COASTAL SEDIMENTATION AND SHORE PROCESSES NATADOLA BEACH, VITI LEVU, FIJI

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SUMMARY

This report describes preliminary results of a field study on the beach morphology, morphodynamics, and sediments of Natadola Beach, southwest Viti Levu, including the long-term evolution of the beach- and dune-ridge sequence landward of the modern beach. This work was carried out over 3 weeks in May-June 1995 and involved control surveys, beach profiling, sampling, coring, and trenching.

The main conclusions are as follows:

- Natadola Beach is an outstanding example of a largely undeveloped, high-energy, reef-gap beach along the southwest coast of Viti Levu.
- It consists of a central swash-aligned sandy beach and berm, with flanking drift-aligned sections fronted by reef-flat platforms.
- The steep berm-face slope giving way to a low-tide terrace implies a potentially wide dynamic range from dissipative to reflective as a function of water level under constant wave input.
- Wave overtopping of the berm appears to be a common occurrence at this site.
- Rip currents at Natadola Beach pose a threat to inexperienced swimmers. Strong undertow may also be a concern under some conditions.
- The berm crest elevation ranges from 1.4 to 2.8 m above mean sea level, reaching a maximum toward the west end of the central part of the beach.
- The mean size of beachface sediments decreases from about 0.9 mm at the northwest end of the beach (near Dubua Point) to 0.16 mm at the southeast end and is relatively constant (0.19-0.23 mm) along the central part of the beach.
- The well developed dune ridge at the northwest corner of the beach is attributed to aeolian transport under prevailing southeast trade winds and to the stabilising effects of the natural vegetation cover.
- Former sea cliffs are stranded behind the beach on both sides of the valley.
- A sequence of beach and dune ridges has built seaward in front of the cliffs, with no systematic variation in ridge elevation. The ridges have changed alignment from east-west in the early stages to southeast-northwest at present, implying a reorientation of the beach as it built out across the Natadola River.
- Up to 7 m of dune and beach sand underlies the ridge complex west of Natadola River and at least 3 m on the eastern side. Most of this material is carbonate, derived from the reef. Beachrock was encountered over a large area at a depth of 4.5 m (about 1.5 m below mean sea level).

Major recommendations include the following:

- Natadola Beach is a site of outstanding natural heritage value and the long-term development of the area should be carried out in a manner that enhances rather than diminishes this value. This need not preclude appropriate resort development.
- Further archeological investigation is desirable prior to any development proceeding.
- An effort should be made to alert visitors to the danger of rip currents at Natadola Beach.
- Every effort should be made to preserve the natural vegetation between the road and the beach in order to prevent excessive erosion during storms or large swell events, to preserve the dune system, and to limit the extent of beach recession if it is occurring.
- Regular monitoring of Natadola Beach is required to determine whether the long-term pattern of seaward growth has been replaced by an erosional tendency, as suggested by preliminary photogrammetric analysis.
- Further coring should be undertaken to establish the limits of the beachrock and, if possible to penetrate through it, in order to estimate the total volume of sand in the system and establish the long-term average rate of sand supply from the river and nearby reefs.

ACKNOWLEDGEMENTS

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Johnson Seeto (USP) identified the mollusc shells collected at Natadola Beach and Christine Burke (Fiji Museum) provided archeological background. Review of the manuscript by Russell Howorth is acknowledged with appreciation.

INTRODUCTION

This report describes work undertaken on the coast of Viti Levu, the largest island in Fiji (Figure 1). The project was carried out at the request of the Mineral Resources Department (MRD) of the Government of Fiji. It is an extension of earlier work initiated by Viliame Baleivanualala, to develop an understanding of coastal morphology and processes in the Natadola Harbour embayment along the southwest coast of Viti Levu (Figures 2 & 3).

Natadola Beach is a popular recreational beach, used primarily as a day-trip destination by urban dwellers from Suva, Nadi, or Lautoka. The fringing reefs, particularly that to the west of Natadola Harbour off Dubua Point (Figure 3), are used extensively by the local population from the village of Sanasana and the surrounding area for fishing. Navo Island, immediately south of Natadola Beach and Sanasana village, contains sites of historic and traditional importance. A long history of human occupation is indicated in this region by sites on Navo Island, by archeological evidence from the nearby Sigatoka Dunes, by ring-fort structures (a prominent example can be seen in the

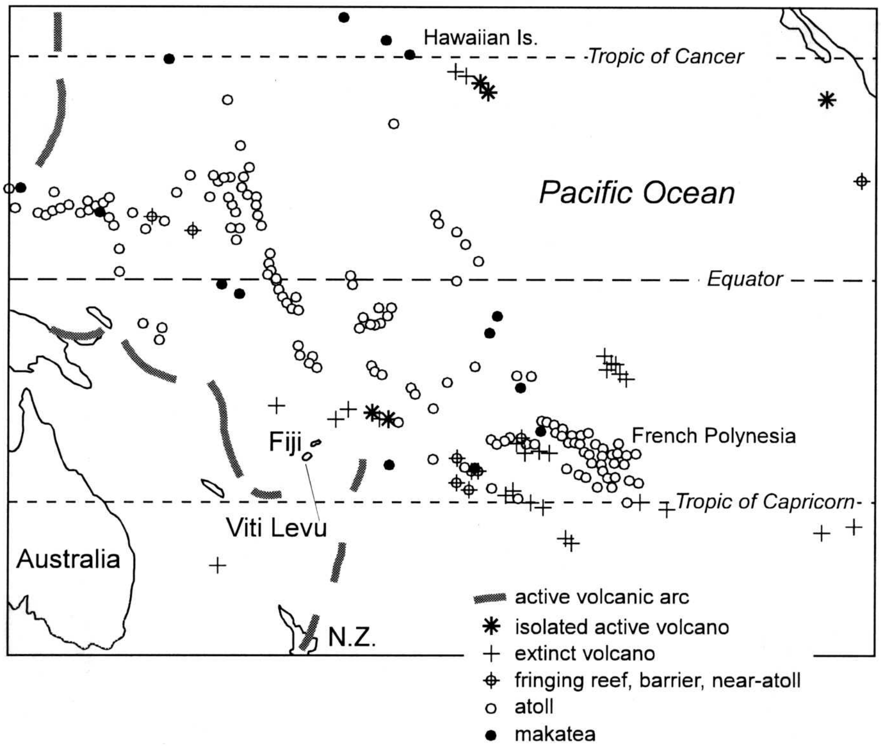

Figure 1. Central Pacific Ocean showing location of Fiji.

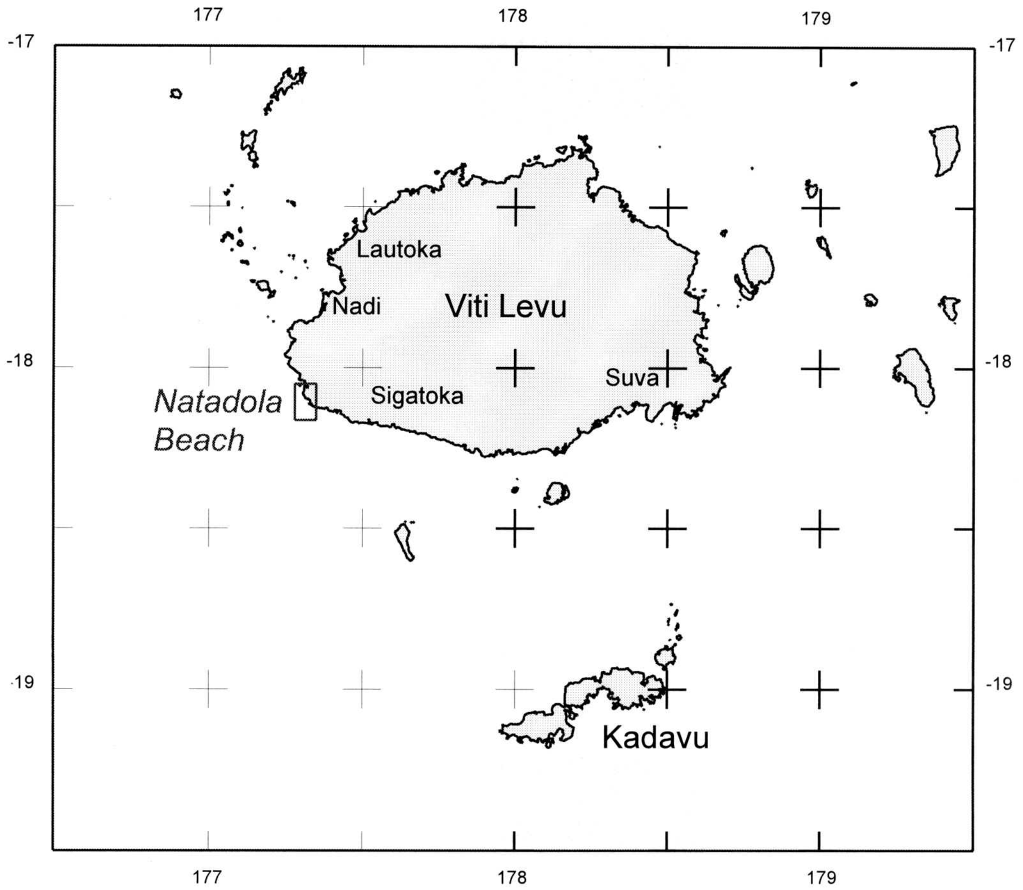

Figure 2. Island of Viti Levu, showing location of Natadola Beach.

Natadola valley about 1 km north of the beach), and by a stone artefact unearthed during the present study (see below). Sugar cane is grown by tenant farmers on land on the northwest side of the harbour, while fields behind the beach in the valley and on hills to the southeast are used as pasture. A small deluxe hotel ("Natadola - Living on Fiji Time") was opened recently by Peter Jones at a site adjacent to the railway line, across from the south end of the beach, in against the hillside. Efforts are reportedly underway by a Japanese consortium in association with Sanasana village to develop land behind the southeast end of the beach adjacent to the Navo Island passage, while Fiji Resorts Limited hold feehold title to much of the western beach and backshore area west of the Natadola River.

