Dune site. At times, like today, when the Sigatoka River was the dominant distributary, abundant sand delivered to the eastern end of the beach front would foster dune growth to bury soil layers beneath drift sand. Evidence that the Volivoli hollow was converted to a terrestrial swamp long before human occupation of the delta seemingly precludes this interpretation for the origin of the discrete, artifact-bearing paleosol horizons at the Sigatoka Dune site.

Some paleogeographic separation of the central delta margin from the mainland is nevertheless attractive because Lapita settlements (sites with dentate-stamped pottery) elsewhere in Oceania were often located on small offshore islets separated from adjacent larger landmasses by tidal channels, reef passages, or lagoons (Green 1979; Lepofsky 1988). Swamplands within the residual Volivoli hollow along the western side of the delta may have achieved analogous isolation of the Sigatoka Dune site from interior hills. Conversion of the landscape to its present configuration would not have occurred until development of a dune field topographically blocked the Volivoli hollow from the coast.

Inception of the dune field in its modern guise can be provisionally dated to the interval 1600–700 years ago from the inference that the paleosols of Levels 1 and 2 were developed on backbeach flats that lay along a low-lying delta margin prior to development of the dune field (Fig. 5), whereas Level 3 represents a stabilized surface within the growing dune field. Alternatively, dunes may have been present to the west of the point between the paleo-beach and the former river channel during the time that the older occupation levels were formed. If so, the paleogeographic setting of the occupation site would have been analogous in a general way to the beach-ridge bar at the mouth of the Sigatoka River today.

There is evidence, however, that the dune field was never much higher or wider at its western end, prior to excavation of the CSR dugway, than at present. A rockshelter (Figs. 3 and 5) lying only 3 m in elevation above the railroad grade near the eastern portal of the dugway lacks any infill of dune sand, and has apparently remained open and unblocked by sand for at least 2000 years (Table 2). Dense shell midden dating to the first millenium A.D. suggests, moreover, that the rockshelter may not have been separated from the shoreline by massive dunes until 1000 years ago or later. This timing for dune encroachment on the bedrock spur west of the Sigatoka delta accords well with our inference of major landscape change along the delta margin after occupation of Levels 1 and 2 but before occupation of Level 3 (Table 1). Gradual dune enlargement over the succeeding centuries may only recently have achieved the expansion observed today.

A second archaeological site (VL 16/22 or Naqarai), more limited in extent and less thoroughly studied (Birks and Birks 1966, 1978), lies along an eroded bank on the beach face at the western end of the dune field (Figs. 3 and 5) near the western (mainland) side of the Volivoli hollow as projected to the coast. Because the site has yielded the same array of pottery types, in apparently the same stratigraphic succession, as the main Sigatoka Dune site (VL 16/1), it may have been

TABLE 2. RADIOCARBON DATES FROM A TEST PIT IN ROCKSHELTER VOLIVOLI 2

LAB. NO.	DATE B.P.	CALIBRATED DATE	DEPTH (M)	CULTURAL PHASE
ANU-10449	1120 ± 20	A.D. 882–1010	0.3–0.4	Navatu (?)
ANU-10450	1960 ± 80	34 B.C.–A.D. 129	0.6–0.7	Navatu (?)
ANU-10451	1080 ± 190	A.D. 729–1166	0.7–0.8	(?)

Note: Volivoli 2 is located on a steep slope below limestone bluffs above the CSR dugway (Figs. 3 and 5), just west of the Sigatoka dune field ($\delta^{13}C$ assumed). The test pit was dug into the cave floor to a basal rock surface at 1.3 m depth below the surface, with shell midden and ceramic fragments recovered to a depth of 0.8 m (including some apparently impressed ware at the lowest cultural level). The presence of numerous boulders within the interval 0.6–0.8 m suggests that the anomalous out-of-sequence radiocarbon age may represent young material that slipped down between the boulders. Data from Australian National University.

