COASTAL MORPHOLOGY, SHORELINE STABILITY, AND NEARSHORE MINERAL RESOURCES OF UPOLU, WESTERN SAMOA

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SUMMARY

A reconnaissance coastal mapping programme was undertaken in Upolu, Western Samoa as a means of identifying potential mineral resources, coastal geohazards, and longterm nearshore processes. Aerial photographs and topographic maps were examined and preliminary interpretations made. These interpretations were checked by limited field observations.

Upolu is a volcanic island surrounded by fringing and barrier reefs. Maximum elevation of the rugged interior is about 1150 m. Age of the volcanic rocks range from Late Pliocene to Holocene and include basaltic lavas, scoria cones, pyroclastics, and tuffs. The coast of Upolu can be broadly subdivided into three basic types based on reef characteristics, depositional features, and hinterland geology:

Type I. Wide fringing reef transitional to a shallow barrier reef. Coastal deposits are generally poorly developed consisting of mixed carbonate/terrigenous sediment in a narrow coastal fringe. The hinterland consists of gently seaward-sloping Mulifanua and some Salani Volcanics.

Type II. Cliffed coast with little or no reef development and limited or no depositional features. The cliffs are composed of either Holocene Puapua Volcanics (lava flows) or older (Pliocene/Pleistocene ?) Fagaloa Volcanics.

Type III. These coasts occur either as: a) fringing reef and narrow coastal strip consisting mostly of storm-derived carbonate sand beach ridge(s) with lesser amounts of terrigenous material, or b) beaches, barrier spits, and coastal swamps associated with rivers and streams. Fronted by a slightly wider fringing reef but prominent gaps occur freshwater output is high. The inshore geology is predominantly Salani Volcanics but may also include Lefaga and Fagaloa Formations.

Engineering structures such as seawalls and groins are common for many areas of the coastline indicating a widespread coastal erosion problem. Causes for the erosion appear to be: a) a possible relative rise of sea level enhanced by island subsidence, b) reclaimed areas and engineering structures extending beyond the natural shoreline in areas prone to wave attack and which interrupt littoral transport of sediment and c) beach mining of sands and gravels for construction purposes.

The well-developed fluvial drainage systems and wide fringing and barrier reefs are conducive to the formation of numerous sites for potential nearshore construction materials. The potential for economically viable placer mineral resources appears to be limited based on the type of source rocks and the relatively small size of the nearshore depositional systems.

ACKNOWLEDGEMENTS

The staff of the Apia Observatory and the Department of Lands and Survey, Apia, are gratefully acknowledged for their assistance in obtaining aerial photographs and maps and for field logistic support. In particular I would like to acknowledge the following people for their contributions: Aleni Fepuleai (base map digitisation), Fa'atoia Malele and Tana Sua (driver, guide, and assistance with sediment sampling), and the Superintendent of the Apia Observatory, Ausetalia Titimaea (logistic support). Lui Bell of the Fisheries Department provided assistance in the field and in discussions on mangrove communities.

Dr Abby Sallenger of the US Geological Survey produced the videotape images of the Upolu shoreline.

INTRODUCTION

Coastal Mapping Programme

A coastal mapping programme was initiated on Upolu Island in Western Samoa as a means of providing a framework within which to identify broad geologic patterns (Roy and Richmond, 1986). The first stage of this programme involved the interpretation of aerial photographs of coastal deposits followed by field verification. Mapping of large areas provides a mechanism whereby the results of more detailed studies can be better applied to the understanding of the entire coastline. The shoreline, reef flats, and coastal plain of Upolu were investigated by a reconnaissance survey designed to examine nearshore mineral resources (primarily construction materials), potential geohazards, and coastal processes. This report is designed to accompany ten 1:20,000 scale maps (4 sheets) produced of the Upolu coastal zone. Appendix I provides brief summary descriptions of the reef types, coastal plains, shoreline stability, and resources for each sheet.

Previous nearshore studies in Upolu by CCOP/SOPAC have included surveys at the following locations: Aleipata (Richmond, 1985; construction materials), Manono (Richmond and Roy, 1989; bathymetry and sediments), Mulinu'u Peninsula (Carter, 1987; engineering applications), Solosolo Beach (Eade, 1979; construction materials), Mulifanua and Salelologa (Gauss, 1982; bathymetric surveys), and Apia and northwest Upolu (Rubin, 1984, Gauss, 1981; bathymetry and construction materials).

A detailed study of shore protection works was completed by the United Nations Development Programme/International Labour Organisation in cooperation with the Government of Western Samoa (Bakx, 1987). The study was undertaken in order to establish areas of long or short-term erosion and to recommend suitable protection works.

Location and Island Geology

Western Samoa is the larger and more westerly segment of the Samoan Archipelago (Figure 1). It is comprised of 2 main islands, Savai'i and Upolu, 2 smaller islands, Apolima and Manono, and several uninhabited islets. The islands lie between 171' 20' and 172' 50' W longitude and 14' 10' and 13' 20' S latitude. Total land area is approximately 2850 km; Upolu occupies just over 1100 km. There are about 155,000 inhabitants of Samoa with 35,000 residing in the capital city of Apia. About 75 % of the people live in Villages on or near the coast. Upolu is roughly elliptical in outline, 75 km long and 25 km wide, and contains a central ridge of volcanic cones as much as 1100 m high.

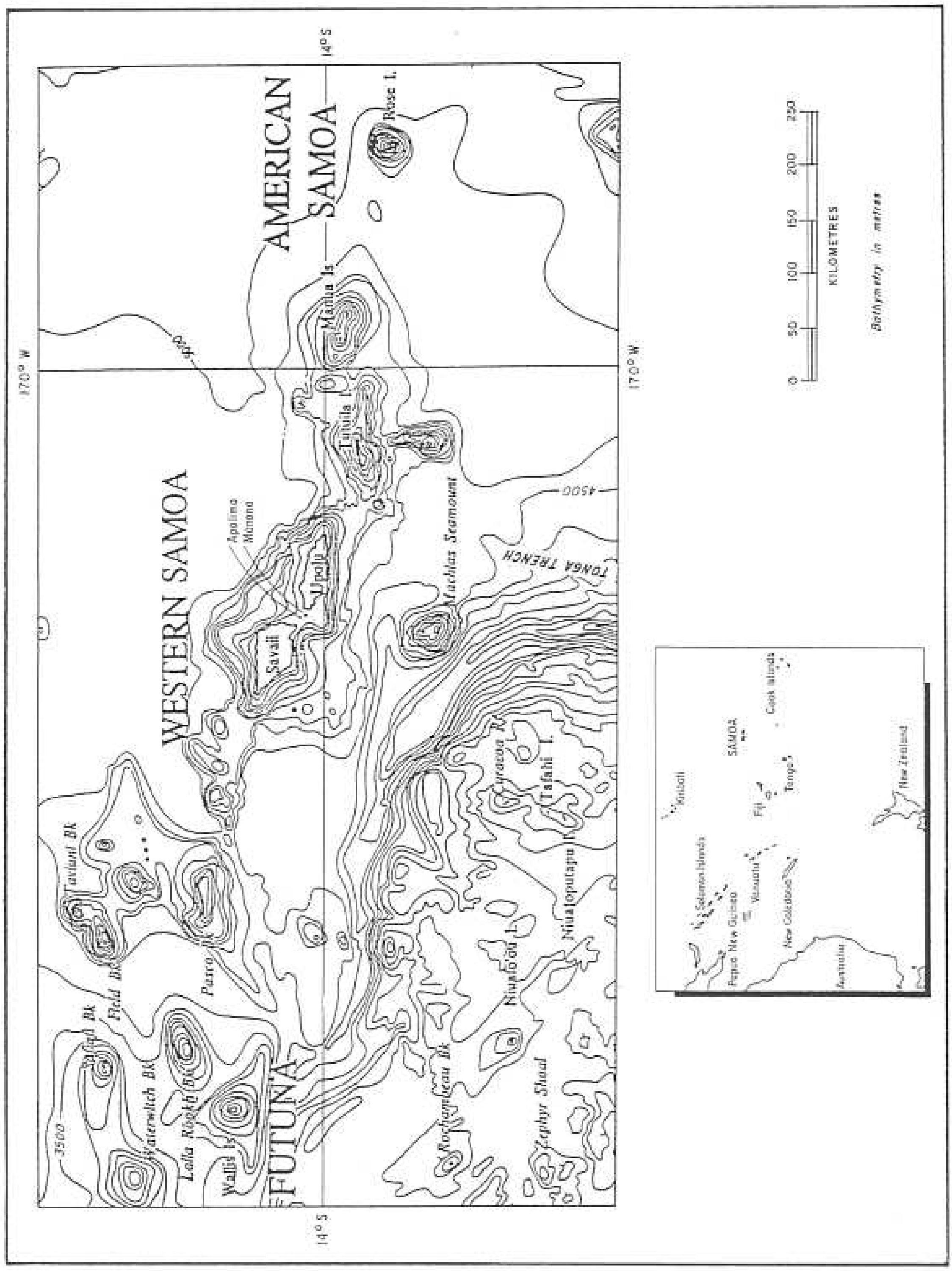


Figure 1. Location and bathymetry of Western Samoa (adapted from CCOP/SOPAC Chart 1: Bathymetry of the Southwest Pacific).

The Samoan Islands are part of a 1200 km linear volcanic chain produced by Pacific Plate bending and rupture associated with subduction at the Tonga Volcanic Arc (Hawkins, 1976). The volcanic rocks are composed mostly of alkalic olivine basalts and their differentiates. Upolu evolved through a stage of shield building and caldera collapse followed by post-caldera eruptive phases and the eruption of highly differentiated lavas (Hawkins and Natland, 1975). The petrology of Samoan rocks has been discussed by Kear and Wood (1959), Hedge and others (1972), Hawkins and Natland (1975), and Ishii (1984).

The age of the volcanic rocks on Upolu range from Holocene to probably Late Pliocene (Kear and Wood, 1959). Table I lists the volcanic formations, ages, and lithologies for Upolu. The ages are poorly known and mainly are based on field relationships between units, relative amount of erosion and weathering, and degree of adjacent reef development.

Of particular importance to the present study is the relationship between the volcanic formations and coastal features. For example barrier reefs occur adjacent to the Mulifanua Volcanics and cliffed coasts are typical of the Puapua and Fagaloa Volcanics (Kear and Wood 1959). Well-developed fluvial systems are usually restricted to the Salani and Fagaloa volcanics. The distribution of the major volcanic formations are shown in Figure 2.

Climate

Western Samoa enjoys a mild tropical climate (Streten and Zillman, 1984). The mean annual temperature for Apia is 26.2'C with little variation around the mean (~23 - 30'C). Average annual rainfall is about 2900 mm/yr with October through March being the wet season. Bright sunshine averages 2575 hours/yr and the most frequent wind direction is from the easterly sectors (tradewind direction).

The frequency and magnitude of major storms is of importance to the development of the coastal zone. Although Western Samoa lies to the north and east of the areas which experience regular tropical cyclones, major storms have been reported. The most recent severe cyclone occurred in January, 1986 and included maximum sustained winds of 60 kts with gusts to 82 kts at Mulinu'u Peninsula (Kerr, 1976). A storm of this magnitude has a recurrence interval of about 40 years (Carter, 1987). Carter (1987) calculated that a significant storm can be expected to strike Samoa about once every seven years. The storms typically travel in a southerly direction and can cause damage along northerly as well as southerly coasts.

Table I. **Volcanic formations of Upolu (after Kear and Wood, 1959)**

FORMATION	AGE	LITHOLOGY
Puapua Volcanic	Middle to late Holocene	Basaltic lavas (pahoehoe) and well-preserved cinder cones with scoria and scoriaceous basalt.
Lefaga Volcanics	Early Holocene	Feldspathic porphyritic basalis (picrite basalis and dolerites) and thick irregular scoria beds (aa) with many bombs and lapilli.
Mulifanua Volcanics	Last Glacial (Late Pleistocene)	Vitreous, porphyritic, and non-porphyritic basalis (olivine basalis, dolerites, and analcite basalis) interbedded with a'a. The upper flow surfaces typically consist of pahoehoe.
Salani Volcanics	Last Glacial and older (Late Pleistocene?)	Picrite basalts, and olivine dolerite and basalts which typically grade upwards from porphyritic basalt through vesicular basalt to rubbly a'a.
Vini Tuff	late Pleistocene(?)	Hard, thick-bedded, calcareous tuff (vitric)
Fagaloa Volcanics	Late Pliocene or Early Pleistocene	Steep weathered slopes of inter-calated a'a and pahoehoe flow rocks, rubbly scoria, ash beds, vitric tuffs. and contemporaneous basaltic dykes.