Various plans have emerged over the past few years for large-scale luxury resort development on this land, including the possibility of two 300-room 5-star hotels with a golf course and other amenities. These proposals raise important questions concerning suitability of the site, impact on the local environment, and issues relevant to the design, engineering, and management of a resort facility. These may include the identification of recreational hazards (such as rip currents),

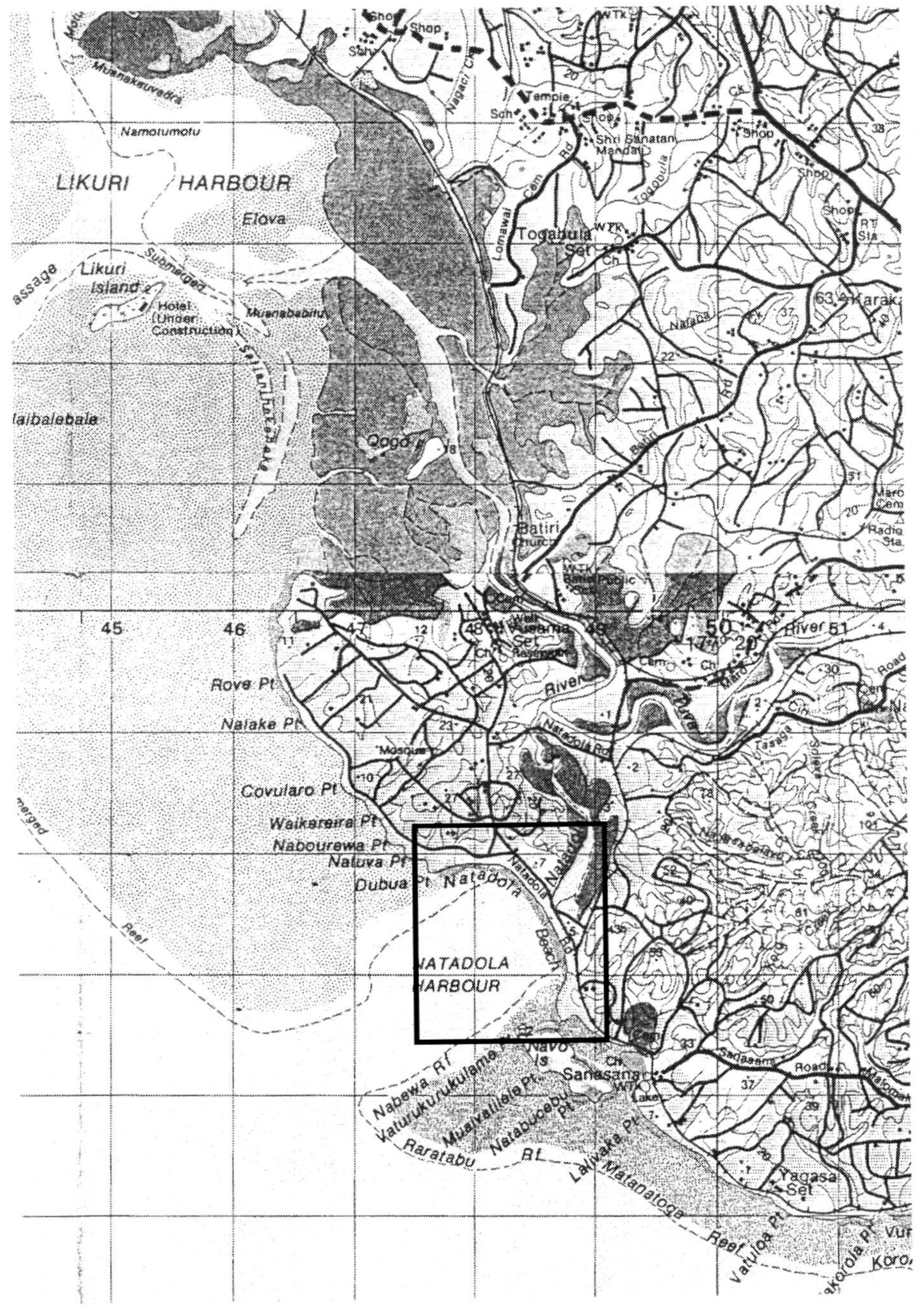

Figure 3. Detail of 1:50 000 topographic map (sheets L28 and L29) showing 1000 m grid and location of Figure 4.

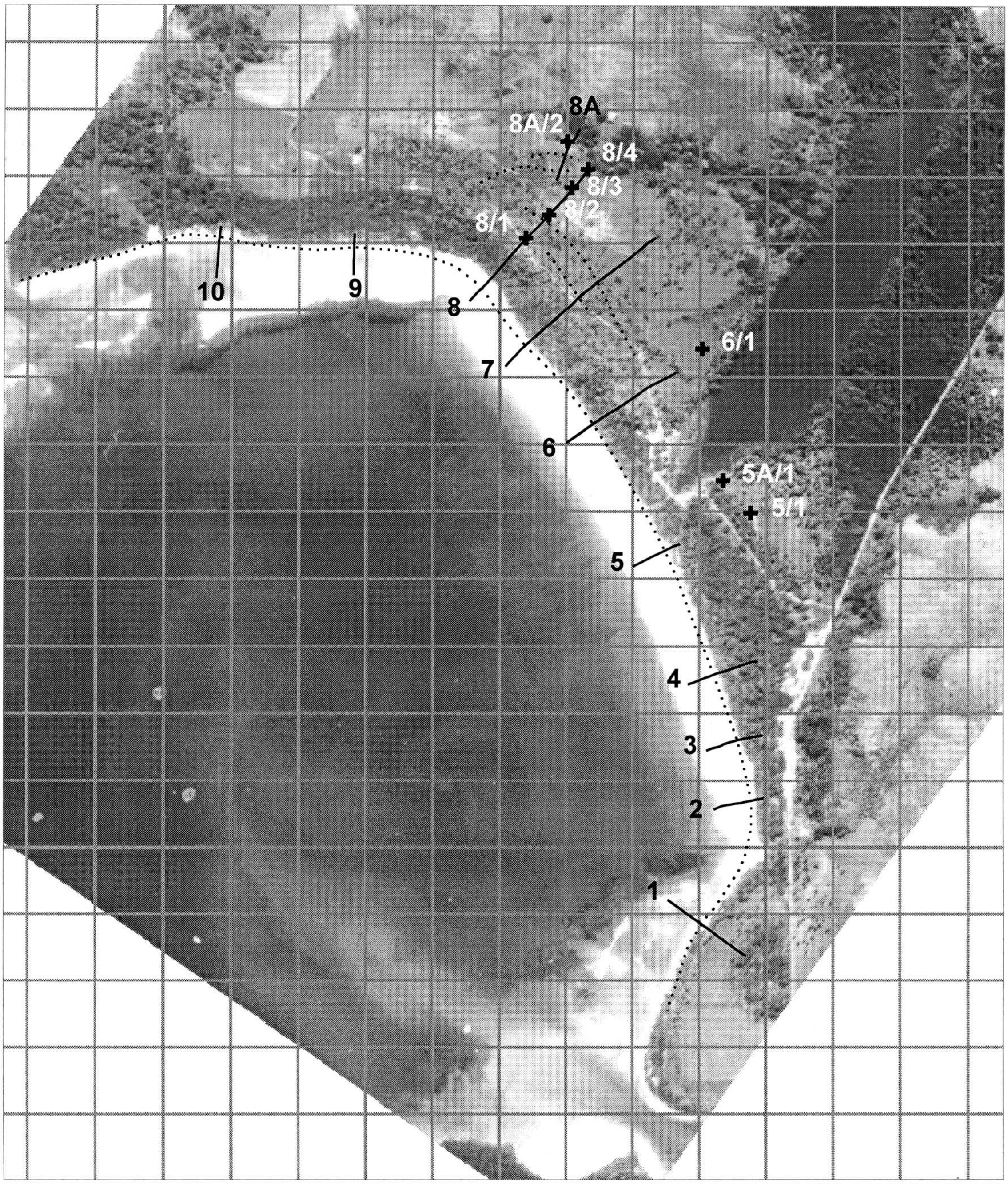

Figure 4. Digitally rectified July 1951 airphoto (15/III/228) with 100 m grid and locations of beach profiles (black numbers) and cores (white numbers with black crosses). Dotted lines show berm crest on beach and surveyed relict dune-ridge crests behind.

factors affecting coastal stability (such as the role of backshore vegetation), foundation conditions (depth to bedrock and the nature of the overlying sediments), flood potential (storm discharge through the Natadola River and risk of flooding adjacent valley terrain), water supply, and other factors.

This study was planned as a multipurpose investigation designed to address the needs of all stakeholders in the area, including the local population, land owners, investors, developers, casual visitors, and government. It is hoped that more detailed information on coastal morphology and processes, sedimentary deposits, and the evolutionary history of the site will contribute to informed decisions on coastal management and development issues by all parties. Should a review of development proposals be undertaken, scientific data will be required by government and other stakeholders to carry out the evaluation. Should large-scale resort development proceed, the detailed design process may benefit from this background, potentially safeguarding investment.

In a broader context, data on long-term development of Natadola Beach may help to provide a better understanding of a variety of coastal issues in southern Viti Levu (cf. Schofield, 1969; Matsushima et al., 1984; Maeda et al., 1986; Ash & Ash, 1985; Rodda, 1986; Sheperd, 1988, 1990; Nunn, 1990a, 1990b), including:

- rates of sand production on the fringing reef,
- the relative importance of reef-generated carbonate sediments and river-supplied volcanic detritus in the coastal sediment budget,
- short- and medium-term morphodynamic variability of beaches exposed to southwesterly storm waves and swell in this environment, including the impact of interannual changes such as the El Niño/ Southern Oscillation (ENSO) phenomenon or major events such as cyclones,
- processes of coastal dune formation, stabilisation, and destabilisation in this environment,
- processes of wave propagation and transformation through reef gaps such as Natadola Harbour and over adjacent reef margins, including wave-driven circulation and rip currents,
- changes in relative sea level at the site over the past few thousand years,
- vulnerability to accelerated sea-level rise or other climate changes such as increased frequency or intensity of tropical storms.

