COASTAL GEOLOGY AND HAZARDS OF NIUE

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EXECUTIVE SUMMARY

This report describes a preliminary study of coastal geology, nearshore processes, coastal engineering concerns, storm waves and other hazards, and related management issues on Niue. This was undertaken following the country's entry into membership of the South Pacific Applied Geoscience Commission (SOPAC). Major issues identified early in the study included: problems of ship access and wharf integrity at Alofi; measures to limit agitation and current velocities adjacent to the wharf; need for improved facilities for small boat handling; the desirability and environmental impact of reef blasting; coastal hazards associated with storm wave runup and overtopping; and requirements for conservation of the fringing reef and scarce coastal sand resources.

The study was carried out during one week in November 1995. Coastal morphology and shore types were mapped using 1981 aerial photographs at 1:10,000 scale (New Zealand Aerial Mapping), supplemented by oblique video of part of the west coast (courtesy of the Royal New Zealand Navy and Niue Broadcasting Commission) and ground observations at a number of representative sites around the island. The resulting map (Forbes, 1996) is incorporated into this report as an enclosure. The map shows a subdivision of the coast into 7 units, defined by coastal orientation and headlands and which were adopted as a basis for assessing variations in coastal geomorphology around the island. Detailed surveys were carried out at a number of representative coastal sites to determine reef platform and beach morphology and other items such as the upper limits of storm-wave damage. Sediments were sampled from beaches and the nearshore platform to determine grain-size characteristics and composition, including the relative contribution of foraminifera and other organisms to the limited sand resources of the island. Meetings were arranged with a number of government representatives and other stakeholders to gather information on perceived hazards, coastal engineering problems and existing policies.

The island of Niue is an uplifted atoll, bounded by steep rock slopes and cliffs (typically 8-25 m high), except at a few very restricted sites where sea tracks give access to the shoreline and three locations with road access (Namukulu Landing, Alofi Wharf, and Avatele Cove). Relict shore terraces occur at 35-40 m, 20-25 m, 11-14 m, and possibly 2-6 m above present sea level and at about 12 and 36 m present water depth. The modern wave-cut platform and fringing reef complex is less than 30 m wide along 64% of the coast and more than 30 m elsewhere, with a maximum width of about 150 m along the northwest

coast. Beach deposits account for less than 1% of the total 66 km shore length and are absent from the south and southeast coast. Beaches are most common in the southwest, occupying 3% of the shoreline in Avatele Bight, where the longest beach (80 m) lies in the cove at Avatele. This is a mixed sand and gravel beach with cobbles and boulders of coral rubble. Sand in the cliff-base pocket beach at Hio, on the northwest coast, includes large proportions of foraminifera (primarily *Baculogypsina sphaerulata* and *Amphistegina lobifera*) in very fresh condition, implying active foraminiferal sand production on the wide platform in that vicinity. Samples from other beaches at Tamakautoga and Avatele on the southwest coast and Tauta on the east coast showed lower concentrations of mostly abraded foraminifera. Much of the coastal sand in Niue is believed to be trapped on submerged terraces down to about 36 m water depth and sand may also be lost over the reef edge to deep water.

The most damaging tropical cyclones in recent memory occurred in 1959 and 1990. Wave runup and overtopping associated with C*yclone Ofa* in February 1990 caused massive damage to buildings, roads, landings, the wharf, and sea tracks from Hikutavake in the northwest to Avatele in the southwest. Coastal orientation with respect to the dominant northwest wave approach behind the storm was the primary factor in localising wave damage, which extended up to 25 m above sea level in some places.

The results of this preliminary study suggest the following recommendations.

Geological and engineering issues

- To conserve limited coastal sediment resources, removal of sand or gravel from beaches and reef platforms should be prohibited. Measures should also be taken to limit changes that may promote seaward removal of sand by wave-driven currents over the reef edge to deeper water.
- Reef blasting should be discouraged unless clear benefit and negligible environmental impact can be established. Blasting should not be permitted if it will result in creation of a new passage across the reef, through which sand could escape and wave energy enter. Blasting should not be carried out in front of existing beaches or below developed cliffs. Environmental assessment and permitting requirements for blasting should also consider ecological impacts and disposition of broken material.
- Any modification or development of boat launching or harbour facilities at Namukulu, Alofi, or Avatele, whether by blasting, excavation, or construction, should be assessed

for potential changes in harbour circulation and agitation under swell and storm conditions (including vulnerability and/or potential enhancement of wave runup during cyclones).

- Seaward currents along the face of the wharf at Alofi can probably be controlled successfully, without adverse impact, by construction of a low diagonal dyke on the reef platform to the south.
- No further blasting should be undertaken in the wharf area without a proper assessment of foundation conditions in the underlying rock. Cave-forming solution processes formerly operated below present sea level, as demonstrated by the presence of submerged shore terraces and unroofed cavities in the modern shore platform. This hazard should be recognized in any further development on the platform, such as the proposed small boat harbour or wharf extension.
- The design wave height for a breakwater on the west side of Niue is likely to be about 18 m, based on the computed H_{max} for *Cyclone Ofa*. This may limit the viability of a small-craft harbour. Efficient facilities for cargo handling and small-craft haul-out may be a more viable option.
- The fuel storage tanks above the wharf in Alofi are potentially vulnerable to storm-wave or tsunami damage and should be relocated to higher ground.
- High porosity in the underlying limestone implies a potential for reef contamination from septic fields on the Alofi Terrace. On the other hand, the narrow width and open-ocean exposure of the reef platform enable high rates of mixing and contaminant removal. An appropriate study of nutrient conditions on the platform may be desirable before embarking on costly modification of existing septic systems.

Coastal management and zoning issues

- Damage sustained during *Cyclone Ofa* and earlier storms in 1959 and 1960, among others, demonstrates the need for setback from the cliff edge on the Alofi Terrace. A coastal hazard zone should be identified, with appropriate restrictions on the nature of development within it.
- Pending delineation of such a hazard zone, any new infrastructure projects, such as schools, churches, hospitals, offices, fuel distribution facilities or industrial structures, except for port facilities, should probably be located on the landward side of the coastal road between Hikutavake and Alofi South. A similar restriction may be appropriate along the southwest coast from Anaana to Avatele.
- Tourist facilities, such as hotels and restaurants, may benefit from coastal views

available only within the hazard zone. If such development is permitted and/or undertaken, the risk of storm-wave damage must be recognized. A similar proviso applies to residential development within the hazard zone.

- Niue is blessed with a fine system of coastal access trails, lookouts, picnic facilities, and related signage. This is a significant asset for the tourist industry, as well as for local fishing and recreational use, and its maintenance is recommended.

Research and survey requirements

- The preliminary coastal morphology map enclosed with this report (Forbes, 1996) could serve as the basis for an expanded and more detailed coastal resource inventory, using GIS technology. SOPAC in collaboration with others could provide advice and assistance in the development of such a planning tool.
- A shallow-water multibeam and acoustic backscatter survey would be useful for delineating reef front morphology, relict shore terraces, and the extent of sandy seabed and other habitat types around the island.
- Deepwater swath bathymetry and/or sidescan surveys would provide information on submarine slope morphology and any evidence of large-scale slope failure in the geological past. This would assist in defining tectonic hazards for Niue.
- It is now 15 years since the last aerial photography was carried out over Niue. Although satellite imagery from SPOT and other sources can provide adequate data for forestry or agriculture applications, coastal morphology and reef-platform ecology can only be resolved adequately with large-scale (1:10000 or better) aerial photography. Serious consideration should be given to acquiring new photography within the next 5 years if this can be arranged.
- Oblique aerial video of the coast, such as the recent video obtained by the Royal New Zealand Navy and Niue Broadcasting Commission, is a useful tool for coastal inventory and shore-zone classification. Extending this coverage to the entire coast of the island would be useful if the opportunity arises.

ACKNOWLEDGEMENTS

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Grain-size analyses were completed by Sekove Motuiwaca (SOPAC). Cartographic assistance and drafting were provided by Phil Woodward (SOPAC). John Collen (Victoria University, Wellington) kindly examined some of the sediment samples and identifed many of the foraminiferal species reported here.

INTRODUCTION

Geographic situation

The island of Niue (19°00'S, 169°55'W) is relatively isolated in the Pacific Ocean (Figure 1), 430 km east of Vava'u in northern Tonga. American Samoa lies 520 km to the northwest; Palmerston Atoll and Rarotonga in the southern Cook Islands are respectively 700 and 1000 km to the east. Niue has a land area of 259 km^2, representing the limestone cap of a submarine volcanic cone that rises more than 4500 m from the surrounding abyssal plain.

Although it is not part of a recognised island group, Niue's 390000 km^2 exclusive economic zone (EEZ) includes a number of seamounts (Figure 2). Reefs are present on two of these: Antiope Reef (18°15'S, 168°22'W) and Beveridge Reef (20°01'S, 167°46'W), the latter enabling the southward extension of the Niue EEZ as defined by the Territorial Sea and Exclusive Economic Zone Act 1978 (Figure 2).

Background and objectives

The isolated location, small population, and distinctive geological character of Niue create a number of challenges for the economic development and social well-being of the country (Schofield, 1959; New Zealand Department of Lands and Survey, 1985; Niue Environmental Task Force, 1991; South Pacific Regional Environment Programme, 1993; Cornforth, 1994). These include:

- high cliffs surrounding the island obstructing access to the sea;
- lack of a protected harbour impeding imports, exports, and fisheries development;
- limited groundwater resource which is vulnerable to surface pollution affecting health, agriculture, and industrial development;
- deep water close to shore, communities and infrastructure vulnerable to storm-wave damage;
- small population and distance to major centres, high cost and limited frequency of air transport;
- limited infrastructure and lack of beaches discouraging tourism despite scenic and cultural attractions of the island.

The *Niue Strategic Development Plan* (Niue Government, 1994) highlights a number of national objectives, among them:

- adequate infrastructure to sustain a viable tourist industry;
- adequate infrastructure to sustain a viable agriculture, fishing and forestry base;
- conservation and sustainable utilisation of Niue’s unique environment.

Policy objectives include:

- instituting a comprehensive system of land/marine use planning and control;
- establishing rules for environmental and cultural impact appraisal;
- tourism development to be linked with environment, culture and planning.

Major constraints identified in the *Strategic Development Plan* (Niue Government, 1994, pp.14-16) include the following items relevant to coastal management.

Fisheries

“Niue has no natural shelter to provide harbour facilities for commercially viable fishing boats and this is a major obstacle to development of a domestic fisher(y) to exploit a substantial marine resource. This could be overcome by using vessels that can be readily removed from the sea by existing equipment or by upgrading wharf infrastructure.”

Tourism

“Niue ... lacks ... attributes commonly associated with [tropical tourism] destinations, such as large safe swimming lagoons and beaches. On the other hand (it) has unique features arising from its geographical nature ....”

Resources

“Niue's water resource is underground and consequently all forms of land based activity will have an impact. All environmental impact reports should quite specifically address the issue of water impact, including quality, runoff effects and usage rates.”

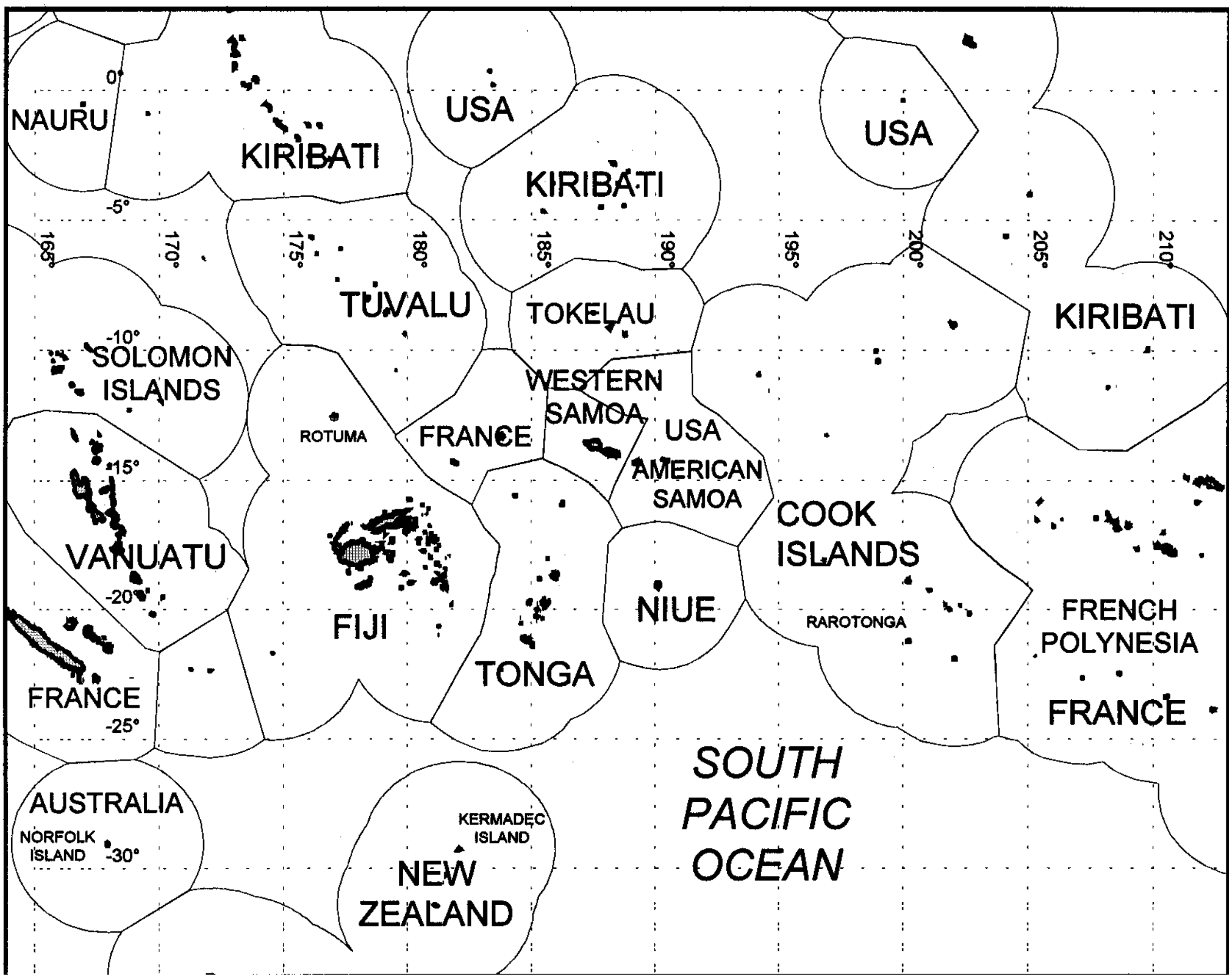

Figure 1. Pacific Ocean, showing location of Niue and indicative maritime jurisdictional limits (after Boyes and Woodward, 1995). Note that the maritime limits shown here for Niue do not include the southward extension using Beveridge Reef (cf. Figure 2).

Transportation

"With the upgrading of airport facilities now in prospect (completed to Boeing 767 standard in November 1995), an improvement of the wharf facilities should now receive consideration. However, the scope of such an improvement will be limited by the lack of a natural harbour and the geological and weather constraints on creating an artificial harbour."

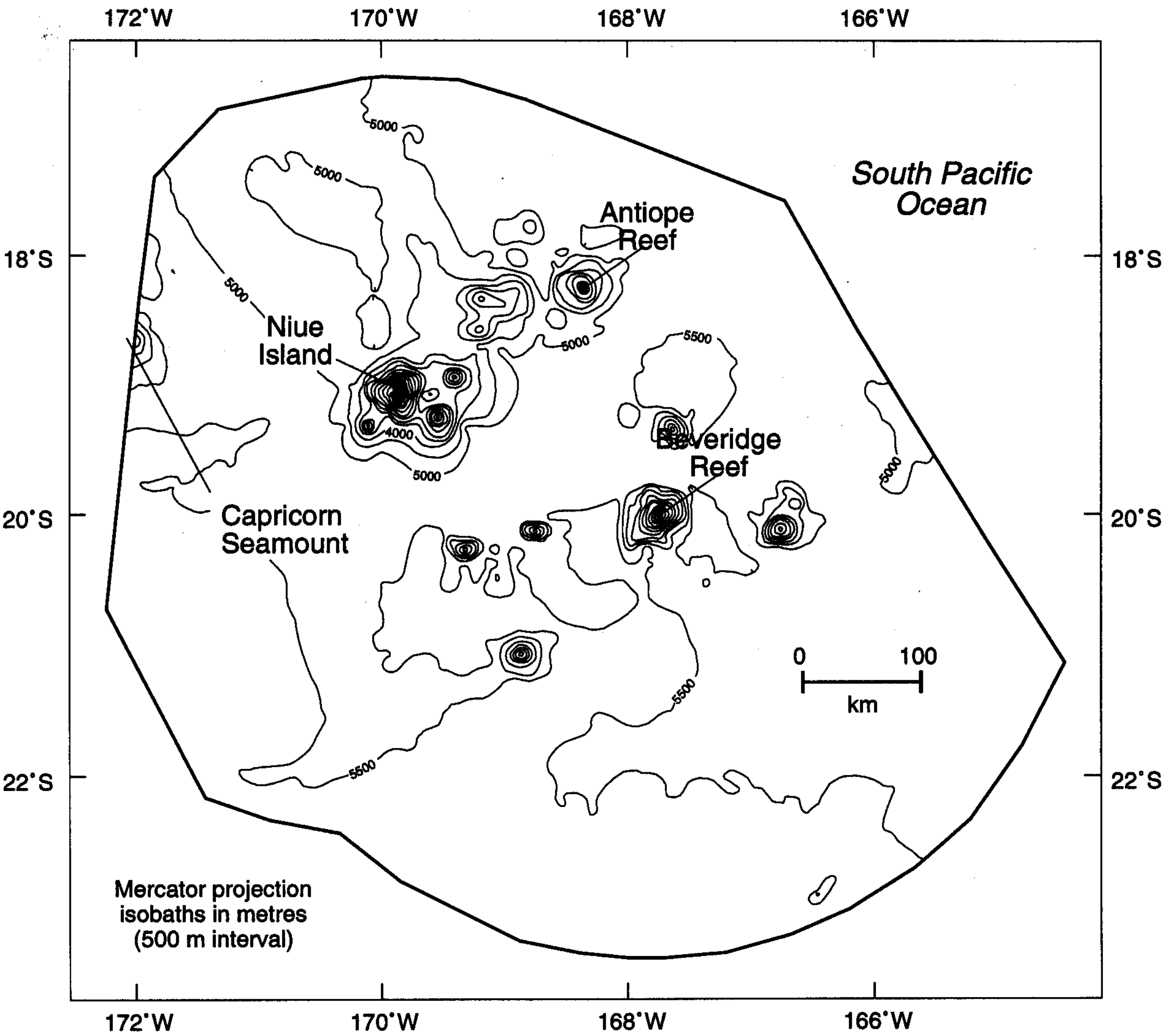

Figure 2. Bathymetry of Niue's exclusive economic zone (after Seafloor Imaging Inc., 1995), including southward extension from Beveridge Reef.

Following the recent entry of Niue into membership of the South Pacific Applied Geoscience Commission (SOPAC) and discussions with the National Representative, Sisilia Talagi, at the 24th Annual Session in Suva (October 1995), SOPAC undertook an initial reconnaissance of technical issues related to coastal development and hazards on the island of Niue in early November 1995. This report summarises the results of the survey and highlights a number of coastal process and engineering concerns that came up during the visit. These include:

- difficulty of ship access to the unprotected wharf at Alofi and instability of the wharf following damage sustained in September 1994, when a blasting project was undertaken to improve access (Anonymous, 1995; conversations with Honourable Terry Coe, 6 November 1995, and Kevin Fawcett, 10 November 1995);
- other coastal engineering issues at Alofi, including, (i) proposed structures to reduce surge and return-flow velocities along the face of the wharf (discussions with Brendon Pasisi, 10 November 1995, and Honourable Terry Coe, 12 November 1995), and (ii) design and viability of a proposed small boat harbour on the north side of the wharf (meetings with Brendon Pasisi and Stan Vandersyp, 10 November 1995);
- the utility and environmental impact of reef blasting proposed or already carried out at various access points around the island (discussions with Honourable Terry Coe, Sisilia Talagi and Molesi Tamate, 6 November 1995);
- the probability of storm-wave damage such as that experienced during *Cyclone Ofa* in 1990 and identification of hazard zones for wave impact from various storm conditions and approach directions (Cornforth, 1994; conversation with Honourable Terry Coe, 6 November 1995);
- measures required for conservation of the reef and scarce coastal sand resources, including the need for a detailed coastal inventory and mapping of inshore bathymetry and bottom type, for ecological management, fisheries conservation, and recreational diving enhancement (discussions with Brendon Pasisi and Kevin Fawcett, 10 November 1995).

PHYSICAL SETTING

Geology and geomorphology

General geology

Niue is an uplifted coral atoll underlain by carbonate sedimentary rocks 300 to 400 m thick, resting on a volcanic cone (Schofield, 1959, 1966; Hill, 1979, 1983). Water wells and exploration boreholes have sampled the carbonate sequence to a depth of 220 m (170 m below sea level) and showed that it includes limestone, dolostone, and coral-foraminiferal-algal sand, partially unlithified (Schofield and Nelson, 1978; Aharon et al., 1987). The rock is jointed and cavernous to considerable depths (Jacobson and Hill, 1980b). These deposits are middle to late Miocene in age (~7 to 12 million years) as shown by fossil evidence of rock-forming organisms encountered in the boreholes (palaeontological analysis by G.C.H. Chapronière in Jacobson and Hill, 1980a). This is consistent with estimates for the age of the volcanic pedestal based on sinking rates and plate motion (Hill, 1983).

Volcanic substructure and submarine morphology

The volcanic substructure of Niue was deduced by Schofield (1959) on the basis of the submarine morphology (Figure 2) and geomagnetic investigations. Gravity and magnetic surveys undertaken by Hill (1979, 1983) indicated that a core of dense volcanic rock, probably basaltic, is present at shallow depth beneath the southwest part of Niue. This volcanic structure is a flat-topped dome, suggesting shallow-water wave planation approximately 350 m below present sea level (Hill, 1983). A sedimentary apron of pyroclastic deposits, volcanic debris, and coral reef talus surrounds the central volcanic core and underlies the northern part of the island (Figure 7 of Hill, 1983). The diameter of the Niue seamount, about 15 km at present sea level, expands to 50 km at the base in depths of 4000-5000 m (Figure 2), implying average slopes of 12°-16°. Bathymetric surveys by Brodie (1966) indicate slopes ranging from less than 4° at about 3500 m to more than 50° at 1500 m water depth off the south coast of Niue, where an abrupt steepening occurs above 2250 m (Figure 3). Off the northeast coast, the submarine slope is more consistent, ranging from 18° in 1000-3000 m to as much as 26° above 1000 m. Off the west and northwest coast, slopes of 10°-32° in depths less than 1000 m diminish to 9°-17° between 1000-3000 m water depth. A broad terrace (less than 5° slope) is present in 500-750 m water depth southwest of Alofi and a similar though less prominent feature occurs in the same depth range south of Mata(tamane) Point (Figure 3). These may be associated with topography on the upper part of the volcanic core or they may be residual features remaining after massive failure on the submarine slope (cf. Keating, 1987, in press; see below).

Three other seamounts occur within a 50 km radius of Niue (Figure 2). The shallowest of these, Lachlan Seamount, is depicted by Brodie (1966) as having twin summits at less than 750 m water depth. None of these nearby seamounts are shallow enough to alter surface waves impinging on the island coast. At least 7 other seamounts are present within the Niue EEZ boundary (Figure 2), excluding the Capricorn Seamount, which lies on the boundary close to the Tonga Trench (Figure 2 of Hill, 1983). The shallowest of the Niue seamounts are Antiope and Beveridge. Antiope Reef is reported to have a depth of 9.5 m and Beveridge Reef encloses a lagoon 4 miles (7.4 km) long by 2 miles (3.7 km) wide

(Seafloor Imaging Inc.,1995) and "therefore seems to be a submerged atoll" (Darwin, 1842 [p. 160 of 1962 edition]). The surrounding abyssal plain is Lower Cretaceous in age (100-140 million years) and lies in mean depths of 5000-5500 m (Seafloor Imaging Inc., 1995).

Tectonics

Niue sits on the lithospheric bulge associated with plate subduction at the Tonga Trench, the axis of which lies 270 km to the west (Dubois et al., 1975). Faulting in the limestone rocks of Niue, as described below, may reflect deformation associated with uplift as the island moves over the bulge toward the trench. There is evidence (from sites undergoing subduction in the North Pacific) that seamounts may be deformed into faulted slivers by the time they reach the inside of the lithospheric bulge and start down-slope into the trench (Barbara Keating, University of Hawaii, pers. comm., 1996). At present Niue lies on the outside of the bulge in an area of very sparse earthquakes (Figure 2 of Hill, 1983), but further deformation would seem to be inevitable in the long term. Fieldes et al. (1960) used radiometric activity in Niue soils to estimate ages of 200000 years and 700000 years, respectively, for emergence of the former atoll rim and lagoon basin above sea level. Using these ages, Dubois et al. (1975) computed a subduction rate of 0.09 metres per year, based on a movement of 64 km along the lithospheric bulge to produce the observed uplift of 70 m. At this rate, Niue has a projected lifespan of 3 million years before subduction into the Tonga Trench.

Relict atoll morphology and geology

The uplifted atoll form of Niue was first recognised in print by Forster (1777). A shallow basin, representing the former lagoon floor, occupies most of the central island surface at about 35 to 40 m above present sea level (Figure 3; Schofield, 1959; Jacobson and Hill, 1980b). This basin was designated the `Mutalau Lagoon' by Schofield (1959) and is underlain by dolomite. Schofield and Nelson (1978) proposed an origin by subsurface seepage of Mg-enriched ground water as the lagoon became isolated during uplift and by subaerial diagenetic alteration. Subsequent analysis (Aharon et al., 1987; Rougerie and Wauthy, 1986, 1989) suggests that the

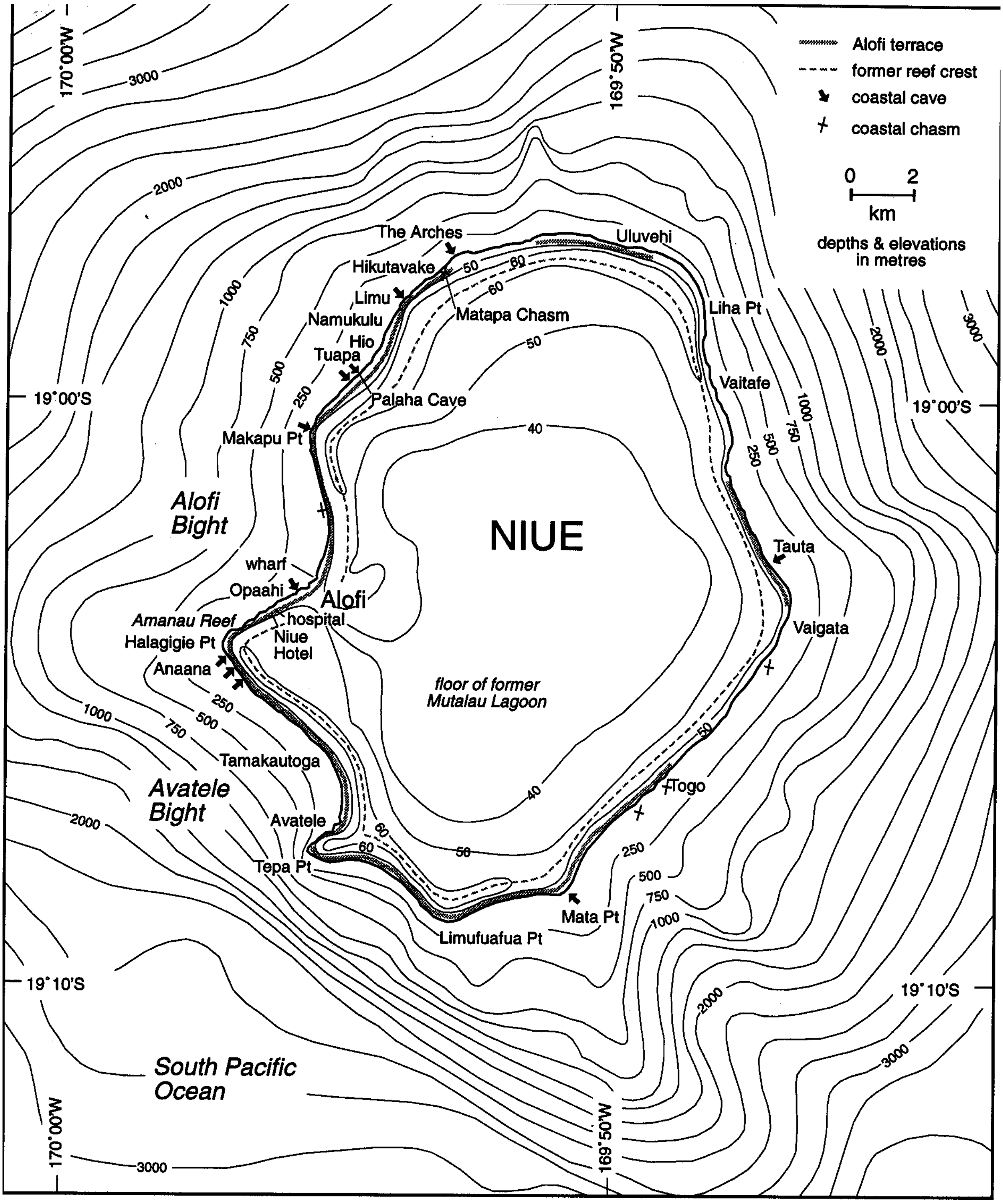

Figure 3. Niue and adjacent seafloor, showing bathymetry (after Brodie, 1996) and topography (after Jacobson and Hill, 1980b) with coastal caves and chasms (various sources) and place names mentioned in this report.

dolomitization was probably caused by geothermally driven upwelling of ocean water through the porous subsurface of the atoll. The surface cover of the former lagoon floor consists of calcarenites (calcareous sand), cemented over about 60% of the area (Wright and van Westerndorp, 1965) and "incipient karrenfelds ... leaving residual pinnacles commonly rising about 5 ft (1.5 m) above the adjacent, flat, uncemented sand" (Schofield, 1959, p. 9). This sand, the youngest of which is less than 700000 years in age (Fieldes et al., 1960), retains its aragonite mineralogy in the uppermost 8 m, where samples indicate a composition dominated by foraminifera (*Amphistegina*, *Marginopora*, *Calcarina*, *Homotrema*, and some miliolids), coralline red algae (*Lithothamnium* and *Lithophyllum*) and minor *Halimeda* (Schofield and Nelson, 1978).

Surrounding the former lagoon basin is a peripheral ridge (the ‘Mutalau Reef’ of Schofield, 1959) rising to almost 70 m above present sea level, representing the reef rim of the former atoll (Figure 3). This consists of late-Miocene limestone capped by Plio-Pleistocene sand and shell beds (Schofield, 1959). A dry valley south of Alofi, at 42 m above present sea level, is interpreted as a former tidal passage.

Terraces

Several terraces mark the outer slope of the relict Mutalau Reef. The ages of the terraces are very poorly constrained. Terrace remnants have been reported at 35-40 m (Schofield, 1959). A prominent surface at 20-25 m above present sea level, known as the `lower' or Alofi Terrace (Figure 3), is well developed along the western, southern, and southeastern sides of the island (Schofield, 1959; Jacobson and Hill, 1980b), but also occurs in places along the northern and eastern coasts (Forbes 1996, copy included as an enclosure with this report). This terrace ranges in width from 200-800 m and appears to have formed as a wave-cut platform, on which up to 1.5 m of cemented beach conglomerate with a basal elevation of about 23 m occurs in some locations (Schofield, 1959). The outer edge of the terrace is marked by prominent limestone sea cliffs (Figure 4), which encircle the island. Other small terrace remnants are found at 11-14 m above present sea level at Alofi, The Arches, and south of Vaitafe (Schofield, 1959), and as low as 4 to 6 m at Hio (see below).

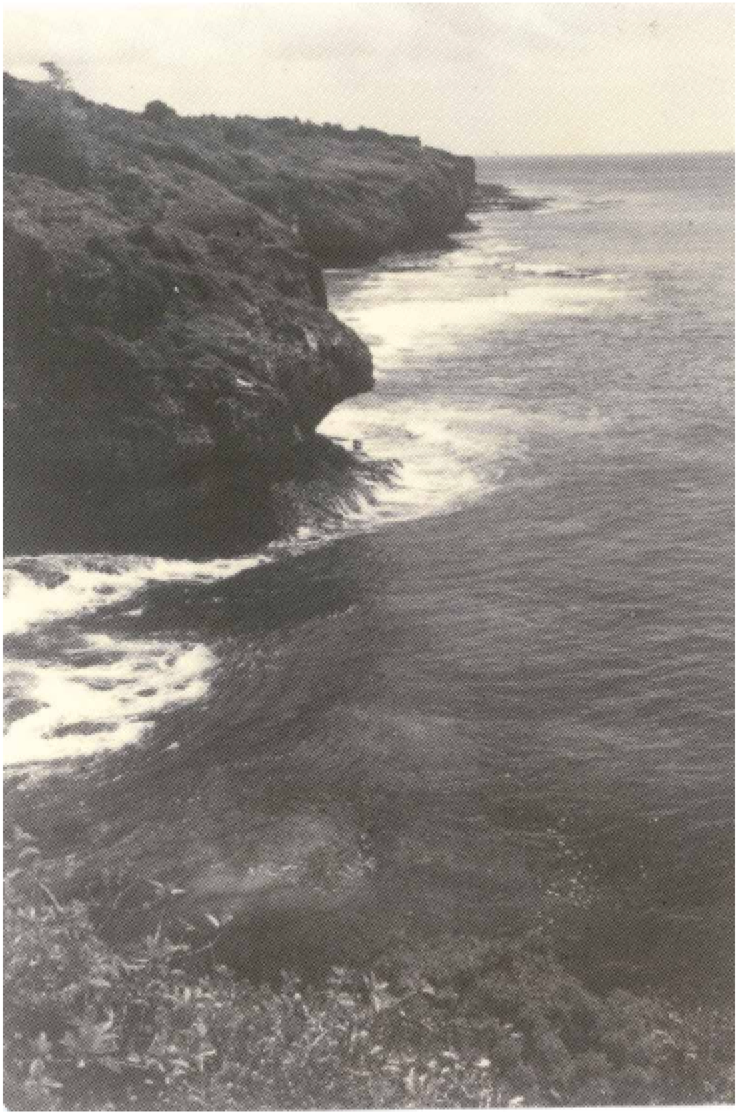

Figure 4. Undercut limstone cliffs along coast of Alofi South (from top of cliff at Niue Hotel). Note the wide reef platform in the distance and its virtual absence in the foreground (DLF/ 5 Nov 1995).