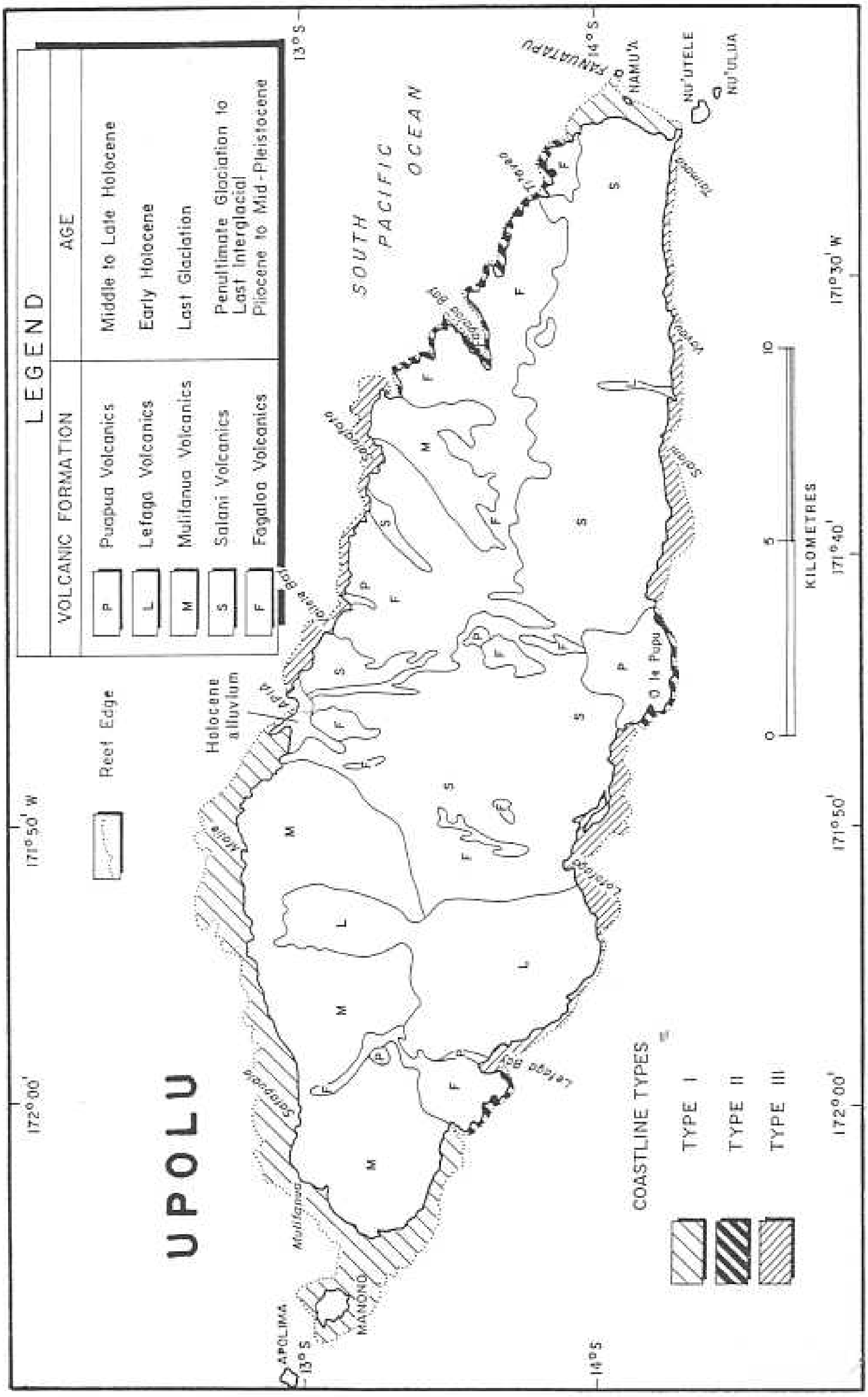


Figure 2. Volcanic Formations and coastline types for Upolu. Geology adapted from Kear and Wood (1959). Coastline types are described in the text.

OBJECTIVES

The work programme was undertaken as part of Project WS.11: "Mapping of coastal and nearshore areas in Western Samoa". Objectives of the exercise are summarised as follows:

a) To describe the geology and morphology of sedimentary deposits in coastal areas.

b) To make preliminary assessments of potential mineral resources such as construction materials and placer deposits in the coastal zone.

c) To provide a scientific framework within which to evaluate broad geological trends, identify environmentally sensitive areas, and assess potential coastal developments.

d) To develop an understanding of the recent geological evolution and to relate this to present day erosion and accretion trends.

e) To train local personnel in the techniques of regional coastal and nearshore mapping and resource assessment.

It is hoped that the maps and accompanying text will provide a useful addition to the knowledge of the Upolu coastal zone and that they will be utilised by planners, engineers, and fisheries personnel as well as geologists.

RESULTS-EXPLANATION OF COASTAL MAP SHEETS

Methods

The survey was conducted by examining published maps and aerial photographs, utilising student maps prepared during the 1985 CCOP/SOPAC-USGS Coastal Mapping Workshop held on Upolu, reviewing videotape images acquired of the shoreline, and sample collection and field observations.

Published maps, available at the Department of Lands and Survey in Apia, consist of a 1:20,000 topographical map series (NZMS 174; contour interval = 50 ft), and a 1:20,000 orthophoto map series produced for the Agricultural Development Programme (contour interval = 10 m). Both series use the same sheet numbering system. Paper multicolor topographic maps were available for the entire coastline, and stable-base blackline orthophoto reproductions were available for all but two coastal sheets (Apia and Lefaga). The maps were used to provide baseline information on the dimensions of reef flat and coastal plain features, location of rivers and reef passages, and accessability for field inspection. Wherever possible the orthophoto maps were used as the primary source of information because they provided more detail than the topographic maps concerning reef flat, reef edge, and submarine terrace features.

Digitised base maps were prepared from stable-base material where available (orthophoto maps) or paper prints (Apia and Lefaga) at a scale of 1:20,000 by a Western Samoan trainee at the CCOP/SOPAC Technical Secretariat (Techsec). Digitisation was performed on a IBM compatible PC/AT using AUTOCAD software. Additional automatic layout software was developed by the Data Management section at Techsec. Final processing and plotting was achieved with a Microvax II and Benson 1625 pen plotter. The digitised base maps show shorelines, reef crests, submarine terraces, and 10- and 20- m contours, rivers/streams, and the main coastal road. These electronically produced maps were then used as the base to be updated by other information and interpretations such as shoreline and reef features and coastal plain geology. The entire coastal region of Upolu is represented at a scale of 1:20,000 on 4 map sheets which follow the same indexing system as the published topographic maps.

1981 vertical aerial photographs (including the negatives) of Western Samoa are held at the Lands and Survey Office, Apia. They were used in stereo pairs to identify morphological and surficial features of the coast and provide details not available in the other mediums. Earlier photographic surveys were completed in 1954 and 1970 and were used in the production of the published topographic and orthophoto maps.

As part of the 1985 CCOP/SOPAC - USGS Coastal Mapping Workshop held in Apia, Upolu, an aerial videotape image of the Upolu coastline was produced. The airplane elevation was approximately 500 feet and the hour-long tape focusses primarily on the shoreline. It was used to provide information on sediments, man-made features, coastal stability, and rock outcrops of the shoreline.

Field checking and sample collection was limited to 3 days during the initial visit (March 1987) and 5 days in April 1989. During the initial sampling survey 37 surface samples were collected from beaches, rivers, and reef flats. Sample locations are shown in Figure 3 and are described in Appendix II. Field checking comprised visual observations at all sample locations and intervening coastal areas that are accessable from the main coastal road.

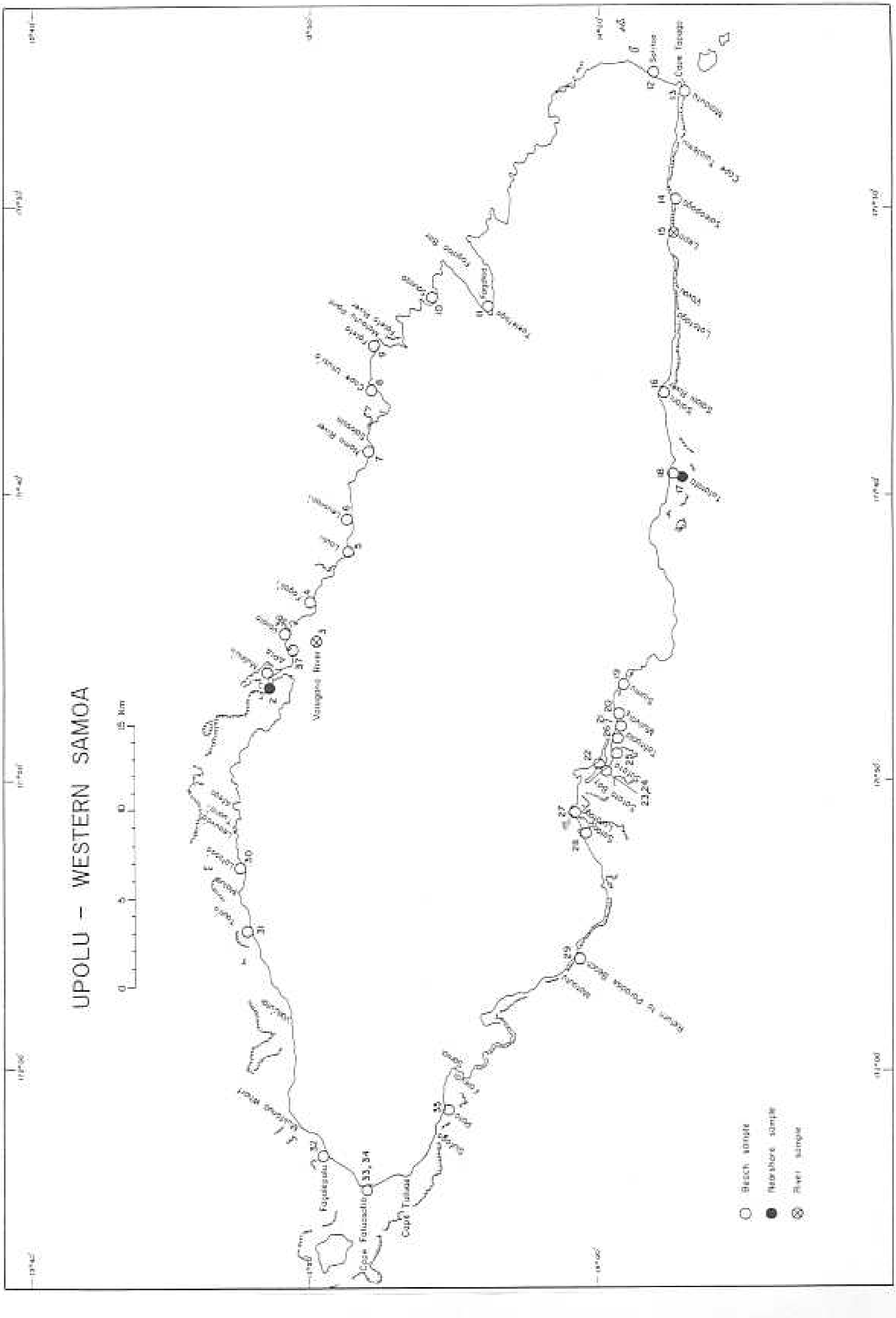


Figure 3. Location of Upolu surface sediment samples collected during this study.

Map Symbols

This section briefly describes the significance of the symbols used on the 1:20,000 coastal morphology maps. Symbol placement on the maps is representative of the features for a general area. For example, the symbols for rock outcrops and sandy shoreline indicates the shoreline consists of sandy beach punctuated by rock outcrops - but there may be more or less rock outcrops than actually shown on the maps. Three basic types of substrate occur on the reefs: coral/algal/pavement, sediment, and marine flora (seagrass and algae). Their relative abundance as determined from the photographs is depicted by symbol density variations on the maps. Because field checking was limited the maps are general representations rather than exact replicates of the existing coast. However, every attempt has been made to produce maps as accurate as possible within the set time frame.

Shoreline Features

Manmade structures . Includes any coastal structure or modification made by man such as groins, jetties, wharves, retaining walls, revetments, channels, causeways, dredge sites, and reclaimed areas. Shoreline armoring and land reclamation has long been practiced in Samoa as evidenced by the numerous basalt-rock revetments and reclaimed areas particularly along the west coast (Mulifanua District). Manmade structures usually indicate areas of shoreline instability; the structures are built to prevent further erosion.

Rock outcrops. Denotes areas where volcanic rocks form the shoreline. Figure 2 shows the distribution of volcanic formations.

Unconsolidated sediments. Marks locations where sediment forms the shoreline or where significant sediment accumulations front other features such as rock outcrops or seawalls. Most shoreline sediment is sand (small dots) but in some cases gravel (larger dots) predominates.

Mangrove and swamp areas. The presence of coastal swamps and mangrove communities is indicative of relatively low energy or protected areas which are usually accompanied by the accumulation of fine-grained sediment. On aerial photographs the mangrove/swamp vegetation is usually easily distinguished from surrounding forest or agricultural land. The boundaries used are based on a combination of aerial photograph interpretation and swamp areas depicted on the topographic maps.

Inferred direction of longshore transport . Figure 4 illustrates shoreline features used to infer local longshore transport direction. In some cases the transport direction is different from that expected (east to west) implying local variations due to complex interactions between the reef, shoreline, and waves and currents.

Coastal Plain Geology

Tafagamanu Sand. Formal geologic name given by Kear and Wood (1959) to beach and beach ridge deposits of carbonate sand occurring up to 2 m or more above sea level. Its use here is slightly expanded to include all Holocene subaerial coastal sand and gravel deposits, a substantial portion of which may be composed of terrigenous sands. Kear and Wood (1959) also used it as evidence of a "5 ft" higher Holocene sea level stand (see discussion on sea level changes).

Alluvium. Alluvium, swamps, talus, and some Tafagamanu sand; as mapped by Kear and Wood (1959). Common along the months of rivers and streams and other low-lying areas.

Coastal cliffs. Shoreline bounded by cliffs of volcanic rocks.

Reclaimed land. Large areas (approx.> 1 ha) of reclaimed land. Smaller areas of shoreline land reclamation are denoted by manmade structure symbols.

Reef Features

Submarine terrace. Taken as the seaward limit of the spur-and-groove zone as seen on aerial photographs. Corresponds to a water depth of around 20-25 m.

Reef crest. Approximate line defined by breaking waves.

Coral/algal/pavement zone. Reef flat and reef crest areas dominated by coral, coralline algae, or rubble pavements. The appearance on aerial photographs is typically as a dark gray zone immediately landward of the reef crest. It is commonly marked by reef-normal lineations of coral or debris.