PHYSICAL SETTING

Natadola Beach extends across the head of Natadola Harbour, a rectangular embayment that constitutes one of several openings in the fringing reef between the Sigatoka River to the east and Nadi Bay on the west coast of the island (Figure 2). The beach extends in a 2000 m arc around the head of the bay between Dubua Point in the west and the passage inside Navo Island in the southeast (Figure 3). The harbour opens to the southwest, where the outer reef gap is about 900 m wide. The beach is set back about 2.1 km from the outer reef. Natadola Beach forms a barrier across the Natadola River valley, in which an elongate lagoon occupies the former Tuva River channel and estuary. The channel, now called Natadola River, connects to the present Tuva River channel about 1.5 km north of the present barrier beach. The river still occasionally breaks out through Natadola Beach during extreme storms, the last occasion being associated with Cyclone Oscar in 1985, when it appears there was some human intervention to reduce flooding in the valley (Leke Nacanieli, pers. comm., 1995). On the northwest side of the river, a beach- and dune-ridge sequence about 300 m wide lies between the active beach and limestone cliffs and outcrop (former sea cliff and platform) at the base of high ground to the north (Figures 4 & 5).

The beach can be divided conveniently into three segments (Figure 4):

1 - a short, west-facing, drift-aligned segment extending about 400 m from the tidal channel inside Navo Island to the end of the marginal reef at the beach (Figure 6);
2 - a central, southwest-facing, swash-aligned segment about 900 m long with a sandy nearshore profile (Figure 7);
3 - a flanking, south-facing, drift-aligned segment approximately 700 m long on the west, terminating at Dubua Point (Figure 8).

Each of the flanking segments is fronted by a reef platform. They are described as 'drift-aligned' because refracting waves break at an angle to the beach and set up longshore currents and associated sediment transport ("longshore drift"). The central section is described as 'swash-aligned' because incoming waves break almost simultaneously along its length. Low dunes are developed behind the western segment of the beach (Figure 8).

The present channel of the Tuva River flows westward 1.5 km north of Natadola Beach and empties into Likuri Bay to the west (Figure 3). A flat floodplain surface fills the former valley

Figure 5. Panorama looking northwest to beach and beach-ridge plain with Natadola River and western dune ridges in the distance.

A

B

Figure 6. A: South end of Natadola Beach, with line 1 at far left, marginal reef flat, and passage inside Navo Island. B: Close-up of surf at inner end of reef flat near line 2, with turbid rip current.

A

B

Figure 7. A: Total station survey instrument at back of berm on line 4, looking east along the top of the beach. B: Low-tide terrace, looking southeast between lines 4 and 5, with rooted stump embedded in beach.

A

B

Figure 8. A: Northwestern marginal reef flat at mid-tide, looking southwest from line 8. B: View from top of the dune at line 9, looking back to line 8.

extending south to Natadola Beach. The river crosses this floodplain in a series of tight meanders, straightening again as it passes into the narrow valley connecting to Likuri Bay.

Nabewa Reef marks the southeast side of Natadola Harbour, extending seaward to the west of Navo Island. It connects with Raratabu Reef to the east (Figure 3). A shallow passage between Navo Island and the mainland (Kyaw & Lum, 1981) carries wave- and wind-driven currents from Raratabu and Matanatoga reefs westward into Natadola Harbour under some conditions (as at the time of the July 1951 photography in Figure 4, which shows a turbid plume emanating from the passage). Eastward wave-driven and tidal flows also occur, as evidenced by a variety of morphological and sedimentary features on the entrance shoal. Further east, the coast is relatively straight for about 5 km. Coastal sand dunes are present near Vinabua settlement. To the west, between Dubua and Rove points, there is a succession of rock-controlled coves, with a small patch of mangrove in the first two and small pocket beaches in the others. Beachrock is exposed in a few places, there are thin veneers of pebble-cobble gravel (volcanic lithologies) on the lower beachface, and deeply pitted limestone outcrop with a planar top surface about 0.5 m above estimated high water level was found near Waikereira Point (Figure 3). Wave runup and swash deposition of sand and coral debris occur to a higher level nearby.

The bedrock geology of this area was mapped by Houtz (1959) and Rodda (1971). The hinterland terrain is dominated by Wainimala Series volcanics of Lower Miocene age or older (Houtz, 1959). Sedimentary rocks of the Cuvu Group are exposed along the coast. These rocks, of Upper Pliocene age, have been divided into three formations (Rodda, 1971):

- Voua Sandstone,
- Naevuevu Siltstone, and
- Volivoli Limestone.

Voua sandstones are exposed along the northern margin of Natadola Beach, while Volivoli limestone makes up Navo Island and the coast from Dubua Point west.

The tidal range along the southwest coast of Viti Levu is approximately 1.3 m at springs and 0.9 m at neaps (Kumar, 1994). The only data on wave conditions in the area are limited satellite observations and 2.3 years of wave measurements off Kadavu, about 100 km to the southeast (Barstow & Haug, 1994). The surface measurements, from June 1991 to October 1993, indicate a monthly variation in the mean deepwater significant wave height from <1.8 m in February-March to >2.2 m in April. Significant wave heights >5 m were recorded in July and December 1992 and July 1993 (Barstow & Haug, 1994). GEOSAT altimeter data for 1986-1989 show mean significant wave height off southwest Viti Levu varying from 1.8 m in October-January to 2.1 m in February-May to 2.3 m in June-September (Barstow & Haug, 1994). However, the waves at Natadola Beach are constrained by the southwest-facing reef opening. Little wave energy outside the sector from 180°-270° can enter the bay, although wave setup over the reef may also be caused by waves from the southeast.

FIELD ACTIVITIES

The field program reported in this preliminary report covered about 8 days between 26 May and 18 June 1995. Following an initial reconnaissance and sampling visit on 26 May, we returned the following week to carry out a control survey and establish beach profiles. This involved 3 days from 31 May to 2 June. The next week was devoted to coring and pit sampling activities from 7 to 9 June. A brief visit on 18 June provided the opportunity to complete the sampling program.

Survey Methods and Control

The surveys at Natadola Beach were carried out using a Sokkia Set 2C electronic total station. This measures the horizontal and vertical angles and the slope distance to a reflector target mounted on a stadia rod. Survey data are recorded digitally for later downloading and analysis on a notebook computer. Data processing was carried out using Microsoft Excel 5.0 spreadsheet software running under Windows 3.11.

Because of the lack of survey benchmarks in the area, the nearest being at Korolevu peak, almost 5 km to the east-northeast and hidden from Natadola Beach, a floating control was established using approximate coordinates (from the 1:50 000 topographic map) for instrument position IP1 on top of the hill above the east end of the beach (Figure 9) and using a compass bearing to establish orientation. It is intended that the coordinates reported here will be adjusted later using differential GPS positioning for two or more of the control points.

Vertical control was also a problem in this project and the only option was to adopt an estimated mean water level from surveys of approximate still-water level and tidal predictions (Kumar, 1994).

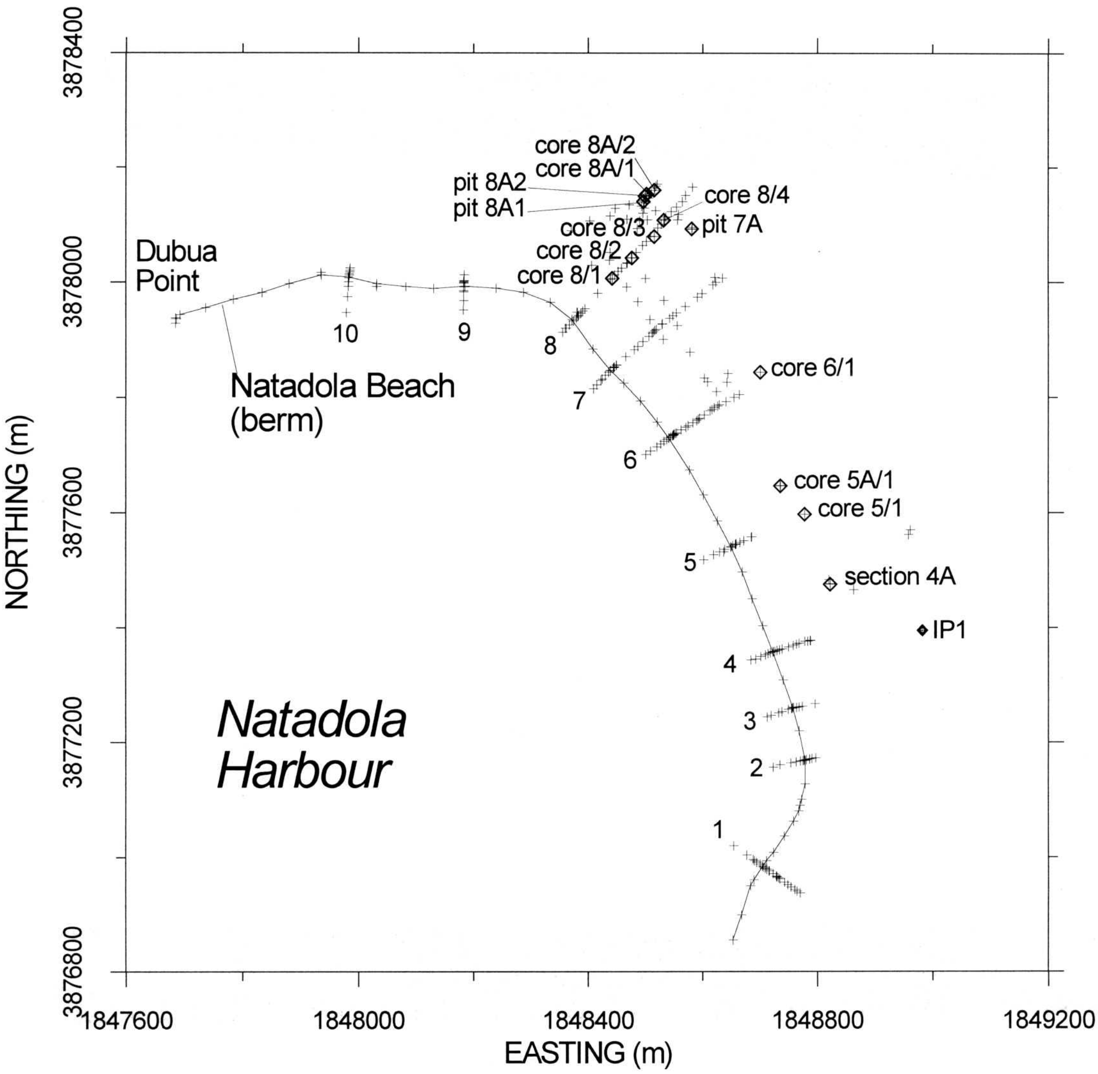

Figure 9. Total-station survey of Natadola Beach showing berm crest, beach profiles, core and pit locations.