Narrow constructional terraces at 2-4 m elevation are found locally between Limufuafua and Tepa Point (Schofield, 1959), elsewhere along the east coast (Jacobson and Hill, 1980b) and near Anaana (Figures 5 and 6). The outer rim of this terrace is built up by nullipores (Agassiz, 1903), which are thought to flourish in spray from blowholes at the Tepa and Anaana sites. Erosional notches at about 2.5 m (the "8 ft notch"), found at Tepa

Point and elsewhere, may support the hypothesis of a relative sea-level stillstand about 2 m above present (Schofield, 1959).

The developing terrace at present sea level consists of a fringing rock platform and reef complex ranging up to 120 m wide (Figures 7 and 8; Forbes 1996). This is described in more detail later in the report. Submarine terraces are present at depths of about 12 m and 36 m along the west coast off Alofi (Figure 8; Schofield, 1959) and reported in depths of about 36 m off Avatele in the south (Kevin Fawcett, pers. comm., 10 November 1995).

Figure 5. Left*: View south along cliffs from Anaana, with southeast swell refracting around Tepa Point. Note the fragmentary 2-4 m platform and lack of platform development at present sea level.* Right*: Narrow 2-4 m platform, looking down from top of cliff at Anaana. (DLF/ 5 Nov 1995).*

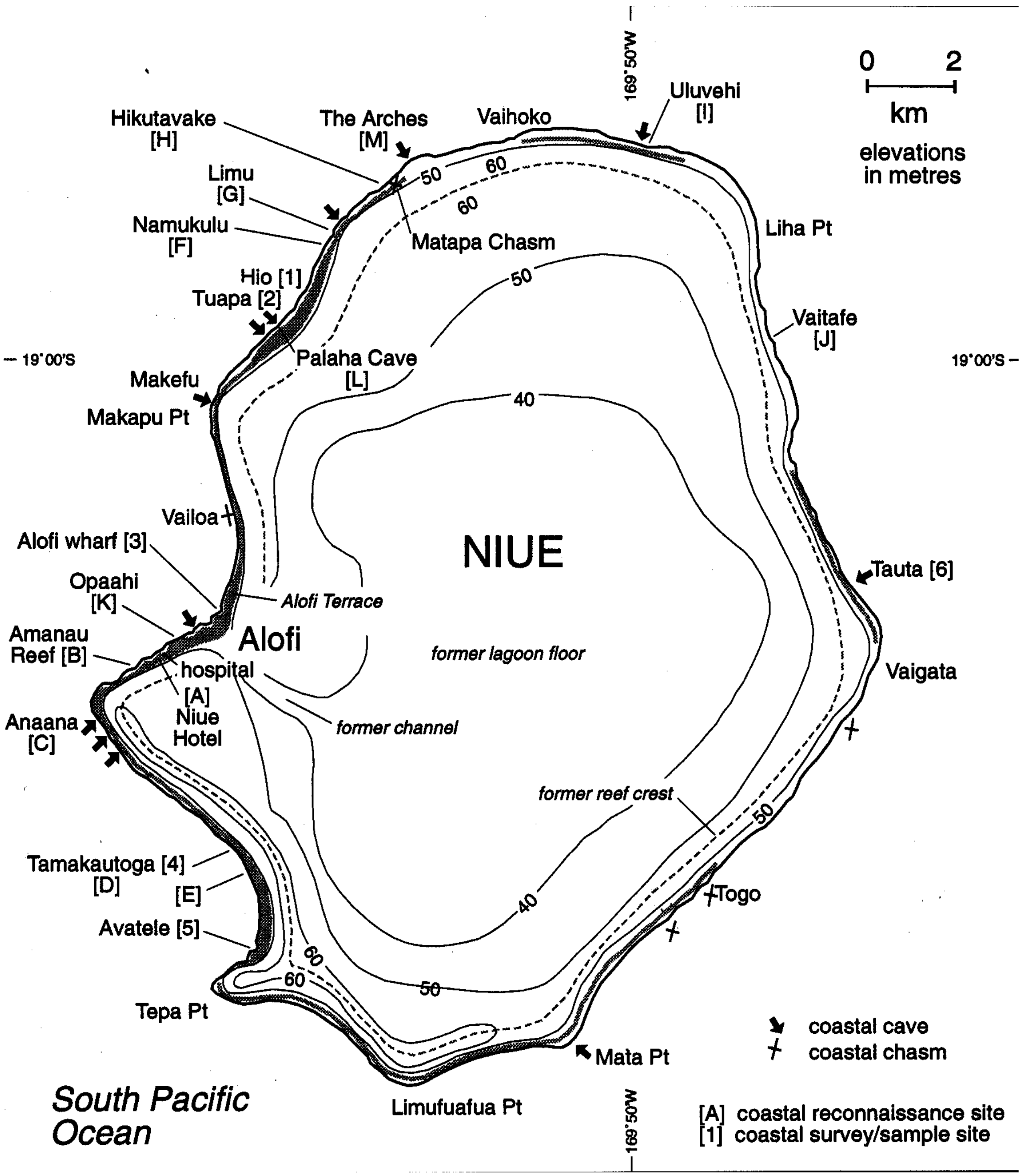

Figure 6. Niue, showing the Alofi Terrace (shaded), raised atoll rim and former lagoon, place names, coastal reconnaissance sites, and locations of surveys and sediment sampling.

Figure 7. Top*: General view of wide reef platform at Tamakautoga, looking northwest from new resort site.* Bottom*: Beach, overhanging cliff, platform and reef at Tamakautoga Beach (survey site 4). (DLF/ 6 Nov 1995).*

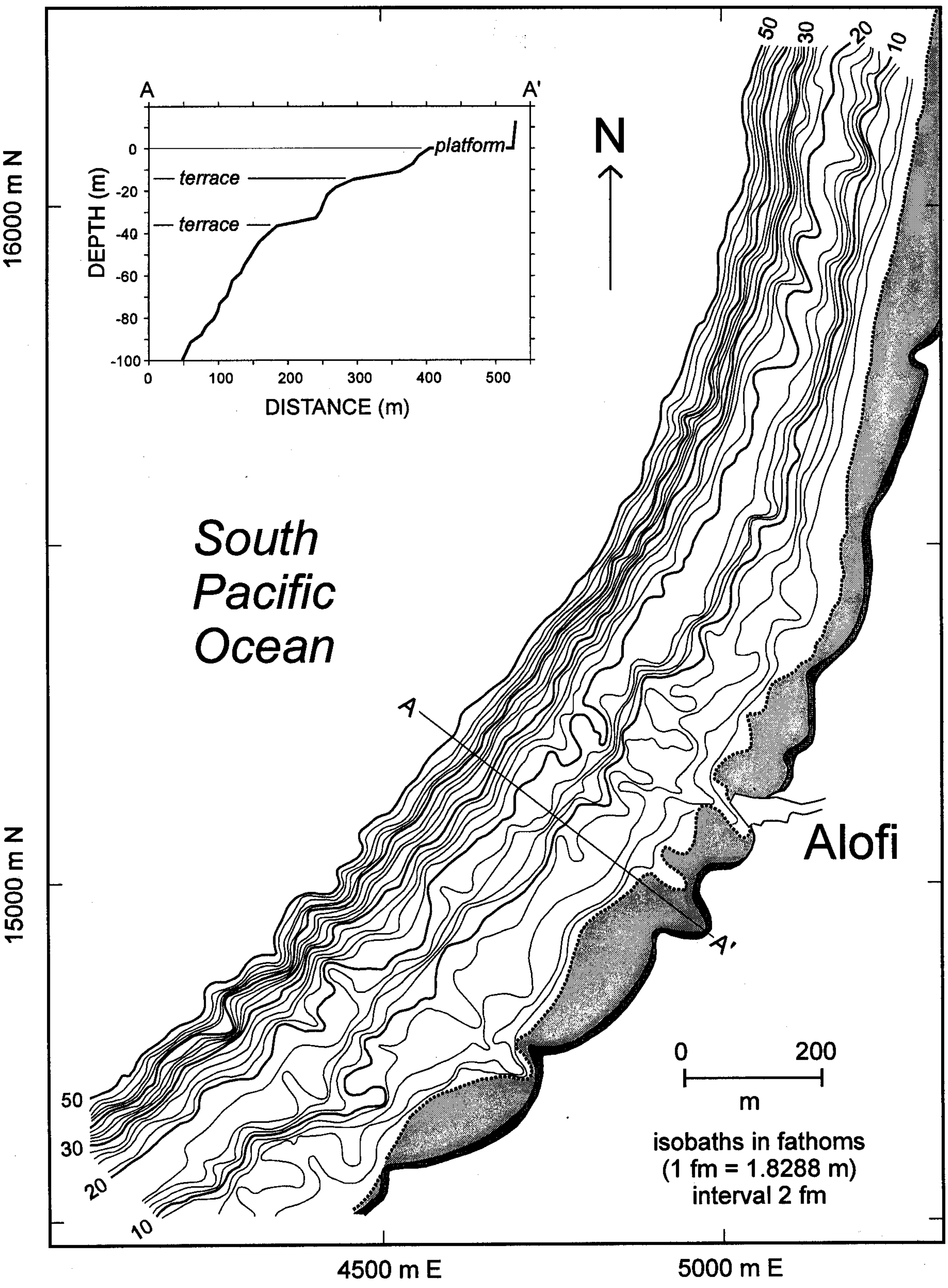

Figure 8. Coast, modern platform, and submarine terrace bathymetry in Alofi Bight (after Schofield, 1959). Isobaths in fathoms (1 fm = 1.8288 m). Locations approximate in Niue Map Grid. Inset: Shore-normal profile (in metres) along Section A-A', showing terraces at 0, ~12, and ~36 m water depth.

Faults, chasms, and caves

A number of chasms, subparallel to the coast, are found at the inland side of the Alofi Terrace (Figure 9) and intersect the coast in some places. They are typically 15-20 m deep, several metres wide, and more than 100 m long. Near-vertical fractures from less than 0.01-1 m wide are also encountered in a number of places. A wide fracture transitional to a chasm occurs just north of Opaahi Landing, while narrow fractures define the embayment occupied by Hio Beach (Figure 10). Schofield (1959) examined the chasm near Vailoa, which does not intersect the coast, and concluded that it is a solution channel following a reverse fault dipping 78°ENE, with the coastal side "downthrown 6 to 8 ft" (1.8-2.4 m). He reported a crush zone exposed on the floor of Matapa Chasm, on the northwest coast, identifying its origin as a fault dipping 76°E, and noted that it must predate cutting of the Alofi Terrace, which is not displaced.

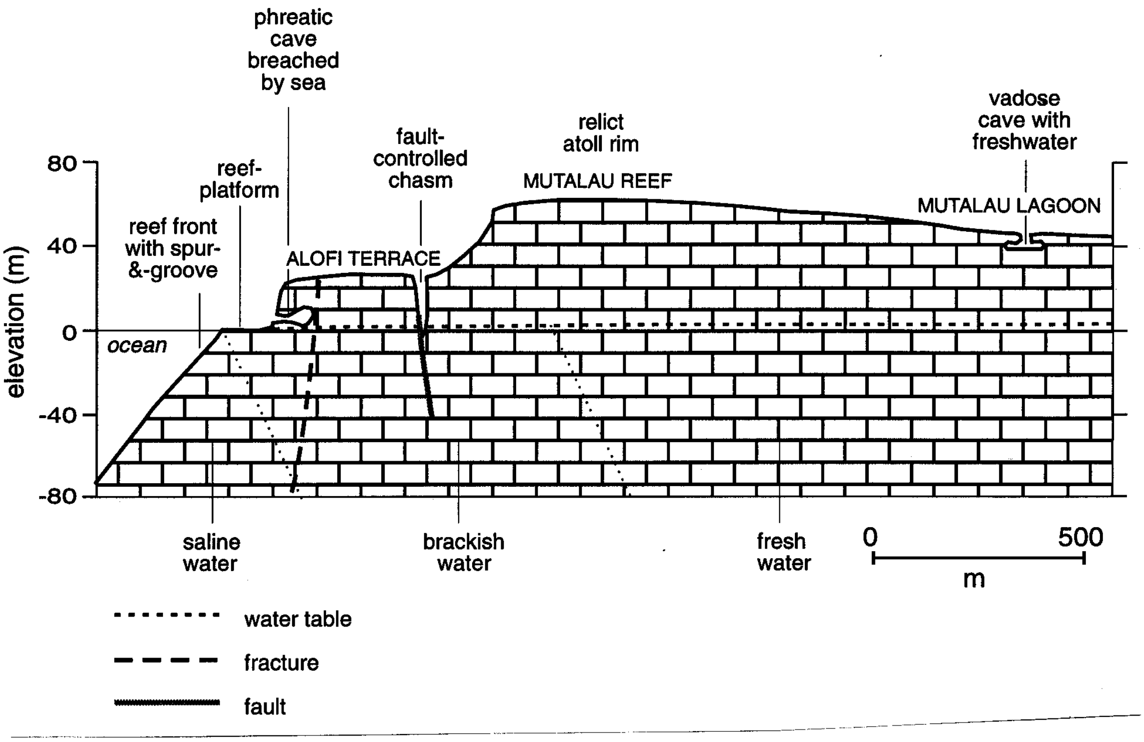

Figure 9. Schematic section showing geomorphology, structure, and hydrogeology along the west coast of Niue (modified after Jacobson and Hill, 1980b).

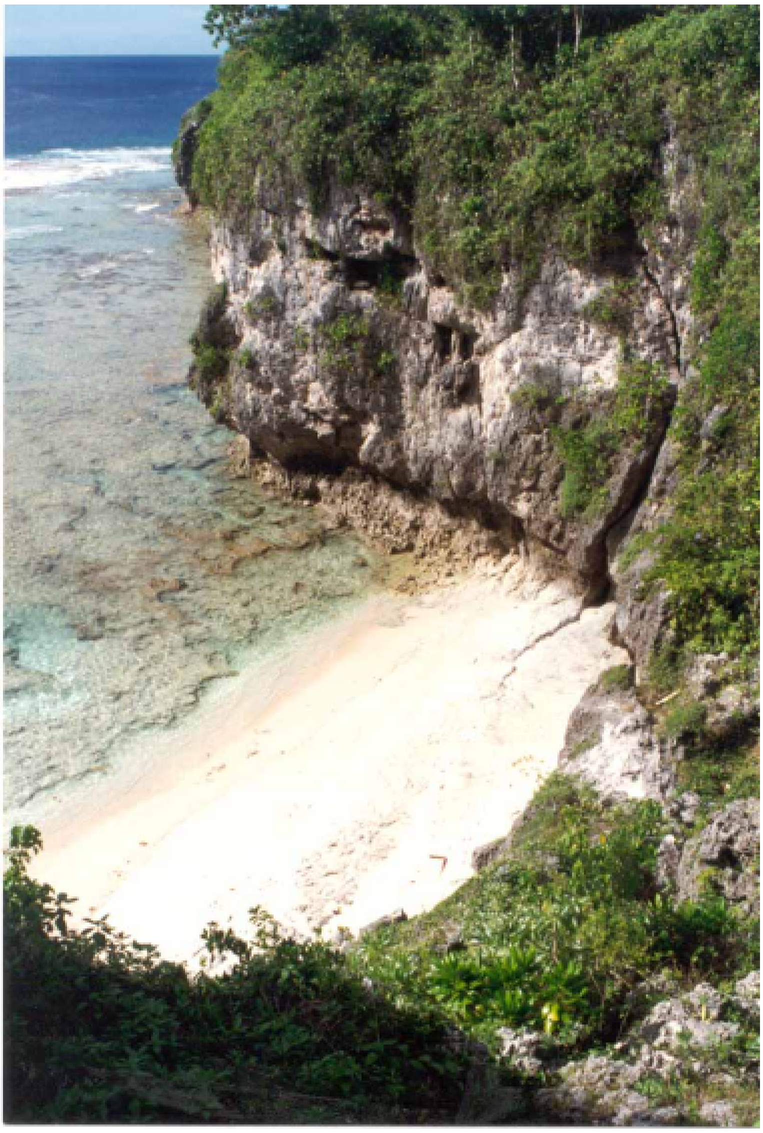

Figure 10. Hilo Beach (survey site 1), from lowest remaining step on access path (17.5 m above sea level). Note wide reef platform, undercut cliffs, steeply dipping fracture at back of beach, lower terrace remnant above and behind beach, and thin sand over rock outcrop (DLF/ 7 Nov 1995).

Karst morphology on Niue takes the form of rough karrenfeld development on limestone surfaces and caves of various kinds. The latter include fault-controlled chasms enlarged by solution processes; phreatic caves, many of which are open to the sea where they intersect the present cliff line (Figure 10) and vadose caves in the island interior. Palaha Cave

(Figure 6), which provides access from a sinkhole in the lower terrace through two passage levels (Figure 11) to the reef, is a good example of a phreatic cave intersected by backcutting of the modern cliff line. The channel and arch at Makalea, just north of Limu (Figure 6), appear to represent truncation and partial unroofing of a cave that discharges fresh water to the sea at this location (Figure 12). Other platform channels and pools of apparent karst origin occur on the modern shore platform at Hikutavake, in several locations between Tuapa and Makapu Point, and just west of the northernmost point on the island. Coastal caves have been used traditionally for reef access and canoe storage, a practice that continues at Uluvehi and Tauta (Figure 13), among other sites.

Climate and oceanography

General weather patterns

The climate of Niue has been summarised by Kreft (1986). It is dominated by the prevailing southeast trades and by the proximity of the South Pacific Convergence Zone (SPCZ). The latter is generally aligned NW-SE and forms the boundary between the southeast trades to the south and divergent easterlies of the southeast Pacific to the north. The SPCZ normally lies to the north of Niue and is an area of cloud and precipitation, commonly more active and further south in the summer. Tradewinds are typically light to fresh, with a marked diurnal variation. The year is divided into two seasons, a "wet" summer season from November to April (when the SPCZ is further south and winds from north through west are more common) and a "dry" winter season from May to October (when the SPCZ usually lies northeast of Niue and tradewind conditions prevail). However, cold fronts approaching from the southwest in winter can become stationary between 15°S and 20°S, producing persistent heavy rainfall from broad altostratus cloud sheets associated with upper air troughs. Tropical cyclones average 8-9 per year in the southwest Pacific, most commonly during the summer months (November to April) and are sometimes very destructive. A storm in February 1959 destroyed the then 110-year old church in Alofi and left only 38% of the island's 770 homes intact (Kreft, 1986). It was followed by another damaging cyclone in January 1960. Some have suggested that these destructive events may have accelerated the exodus of Niuean migrants to New Zealand (Rex and Vivian, 1982).

Figure 11. Top*: Double-storey passage to the sea in Palaha Cave, northwest coast south of Tuapa.* Bottom*: Small beach with rippled sand immediately north of Palaha Cave. (DLF/ 11 Nov 1995).*

Figure 12. Top*: Arch representing seaward extension of unroofed cave at Makalae, north side of Limu Sea Track.* Bottom*: Path and picnic facilities damaged during Cyclone Ofa, Makalaea, Limu Sea Track (DLF/ 11 Nov 1995).*

Figure 13. Top*: Heavy surf under southeast tradewinds, showing waves breaking along the outer reef rim, framed by roof of cave at Tauta (sampling site 6).* Bottom*: Canoe access steps in cave at Tauta (DLF/ 9 Nov 1995).*

Precipitation

Mean annual precipitation at Alofi is 2009 mm (1905-1977) and is mostly convective (Kreft, 1986), although heavy rainfall can occur during tropical storms or ahead of cold fronts. The heaviest recorded one-day rainfall (388 mm) was associated with a tropical cyclone passing nearby on 25 December 1930. Up to 1977, the highest annual precipitation recorded was 3184 mm in 1924 and the lowest was 1066 mm in 1931, when crops were severely damaged by drought (Kreft, 1986). On average, 68% of the precipitation falls during the wet season (November-April) and 41% during the first quarter of the year (January-March). There are no surface streams on Niue and droughts (defined as more than 15 days with rainfall of less than 1 mm) average 1.2 occurrences per year (Kreft, 1986).

Wind

The wind climate is dominated by the southeast trades. Mean wind speeds from land-based observations (Kreft, 1986) range from 3.5-10 knots (1.8-5.2 m/s). GEOSAT altimeter data indicate a mean annual over-water wind speed of 7.0 m/s at Niue between 1986 and 1989 (Barstow and Haug, 1994d). Gale-force winds occur typically about once per year, sometimes from the southeast and west but more frequently from the northwest, produced by squall lines or tropical storms (Kreft, 1986). The strongest winds are usually from the northwest through northeast, associated with tropical storms passing north of Niue.

Tropical cyclones

Kreft (1986) identified a total of 17 tropical cyclones that affected Niue during the years 1905 to 1979. She also presented a map of tropical storm and cyclone paths for the 30 years from 1939 to 1969, during which moderate to severe damage was experienced at Niue in March 1941, January 1944, December 1946, February 1959, January 1960, and February 1968. Data obtained from the Fiji Meteorological Service (Bruce Ereckson, pers. comm., April 1996) indicate that at least 25 "notable storms" (1905-1939), tropical storms, and tropical cyclones occurred within the 5°x 5° square centred near Niue (17°-22°S and 168°-173°W) from 1905 to 1990 (Appendix 3). One occurred in November, four in December, nine in January, nine in February, and two in March.

Sustained wind speeds of more than 100 knots (more than 52 m/s) were recorded at Alofi in the February 1959 storm, before the anemometer was knocked down. During passage of the cyclone in January 1960, the pressure dropped below 950 hPa and hurricane-force winds blew from the northeast for an hour before passage of the eye, after which they blew from the south. Kreft (1986) noted that 175 mm of rain fell during 7 hours in this storm. During the February 1968 storm, the pressure at Alofi fell to a minimum of 952 hPa and hurricane-force winds were endured for 7 hours (Kreft, 1986), with a maximum sustained windspeed of 80 knots (41 m/s).

The most destructive storm in recent memory was *Cyclone Ofa* (Prasad, 1990), the centre of which passed southward about 60 km west of Niue on the afternoon of 5 February 1990 (local time). This storm had caused severe damage in Western Samoa (Carter, 1990; Rearic, 1990), where a minimum pressure of 986 hPa and a windspeed of 70 knots (36 m/s) were recorded at Apia, 200 km east of the storm track (Figure 14). The surge (barometric tide and setup) plus tide at Apia amounted to 1.6 m with 0.5 m of washover on the lowlying Mulinu'u Peninsula (Carter, 1990; Solomon, 1994). The Fiji Meteorological Service estimated maximum sustained winds in *Cyclone Ofa* at 100 knots (51 m/s), with gusts to 140 knots (70 m/s). *Ofa* had a forward speed of about 12 knots (6.2 m/s) in the vicinity of Niue and the minimum pressure recorded at Alofi was 962.4 hPa (Prasad, 1990). The maximum windspeed at Alofi was 60 knots (31 m/s) at 0600 UTC 5 February, with gusts to 88 knots (45 m/s). These are overland windspeeds, which may partially account for the difference between the measured speed and the estimated maximum windspeed of 51 m/s.

Ocean surface waves

There are no published data on wave climate in the vicinity of Niue, but measurements from the neighbouring island groups of Western Samoa, Tonga, and Cook Islands (Barstow and Haug, 1994a, 1994b, 1994c) and a compilation for the southwest Pacific Ocean (Barstow and Haug, 1994d) provide a reasonable picture of conditions in the Niue sector. The mean annual significant wave height, from GEOSAT altimeter data for 1986-1989, is approximately 2.4 m (Barstow and Haug, 1994d). The mean significant wave height increases to more than 2.5 m in the summer months. The GEOSAT data include a number of observations of H_s more than 5 m in the 5°x 5° square west of Niue (15°-20°S, 170°-175°W), and many more than 5 m with some more than 7 m in the 5°x 5° square to the east (15°-20°S, 165°-170°W) (Figure 10 of Barstow and Haug, 1994d). In general, the eastern coast of Niue experiences rougher conditions than the west under prevailing southeast trades. This was the case during the November 1995 field survey, when breaker heights H_b more than 2 m were observed on the eastern reef (Figure 15) while a low swell was experienced on the leeward shore (Figure 4). The southwest coast (Avatele Bight) was affected by waves refracting around Tepa Point (Figures 3 and 5).

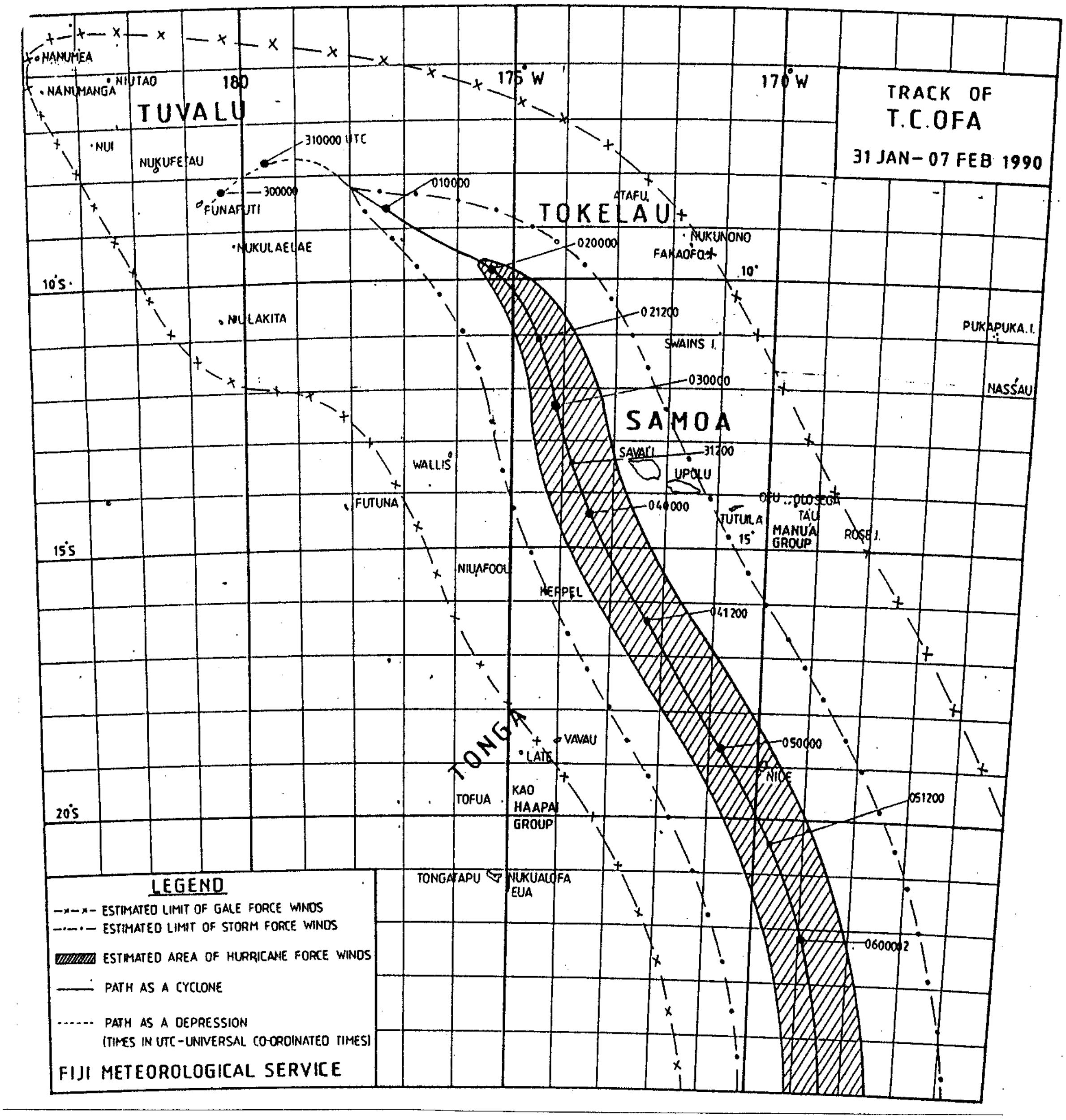

Figure 14. Track and history of Cyclone Ofa, 31 January to 7 February 1990 (reproduced from Prasad, 1990).

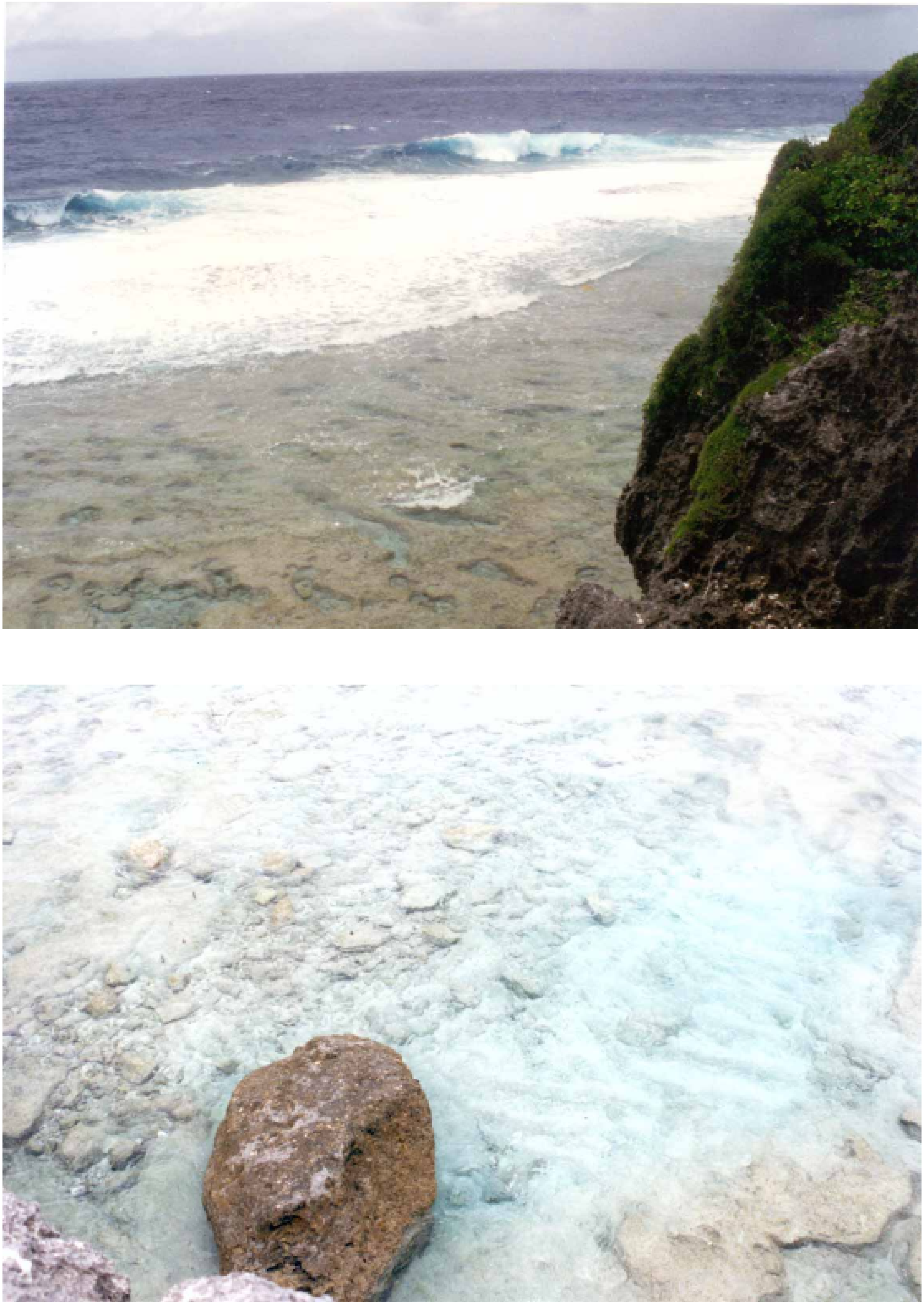

Figure 15. Top*: Surf break at outer reef rim and bore propagating across the platform at Vaitafe, northeast coast.* Bottom*: Boulder, blasted pool, rock debris, and thin sand on inner platform at Vaitafe (DLF/ 9 Nov 1995).*

Niue can be affected by swell originating from mid-latitude storms in both the northern and southern hemispheres. Matthews (1971) reported coastal damage in Western Samoa in December 1969 resulting from an intense storm in the North Pacific. Swell from this storm travelled more than 7000 km and affected island groups from the Gilberts, Tuvalu, and Samoa to the Cook Islands and French Polynesia (Howorth, 1983; Barstow and Haug, 1994d). Though not mentioned specifically, Niue was almost certainly affected. Another event in January 1991 seems to have involved swell from northern and southern hemisphere storms arriving in the South Pacific at about the same time. Waves with peak period T_p= 20 s were recorded at several stations, including Tongatapu, where the corresponding significant wave height was about 2 m (Barstow and Haug, 1994b). In general, swell from the North Pacific is more prevalent in the northern winter and swell from the Southern Ocean tends to be more energetic in the southern winter (although it may occur at any time). Damaging southerly swell experienced along the south coast of Rarotonga on several occasions (Barstow and Haug, 1994a) would also very probably have affected Niue.

Reports of large storm waves at Niue include; "very high" seas in December 1946, "rough" seas in December 1948, "tremendous" waves in January and February 1956, and "gigantic" waves in February 1990 (Appendix 3). No wave measurements for *Cyclone Ofa* are available from Niue, but a waverider buoy south of the passage between Savai'i and Upolu (Western Samoa) recorded a maximum significant wave height of 8.1 m with a peak period of 13 s (Barstow and Haug, 1994c).