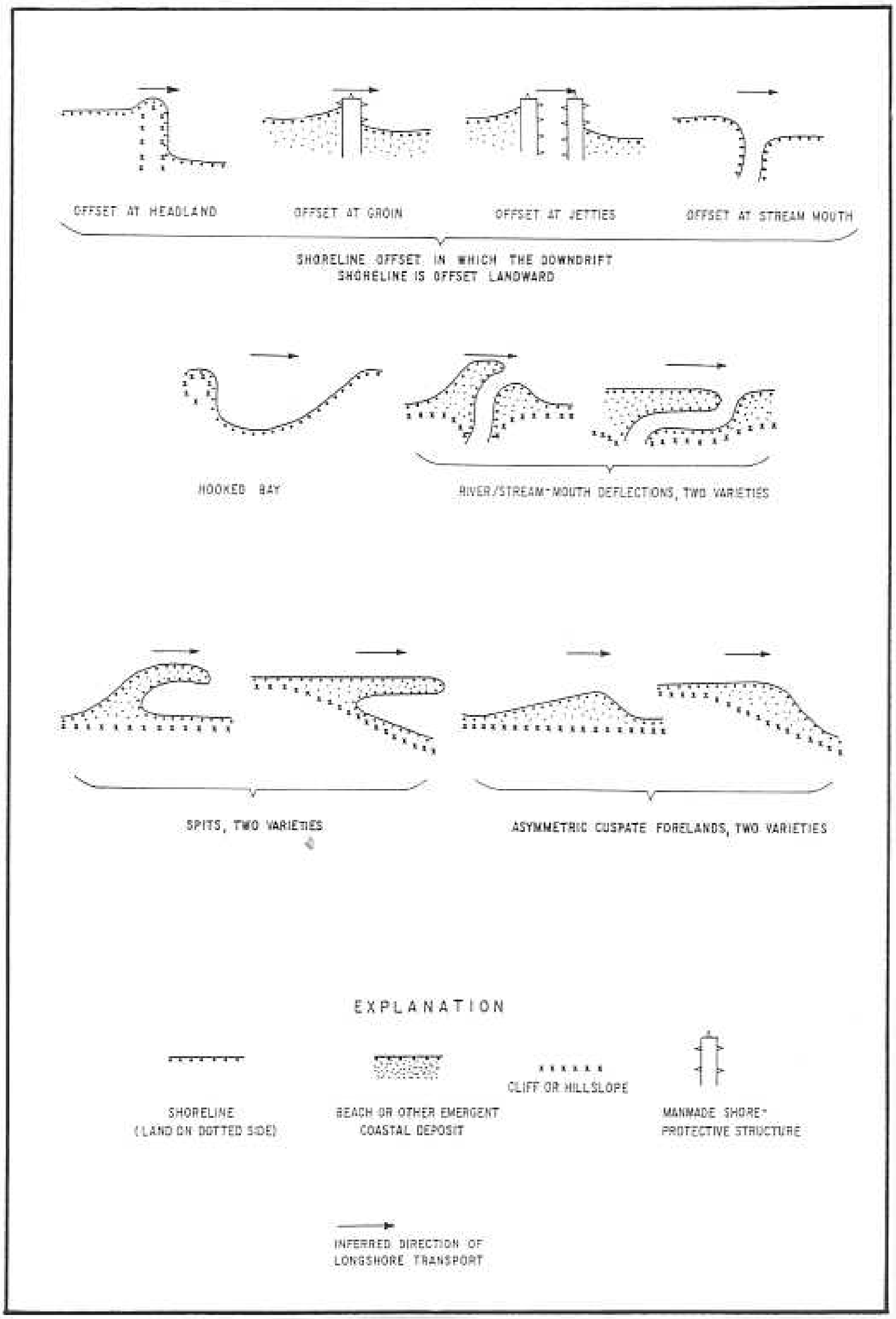


Figure 4. Diagram illustrating coastal morphology features used to infer local direction of longshore transport (modified from Hunter and others, 1979).

Sediment zone. Reef flat, lagoonal, and submarine terrace beds covered mostly by sediment. The sediment is predominantly coarse sand, but gravel and minor amounts of mud also occur. Appears as a white to light gray area on the aerial photographs.

Marine flora zone. Sediment floored areas that are covered by marine flora such as seagrass, green algae (Halimeda sp.), and brown algae. The sediments are usually finer than in the sediment zone because of lower energy conditions and trapping and binding of the tines by flora. Large seagrass beds are discernible on aerial photographs as scalloped-shaped patches.

Blue holes/steep slopes. Drowned karst sinkholes or steep slopes situated within the reefs and caused by debris slides or limestone dissolution. On aerial photographs they appear as deepwater areas within the reefs.

Reef flat lineations. Lineations or striations on reef flat surfaces that are defined by the alignment of coral and other reef materials. They are generally perpendicular to the reef crest and most likely denote sediment transport pathways during storms.

RESULTS - DEPOSITIONAL ENVIRONMENTS AND DISTRIBUTION OF COASTAL FEATURES

Coastal Classification

The coast of Upolu can be broadly subdivided into three basic types based on reef characteristics, depositional features, and inshore geology:

Type I. Wide fringing reef transitional to a shallow barrier reef. Coastal deposits are generally poorly developed consisting of mixed carbonate/terrigenous sediments in a narrow coastal fringe. The hinterland consists of gently seaward-sloping Mulifanua and SalaniVolcanics.

Type II. Cliffed coast with little or no reef development and limited or no depositional features. The cliffs are composed of either Holocene Puapua Volcanics (lava flows) or older (Pliocene/Pleistocene ?) Fagaloa Volocanics.

Type III. These coasts occur either as: a) fringing reef and narrow coastal strip consisting mostly of storm-derived carbonate sand beach ridge(s) with lesser amounts of terrigenous material, or b) beaches, barrier spits, and coastal swamps associated with rivers and streams. Fronted by a slightly wider fringing reef but prominent gaps occur where freshwater output is high. The inshore geology is predominantly Salani Volcanics but also may include Lefaga and Fagaloa Formations.

The distribution of coastline types is shown in Figure 2. Type III coastlines are slightly more extensive than type I which, in turn, are slightly more extensive than type II coasts.

Depositional environments that were formed during the Holocene - the period of time where sea level reached its approximate present position, about the last 4000 to 6000 years - are important geologic features to recognise. They are the sites of accumulation of construction materials and other mineral resources. Mapping of depositional environments can also provide much useful information regarding coastal processes in the area. A number of interrelated coastal depositional environments are present on the island of Upolu including: a variety of reef environments, beaches, river/stream months and deltas, swamps, and mangrove communities.

Reefs

Reefs encircle nearly the entire coast of Upolu. Fringing reefs are the most common type, with barrier and patch reefs also present. Definitions for the different reef types are as follows (from the American Geological Institute - Glossary of Geology):

Fringing reef: "a coral reef that is directly attached to or borders the shore of an island or continent, having a rough, table-like surface that is exposed at low tide; it may be more than 1 km wide, and its seaward edge slopes sharply down to the sea floor. There may be a shallow channel or lagoon between the reef and the mainland, although strictly there is no body of water between the reef and the land upon which it is attached.

Barrier reef: "a long, narrow coral reef roughly parallel to the shore and separated from it at some distance by a lagoon of considerable depth and width. It typically encloses a volcanic island (either wholly or in part), or it lies at a great distance from a continental coast".

Patch reef: "a small, subequidimensional or irregularly shaped, flat-topped organic reef...". Patch reefs on Upolu typically rise from the submarine terrace, are tens to several hundreds of meters in diameter, and may have foundations that are relict karst features.

True fringing and patch reefs are common reef types on Upolu. The barrier reefs of Upolu. are typically shallow, generally less than 5 m, except for deeper blue holes. They appear to be transitional between true fringing and barrier types; i.e. a deep fringing reef or a shallow barrier reef. Since they have already been described as barrier reefs (for example, Kear and Wood, 1959) that terminology will be continued here. Reef components which were mapped include: reef flats, reef crests, submarine terraces, blue holes and shallow lagoons.

Reef Flat

Reef flat is a general term for near-planar reef surfaces - vertical relief is on the order of 1 m. They are commonly graded to a level near the mean low spring water level. Subtle channels or moats may be present. On Upolu reef flats are widespread and are composed of a variety of substrates such as coral, algae, carbonate and terrigenous sand and gravel, cemented reef pavement, and a variety of marine plants (Figure 5). Typically there is a seaward to landward gradation of substrates (Figure 6):

a) A coral zone containing abundant compact coral communities. Interspersed with the coral may be coarse sand and gravel distributed in thin patches. Encrusting coralline algae may cover extensive areas. Large storm-derived reef blocks may also be present. Drilling in this zone along the south coast near Mulivai, Matsushima and others (1984) found small sections of in-situ coral and calcareous algae separated by larger zones of gravelly sand.

b) A sediment-rich zone which grades from gravel/rubble to sand in a landward direction. These unconsolidated sediments may be 3 or more metres thick and are predominantly derived from the adjacent reef front, reef crest, and reef flat calcareous communities. In more exposed locations the upper surface is usually rippled.

c) A marine flora zone characterised by broad coverage of seagrass, and green and brown algae overlying a sandy substrate. Silt and organic matter content of the sediment is higher than in bare sand areas because the plants retard water currents and stabilize bottom sediments. A prolific burrowing infauna is supported and these areas are important habitats for commercially important juvenile animal species. As a general rule the marine flora zone occupies inner reef flat areas and is slightly raised above adjacent sandy areas.

d) Cemented reef material forms a widespread crust or pavement on the reef flats. It is common along the inner reef flat; its occurrence further offshore is not well documented. The overall areal

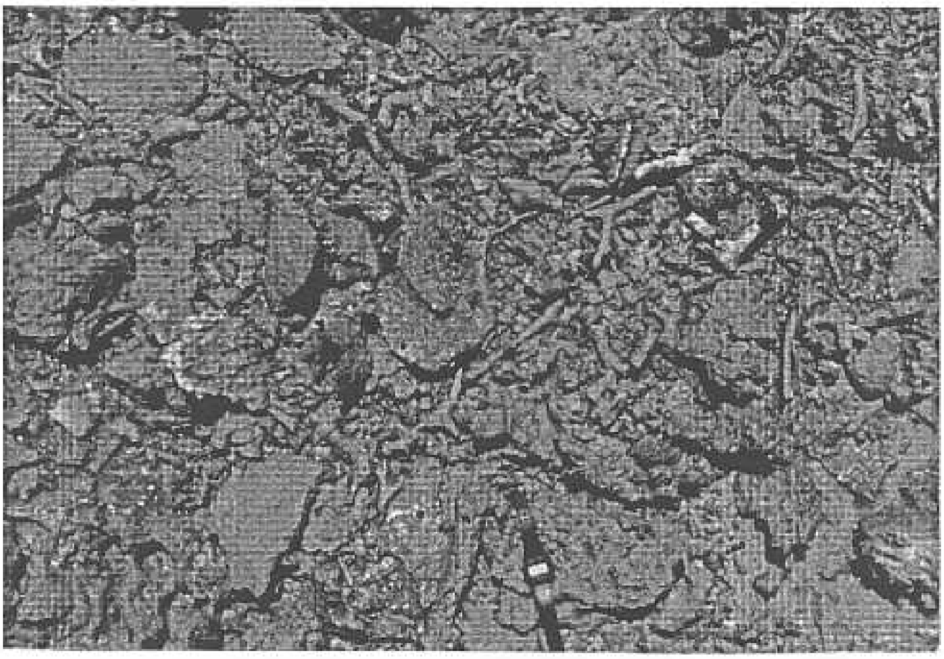


Figure 5. Photographs illustrating various features of the reef environment. Top: a) Small surge channel, approximately 1 m wide, near the reef crest. Coralline algae and compact coral colonies are the dominant biota. View to the north, near Matautu Point, Falefa, N. Upolu. Bottom: b) Reef rubble composed mostly of broken coral fragments, landward of the reef crest, Matautu Pt. Watch in lower center for scale.

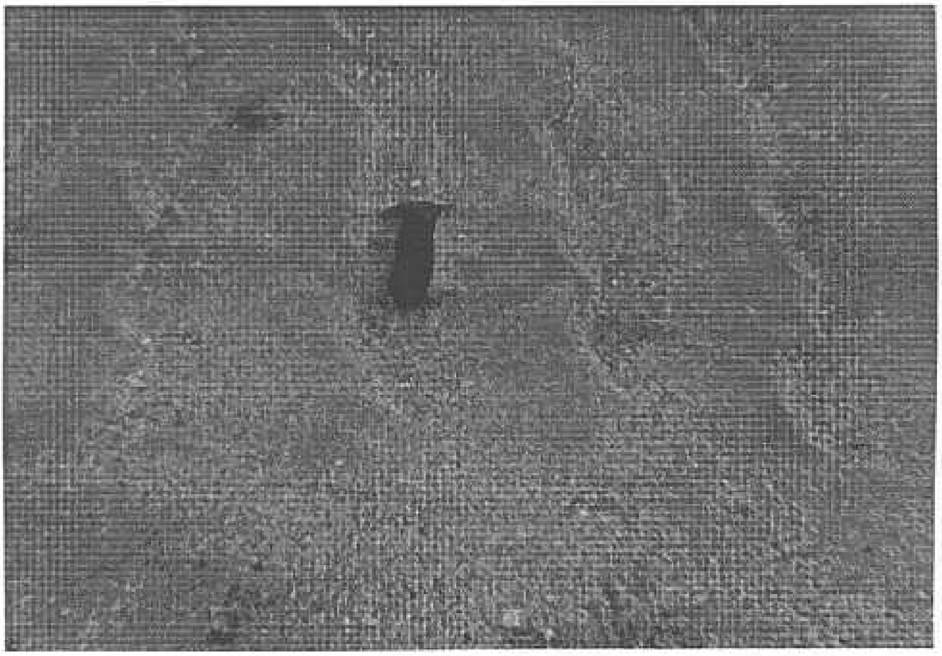


Figure 5. Top: c) Underwater photograph of coral colonies (*Acropora sp*. and others) from a shallow reef flat moat, Saleilua, S. Upolu. Knife inbedded in carbonate sand in center of photograph. Bottom: d) Underwater photograph of rippled sand bottom, inner reef flat, Saleilua. Knife for scale.

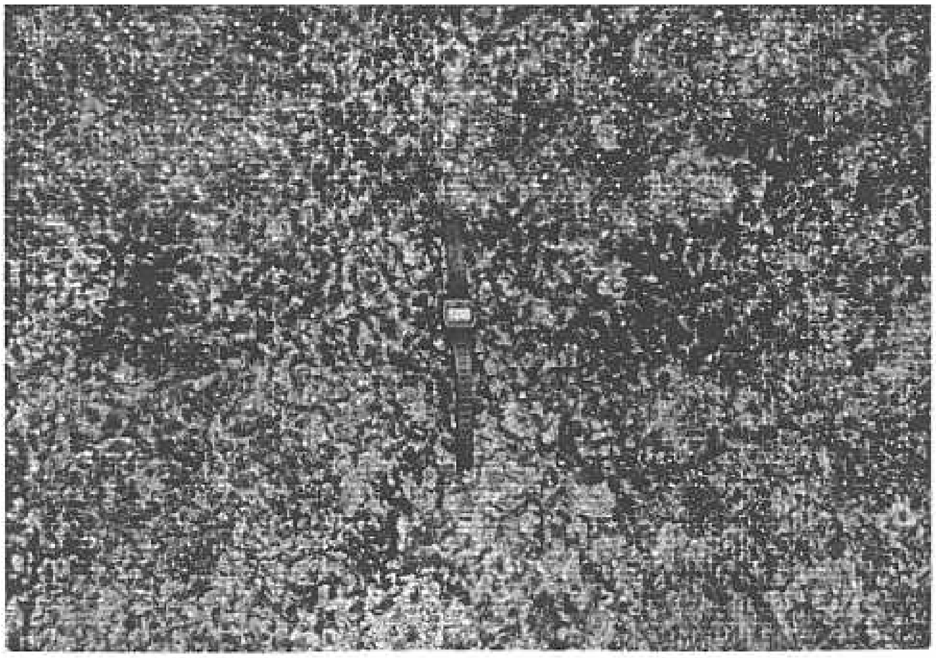


Figure 5. Top: e) Seagrass (*Halophila ovata* ?) from reef flat near Matautu Pt. Watch for scale.
Bottom: f) Seagrass beds (*Syringodium isoetifolium* ?) of the inner reef flat near Tafitoala, S. Upolu.