Control points were marked in the field using 2 m lengths of rebar (steel rod) driven into the ground. Unfortunately, these are attractive items for tethering animals and other purposes. Despite a request to the local community to respect these markers for the duration of the project, several had been removed before completion of the present field program.

Aerial photographs from 1951, 1978, and 1990 were scanned using Adobe Photoshop. The .TIF raster images were transferred to a Sun SPARC work station for rectification under the public-domain Geographic Resource Analysis System (GRASS) developed by the US Army Corps of Engineers. Following rectification of the images to the floating coordinate system used for the field surveys, the survey points (including core locations) were superimposed as vector and point data on the 1951 airphoto (Figure 4).

Beach and Dune-ridge Surveys

Ten cross-shore profile lines were established on Natadola Beach (Figures 9 & 10; Appendix 1). These were numbered from 1 at the southeast to 10 at the northwest. Line 1 represents the southeast flanking segment, lines 9 and 10 represent the segment on the opposite side of the bay, and lines 2 to 8 represent the central, swash-aligned part of the beach. A shore-parallel profile was surveyed along the berm crest from south of line 1 to Dubua Point, in order to establish the longshore variation in berm height (Figure 11).

The cross-shore profiles were extended landward over low foredunes at lines 3 to 7 and over the high foredune ridge at line 9. Lines 6, 7, and 8 were extended back across the beach- and dune-ridge complex between the modern beach and the former sea cliff at the back (Figure 12). An additional line (8A) was surveyed at an angle to line 8, across the two oldest ridges at the north end of the field and a muddy depression (interpreted as a former back-barrier lagoon) behind the oldest ridge. Ridge crest profiles were surveyed along four of the most prominent dune ridges intersecting lines 6 to 8A (Figures 4 & 9).

Sediment Sampling and Coring

Ten surface samples of beach sand (Appendix 2) were collected near the high-tide level (Figure 11), one at each cross-shore profile line (samples 101 to 110). In addition, one sample was collected from the dune crest at line 9 (sample 111) and another from the berm crest at line 5 (sample 112).

Nine cores were obtained using a hand-operated auger and bailer system (Figures 9 & 13). Core lengths varied from 2 to 7 m (Figures 12 & 14). Samples of representative sections were bagged (Appendix 2) and the remainder of the core material was described and discarded in the field.

Grain-size analyses were carried out using conventional dry sieving at 0.5 ϕ intervals (where the grain size in ϕ units is related to the size in millimetres by the relation $d_{\phi} = -\log_2 d_{mm}$). Thus, increasing ϕ values indicate decreasing grain size. The results, including summary moment statistics, have been summarized in Excel spreadsheet files.

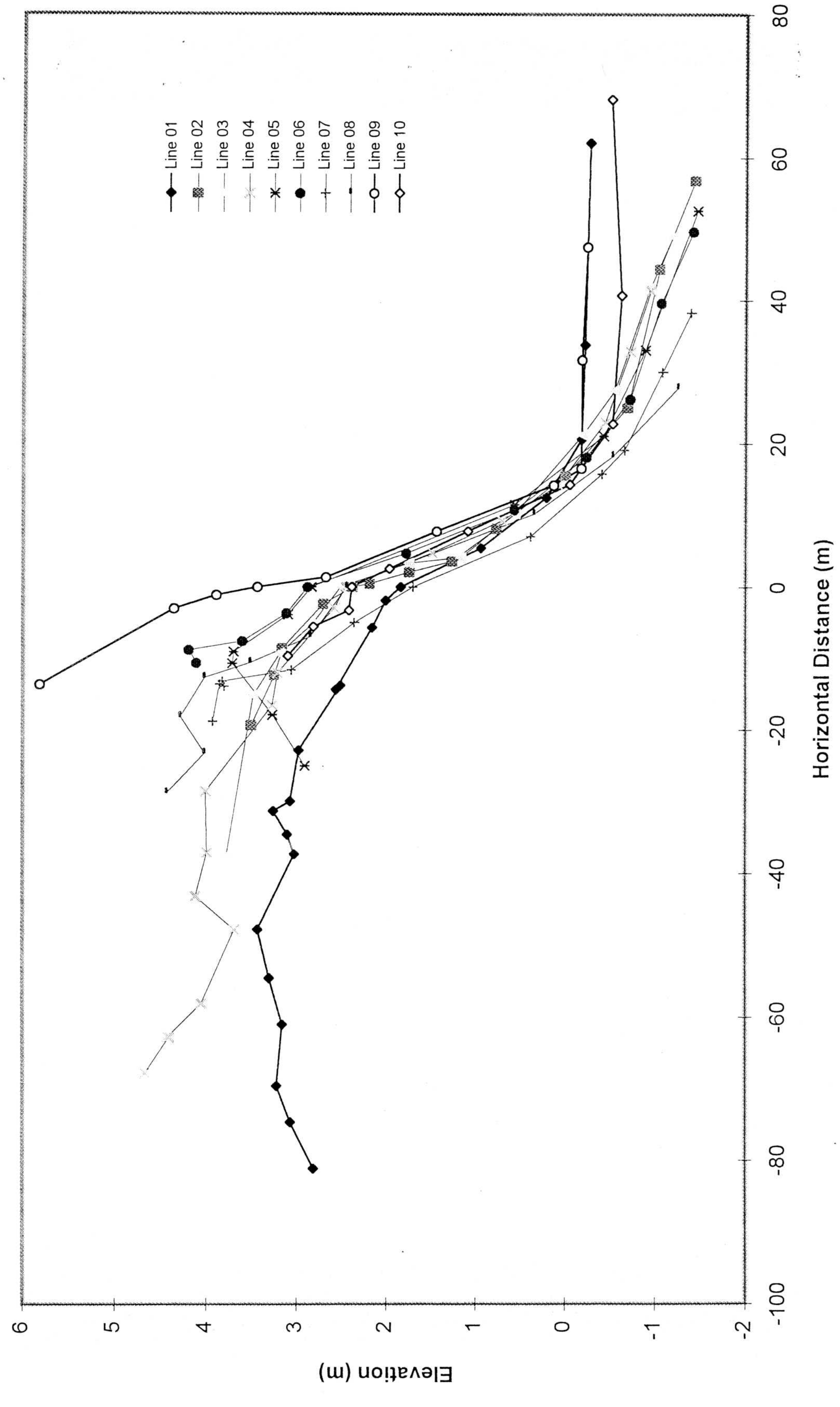

Figure 10. Beach profiles (lines 1 to 10) surveyed in May 1995. Vertical datum is approximate mean sea level.

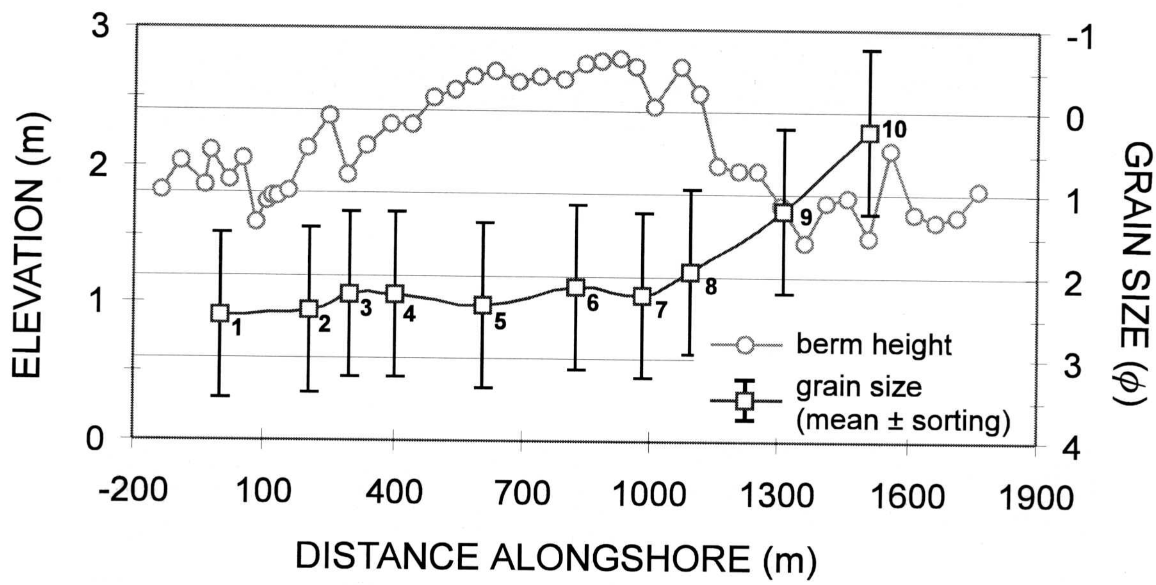

Figure 11. Shore-parallel profile showing berm height and lower beachface grain size (mean ± standard deviation) as a function of distance along the beach from line 1 (i.e. looking seaward). Sample locations are at profile lines 1 to 10.