Computations of wave characteristics for passage of *Cyclone Ofa* close to Niue, using equations 3-59a and 3-60a of the Shore Protection Manual (USA Corps of Engineers, 1984) with realistic storm parameters (radius of maximum winds R= 60 km, barometric depression Dp= 44 hPa, forward speed C_f= 6.2 m/s, and windspeed U_w= 51 m/s), yield estimates of significant wave height H_s= 9.6 m and period T_p= 12 s (assuming a= 1). Observations during the storm, taken from video footage (Niue Broadcasting Commission, 1990), include two individual waves breaking at the seaward end of Alofi Wharf at first light on Sunday 4 February (local time). The breaker heights H_b appear to be in the range of 7 to 8 m and the wave period ~13 s. The highest waves observed off Western Samoa during the passage of *Ofa* occurred in the westerlies behind the storm (Barstow and Haug, 1994c) and it is reasonable to assume that the same applied at Niue, where the greatest damage was observed overnight from Sunday to Monday (Niue Broadcasting Commission, 1990). Assuming a duration of t= 2.7 hours for the largest waves (R/C_f= 9677 s), the maximum wave height can be estimated (following USA Corps of Engineers, 1984, equation 3-67) as

$$H_{max} = 0.71\ H_s\ (\ln N)^{0.5} = \sim 18\ m \qquad (1)$$

where N= 810 is the total number of waves in 2.7 hours.

Sea surface temperatures

The surface water temperature in the region of Niue ranges from 24°C to 28°C (Taylor and Thompson, 1980). It follows the annual cycle of air temperature, the latter being generally 1-2°C cooler in all months (Kreft, 1986).

Tides and water levels

The tide at Niue is semidiurnal (Figure 16) with a range of 0.7 m at springs and 0.5 m at neaps (1995 Admiralty Tide Tables). Because of the steep submarine slopes surrounding the island, there is limited scope for wind-driven setup and storm surge, but inverse barometric anomalies of up to 0.5 m may occur during passage of intense cyclonic depressions. Fluctuations in mean sea level of less than 0.5 m may be anticipated in association with ENSO cycles or other factors affecting oceanic circulation and upper-layer volume, based on observations elsewhere in the Pacific, but this cannot be verified without longer term tidal observations or satellite data for the Niue region.

LOGISTICS AND STUDY METHODS

Logistics

At the time of this survey in November 1995, the only air access to and from Niue was by weekly Royal Tongan Airlines flights WR121 Auckland-Niue-Tongatapu and WR120 Tongatapu-Auckland, departing Auckland on a Monday at 0700, arriving Niue on Sunday morning at 1030, Tongatapu at 1225 Monday, and returning to Auckland at 1620 Monday. The service was

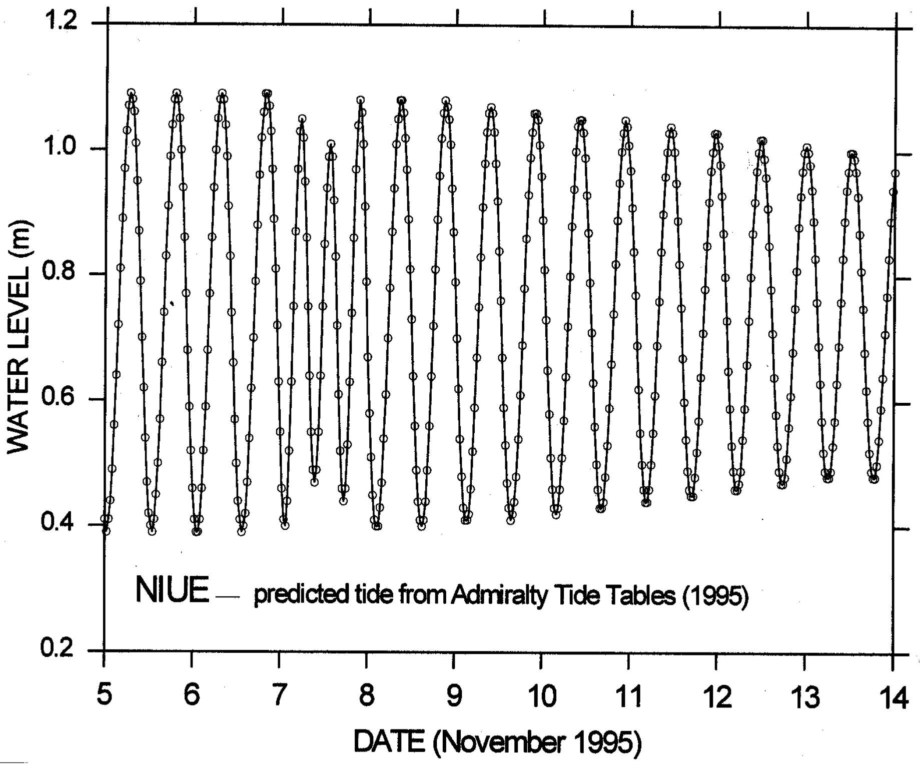

Figure 16. Predicted tide levels for Niue, 5-13 November 1995, from simplified harmonic method and data in 1995 Admiralty Tide Tables.

operated using a chartered Air Pacific Boeing 737-300. The field survey described in this report was designed to be completed in one week from arrival on Sunday 5 November to departure 7 days later on Sunday 12 November.

Niue is also served by ships calling several times per year. Fuel is delivered by tanker from Suva and is landed by floating pipeline. Freight has traditionally been landed by lighter from ships lying off the wharf. During 1995, ships were brought alongside the wharf for the first time to offload heavy equipment for the airport runway extension project. Blasting was carried out by the Royal New Zealand Navy to remove coral heads that posed a hazard to ships approaching the wharf. Unfortunately, this resulted in undermining of the wharf substructure (Kevin Fawcett, pers. comm., 11 November 1995), producing a crack about 5.4 m from the outer face of the wharf. This crack widened perceptibly under light swell during the week of the field survey in November 1995 and required urgent attention to safeguard the long-term stability of the wharf. At this time, a considerable amount of loose material was dredged from the approach and basin by improvised dragline and piled temporarily on the outer end of the wharf (Figure 17).

The perimeter of Niue is about 66 km, and a good quality road encircles the island. It is tar-sealed except for the section between Hakupu and Avatele. During the November 1995 survey, it was necessary to rent a car for the week because of the limited number and availability of government vehicles on the island. In future SOPAC surveys, budget limitations may preclude rentals, necessitating access to government transport. A 4WD van belonging to MAFF was used for visits to two sites on the east coast of the island. Plans for coastal reconnaissance by boat were abandoned because of persistent moderate easterly winds and heavy seas along the east coast. Under suitable conditions, the MAFF catamaran (Figure 18) could be used to circumnavigate the island and would be suitable for small-scale bathymetric and marine geology surveys close to the coast.

Boat ramps accessible to road vehicles exist at 3 locations around the island (Figure 6); Namukulu, Alofi Wharf, and Avatele. Launching and recovery would be difficult at low tide at all sites, with the possible exception of Avatele, where the ramp extends down to 1.3 m below MSL. Most fishing activity on the island is undertaken using traditional outrigger canoes, which are carried down to the water and launched over the reef edge as wave action permits.

The network of sea tracks, many improved recently with parking facilities, sealed paths, and concrete steps, plays an important role in facilitating access down the steep slopes from the lower terrace to the reef. This functions not only to support traditional fishing activity, but also for local and tourist recreational access (Figure 12 bottom, and Figure 19). Parts of this access network along the west coast were damaged or destroyed by wave action during *Cyclone Ofa* in 1990 and some parts had still not been repaired five years later (compare with Figure 10, where former access to the beach down a steep slope seen in lower right corner of photo was completely destroyed and has not been replaced). This is partly because of concern about the ongoing costs of upkeep if damage can be expected on a regular basis (see later discussion). Most of the sea tracks and some other features are identified by attractive carved wooden signs (Figure 20), which are a significant and positive contribution to the tourism infrastructure. Some of these show evidence of wear and minor vandalism, but maintenance should be relatively low-cost and a worthwhile investment.

Figure 17. Top*: Alofi Wharf from the upper road.* Bottom*: Dragline operations to clear debris from channel, Alofi Wharf. (DLF/ Nov 1995).*

Figure 18. MAFF catamaran with rental car for scale. Fuel storage tanks is background, Alofi (DLF/ 12 Nov 1995).

Figure 19. Amanau Reef from halfway down the sea track. Note irregular platform, reef rim, and undercut cliff with collapse block. Teenagers for scale (DLF/ 5 Nov 1995).

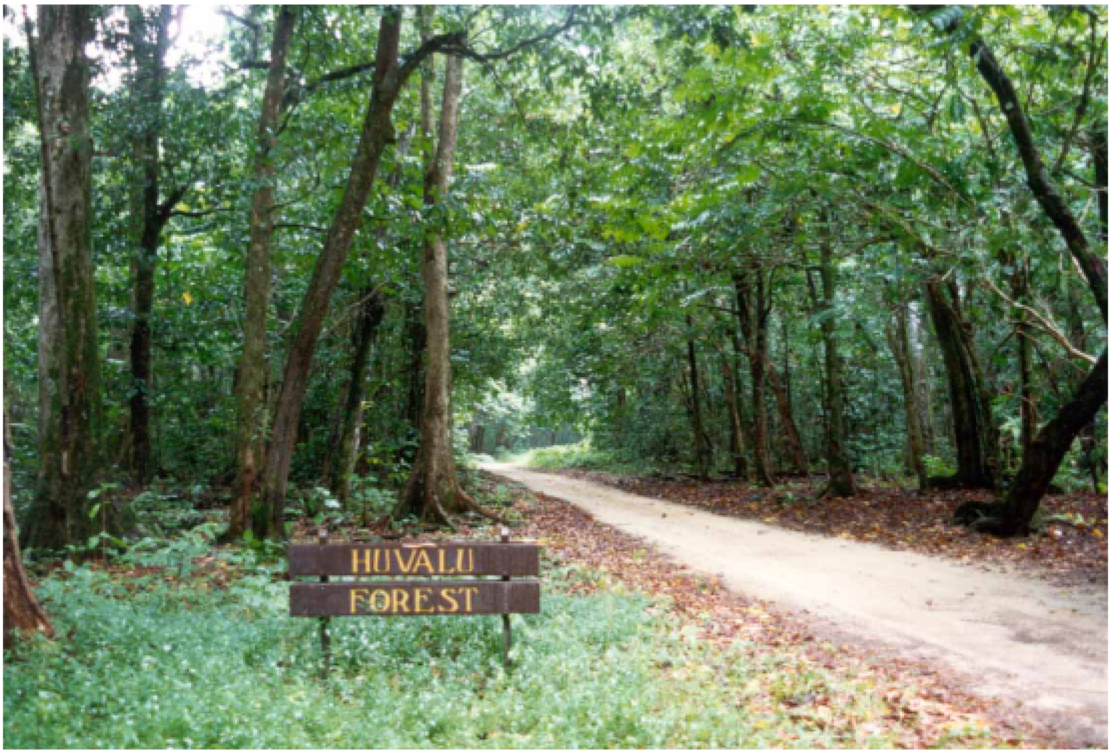

Figure 20. Top*: Access road down to Avatele Beach.* Bottom*: Main road through Huvalu Forest. (DLF/ 11 Nov 1995).*

Methods

Coastal reconnaissance

General reconnaissance of Niue's coast was undertaken on four occasions during the visit. Preliminary exploration of the western corner of the island was carried out by foot on the day of arrival, visiting various sites (Figure 6) from the cliffs at the Niue Hotel (site A) and Amanau Reef (B) to the Anaana cliffs and blowholes (C). Part of the following day was devoted to a general reconnaissance by road, with emphasis on coastal access points, guided by Molesi Tamate. This included Tamakautoga Landing (D), the new resort development site (E) nearby, and Avatele Beach and boat ramp (5) along the southwest coast; Alofi Wharf (3), Tuapa Sea Track (2), Hio Beach (1), Namukulu Landing boat ramp (F), Limu Sea Track (G), and Hikutavake (H) on the west coast; and Uluvehi Landing (I) near Mutalau in the north. A visit to sites on the east coast was arranged later in the week, when the landings at Vaitafe (J) near Lakepa and Tauta (6) near Liku were inspected. Parts of the final weekend were devoted to additional reconnaissance with brief visits to sites at Opaahi Landing (K), various sites in Alofi, Palaha Cave (L), and The Arches (M), as well as additional observations at various sites visited earlier. Plans for a circuit of the island by boat on 7 November had to be abandoned because of the sea state along the east coast.

Airphoto analysis and coastal mapping

Aerial photography of Niue was carried out by New Zealand Aerial Mapping in 1981. Copies of the contact prints were kindly made available for study in Niue by Hubert Kalauni and George Sioneholo in the Lands and Survey office. A subset covering the coastal areas of Niue was subsequently purchased for the SOPAC collection. These are colour photographs at a scale of 1:10000 and formed the primary source for a preliminary classification and shore-type map of the island (Forbes 1996). Additional information was obtained from the ground-based coastal reconnaissance, from low-level oblique video of the west coast (Matapa Chasm to Amanau Reef) by the Royal New Zealand Navy (kindly furnished by Patrick Lima of Niue Broadcasting Commission) and from the 1:50000 scale topographic map (New Zealand Department of Lands and Survey, 1985). The topographic map is based on earlier aerial photography (1965).

The mapping effort recognised the following restricted set of coastal features:

- cliffs and steep rock slopes;
- beaches;
- wave-cut platform and fringing reef (combined as a single feature);
- reef-crossing channels (partly blasted).

Narrow and wide reef platforms were discriminated using a width of 30 m as the cutoff and the outer edge of the reef rim as the outer boundary. In general, the reef extends beyond this limit to include a spur-and-groove zone or outer submarine reef slope (Figure 21), but this could not be consistently observed in the aerial photography.

Figure 21. Detail of 1981 air photograph of northwest coast in the vicinity of Tuapa, showing village green, road, cliffs, platform. reef rim, and seaward slope of reef with spur-and-groove morphology. Hio Beach at right. Box outlines the extent of Figure 26.

The physical shore-zone characteristics were mapped at 1:50000 scale using the New Zealand Department of Lands and Survey (1985) topographic map as a base (Forbes, 1996). The coast was then subdivided into seven units as a basis for assessing geographic variability in the distribution of shore types and features around the island (Enclosure 1). Platform widths and the lengths of individual beaches were measured directly from the aerial photographs. The alongshore lengths of individual platform units were measured at 1:50000 scale using a step length of 100 m and collated for statistical analysis (see Table 3 in later section).

Shore-zone surveys

Beach and platform features at Hio Beach, Tuapa Landing, Alofi, and Avatele were surveyed using a Sokkia Set 2C total-station survey instrument (Figure 22). Vertical and horizontal control were provided by Lands and Survey monuments in the vicinity of each site, as shown in Table 1. Data were provided by the Land Titling Project Office (courtesy of Hubert Kalauni and colleagues) and taken from Archbold (1992).

Figure 22. Tuapa Landing from top of sea track, with Sokkia Set 2C total station survey instrument in foreground. Chainman Sione Tongiakona, carrying the survey target, is halfway across the reef platform in the distance. (DLF/ 7 Nov 1995).

Table 1. Horizontal and vertical control for coastal surveys.

location/ (site #)	control/ benchmark	NMG easting (m)	NMG northing (m)	elevation (m)
Hio/Tuapa	A35 Tuapa			24.78
(1 and 2)	N010 Tuapa	6952.49	22292.50	24.18
	N038 XXIII	7075.40	22506.19	23.85
Alofi	BM2 HMNZS Monowai			2.85
(3)	N001 Tomb Point	5000.00	15000.00	18.86
	RM Mapua	4601.53	14556.78	
	OLP I plan 294	5069.03	14948.26	
Avatele	N005 XCII	5905.81	6893.70	17.12
(5)	IS/VIII	5918.22	6881.63	

Coordinates in Niue Map Grid (NMG) from Land Titling Project office.
Elevations relative to HMNZS Lachlan (1955) mean sea level "6.0 feet [1.83 m] below stand-pipe in steps of Alofi Wharf" (Archbold, 1992, Appendix E) and other unpublished data in Land Titling Project office.

Table 2. Geographic coordinates (NGD 1991) for principal control points at each site.

location [site]	control	latitude	longitude
Hio/Tuapa [1 and 2]	N010/ Tuapa	18°59'16.78"S	169°54'08.40"W
Alofi [3]	N001/ Tomb Point	19°03'13.96"S	169°55'15.15"W
Avatele [5]	N005/ XCII	19°07'37.60"S	169°54'44.16"W

Niue Geodetic Datum 1991 (NGD 1991), based on the geocentric GRS80 reference system and ellipsoid, as recommended by the XVII General Assembly of the IUGG (Archbold, 1992).

The survey data were stored on magnetic card in the total-station survey instrument and downloaded through an RS232 port to a notebook computer at the end of each day.

Communications were established using SoftKlone Mirror III software running under MS-DOS 6.1 and data reduction was accomplished using Microsoft Excel 5.0 and 7.0 spreadsheet software running under Windows 3.11 and Windows 95, respectively. The survey data were plotted and contoured using Golden Software Grapher and Surfer packages running under Windows 95. Gridding was by triangulation with linear interpolation and contouring employed minimal smoothing.

The survey at Tamakautoga was carried out using a hand-level, staff, and tape. This did not permit connection to the cadastral survey network or vertical control. The survey beach (site 4) is the first beach north of the Tamakautoga landing beach and the NMG coordinates of the line origin, in the cliff recess at the head of the beach, were estimated from the 1:50000 scale topographic map. The line bearing was 228°TN seaward. Elevation was estimated from the measured water level at the time of the survey and predicted tides (Figure 16), using the simplified harmonic method in the 1995 Admiralty Tide Tables and a mean water level of 0.74 m above chart datum.

The datum of the Admiralty Tide Tables (MWL-0.74 m) appears to be 25 mm higher than that adopted by HMNZS Lachlan (1955), according to data in Schofield (1959) and Archbold (1992, Appendix E). Schofield indicates that chart datum is 8.51 feet (2.594 m) below the stand-pipe in the steps of Alofi Wharf, while Archbold cites a 1964 document from the Land Titling Project Office, which gives mean sea level as 6.0 feet (1.829 m) below the stand-pipe. This stand-pipe was not observed during the 1995 survey, but elevations were tied to the Niue Fundamental Station at Tomb Point (elevation 18.86 m) and to the benchmarks established at the wharf by HMNZS Monowai in 1994 (Robbins, 1994), primarily BM2 (elevation 2.85 m). Elevations for the Tomb Point mark and other control points in Table 1 are presumed to be with reference to the 1955 mean sea level (6.0 feet below the stand-pipe). The chart datum established by HMNZS Monowai (1994) is 0.314 m below this MWL datum or 0.45 m higher than the HMNZS Lachlan (1955) chart datum. The 1994 chart datum is close to mean low water at spring tides. The bathymetry reproduced off Alofi (Figure 8, after Schofield, 1959) is based on the 1955 chart datum, while all survey elevations reported here are relative to MWL.

Sediment sampling and analysis

Sand samples of approximately 300 g or less were collected as grabs (underwater) or thin slabs from a limited number of sedimentation units (on beaches). Sampling sites included Hio Beach (site 1), Tamakautoga Beach (site 4), Avatele Beach (site 5), and Tauta (site 6). The samples were shipped to SOPAC in Suva for analysis of composition and texture. The procedure involved oven-drying at 60°C, splitting approximately 50% to 100 g, and sieving at 0.5ϕ intervals to obtain the particle sizes as a mass-frequency distribution in the usual way. Standard moment measures (mean, standard deviation, skewness, kurtosis) were determined on the ϕ-transformed data (grain size $D\phi = -\log_2 D_{mm}$) and the modes were determined directly from the size distributions.

The individual sieve fractions were retained in plastic bags for examination under a binocular microscope. The sand composition was analysed for each fraction, with particular attention to the species composition of the larger foraminifera, which account for much of the sand production on fringing reefs of other islands in the South Pacific such as Tongatapu (Tappin, 1993) and Funafuti (Collen, 1995). Preliminary identification of the commoner foraminifera and analysis of their concentration in each 0.5ϕ fraction were carried out in Suva by the author. Six samples (from Hio, Tamakautoga, and Tauta) were then shipped to Victoria University in Wellington, where John Collen kindly examined the samples for identification of additional species and verification of the results obtained in Suva.

It was impractical to sample the pebble-cobble gravels of Avatele Beach or to ship gravel samples to Fiji. As an alternative, five samples were photographed in situ with a tape measure for scale. The photographs were enlarged to A4 size and a 20-mm grid was superimposed on the images. Projected B-axis lengths were measured for particles under each grid intersection to obtain the particle sizes as a number-frequency distribution. The mean, sorting (standard deviation), and standard error were estimated from the logarithmic ϕ transformations of the grain size data. Skewness and kurtosis were not computed because of the limitations of the sampling method.

Locations and summary data for all samples (NU9501-01 to NU9501-08) and sample photographs (FZ9546-p16 to FZ9546-p20) are listed in Appendix 2.

COASTAL GEOMORPHOLOGY

Shore types

The coast of Niue is characterised by relatively few shore types. Except for part of the southern coast and rare exceptions elsewhere, the entire coast is cliffed and fronted by an actively developing wave-cut platform and fringing reef complex. Parts of the southern coast east of Tepa Point are less distinctly cliffed, being backed by a rugged rock slope of 17° to 22° extending from sea level to the Alofi Terrace (Schofield, 1959).

Cliffs

Most cliffs are developed in the Alofi Terrace and are typically about 18 to 25 m high, although reworking of the outer terrace margin reduces the height to less than 10 m in some places and rarely less than 5 m. Along the southwest coast from Tamakautoga to Avatele, the outer terrace slopes seaward, so that the cliff height in that sector is commonly less than 10 m. In places, the cliff intersects a narrow, discontinuous, 12-14 m terrace described by Schofield (1959) from Alofi, Lakepa, and The Arches, where he described the "35 ft high" [10.7 m] level as a remnant of this terrace (Figure 23 top). The arch depicted is one of several, the others having higher bases above the present wave-cut terrace.

Many cliffs are vertical to overhanging (Figures 4, 5, 7, 10, 12, and Figure 23 bottom) or very steep (Figures 15, 19) and most are notched at the base. The notch is presumably formed by a combination of solution and abrasion, while some sites show evidence of block collapse (Figure 19), which may be attributed to undercutting, fracturing, and wave pressure shock and drag forces. Schofield (1959) cited Kuenen (1933), who propounded the notion that most notches are solution features formed in the intertidal zone. This view is consistent with the solutional morphology of lobed ribs on the foot ramp of the notch at Tamakautoga (Figure 24). On the other hand, despite the very limited volumes of sand and few beaches on Niue, abrasive material is present in many places and undoubtedly plays a part. Schofield (1959) notes the presence of silt and loose shell material on bare rock on top of the cliffs at Tepa Point and similar observations elsewhere indicate that such material can be carried up over the cliffs by energetic waves. During *Cyclone Ofa* in 1990, large quantities of material up to boulder size were carried over the 16 m cliffs at the Niue

Hotel (see below). Most of the cliff notches are much higher than mean high water spring tides, typically extending to at least 2 m above MWL, suggesting that Kuenen's restriction of notch development to the intertidal zone may be inappropriate. Wave runup and spray against the cliff can obviously extend well above the tidal limit on exposed coasts such as Niue's. In places, distinct higher-level features appear to be present, as at Tepa Point (Schofield, 1959), or the active notch may coalesce with a higher one, while elsewhere the lowest notch appears to be higher than average (Figure 4). This may simply reflect more energetic wave action on less protected parts of the coast such as where the platform is narrow or absent (Johnson, 1933).

Caves and chasms intersect the cliffs in many places along the coast. Some sites, such as the Hio Beach reentrant, appear to have lost a portion of the outer Alofi Terrace back to a limit defined by coast-parallel fractures (Figure 10) and the same effect may explain several other embayments, such as at Amanau Reef (Figure 19). Arches are present at several places, some at least resulting from partial unroofing and erosional isolation of the seaward parts of coastal caves (Figures 11 and 12).

Wave-cut platform and fringing reef

The actively forming terrace around the coast of Niue consists of a coalescing erosional platform and constructional reef (Figures 7, 8, 15, 19, 22, 23). The combined width is up to 150 m, although frequently less than 30 m and virtually absent in places (Figures 4 and 5). Schofield (1959) pointed out that the platform width frequently decreases toward small headlands (Figure 8). The platform is generally narrower in the vicinity of the major headlands on the island as well, except north of Liha Point and near the northern extremity of the island, where wide platforms (up to about 60 m) are present on protruding sections of the shore.

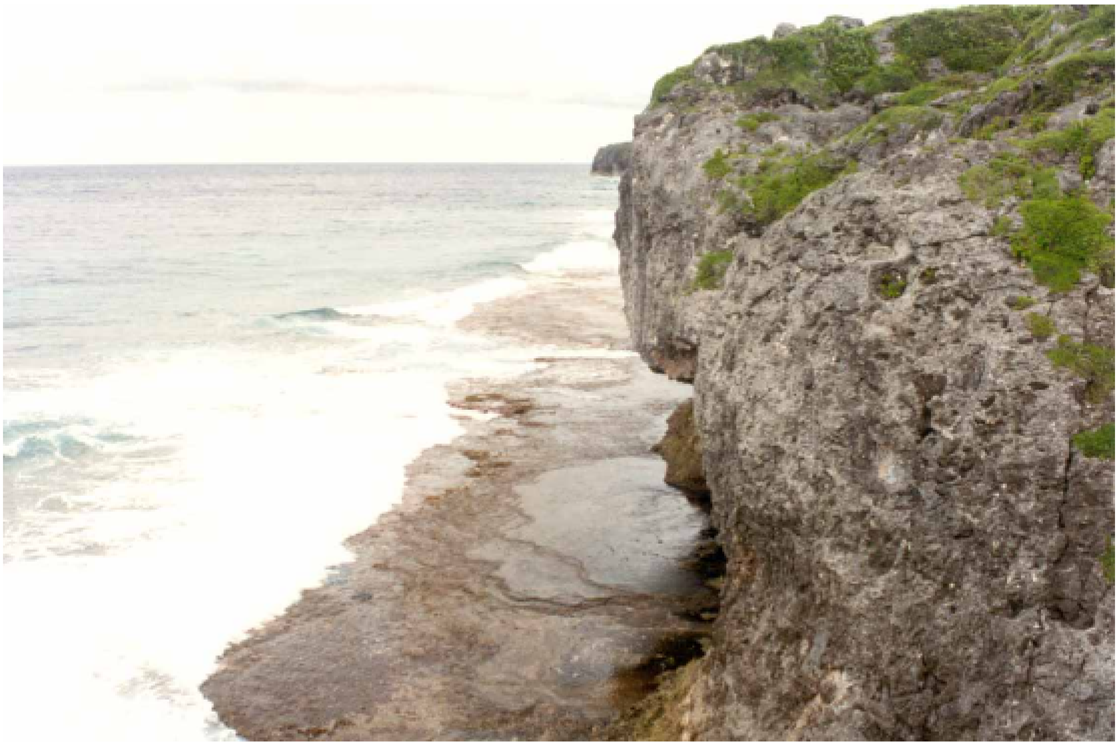

Figure 23. Top*: Erosional shore platform and limestone arch at Talava ("The Arches"), north coast.* Bottom*: Narrow platform and undercut cliffs, looking east from Uluvehi Landing toward Vaihakea, north coast near Mutalau. (DLF/ 11 and 6 Nov 1995).*

Figure 24. Top*: Erosional notch in cliffs adjacent to Tamakautoga Beach (survey site 4). Notebook 181 x 121 mm provides scale.* Right*: Linear solution lobe structures on basal ramp of notch. Lens cap 62 mm diameter for scale (DLF/ 7 Nov 1995).*

The coast has been subdivided on the basis of the combined reef-platform width (Forbes,1996) differentiating narrow (less than 30 m) and wide (more than 30 m) platforms. Detailed surveys of reef-platforms at Hio Beach, Tuapa Landing, Alofi, and Avatele are presented later in the report. On average, the wave-cut platform is 20 to 30 m wide, but in places its width is 80 m or more. Wherever the platform is wide, it is accompanied by a fringing reef. Schofield (1959) distinguished two subequal zones on well-developed platforms, the inner characterised by potholes up to 0.6 m deep and 1-2 m wide, the outer without potholes. Observations during the present survey indicate quite variable morphology, with irregular pits and hollows on the inner platform at some locations and on the outer platform near Alofi Wharf. It is not clear how many of these may have been artificially deepened. At Tamakautoga (Figure 7), the inner-platform hollows are quasi-linear and shore-normal, giving the appearance of grooves. Well-developed micro-atolls are superimposed on the ridges very close to the beach. Beyond the wave-cut platform, the reef rim rises typically almost to MWL and in some cases much higher, reaching 0.6 m on the north side of Alofi Wharf and a comparable elevation at Tuapa (see below). The reef rim is rarely wider than 30 m and consists primarily of massive pink algal limestone, broken by irregular gaps (Schofield, 1959; Figure 3A), some of which extend seaward to merge with grooves in the spur-and-groove zone of the upper reef slope. Most parts of the reef platform are free of sediment, except for scattered blocks in many places, but sand is present in pockets, particularly in the vicinity of beaches.

Beaches

Cliff-base pocket beaches account for less than 1% of the total shore length. Altogether, they represent a very limited sediment volume, most being less than 1 m thick. Of a total of 32 beaches identified in the mapping exercise, 24 (75%) are less than 20 m in alongshore extent and typically less than 15 m wide. Six (19%) are 25 to 30 m long, one is about 50 m, and the largest (the covehead beach at Avatele) is approximately 80 m. This and a few others are described in more detail below.

Geographical distribution of shore types

For the purposes of analysis, the island coast has been subdivided into seven coastal units, designated A to G (Forbes, 1986). The total shore length (based on 100 m step lengths) and the relative proportions of narrow and wide platforms and of beaches are summarised in Table 3, which also shows the maximum platform width in each unit. It is clear from these data that distinctive geographical variations in shore type occur around the island (Forbes, 1996).

Table 3. Summary of total length, reef-platform width, and beach occurrence by coastal unit.

unit	***shore length*** (km)	***reef-platform*** % <30 m	***reef-platform*** % >30 m	***max width*** (m)	***beach*** %	(km)
A	9.36	100	0	<30	0	0.00
B	11.64	76	24	70	0	0.00
C	11.17	63	37	110	1	0.06
D	8.60	64	36	120	1	0.06
E	7.70	47	53	150	1	0.05
F	9.15	51	49	120	1	0.07
G	8.92	38	62	90	3	0.30
TOTAL	66.5	64	36	150	0.8	0.54

Overall, 64% of Niue’s 66 km shoreline is bounded by narrow platforms (less than 30 m wide), in some cases very narrow or absent. Where the platform is wider, along 36% of the coast, maximum widths range from 30-150 m, the widest examples being found along the northeastern and northern to western sections of the coast (Table 3; Forbes 1986). The total length of beaches on the island is less than 1 km (0.8%).

South and southeast coast (units A and B)

The south and southeast coast from Tepa Point to Vaigata have relatively narrow fringing platforms, less than 30 m wide throughout unit A and along 76% of unit B. This part of the island is almost completely devoid of beaches, although sand is present in the chasm at Togo. Exposure to the prevailing southeast tradewinds and associated wave action produces almost constant spray. The result is a very rugged karrenfeld of limestone pinnacles and crevices extending up to the Alofi Terrace at slopes of 17° to 22° (Schofield, 1959). Cliffs *sensu stricto* are least well developed along parts of this coast in unit A. Blowholes and low (2-4 m) terrace development occur near Tepa Point (Schofield, 1959), a cave is present at Mata Point, and coastal chasms are found at Ana, Togo, and Vaikona (Figure 6). A canoe landing exists at Tuhia-atua near Hakupu and footpaths provide access to Togo and Viakona.

East coast (unit C)

The proportion of wider platform development increases to 37% on this part of the coast, from Vaigata to Liha Point. The maximum platform width also increases from 70 m in unit B to 110 m in unit C. Total beach length is about 60 m, representing 0.5% of the unit shore length. This part of the coast is also exposed to the prevailing trades and wave conditions on the reef edge are typically rough (Figures 13 and 15), restricting fishing access. Canoe landings at Tauta and Vaitafe (Figure 6) were examined during the survey. The former is reached at the end of the Liku Sea Track, which descends steeply from the Mutalau reef rim to the Alofi Terrace a short distance before reaching the coast. The landing consists of concrete steps extending to the platform by way of a cave (Figure 13). A small pocket beach (site 6) immediately north of a small headland at the landing was sampled for sediment size and composition, results of which are given below. The landing at Vaitafe (site J), at the end of the Lakepa Sea Track, consists of recently completed concrete steps descending a very steep slope to a small platform awash at high tide. A small pocket beach occurs a little distance to the north of Vaitafe and a limited amount of sand was observed in a partially blasted hole on the inner platform (Figure 15, bottom).

North coast (unit D)

Platforms more than 30 m wide occupy 36% of the north coast, from Liha Point to The Arches, almost the same proportion as in unit C. The maximum platform width is about 120 m in a broad embayment toward the west end of unit D between Vaihoko and The Arches. All of the beaches on this part of the coast are concentrated there. Much of the northeast coast is forbidding, with relatively high cliffs, high notches, and long sections of very narrow platform development (Figure 23, bottom). However, as noted earlier, this is the one part of the island where platform widths more than 30 m occur on protruding parts of the coast, north of Liha Point and east of Vaihoko. The landing at Uluvehi (site I) is reached by sea track from the village of Mutalau, descending steeply to the lower terrace shortly before the coast. As at Vaitafe, the access consists of recently refurbished concrete steps with a very narrow platform at the base. A cave opening in from the cliff several metres above sea level is used for storing canoes.

Northwest coast (unit E)

This section of the coast extends from The Arches (site M; Figure 23, top) at Talava to just north of Makapu Point (Figure 6). It is highly varied, with sections of narrow and wide platform development, including the widest platform on the island (150 m) near Tuapa (Figure 22). Platforms more than 30 m wide account for 53% of this unit. Numerous caves and chasms intersect the coast (Figure 11, top) and abrupt reentrants elsewhere are partly related to structurally defined erosion or cave exposure (Figures 10 and 12). Deep pools and channels of possible karst origin dissect the platform near Hikutavake (site H), Limu (site G), Namukulu Landing (site F), and north of Makefu. The channel at Namukulu Landing has been expanded by blasting and provides one of only three access points for boats with outboard motors. The Alofi Terrace reaches its maximum width in this area near Tuapa and numerous villages occupy the terrace from Hikutavake to Makefu. Lower terrace remnants occur at The Arches, near Hikutavake, and near Limu. Beaches are present at Hio (site 1; Figure 10), Tuapa Landing (site 2), north of Palaha Cave (site L; Figure 11, bottom), and near Makefu. Their total length is about 78 m, accounting for 1% of the shore length of this unit.