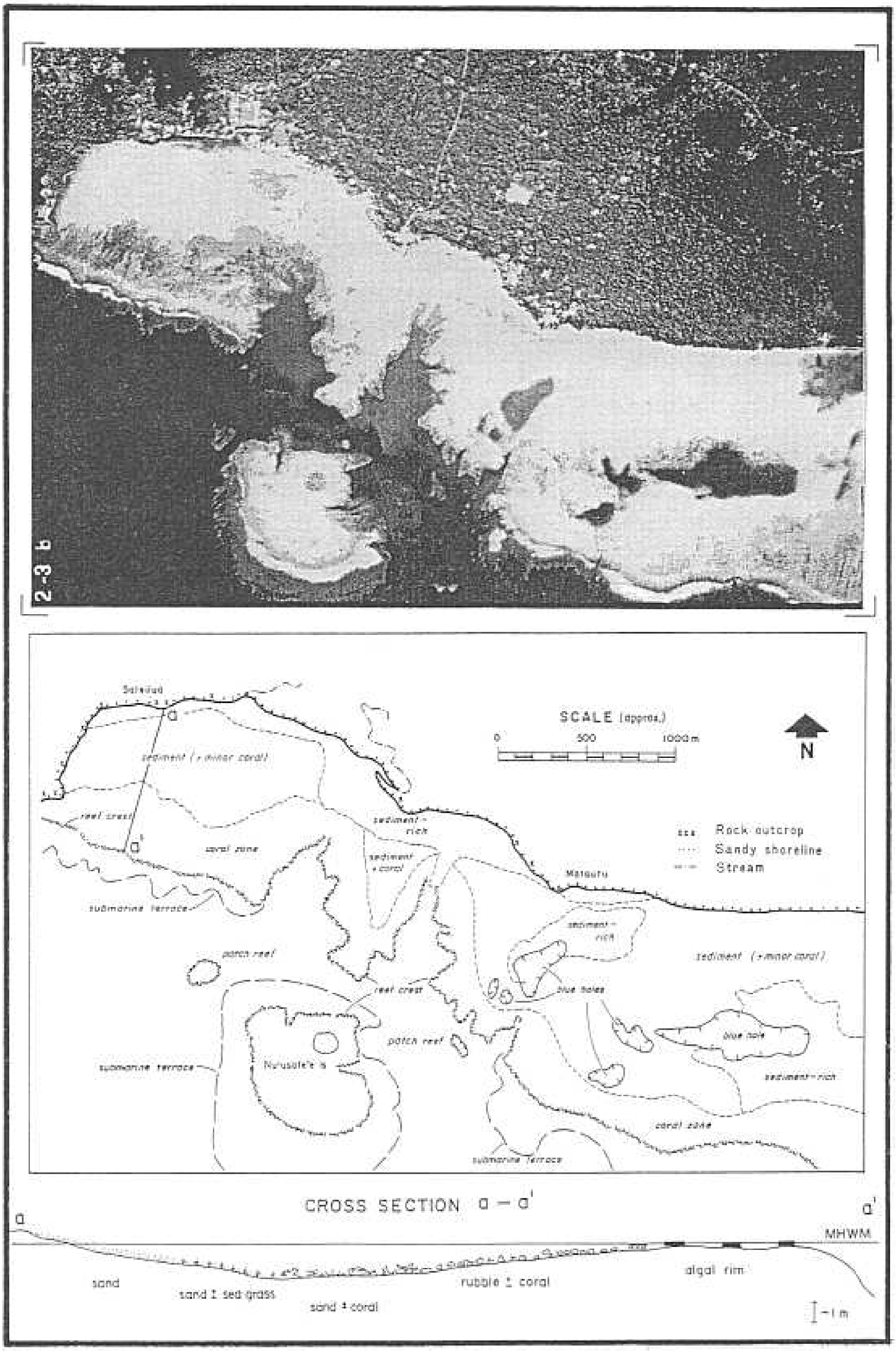


Figure 6. Vertical aerial photograph, interpretive sketch, and schematic cross section showing the fringing reef and associated features near Saleilua-Matautu, Falealili, S. Upolu. The deep reef reentrants are related to onland drainage systems.

distribution of the pavement is poorly known, in part because it is not readily identifiable on aerial photographs. The stratigraphy at the dredging site for the Mulifanua Ferry indicates a crust about 0.9 m thick has formed in less than 3000 years (Jennings, 1974).

The above surficial facies descriptions are greatly simplified - in practice reef flat areas are very complex structures responding to a variety of physical, chemical, and biological controls. A detailed account is beyond the scope of the present study, however, two recent studies of Upolu reefs are given by Morton et al. (1988), and Andrews and Holthus (1988; Aleipata District)

Reef Crest

The reef crest is the highest part of the reef and is composed of either compact coral colonies, encrusting coralline algae, or a rubble pavement. Where an algal rim is present it is characterised by red corraline algae (Porolithon). In shallow pools, coral colonies such as Acropora, encrusting Montipora, and Porites may be present. Sediments are coarse and sparsely distributed, occupying the interstices between corals and algae. Wave energy is high and the boundary with the reef flat is often marked by a debris slope of reef-derived, landward-transported material. The relationship between the reef crest and the adjacent reef flat and reef front/submarine terrace are shown in the echosounder profile of Figure 7.

Submarine Terrace

Wherever the fringing and barrier reefs are well developed they are usually fronted by a submarine terrace. The terrace is identifiable on aerial photographs, appearing as a spur-and-groove zone of coral growth often with a highly irregular seaward margin. Depth information is sparse but the terrace is most prominent between 5 and 25 m water depth. It is separated from the reef crest by a very steep reef front. Formation of the terrace may be related to former sea level positions, however without precise depth and morphology information it is uncertain how uniform the terrace really is and the cause of its formation.

Based on diver observations, the terrace is mostly covered by wave resistant compact corals and coralline algae. Sediment is mostly algal-encrusted coral gravel except in sand-floored channels which traverse the terrace. The seaward edge drops abruptly and there may be further terraces downslope. For example, along the southcoast in the vicinity of the Salani River, Carter (1988) measured a terrace between 30 and 60 m depth to a distance of nearly 1000 m from the reef. This

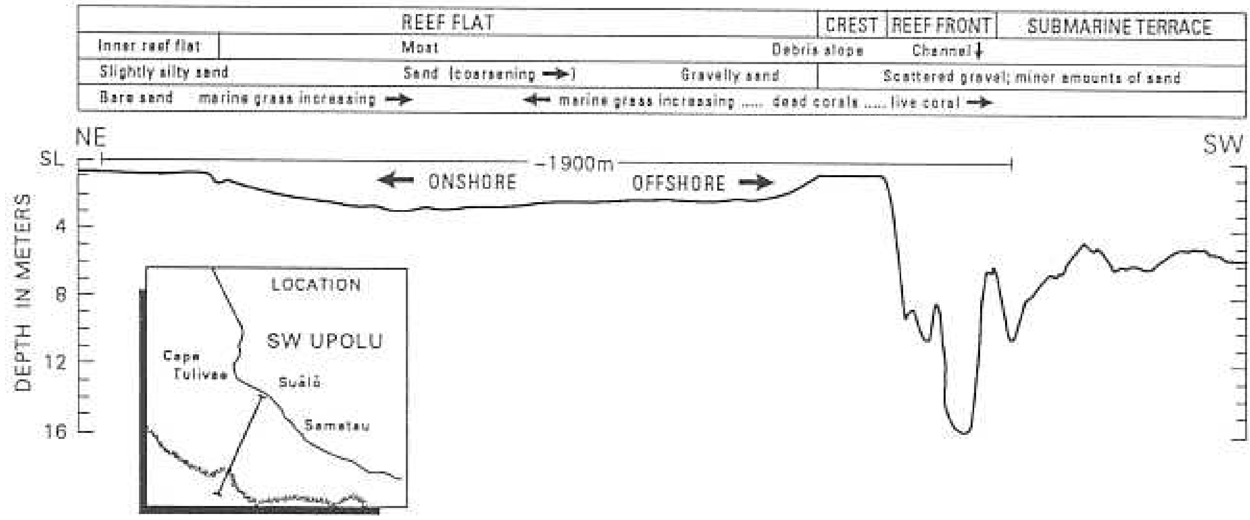


Figure 7. Precision echosounder profile showing sedimentary environments from shore to submarine terrace at Sualo, SW Upolu. Profile taken at high tide; same as line 6 in Richmond and Roy (1989).

terrace is faintly visible on aerial photographs of the area. The approximate submarine terrace distribution for northwest Upolu is shown in Figure 8.

Using diver observations and aerial photographs, Andrews and Holthus (1988) subdivided the Aleipata reef front and submarine terrace into 5 distinct morphologies: 1) Spur-and-groove with drop off. A dissected reef terrace supporting well-developed coral growth with a steep drop off which grades into a sand/rubble debris slope at about 25 m depth. 2) Spur-and-groove with broad dissected lower slope. Similar to (1) but with a wider spur-and-groove zone and a gently sloping terrace to about 25 m depth. 3) Scoured reef platform. A wide submerged platform extending from 10 to as much as 30 m depth and consisting of a scoured surface indicating strong current activity. 4) Spur-and-groove with short slope. A narrow shallow terrace fronted by a steep slope. Reef-rubble flats occur at about 20-25 m. 5) Reef channels (passages). The nearshore ends are characterised by a debris slope of reef talus which extend to a sand floor at about 20 m.

Blue Holes

Blue holes are sinkholes created in limestone reefs by freshwater during lower sea level stands (Backshall and others, 1979). Blue holes are fairly common features of the western half of Upolu. They are best developed within the barrier reef between Upolu and Manono but also occur along the north and south coasts. They vary from a few tens to hundreds of metres wide. Depths as much as 14 m have been measured (Figure 9a).

Blue hole sedimentation patterns follow a typical sequence (Figure 9b): a) A rim of coarse coral debris, in-situ dead and living coral colonies, and sand. b) A steep (~33') debris slope of sand and gravel; sediment tines in the downslope direction. c) A silty mud-filled basin. Variations in this sequence include finer rim sediments on the landward side and in places the avalanche slope is replaced by near vertical limestone walls covered with corals.

Shallow Lagoons

Lagoons, situated behind the barrier reef, are as much as several kilometres or more in width. Depth information is limited but they probably average between 2 and 5 m deep. Bottom type varies from smooth-floored sediment or marine floral blanketed substrates to very irregular areas composed of coral pinnacles interspersed with sediments. Morton and others (1988) described a general sequence of coral variation from higher to lower energy conditions: Pocillopora (+ Millepora)... Acropora..

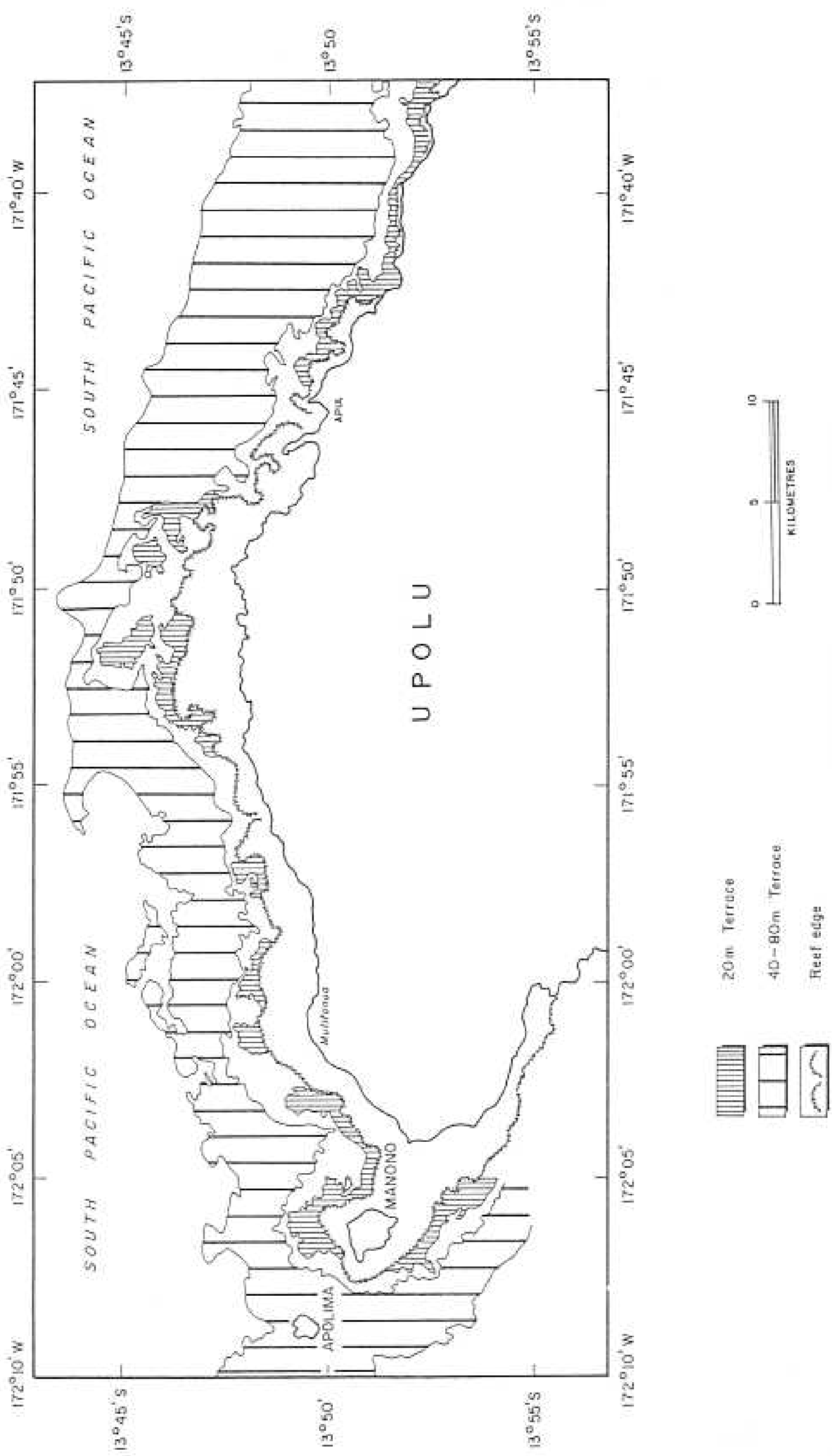
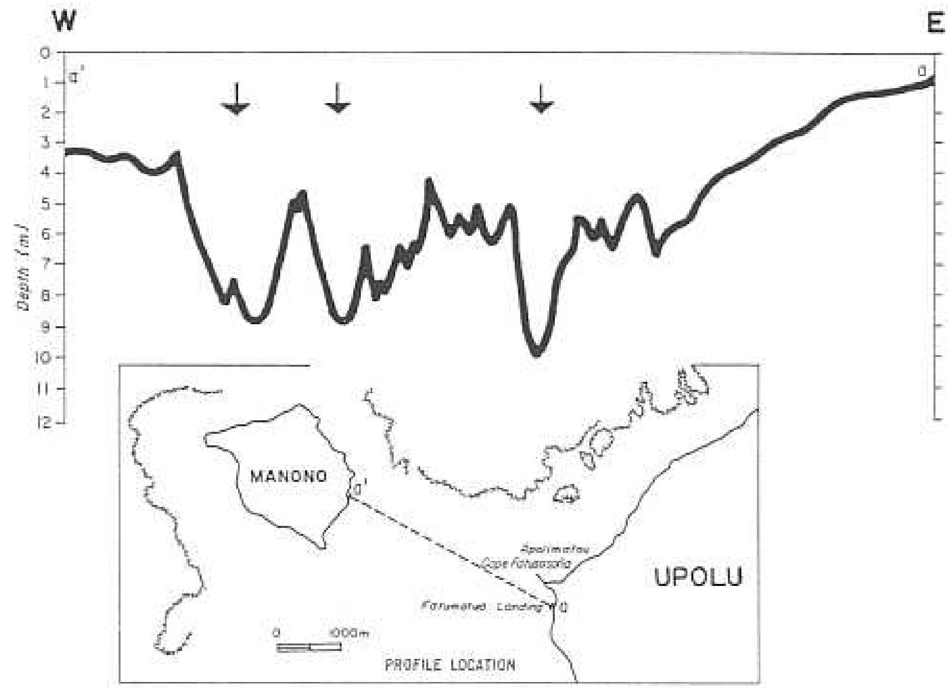