Shallow pits (Figure 9) were excavated at the base of the former sea cliff east of line 8 (pit 7A) and at two locations on the crest and backslope of the oldest dune ridge on line 8A (pits 8A1 and 8A2). These provided enhanced observations of shallow lithostratigraphy. The primary objective, however, was to collect chronostratigraphic material that might be used to establish the age of the beach and dune ridges and the rate of beach progradation and valley filling during the development of Natadola Beach.

A set of shell samples was obtained from beach sands in pit 7A (Table 1; Figure 15). It is anticipated that radiocarbon determinations on specimens from this collection will establish the age of the beach- and dune-ridge plain. No shell material was recovered from the dune sand in the pits on line 8A, but a stone tool (Figure 16) was unearthed by Alipate Sarileva during excavation of pit 8A2 on the dune-ridge backslope. This intriguing artefact, finely carved from a piece of gabbro, has been turned over to archeologists at the Fiji Museum. Additional shell material (Table 1) was obtained from beach-ridge sands in an existing shallow cut (designated section 4A) by the railway siding landward of line 4 (Figure 9). A radiocarbon age on this material would help to establish the rate of progradation in this southeastern part of the beach, east of the Natadola River.

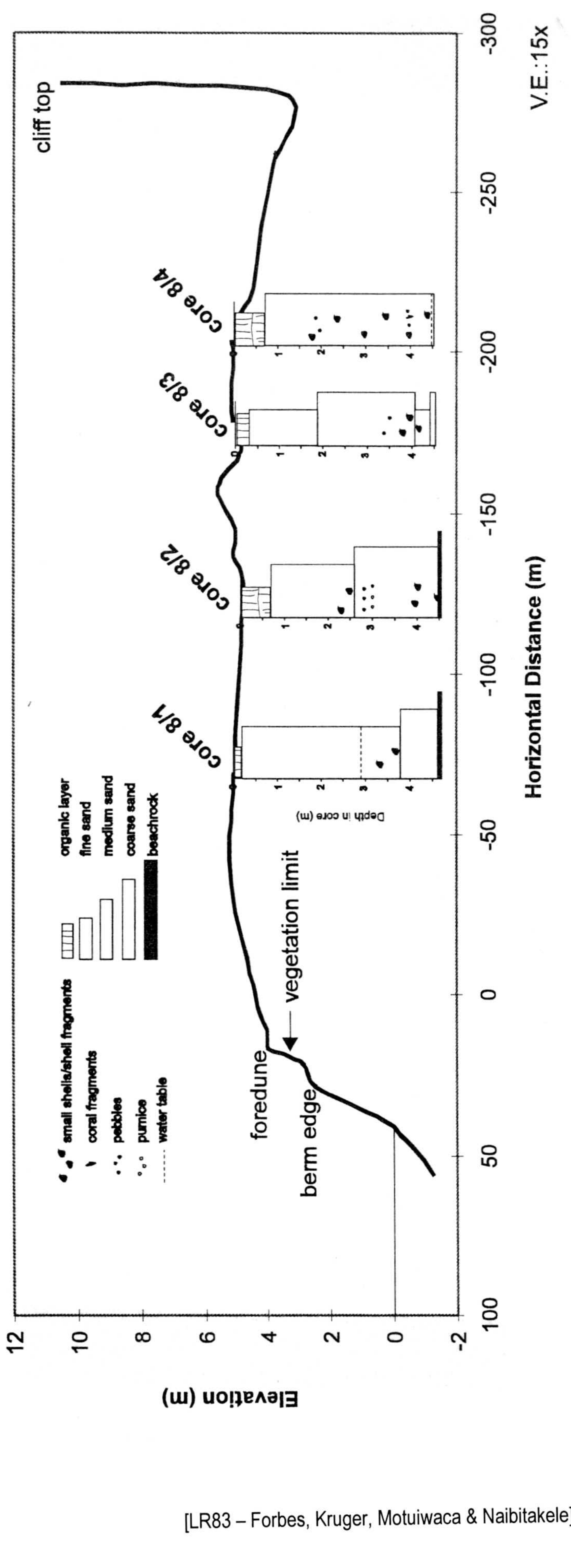

Figure 12. Shore-normal profile along line 8 from former sea cliff at right to modern beach at left, showing core locations and lithostratigraphy.

Figure 13. Coring operations in beach- and dune-ridge complex along line 8. From left: Maika Tukana, Leke Nacanieli, and Sekove Motuiwaca at core site 8/1.

PRELIMINARY RESULTS

Natadola Beach is an outstanding example of a largely undeveloped, high-energy, reef-gap beach along the southwest coast of Viti Levu. It consists of a central, swash-aligned, sandy beach and berm (Figure 7), with flanking drift-aligned sections fronted by reef-flat platforms (Figures 6 & 8). Profiles along the central section of the beach show relatively steep berm-face slopes of 9.8° to 17° passing seaward onto a wide low-tide terrace (Figure 7) with a slope of 1.5° to 2.2° (Figure 10). This implies a potentially wide variation in nearshore wave dynamics, from dissipative to reflective, as the tide and/or setup level varies from low to high. Reflective conditions at high tide are indicated by cusp formation along the berm. Overtopping of the berm was observed on at least three occasions during the three-week field program, associated with high tides and southwesterly waves or swell.

Rip currents are a common feature of the nearshore dynamics at Natadola Beach. Several rip plumes can be seen along the beach in Figure 5 and another, at the end of the reef platform at line 2, is shown in Figure 6. A slight protrusion of the beach close to line 7, visible both in the

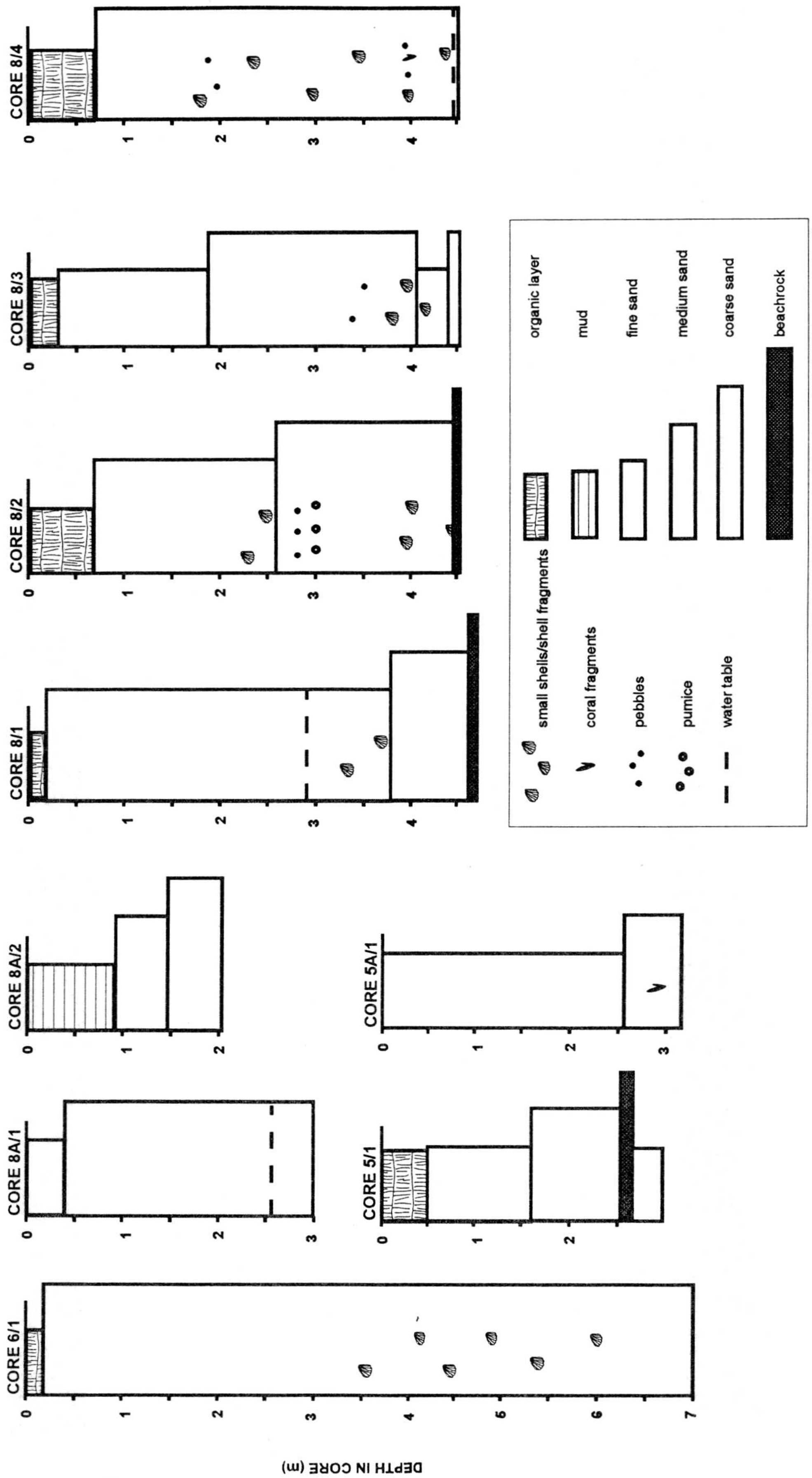

Figure 14. Composite plot of lithostratigraphy in cores.