located along the seaward edge of a beach-ridge complex that blocked the exit of the Volivoli hollow to the coast prior to the development of large dunes (Fig. 5). A dentate-stamped (Lapita) sherd from Naqarai has yielded a single thermoluminescence (TL) date of 2200 ± 250 years, whereas four paddle-impressed sherds from the site have yielded TL dates of 1600–1750 years, with a comparable average uncertainty (Prescott et al. 1982). The multiple TL dates for the latter overlap broadly with available radiocarbon ages for Level 2 at the Sigatoka Dune site containing analogous paddle-impressed sherds (Table 1). The single TL date for the former is younger, by perhaps 500 years if mean values are compared, than radiocarbon dates for Lapita-bearing Level 1, but is essentially concordant at the stated limits of error of the two methods (Table 1).

In any case, no postulated Volivoli paleo-channel could have forged a course to the sea once a sizable dune field formed across its path. Although the Volivoli hollow trends toward the artificial gap in dune sand along the CSR dugway at the base of bedrock cliffs west of the delta (Fig. 3), the Volivoli path to the sea was blocked from the delta margin by the widest part of the dune field until early in the present century. Remnants of dune sand banked as residual ramparts against the base of bedrock outcrops west of the CSR dugway show that migrating dunes formerly reached at least the base of the bedrock cliffs beyond the Volivoli trend. As delta subsidence has surely not been rapid enough to carry Holocene dune fields below sea level, removal of the dune barrier would seemingly require wholesale eolian deflation of the dune tract. Such massive deflation would be difficult to achieve under either of the alternating dune regimes suggested by Parry (1987): a fresh supply of sand to active dunes from the Sigatoka River mouth, or stabilization of the dunes by the growth of vegetation in the absence of a fresh sand supply. The dune field now incorporates a volume of sand on the order of 75×10^6 m^3, and we infer that it has been a persistent landscape feature ever since it began to form, although the volume and height of individual dunes have doubtless fluctuated through time.

Dune Development

We can only speculate why dune growth was substantially enhanced after the occupation of Layers 1 and 2, but human modification of the interior landscape

within the Sigatoka drainage basin, by the spread of settlement inland, may have played a key role. Although late Holocene climatic changes may have promoted deterioration of forest cover on Pacific islands, land clearance for shifting agriculture severely decimated many island forests within about 1000 years of initial settlement on each island (Nunn 1990*a*). Most observers conclude that the open grasslands and fernlands occupying much of the dry western zone of Viti Levu (Fig. 2) resulted from anthropogenic firing of an originally forested landscape (Enright and Gosden 1992 : 190), as first suggested by Wilkes (1985 : 205). Aridity during the last glacial maximum may have fostered precursors of modern grasslands on many Pacific islands including Fiji, and late Holocene climatic change may also have played a supplemental role in more contemporary forest clearance (Nunn 1992). Nevertheless, modern firing of the landscape is demonstrably capable of maintaining open land free of forest trees, and pollen studies within Fiji suggest little or no climatic variation over the past 6000 years (Southern 1986).

Cochrane (1969) thought that the savannah-like vegetation of western Viti Levu stems mainly from human-set fires kindled over the past century after European contact. Ethnohistorical accounts dating from the period 1845–1876 and cited by Parry (1987) indicate, however, that systematic burning of vegetative cover represents a widespread and long-standing cultural tradition reaching back into the prehistory of the highlands in western Viti Levu. The inhabitants of the interior engaged in wholesale burning of the forests to expose and locate wild yams for food, to clear patches of land favorable for gardens, to flush out feral pigs as prey, to improve visibility for the defense of fortified hill sites, and perhaps to reduce the risk to habitations of accidental fires set by lightning. It is important to note that their practices were not simply wanton destruction of forest, as perceived by early European visitors, but constituted a deliberate program of environmental improvement from the standpoint of the ancient inhabitants.