Figure 8. Submarine terrace distribution for northwest Upolu based on the map "Bathymetry of Apolima Strait and Apia Coast" by Kear and Wood (1959).



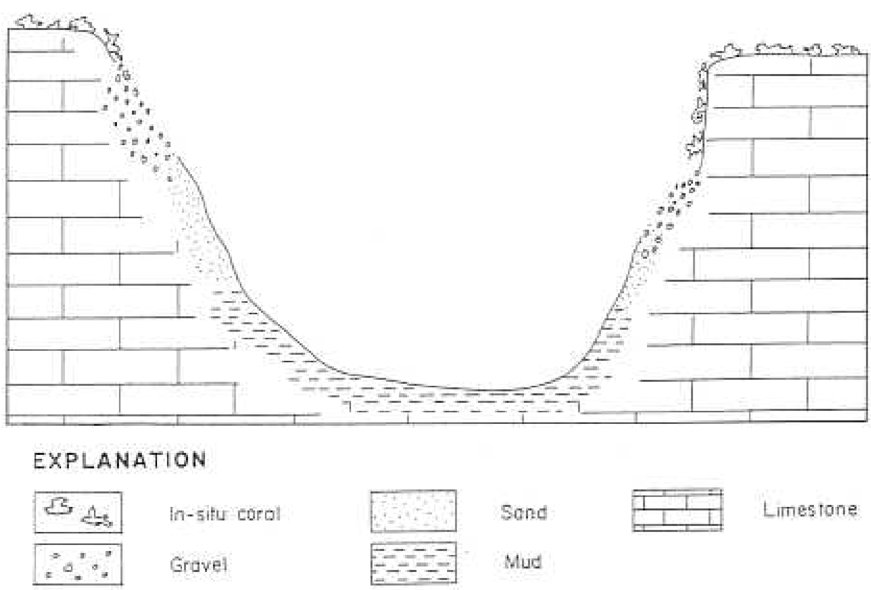


Figure 9. a) Echosounder profile between Upolu and Manono Islands showing several blue holes (arrows) developed within the barrier reef. Average lagoon depth is about 4-5 m. Profile 1b from Richmond and Roy (1989). b) Schematic sketch of a blue hole illustrating facies variation.

Porites + Pavona. Andrews and Holthus (1988) subdivided the shallow lagoon at Aleipata into 8 different habitats based on substrate type, dominant seagrass, dominant cord, and geomorphology. In general, the lagoons are characterised by the deposition of large volumes of reef-derived sediment (for example at Aleipata and opposite Faleolo International Airport) which makes them potential construction material repositories.

Beaches

A beach is an unconsolidated inter- to supratidal deposit of sediment formed at the shoreline typically consisting of sand or more rarely gravel. They act as a buffer between the sea and the land, constantly changing in profile and alignment as wave conditions vary. During storms, beaches are prone to erosion and during fair-weather they tend to build out. The immediate source for the beach sediment is the adjacent reef flat, which in turn derives its sediment from the reef and nearby rivers and streams.

Naturally occurring beaches are ubiquitous features of Upolu and constitute a large portion of the south, east and west coasts. Appendix II lists the beach samples collected during the present survey; their locations are shown on Figure 3. Sand is the dominant textural component of Upolu beaches. Composition varies from nearly pure carbonate sand, those composed primarily of volcanic material, and mixtures of both. Volcanic-rich beach deposits are generally restricted to areas in close proximity to river/stream mouths. Carbonate sediments are produced in reef environments around the entire perimeter of the island, however the finest examples of carbonate sand beaches occur along the high-energy south coast.

Beach elevation above mean sea level is related to the incident wave energy and width of the adjacent reef flat. The highest beaches occur along the southeast coast in the Lepa district. Here, the beach ridge crest is several metres above mean sea level which prompted Kear and Wood (1959) to hypothesize a higher sea level stand. However, the ridges are breached occasionally during storms therefore indicating they could be formed under the present sea level position (see section on sea level).

The beaches usually occur either as (semi-) continuous stretches of coast or as discrete pocket beaches bounded by rock headlands (Figure 10a). Pocket beaches are the most common type on Upolu. The longest continuous beach on Upolu is the beach fronting the Vaie'e Peninsula barrier spit in the Safata District (~4 km).

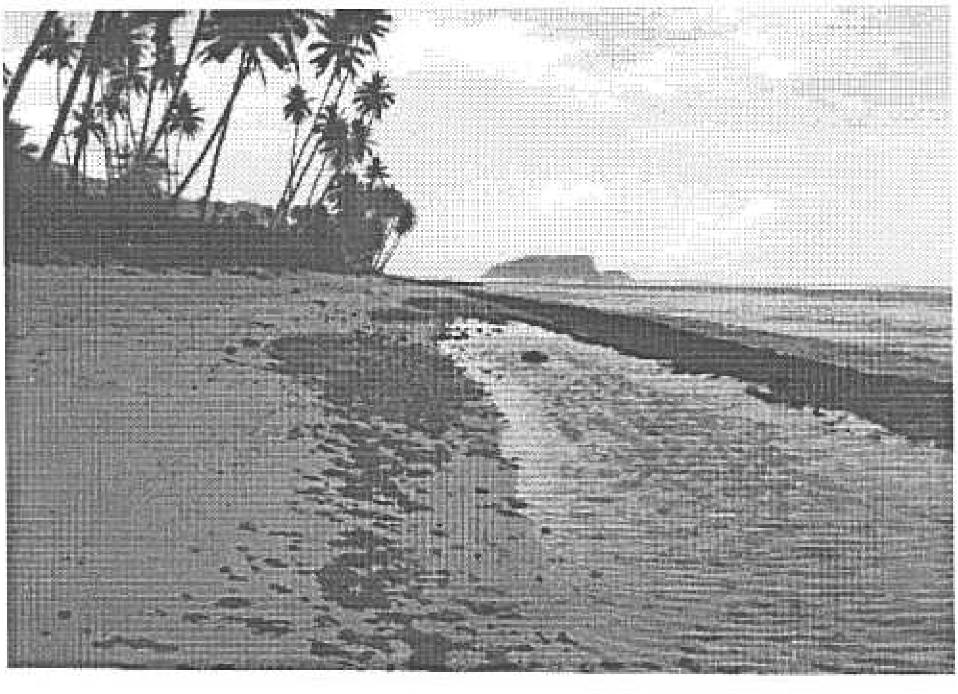


Figure 10. Top: a) Photograph of a pocket beach of carbonate sand bounded by outcrops of Lefaga basalts, southeast of Matautu, Lefaga (Return to Paradise Beach). View to northwest.
Bottom: b) Photograph of carbonate sand beach with prominent beachrock exposures (centre and centre-right). The beachrock demarks a former shoreline position which is slightly oblique to the present shoreline indicating some realignment has taken place. Photograph taken near Saleapaga, Lepa. View to east.

Where coastal progradation proceeds regularly, beach ridges are the typical product. However, extensive beach ridge plains are not common features of Upolu. This could be due in part to human activities (house building etc.) disturbing the ground surface and making their recognition difficult or because of the narrow coastal plain. One of the wider coastal plains is situated along the east coast in the Aleipata district. Although no prominent beach ridges are visible, the ground surface in undisturbed areas is hummocky and carbonate sand underlying 0.8 m of alluvium was found nearly 300 m inland (Figure 11). The lack of beach ridges at this site may be due to human activity, aeolian modification, erosion of the summits and infilling of the swales, or possibly they were never formed.

A common feature of tropical coasts composed of carbonate sediment is the formation of beachrock - calcium carbonate cemented beach sediment. Although its formation is not entirely understood, beachrock cementation proceeds intertidally and at depth within the sediment column. Therefore, surficial beachrock exposures indicate erosion has taken place. Beachrock exposures of Upolu are most prominent along the south coast (Figure 10b) but also occur elsewhere.

Stream and River Mouths

Rivers and streams have two pronounced effects on the coastline. Fist they provide a mechanism for delivering large amounts of sediment to the coast and, secondly, the freshwater flow and increased turbidity inhibits coral growth. Where rivers enter the sea there is usually a deceleration of current flow resulting in deposition of sediment. In Samoa, rivermouth spits are the most common fluvial depositional feature; more rarely small deltas are formed. The deltas, where present, are usually small, wave-dominated, and typically submerged except for flood-deltas developed on the reef flats. Gaps in the reef may occur off the larger rivers. Large deltas are not formed primarily because of the high wave energy along the coast and the narrow shelf.

The river/stream mouths of Upolu can be adequately described by three different types:

a) A prominent gap in the reef where the river/stream discharges directly to the open sea. If a shallow offshore terrace or platform exists a submerged delta may form. Figure 12 showing the mouth of the Vaisigano River, Apia, is an example of this type of delta. There is a 500 m wide break in the reef presumably caused by freshwater outflow. The overall surface sediment pattern is seaward fining out to mid-harbour where an influx of reef-derived material is reflected in a coarsening trend. A “soupy mud covers the bottom over much of the delta front area (Gauss, 1981). Where the river first enters the sea an extensive gravel body, as much as 2 m or more in thickness, is developed. It is progressively covered by finer and finer material but is still detectable at depth over 125 m from the

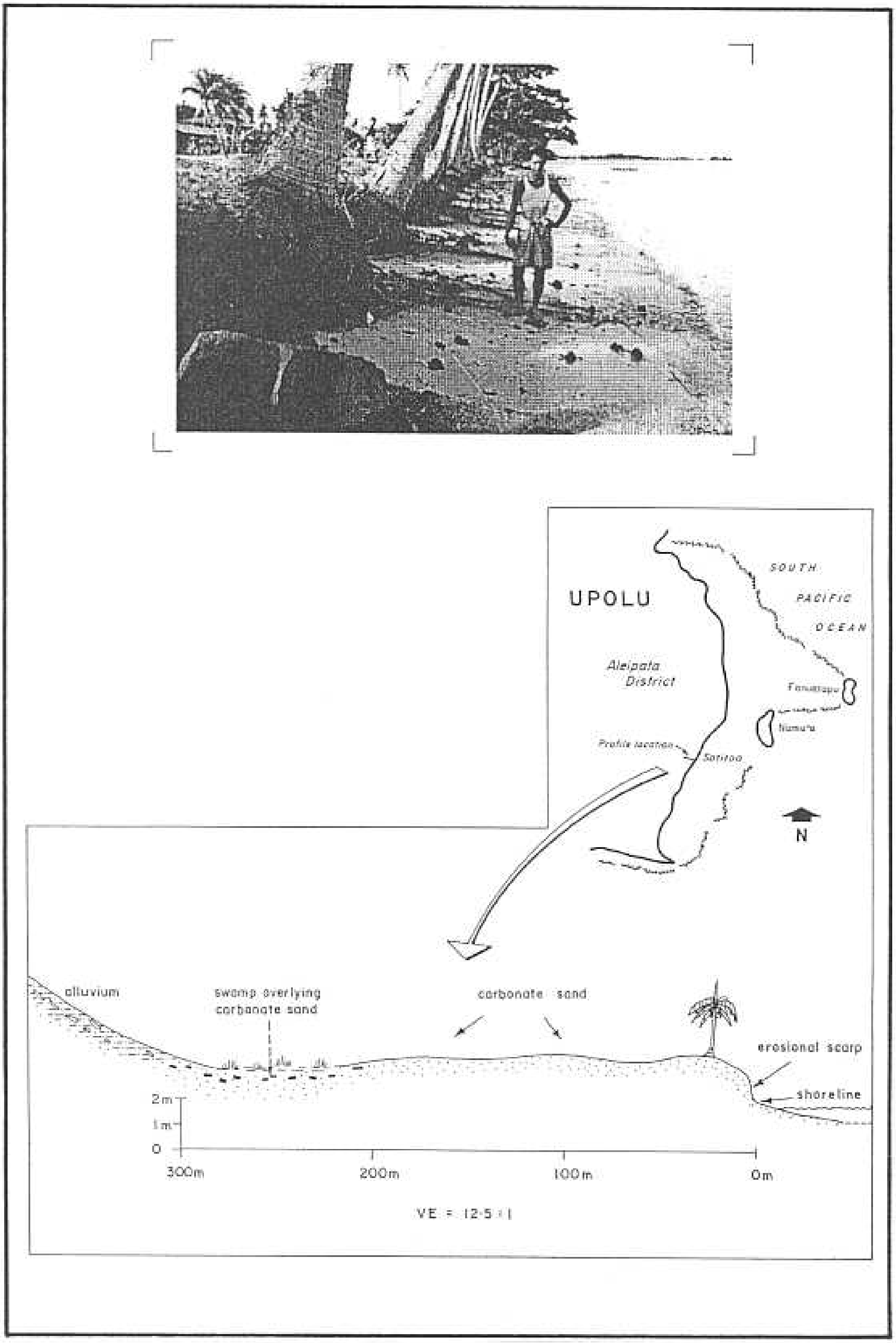


Figure 11. Beach and coastal plain near Satitoa, Aleipata. a) Photograph of carbonate sand beach backed by an erosional scarp formed along the base of the coconut palms. View to north. b) Sketch map of traverse across the coastal plain. The surface topography is hummocky; individual crests could only be traced for short distances.