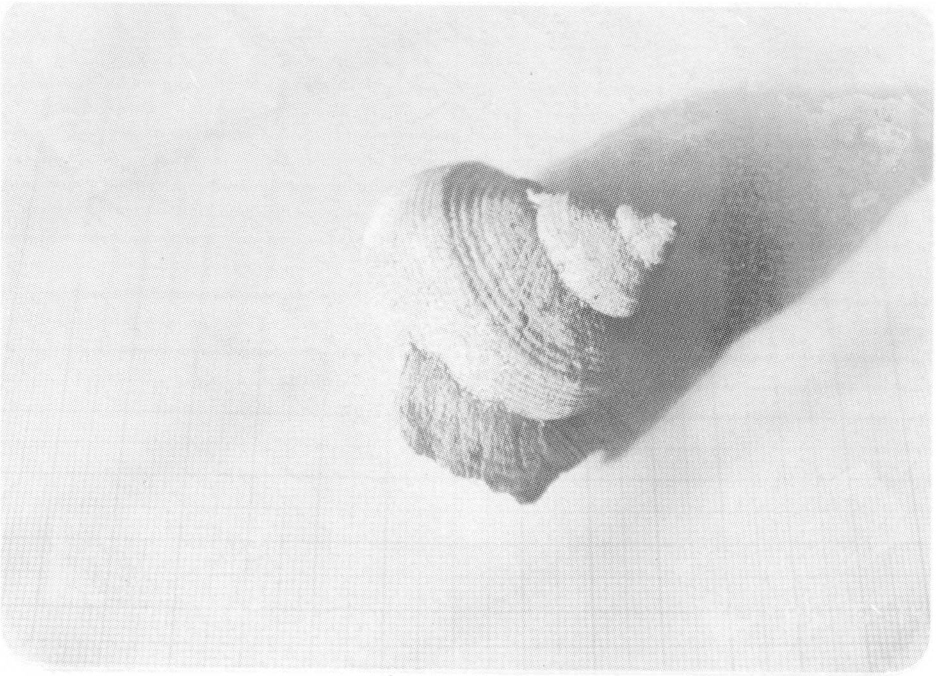

Figure 15. Sample of Turbo sp. gastropod obtained from pit 7A, in beach sands at foot of former sea cliff.

Figure 16. Drawing of stone tool unearthed in pit 8A2.

1951 airphoto and in the 1995 berm survey (Figure 4), appears to be a semi-permanent feature that is associated with convergent longshore flow and the common presence of a rip current in that area. This may be enhanced by large-scale circulation in the bay under conditions when wave setup on the outer reef drives outflow from the Navo Island passage (as at the time of photography in 1951). These currents represent a danger to swimmers and it may be desirable to erect warning signs or otherwise alert visitors to the risk. The 1951 photography also shows prominent shore-normal lineations in the nearshore (Figure 4), which may be associated with strong undertow at the time. The adjacent photograph, with a different sun angle, shows 10 s swell (160 m wavelength) running onto the beach.

The 1995 berm crest survey (Figures 9 & 11) shows a clear 3-part subdivision that correlates with the planform subdivision of the beach. The berm crest is low (between 1.8 and 2.1 m) along the southeast flanking section (-200 to +75 m alongshore) and dips to a minimum of about 1.6 m at the end of this section. The berm elevation rises toward the middle of the swash-aligned segment, reaching about 2.8 m between lines 6 and 7 (at about 930 m alongshore). It drops again to a low value of about 2.0 m at the junction with the western drift-aligned segment, between lines 8 and 9 (1200 m along the beach), and varies between 1.4 and 2.2 m alongshore to Dubua Point. This morphology reflects the lower runup along the drift-aligned segments, largely because of wave energy losses on the reef-flat platforms, and higher runup toward the centre of the beach, associated with minimum energy dissipation along the axis of the bay. The highest berm elevation is offset from the axis, for reasons that are not entirely clear, but may relate to interaction between the angle of deepwater wave approach and the shape of the reef-gap window (Figure 3).

Beachface sediments show a longshore variation (Figure 11) that correlates weakly with the berm height. Grain size diminishes in a roughly log-linear fashion along the beach from line 10 to line 7, is effectively constant along the remainder of the central beach from line 7 to line 3, and decreases slightly at lines 2 and 1. This pattern is interpreted as reflecting influx of sediment along the western shore from the wide reef flat in that area, effectively constant energy and transport conditions along most of the central beach, and limited sediment supply and lower wave energy at the southeast end of the beach. It is interesting to note that the change in the grain-size trend toward the west end of the beach appears to coincide with the highest berm elevation.

The well developed dune ridge at the northwest corner of the beach is presumably related to wind transport along the central segment under prevailing southeast trade winds. The dunes in the vicinity of line 9 are almost 6 m high and partly stabilised by vegetation. Backshore vegetation plays a potentially important role in stabilising the crest of the central beach, particularly west of the Natadola River channel (lines 6 to 10), where the natural vegetation has remained relatively undisturbed. An important objective of any management or development strategy should be to preserve as much of this natural buffer as possible, to maximise beach stability under large waves at high water.

The airphoto interpretation and field surveys show that former sea cliffs extend from line 8 almost to the Natadola River and are also present behind the hotel on the east side of the valley. The oldest ridge (Figure 4) is aligned east-west and extends from behind the present beach at line 10 to the former cliff near line 8. At the time this ridge was forming, the beach was entirely drift-aligned. A small lagoon was present behind what may initially have been a spit near line 8A. Longshore transport along this beach-spit system eventually led to beach sedimentation in front of the former cliff, and ultimately to a major realignment of the entire complex. This is a process commonly observed in systems of this kind (cf. Forbes et al., 1995).

The coring program revealed up to 7 m of dune and beach sand underlying the ridge complex west of Natadola River and at least 3 m on the eastern side (Figure 14). Most of this sand is carbonate, indicating an origin on the reef, with relatively little influx of volcanic material from the river. Beachrock is exposed in the corner by the stream channel at the southeast end of the beach (between lines 1 and 2) and was uncovered near the old sea cliff at that end during excavation of the swimming pool at the Natadola hotel. Cores along line 8 (Figure 12) encountered beachrock at about 4.5 m downcore (approximately 1.5 m below mean sea level) in two cores and probably all four (no beachrock recovered from 8/3 or 8/4, but coring met resistance at this level). This transect, therefore, depicts a near horizontal base across 200 m of the beach-ridge plain. Note also that the surface elevation decreases toward the rear, implying more limited sediment supply and/or dune development in the initial stages of progradation out from the former sea cliff (Figure 12). There is no systematic variation in ridge-crest elevation seaward across the deposit.

The relation between beach-ridge progradation on each side of Natadola River and the maintenance of the channel across the beach-ridge plain remains to be established in more detail. Anecdotal evidence of river flow across the beach during cyclones implies that the river channel has been regularly extended as the beach-ridge complex built seaward. The small proportion of volcanic lithologies in the beach-ridge sands suggests relatively little sand transport associated with these breakouts.

Preliminary analysis of the 1951 photography in relation to the 1995 surveyed berm crest (Figure 4) suggests slight landward recession in the west central part of the beach (the area of the highest berm elevation). There also appears to be some recession of the vegetation line at the southeast end of the beach near line 1. These observations are very preliminary and should be qualified by noting the lack of common control points between 1951 and the present. This suggests a need for monitoring of the beach to establish whether the long-term pattern of progradation has ceased (and, if so, why).

CONCLUSIONS

- Natadola Beach is an outstanding example of a largely undeveloped, high-energy, reef-gap beach along the southwest coast of Viti Levu.
- It consists of a central swash-aligned sandy beach and berm, with flanking drift-aligned sections fronted by reef-flat platforms.
- The steep berm-face slope giving way to a low-tide terrace implies a potentially wide dynamic range from dissipative to reflective as a function of water level under constant wave input.
- Wave runup overtopping the berm appears to be a common occurrence at this site.
- Rip currents are a common feature of the nearshore dynamics at Natadola Beach and pose a significant risk to inexperienced swimmers. Strong undertow may also be a concern under some conditions.
- The berm crest elevation ranges from 1.4 to 2.8 m above estimated mean sea level, reaching a maximum toward the west end of the central beach segment, a little off the central axis of the bay.
- The mean size of beachface sediments decreases along the western flanking beach from 0.2 ϕ (~0.9 mm) at line 10 to 2.0 ϕ (~0.25 mm) at line 8. It holds steady between about 2.1 and 2.4 ϕ (~0.19 to 0.23 mm) along the central beach from line 7 to line 3, and falls again to about 2.6 ϕ (~0.16 mm) in the vicinity of lines 2 and 1.
- The well developed dune ridge at the northwest corner of the beach is attributed to wind transport along the central beach under prevailing southeast trade winds and to the stabilising effects of the natural vegetation cover.
- Former sea cliffs are stranded behind the beach on both sides of the valley.
- A sequence of beach and dune ridges has built seaward in front of the cliffs, with no systematic variation in ridge elevation. The ridges have changed alignment from east-west in

the early stages to southeast-northwest at present, implying a reorientation of the beach as it built out across the Natadola River.

- Up to 7 m of dune and beach sand underlies the ridge complex west of Natadola River and at least 3 m on the eastern side. Most of this material is carbonate, derived from the reef. Beachrock along line 8 restricted penetration to about 4.5 m (~1.5 m below mean sea level).

RECOMMENDATIONS

- Natadola Beach is a site of outstanding natural heritage value and the long-term development of the area should be carried out in a manner that enhances rather than diminishes this value. This need not preclude appropriate resort development.
- Further archeological investigation is desirable prior to any development.
- An effort should be made to alert visitors to the danger of rip currents at Natadola Beach.
- Every effort should be made to preserve the natural vegetation between the road and the beach, to prevent excessive erosion during storm or large swell events, to preserve the dune system, and to limit the extent of beach recession if it is occurring.
- Regular monitoring of Natadola Beach is required to determine whether the long-term pattern of seaward growth has been replaced by an erosional tendency, as suggested by preliminary photogrammetric analysis.
- Further coring should be undertaken to establish the limits of the beachrock on line 8 and (if possible) to penetrate through it, in order to estimate the total volume of sand in the system and establish the long-term average rate of sand supply from the river and nearby reefs. This will also be important to establish foundation conditions in the event that development proposals go ahead.

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Table 1. Molluscan and other marine fauna recovered from Holocene beach and dune sands at Natadola Beach (identifications by Johnson Seeto, University of the South Pacific).