West coast (unit F)

This unit represents the coast of Alofi Bight, from Makapu to Halagigie Point (Figure 6). Wide erosional and reef platforms make up 49% of this shore, with maximum widths of about 120 m (Figure 8) but no platform at all in some places (Figure 4). In such cases, a narrow subtidal platform is sometimes present, providing limited wave energy dissipation, although much of the energy is reflected from the cliffs. The Alofi Terrace is again widely developed in this area and is extensively urbanised. Lower terrace remnants are present locally in Alofi. This section of the coast includes the main wharf and fuel tanks at Alofi (site

3; Figures 17 and 18) and other coastal access points, including Opaahi Landing (site K; Figure 25) and Amanau Reef (site B; Figure 19). Beaches are present along this part of the coast south of Makapu Point and in Alofi. Their total length is about 90 m, accounting for almost 1% of the total shore length in this unit.

Southwest coast (unit G)

The southwest coast, representing Avatele Bight, from Halagigie Point to Tepa Point (Figure 6), is strikingly different from other parts of the island and particularly from adjacent unit A. Unit G has the highest proportion of wide reef platform (62%) and the greatest extent of beaches (300 m or 3%), including the only covehead beach on the island, at Avatele (site 5; Figure 20). The bight has a roughly log-spiral form in the lee of Tepa Point, and the platform decreases in width northwestwards toward Anaana and Halagigie Point. Caves and blowholes are present near Anaana (site C), where sheer cliffs rise to the Alofi Terrace level and narrow reef terrace development has occurred at 2-4 m elevation at the base of the cliffs (Figure 5). There is very little reef platform at present sea level in this area. The beaches in unit G are concentrated in the southern half of the bight, backed by reef platforms up to 90 m wide in the vicinity of Tamakautoga (Figure 7). The Alofi Terrace is relatively wide in this area, but slopes gently seaward at its outer edge, resulting in generally lower cliffs (Figure 7; and Figure 24, top).

MORPHOLOGY AND SEDIMENTOLOGY OF STUDY SITES

Site 1: Hio Beach

This is a cliff-base pocket beach (Figures 6 and 10) behind a wide erosional platform and fringing reef on the northwest coast. It occupies a deep reentrant in the cliff line (Figures 21 and 26), the back of which is aligned at each side with a coast-parallel fracture dipping steeply seaward (Figure 27, bottom). An erosional terrace remnant at 4-6 m elevation lies in the head of the embayment, hemmed in by cliffs rising 18-20 m to the Alofi Terrace level (Figure 28). The lower terrace remnant has a cliff at its seaward margin, forming the back of the beach.

Figure 25. Top*: Opaahi Landing, showing rough gravel access track, canoes, and damaged concrete structure.* Bottom*: Detail of coral structures in limestone at Opaahi Landing. NZ$1 coin (22 mm diameter) for scale (DLF/ 11 Nov 1995).*

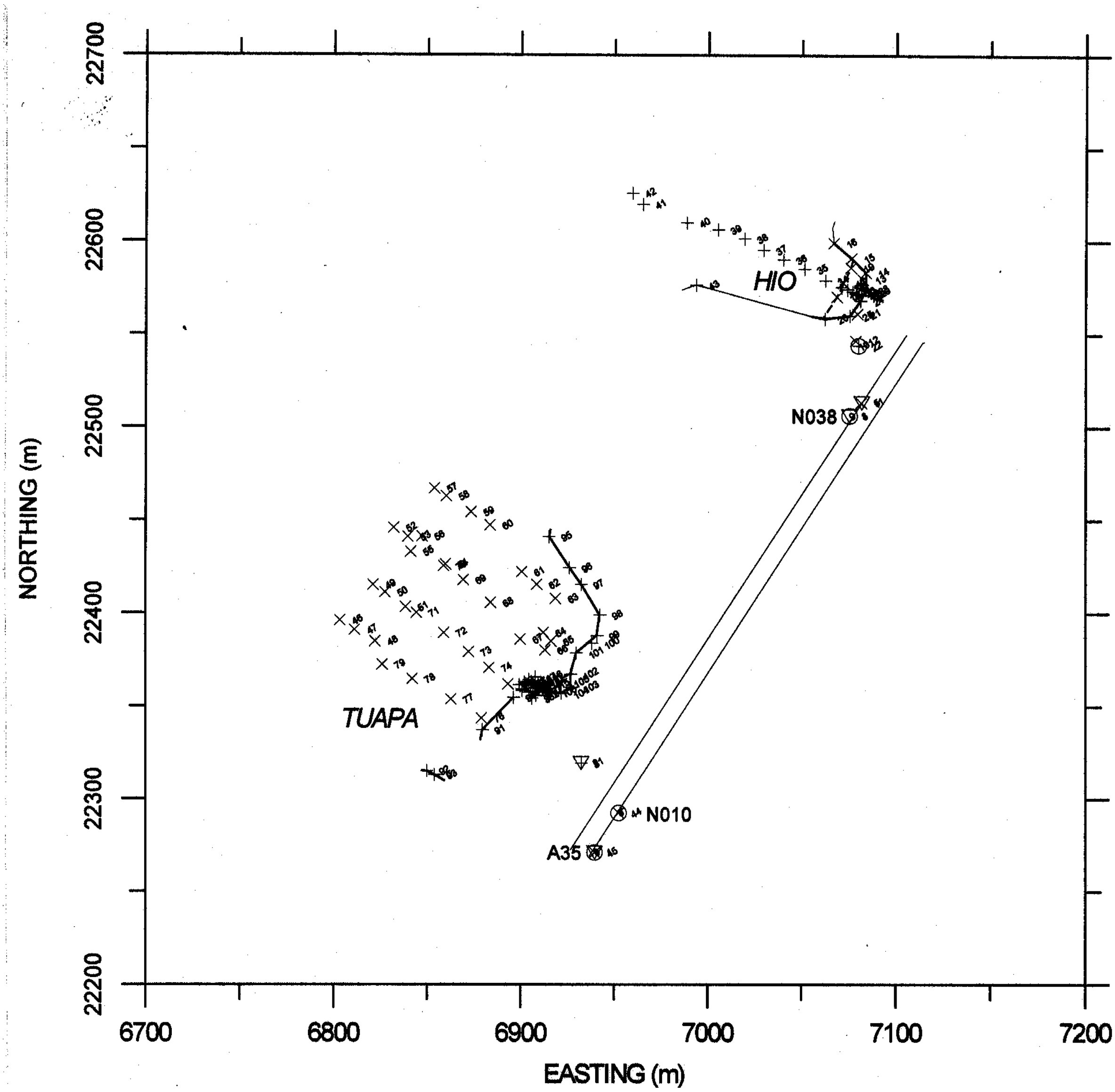

Figure 26. Plan showing November 1995 survey points, cliff line, road, and control points A35, N010, and N038, Hio Beach and Tuapa Landing (sites 1 and 2). Niue Map Grid. Ocean at top left.

The beach is narrow and very thin, less than 0.1 m across the upper beach and less than 1 m near the step at the base. An erosional rock platform crops out across much of the beach (Figure 27, bottom). The lower beachface slope at the time of the survey was 7.4°, increasing to more than 12° across the basal step. The fringing platform at Hio is awash at mid-tide (Figure 27). The inner part of the platform near the beach has several irregular shallow depressions partly filled with wave-rippled sand. The wave-cut platform is about 90 m wide with a 30 m wide reef rim at

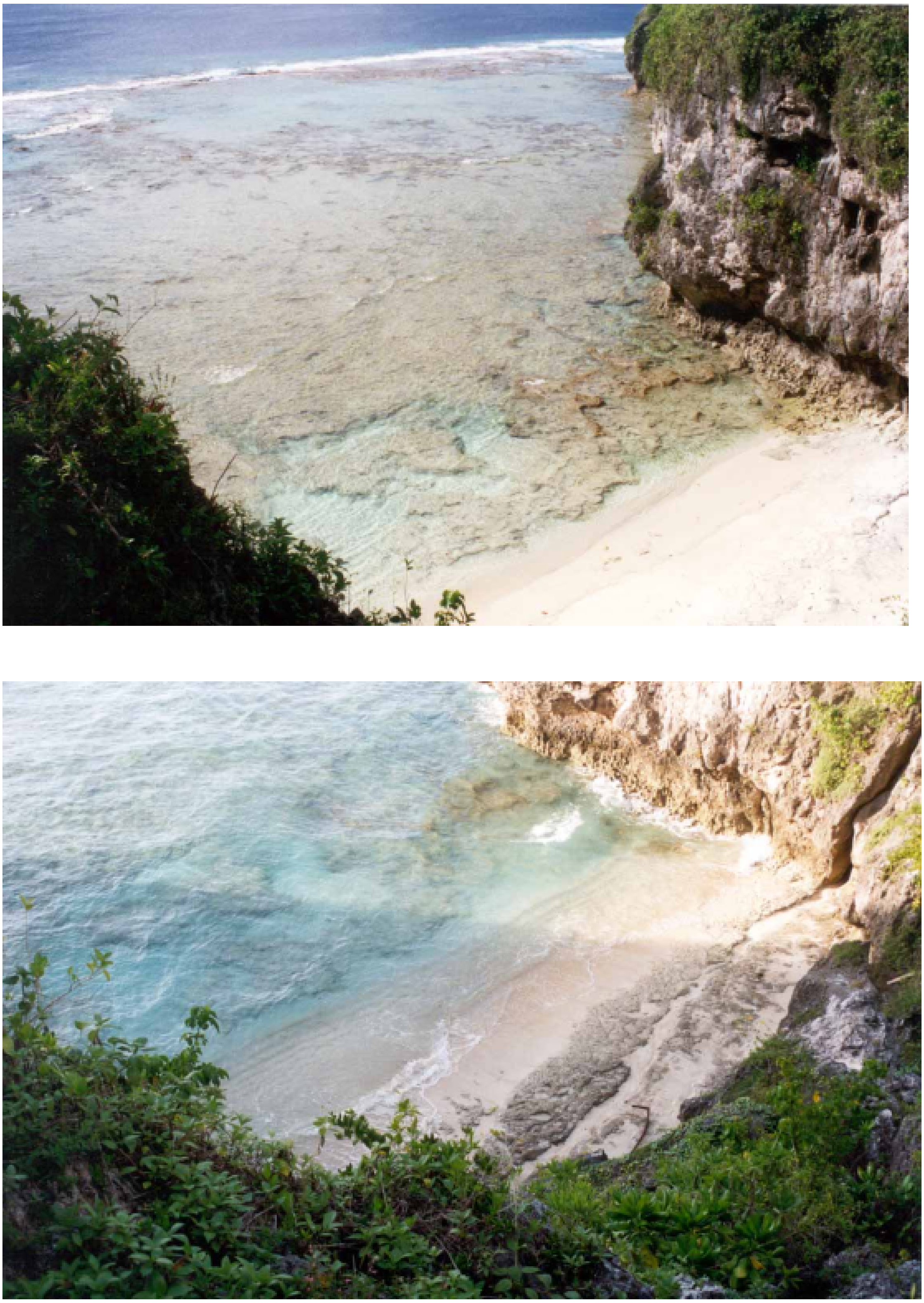

Figure 27. Hio Beach platform and reef, seen from top of cliff at low tide. Bottom*: Close-up of beach and nearshore sands sampled at Hio Beach, mid-tide. Note fracture cutting across head of embayment at back of beach (DLF/ 7 Nov 1995).*

its outer margin. This site is somewhat anomalous in that the erosional platform is higher than the reef rim, which nevertheless has positive relief with a shallow moat to landward (Figure 28).

Two samples were collected at Hio, sample 3 from the sand veneer on the lower beach and sample 4 from a rippled sand patch on the rock platform 12 m seaward of the beach. The grain-size distribution (Figure 29) indicates that sample 3 is a well sorted coarse sand with mean size D_{mean}= 0.78 mm (0.35ϕ) and modal (most abundant) size D_{mode}= 0.8 mm, sorting s_D= 0.48ϕ, slightly negative skewness of -0.2 and kurtosis of 4.7. Sample 4 from the nearshore platform consists of poorly sorted medium to coarse sand with D_{mean}= 0.49 mm (1.0ϕ) and D_{mode}= 0.3 mm, sorting s_D= 0.93ϕ, high negative skewness of -1.3 and kurtosis of 5.4.

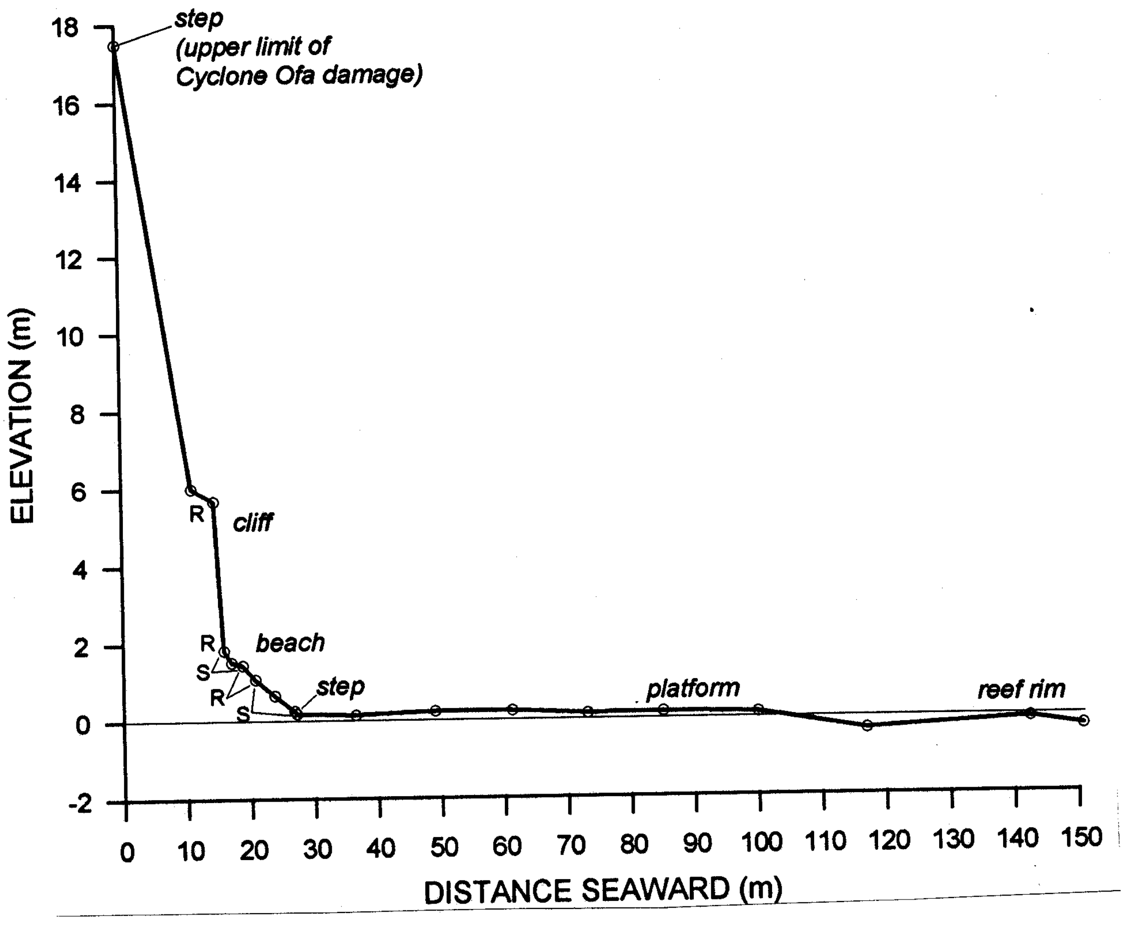

Figure 28. Surveyed profile across reef platform, beach, and cliff at Hio Beach, 7 November 1995 (see Figure 26 for location). Note distinct reef rim, high platform, linear beach slope, 6 m terrace remnant, and upper limit of damage in Cyclone Ofa (lowest surviving concrete step at 17.5 m).

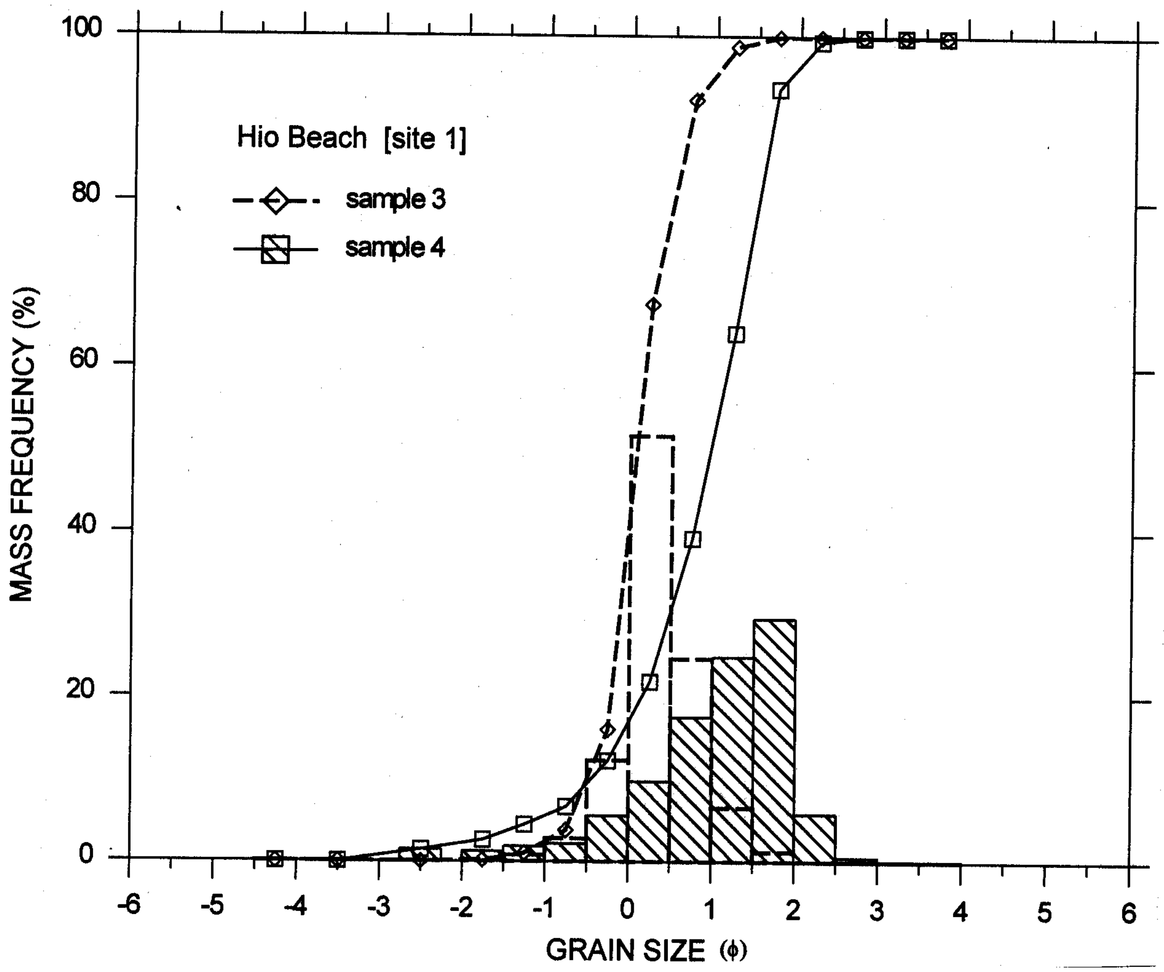

Figure 29. Grain-size distributions of beach and nearshore sand from Hio Beach.

Sample 3 from the beach shows large numbers of *Baculogypsina sphaerulata*. These are most abundant in the coarser than 1 mm fraction (sediment retained on the 1 mm sieve), where they account for 19% of clasts. *Amphistegina lobifera* total 10%. Smaller numbers of *B. sphaerulata* are found in the coarser than 0.7 mm and coarser than 0.5 mm fractions, where *Amphistegina* predominate (21% *A. lobifera* and 10% *B. sphaerulata* in the modal coarser than 0.7 mm sand). Specimens of both species are found in good condition, though not as well preserved as in sample 4. Coral, algal, and shell fragments predominate throughout the sample and make up almost all of the fine-medium sand and granule size fractions.

In sample 4, from the platform, the coarse sand and granule fractions are dominated by *Marginopora (*or *Sorites?)* sp. discs up to 5 mm in diameter. These constitute more than 40% of the coarser than 2 mm fraction, the remainder being made up of algal, coral, and molluscan fragments. The coarser than 1 mm fraction of sample 4 is 76% foraminiferal sand, comprising 60% *B. sphaerulata*, 10% *Marginopora (Sorites?)* sp., and 6% *A. lobifera*. The abundant *B. sphaerulata* and the numerous *A. lobifera* are in very good condition, some appear undamaged and retain chloroplasts. The coarser than 0.5 mm fraction is dominated by coral and algal fragments with a few *A. lobifera* (less than 3%) and a few small specimens of *B. sphaerulata*. The modal coarser than 0.25 mm fraction is dominated by worn and abraded coral and algal fragments with very rare small *B. sphaerulata*. Other types found in this sample (John Collen, pers. comm., 4 April 1996) include common *Rosalina* sp., rare *Heterostegina depressa*, and one damaged specimen of *Calcarina* (possibly *C. spengleri*).

The undamaged condition of *B. sphaerulata* and *A. lobifera* in this sample suggest that these species are living in very close proximity, consistent with the shallow water preference of *A. lobifera* (John Collen, pers. comm., 4 April 1996). The damaged specimen of *Calcarina* sp. may be reworked from older deposits. It is remarkable that the large discoid specimens of *Marginopora (*or *Sorites?)* in sample 4 are completely absent from sample 3, collected from the nearby beach.

Site 2: Tuapa Landing

This site is centred on the canoe landing at the bottom of Tuapa Sea Track (Figures 21 and 22), opposite the north end of the village green (across the road from benchmark A35). It is a short distance south of Hio Beach (Figure 26) and is representative of the unusually wide platform and reef along this part of the coast. Apart from the relatively gentle gradient down the sea track (averaging about 20°), the platform and reef here are also surrounded by steep cliffs (Figure 30). As at Hio, there appears to be a low terrace remnant (here just landward of the landing platform) with a low cliff at its base. The form of the cliff reentrant is also apparently related to a near-vertical fracture (Figure 30), possibly the same as the one that cuts across the back of Hio Beach (Figure 26). Two very small, cliff-base, pocket beaches are present north of the landing. The larger and nearer one is gravel with a beachface slope of about 10°; the smaller more distant one is sandy.

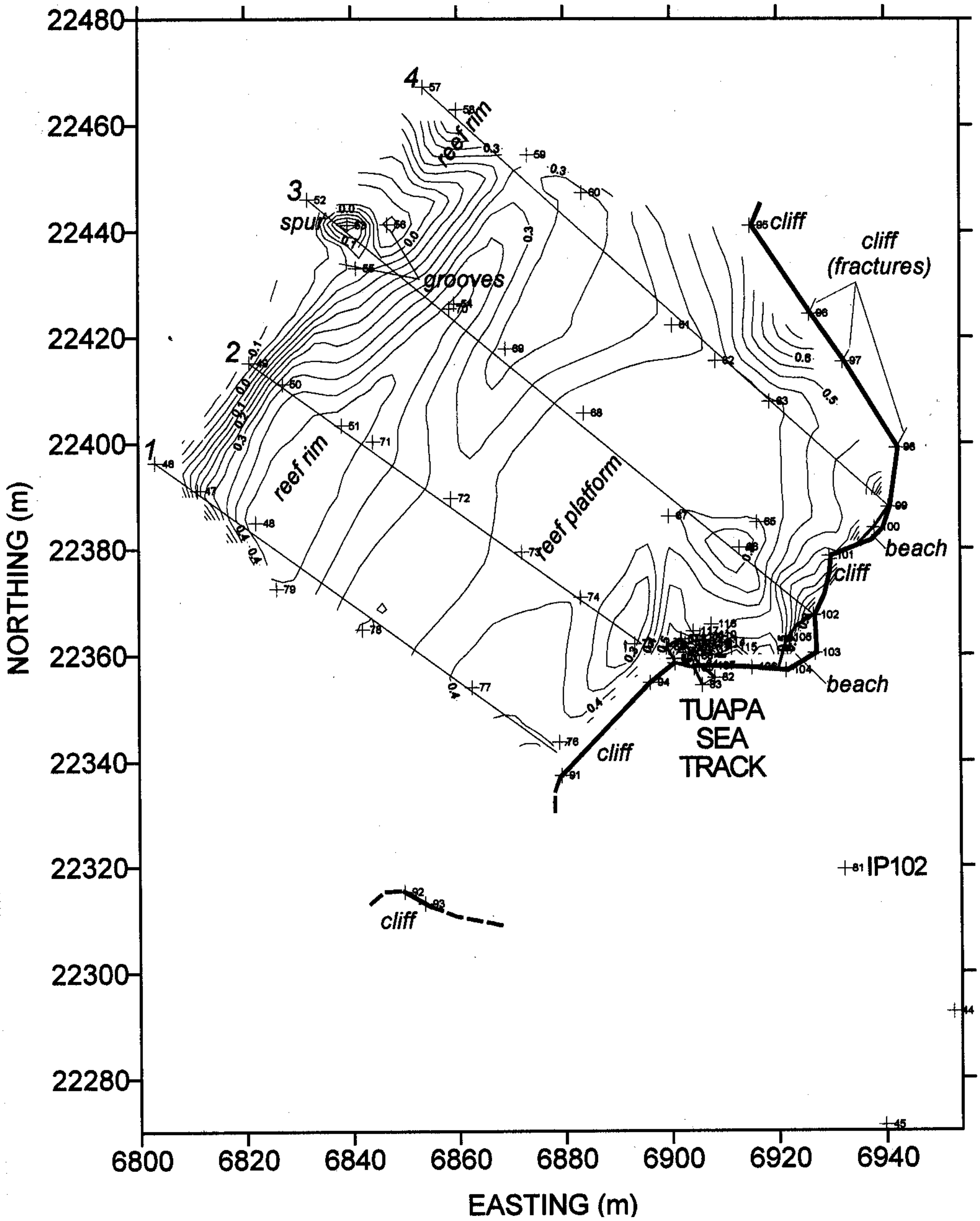

Figure 30. Reef rim, platform, and pocket beaches in vicinity of Tuapa Landing, from total-station survey, 7 November 1995. Also shown are profile lines 1 to 4, cliff line, landing platform, instrument position IP102 (Figure 22), and benchmark A35. Niue Map Grid.

The wave-cut platform at Tuapa is relatively high and ranges in width from 45 m to about 90 m (Figure 31). The maximum width of the platform and reef in this area is about 125 m, the reef rim ranging from 25-50 m wide. The form of the reef rim is almost identical on profile lines 1 to 3 but is different on line 4, north of a cross-cutting channel. In contrast to the reef at Hio Beach, the reef rim is consistently higher than the platform and a broad moat is present on the outer platform. Large boulders are present at several places on the inner platform and another at the base of the larger beach. Three closed depressions occur, two shallow basins west and east of the landing and one deep depression immediately adjacent to it on the east side. This last one is steep-walled and about 0.5 m deep.

No sediment samples were collected from this site.

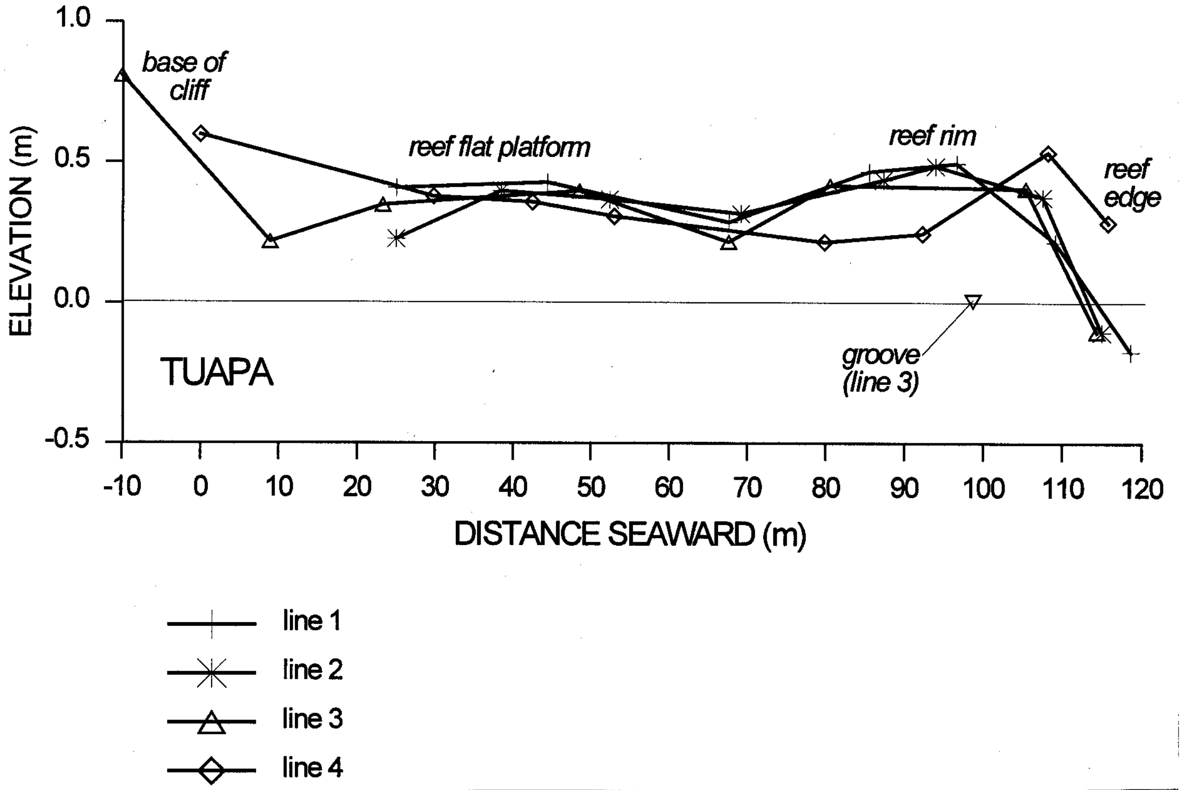

Figure 31. Surveyed profiles across reef rim and erosional platform at Tuapa Landing, 7 November 1995 (see Figure 30 for locations). Note similarity of lines 1 to 3 and contrasting profile on line 4.

Site 3: Alofi Wharf

The wharf and adjacent coast and reef at Alofi were surveyed because of concern about recent damage sustained there and various proposals for improvement or other developments at this site (Figures 17, 32, 33). The platform here ranges from 50-100 m wide, the reef rim occupying the outer 30 m or so, with an erosional platform landward of this (Figure 34). Low cliffs define the landward limit of the platform north and south of the wharf. Small gravel beaches are present on the north side below the fuel storage tanks (Figure 33, bottom) and on the south side immediately landward of a boulder patch (Figure 34). A channel and basin up to 5 m deep (HMNZS Monowai 1994 chart datum and unpublished data) extends along the southwest side of the wharf and reaches a depth of 10 m within 50 m seaward of the end of the wharf. Unpublished

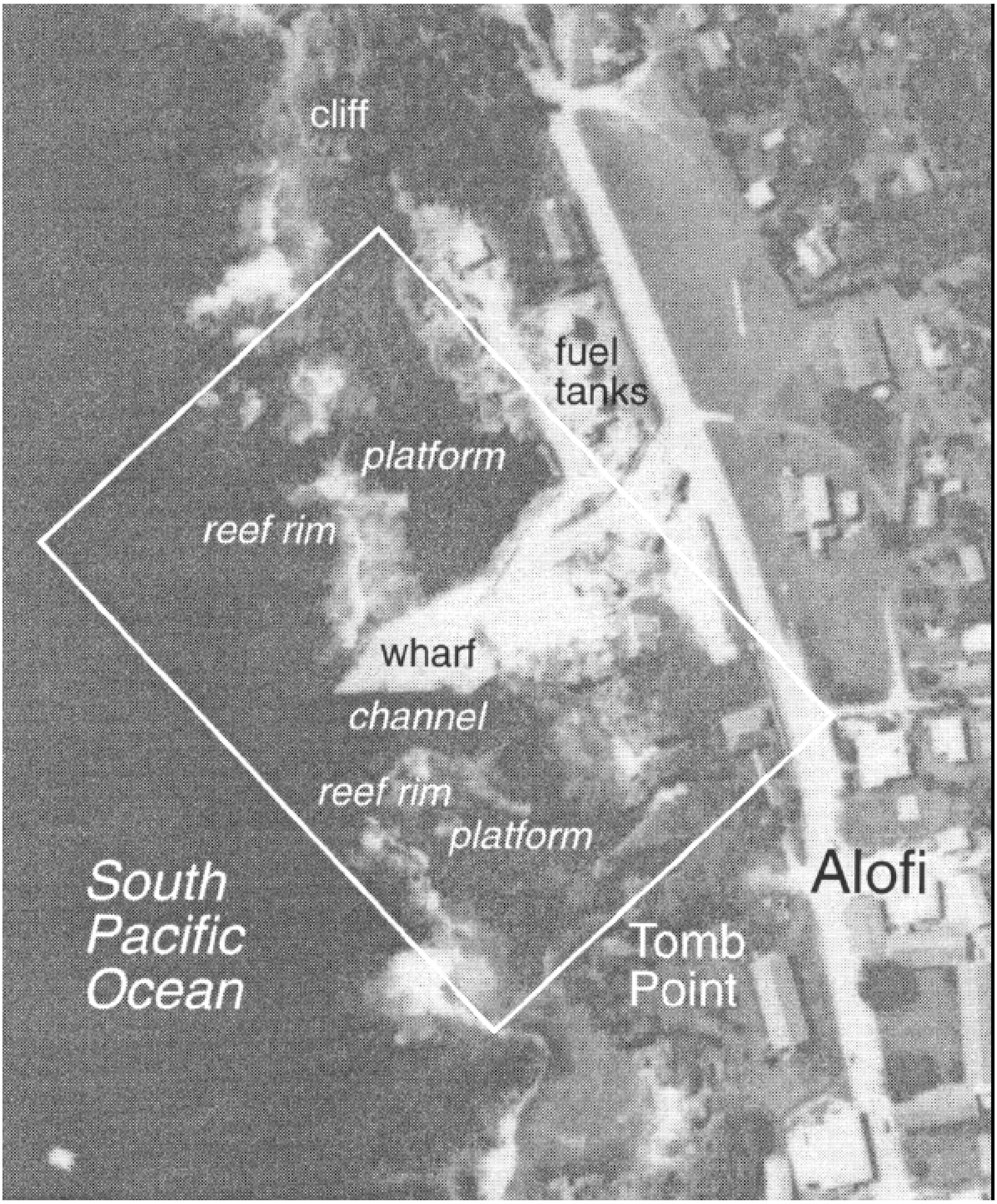

Figure 32. Detail of 1981 air photography showing Alofi Wharf and surroundings, including fuel tanks, wave-cut platform, and reef rim. Box outlines area shown in Figure 34.