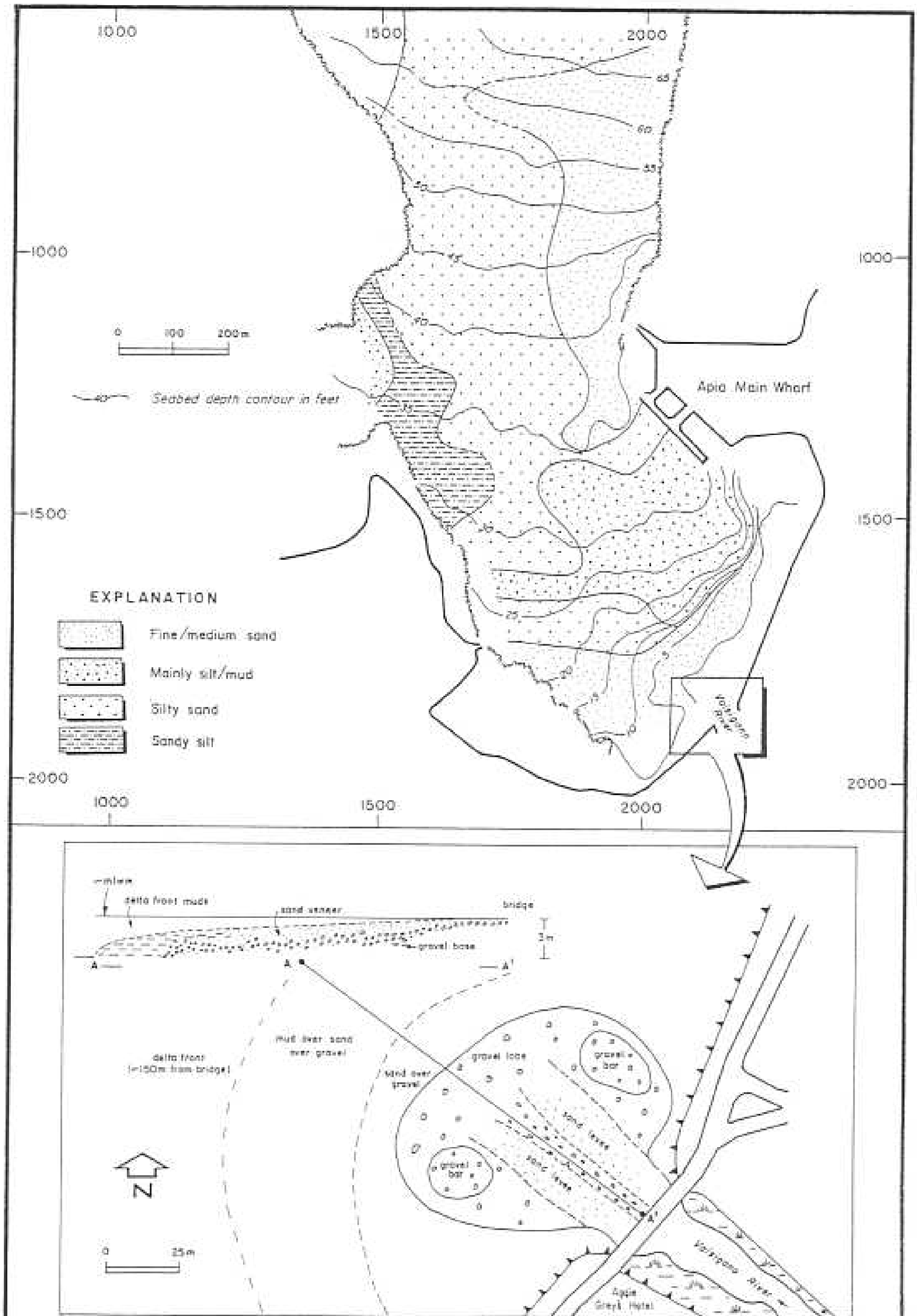


Figure 12. Delta development at the mouth of the Vaisigano River, Apia. a) Offshore bathymetry and surface sediment distribution (adapted from Gauss, 1981; dredging of the harbour occurred prior to the survey therefore the contours may not be representative of a natural situation). b) Sketch map and cross section of the intertidal to shallow subtidal delta at the mouth (based on data collected in September, 1988; Harper and Richmond, in prep.).

mouth. Terrigenous sands and gravels at the mouth are periodically excavated for construction materials however, they are replaced during floods.

The reef-gap river/stream mouth type is prevalant along the northeast coast. Rivers/streams which display this type of morphology include: Vaivase Stream (Fagali'i, Apia); Letogo Stream, Lauli'i Stream, Maepu Stream, Namo River, Falefa River (Lepa); and several unnamed streams in the Lepa andFagaloa Districts.

b) Barrier impounded river/stream mouths characterised by barrier spits, meandering channels near the mouth, well developed swamps or mangrove communities, and with or without an adjacent gap in the reef. Submerged deltas may be present. They differ from the reef-gap type in having more extensive barrier/swamp deposits and a less prominent break in the reef, although transitional types exist.

The best examples, the Mulinu'u and Vaie'e barrier spits, are not presently associated with large rivers. They may represent older Holocene deposits and are therefore probably partially relict features. The generalised sediment distribution in the vicinity of the Mulinu'u barrier spit is shown in Figure 13. Other barrier impounded river/stream mouths include: Mataloa Stream, Vaifaliuga Stream, Vailoa Stream, and Mulifagatoloa River (Falealili); Vaiania Stream (Satafa); and Vaisala Stream (Lepa).

c) Ephemeral streams which deposit directly onto the reef flat. During extreme events a flood-delta may form. Flood-deltas form rapidly during high-discharge events and deposit large amounts of mixed sediment. Reworking of the flood deposit by waves and currents often leaves behind a lag of coarse debris (Figure 14). Reef re-entrants commonly occur nearby but usually there is a reef flat fronting the mouth. This type of river/stream mouth is typical of the south coast ephemeral streams.

Sediment discharge

The amount of sediment delivered to the coast from rivers and streams is unknown. Unpublished streamflow records from the Hydrology Section of the Apia Observatory were examined to obtain peak discharges for a number of rivers and streams of Upolu. Although the records are incomplete they do provide an indication of potential discharge during flood events. Using relationships between discharge and sediment load established in the United States (Nordin and Beverage, 1965) approximate values of bed-load transport were determined (Table II). These values give an order of

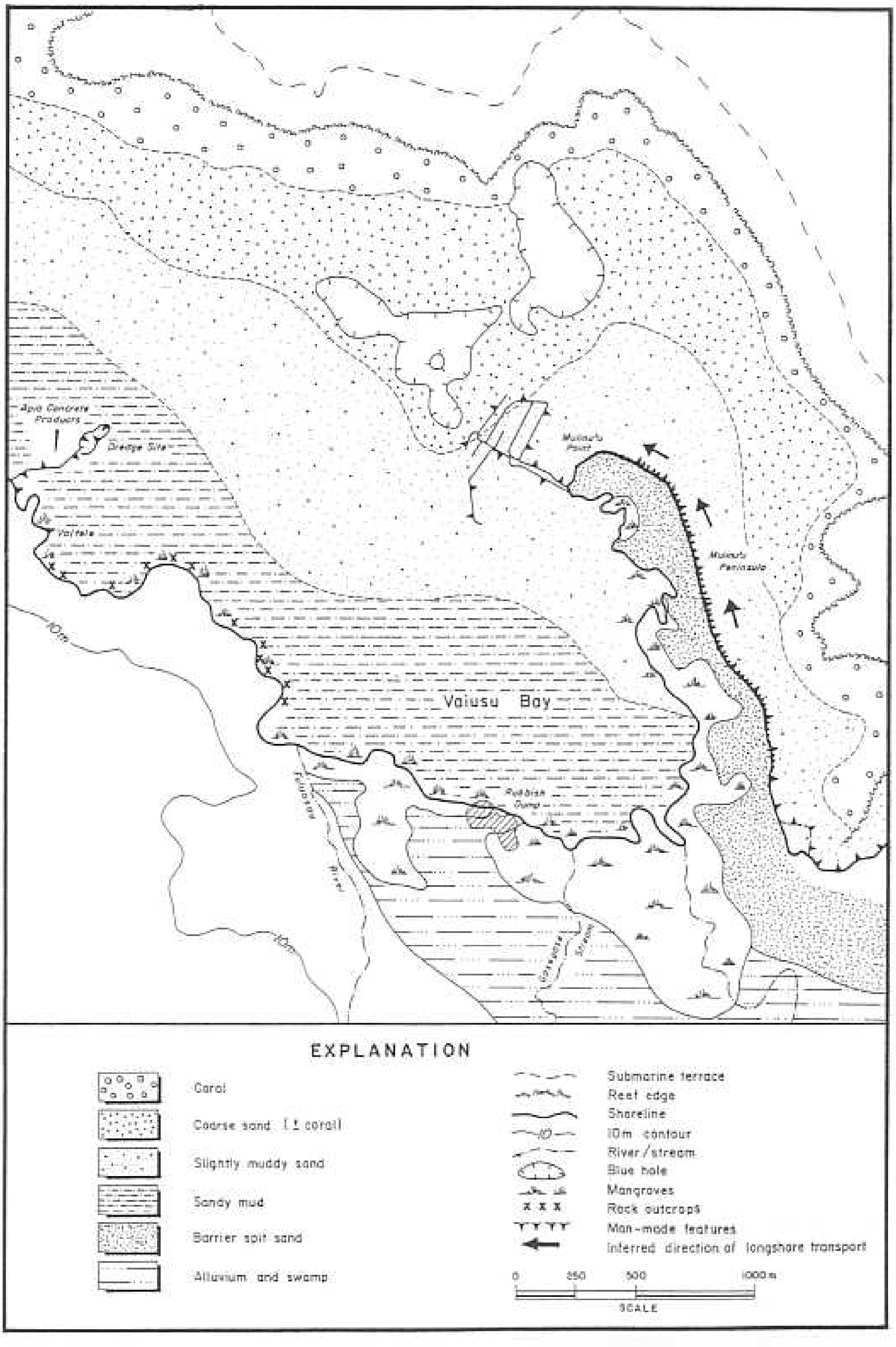


Figure 13. Sediment facies of the barrier-impounded river/stream mouths at Vaiusu Bay, Apia. The Fulusou River and Gasegase Stream mouths are protected from the open sea by the Mulinu'u barrier spit which is composed of terrigenous and carbonate sands. Extensive mangrove communities are developed within the bay. Sediments coarsen and increase in carbonate content seaward. The blue holes are probably related to paleo- drainage systems. The material from the dredge site is a mixture of terrigenous (~30-50 %) and reefal sand and gravel with a small amount of fine material.

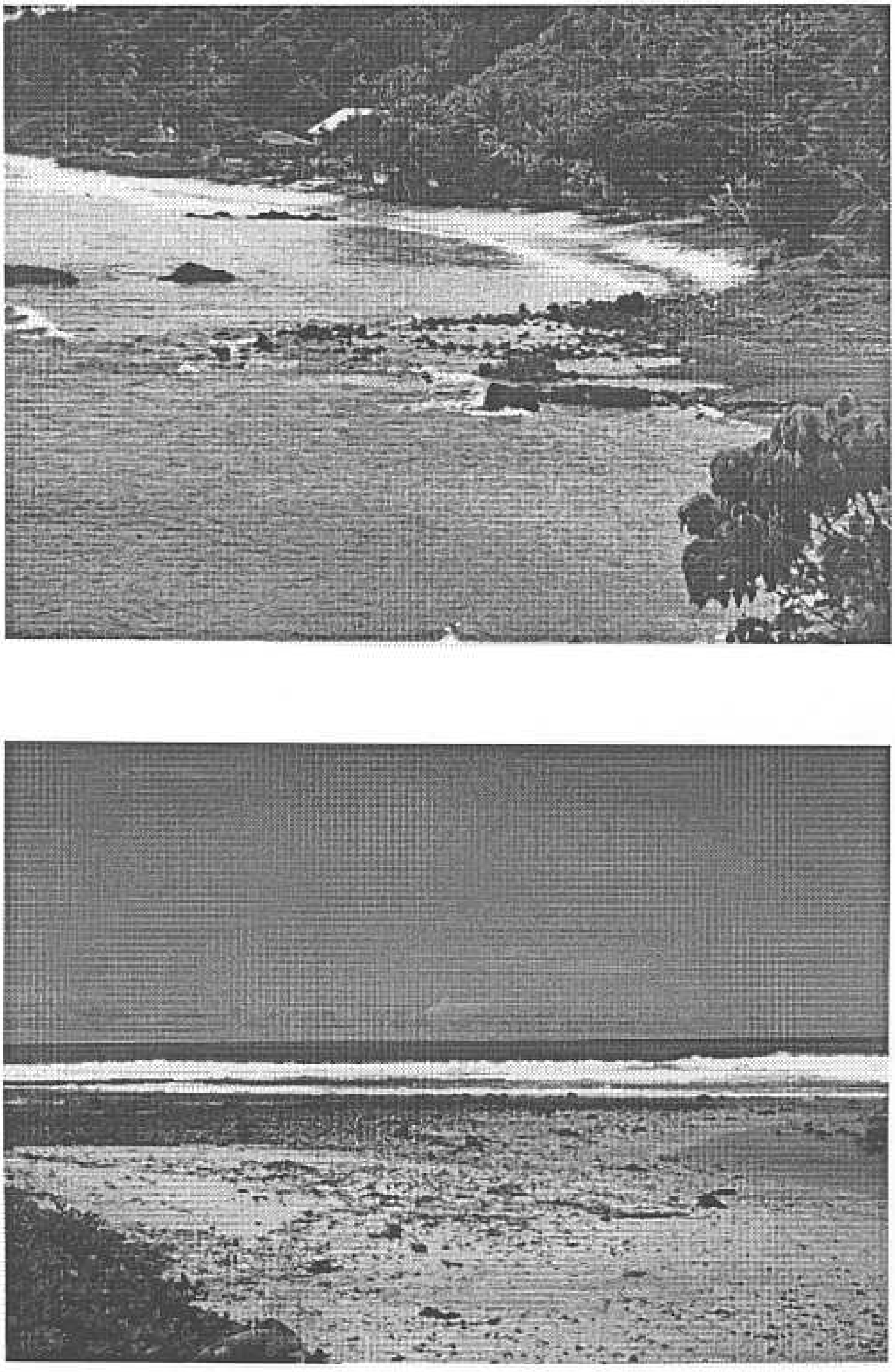


Figure 14. Top: a) Photograph of flood delta composed of terrigenous sediments (volcanics) at the mouth of an unnamed stream, Vavau, Lepa. Presumably the initial flood delta was much larger - the overlying sands having been winnowed away leaving behind a gravel base. View to west.
Bottom: b) Photograph of volcanic-gravel flood delta base overlain by carbonate sands. Mouth of Sinoi Stream, Lepa. View to south.