SECTION 4A

Atactodea striata (two single valves)

Chama sp. (single fragment)

Periglypta reticulata (large fragment)

Turbo sp. (gastropod - large fragment)

Turbo chrysostomus (gastropod - one individual)

Siphonaria sp. (limpet)

fragment of crab chelae

PIT 7A

?*Gafrarium* sp. (single valve)

Trochus niloticus (gastropod - large individual and numerous fragments)

Tonna sp. (gastropod fragment)

Turbo sp. (gastropod - large individual and fragments)

? bivalve *a* (single valve and fragment)

? bivalve *b* (single valve)

APPENDIX 1

Beach Profile Data

NATADOLA BEACH ***line 01***
Viti Levu
Fiji
Jun-95

X (m)	*Z* (m)	*EASTING* (m)	*NORTHING* (m)	*PT*	*DESCRIPTION*
-72.90	2.81	1848770.45	3876936.96	639	line 01
-66.48	3.07	1848765.04	3876940.40	640	line 01 edge trees
-61.43	3.22	1848760.74	3876943.06	641	line 01 grass
-52.88	3.16	1848753.83	3876948.09	642	line 01 grass
-46.40	3.30	1848748.66	3876952.01	643	line 01 grass
-39.60	3.44	1848743.28	3876956.15	644	line 01 grass
-29.12	3.03	1848734.66	3876962.10	645	line 01 grass
-26.38	3.10	1848732.41	3876963.67	646	nr side track
-23.16	3.26	1848729.88	3876965.67	647	s line 01 veg
-21.79	3.07	1848728.79	3876966.50	648	line 01 r2b
-14.62	2.98	1848723.09	3876970.84	650	s line 01 trees
-5.60	2.52	1848715.77	3876976.11	651	s line 01 trees
-5.05	2.57	1848716.25	3876975.84	652	s line 01 trees
3.61	2.16	1848709.13	3876980.77	653	s foredune line 01
7.39	2.01	1848705.92	3876982.78	654	s edge veg line 01
9.34	1.85	1848704.56	3876984.17	655	s berm line 01
14.70	0.94	1848700.27	3876987.38	656	s line 01
21.76	0.21	1848694.40	3876991.30	657	s WL@0853 FST
29.93	-0.19	1848687.73	3876996.02	658	s line 01
43.11	-0.22	1848677.01	3877003.69	659	reef flat line 01
71.34	-0.28	1848654.14	3877020.23	660	reef flat line 01

NATADOLA BEACH ***line 02***
Viti Levu
Fiji
Jun-95

X (m)	*Z* (m)	*EASTING* (m)	*NORTHING* (m)	*PT*	*DESCRIPTION*
-14.63	3.51	1848797.13	3877173.08	548	line 02 r2b
-3.85	3.25	1848790.29	3877171.80	568	line 02 veg
0.00	3.16	1848786.63	3877170.64	546	line 02 r1b
0.02	3.16	1848786.64	3877170.63	564	s foredune line 02
6.16	2.71	1848780.57	3877169.47	569	s line 02
8.54	2.38	1848778.25	3877168.94	570	s berm line 02
8.98	2.19	1848777.83	3877168.81	571	s line 02
10.59	1.75	1848776.26	3877168.48	572	s line 02
12.11	1.26	1848774.78	3877168.14	573	s line 02
16.69	0.76	1848770.25	3877167.40	574	s line 02
24.14	-0.01	1848763.00	3877165.70	575	s swash line 02
33.59	-0.69	1848753.63	3877164.33	576	s WL@1505 FST
52.94	-1.05	1848734.60	3877160.85	577	s line 02
65.35	-1.44	1848722.91	3877156.10	578	s line 02

NATADOLA BEACH ***line 03***
Viti Levu
Fiji
Jun-95

X ***(m)***	***Z*** ***(m)***	***EASTING*** ***(m)***	***NORTHING*** ***(m)***	***PT***	***DESCRIPTION***
-22.44	3.78	1848795.55	3877267.38	550	line 03 r2b
0.00	3.49	1848773.53	3877263.09	552	line 03 r1b
5.87	3.19	1848767.79	3877261.85	554	s foredune
9.87	2.84	1848763.93	3877260.79	555	s edgeveg 3
15.19	2.52	1848758.66	3877260.05	556	s line 03
18.53	1.75	1848755.47	3877259.09	557	s berm line 03
19.27	1.17	1848754.75	3877258.93	558	s base of cut
25.41	0.56	1848748.83	3877257.27	559	s line 03
36.43	-0.20	1848738.41	3877253.69	560	s line 03
42.67	-0.56	1848732.65	3877251.29	561	s WL@1450 FST
57.00	-0.94	1848718.97	3877247.02	562	s line 03
64.24	-1.19	1848712.43	3877243.92	563	s line 03

NATADOLA BEACH ***line 04***
Viti Levu
Fiji
Jun-95

X ***(m)***	***Z*** ***(m)***	***EASTING*** ***(m)***	***NORTHING*** ***(m)***	***PT***	***DESCRIPTION***
-51.39	4.66	1848787.71	3877377.58	535	vs line 04 r2b
-46.34	4.41	1848782.76	3877376.59	534	vs line 04
-46.30	4.42	1848782.72	3877376.58	533	vs line 04
-41.54	4.05	1848777.98	3877376.12	532	vs line 04
-31.25	3.69	1848768.18	3877373.00	531	vs line 04
-26.57	4.12	1848763.85	3877371.20	530	line 04 road
-20.49	3.99	1848758.10	3877369.22	529	line 04 road
-11.96	4.01	1848750.00	3877366.55	528	vs line 04
0.00	3.28	1848738.66	3877362.77	526	vs line 04 r1b
4.57	3.21	1848734.30	3877361.39	537	s foredune
13.66	2.59	1848725.57	3877358.85	538	s line 04
16.63	2.46	1848722.81	3877357.77	539	s berm line 04
21.36	1.49	1848718.39	3877356.10	540	s line 04
25.87	0.70	1848714.20	3877354.40	541	s line 04
30.79	0.08	1848709.55	3877352.78	542	s line 04
39.55	-0.45	1848701.42	3877349.53	543	s WL@1358 FST
49.44	-0.72	1848692.34	3877345.62	544	s line 04
58.00	-0.95	1848684.15	3877343.13	545	s line 04

NATADOLA BEACH ***line 05***
Viti Levu
Fiji
Jun-95

X	*Z*	*EASTING*	*NORTHIING*	*PT*	*DESCRIPTION*
(m)	*(m)*	*(m)*	*(m)*		
-14.28	2.91	1848671.87	3877550.98	582	line 05 veg
-7.17	3.27	1848665.22	3877548.47	581	line 05 veg
0.00	3.72	1848658.53	3877545.89	579	line 05 r1b
1.63	3.70	1848657.18	3877544.98	583	s foredune
6.89	3.10	1848652.39	3877542.81	584	s edge veg
10.75	2.84	1848648.93	3877541.11	585	s line 05
22.21	0.56	1848638.60	3877536.14	586	s line 05
31.77	-0.43	1848630.01	3877531.95	587	s swash line 05
43.82	-0.89	1848619.15	3877526.72	588	s WL@1526 FST
63.31	-1.46	1848601.80	3877517.85	589	s line 05

NATADOLA BEACH ***line 06***
Viti Levu
Fiji
Jun-95

X	*Z*	*EASTING*	*NORTHING*	*PT*	*DESCRIPTION*
(m)	*(m)*	*(m)*	*(m)*		
60.35	-1.42	1848500.81	3877701.47	601	s line 06
50.32	-1.06	1848509.07	3877707.17	600	s line 06
36.89	-0.72	1848520.25	3877714.62	599	s WL@1546 FST
28.79	-0.24	1848526.71	3877719.50	598	s swash line 06
21.42	0.56	1848532.54	3877724.00	597	s line 06
15.37	1.78	1848537.55	3877727.41	596	s line 06
10.70	2.88	1848541.44	3877729.98	595	s berm line 06
7.06	3.12	1848544.36	3877732.16	594	s edge veg
3.14	3.61	1848547.63	3877734.32	593	s line 06
1.83	4.19	1848548.82	3877734.86	592	s crest line 06
0.00	4.11	1848550.24	3877736.02	590	line 06 r1b
-3.51	4.20	1848552.46	3877738.32	466	line 06 stump
-5.64	3.54	1848554.52	3877738.83	467	s brk slope
-15.30	3.01	1848562.73	3877743.92	468	s backslope
-24.64	2.87	1848570.81	3877748.63	469	s backslope
-29.02	3.52	1848574.52	3877750.94	470	s ridge crest
-39.53	3.66	1848583.39	3877756.58	471	s
-46.67	4.07	1848589.36	3877760.49	472	s
-50.39	4.10	1848592.52	3877762.45	473	s
-62.87	3.74	1848602.72	3877769.65	474	s
-75.46	4.51	1848613.11	3877776.74	475	s
-79.29	4.56	1848616.08	3877779.17	476	s
-84.29	3.81	1848620.11	3877782.13	477	edge road
-91.60	4.23	1848626.59	3877785.51	478	edge road
-94.48	4.58	1848628.96	3877787.15	479	fence post b
-107.67	4.47	1848640.83	3877792.91	481	s
-123.48	4.36	1848654.80	3877800.30	482	s
-134.40	4.44	1848664.45	3877805.42	483	s EOL

NATADOLA BEACH ***line 07***
Viti Levu
Fiji
Jun-95

X *(m)*	*Z* *(m)*	*EASTING* *(m)*	*NORTHING* *(m)*	*PT*	*DESCRIPTION*
0.00	3.93	1848449.77	3877855.86	610	line 07 r1b
5.20	3.86	1848445.58	3877852.78	612	line 07
5.43	3.80	1848445.84	3877852.91	613	line 07 veg
5.62	3.83	1848445.20	3877852.58	614	line 07 edge veg
7.20	3.06	1848444.16	3877851.40	615	s berm line 07
13.87	2.36	1848439.35	3877846.78	616	line 07 stake tbm
18.83	1.71	1848435.67	3877843.45	617	s berm line 07
25.88	0.38	1848430.49	3877838.66	618	s line 07
34.61	-0.41	1848424.92	3877831.94	619	s line 07
37.98	-0.66	1848422.54	3877829.55	620	s WL@1704 FST
48.83	-1.08	1848415.02	3877821.73	621	s line 07
57.14	-1.40	1848409.73	3877815.32	622	s line 07