Figure 33. Top*: Alofi Wharf from the fuel tanks.* Bottom*: Pocket beach at base of seawall north of Alofi Wharf. (DLF/ 10 Nov 1995).*

HMNZS Monowai soundings also show depths of 1.8 m (a presumed coral head) and 1.5 m (reef edge) less than 40 m southwest of the outer end of the wharf and depths of 0.5 m about 60 m west-southwest of the wharf. This indicates that the southern reef extends well seaward of the limit indicated in our surveys (Figure 34) and restricts access from that side, while also funnelling wave motion into the channel alongside the wharf. The reef rim south of the wharf rises to MWL; on the north side, it comes up to above 0.6 m elevation, comparable to the heights observed at Tuapa. A closed basin almost 1 m deep is present landward of the reef rim on the outer platform north of the wharf. Several large blocks are present on the inner platform east of this (Figure 33). On the southwest side of the wharf, the platform is cut by shallow channels oriented toward the east, parallel to shore and toward the wharf. These appear to function as conduits for water moving onto the reef and platform in wave-driven bores and returning alongside the wharf (Figure 34). A shallow cut extending the line of the channel at its headward end has a very smooth base, ramping up landward. This was apparently excavated in an effort to reduce oscillation in the basin alongside the launching ramp, but its form is such that it may enhance wave reflection at the head of the channel and aggravate motion alongside the wharf.

No sediment samples were taken at this site.

Site 4: Tamakautoga

This is a small, cliff-base, pocket beach on the southwest coast (Figure 6) behind a relatively wide platform and fringing reef (Figure 7). The beach occupies a V-shaped reentrant in the cliffs, which range from 8-15 m high, just north of the Tamakautoga Landing beach. The embayment at site 4 is less than 2 m wide at the head of the beach, 13 m at the berm (which is restricted to the southern half of the beach off the axial profile), and about 23 m across the base of the beach (Figures 7 and 35). Down the axial profile line (Figure 36), beach slope decreases from 10° at the top to as little as 2.3° on the lower beachface, increasing again to 35° over the basal step. The cliffs on either side are notched at the base (Figures 7, 24, 35) and a more-or-less flat-topped rock outcrop is exposed in the northern half of the lower beachface. A thin strip of sand extends along the base of the cliffs to the north for about 50 m (Figure 35).

Two samples were taken from the beach at Tamakautoga (Figure 36), sample 1 from the lower beachface at 0.32 m above MWL and sample 2 from higher on the beach at 0.78 m elevation.

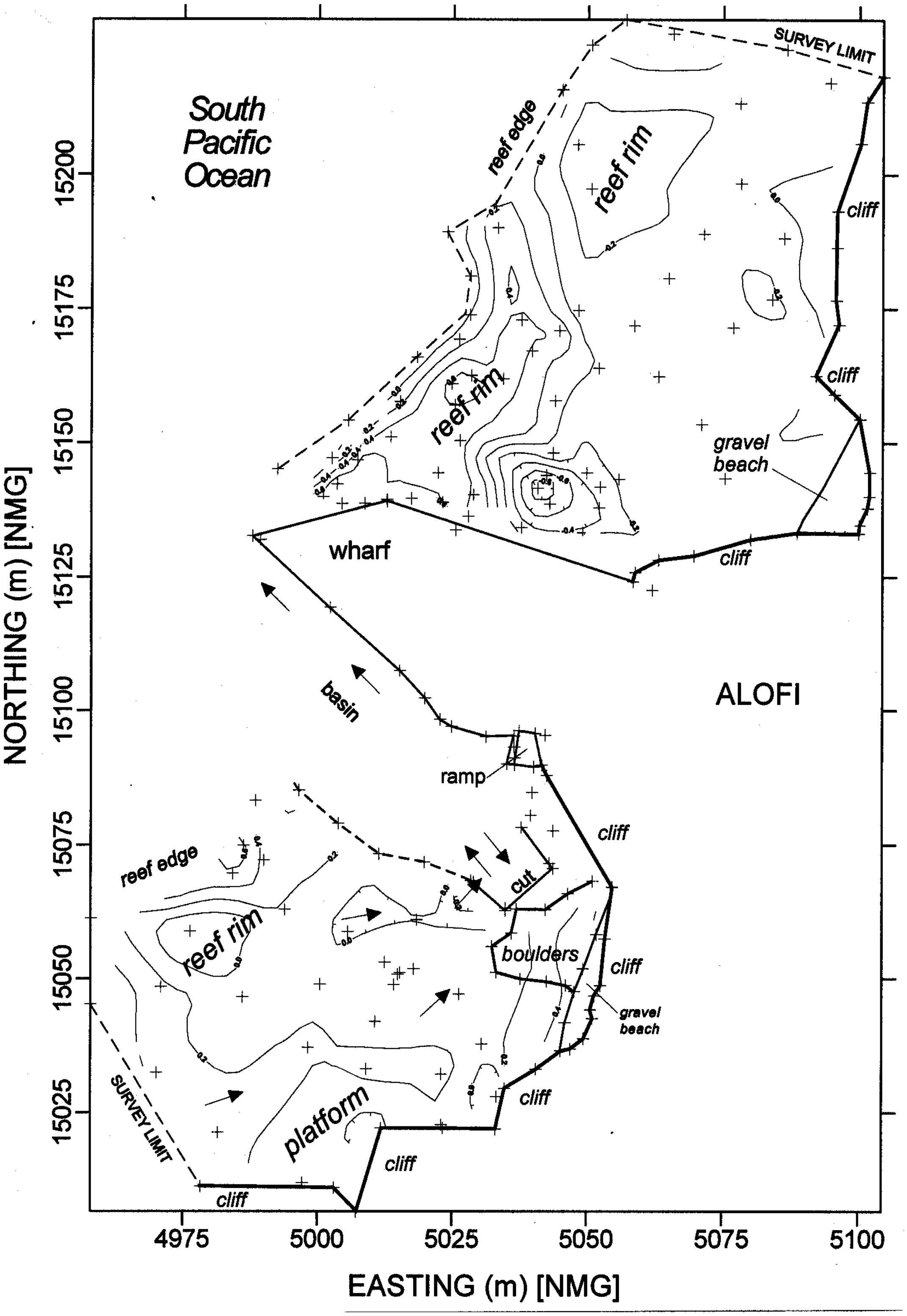

Figure 34. Plan of Alofi Wharf with platform and reef topography, from total-station survey, 9-10 November 1995. Arrows indicate typical circulation pattern over platform and along wharf face. Niue Map Grid.

Figure 35. Left*: Inner part of platform from top of cliff, Tamakautoga Beach (site 4).* Right*: Detail of sediment on beach berm at same site. NZ$2 coin (26 mm diameter) for scale. (DLF/6 Nov 1995).*

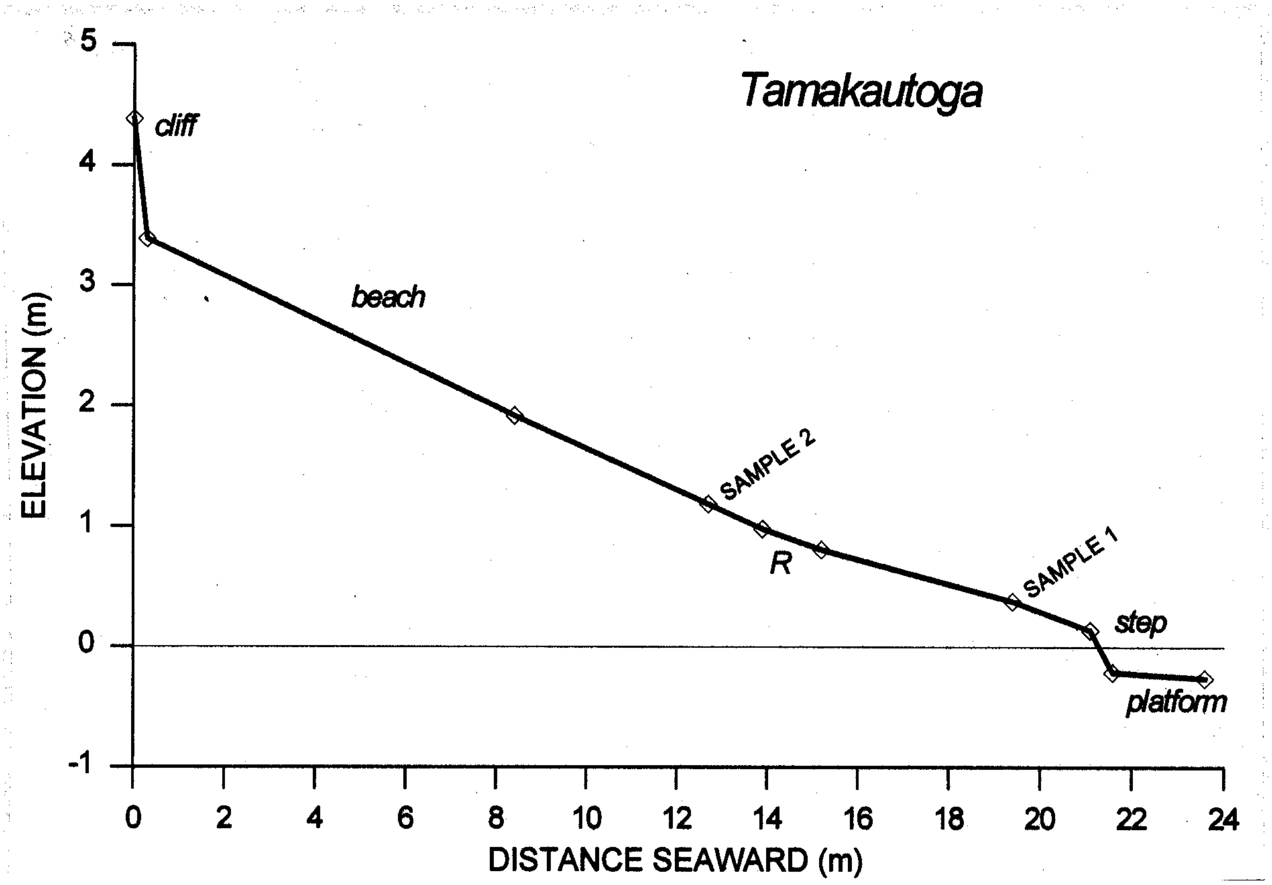

Figure 36. Surveyed profile of Tamakautoga Beach, 6 November 1995.

Sample 1 consists of well sorted coarse sand and granules (Figure 37) with D_{mean}= 1.59 mm (-0.67ϕ) and D_{mode}= 1.7 mm, sorting s_D= 0.37ϕ, skewness -0.2 and kurtosis 4.4. Sample 2, from higher on the beach, has a similar D_{mean}= 1.60 mm (-0.68ϕ) but poorer sorting s_D= 0.90ϕ, high negative skewness of -1.1 and kurtosis of 4.6 (Figure 37). Sediments on the berm at the south side of the beach against the cliff consist of fine pebbles of coral and algal origin (Figure 35, bottom).

In sample 1, the coarser than 1.4 mm modal fraction is dominated by abraded coral fragments, some highly polished. The 1.0-1.4 mm sand contains a small number (less than 3%) of partially abraded foraminifera (predominantly *Amphistegina lobifera* with one or two abraded *Baculogypsina sphaerulata* tests). *A. lobifera* constitute about 15% of the coarser than 0.7 mm fraction.

As implied by the high negative skewness, sample 2 contains a fine tail of medium sand consisting predominantly of rod-like spicules. The coarser than 0.5 mm sand contains a few small *A. lobifera* tests and these become abundant (more than 15%) in the coarser than 0.7 mm and coarser than 1.0 mm fractions. Rare specimens of *Textularia* sp. are also present in this sample (John Collen, pers. Comm., 4 April 1996).

Site 5: Avatele

The covehead beach at Avatele (Figures 6 and 38) is unique on the island. It is a coarse gravel beach (Figure 39), facing northwest, and partially protected by a barrier reef, cut by a reef channel that was enlarged by blasting in the 1980s. A concrete ramp has been constructed at the east end of the cove near the entrance channel (Figure 39). Low cliffs, representing part of a fragmentary terrace below the Alofi Terrace level, border the cove on the northeast side and somewhat higher cliffs form the boundary on the west (Figure 40). Behind the cove, the land slopes up at about 9° to the Alofi Terrace level (above 16 m) in the village of Avatele.

The barrier reef at Avatele is up to about 60 m wide, cut by the partly blasted access channel and by other, natural, reef-normal channels (Figure 40). West of the cove the reef merges with the coastal platform and fringing reef (Figure 38). The reef rim is relatively low, rising to about 0.2 m below MWL. The cove basin inside the reef is up to 2 m deep in front of the launching ramp and typically 1.5 m deep off the beach (Figure 40 and 41).

The beach at Avatele is the largest on Niue, about 80 m long and 30 m wide. The beach deposits grade from large boulders at the east end near the ramp (Figure 39) to coarse sand and fine gravel under the cliffs at the west end (Figures 40 and 42). Most of the beach is composed of pebble and cobble size material (Figures 42 and 43), generally finer on the lower beachface where sand occurs,and becoming coarser up the beachface toward the berm and crest (Figure 43). The beach slope increases from about 7° at the sand to sand-pebble transition on the lower beach to 10° on the upper beachface and 21° on the face of the berm (Figure 41). The berm elevation ranges from 1.1-1.5 m above MWL and the beach crest (where a distinct crest is present east of line 2 in Figure 40) from 1.6-1.8 m. Storm-ridge cobble gravel behind the crest is noticeably weathered in comparison to the fresh surfaces of the active beach sediment. Schofield (1959) mentioned the presence of “cemented beach conglomerate several feet thick ... in a sheltered bay at Avatele." While no trenching of the beach was attempted in this study, it is clear that the upper part of the gravel, at least, is uncemented and actively reworked on a regular basis. In the middle of the beach, the free-standing crest gives way to an upper slope that rises to almost 3 m. It is probable that runup during *Cyclone Ofa* extended to this level at least and refraction of southwesterly swell into the cove may maintain the berm.

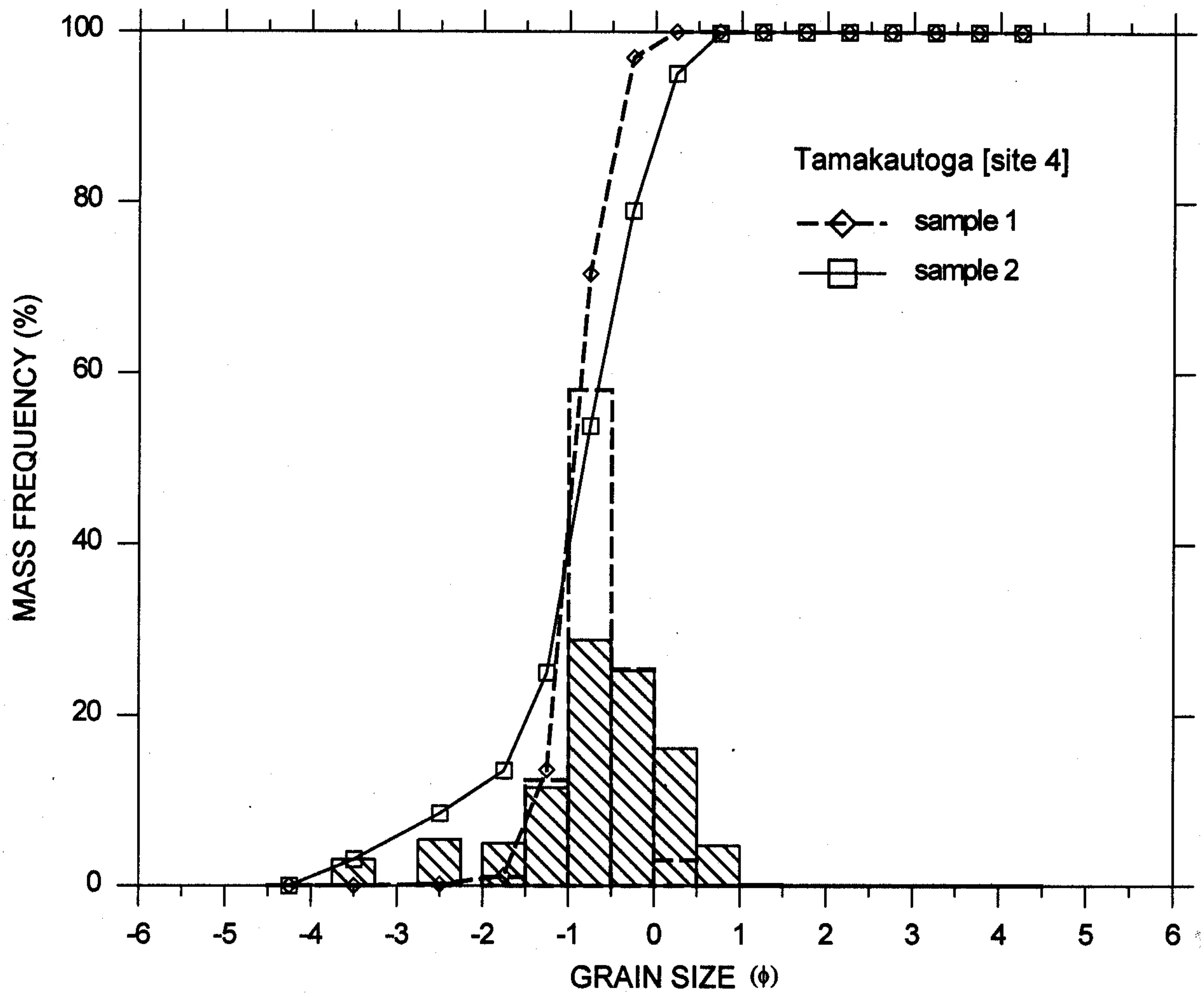

Figure 37. Grain-size distributions of samples 1 and 2 from Tamakautoga Beach.

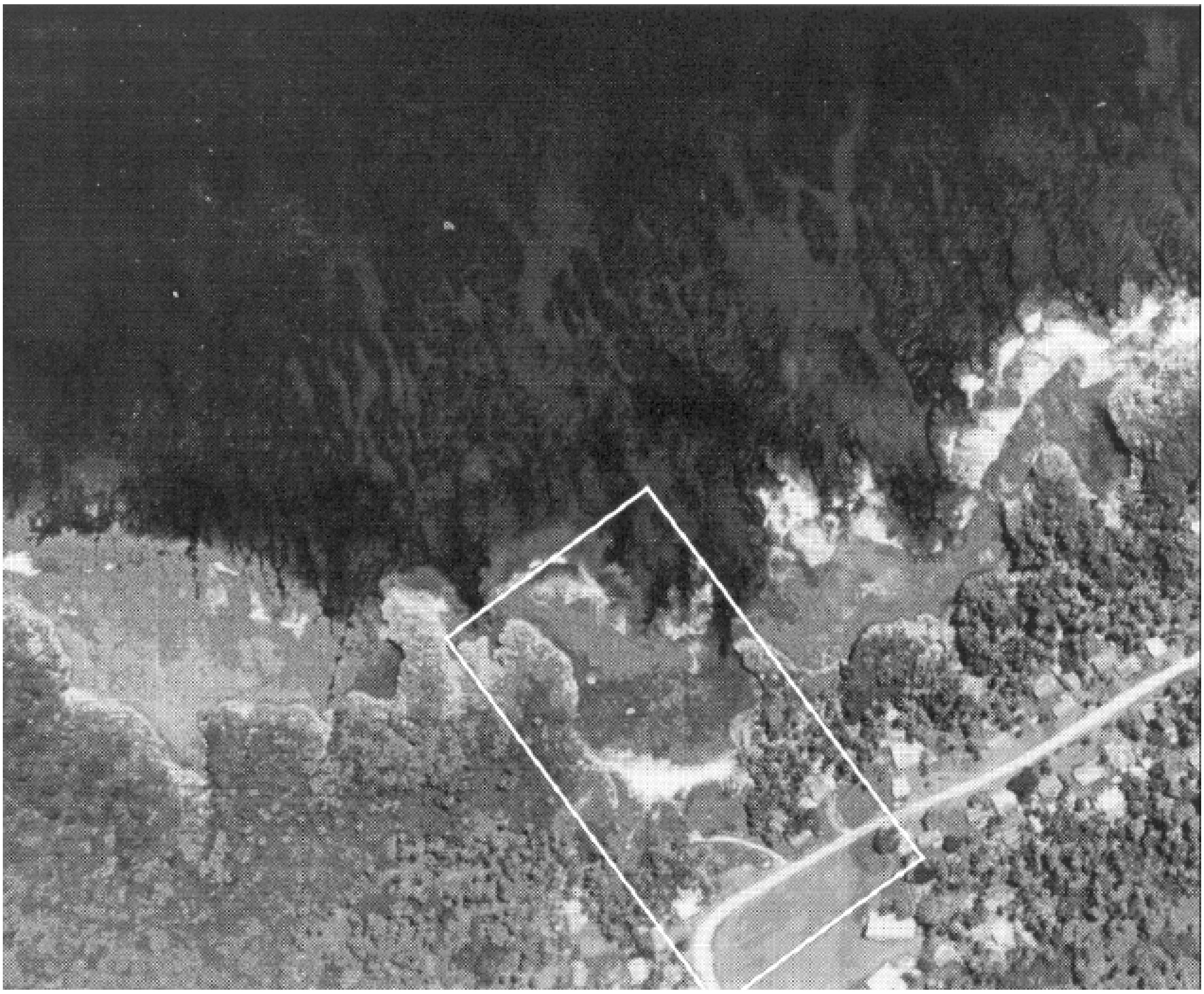

Figure 38. Part of 1981 air photograph showing Avatele Beach and vicinity before blasting and construction of boat-launching ramp. Note irregular reef edge and sand on shallow terrace outside reef. Box outlines area shown in Figure 40.

The sample and photo-sample locations at Avatele are indicated on the survey plan (Figure 40). Sample p19 is the lowest of the gravel samples, taken at an elevation of 0.2 m on the beachface below the berm on line 3. This sample is a very poorly sorted mixture of coarse sand to cobble gravel, with intermediate (B-axis) mean size B_{mean}= 8.2 mm and s_D= 1.8ϕ. Sample p20, from a swash lobe truncating the berm near line 1, is a relatively well sorted fine pebble gravel (Figure 43, bottom), with B_{mean}= 12 mm and s_D= 0.72ϕ. The remaining photo-samples are taken from line 3 in progression up the beach from the berm to the crest to the backshore storm ridge (Figures 40 and 41). Samples p16 and p17 from the berm and beach crest are very similar coarse-pebble gravels with B_{mean} values of 25 mm (s_D= 0.74ϕ) and 24 mm (s_D= 0.78ϕ), respectively. The weathered storm-ridge gravel of sample p18 (Figure 43, top) is a pebble-cobble mixture with B-axis mean size B_{mean}= 60 mm (-5.9ϕ) and the best sorting of all the gravel samples (s_D= 0.62ϕ), although this may reflect the small sample size.

Figure 39. Top*: Avatele Beach, looking west along crest from access road.* Bottom*: General view of cove and boat launching ramp at Avatele (DLF/ 8 Nov 1995)*

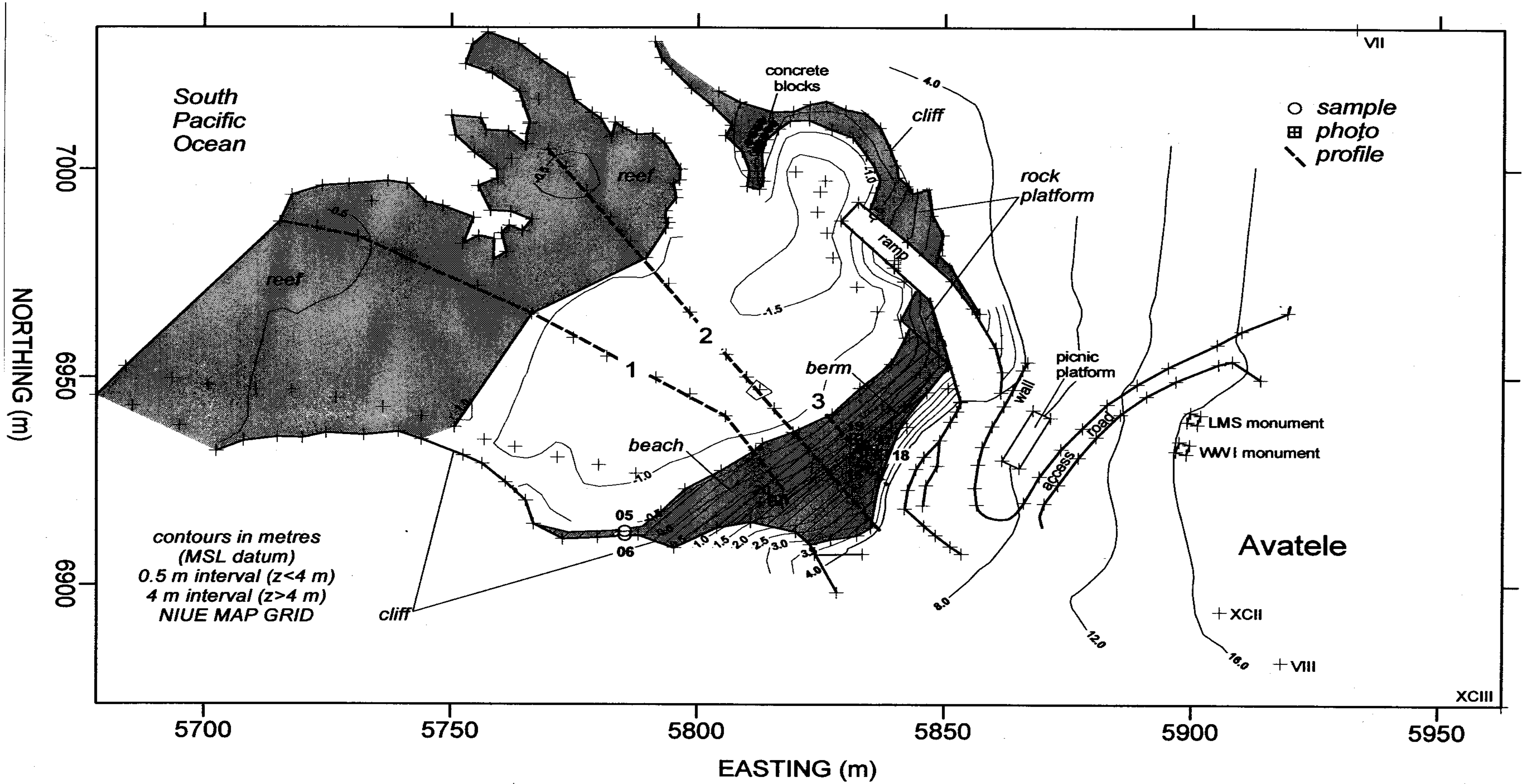

Figure 40. Total-station survey at Avatele, showing reef, basin, and beach morphology, backshore topography, and control points XCII, VII, and VIII, 8 November 1995. Also show locations of grab samples and sediment photos and profile lines 1 to 3. Niue Map Grid.

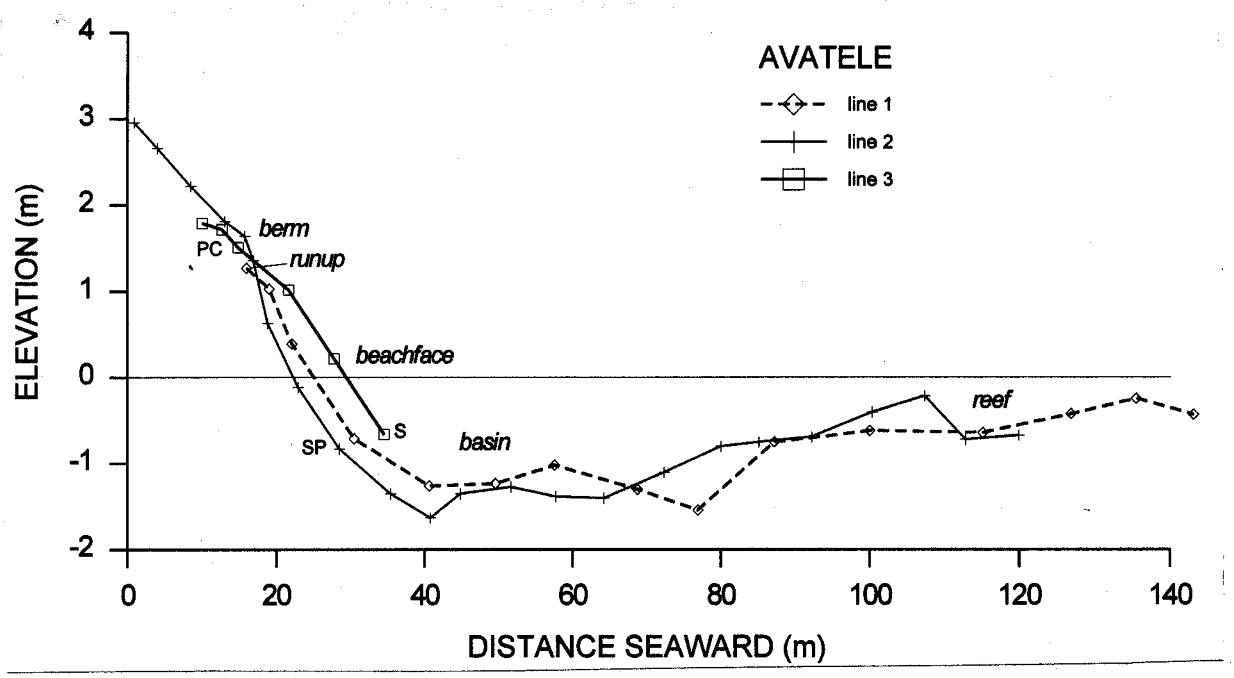

Figure 41. Surveyed profile across beach, cove basin, and barrier reef at Avatele, 8 November 1995 (see Figure 40 for locations).

Two samples of finer material were taken under the cliff at the west end of the beach (Figures 40 and 42). Sample 5, collected from a thin sandy beachface deposit, consists of coarse sand and granules with mean sieve size D_{mean}= 1.5 mm (-0.58ϕ), sorting s_D= 0.76ϕ, skewness of -0.7 and kurtosis 3.5 (Figure 44). Sample 6 was taken just 2 m from sample 5, from a low, notched berm at the base of the cliff (Figure 42, bottom). It is coarser, with D_{mean}= 2.7 mm (-1.4ϕ) and D_{mode}= 5.7 mm, poorly sorted (s_D= 1.1ϕ), has slightly negative skewness of -0.2 and relatively low kurtosis 2.2 (Figure 44).

In sample 5, the coarse modal size (more than 1.4 mm) contains no foraminfera and is made up entirely of coral, algal, and shell fragments, some of which may be reworked from older limestone. Very rare *Amphistegina lobifera* (less than1%) are found in the coarser than 1.0 mm coarser than 0.7 mm and coarser than 0.5 mm fractions and none in the finer components. One suspected specimen of *A. lessonii* and one relatively undamaged test of *Baculogypsina sphaerulata* are present in this sample.