Detailed relations described by Best (1984) at and near the Lapita site on Lakeba in the Lau Group of eastern Fiji suggest that the post-Lapita spread of human settlement into the interior of the island was accompanied by removal of vegetation by burning, with enhanced soil erosion and a marked increase in fluvial sedimentation rates along the coastal strand as consequences (Enright and Gosden 1992 : 187–188). A massive episode of sediment mobilization at Waitabu on Lakeba between 1900 and 1750 B.P. (Hughes et al. 1979) has been attributed to human impact, and more than 3.4 m of regolith containing fragments of charcoal accumulated locally during that short interval of time.

Deforestation of the Sigatoka River catchment may have induced an analogous increase in the supply of coarse sandy sediment to the Sigatoka delta, with resulting accelerated growth of the coastal dune field. Studies on the Nadrau Plateau at the head of the Sigatoka River (Fig. 2) indicate that deforestation associated with (anthropogenic) burning began c. 2000 years ago (Southern 1986 : 148), and continued apace until perhaps 1000 years ago (Enright and Gosden 1992 : 190). The same time interval (2000–1000 years ago) is inferred for the key episode of hillslope erosion associated with anthropogenic burning on Lakeba in Lau (Bayliss-Smith et al. 1988 : 18). The time frame for reduction of original forest in the Sigatoka drainage basin seems generally compatible with evidence for a transition in the nature of the delta landscape between 1600 and 700 years ago, the approximate time bounds of the interval between Levels 2 and 3 of the archaeo-

logical site. Prior human impact on the delta surface itself is implied by evidence for significant changes in the dryland vegetation of the Rewa and Navua deltas, lying farther east along the south shore of Viti Levu, c. 3000 years ago, near the time of initial human occupation of the coastal belt of the island (Southern 1986 : 175).

Direct evidence indicative of significant prehistoric human impact on landscape evolution in the lower reaches of the Sigatoka River drainage basin is now coming to light. Nadrala Creek, a small tributary of the Sigatoka River at a point 12 km inland from the coast, has been blocked near its mouth by a river terrace, and has consequently infilled its valley for a distance of 2 km upstream from its mouth. The infill has in turn blocked off a side valley in which the sedgeland of Doge Swamp (c. 5 ha) has formed at an elevation of 14 m above mean sea level. A core from the clay substrate of the sedgeland swamp has yielded conventional radiocarbon ages of 1330 ± 130 B.P. (Australian National University #10104) and 2090 ± 160 B.P. (Australian National University #10103) for organic-rich horizons lying 1.6–1.8 m and 2.05–2.25 m, respectively, below the present ground surface. Stream aggradation to block local drainages apparently reflects increasing sediment supply by 2000 years ago, a timing coordinate with development of a levee-dammed swamp on the Nadrau Plateau in the headwaters of the Sigatoka River (Southern 1986 : 148). Abundant fragments of fine charcoal within the clays of Doge Swamp reflect frequent fires, and are supportive of the concept that deforestation through anthropogenic firing of inland forests was the factor that led to increased sediment influx to the river system.

ARCHAEOLOGICAL IMPLICATIONS

Despite our elucidation of the paleogeography of the Sigatoka Dune site, some of the same enigmas remain about the nature and purpose of prehistoric human occupation, and the reasons for repetitive abandonment and reoccupation of the site. The lack of any evidence for residential structures at the site led Birks (1973) to suggest that it may represent a series of temporary camps established for turtle-catching. The suggestion is attractive because the sandy strand of the Sigatoka delta may have been a preferred place for nesting by marine turtles before human predation by prehistoric voyagers had reduced their numbers in surrounding waters. The likelihood that proximity to sources of freshwater fish or mollusks in the adjacent Sigatoka River was a key attraction of the site occurs to us as another speculative cause for its location. The possibility can even be raised that site function in the past was the same as today, for limited resource exploitation and recreation (Hudson 1994). There is the further possibility that different resources or features attracted the prehistoric peoples who used the site at each of the separate culture levels. Reconstruction of the local landscape, in combination with archaeological data, indicate that the site environment changed through time.