Table II. Peak discharge and predicted sediment loads for some Upolu rivers and streams.

LOCATION	YEAR	PEAK DISCHARGE* (m'/s)	PREDICTED+ SEDIMENT LOAD (m'/day)
Salani R., Sopo'aga	197s	164	34,300
Salani R., Vaipu	1974	47	4,600
Vaisigano R., Alaoa W.	1974	90	13,100
Vaisigano R., Alaoa E.	1976	186	45,700
Vaisigano R., Tiapapata	1974	55	6,900
Mulivai S., Ti'avea	1978	41	4,000
Falefa R., Sauniatu	1976	144	25.700
Falese'ela S., Falese'ela	1975	15	1,500

* Peak discharge values from unpublished records of the Hydrologic Section, Apia Observatory. The values are determined from several different measuring techniques and do not represent a comprehensive analysis of all available records. It is not known at what frequency these discharges are likely to occur.

+ Predicted sediment load by comparing peak discarge values with published sediment bed-load data for the Rio Grande River, New Mexico (Nordin and Beverage, 1965). Assumptions used include a particle density of 2.65 g/cm and a porosity of 40 %. Not corrected for temperature differences. The variation between erosion potential between Western Samoa and the temperate climate site are unknown, however, data from Fiji suggests the lowest erosivity rates there equal some of the highest rates in the United States (Nelson, 1987).

magnitude estimation of the amount of material transported to the coast during floods. Floods are a major contributor of sediment to the coastal zone. Some of this material forms depositional coastal features but the majority of it is probably transported into deeper water offshore.

Rubin (1984) estimated the rate of harbour infilling at Apia (~1500 m'/yr) and the rate the Vaisigano River could supply sediment during a flood (~10,000 m'/day). These calculations show the Vaisigano could easily supply enough material in one day of flooding to account for a yearly rate of harbour infilling. The excess material is presumably lost offshore.

Swamps and Mangrove Communities

Low-lying coastal swamps and mangrove communities are common features of the drowned valleys and barrier impounded river/stream mouths of Upolu. The largest mangrove swamps are situated behind the large barrier spits at Mulinu'u and Vaie'e. Swamps also inhabit many areas backing beach ridges of Tafagamanu Sand. They form important habitats for many commercial fish and (other marine fauna species (Bell, 1985). Historically mangroves were more extensive, often fronting protected sand beaches, but were removed for firewood - a practice which may have contributed to coastal erosion. Mangrove swamps are also common targets for land reclamation activities.

Wright (1963) recognised several types of coastal swamp communities: 1) Tidal forests which are dominated by mangroves (Rhizpora *mangle,* and Bruguira conjugata) and occur in sheltered bays, estuaries, and lagoons where fine sediment is accumulating. 2) Lowland rush and reed swamps which typically form a fibrous peat deposit. Drier areas may contain ferns. The ground water varies from brackish to almost fresh. Several large swamps occur to the south of Mulifanua. 3) Swamp forests in low-lying coastal areas with *Pandanus* usually conspicuous.

Figure 15 shows the vertical facies distribution within a mangrove swamp at Lefaga Bay on the south coast. A vertical succession from barrier spit to estuary to swamp indicates subsidence and seaward progradation of facies. This sequence is probably typical of other swamp deposits.

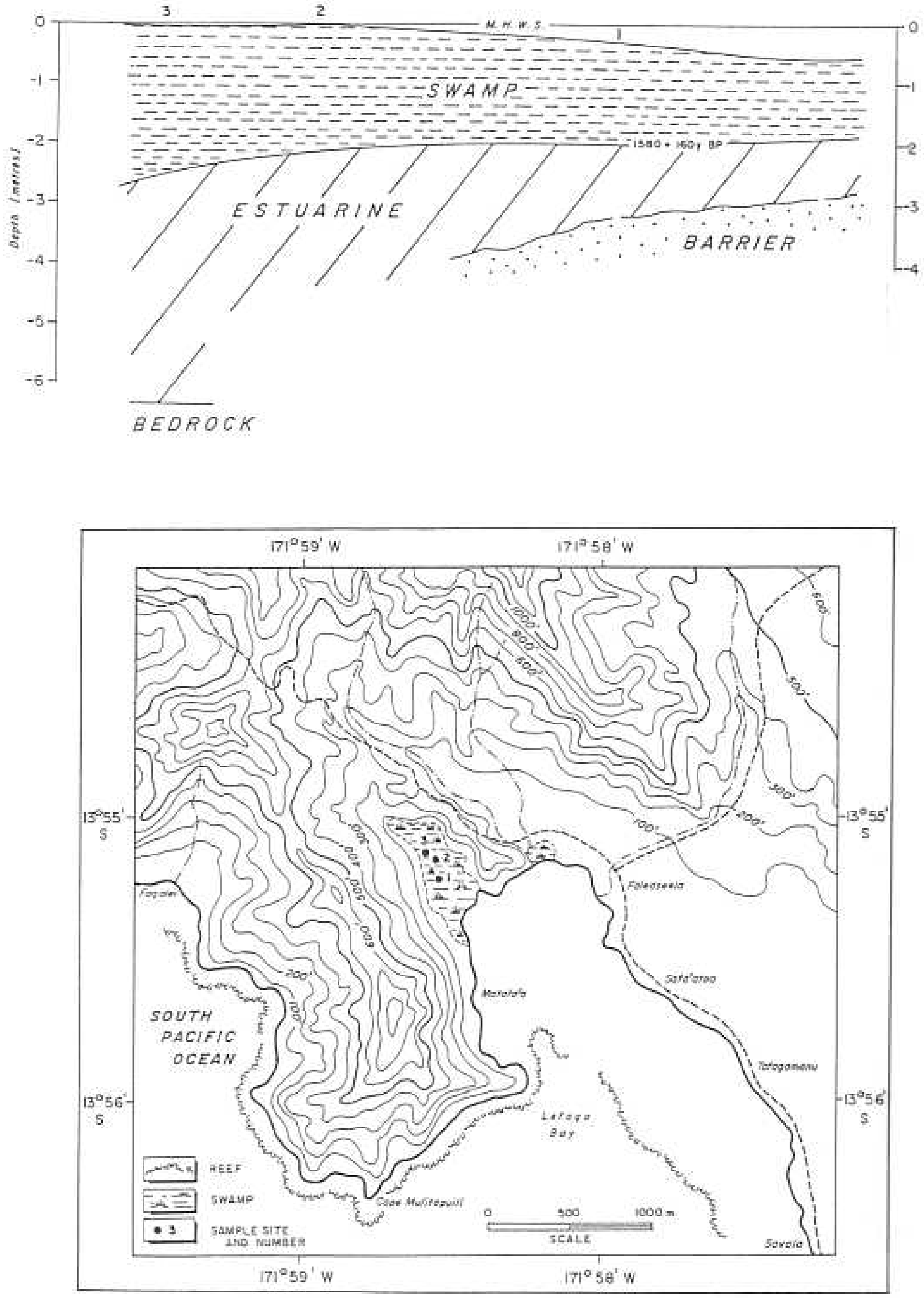


Figure 15. Top: a) Simplified geologic cross section through the mangrove swamp at the head of Lefaga Bay. The swamp deposits consist of a black-brown silty peat with transported shells, coral, and lapilli. The underlying estuarine unit is a blue-brown to grey silty sand with mollusc and coral fragments. The boundary between the swamp and estuarine units was radiocarbon dated at 1580 yrs b.p. The basal sand cored at site 1 is probably a buried barrier spit. Modified from Sugimura and others (1988). Bottom: b) Location of swamp and core sites.

DISCUSSION - COASTAL PROCESSES AND GEOHAZARDS

Sediment Transport

Because of a lack of data regarding the direction, strength, and variability of nearshore currents around Upolu a discussion of coastal processes must be based on inferred transport patterns deduced from morphology and a knowledge of the general climatic circulation for Samoa. Overall, the nearshore waves and currents are driven by the predominant easterly winds. A simple model of longshore transport infers east to west movement of nearshore sediment. The orientation of some of the major depositional features, such as spits, confirms this transport direction. The relative contributions to shoreline deposition by longshore versus cross-shore (on/offshore) transport is unknown although both processes undoubtedly occur. Elongated barrier spits are typical longshore generated features while pocket beaches require a significant amount of cross-shore sediment movement.

Factors which complicate a simple model of east to west circulation and transport include: 1) local bathymetry and exposure, 2) passage of storm fronts, and 3) extended shifts in weather patterns such as periods of strong westerly winds associated with ENSO events (El Nino - Southern Oscillation).

Wave Refraction

Wave refraction around reef reentrants and passages can cause local variations in the angle of wave approach. Reef passages are generally situated in broad lows; water passing over adjacent reef crests is gravity driven towards these lows which behave as conduits for seaward return flows during most of the tidal cycle (Figure 16a). Consequently predominant current directions on the western side of a passage may be towards the east.

Shielding of the coastline by prominent headlands may allow only waves/currents of certain directions to be effective (Figure 16b). For example, the Holocene basalt flows of 'O le Pupu' on the south coast have created an impediment to westerly transport - spit orientations near Si'umu suggest easterly drift predominates. Further westwards the principal transport direction returns to westerly.

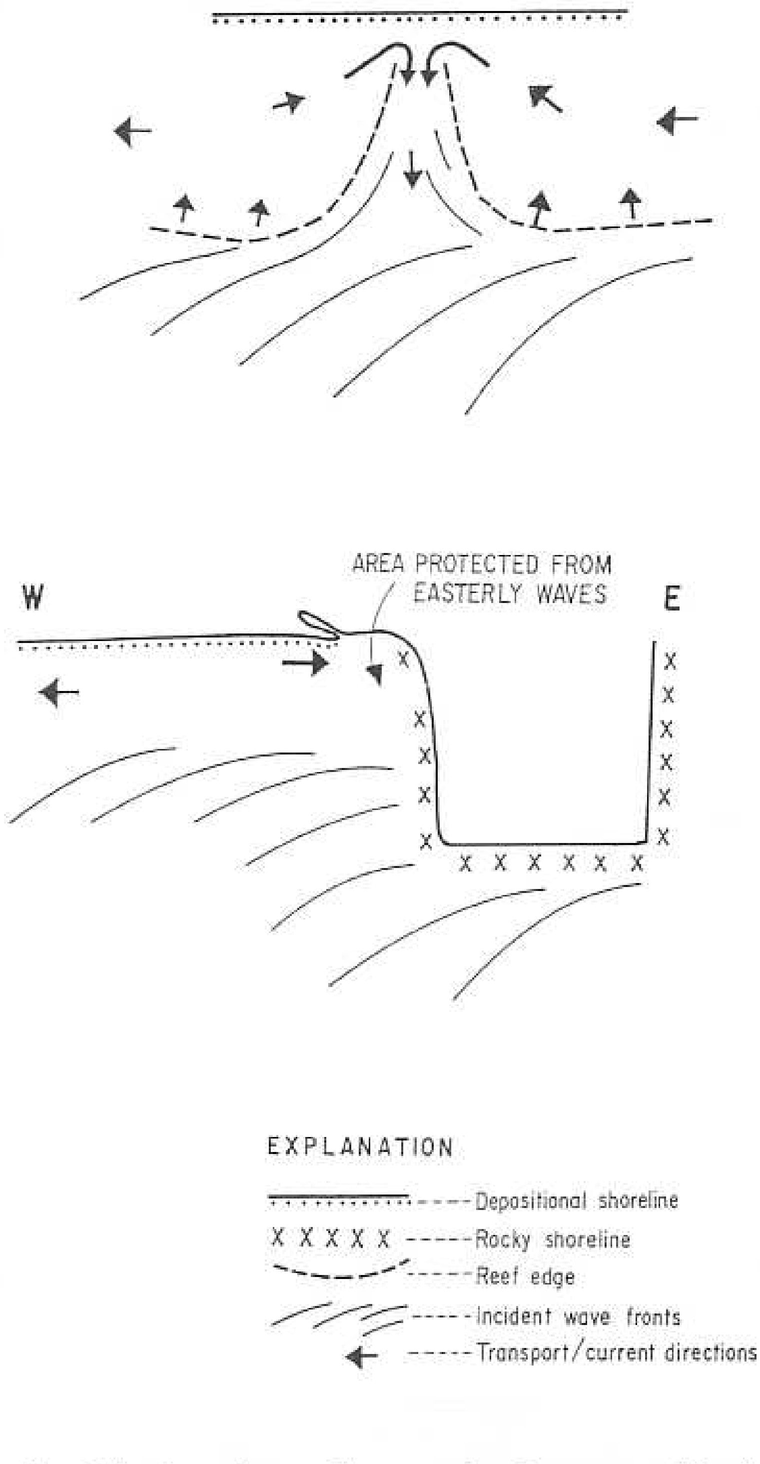


Figure 16. Conceptual models of wave/current flow around reef passages and headlands.
Top: a) Flow in the passages is typically ebb dominant and mostly gravity driven by wave set-up at the reef crest. Flow is towards the passage from both sides regardless of the direction of wave approach. Middle: b) Transport reversal in the lee of a large headland. The headland protects a section of coast from easterly conditions allowing westerly conditions a relatively greater impact.

Storms

Storms, and in particular tropical cyclones, can cause significant changes in nearshore circulation patterns over very short periods of time. They can be very erosive, but alternatively they are perhaps the main mechanism for the shoreward transport of reef and fore-reef material. Major storm deposits (hurricane banks) occur on the reef flat near Si'ufaga, Mulifanua. Other minor deposits are scattered on reefs around the island. Storm impact can be most effective by: a) increasing sediment input to the coastal zone through flooding and shoreward transport of reef material; b) creating strong wave/current activity in normally protected areas; and c) shoreline erosion and the flushing of sediment from reef passages.