Figure 42. Top*: Avatele Beach, looking east along beachface below berm. Rental car on access ramp in background.* Bottom*: Same as above, from a point further west along the beach below the cliff, at location of samples 5 and 6. (DLF/ 10 Nov 1995).*

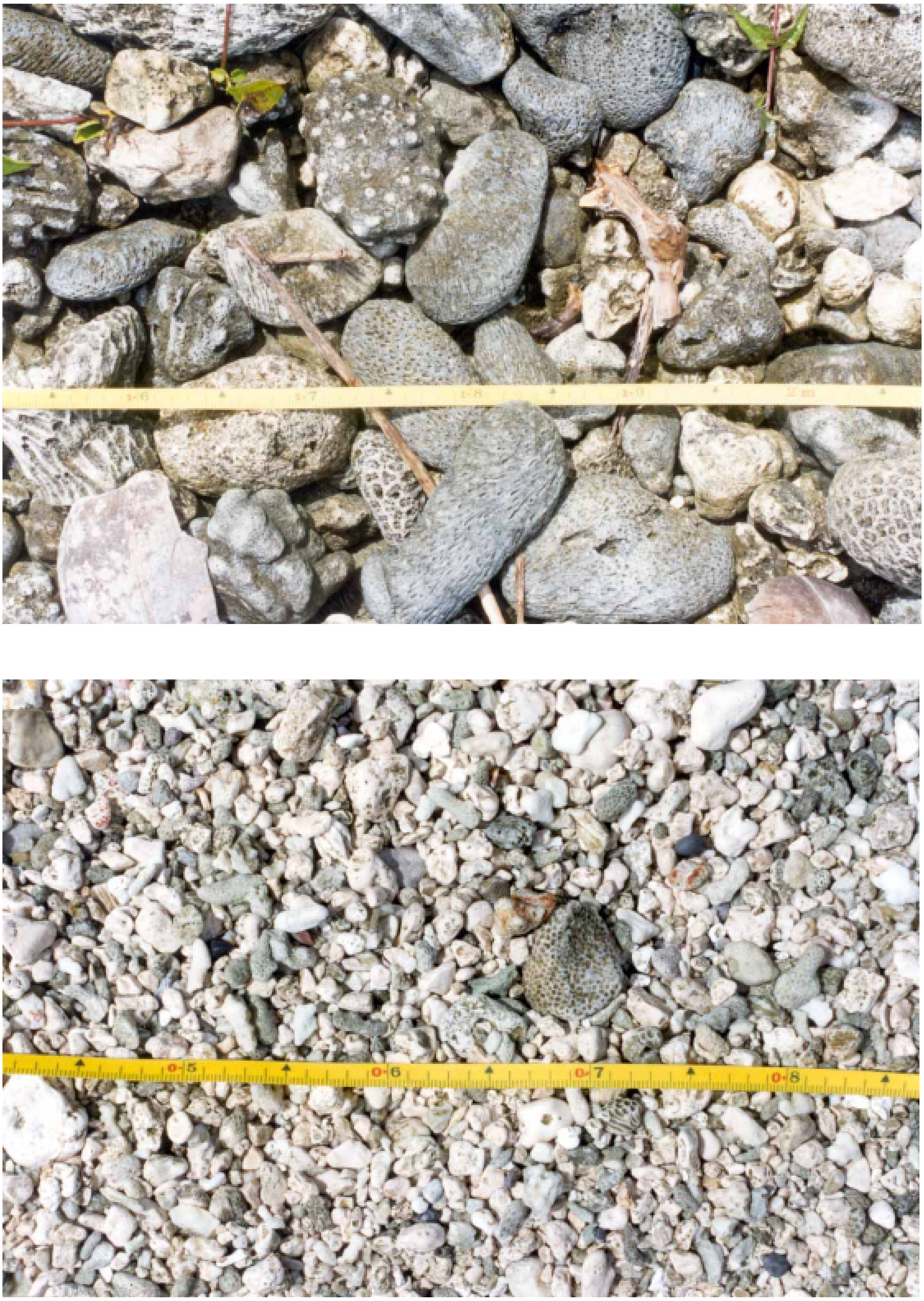

Figure 43. Top*: Sample p18, storm ridge, Avatele Beach.* Bottom*: Sample p20, beachface swash lobe, Avatele Beach. See Figure 40 for locations. Scale in metres with 2 mm graduations (DLF/ 10 Nov 1995).*

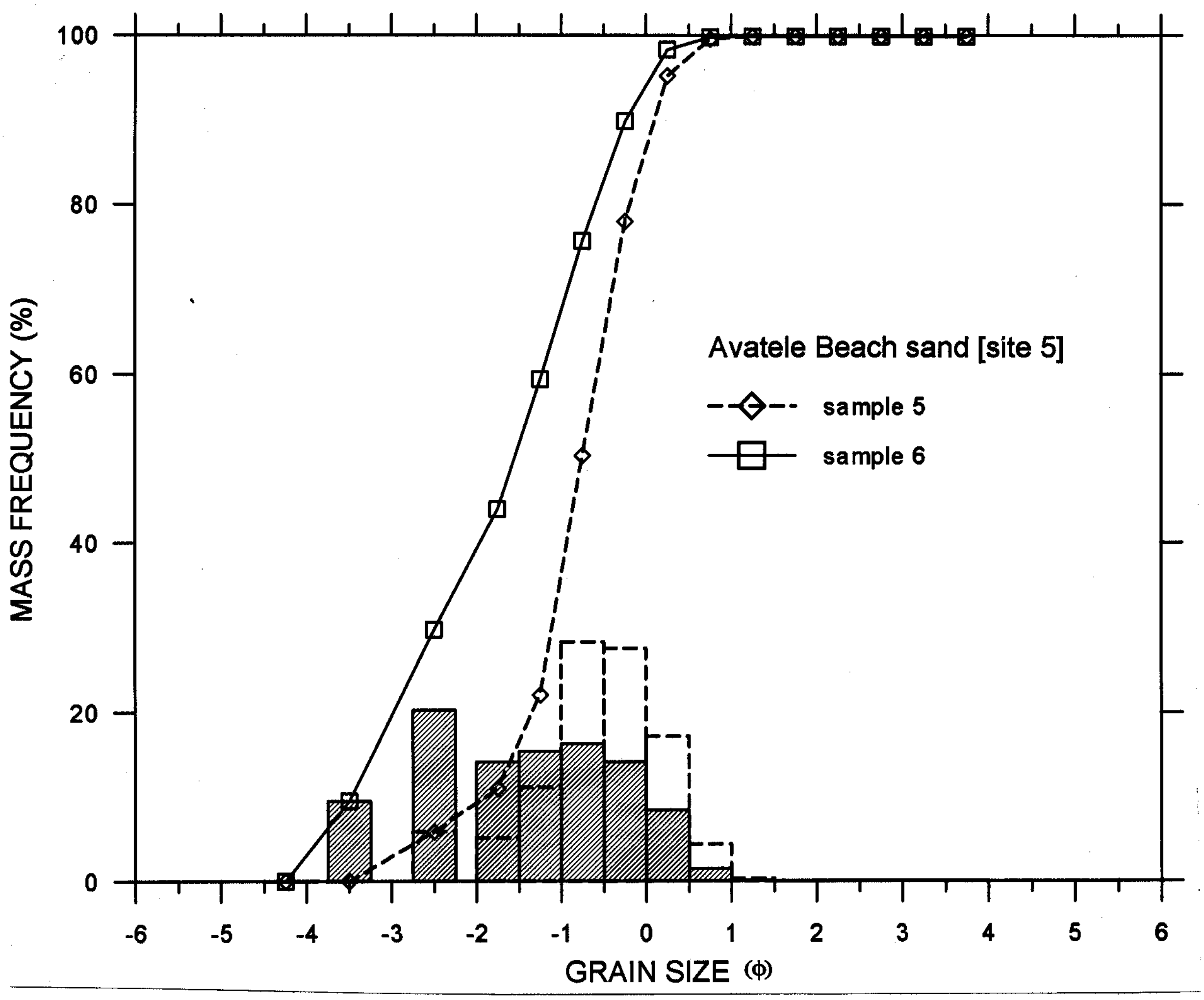

Figure 44. Grain-size distributions of sand samples (5 and 6) from Avatele Beach.

Sample 6 is also relatively barren of foraminifera. None are present in the coarser than 1.0 mm part of the sample. Very rare and severely abraded specimens of *Marginopora (Sorites?)* (single disc), *Amphistegina lobifera* (2 tests) and *Baculogypsina sphaerulata* (6 specimens) were found in the coarser than 0.7 mm fraction and no foraminifera in the finer sizes.

Site 6: Tauta

This is a very small, cliff-base, pocket beach on the east coast (Figure 6). It has a relatively wide platform and fringing reef (Figures 13 and 45; Forbes 1996). This beach was not surveyed because it was only accessible by wading around the headland from the cave access at the end of Liku Sea Track (Figure 13). The beach occupies a small reentrant in the cliff line and is backed by cliffs up to 18 m high. Two large boulders rest in the middle, one at mid-beach level and the other at the base of the beach (Figure 45, bottom; Figure 46, left). The inner part of the wave-cut platform in front of the beach is heavily dissected with potholes, extending from the beach to halfway across the platform (Figure 46). The sand on the beach is very thin and platform rock crops out on the north side (Figure 45, bottom). Wave-rippled sand occupies depressions on the inner platform in front of the beach but is largely absent from other parts of the platform (Figure 46).

Two samples were obtained here, sample 7 from a small patch of rippled sand on the inner platform and sample 8 from the middle beachface between the two boulders (Figure 46, left). Sample 7 consists of moderately sorted medium to coarse sand with D_{mean}= 0.46 mm (1.1ϕ) and s_D= 0.53ϕ, strong negative skewness of -1.2 and high kurtosis of 5.8 (Figure 47). Sample 8 is a poorly sorted coarse sand with D_{mean}= 0.90 mm (0.15ϕ) and D_{mode}= 0.6 mm, s_D= 0.97ϕ, skewness -1.0 and kurtosis 3.9.

In sample 7 from the inner platform, the fraction coarser than 1 mm contains a single 4 mm *Marginopora (*or *Sorites?)* disc and several irregular disc-like fragments. The coarser than 1 mm fraction contains numerous *Amphistegina lobifera* (23%), which are also present but less numerous in the coarser than 0.7 mm fraction (16%) and much less abundant in the coarser than 0.5 mm sand (6%). Very rare abraded *A. lobifera* occur in the coarser than 0.35 mm fraction and no forams are present in the finer sand. One specimen of the deeper water species *A. lessonii* was also found in this sample (John Collen, pers. comm., 4 April 1996).

In sample 8 from the beach, very few worn *Marginopora (Sorites?)* tests, ranging from 3.0 to 4.0 mm in diameter, are present in the coarser than 2.0 mm sieve fraction. The coarser than 1.4 mm fraction contains about 1% *Amphistegina lobifera* and several varieties of small gastropods. The coarser than 1.0 mm size has small concentrations of *A. lobifera* (5%) and abraded *Baculogypsina sphaerulata* (2%). Much larger concentrations of *A. lobifera* (16%) are found in the coarser than 0.7 mm fraction, while the modal size fraction coarser than 0.5 mm has 5% *A. lobifera,* slightly abraded.

Figure 45. Top*: North side Tauta Beach and overhanging cliff beyond.* Bottom*: Looking down into Tauta Beach embayment from top of cliff. (DLF/ 10 Nov 1995).*

Figure 46. Left*: Tauta Beach from top of cliff at head of embayment. Sample 7 from nearshore seaward and to right of block. Sample 8 from beachface on near side of block.* Right*: Detail of pits and channels on platform surface off south side of Tauta Beach (DLF/ 10 Nov 1995).*

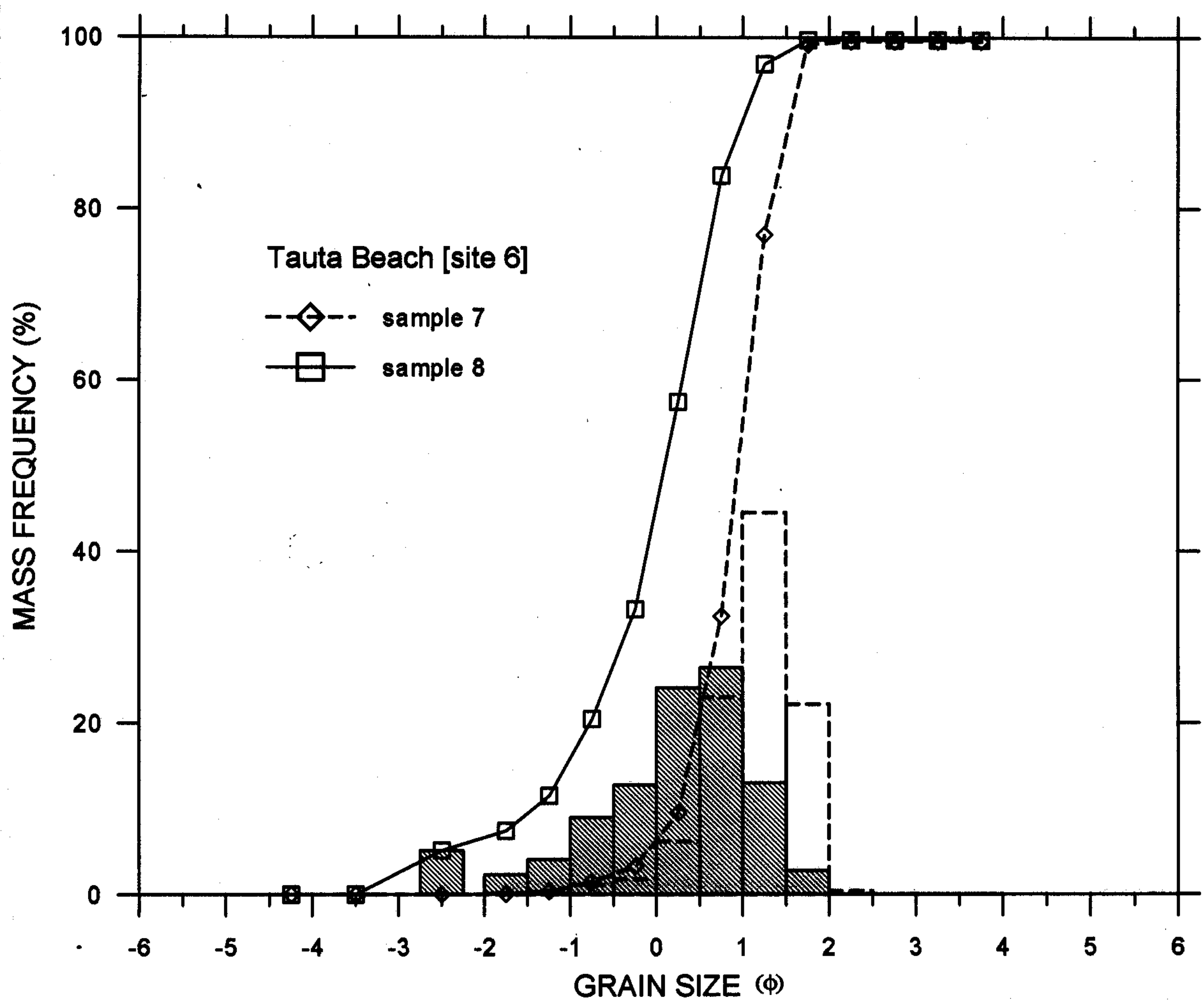

Figure 47. Grain-size distributions of samples 7 and 8 from Tauta Beach.

COASTAL MANAGEMENT ISSUES AND ENVIRONMENTAL HAZARDS

Sediment sources and sinks

Sand forming the small beaches of Niue is actively sourced on the fringing reef and platform. In particular, the *Baculogypsina sphaerulata* specimens in Hio Beach included living or recently-live individuals at the time of sampling. Specimens of this species from the other sites were relatively scarce and worn, implying a more distant source. Further sampling is warranted, but the present evidence suggests that the northwestern shore near Hio is a favourable location for sand production by this species. Large numbers of the shallow-water species *Amphistegina lobifera* were found in samples from several sites, suggesting a broader range and larger population. Other genera such as *Calcarina*, which has been reported from early Pleistocene sands of the relict Mutalau Lagoon (Schofield and Nelson, 1978) but not from modern sediments, may conceivably be reworked from older deposits, but further sampling is clearly needed.

Sand and gravel may be derived in small quantities from older limestone through platform and cliff erosion. This may be the source for some of the coarser gravel at Avatele. However, most of the sediment is believed to be formed on the modern reef and transported onshore by waves. Unfortunately, much of the sand being produced on the reef is probably lost to deeper water.

Extensive sands have been reported from approximately 36 m water depth off Avatele (Kevin Fawcett, pers. comm., 11 November 1995) and sand is present in approximately 12 m depth outside Avatele channel as well (Stan Vandersyp, pers. comm., 11 November 1995; Figure 38). Note that these reported depths correspond to the depths of the charted terraces off Alofi (Figure 8). There is some evidence, from local sources and the 1981 air photographs, to suggest that blasting of the channel at Avatele in the 1980s, construction of the access road and boat ramp across the east end of the beach, and storm wave action (particularly during *Cyclone Ofa* in 1990) may have removed some sand that used to be present in the cove. On the other hand, Schofield's (1959) reference to cemented conglomerate and the weathered nature of the older storm-ridge gravels suggests that gravel has been a significant component of this beach for a long time.

Sand is also present on the submarine terraces off Alofi (Brendon Pasisi, pers. comm., 11 November 1995). This is corroborated by observations of Agassiz (1903), who noted that "we anchored off Alofi ... in 24 fathoms (approximately 44 m water depth), where an extensive flat of white sand makes out from the shore reef platform." It is clear that a large proportion of the sand produced around the coast of Niue is trapped on terraces outside the reef or else lost to deeper water. This makes it imperative to discourage removal of any sand or gravel from beaches on the island if the limited beach resources are to be conserved and encouraged to grow. With careful management and good luck (limited cyclone activity), some beaches on the island may gradually gain sand over time.

Reef blasting and coastal access

Reef blasting has been carried out on a small scale at a number of sites around the coast of Niue. One objective of the present study was to assess the level of this activity and its probable consequences, in order to determine the advisability of this practice. Blasting has been carried out to widen and expand access channels to boat ramps at Avatele and Namukulu (Honourable Terry Coe, pers. comm., 6 November 1995), to create swimming holes and/or improve canoe access (Sisilia Talagi and Molesi Tamate, pers. comm., 6 November 1995) at Tamakautoga Landing (Figure 48) and Vaitafe (Figure 15), and to deepen the ship channel alongside the wharf in Alofi (Honourable Terry Coe, pers. comm., 6 November 1995; Kevin Fawcett, pers. comm., 11 November 1995; Anonymous, 1995). Each of these classes of activity and each site needs to be treated individually.

As a general rule, the blasting carried out to improve canoe access or create swimming holes appears to be fairly ineffectual and perhaps damaging. The two examples observed (Figures 15 and 48) showed evidence of infilling by sand. At Vaitafe, it appeared that the blasted material had not been fully removed, so that this blasting had simply broken up and loosened material on the inner reef flat. It is arguable that this could have a beneficial effect in encouraging the breakdown of platform rock to sand and providing a receptacle for sand accumulation. On the whole, though, the benefits hardly justify the effort. The prevalence of natural depressions on the wave-cut platform suggests that creation of small enclosed basins by blasting may have little detrimental effect at many sites. However, removal of this material may weaken the platform structure, trap sand that might otherwise accumulate on the beach, and increase wave action over the platform under storm conditions.

The ecological status of the reef and platform at each site should be assessed before blasting for swimming holes or canoe landings is permitted. Blasting should not result in creation of a continuous passage across the reef through which sand could escape and wave energy enter. Nor should blasting be carried out in front of existing beaches because it may contribute to loss of sand from the beach to the platform. Blasting below cliffs may increase the risk of cliff failure or enhance wave overtopping during storms. In general, this practice should be discouraged unless there are clear benefits to be gained by the community as a whole and potential environmental impacts have been assessed.

Boat access channels have been blasted at Avatele and Namukulu. Though perhaps necessary at Avatele, where even now the shallow lip at the inner end of the channel can create problems for outboard motors at low tide (Stan Vandersyp, pers. comm., 11 November 1995), the expanded channel may have played a role in removal of sand from the cove. It has been suggested that blasting damage to the reef at Avatele was a short-term impact because coral has recolonised the sides of the blasted channel in recent years (Honourable Terry Coe, pers. comm., 6 November 1995). As a general principle, however, extreme caution should be exercised before manipulating the shape of any small boat harbour such as Avatele. In other jurisdictions, it is common practice to carry out numerical or physical modelling to assess the effects of changes in harbour shape on the circulation and oscillation characteristics of the basin. Furthermore, it is probably desirable to retain a lip on the channel if maintenance and possible enhancement of Avatele Beach are to be achieved. The unique status of Avatele as the only partially protected cove on the island is a reason to be very cautious about making changes and an argument for careful management of the existing site.

Figure 48. Tamakautoga Landing beach from top of steps, with Molese Tamate in foreground. Note blasted pool at base of overhanding cliff. (DLF/ 6 Nov 1995).

At Namukulu, the landing site is more exposed and the basin much smaller. Again, it is difficult to predict the impact of changes in the channel shape on navigability and wave motion in the basin without more detailed study. The best advice is to exercise caution and not to do further blasting unless absolutely necessary. If any changes are contemplated at Namukulu, the effects on circulation and oscillation at the boat ramp should be considered, and preferably modelled, before proceeding.

Port infrastructure at Alofi

The situation at Alofi is a special case. Damage sustained to the wharf foundation by recent blasting was unfortunate. The difficulty in this case is that, without geotechnical borehole data to assess the competence of the rock underlying the wharf, it is impossible to predict the effects of blasting, or to determine the long-term stability of the wharf structure. The submerged terraces seaward of Alofi (Figure 8) and karst depressions on the modern shore platform, on which the wharf sits, indicate that solution processes have operated to depths below present sea level. This means that large cavities could exist below the wharf or other proposed blasting or construction sites. If equipment is available or can be obtained on the island, it would be advisable to carry out some drilling to determine the nature of the underlying rock.

With respect to circulation and harbour oscillation, which have caused some concern at the wharf, it may be possible to improve the situation. The present bathymetry may favour wave reflection from the head of the basin and aggravate the motion alongside the wharf. One option might be to remove part of the reef across from the wharf to expand the basin. This should not be undertaken without proper engineering evaluation and, preferably, some modelling effort. Addition of coarse rubble at the head of the basin is another option, which might help by dissipating wave energy and reducing reflection. However, its effect on swell waves might be limited and it might be difficult to prevent material from shifting to deeper water alongside the wharf.

The other factor causing difficulty at this site is the strong seaward current experienced at times along the face of the wharf (Brendon Pasisi, pers. comm., 11 November 1995). This is probably a result of wave setup over the reef to the south, with water draining back to sea via channels on the platform that direct the flow towards and along the wharf (Figure 34). The proposal to construct a low dyke across the platform to deflect this return flow has merit. The alignment and exact placement of such a structure will need to be chosen carefully and SOPAC could examine this proposal further if requested.

Tropical storm hazards

Waves striking the coast of Niue during *Cyclone Ofa* in February 1990 caused massive damage. A compilation of damaged sites (Figure 49) shows that coastal alignment was a major factor, with all the major damage sustained on shores facing northwest. Reef width appears to have been less relevant, since severe damage occurred at sites with wide reefs and platforms (for example Hio Beach and Hikutavake) and sites with no platform at all (for example Niue Hotel; Figure 50).

A partial list of coastal damage experienced during the passage of *Cyclone Ofa* includes the following major items (Figure 49):

- destruction of the church at Hikutavake: structure near cliff edge at approximately 25 m above sea level;
- partial collapse of roadway near Limu Sea Track, elevation approximately 25 m at head of chasm;
- severe damage to picnic tables and paths at Limu in protected rocky embayments to more than 3 m above sea level (Figure 12);
- destruction of Hio Sea Track concrete steps removed to more than 17 m above sea level (Figure 28);
- destruction of Namukulu Sea Track, lower part of concrete roadway removed;
- severe damage to wharf and access at Alofi, access road washed away;
- damage to access at Opaahi Landing; concrete structures damaged (Figure 25);
- severe damage to 50% of hospital; structure near cliff edge at approximately 18 m above sea level*)*;
- extreme damage at Niue Hotel; buildings defaced and boulders deposited approximately 18 m above sea level (Figures 51 and 52);
- partial destruction of access road at Avatele, concrete roadway removed to approximately 3 m elevation (Figure 40).

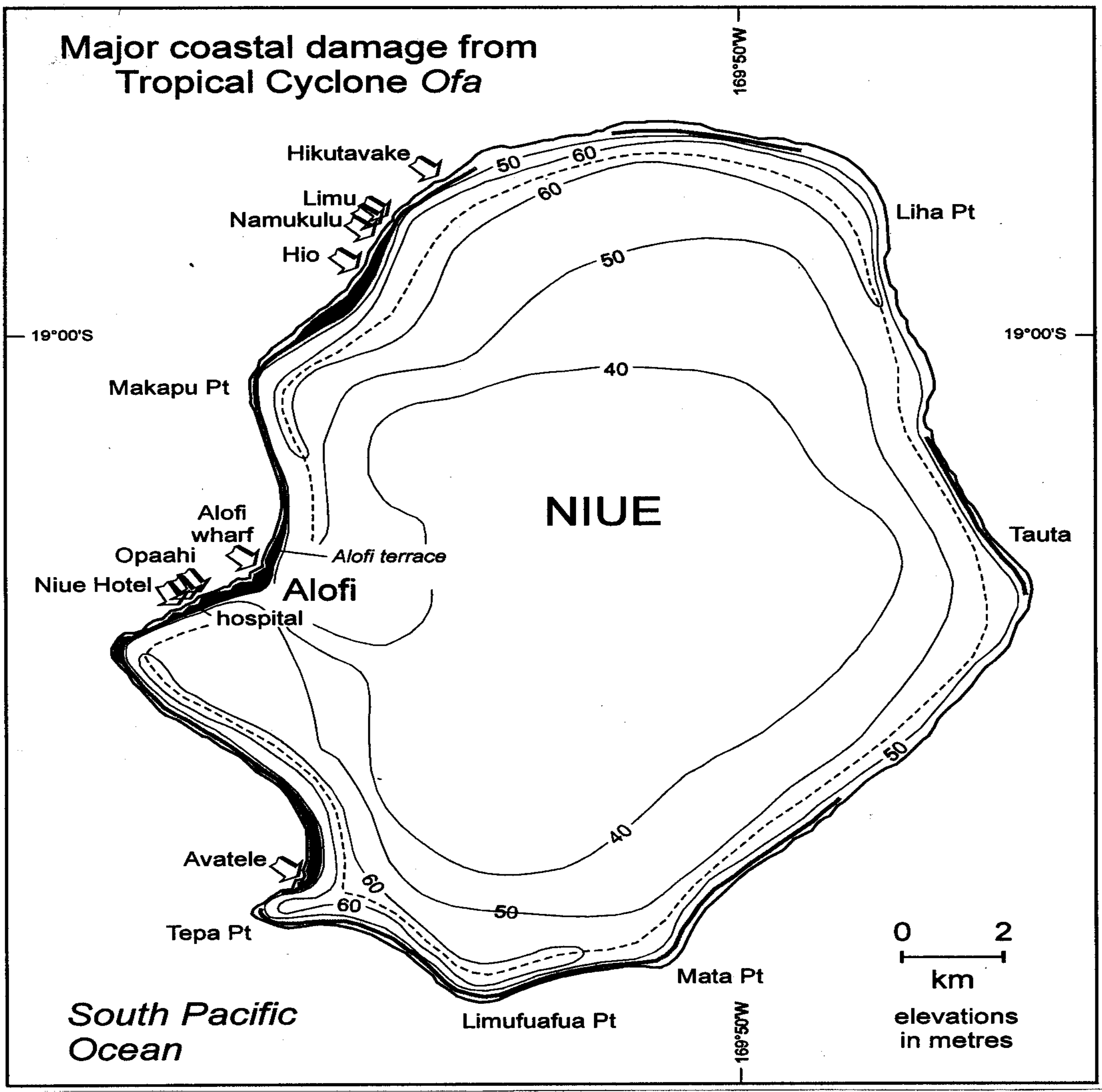

Figure 49. Sites of major coastal damage sustained during Cyclone Ofa, February 1990.

The extent of damage is well illustrated in a documentary video on the storm (Niue Broadcasting Commission, 1990). This shows vegetation damaged by salt spray to a considerable distance inland on the upper terrace. It shows 13-14 second waves, 6-8 m high, breaking over the wharf in the early hours of Sunday 4 February and again at first light. It shows a wave breaking over the roof of the hospital, dousing the video camera. It shows efforts to recover personal items from a cliff-top house demolished by a wave. It shows waves breaking over the cliff top at the Niue Hotel.

The hospital was evacuated by noon on Sunday 4 February. By the following morning the wharf access road at Alofi had been completely washed away and the crane (Figure 17) had been knocked down or carried away, only the main decking survived, having been only recently reconstructed. At the hotel site, the video shows progressive accumulation of coarse gravel and boulders across the lawn, culminating in the deposition of a 2-3 m boulder in the hotel bar, about 100 m back from the cliff top and approximately 18 m above sea level (Figures 51 and 52). The north facade of the main 2-storey bedroom wing was severely damaged; the lawn was quarried to a depth of more than 1 m at the seaward end of the swimming pool; and the pool was half-filled with gravel. The severity of damage at the hotel may be related to the virtual absence of a

Figure 50. Narrow platform, notched cliff, and ramping backshore rock face, partly stripped of vegetation by wave runup during Cyclone Ofa, south side of Niue Hotel, Alofi South (DLF/ 5 Nov 1995).

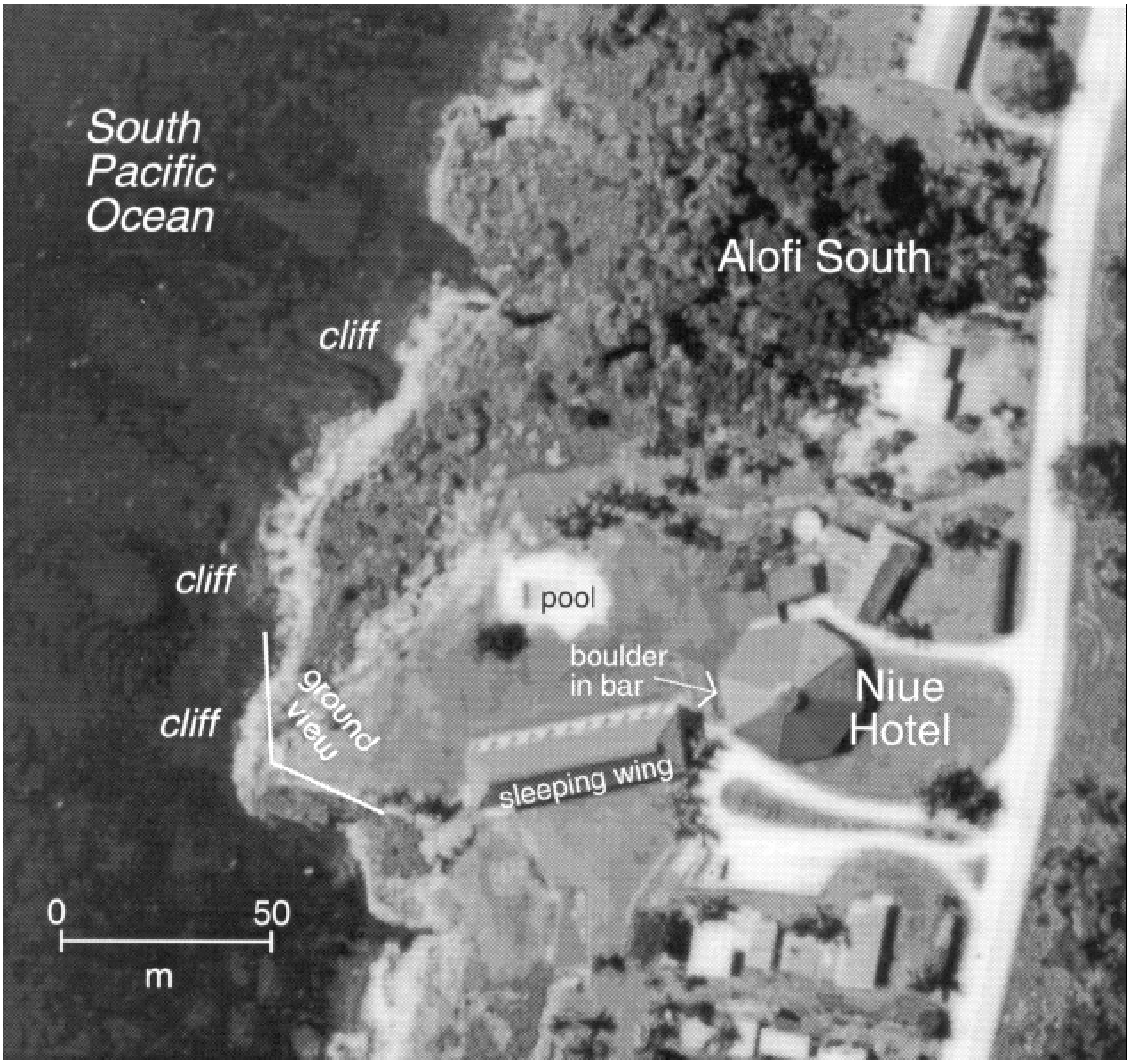

Figure 51. Detail of 1981 air photograph showing Niue Hotel.

modern platform and reef in this area (Figure 4), allowing waves to break directly against the cliff base. The ramping morphology of the cliff to the south may also have contributed to the runup. Five years after the storm, bare rock on the lower cliff face (Figure 50) and a distinct trim line in the vegetation on top of the terrace (Figure 52) attest to the long-term effects of this storm.

These observations demonstrate a significant risk of severe damage to any structures located along the outer margin of the Alofi Terrace as well as to all the major ocean access facilities (Namukulu, Alofi, and Avatele).

Figure 52. Composite panaroma showing cliff and site of Niue Hotel. Note bedroom wing at extreme right, severely damaged during Cyclone Ofa, lawn that was covered with coarse gravel, and main building with bar that was damaged by a very large boulder, on slight topographic rise in distance. (DLF/ 6 Nov 1995).

Submarine slope hazards and stability of the Alofi Terrace

Some concern has been raised about the long-term stability of the Alofi Terrace, on which a large concentration of the population resides and about 70% of the private dwellings are located (Niue Statistics/Immigration Unit, 1991). In the absence of hard data, this hazard is difficult to evaluate, but the following background and comments may be helpful.

In deciphering the form of the underlying volcanic core of the island, Schofield (1959, pp. 18-19) suggested that [submarine] landslides "almost certainly have removed large areas of the western slopes of the Niue substructure to produce the present unusual shape of the coast" and he interpreted chasms in the Alofi Terrace as "solution channels along fault zones caused during slumping of the underlying volcano." This implies involvement of the carbonate sedimentary cover, indicating that the slope failure occurred long after cessation of volcanic activity. Hill (1983) also suggested that the eccentric location of the volcanic core beneath Niue implies partial removal by landslides, primarily in the south and west. This is consistent with the steep submarine slopes off the southern coast and with the coastal embayments of Avatele Bight in the south and Alofi Bight in the west (Figure 3). The bathymetry of the submarine cone supporting Niue suggests a number of candidate areas for past slope failure (Figure 3).

While there is abundant evidence for submarine slope failures on relatively young volcanic islands (for example Gillot et al., 1994; Moore et al., 1994), new evidence is accumulating to show that large-scale slope failure is common on older guyots and atolls, where the post-volcanic carbonate caps are also involved (Keating, 1987, in press). This implies that large-scale submarine landslides probably have occurred on the slopes surrounding Niue. Acoustic (sidescan sonar and/or multibeam bathymetry) surveys would provide a basis for assessing the history of these processes. It is possible that a future failure could cause devastating tsunami runup on Niue. It is also possible that movement could occur on the Alofi Terrace. The probability of such events on a human timescale is extremely low, however, and there is presently no reasonable way to guard against them.

Overhanging cliffs defining the outer limit of the Alofi Terrace are another hazard, although there seems to be little concern about cliff fall in the community. Fractures were observed at a number of places, such as Anaana, Opaahi, and Hio Beach, and these represent lines of potential failure and rock fall. Large blocks resting at the base of cliffs or beneath overhangs, as at Amanau Reef (Figure 19), Vaitafe (Figure 15), and Tauta (Figure 45) attest to rockfall events in the past.