NATADOLA BEACH ***line 08***
Viti Levu
Fiji
Jun-95

X (m)	Z (m)	EASTING (m)	NORTHING (m)	PT	DESCRIPTION
56.52	-1.26	1848355.55	3877913.22	636	s line 08
47.02	-0.54	1848362.18	3877920.04	635	s WL@1728 FST
38.95	0.34	1848367.60	3877926.02	634	s line 08
28.77	2.45	1848374.92	3877933.08	633	s berm line 08
21.82	2.85	1848379.81	3877938.02	632	s line 08
18.21	3.52	1848382.29	3877940.65	631	s line 08 edge veg
16.11	4.02	1848383.53	3877942.34	630	s foredune line 08
10.61	4.28	1848387.20	3877946.44	629	s foredune line 08
5.49	4.02	1848390.80	3877950.07	628	s line 08
0.00	4.43	1848394.48	3877954.15	625	line 08 r1b
-34.96	5.17	1848417.25	3877980.81	623	line 08 r2b
-67.92	5.09	1848439.03	3878005.55	413	line 08 r3b
-128.12	4.76	1848446.61	3878013.19	416	line 08 profile
-136.48	5.10	1848452.57	3878019.05	417	line 08 profile
-144.70	5.01	1848458.50	3878024.75	418	line 08 profile
-157.62	5.58	1848467.33	3878034.19	419	line 08 profile
-169.66	4.83	1848475.45	3878043.08	420	line 08 profile
-182.12	5.16	1848484.02	3878052.13	421	line 08 profile
-198.64	5.09	1848495.39	3878064.10	422	line 08 profile
-208.49	5.11	1848501.78	3878071.60	423	line 08 profile
-219.86	4.47	1848509.25	3878080.17	424	line 08 profile
-238.87	4.24	1848521.81	3878094.44	425	line 08 profile
-258.01	3.85	1848533.28	3878109.76	426	line 08 r4b
-281.12	3.53	1848556.35	3878108.46	436	base of cliff
-284.27	10.56	1848558.10	3878118.35	435	top of cliff

NATADOLA BEACH   ***line 09***
Viti Levu
Fiji
Jun-95

X	*Z*	*EASTING*	*NORTHING*	*PT*	*DESCRIPTION*
(m)	*(m)*	*(m)*	*(m)*		
-10.67	5.81	1848183.70	3878013.21	714	line 09 r2b
0.00	4.35	1848183.36	3878002.60	738	line 09 r1b
1.88	3.89	1848183.04	3878000.75	740	s line 09
3.02	3.44	1848182.99	3877999.61	741	s line 09
4.38	2.68	1848182.92	3877998.25	742	s line 09
10.74	1.44	1848182.93	3877991.89	743	s line 09
17.19	0.12	1848182.78	3877985.44	744	s line 09
19.61	-0.18	1848183.02	3877983.03	745	reef flat line 09
34.74	-0.19	1848182.73	3877967.91	746	reef flat line 09
50.47	-0.25	1848182.31	3877952.18	747	reef flat line 09

NATADOLA BEACH   ***line 10***
Viti Levu
Fiji
Jun-95

X	*Z*	*EASTING*	*NORTHING*	*PT*	*DESCRIPTION*
(m)	*(m)*	*(m)*	*(m)*		
-9.66	3.10	1847985.69	3878024.67	749	line 10 r2b
-5.59	2.82	1847985.20	3878020.63	748	s line 10 bush
-3.32	2.42	1847984.94	3878018.36	751	s line 10 veg
0.00	2.39	1847984.19	3878015.13	721	line 10 r1b
2.51	1.97	1847983.83	3878012.65	752	s line 10 edge veg
7.75	1.09	1847983.39	3878007.43	753	s line 10 HWL
14.23	-0.06	1847982.70	3878000.98	754	s WL@1148 FST
22.73	-0.53	1847982.30	3877992.48	755	s line 10
40.70	-0.62	1847981.06	3877974.55	756	reef flat line 10
68.09	-0.51	1847978.87	3877947.26	757	reef flat line 10

APPENDIX 2

Sediment Samples

SAMPLE INVENTORY *May-June 1995*
Natadola Beach

SITE	*EASTING*	*NORTHING*	*SAMPLE*	*DEPTH (m)*	*DESCRIPTION*
section 4A	1848822.41	3877475.32			
			4A-01	0.0-0.3	sand
			4A-02	0.0-0.3	shells
core 5/1	1848778.01	3877597.13			
			5/1-01	0.9-1.0	brown medium sand
			5/1-02	1.9-2.0	brown medium sand
			5/1-04	2.8-2.9	coarse sand
core 5A/1	1848735.74	3877646.77			
			5A/1-01	2.5-2.7	coarse sand
			5A/1-02	3.0-3.1	coarse sand
core 6/1	1848700.57	3877843.18			
			6/1-01	0.4-0.5	gravelly sand
			6/1-02	0.9-1.0	fine sand
			6/1-03	1.9-2.0	fine sand
			6/1-04	2.9-3.0	fine sand
			6/1-05	3.4-3.5	sand & shell frags
			6/1-06	4.8-5.0	sand & shell frags
			6/1-07	5.8-6.2	sand & shell frags
			6/1-08	6.6-7.0	sand & shell frags
pit 7A	1848581.53	3878092.90			
			7A-01	0.1-0.5	sand
			7A-02	0.1-0.5	shells
core 8/1	1848442.61	3878006.87			
			8/1-01	0.3-0.5	yellow fine-coarse sand
			8/1-02	0.9-1.0	yellow fine-coarse sand
			8/1-03	1.4-1.5	yellow fine-coarse sand
			8/1-04	1.9-2.0	yellow fine-coarse sand
			8/1-05	2.4-2.5	yellow f-c sand & shell hash
			8/1-06	3.0-3.3	sand
			8/1-07	3.8-4.2	sand
			8/1-08	4.3-4.5	sand & cemented aggregates
			8/1-09	4.5-4.6	beachrock
core 8/2	1848476.97	3878042.13			
			8/2-01	0.7-0.9	yellow fine-medium sand
			8/2-02	1.5-1.7	yellow fine-medium sand
			8/2-03	2.3-2.6	yellow f-m sand & shell frags
			8/2-04	3.4-3.7	yellow f-m sand & shell frags
			8/2-05	3.9-4.1	f-m sand with aggregates & shell frags
			8/2-06	4.2-4.4	f-m sand with aggregates & shell frags
			8/2-07	4.4-4.5	beachrock & shell frags
core 8/3	1848515.83	3878079.71			
			8/3-01	1.1-1.3	grey-yellow fine sand
			8/3-02	2.0-2.2	brown fine sand & minor coarse sand
			8/3-03	2.4-2.7	bown fine-medium sand
			8/3-04	3.0-3.2	bown fine-medium sand
			8/3-05	3.3-3.5	brown medium sand & pebbles
			8/3-06	3.7-3.9	medium sand & shells
			8/3-07	4.1-4.3	grey silty sand & shells
			8/3-08	4.3-4.5	grey sand & shells
			8/3-09	4.4-4.6	grey sand & aggregates

SAMPLE INVENTORY (continued)

ID	***EASTING***	***NORTHING***	***SAMPLE***	***DEPTH (m)***	***DESCRIPTION***
core 8/4	1848532.39	3878108.00			
			8/4-01	0.8-1.0	grey medium-coarse sand & aggregates
			8/4-02	1.8-2.0	grey medium-coarse sand & aggregates
			8/4-03	2.7-2.8	brown gritty medium sand & shell frags
			8/4-04	3.3-3.5	brown gritty medium sand & shell frags
			8/4-05	4.1-4.2	grey medium pebbly sand & shell frags
			8/4-05A	4.1-4.2	shell
			8/4-06	4.2-4.3	grey medium pebbly sand & shell frags
			8/4-07	4.3-4.5	grey medium pebbly sand & shell frags
pit 8A1	1848497.23	3878140.04			
			8A1-01	0.4-0.6	brown medium sand
pit 8A2	1848499.58	3878149.38			
			8A2-01	0.4-0.6	brown medium sand
			8A2-02	0.6-0.7	stone tool (microgabbro)
core 8A/1	1848502.22	3878153.86			
			8A/1-01	0.4-0.5	silty fine sand
			8A/1-02	0.8-1.0	silty fine sand
			8A/1-03	1.3-1.5	silty fine sand
			8A/1-04	1.8-2.0	silty fine sand
			8A/1-05	2.3-2.5	silty fine sand
core 8A/2	1848516.23	3878160.20			
			8A/2-01	0.8-0.9	brown mud
			8A/2-02	1.1-1.2	brown fine sand
			8A/2-03	1.6-1.7	white medium-coarse sand
line 01	1848700.27	3876987.38	101	0.0-0.1	fine-medium sand (beachface)
line 02	1848770.25	3877167.40	102	0.0-0.1	fine-medium sand (beachface)
line 03	1848748.83	3877257.27	103	0.0-0.1	medium sand (beachface)
line 04	1848714.20	3877354.40	104	0.0-0.1	medium sand (beachface)
line 05	1848630.01	3877531.95	105	0.0-0.1	medium sand (beachface)
line 06	1848532.54	3877724.00	106	0.0-0.1	medium sand (beachface)
line 07	1848430.49	3877838.66	107	0.0-0.1	medium sand (beachface)
line 08	1848367.60	3877926.02	108	0.0-0.1	medium sand (beachface)
line 09	1848182.93	3877991.89	109	0.0-0.1	coarse sand (beachface)
line 10	1847983.39	3878007.43	110	0.0-0.1	coarse sand (beachface)
line 09	1848183.70	3878013.21	111	0.0-0.1	medium sand (dune)
line 05	1848648.93	3877541.11	112	0.0-0.1	medium sand (berm crest)