Level 1 (Sigatoka Phase)

The earliest archaeological materials at the site, although locally grouped into the Sigatoka phase, are representative of the broader Lapita cultural complex (Green

1992), responsible for the exploration and colonization of many island groups c. 3500–3000 years ago (Green 1997; Kirch 1997). Lapita sites in Fiji and western Polynesia are a regional expression of the complex, and are assigned to an Eastern Lapita province (Fig. 1), as opposed to Western and Far Western Lapita groups (Green 1979, 1995; Anson 1986). Considerable debate has surrounded the nature of the Lapita subsistence adaptation, whether dependent wholly on the exploitation of natural resources or with a mixed horticultural base (Groube 1971; Kirch 1988; among many). This debate has yet to be resolved, but faunal assemblages from Eastern Lapita sites of Tonga and in the Lau Group of Fiji document an intensive exploitation of natural resources by the first settlers (Best 1984; Dye and Steadman 1990; Shutler et al. 1994). There seems little doubt that Lapita settlements were specifically situated to maximize this exploitative strategy, especially for the procurement of sea turtle. The Birks (1973) argument for turtle-catching as a primary site function was well reasoned for the initial occupation of Level 1, and is supported by extant interpretations of Eastern Lapita settlement patterns and adaptations. In the Ha'apai Group of Tonga, Lapita settlements were located exclusively near the back of coral sand beaches well suited for turtle nesting, and turtle accounts for as much as 50% of dietary meat weight in identified faunas (Dye and Steadman 1990). Prior to the massive accumulation of dune sand near the site, the delta environment may also have supported a diverse array of land and sea birds and these, too, were a resource heavily exploited by Lapita peoples (Steadman in press).

Level 1 dentate-stamped ceramics associated with the initial Lapita occupation are limited in numbers and spatially concentrated within one specific area at the Sigatoka Dune site (Hudson 1994). Most Level 1 ceramics, and nearly all the sherds excavated by Birks (1973), are identified as late Eastern Lapita or of correlated Lapitoid form, an interpretation supported by radiocarbon chronology (Table 1). These sherds were distributed over an area more than 150 m in length, indicating a significant expansion in site limits and probable population numbers. The absence of evidence for architectural features at the site presents difficulties for any interpretation involving permanent settlement, but such a settlement for Level 1 cannot be dismissed facilely. First, the backbeach setting envisioned for this occupation would have been as stable and protected as many other prehistoric coastal sites in the southwest Pacific region. Second, access to the site by voyaging canoes provided by the break in the fringing reef off the Sigatoka delta, coupled with the existence of a low coastal flat provided by a broad backbeach on the delta margin, would have represented significant inducement for occupation. Third, the range of pottery vessels recovered from Level 1, and their abundance, suggests sustained occupation rather than specialized or expedient site use. The identification of household features for Lapita sites elsewhere in Fiji and western Polynesia has been difficult in many places, and the Sigatoka Dune site is no exception in that respect. The paucity of nonceramic remains may reflect differential survival of artifacts encased in porous dune sand.

Level 2 (Navatu Phase)

No ready geomorphic explanation comes to mind to explain the cultural hiatus between the occupations of Levels 1 and 2. Sediment dynamics at the site evi-

dently discouraged paleosol development in favor of sand accretion during the half millenium between 400 B.C. and A.D. 100, but the basic reason for the temporary instability of the substratum remains obscure. Disruption of habitation by an episode of cyclone or tsunami waves is an unevaluated possibility. As the elevation of Level 2 fluctuates along the trend of the beach face by nearly 5 m, and rises westward (Birks 1973), the size of backbeach dunes may already have begun to increase by 2000 years ago as deforestation got underway inland. Despite this possibility, our overall geomorphic interpretation of the Level 2 landscape does not differ from that for Level 1, and many of the same arguments can be made about the nature of the two occupations. There is one apparent difference, however, in the Level 2 use of the point beside the river mouth for interment of the dead (Best 1988). The burial complex is a structured cemetery with different degrees of elaboration of mortuary practices suggestive of social inequalities. Moreover, excavations of the burials encountered numerous large pieces of burned wood, in original growth position, predominantly of the species *Casuarina litoralis*. While these old trees could represent an ancient forest cover on the delta front, casuarina trees are commonly planted around sacred burial sites of Fiji and western Polynesia today.