Wholesale removal of parts of the outer terrace back to a line of fracture, as at Hio Beach and other sites, shows that wave quarrying and cliff erosion are ongoing processes, characterised both by slow abrasion and solution of the cliff base notch and by episodic collapse of large blocks.

CONCLUSIONS AND RECOMMENDATIONS

Concluding discussion

Although coastal damage sustained during *Cyclone Ofa* was concentrated along shores facing northwest, consistent with heavy seas in the trailing westerlies behind the storm, there is a potential for damage of equivalent severity on other parts of the coast if comparable storms approach the island on different tracks. Potentially vulnerable infrastructure includes the fuel storage tanks in Alofi and a number of tourist facilities, other businesses, and homes located on the seaward side of the road along the entire west coast from Avatele to Hikutavake (Figure 49). Although tourist accommodation is obviously more desirable with an ocean view, the risk of storm-wave damage should be factored into the investment decision. Other major facilities such as the hospital would be better located in a less vulnerable location. The fuel storage tanks are cause for particular concern because of the risk of rupture in their present location. Relocation of these tanks should be a matter of priority.

Karst (solution) caverns are intersected by the present coast and erosion platform. The existence of older shore terraces at around 12 m and 36 m below present sea level (Figure 8) implies that cavities may exist down to those depths below the shore platform. This should be considered in any undertakings such as wharf construction or reef blasting.

Wave runup and nearshore circulation are strongly affected by reef, platform, and channel morphology. Therefore, any modification of the platform by blasting or installation of structures should be evaluated for its probable effect on oscillation (affecting boat launching or ship handling alongside), runup, and possible beach erosion.
Beach sands are extremely limited on Niue, although ongoing production is demonstrated by sand-producing foraminifera at sites along the west coast and possibly elsewhere. Other sand and gravel sources include corals, algae, molluscs, and other organisms from the reef rim and

platform, as well as ongoing wave erosion of the limestone cliffs.

The foregoing results point to the need for an integrated coastal management strategy that addresses all aspects of coastal development, resources, and hazards. Issues to be considered include potential pollution (for example from septic fields on the Alofi Terrace), the health of reef platform ecosystems, setback requirements for new development to reduce the risk of storm-wave damage, conservation of beach sands and other scenic attractions, changes in shore-zone circulation and wave runup that might result from reef blasting, and a number of other items.

In this connection, the Niue Government's initiative in moving toward a comprehensive coastal management program is encouraging. Issues related to geological conditions, physical processes in the coastal zone, and coastal storm hazards should not be overlooked in this process. An integrated and effective coastal management strategy requires a holistic approach to coastal systems, including the physical environment, non-living and living resources, human uses, education, and an appropriate regulatory framework.

In a recent useful assessment of integrated coastal management needs in Niue, Cornforth (1994, p. 4) recommended identification of the coastal zone as comprising "all that land and sea between the 12 mile limit and the top of the lower coastal terrace;" further that "the existing definitions of 'foreshore' and 'coastal zone' [be replaced] with more appropriate ones - perhaps restricting 'foreshore' to the top of the coastal cliff, and widening 'coastal zone' to include all the lower terrace," the latter quote referring to a proposed revision of the Conservation Bill. While these are among a large number of excellent recommendations in Cornforth's report, there is a potential for confusion when a technical term such as 'foreshore' is adopted in legal language with a non-standard definition. The standard usage of 'foreshore' in coastal engineering and geology refers to the area between high and low tides and this definition is widely adopted in legal documents as well. The intent of the recommendation, to provide for management of the entire range of active shore processes and human interactions from the reef edge to the top of the cliff, could be achieved by adopting a less specific term such as 'shore zone' with appropriate definitions. Ambiguous phrases such as "all of the lower terrace" should also be discouraged. Instead, the upper limit of the 'coastal zone' should be defined in terms of elevation, setback, or a designated line on the map. This may well correspond in practice to the landward limit of the so-called "lower" or Alofi Terrace (in fact the middle terrace).

Adoption of a formal environmental impact assessment (EIA) process was recommended by Cornforth (1994, p. 5) "for any development proposal ... likely to result in:

- long-term harm to, or unacceptable depletion of, living marine resources,
- unsustainable or hazardous development of the marine environment,
- increased sedimentation on the reef flat,
- increased land-based pollution of the marine environment,
- undesirable ... conflict between uses and users of (coastal) resources,
- unsustainable development in areas likely to be hazardous during major cyclones ...,
- development ... (detracting) from the tourism potential of the coastal zone."

This list encompasses most of the major concerns identified in this report. The need to identify a coastal hazard zone along the cliff edge is also strongly endorsed by the present study.

Recommendations

Geological and engineering issues

- To conserve limited coastal sediment resources, removal of sand or gravel from beaches and reef platforms should be prohibited. Measures should also be taken to limit changes that may promote natural seaward removal of sand over the reef edge to deeper water.

- Reef blasting should be discouraged unless clear benefit and negligible environmental impact can be established. Blasting should not be permitted if it will result in creation of a new passage across the reef, through which sand could escape and wave energy enter. Blasting should not be carried out in front of existing beaches or below developed cliffs. Environmental assessment and permitting requirements for blasting should also consider ecological impacts and disposition of broken material.

- Any modification or development of boat launching or harbour facilities at Namukulu, Alofi, or Avatele, whether by blasting, excavation, or construction, should be assessed for potential changes in harbour circulation and agitation under swell and storm conditions (including vulnerability and/or potential enhancement of wave run-up during cyclones).

- Seaward currents along the face of the wharf at Alofi can probably be controlled successfully, without adverse impact, by construction of a low diagonal dyke on the reef platform to the south.

- No further blasting should be undertaken in the wharf area without a proper assessment of foundation conditions in the underlying rock. Cave-forming solution processes formerly operated below present sea level, as demonstrated by the presence of submerged shore terraces and unroofed cavities in the modern shore platform. This hazard should be recognized in any further development on the platform, such as the proposed small boat harbour, or wharf extension.

- The design wave height for a breakwater on the west side of Niue is likely to be about 18 m, based on the computed H_{max} for *Cyclone Ofa*. This may limit the viability of a small-craft harbour. Efficient facilities for cargo handling and small-craft haul-out may be a more viable option.

- The fuel storage tanks above the wharf in Alofi are potentially vulnerable to storm-wave or tsunami damage and should be relocated to higher ground.

- High porosity in the underlying limestone implies a potential for reef contamination from septic fields on the Alofi Terrace. On the other hand, the narrow width and open-ocean exposure of the reef platform enable high rates of mixing and contaminant removal. An appropriate study of nutrient conditions on the platform may be desirable before embarking on costly modification of existing septic systems.

Coastal management and zoning issues

- Damage sustained during *Cyclone Ofa* and earlier storms in 1959 and 1960, among others, demonstrates the need for setback from the cliff edge on the Alofi Terrace. A coastal hazard zone should be identified, with appropriate restrictions on the nature of development within it.

- Pending delineation of such a hazard zone, any new infrastructure projects, such as schools, churches, hospitals, offices, fuel distribution facilities or industrial structures, except for port facilities, should probably be located on the landward side of the coastal road between Hikutavake and Alofi South. A similar restriction may be appropriate along the southwest coast from Anaana to Avatele.

- Tourist facilities, such as hotels and restaurants, may benefit from coastal views available only within the hazard zone. If such development is permitted and/or undertaken, the risk of storm-wave damage must be recognized. A similar proviso applies to residential development within the hazard zone.

- Niue is blessed with a fine system of coastal access trails, lookouts, picnic facilities, and related signage. This is a significant asset for the tourist industry, as well as for local fishing and recreational use, and its maintenance is recommended.

Research and survey requirements

- The preliminary coastal morphology map enclosed with this report (Forbes, 1996) could serve as the basis for an expanded and more detailed coastal resource inventory, using GIS technology. SOPAC in collaboration with others could provide advice and assistance in the development of such a planning tool.

- A shallow-water multibeam and acoustic backscatter survey would be useful for delineating reef front morphology, relict shore terraces, and the extent of sandy seabed and other habitat types around the island.

- Deepwater swath bathymetry and/or sidescan surveys would provide information on submarine slope morphology and any evidence of large-scale slope failure in the geological past. This would assist in defining tectonic hazards for Niue.

- It is now 15 years since the last aerial photography was carried out over Niue. Although satellite imagery from SPOT and other sources can provide adequate data for forestry or agriculture applications, coastal morphology and reef-platform ecology can only be resolved adequately with large-scale (1:10000 or better) aerial photography. Serious consideration should be given to acquiring new photography within the next 5 years if this can be arranged.

- Oblique aerial video of the coast, such as the recent video obtained by the Royal New Zealand Navy and Niue Broadcasting Commission, is a useful tool for coastal inventory and shore-zone classification. Extending this coverage to the entire coast of the island would be useful if the opportunity arises.

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APPENDIX 1

SURVEY DATA

APPENDIX 1.01
(file niue01.xls)

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	EASTING	NORTHING
Tuapa-Hio	*control*		*(°T)*	*(m)*	*(m MWL)*	*(m NMG)*	*(m NMG)*
NIUE							
07-Nov-95							
setup on N010							
inst height							
1.380	A35_bm (Tuapa)	1	200.456	24.95	24.78	6939.74	22271.05
	I102 (above Tuapa)	2	312.996	33.63	20.89	6932.38	22319.46
elev inst	N038 (face 1)	3	19.623	246.50	23.98	7075.38	22506.18
24.23	N038 (face 2)	4	199.620	-246.50	23.94	7075.37	22506.19
	I103 (Hio Sea Track)	5	20.062	255.90	23.79	7081.76	22513.35
easting inst							
6952.49							
northing inst							
22292.50							
grid angle difference							
10.28							

APPENDIX 1.02
(file niue02.xls)

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	EASTING	NORTHING
Hio Beach			*(°T)*	*(m)*	*(m MWL)*	*(m NMG)*	*(m NMG)*
NIUE							
07-Nov-95							
setup on I103							
inst height							
1.560	I101=N010 (face 1)	6	199.479	255.91	24.23	6952.48	22292.50
	I101=N010 (face 2)	7	19.477	-255.90	24.20	6952.49	22292.50
elev inst	A35_bm (Tuapa)	8	199.514	280.85	24.79	6939.73	22271.07
23.79	N038	9	210.834	9.61	23.98	7075.37	22506.18
	I104(above Hio)	10	346.251	30.76	18.86	7080.21	22544.07
easting inst							
7081.76							
northing inst							
22513.35							
grid angle difference							
10.865							

APPENDIX 1.03
(file niue03.xls)

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	PROF DIST	EASTING	NORTHING
Hio Beach			*(°T)*	*(m)*	*(m MWL)*	*(m)*	*(m NMG)*	*(m NMG)*
NIUE								
07-Nov-95								
setup on IP104								
inst height								
1.490	I103	11	166.906	30.76	23.78	0.00	7081.45	22513.33
	top step	12	317.337	3.14	17.49	33.53	7078.56	22546.74
elev inst	I105	13	352.479	35.65	1.42		7082.25	22579.66
18.86	base cliff fracture	14	354.498	39.48	1.44		7083.86	22583.38
	base cliff beach	15	344.344	47.12	0.64		7076.23	22591.02
	base cliff corner	16	335.561	56.77	0.25		7066.83	22599.24
easting inst	base beach	17	335.494	34.72	0.24		7071.99	22577.81
7080.21	base beach	18	325.510	28.75	0.24		7068.66	22570.40
northing inst	base beach	19	343.370	42.20	0.45		7075.93	22586.05
22544.07	top cliff	20	357.703	29.20	4.76		7084.53	22572.96
	top cliff	21	346.971	17.11	5.68	47.99	7079.55	22561.17
	base cliff	23	154.018	5.80	1.76	49.32	7083.81	22574.07
grid angle difference								
10.8								

APPENDIX 1.04
(file niue04.xls)

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	PROF DIST	EASTING	NORTHING
Hio Beach			*(°T)*	*(m)*	*(m MWL)*	*(m)*	*(m NMG)*	*(m NMG)*
NIUE								
07-Nov-95								
setup on IP105								
inst height								
1.540								
elev inst	IP104	22	172.826	35.64	18.85		7080.22	22544.08
1.42	base cliff	23	154.018	5.80	1.76		7083.81	22574.07
	base cliff at step	24	175.400	11.42	1.82		7081.09	22568.31
	base cliff fracture	25	188.758	20.73	1.44		7075.44	22560.09
easting inst	base cliff beach	26	213.071	29.07	0.26		7062.24	22558.58
7082.25	base cliff SOL1	27	175.707	8.70	1.83	0.00	7081.32	22571.02
northing inst	S 0.1 m beach	28	183.850	8.38	1.52	1.25	7080.19	22571.55
22579.66	R start outcrop	29	195.285	8.33	1.45	2.92	7078.64	22572.16
	R base outcrop	30	208.538	8.61	1.08	4.89	7076.84	22572.97
	S 0.1 m beach	31	226.377	9.74	0.67	7.95	7074.10	22574.33
	S step	32	238.797	11.80	0.27	11.05	7071.22	22575.48
	S base step	33	239.750	12.04	0.20	11.36	7070.93	22575.58
	R reef flat	34	258.006	19.90	0.15	20.63	7062.36	22579.12
grid angle difference	R reef flat	35	269.644	31.44	0.23	33.24	7051.30	22585.17
10.445	R reef flat	36	273.698	43.32	0.23	45.40	7040.24	22590.25
	R reef flat	37	276.259	55.02	0.15	57.31	7029.55	22595.48
	R reef flat	38	278.775	66.66	0.17	69.24	7019.31	22601.61
	R reef flat	39	278.613	81.57	0.13	84.15	7005.16	22606.30
	R reef flat	40	277.552	98.51	-0.33	101.18	6988.56	22610.10
	R reef	41	278.530	123.95	-0.08	126.69	6965.03	22619.97
	R reef	42	280.243	131.26	-0.28	134.92	6959.46	22626.03
	corner cliff	43	257.462	88.74	-0.35		6993.58	22576.42

APPENDIX 1.05
(file niue05.xls)

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	EASTING	NORTHING
Tuapa			*(°T)*	*(m)*	*(m MWL)*	*(m NMG)*	*(m NMG)*
NIUE							
07-Nov-95							
setup on IP102							
inst height							
1.480							
elev inst	IP101_N010	44	133.182	33.63	24.22	6952.49	22292.50
20.89	A35_BM	45	161.261	48.97	24.77	6939.74	22271.04
	reef edge	46	290.645	150.31	-0.17	6803.20	22396.30
	reef rim	47	290.474	140.85	0.22	6811.11	22391.10
easting inst	reef rim	48	290.580	128.34	0.50	6822.01	22384.94
6932.38	reef edge	49	300.562	146.98	-0.10	6820.88	22415.23
northing inst	reef rim	50	300.994	139.60	0.38	6827.17	22411.21
22319.46	reef rim	51	301.605	126.13	0.49	6838.22	22403.37
	reef spur	52	311.439	161.61	-0.10	6831.86	22446.00
	reef rim	53	312.542	153.16	0.41	6839.44	22441.20
	reef flat	54	315.571	129.38	0.44	6859.42	22426.30
	groove	55	311.064	145.81	0.01	6840.94	22433.03
	groove	56	314.871	148.85	-0.16	6846.94	22441.34
grid angle difference	reef edge	57	321.836	167.41	0.29	6853.62	22467.18
10.1	reef rim	58	323.116	160.75	0.54	6859.94	22462.96
	reef flat	59	326.256	147.36	0.25	6873.28	22454.45
	reef flat	60	328.978	136.88	0.22	6883.50	22447.31
	reef flat	61	332.613	107.65	0.31	6900.39	22422.24
	reef flat	62	335.932	98.96	0.36	6908.49	22415.49
	reef flat boulder	63	341.015	89.42	0.38	6918.57	22407.80
	boulder	64	333.750	73.05	1.48	6912.06	22389.63
	reef flat	65	336.065	67.48	0.35	6916.24	22384.98
	reef flat	66	332.081	63.77	0.22	6912.86	22380.17
	reef flat	67	323.807	74.23	0.35	6899.73	22386.12
	reef flat	68	320.496	98.95	0.40	6883.80	22405.66
	reef flat	69	317.148	117.04	0.22	6869.06	22417.88
	reef flat	70	315.006	129.10	0.42	6858.53	22425.35
	reef flat	71	302.388	119.70	0.44	6844.11	22400.31
	reef flat	72	303.493	101.69	0.32	6858.73	22389.57
	reef flat	73	304.669	85.02	0.37	6872.02	22379.33
	reef flat	74	306.029	71.17	0.40	6883.06	22370.76
	reef flat	75	307.219	57.79	0.23	6893.20	22361.94
	reef flat	76	284.243	58.58	0.41	6879.01	22343.60
	reef flat	77	286.172	77.80	0.43	6862.62	22353.89
	reef flat	78	286.530	101.11	0.29	6842.00	22364.77
	reef flat	79	286.359	118.99	0.47	6825.85	22372.47
	IP106	80	313.674	50.74	0.71	6902.39	22360.39

APPENDIX 1.06
(niue06.xls)

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	EASTING	NORTHING
Tuapa			*(°T)*	*(m)*	*(m MWL)*	*(m NMG)*	*(m NMG)*
NIUE							
07-Nov-95							
setup on IP106							
inst height							
1.580							
elev inst	IP102	81	134.295	50.73	20.86	6932.37	22319.46
0.71	step	82	119.333	7.51	3.71	6908.24	22355.68
	step	83	140.626	7.06	3.64	6905.91	22354.27
	step	84	117.593	3.66	1.87	6905.31	22358.19
easting inst	step	85	136.293	3.50	1.87	6904.36	22357.50
6902.39	platform	86	100.212	2.11	0.75	6904.37	22359.68
northing inst	platform	87	339.332	2.58	0.61	6901.89	22362.92
22360.39	platform	88	279.129	3.39	0.61	6899.18	22361.47
	platform	89	228.193	2.20	0.52	6900.53	22359.21
	platform	90	210.529	2.59	0.52	6900.73	22358.41
	base of cliff	91	215.294	32.53	0.58	6879.48	22337.30
	base of cliff	92	219.903	69.36	0.20	6849.75	22315.24
	base of cliff	93	216.383	67.96	0.54	6853.62	22313.06
grid angle difference	base of cliff	94	218.346	8.43	0.58	6896.14	22354.73
9.48	base of cliff	95	359.389	81.62	0.52	6914.98	22441.04
	base of cliff fracture	96	10.766	68.21	0.83	6926.00	22424.38
	base of cliff fracture	97	19.025	62.60	0.59	6932.27	22415.40
	base of cliff fracture	98	36.372	55.54	0.53	6942.25	22399.08
	S base of cliff beach	99	44.881	47.15	0.60	6940.71	22387.86
	S base of sand beach	100	47.125	42.73	0.53	6938.07	22383.91
	base of cliff	101	46.812	32.83	0.59	6929.70	22378.61
	base of cliff beach	102	64.605	25.27	0.81	6926.69	22367.32
	base of cliff beach	103	80.842	24.62	1.62	6927.01	22360.25
	base of cliff beach	104	90.511	19.45	0.56	6921.55	22357.02
	B base of beach	105	72.461	19.47	0.50	6921.67	22363.12
	base of cliff	106	92.766	13.09	0.20	6915.18	22357.61
	base of cliff	107	107.522	5.55	0.51	6907.34	22357.87
	lip of depression	108	38.242	1.26	0.31	6903.32	22361.24
	bottom of depression	109	3.091	1.64	-0.10	6902.75	22361.99
	bottom of depression	110	48.819	6.11	0.01	6907.59	22363.60
	bottom of depression	111	35.351	4.34	-0.10	6905.45	22363.47
	bottom of depression	112	48.203	4.32	-0.01	6906.05	22362.70
	lip of depression	113	58.746	4.40	0.27	6906.48	22362.02
	lip of depression	114	65.273	7.11	0.38	6909.25	22362.26
	lip of depression	115	74.849	9.08	0.50	6911.43	22361.29
	lip of depression	116	35.231	7.38	0.47	6907.59	22365.64
	lip of depression	117	16.073	4.39	0.43	6904.28	22364.35
	lip of depression	118	340.919	2.56	0.46	6901.97	22362.91

APPENDIX 1.07
(file niue07.xls)

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	EASTING	NORTHING
Avatele			*(°T)*	*(m)*	*(m MWL)*	*(m NMG)*	*(m NMG)*
NIUE							
coordinates in:	*Niue Map Grid*						
08-Nov-95							
setup on XCII							
inst height	VIII	119	124.551	17.31	17.60	5918.22	6881.63
1.810	XCIII (face 1)	120	101.551	61.31	19.14	5962.98	6871.54
	XCIII (face 1)	121	101.551	61.32	19.14	5962.98	6871.54
elev inst	VII (face 1)	122	1.401	142.86	20.01	5933.16	7033.92
17.12	VII (face 2)	123	181.405	-142.87	19.99	5933.17	7033.92
	IP108 cnr LMS monument	124	343.117	48.31	16.48	5899.72	6941.63
easting inst	cnr LMS monument	125	341.876	46.16	16.49	5899.00	6939.35
5905.81	cnr LMS monument	126	344.333	45.26	16.49	5901.06	6938.71
northing inst	cnr LMS monument	127	345.509	47.45	16.40	5901.80	6940.98
6893.70							
grid angle difference							
9.637303							

APPENDIX 1.08
(file niue08.xls)

INFO	DESCRIPTION	PT NO	*H ANG*	*H DIST*	*ELEV*	*EASTING*	*NORTHING*
Avatele			*(°T)*	*(m)*	*(m MWL)*	*(m NMG)*	*(m NMG)*
NIUE							
coordinates in:	*Niue Map Grid*						
08-Nov-95							
setup on IP108							
inst height	XCII	128	161.469444	48.29	17.11	5905.81	6893.72
1.270	XCIII	129	126.634444	94.40	19.13	5962.99	6871.56
	VII	130	8.632222	98.18	20,00	5933.17	7033.94
elev inst	road corner	131	28.002500	31.12	16.45	5919.43	6965.72
16.48	road corner	132	16.649444	22.13	16.16	5910.09	6961.19
	road corner	133	23.054722	15.01	15.54	5908.19	6954.02
easting inst	road corner	134	49.673333	16.24	16.35	5913.92	6949.51
5899.72	WWI monument	135	170.116944	7.72	16.48	5899.53	6933.91
northing inst	WWI monument	136	186.744167	7.40	16.45	5897.43	6934.60
6941.63	WWI monument	137	186.644167	9.86	16.47	5896.68	6932.25
	WWI monument	138	173.956667	10.09	16.48	5898.80	6931.58
grid angle difference	roadway	139	6.727222	17.22	15.63	5905.04	6958.00
11.285081	roadway	140	14.683333	12.95	15.02	5905.39	6953.27
	roadway	141	325.868056	11.86	14.00	5895.12	6952.56
	roadway	142	326.782500	8.15	13.54	5896.67	6949.19
	roadway	143	290.534167	12.85	12.86	5888.80	6948.41
	roadway	144	282.192222	9.83	12.48	5890.71	6945.55
	roadway	145	265.337500	17.09	11.76	5882.74	6943.60
	roadway	146	256.634722	14.33	11.39	5885.40	6941.11
	roadway	147	248.915833	22.26	10.73	5877.78	6937.84
	roadway	148	241.524444	20.10	10.37	5880.52	6935.69
	roadway	149	239.944444	27.64	9.98	5873.55	6932.74
	roadway	150	233.127222	25.20	9.66	5876.99	6930.75
	roadway	151	231.927500	34.21	9.23	5869.18	6926.21
	roadway	152	225.679722	31.99	8.99	5872.90	6924.19
	roadway	153	225.883056	40.07	8.40	5866.05	6919.90
	roadway	154	222.085556	36.83	8.46	5870.16	6919.65
	picnic platform	155	237.502500	37.13	8.47	5865.10	6928.19
	picnic platform	156	241.846389	39.85	7.78	5861.59	6930.07
	picnic platform	157	259.604444	31.86	8.11	5867.86	6942.12
	picnic platform	158	255.968889	28.38	8.18	5871.37	6940.27
	IP109 (face 1)	159	293.671667	62.99	1.02	5848.10	6977.72
	IP109 (face 2)	160	113.665278	-62.99	1.02	5848.09	6977.71

APPENDIX 1.09
(file niue09.xls)

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	EASTING	NORTHING
Avatele			*(°T)*	*(m)*	*(m MWL)*	*(m NMG)*	*(m NMG)*
NIUE							
coordinates in:	*Niue Map Grid*						
08-Nov-95							
air temperature	*30°C [E]*						
atmospheric pressure	*1015 hPa [E]*						
prism offset	*-30 mm*						
setup on IP109							
inst height	IP108	161	113.0083	62.98	16.47	5899.71	6941.64
1.542	IP108	162	292.9931	-62.97	16.46	5899.72	6941.65
	base of stone wall	163	159.8661	58.95	6.53	5856.49	6919.37
elev inst	base of stone wall	164	159.7194	54.86	6.29	5856.05	6923.43
1.03	base of stone wall	165	158.0153	49.38	5.85	5856.71	6929.09
	base of stone wall	166	155.9506	45.40	5.25	5857.62	6933.33
easting inst	base of stone wall	167	151.8422	41.07	4.71	5859.56	6938.28
5848.10	base of stone wall	168	146.2836	37.28	4.50	5861.93	6943.10
northing inst	base of stone wall	169	140.9283	34.42	3.92	5863.79	6947.09
6977.72	base of stone wall	170	133.7497	31.34	3.63	5865.76	6951.83
	base of stone wall	171	130.2400	30.40	3.68	5866.74	6953.70
grid angle difference	base of stone wall	172	163.6989	70.39	6.81	5853.44	6907.54
11.948415	base of stone wall	173	165.4794	68.45	7.00	5851.17	6909.34
	base of stone wall	174	168.0331	65.70	7.01	5848.12	6912.02
	base of stone wall	175	170.1186	63.45	6.86	5845.81	6914.31
	road	176	170.5331	58.63	6.75	5845.56	6919.14
	road	177	170.0828	53.70	6.46	5846.20	6924.05
	road	178	167.6244	49.03	6.14	5848.47	6928.69
	top rubble slope	179	174.0778	59.58	6.70	5841.84	6918.46
	top rubble slope	180	173.9022	55.10	6.61	5842.48	6922.91
	top rubble slope	181	172.5886	49.96	6.16	5844.15	6927.91
	top rubble slope	182	170.8631	46.93	6.02	5845.80	6930.85
	top concrete wall	183	166.9167	42.85	5.65	5848.95	6934.88
	top concrete wall	184	163.5442	38.51	4.80	5851.13	6939.33
	top concrete wall	185	159.4336	34.00	4.07	5853.20	6944.10
	top concrete wall	186	161.1500	36.12	4.41	5852.44	6941.86
	top of ramp	187	159.3522	33.94	3.86	5853.23	6944.17
	edge of ramp	188	163.4400	19.85	2.22	5849.70	6957.94
	edge of ramp	189	175.4122	9.23	1.22	5846.92	6968.56
	edge of ramp	190	249.6000	8.60	0.58	5839.60	6976.46
	crane foundation	191	249.7844	8.64	1.04	5839.55	6976.48
	crane foundation	192	261.5894	8.52	1.03	5839.60	6978.25
	crane foundation	193	255.3861	7.65	1.06	5840.46	6977.36
	edge of ramp	194	298.1272	7.62	0.43	5842.27	6982.62
	edge of ramp	195	133.1989	5.47	1.23	5851.23	6973.23
	edge of ramp	196	134.3828	13.26	1.73	5855.45	6966.68
	edge of ramp	197	137.3422	23.90	2.87	5860.31	6957.17
	edge of ramp	198	141.1139	29.61	3.42	5861.51	6951.32
	edge of ramp	199	145.2486	34.03	3.81	5861.29	6946.35
	base rubble slope	200	163.2472	30.35	3.32	5850.64	6947.47
	base rubble slope	201	176.3978	40.10	2.77	5842.28	6938.05
	base of slope	202	161.9378	24.93	1.30	5850.75	6952.94
	base of slope	203	171.2836	31.36	1.34	5846.33	6946.41
	base of slope	204	178.1897	39.30	1.65	5841.18	6939.04
	PC beach crest	205	180.7642	40.73	1.64	5839.14	6937.99
	PC beach crest	206	183.2058	44.25	1.71	5836.53	6935.01
	PC beach crest	207	184.8672	47.83	1.67	5834.26	6931.94
	PC beach crest	208	186.3372	50.64	1.72	5832.21	6929.64
	PC top of beach	209	183.4242	51.10	1.79	5834.55	6928.44
	PC top of beach	210	182.0914	47.64	1.59	5836.54	6931.50
	PC top of beach	211	180.6967	43.86	1.59	5838.50	6934.92
	PC top of beach	212	179.3442	40.66	1.68	5840.14	6937.85
	base of slope	213	180.3122	53.45	2.18	5836.75	6925.49

APPENDIX 1.09
(file niue09.xls)

	base cliff at beach	214	205.6394	86.69	0.50	5795.22	6909.02
	base cliff at beach	215	202.6986	77.67	0.81	5803.94	6913.82
	base cliff at beach	216	198.9119	72.77	1.55	5810.77	6915.25
	PC berm washover	217	196.0003	65.90	1.27	5817.22	6919.51
	PC berm	218	193.0311	57.21	1.34	5823.94	6925.86
	PC berm	219	187.8683	48.92	1.51	5831.52	6931.70
	PC berm	220	183.4561	41.72	1.35	5837.02	6937.50
	PC berm	221	177.9439	35.37	1.39	5842.02	6942.88
	PC berm	222	170.5656	27.67	1.10	5846.89	6950.07
	B	223	172.6017	23.94	0.43	5846.20	6953.86
	PC base of berm	224	178.5919	35.21	1.03	5841.66	6943.10
	PC base of berm	225	184.7239	42.59	1.02	5835.88	6936.92
	PC base of berm	226	188.8242	48.72	1.04	5830.82	6932.17
	PC runup limit	227	197.2856	63.27	1.03	5817.20	6922.51
	PC runup limit	228	197.7111	66.40	1.14	5815.24	6920.02
	PC runup limit	229	199.5186	68.03	1.05	5812.59	6919.70
	RPC foreshore	230	199.6111	61.49	0.39	5815.92	6925.32
	SP foreshore	231	194.9850	55.28	0.47	5823.06	6928.43
	SP foreshore	232	190.9953	46.31	0.22	5830.05	6935.07
	PCB foreshore	233	185.1225	36.87	0.27	5837.28	6942.48
	B foreshore	234	174.8622	26.54	0.61	5844.95	6951.37
	base of wall	235	165.8986	17.60	0.94	5848.76	6960.13
	base cliff at beach	236	191.5661	70.71	1.95	5819.89	6912.88
	base cliff at beach	237	188.5425	72.57	2.80	5822.70	6909.74
	top of beach	238	185.6647	69.96	2.90	5826.93	6911.04
	top of beach	239	181.6681	67.71	3.03	5832.16	6911.92
	top of beach	240	179.6661	65.26	2.97	5834.96	6913.80
	top of slope	241	179.9567	71.76	4.52	5833.30	6907.50
	top of slope	242	187.2294	74.43	4.37	5823.65	6907.42
	base of cliff	243	182.1683	81.88	4.44	5828.13	6898.31

APPENDIX 1.10
(file niue10.xls)