The presence of a planned cemetery bespeaks of a nearby village, and extensive concentrations of Level 2 ceramic sherds beginning only 150 m west of the cemetery are suggestive of its location. The sherds recovered by Birks (1973) from Level 2 were mostly from an area approximately 60 m in length, with a few scatters of pottery outside that concentration. Because of the erosive impact of Hurricane Kina in 1993, present exposures of the Level 2 paleosol are significantly greater, and have revealed dense sherd concentrations, together with rock and coral lithic scatters, extending westward for a linear distance of 500 m or more. The occurrence of similar ceramics in limited numbers in the open field lying inland from the dune tract (Burley 1997) potentially indicates an even larger area for Level 2 settlement. The Level 2 ceramic assemblage incorporates a range of domestic vessel types including paddle-impressed pots and bowls made with the use of carved paddles. Also present are crudely made trays with leaf impressions on their bottoms. Archaeologists have yet to identify with confidence the function of these trays, but one intriguing possibility is use as evaporation dishes for the extraction of sea salt (Birks 1973). Sea-salt production for inland trade is documented in the early Fijian historical record (Williams 1858), and the leaf-impressed trays may indicate another type of economic activity at the Sigatoka Dune site.

Paddle-impressed ceramics of the Navatu phase in Level 2 are significantly different from the earlier Lapita/Lapitoid vessels of Layer 1. The contrast in ceramic types might well be attributed to cultural evolution within Fiji during the indicated hiatus of 500 years in the occupation of the site. Alternate arguments for population replacement or migrations into Fiji are contentious (Hunt 1986, 1987), but the presence of Navatu phase ceramics in Fiji has been interpreted by some as the result of influx, or at least influence, of settlers from the west (Frost 1979). There is a widespread view that Lapita ceramic wares were manufactured by a group ancestral to the Polynesians (Kirch 1997), whereas the impressed ceramic wares of the Navatu phase have their closest antecedents within modern Melanesia. Relations at the Sigatoka Dune site provide no clearcut means to choose between the

hypotheses of indigenous development or outside introduction for the change in ceramic type.

Level 3 (Vuda Phase)

The undulatory morphology of the Level 3 paleosol and the identical mineralogical character of the sands above and below identify it as a temporarily stabilized surface within a growing coastal dune field not generically different from vegetated parts of the dune field today. We conclude that presumed abandonment of the site during all or part of the millenium A.D. 400–1300 reflected unstable conditions related to enhanced volumes of wind-blown sand resulting from anthropogenically induced erosion in the drainage basin of the Sigatoka River. One need only spend an afternoon on the Sigatoka beach front today to appreciate the difficulty of maintaining a settlement in the face of blowing dune sand. Temporary visits to the dunes through the centuries since the modern dune field formed are suggested, however, by the presence of late prehistoric to protohistoric ceramic assemblages scattered throughout the extent of the dune field (Burley 1997).

Evidence from Pacific islands for a sharp climatic deterioration c. A.D. 1300, coinciding approximately with the onset of the Vuda cultural phase, has been assembled elsewhere (Nunn 1992, 1994*b*). Cooler weather and a brief episode of enhanced rainfall may have led to societal breakdown and warfare that might account partly for the movement of people in Fiji from undefended coastal settlements to the fortified hilltops characteristic of the Vuda phase in many places.