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	PROF DIST	EASTING	NORTHING
Avatele			*(°T)*	*(m)*	*(m MWL)*	*(m)*	*(m NMG)*	*(m NMG)*
NIUE								
coordinates in:	*Niue Map Grid*							
08-Nov-95								
air temperature	*31°C [E]*							
atmospheric pressure	*1015 hPa [E]*							
prism offset	*-30 mm*							
setup on IP109								
inst height	IP108	244	114.7419	62.97	16.47		5899.71	6941.64
1.570	IP108	245	294.7478	-62.98	16.46		5899.71	6941.63
	WLO @1330LT	246	186.4917	18.83	-0.48		5842.69	6959.68
elev inst	R base of wall	247	224.4542	7.94	-0.57		5841.62	6973.13
1.03	R	248	197.2369	15.51	-0.34		5840.95	6963.95
	S	249	188.4667	19.16	-0.56		5841.96	6959.57
easting inst	S	250	190.1536	26.12	-0.53		5839.01	6953.23
5848.10	S	251	196.8383	33.98	-0.68		5832.65	6947.46
northing inst	S	252	199.6372	42.18	-0.66		5827.10	6941.14
6977.72	S base approx.	253	203.7992	49.47	-0.73		5820.43	6936.72
	SP base	254	208.6378	58.08	-0.71		5811.67	6932.49
grid angle difference	SP	255	210.6319	66.26	-0.67		5804.76	6927.60
10.214804	SP	256	212.5922	74.49	-0.63		5797.48	6923.07
	SP	257	212.5506	81.78	-0.63		5792.57	6917.68
	base of cliff	258	212.2853	89.05	-0.35		5787.94	6912.07
	base of cliff	259	215.6861	95.25	-0.39		5779.70	6911.44
	base of cliff	260	218.3619	100.73	-0.33		5772.57	6911.08
	base of cliff	261	222.0728	102.99	-0.42		5766.63	6914.72
	base of cliff	262	225.1283	100.94	-0.34		5765.07	6920.32
	base of cliff	263	228.4614	101.97	-0.54		5760.99	6924.71
	base of cliff	264	231.9378	103.85	-0.64		5756.27	6929.21
	base of cliff	265	233.8567	106.38	-0.66		5752.43	6931.20
	base of cliff	266	237.4822	112.55	-0.68		5743.97	6935.01
	base of cliff	267	239.1919	116.13	-0.63		5739.39	6936.87
	base of cliff	268	239.9892	123.01	-0.76		5732.35	6936.06
	base of cliff	269	241.3597	130.08	-0.64		5724.69	6936.61
	base of cliff	270	241.5183	135.04	-0.61		5719.87	6935.39
	base of cliff	271	242.2378	139.78	-0.59		5714.83	6935.58
	base of cliff	272	242.7094	146.64	-0.51		5707.92	6934.66
	base of cliff	273	242.4364	152.59	-0.52		5702.45	6932.22
	reef	274	245.3500	158.04	-0.41		5695.05	6938.32
	reef	275	247.7633	166.30	-0.18		5685.44	6943.08
	reef	276	249.0800	173.01	-0.25		5678.10	6945.58
	reef	277	251.0681	165.96	-0.22		5684.06	6952.57
	reef	278	249.4578	157.19	-0.14		5693.46	6949.54
	reef	279	248.3828	150.30	-0.26		5700.77	6948.01
	reef	280	247.2194	141.05	-0.55		5710.42	6947.03
	reef	281	246.4978	133.94	-0.66		5717.74	6946.94
	reef	282	244.6786	125.79	-0.67		5726.66	6944.94
	reef	283	242.4064	117.23	-0.68		5736.22	6942.70
	reef	284	240.1633	110.46	-0.77		5744.05	6940.62
	reef	285	237.6208	105.22	-1.18		5750.66	6938.03
	west side large block	286	234.7164	100.89	-0.70		5756.71	6934.97
	basin	287	232.2161	96.16	-1.46		5762.86	6933.21
	basin	288	228.3008	89.92	-0.82		5771.42	6930.76
	basin	289	224.1736	83.88	-1.28		5779.90	6928.88
	basin	290	219.8033	79.11	-1.07		5787.48	6926.89
	SP	291	208.5475	55.96	-0.84		5813.07	6934.09
	basin	292	218.6981	56.33	-1.26		5805.65	6940.70
	basin	293	227.2278	58.90	-1.23		5798.45	6946.02
	basin	294	233.6944	63.01	-1.02		5791.52	6950.01
	basin	295	240.9717	70.39	-1.30		5781.47	6955.02
	basin	296	245.8261	75.67	-1.54		5774.67	6959.47

	reef	297	251.2022	82.81	-0.75		5766.22	6965.36
	reef	298	256.3044	92.99	-0.62		5755.28	6972.07
	reef	299	260.3814	106.38	-0.64		5741.73	6978.83
	reef	300	262.7750	117.13	-0.42		5731.12	6983.83
	reef	301	263.6672	125.59	-0.24		5722.79	6986.22
	reef	302	263.9536	133.17	-0.43		5715.28	6987.40
	reef	303	266.7919	131.38	-0.66		5717.70	6993.75
	reef	304	268.1789	125.58	-0.94		5723.86	6996.05
	reef	305	268.7264	120.29	-0.79		5729.28	6996.41
	reef	306	267.0658	115.22	-0.71		5733.81	6992.32
	reef	307	269.7089	112.67	-0.84		5737.12	6997.14
	reef	308	269.7303	108.75	-0.88		5740.98	6996.50
	reef	309	267.7300	104.27	-0.76		5744.83	6992.13
	reef	310	267.4722	100.77	-0.62		5748.24	6991.20
	reef	311	266.2944	94.34	-0.78		5754.37	6988.41
	reef	312	262.4483	95.95	-0.77		5752.25	6982.18
	reef	313	263.7089	92.88	-0.68		5755.44	6984.08
	reef	314	263.3181	89.70	-1.00		5758.57	6983.25
	reef	315	260.1900	89.75	-0.82		5758.35	6978.35
	reef	316	261.4075	87.04	-0.87		5761.09	6980.18
	reef	317	264.3556	88.29	-0.66		5760.09	6984.76
	reef	318	265.5964	86.94	-0.61		5761.61	6986.52
	reef	319	264.8950	84.21	-0.68		5764.22	6985.22
	reef	320	266.9350	82.54	-0.74		5766.20	6987.99
	reef	321	267.8108	87.04	-0.71		5761.91	6989.87
	reef	322	267.5911	91.14	-0.74		5757.81	6990.10
	reef	323	270.9428	94.54	-0.78		5755.35	6996.01
	reef	324	272.5439	91.09	-0.80		5759.25	6997.84
	reef	325	273.8611	91.83	-0.78		5759.02	7000.05
	reef	326	275.8911	89.53	-0.87		5762.08	7002.56
	reef	327	275.4867	97.17	-0.64		5754.56	7004.02
	reef	328	277.1122	101.96	-0.77		5750.77	7008.09
	reef	329	279.4847	104.22	-1.03		5749.98	7012.85
	reef	330	280.2850	98.52	-0.75		5755.81	7012.22
	reef	331	278.9378	96.57	-0.79		5756.87	7009.40
	reef	332	279.6939	92.19	-0.73		5761.42	7009.11
	reef	333	278.5897	87.81	-0.84		5764.98	7006.03
	reef	334	280.1722	88.50	-0.82		5765.14	7008.55
	reef	335	281.9553	88.94	-0.64		5765.73	7011.28
	reef	336	284.4903	92.32	-0.65		5764.23	7016.30
	reef	337	285.6194	89.51	-0.90		5767.53	7016.73
	reef	338	285.6275	93.75	-0.84		5763.72	7018.59
	reef	339	286.4769	100.69	-0.94		5758.14	7022.95
	reef	340	286.2753	106.54	-0.85		5752.75	7025.24
	reef	341	288.8553	107.46	-0.86		5754.18	7029.93
	reef	342	291.0067	106.24	-0.90		5757.24	7032.79
	reef	343	291.5461	99.46	-0.84		5763.53	7030.08
	reef	344	290.9689	93.96	-0.76		5767.72	7026.37
	reef	345	290.4183	86.81	-0.73		5773.40	7021.96
	reef	346	287.7464	83.12	-0.79		5774.68	7016.69
	reef	347	286.9964	78.46	-0.71		5778.33	7013.60
	reef	348	286.6703	76.23	-0.61		5780.11	7012.19
	reef	349	284.2972	72.25	-0.85		5782.36	7007.70
	reef	350	287.0919	73.23	-0.63		5783.03	7011.32
	reef	351	286.8075	71.26	-0.61		5784.62	7010.09
	reef	352	286.5408	67.93	-0.75		5787.44	7008.30
	reef	353	288.0647	65.17	-0.82		5790.71	7008.59
	reef	354	287.1997	61.95	-0.93		5793.11	7006.24
	reef	355	283.1747	56.33	-0.67		5796.40	7000.08
	reef	356	280.6211	55.58	-0.91		5796.15	6997.49
	reef	357	279.4339	56.47	-1.02		5794.92	6996.71
	reef	358	278.0283	55.71	-0.84		5795.19	6995.16
	reef	359	276.1717	54.85	-0.85		5795.48	6993.19
	reef	360	272.4336	56.09	-0.81		5793.37	6990.00

	reef	361	270.7792	55.80	-0.85		5793.33	6988.36
	reef	362	269.7419	55.01	-0.99		5793.92	6987.23
	reef	363	268.3294	55.31	-0.98		5793.40	6985.94
	reef [start profile]	364	281.6917	88.82	-0.67	120.00	5765.69	7010.86
	reef	365	278.7686	83.14	-0.72	112.82	5769.48	7004.77
	reef	366	276.7736	78.49	-0.21	107.39	5773.04	7000.65
	reef	367	273.4953	72.93	-0.40	100.34	5777.25	6995.00
	reef	368	269.1356	66.81	-0.69	92.24	5782.17	6988.58
	reef	369	264.4336	62.04	-0.75	85.12	5786.26	6982.75
	reef	370	260.7844	58.65	-0.80	80.00	5789.45	6978.74
	basin	371	254.3981	54.28	-1.10	72.34	5794.06	6972.62
	basin	372	246.2156	51.22	-1.40	64.22	5798.31	6965.70
	basin	373	238.9806	49.70	-1.38	57.67	5801.64	6960.07
	basin (coral)	374	232.2225	47.88	-1.27	51.64	5805.66	6955.57
	basin	375	224.0211	47.13	-1.35	44.81	5809.86	6950.17
	S	376	219.0500	46.96	-1.63	40.72	5812.52	6947.08
	S	377	212.6700	47.92	-1.35	35.36	5815.49	6942.60
	S	378	204.9828	50.07	-0.83	28.45	5819.24	6936.81
	SP	379	199.1694	52.06	-0.11	22.90	5822.55	6932.35
	SP	380	195.0778	53.67	0.63	18.80	5825.17	6929.19
	SP	381	193.2897	54.57	1.36	16.89	5826.34	6927.68
	SP	382	192.3372	55.27	1.64	15.73	5826.90	6926.68
	SP	383	190.1175	56.83	1.81	13.06	5828.35	6924.43
	SPC	384	186.2547	59.26	2.22	8.45	5831.30	6920.89
	SPC	385	182.9844	62.06	2.66	4.00	5833.93	6917.30
	SPC [end profile]	386	181.5231	64.76	2.96	0.86	5834.93	6914.32
	basin	387	215.2161	16.76	-1.10		5836.16	6965.96
	basin	388	239.7611	17.09	-1.35		5832.04	6971.87
	basin	389	262.9883	20.96	-1.85		5827.17	6978.89
	basin	390	277.6025	23.25	-1.99		5825.97	6984.83
	basin	391	286.5592	26.95	-1.83		5824.04	6989.86
	basin	392	295.5692	28.97	-2.00		5824.60	6994.66
	basin	393	300.9125	29.82	-1.96		5825.64	6997.33
	basin	394	297.2033	35.90	-1.84		5819.59	6999.53
	reef	395	285.3103	42.42	-1.01		5809.82	6996.00
	reef	396	285.9228	39.87	-0.87		5812.31	6995.28
	reef	397	290.0267	43.79	-0.82		5810.27	6999.78
	reef	398	293.9117	47.42	-0.73		5808.85	7004.32
	reef	399	295.3075	52.34	-0.73		5805.50	7008.13
	reef	400	298.3122	52.80	-0.76		5806.80	7010.61
	reef	401	299.4892	58.75	-0.71		5802.90	7015.25
	reef	402	299.8628	64.75	-1.05		5798.56	7019.41
	reef	403	300.6003	70.68	-0.66		5794.60	7023.92
	reef	404	301.1258	74.11	-0.57		5792.45	7026.68
	reef	405	302.6800	77.68	-0.77		5791.19	7030.59
	base of cliff	406	302.7469	60.11	-0.46		5804.11	7018.69
	base of cliff	407	303.8153	55.21	-0.45		5808.41	7016.09
	base of cliff	408	307.2094	48.94	-0.25		5814.99	7013.76
	base of cliff	409	311.0678	46.27	-0.33		5819.16	7013.83
	base of cliff	410	315.7139	45.70	-0.23		5822.50	7015.58
	base of cliff	411	319.7419	44.51	-0.32		5825.82	7016.25
	base of cliff	412	323.0522	40.88	-0.35		5829.71	7014.23
	base of cliff	413	327.7200	38.47	-0.42		5833.65	7013.37
	base of cliff	414	330.3953	34.16	-0.06		5836.76	7009.94
	base of cliff	415	330.6739	28.57	-0.02		5838.74	7004.72
	base of cliff	416	330.7594	24.61	-0.06		5840.08	7000.98
	base of cliff	417	328.9942	21.77	-0.32		5840.37	6998.07
	base of cliff	418	332.8192	19.16	-0.30		5842.51	6996.05
	base of cliff	419	333.5717	17.17	0.47		5843.30	6994.21
	base of cliff	420	345.2442	17.62	1.14		5846.71	6995.28
	base of cliff	421	346.2700	11.28	1.00		5847.41	6988.98
	base of cliff	422	2.3842	6.71	1.47		5849.56	6984.27
	base of cliff	423	5.1258	1.79	1.22		5848.57	6979.45
	base of cliff	424	95.5956	2.93	1.26		5850.91	6976.92

APPENDIX 1.10
(file niue10.xls)

	base of cliff	425	134.1242	15.20	1.92		5856.96	6965.37
	cliff	426	11.6197	3.38	4.54		5849.36	6980.86
	base of ramp	427	287.0714	21.73	-1.33		5828.79	6987.68
	base of ramp	428	302.3278	21.45	-1.41		5832.30	6992.22
	reef	429	303.4544	18.54	-0.73		5834.69	6990.52
	reef	430	313.7447	20.81	-0.61		5835.86	6994.55
	reef	431	319.7028	22.83	-0.82		5836.66	6997.48
	reef	432	321.0200	26.10	-0.87		5835.54	7000.60
	reef	433	320.8611	29.44	-0.89		5833.86	7003.48
	reef	434	320.3942	34.45	-0.82		5831.19	7007.74
	reef	435	316.1797	38.22	-0.90		5826.95	7009.55
	reef	436	312.7456	42.73	-0.79		5822.36	7011.83
	reef	437	308.7169	45.02	-0.86		5818.53	7011.66
	reef	438	304.7986	45.20	-0.72		5816.15	7009.69
	reef	439	300.3419	45.34	-0.76		5813.65	7007.20
	reef	440	296.4725	44.02	-0.80		5812.80	7004.02
	reef	441	288.9642	40.09	-0.93		5813.10	6997.27
	concrete block	442	289.2858	41.34	0.24		5812.12	6998.07
	concrete block	443	290.9611	42.29	0.24		5811.92	6999.61
	concrete block	444	292.8511	43.67	0.24		5811.51	7001.54
	concrete block	445	296.4003	45.28	0.21		5811.76	7004.72
	concrete block	446	297.0281	47.76	0.24		5810.08	7006.62
	concrete block	447	298.5153	45.92	0.22		5812.28	7006.45
	concrete block	448	299.2069	48.17	0.23		5810.89	7008.31
	concrete block	449	300.9183	46.25	0.21		5813.27	7008.14
	concrete block	450	301.5414	48.48	0.24		5811.94	7010.00
	concrete block	451	302.9214	46.64	0.25		5814.06	7009.61
	concrete block	452	303.6819	48.84	0.24		5812.91	7011.58
	concrete block	453	304.9728	46.88	0.27		5815.08	7010.98

APPENDIX 1.11
(file niue11.xls)

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	EASTING	NORTHING
Tomb Point			*(°T)*	*(m)*	*(m MWL)*	*(m NMG)*	*(m NMG)*
Alofi							
NIUE							
09-Nov-95							
setup on Tomb Pt control							
inst height	Mapua control	454	209.3442	595.99	21.21	4707.93	14480.48
0.770	Alofi wharf 1	455	7.2222	104.59	2.30	5013.15	15103.76
	BM2	456	11.2467	104.36	2.88	5020.35	15102.36
elev inst	OLP1	457	114.2269	86.27	21.00	5078.67	14964.60
18.86							
instrument easting							
5000.00							
instrument northing							
15000.00							

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	EASTING	NORTHING
Alofi			*(°T)*	*(m)*	*(m MWL)*	*(m NMG)*	*(m NMG)*
NIUE							
coordinates in:	*Niue Map Grid*						
09-Nov-95							
air temperature	*29°C [E]*						
atmospheric pressure	*1015 hPa [E]*						
prism offset	*-30 mm*						
setup on Alofi wharf 1							
inst height	Tomb Point control	458	187.588333	104.56	18.84	5000.01	15000.03
1.610	BM2	459	101.419444	7.35	2.85	5042.21	15095.44
	BM1	460	35.407778	35.88	5.26	5062.00	15122.56
elev inst	wharf	461	29.421389	34.50	2.69	5058.42	15124.16
2.30	wharf	462	318.665833	46.63	2.50	5012.81	15139.14
	wharf	463	293.512500	58.71	2.74	4987.84	15132.70
easting inst	Alofi wharf 2	464	293.791389	57.11	2.76	4989.30	15131.99
5035.48	wharf	465	289.883056	39.30	2.75	5002.20	15119.29
northing inst	wharf	466	281.681389	22.25	2.72	5015.14	15107.41
15098.39	wharf	467	271.641944	16.11	2.53	5019.84	15102.26
	wharf	468	257.580000	12.83	2.24	5022.65	15098.35
grid angle difference	top of ramp	469	126.495556	2.86	2.25	5037.37	15096.24
12.243889	top of ramp	470	106.299167	5.55	2.25	5040.36	15095.74
	base of cliff	471	133.914722	12.60	0.47	5042.50	15087.93
	base of cliff	472	136.222500	36.68	0.82	5054.66	15067.13
	base of cliff at beach	473	144.241111	44.65	0.79	5053.29	15057.45
	base of cliff at beach	474	148.818889	52.46	1.52	5052.51	15048.77
	base of cliff at beach	475	150.598333	53.96	1.37	5051.40	15046.83
	base of cliff at beach	476	152.134444	56.26	1.26	5050.63	15044.20
	base of cliff at beach	477	152.200833	57.87	1.51	5051.00	15042.64
	base of cliff at beach	478	154.611667	61.16	1.19	5049.39	15038.84
	base of cliff at beach	479	157.189444	62.54	0.63	5046.95	15036.91
	base of beach	480	157.270000	57.49	0.48	5045.94	15041.86
	base of beach	481	154.274167	52.15	0.49	5047.64	15047.67
	base of beach	482	151.222222	48.50	0.73	5049.28	15051.89
	base of beach	483	145.660278	43.33	0.57	5051.78	15058.25
	B edge boulder patch	484	140.471667	33.89	0.35	5051.02	15068.27
	B edge boulder patch	485	149.034722	34.31	0.34	5046.49	15065.90
	B edge boulder patch	486	156.880278	36.13	0.26	5042.30	15062.91
	B edge boulder patch	487	165.414722	35.38	0.00	5036.93	15063.04
	B edge boulder patch	488	167.029444	39.85	0.15	5035.99	15058.54
	B edge boulder patch	489	171.994722	42.46	0.14	5032.34	15056.05
	B edge boulder patch	490	170.586111	47.18	0.18	5033.15	15051.27
	B edge boulder patch	491	165.176944	48.44	0.16	5037.66	15050.00
	B edge boulder patch	492	159.527778	49.36	0.24	5042.54	15049.54
	B edge boulder patch	493	155.681111	50.71	0.32	5046.09	15048.80
	edge of blasted cut	494	168.784167	35.63	0.01	5034.84	15062.77
	edge of blasted cut	495	168.794444	35.21	-0.23	5034.84	15063.19
	edge of blasted cut	496	151.316111	28.93	0.30	5043.67	15070.64
	edge of blasted cut	497	151.966389	27.82	-0.24	5043.05	15071.62
	edge of blasted cut	498	161.069444	20.20	0.07	5037.83	15078.32
	edge of blasted cut	499	180.881667	30.80	0.21	5028.48	15068.39
	edge of blasted cut	500	179.983889	31.00	-0.48	5028.91	15068.09
	reef	501	198.371111	30.81	0.14	5019.79	15071.87
	reef	502	211.687222	34.72	0.04	5011.39	15073.38
	reef	503	226.286944	37.13	0.31	5003.81	15079.01
	reef	504	239.043333	41.15	0.10	4996.51	15085.19
	reef	505	239.982778	49.41	0.29	4988.43	15083.31
	reef	506	227.872222	52.49	0.36	4989.97	15072.24
	reef	507	232.327500	54.56	0.70	4986.21	15074.96
	reef	508	228.560000	58.74	0.61	4984.20	15069.74
	reef	509	217.355000	54.70	0.17	4993.82	15062.94
	reef	510	204.810278	49.60	-0.07	5005.59	15058.80
	reef	511	190.965278	51.33	-0.21	5015.25	15051.21
	reef	512	177.998611	52.05	0.04	5026.22	15047.17
	reef	513	172.436111	60.73	0.10	5030.52	15037.86
	reef	514	169.551111	70.34	-0.24	5033.28	15028.08
	reef	515	177.096111	76.61	0.16	5023.05	15022.80

	reef	516	178.452500	67.29	0.29	5022.99	15032.27
	reef	517	189.831667	70.32	0.27	5009.05	15033.22
	reef	518	191.526667	61.55	0.09	5010.67	15042.06
	reef	519	199.092222	71.65	0.24	4998.22	15037.19
	reef	520	203.135278	60.54	0.14	5000.43	15049.03
	reef	521	211.459444	71.53	0.07	4986.06	15046.68
	reef	522	224.010556	71.15	-0.30	4976.31	15058.86
	reef	523	220.074722	81.54	0.26	4970.95	15048.55
	reef	524	232.162222	85.85	0.34	4958.05	15061.30
	reef	525	223.356667	93.94	0.66	4957.97	15045.32
	reef	526	212.542222	92.75	0.28	4970.14	15032.56
	reef	527	202.753056	94.05	0.28	4981.54	15021.35
	reef	528	191.621389	94.58	0.06	4997.21	15011.90
	base of cliff	529	201.012778	104.24	0.33	4978.32	15011.22
	base of cliff	530	188.108056	93.27	0.42	5003.04	15010.94
	base of cliff	531	188.105000	93.27	0.42	5003.05	15010.94
	base of cliff	532	184.881667	96.15	0.29	5007.17	15006.50
	base of cliff	533	184.881944	96.15	0.29	5007.17	15006.50
	base of cliff	534	184.980000	79.80	-0.08	5011.85	15022.16
	base of cliff	535	176.854722	77.23	0.26	5023.27	15022.13
	base of cliff	536	169.542222	76.49	0.21	5033.10	15021.94
	base of cliff	537	168.310278	68.79	0.29	5034.81	15029.60
	base of cliff	538	163.278611	65.39	0.37	5040.59	15033.19
	base of cliff	539	158.927778	62.54	0.50	5045.08	15036.60
	reef ledge	540	188.566944	49.71	0.18	5017.82	15051.92
	reef ledge	541	194.743611	50.75	0.21	5012.45	15053.17
	reef ledge	542	191.121667	53.83	0.14	5014.13	15048.97
	base of ledge	543	191.232500	51.77	-0.17	5014.86	15050.91
	reef flat	544	192.355833	41.12	0.00	5018.36	15061.00
	reef flat	545	146.160278	22.31	0.34	5043.69	15077.64
	reef flat	546	154.847500	18.29	0.35	5039.57	15080.56
	reef flat	547	150.186389	14.27	0.24	5039.79	15084.78
	reef flat	548	170.232500	8.29	0.39	5035.12	15090.11
	reef flat	549	220.387222	5.33	0.37	5031.24	15095.15
	reef flat	550	250.587222	10.79	0.40	5024.78	15097.04
	base of ramp	551	160.741944	8.52	0.60	5036.52	15089.93
	base of ramp	552	140.414444	9.99	0.57	5040.07	15089.51
	base of ramp	553	132.234444	10.48	0.49	5041.57	15089.86
	steps	554	159.297500	7.22	0.68	5036.54	15091.25
	steps	555	157.213333	5.25	1.34	5036.44	15093.23
	steps	556	150.192222	3.22	1.90	5036.45	15095.32
	IP110 north side wharf	557	332.063333	36.78	2.04	5025.53	15133.80

INFO	DESCRIPTION	PT NO	H ANG	H DIST	ELEV	EASTING	NORTHING
Alofi			*(°T)*	*(m)*	*(m MWL)*	*(m NMG)*	*(m NMG)*
NIUE							
coordinates in:	*Niue Map Grid*						
10-Nov-95							
air temperature	*28°C [E]*						
atmospheric pressure	*1015 hPa [E]*						
prism offset	*-30 mm*						
setup on Alofi wharf IP110							
inst height	Tomb Point control	558	183.173				
1.590	Mapua control	559	208.680				
	Beacon 2	560	144.741				
elev inst	Beacon 1	561	130.177				
2.04	Beacon 3	562	13.079				
	Alofi wharf 1	563	156.694				
easting inst	Alofi wharf 2	564	156.694	36.84	2.26	5035.50	15098.33
5025.53	BM1	565	148.878	41.82	2.84	5042.21	15095.46
northing inst	BM2	566	99.519	38.17	5.24	5062.01	15122.56
15133.80	base of cliff	567	95.773	34.22	0.12	5058.82	15125.88
	base of cliff	568	90.851	38.08	-0.14	5063.19	15128.20
grid angle difference	base of cliff	569	88.604	44.39	-0.12	5069.66	15128.99
7.613333	base of cliff	570	84.255	54.59	-0.08	5080.09	15132.02
	base of cliff	571	82.951	63.12	-0.18	5088.64	15133.18
	S base of sand	572	80.643	64.08	-0.21	5089.59	15135.75
	S base of sand	573	75.938	68.15	-0.10	5093.25	15141.46
	base of cliff	574	77.736	76.59	0.12	5101.87	15140.01
	base of cliff	575	79.354	76.15	0.48	5101.57	15137.83
	base of cliff	576	81.716	74.51	0.92	5100.04	15134.67
	base of cliff	577	82.878	74.40	1.10	5099.92	15133.16
	SPC beach	578	81.184	71.24	0.77	5096.75	15135.30
	SPC beach	579	80.750	67.64	0.50	5093.14	15135.73
	SPC WLO @1445	580	79.956	64.94	0.27	5090.41	15136.55
	base of cliff	581	74.371	77.22	0.04	5101.99	15144.57
	SP beach	582	66.941	77.40	0.01	5100.14	15154.42
	base of cliff	583	62.573	74.31	0.07	5095.45	15158.99
	base of cliff	584	59.044	72.47	-0.03	5092.07	15162.52
	base of cliff	585	53.978	80.42	0.08	5096.26	15172.06
	base of cliff	586	51.019	82.26	0.32	5095.77	15176.62
	base of cliff	587	45.597	87.90	0.21	5095.93	15186.45
	base of cliff	588	42.254	92.18	0.16	5096.01	15193.22
	base of cliff	589	38.442	103.81	-0.04	5100.28	15205.84
	base of cliff	590	35.918	110.12	-0.11	5101.38	15213.64
	base of cliff	591	35.376	115.49	0.08	5104.28	15218.28
	reef rim	592	15.872	100.80	0.18	5065.70	15226.25
	reef rim	593	10.705	100.15	-0.22	5057.01	15228.87
	reef rim	594	7.928	93.84	0.02	5050.67	15224.21
	reef rim	595	5.879	84.34	0.12	5045.21	15215.81
	reef rim	596	5.878	84.31	0.13	5045.20	15215.79
	reef rim	597	9.846	75.25	-0.36	5048.11	15205.59
	reef rim	598	13.936	68.31	-0.35	5050.62	15197.34
	reef rim	599	359.329	60.79	0.26	5032.88	15194.15
	reef rim	600	350.746	55.58	-0.15	5023.94	15189.36
	reef rim	601	0.179	56.82	0.38	5033.23	15190.10
	reef rim	602	355.665	47.42	-0.13	5028.24	15181.14
	reef rim	603	356.107	40.17	-0.02	5028.14	15173.89
	reef rim	604	9.643	40.99	0.52	5037.69	15172.94
	reef rim	605	353.248	35.51	0.08	5026.07	15169.31
	reef rim	606	339.707	32.97	-0.15	5018.30	15165.96
	reef rim	607	328.794	25.99	0.17	5015.13	15157.62
	reef rim	608	307.911	28.53	-0.20	5005.54	15154.16
	reef rim	609	292.544	26.63	-0.07	5002.51	15147.18
	reef rim	610	281.295	35.01	-0.04	4992.41	15145.15
	reef rim	611	276.491	25.37	0.52	5000.93	15139.98
	reef rim	612	275.479	21.71	0.67	5004.39	15138.72
	reef rim	613	278.793	17.61	0.65	5008.64	15138.77
	reef rim at cnr wharf	614	286.143	13.97	0.61	5012.74	15139.43
	reef rim at cnr wharf	615	297.737	10.10	0.64	5017.29	15139.65

	back of reef rim	616	80.314	12.22	-0.55	5037.74	15134.24
	back of reef rim	617	55.249	17.06	-0.89	5040.71	15141.58
	backreef shelf	618	58.725	26.55	-0.33	5049.85	15144.46
	backreef shelf	619	65.729	27.97	-0.42	5052.32	15141.82
	backreef shelf	620	73.592	26.93	-0.41	5052.15	15137.92
	backreef shelf	621	83.581	23.56	-0.35	5049.09	15133.31
	reef	622	66.820	18.08	-0.73	5042.95	15138.65
	back of reef rim	623	43.844	23.06	0.00	5043.57	15148.17
	back of reef rim	624	29.966	30.29	0.07	5044.00	15157.80
	back of reef rim	625	33.707	40.15	-0.06	5052.04	15163.96
	back of reef rim	626	21.439	46.79	-0.09	5048.25	15174.70
	reef rim	627	19.734	41.84	0.42	5044.75	15170.96
	reef rim	628	15.288	36.15	0.34	5039.60	15167.11
	reef rim	629	9.786	29.49	0.53	5034.35	15161.95
	reef rim	630	351.813	23.20	0.62	5025.30	15157.00
	reef rim	631	354.993	16.69	0.42	5026.29	15150.47
	reef rim	632	334.973	11.16	0.43	5022.19	15144.45
	reef rim	633	327.270	5.69	0.28	5023.12	15138.95
	reef rim	634	283.570	23.59	0.78	5003.53	15142.33
	reef rim	635	297.944	22.46	0.64	5007.26	15146.86
	reef rim	636	317.431	21.10	0.57	5013.44	15151.09
	reef rim	637	350.744	27.21	0.72	5024.75	15161.00
	reef rim	638	358.029	28.91	0.74	5028.37	15162.57
	reef rim	639	19.166	7.39	0.54	5028.86	15140.40
	reef rim	640	34.898	3.47	0.51	5027.88	15136.36
	backreef depression	641	51.158	19.67	-1.05	5042.35	15144.00
	reef flat	642	65.037	31.68	-0.10	5055.77	15143.25
	reef flat	643	71.428	50.77	-0.06	5075.38	15143.45
	reef flat	644	59.026	49.58	-0.17	5071.04	15153.46
	reef flat	645	45.182	47.19	-0.14	5063.12	15162.34
	reef flat	646	33.334	50.43	-0.17	5058.58	15171.89
	reef flat	647	32.412	61.25	-0.05	5064.92	15180.71
	reef flat	648	46.079	63.70	-0.13	5076.87	15171.52
	reef flat	649	46.106	72.57	-0.27	5084.03	15176.75
	reef flat	650	40.512	81.53	-0.10	5086.24	15188.22
	reef flat	651	32.153	71.80	-0.13	5071.46	15188.99
	reef flat	652	31.644	83.39	-0.05	5078.30	15198.37
	reef flat	653	25.880	95.32	-0.17	5078.13	15213.30
	reef flat	654	26.720	108.44	-0.08	5086.69	15223.35
	reef flat	655	32.030	108.22	-0.08	5094.58	15217.13

APPENDIX 2

SAMPLE LIST AND DATA

APPENDIX 2

NIUE
Sample Inventory *NU9501*
November 1995

sample ID1	*date*	*location*	*feature*	*material*	*easting (m)*	*northing (m)*	*elevation4 (m)*	*Dmean (mm)*	*Dmean (ϕ)*	*sD (ϕ)*	γΔ	κΔ
1	06-Nov-95	Tamakautoga	beachface	sand	~52082	~93072	0.3	1.59	-0.67	0.37	-0.16	4.43
2	06-Nov-95	Tamakautoga	beachface	sand	~52112	~93102	0.8	1.60	-0.68	0.90	-1.11	4.56
3	08-Nov-95	Hio	beachface	sand	70743	225743	0.7	0.78	0.35	0.48	-0.18	4.68
4	08-Nov-95	Hio	nearshore	sand	70603	225743	0.0	0.49	1.02	0.93	-1.32	5.43
5	10-Nov-95	Avatele	beachface	sand	57843	69103	-0.3	1.49	-0.58	0.76	-0.69	3.48
6	10-Nov-95	Avatele	berm	sand	57843	69123	0.5	2.65	-1.41	1.12	-0.23	2.19
p16	10-Nov-95	Avatele	berm crest	gravel	58333	69333	1.5	25.1	-4.65 ±0.08	0.74		
p17	10-Nov-95	Avatele	beach crest	gravel	58343	69323	1.7	23.9	-4.58 ±0.08	0.78		
p18	10-Nov-95	Avatele	storm ridge	gravel	58373	69313	1.6	59.7	-5.90 ±0.07	0.62		
p19	10-Nov-95	Avatele	beachface	gravel	58323	69353	0.2	8.2	-3.03 ±0.18	1.76		
p20	10-Nov-95	Avatele	swash lobe	gravel	58153	69203	1.1	12.0	-3.58 ±0.07	0.72		
7	10-Nov-95	Tauta	nearshore	sand	~196472	~154432	~0.0	0.46	1.13	0.53	-1.23	5.83
8	10-Nov-95	Tauta	beachface	sand	~196402	~154442	~0.5	0.90	0.15	0.97	-1.04	3.88

Notes:

1 - Sample numbers omit prefix NU9501-; p numbers refer to scaled photographs FZ9546-ff (frame number).
2 - Tamakautoga and Tauta positions approximate (from 1:50 000 topographic map, NZMS 250 Niue, 3rd edition, 1985).
3 - Coordinates for all other sites surveyed in terms of Niue Map Grid (Archbold, 1992).
4 - Metric heights above mean sea level as determined by HMNZS Lachlan in 1955,
viz. 6.0 feet below standpipe in steps of Alofi wharf (from Land Titling Project Office, Alofi);
elevations at Tamakautoga and Tauta estimated from Admiralty Tide Tables 1995.

APPENDIX 3

STORM HISTORY

APPENDIX 3

Storms passing through 5°x5° square centred near Niue

17°-22°S
168°-173°W

date	*sum*	*Pmin (hPa)*	*wind (knots)*	*direction*	*duration (hours)*	*track re Niue*	*damage (NZ$)*	*rating*	*seas*
1915 Jan	1								
1920 Jan	2								
1929 Jan	3								
1930 Nov	4								
1930 Dec (i)	5								
1930 Dec (ii)	6								
1941 Mar	7	970				E		M-S	
1944 Jan	8	<991	gales		12	N		M	
1946 Jan	9		<47	WNW		W		L	
1946 Dec	10	990	<63	N	5	W		M	"very high"
1948 Dec	11		<47			S		L	"rough"
1950 Feb	12					N(-W)		0	
1952 Feb	13					S]		0	
1956 Jan	14					N		L	"tremendous"
1956 Feb	15		<47		>4	SW		L	"tremendous"
1957 Feb	16	985	<34			O		0	
1959 Feb (i)	17					SW		0	
1959 Feb (ii)	18		>100			W	1500000	S	
1960 Jan	19	<950	>90	NE-S		O	32000	S	
1968 Feb	20	<950	>63	E-S	7	O	33000	S	
1969 Jan	21					SW		0	
1983 Mar	22		<37			E		0	
1986 Feb	23					N			
1989 Jan	24		<34			SW		L	
1990 Feb	25	962	~100	W		W	3000000	S	"gigantic"

Sources:
Kreft (1986), Prasad (1990), and storm reports in Fiji Meteorological Service files (courtesy Bruce Ereckson, 1996).