The archaeological remains in Level 3 are the least abundant and most widely scattered at the Sigatoka Dune site. We infer that use of the site during Level 3 time, though enigmatic in detail, was connected to outlying activities associated with permanent residence on the delta plain inland from the dune field. Systematic test excavations (Burley 1997) have identified one locale, on the delta plain just west of the paleo-cutbank (Fig. 3), where evidence for delta-plain settlement during the Vuda phase is present. Additional late prehistoric pottery scatters have been found within and adjacent to higher elevations in nearby Kulukulu Village (Fig. 3). The Gifford (1951: Plate 14) photograph of a Fijian *bure* standing on ground close to the field where test excavations for this study were dug indicates that similar types of inland settlement continued into modern times. Burial of the dead on seaward-facing dunes continued through Level 3 time and into the historic era (Best 1988; Burley 1997). These late burials seem far fewer in number, more widely scattered, and essentially random in their distribution by comparison to those in the former cemetery of Level 2, but further exposure of the Level 3 paleosol by continued erosion near the eastern end of the dune field may prove this observation premature.

CONCLUDING REMARKS

Our goal, with application to the Sigatoka Dune site, has been to illustrate the advantages of interdisciplinary archaeological and geomorphic interpretations for studies of prehistoric sites in Oceania. Over the course of the past three millenia, the Sigatoka delta was an attractive locale for human settlement and resource ex-

ploitation, as indicated by its long, though intermittent, archaeological record. The massive parabolic dune field that exists along the delta margin today masks the landscape features that initially attracted settlement. We have discussed the past landscapes at length and need not restate our conclusions about them here. The most significant development, relative to both the geological and the human history of the site, was the rapid emergence of the dune field itself late in Holocene time. The available radiocarbon chronology for the site suggests that enhanced dune growth began c. 1500 years ago, probably in response to an augmented sediment load of the Sigatoka River. Although natural forces such as climate change may have come into play to some unknown extent, the primary causal factor of increased sedimentation may well have been anthropogenic alteration of the landscape in the upstream drainage basin of the Sigatoka River, chiefly by deforestation as human settlement expanded into the highlands of Viti Levu. Incipient dune development may have begun as early as c. 2000 years ago, but extension of the dune field to the western edge of the delta plain may have been delayed until c. 1000 years ago. Those limiting dates nicely bracket the period of progressive inland deforestation.

If our inferences are correct, landscape change resulting from attempts to improve environmental conditions for human habitation in the interior of Viti Levu may have inadvertently spoiled formerly viable coastal occupation sites on the Sigatoka delta margin. This presumed linkage underscores the tendency of human beings to act for immediate benefit without perceiving potentially deleterious environmental consequences. Paradoxically, however, growth of the dune field over previously attractive occupation sites also created a marvelously scenic coastal landscape of shifting dunes, with a unique ecology, that has now been set aside for perpetuity as Fiji's first national park.

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ABSTRACT

Understanding the geomorphic setting of the Sigatoka dune field on the south coast of Viti Levu in Fiji is critical for interpreting the associated archaeological site, with culture levels dating back to 3000 years ago. The dune field lies along the seaward fringe of the Holocene delta of the Sigatoka River, which drains interior highlands astride the boundary between the wet windward and dry leeward climatic zones of Viti Levu. Sand brought down to the shoreline by the Sigatoka River is transported longshore westward by surf along the delta front and blown inland oblique to the shore by the prevailing trade winds. Three successive culture levels, dating to approximately 900–400 B.C., A.D. 100–400, and A.D. 1300–1500, respectively, occur in three discrete paleosol horizons that are buried near the present beach face under younger dune sand. Our geomorphic analysis of the Sigatoka delta plain and its environs reveals a complex Holocene history of progradation and aggradation, shifting distributaries, sea-level change, subsidence owing to sediment compaction, and enhancement of dune development through time. The oldest two of the three paleosols that have yielded artifacts evidently formed on a low-lying backbeach coastal flat, located behind a beach-dune berm-crest ridge of low relief, with only the youngest of the three paleosols representing a temporarily stabilized surface within a growing dune field. Enhanced dune growth may have been fostered by augmented sediment delivery to the coast as a result of wholesale inland deforestation associated with population movement into the interior highlands of the Sigatoka drainage basin. KEYWORDS: coastal dunes, deltas, Fiji, geoarchaeology, Lapita, Sigatoka, Viti Levu.