ENSO Events

ENSO events typically create strong westerly conditions for as much as several months at a time during which important changes in nearshore circulation may take place. Areas protected from easterly storms but exposed to the west may undergo significant changes. For example the west coast near Mulifanua would become the windward side of the island and areas that are normally sheltered may be exposed to higher incoming wave energy.

Holocene Sea Level

Published information regarding the local Holocene sea level history for Upolu is somewhat conflicting. Kear and Wood (1959) relate the Tafagamanu Sand to a 5-foot stand of sea level during the Holocene. A coral sample from the base of a 1.5 m sand bank at Tafagamanu was dated at 1180 yrs bp (Rodda, 1988). These deposits however, can easily form during storm washover and therefore do not require a higher position of sea level for their formation. Sugimura and others (1988) inferred the existence of a highstand preserved in "emerged" beachrock along the southcoast. They measured beachrock up to 0.95 m above mean sea level, however all beachrock observed is within intertidal limits and could form at its present position relative to the current mean sea level. "Emerged" reef remnants on the reef flat in Fagali'i Bay on the northcoast (Rodda, 1988: Stearns, 1944) were briefly examined during the present study. The outcrops border a main reef passage and upon examination appeared to consist of reef flat pavement that has been undercut and tilted. They are not in-situ remnants of a reef formed at a higher sea level.

Lapita pottery sherds were recovered from submerged "beach" deposits during dredging at the Mulifanua Ferry site (Green and Richards, 1975; and Jennings, 1974). Typical stratigraphy of the site consists of a 0.8 m cemented hardground overlying about 5 m of coral sand , staghorn coral, and basalt pebbles which in turn overlie basalt boulders (–3m) and basalt basement. The pottery occurs about 2.5-3 m below present mean sea level. Shells from the level that the sherds were found have radiocarbon ages of around 2890 yrs bp. Lapita pottery typically is associated with beach ridges a metres or two above sea level.

Based on radiocarbon dates (Table III) from basal mangrove peat deposits along the southcoast (Lefaga?), Bloom (1980) presented a Holocene sea level curve for Upolu (Figure 17). Bloom considered Upolu to be undergoing relative subsidence at a rate of about 1 m/1000 yrs in later Holocene time. The subsidence is presumably tectonically controlled and perhaps related to crustal loading by recent volcanism.

In the present study there was no unequivocal evidence observed indicating a recognisable higher than present Holocene sea level stand. The archaeological evidence, abundant shoreline erosion, and sea level curve of Bloom (1980) all suggest that Upolu is undergoing relative subsidence.

Coastal Stability

As noted by Bakx (1987) Western Samoa is experiencing recent widespread coastal erosion which in some places is quite severe. Bakx (1987) identified coastal sites requiring shore protection measures such as rock revetments and revegetation. The cause of the shoreline erosion was cited as "direct wave attack". Results from the present survey support the existence of widespread coastal instability and the need for shore protection measures. However the cause of the erosion is probably due to a number of interrelated factors. If the assessment regarding relative subsidence of Upolu is correct then the relative sea level rise associated with island sinking could be responsible for increased erosion. The reefs theoretically can keep pace with the change in sea level by vertical growth. The shoreline however needs to readjust to the new level. This readjustment involves shoreline retreat coincident with nearshore deposition. This could be the case in Upolu since "direct wave attack" does not explain erosion of coastal depositional landforms unless there has been a change in the coastal regime to promote greater wave attack. A relative rise in sea level would accomplish this.

Other factors responsible for shoreline erosion include:

Table III. Published radiocarbon age dates for Upolu.

SAMPLE No.	LOCALITY	MATERIAL	ELEVATION (m)	AGE (yrs bp)	REFERENCE
I-8072	S. Upolu (Lefaga?)	peaty mud	-3.6 to -4.3*	3060 ± 95	Bloom, 1980
I-8074	" " "	"	-5.2 to -5.5	4655 ± 95	"
I-8075	" " "	"	-5.6 to -6.1	4845 ± 95	"
I-8076	" " "	"	-2.7 to -3.0	1595 ± 85	"
S.1-9	Lefaga Bay	Coral from core	-1.9 to -2.2	1580 ± 160	Matsumoto & Togashi (1984)

* Reported as depth below the present equivalent environment (mangrove swamps - slightly below high-tide level).

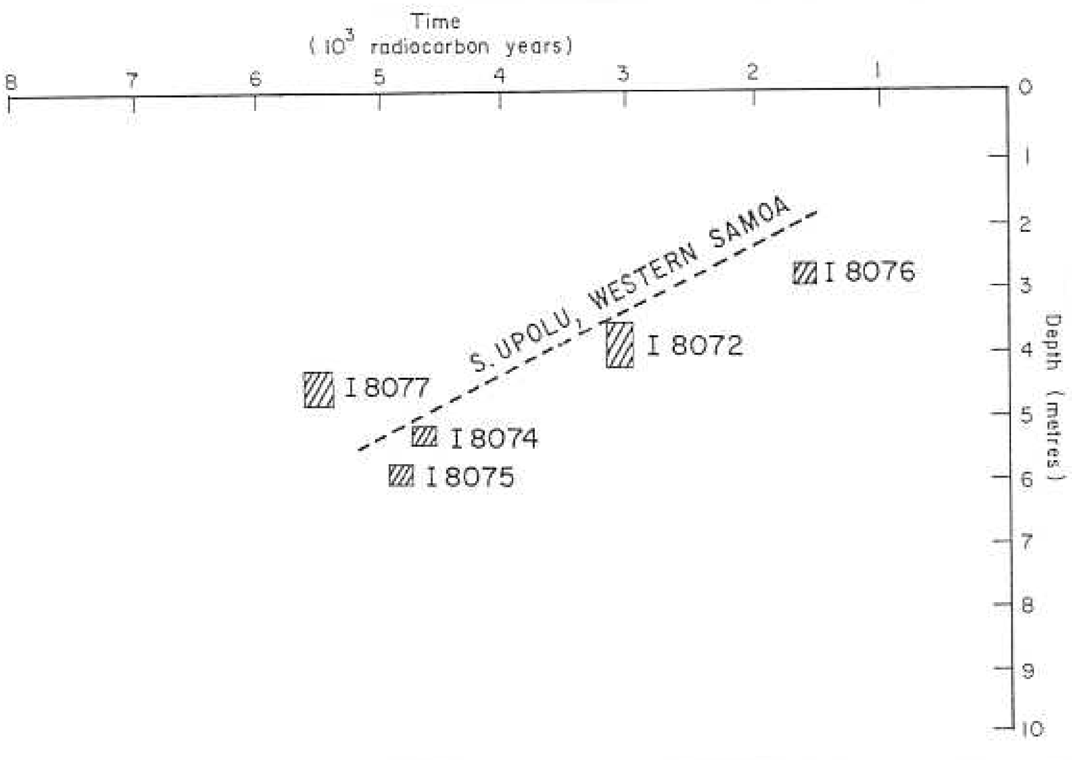


Figure 17. Holocene sea level curve as determined from swamp deposits along the south coast of Upolu. Adapted from Bloom (1980). Details of the age dates are shown in Table III.

a) Sand mining, particularly along beaches. This is a widespread practice in Samoa but the volumes taken are probably small when compared to the overall sediment budget. In areas where there already is a net loss of sediment, mining will accelerate the problem;

b) Poorly designed sea walls and revetments. Coastal engineering structures with vertical walls tend to scour at the base increasing erosion. Rock groins deprive downdrift beaches of sediment and, in effect, displace the erosion problem further alongshore; and

c) Description of vegetation and habitats. Removal of coastal plants exposes the substrate to increased erosion susceptibility by storm waves, prescipitation, and wind. In 1963 Wright noted (p.33) "A certain amount of coastal erosion may have resulted from the destruction of the mangrove screen although the main cause of shoreline regression has undoubtedly been the constant removal of sand and shingle to pave the village houses". Modification of habitats such as coastal swamps may have unforeseen consequences on local sediment budgets and transport pathways.

In general, the severest erosion problems occur along the Type I coasts which are fronted by wide fringing and barrier reefs. This could be the result of deepening lagoonal water levels allowing greater wave energy to reach the shoreline. Type III shorelines are also experiencing shoreline retreat whereas Type II coasts are relatively stable.

NEARSHORE MINERAL RESOURCES

Placer Minerals

The non-living nearshore and coastal mineral resources of Upolu fall into two categories - placer minerals and construction materials (there is no indication of phosphorites). Placer deposits are concentrations of economically valuable, weathering-resistant minerals having a specific gravity heavier than quartz (2.65 g/cm) such as gold and silver. Placer mineral exploration was not a major component of the present study and there does not appear to be any existing detailed information pertaining to placers in Samoa. However, based on the geology of Upolu certain broad assumptions can be made regarding potential placer deposits. The alkalic basalts and associated volcanics can be expected to produce titanomagnetite-rich weathering products. Whole rock chemical analyses (Hawkins and Natland, 1975; Ishii, 1988) show a relative enrichment in titanium.

Sediment samples collected from some of the beaches and river/stream mouths are high in heavy mineral content (Table IV; F. Wong, written communication). Separations of grains less than

Table IV. Percentage of heavy minerals for selected samples*

SAMPLE NO.	LOCATION	G > 2.86
5	Lauli'i	74.6
6	Leusoali'i	40.6
7	Namo River	62.5
9	Matautu Pt.	73.6
15	Lepa	75.9
19	Si'umu	92.8
21	Mulivai	18.2
27	Sataoa	57.9
28	Sataoa	47.7
37	Vaisigano River	80.7

* Written communication, F. Wong, US Geological Survey

1 mm in diameter yielded concentrations of up to 92.8 % heavy (> 2.86 g/cm) minerals most of which were opaque. The larger terrigenous-rich sand deposits are situated at the barrier spits at Vaie'e and Falefa.

Eade (1979) estimated the occurrence of approximately 12,000 m of very fine dark sand at Solosolo beach. Stach (1969), in discussing the same beach, indicated no detrital heavy mineral concentrations of economic value are likely. For placer deposits to be economically viable high concentrations and very large deposits are usually required.

There are unconfirmed reports of a gold mine operating in the eighteenth century but no documentation has been located concerning its operation. Over 200 river/stream bed samples were collected as part of a recent gold survey (F. Malele, Apia Observatory, written communication). Gold was detected in only about 10% of the samples. In all cases hut one the gold content was near the detection limit (approx. 0.01 ppm). The one anomalous sample (approx. 0.9 ppm) in the Fuluasou River may require further investigation in the area but overall the potential is very low.

The lack of ultramatic rocks on Upolu severely limits the potential for placers containing nickel, platinum, and chromium.

Construction Materials

Sand and gravel deposits for construction and landfill purposes represent a major nearshore mineral resource on Upolu. Most of the earth materials used in the greater Apia area are presently mined from the nearshore in the Mulinu'u Peninsula - Vaiusu Bay area. Conservative estimates for the amount of material excavated at Mulinu'u are about 28,000 m'/yr with a total of about 420,000 m' removed in the 15 years of mining operation (Mataafa and others, 1988; based on conversations with the dredging operators). The material mined is a poorly-sorted silty gravelly sand composed of a mixture of back-reef and terrigenous deposits. Apia Concrete Products, on the western shore of Vaiusu Bay, removes nearly 8000 m'/yr (or approximately 64,000 m' in their 8 years of operation). The deposits are similar to those at the Mulinu'u operation except they are overlain by as much as 1 m of fine sediment. Dredged areas are commonly partially infilled after storms by westward flowing currents (oral communication, Anthony Brighouse, Apia Concrete Products).

There are many areas where nearshore deposits have been utilised for the dual purpose of land reclamation and channel construction, for example: Mulifanua Ferry site; Royal Samoan Hotel; near the 'Home of Old People', Vailele, Luatuanu'u; and the wharf and access road near Satitoa, Aleipata. In all of these locations back-reef deposits have been used as a fill for land reclamation while the dredge sites are left as deep water access areas.

Sand mining of beach, beach ridge, and harrier spit deposits is a widespread practice. It is done both on a private and commercial scale but there are no permanent quarries established at present. Areas that have been periodically mined include: the spit at the mouth of Tuafaleloa Stream near Solosolo, Luatuanu'u; beach and beach ridge deposits near Salamumu, Lefaga; and flood delta deposits at the mouth of the Vaisigano River, Apia. Private mining using shovels and trucks occurs at nearly every beach that is accessable by road.

Promising nearshore areas for further earth material resources are scattered around the island. Based on previous CCOP/SOPAC surveys some potential sites include: opposite Faleolo airport (Rubin, 1984), the barrier reef between Mulifanua and Manono (Richmond and Roy, 1989), the shallow lagoon at Aleipata (Richmond, 1985; Lewis and others, 1989), and the Vaie'e Peninsula.

The environmental consequences of nearshore mining have not been fully assessed in Western Samoa. Potential problems created by nearshore mining include: accelerated coastal erosion due to an imbalance in the local sediment budget and a change in the nearshore profile allowing greater wave energy to reach the shoreline; and increased turbidity damaging the local ecosystem and fisheries. Although there is some shoreline erosion on the Mulinu'u Peninsula there is no strong evidence indicating either coastal erosion or fisheries destruction is occurring as a result of the dredging operations. The operation is sited in an area where periodic flooding creates natural turbid conditions, therefore coral and other species inhabiting the area are tolerant to such conditions. However, a well-designed monitoring programme is needed to accurately determine the effects of the dredging.

CONCLUSIONS

1. **Mapping Programme.** A coastal mapping programme was completed for the island of Upolu, Western Samoa. Maps at a scale of 1:20,000 were prepared showing shoreline characteristics, reef flat features, and coastal plain geology. Data for the maps included previously published topographic maps, aerial photographs, and limited field checking and sampling.

2. **Coastal Types.** Three general types of coast occur on Upolu: I) Wide fringing and barrier reefs backed by gently-sloping volcanic rocks; II) Cliffed coast with little or no reef development; and, III) Fringing reef and narrow coastal plain typically consisting of a storm ridge or river/stream mouth deposits.

3. **Reefs.** Fringing, barrier, and patch reefs surround most of Upolu. Reef features that were mapped include submarine terraces, reef crests, reef flats, shallow lagoons, and blue holes. Reef surfaces can be categorised into three types: coral/algal/pavement, sediment covered, and marine flora zone.

4. **Beaches.** Beaches are widespread and consist of sands and gravels composed of carbonate and terrigenous material, or a mixture of the two materials. Terrigenous composition is related to the proximity of a fluvial source. Beach height is directly related to exposure and width of the adjacent reef.

5. **Stream and river mouths.** Barrier spits, swamps, submerged deltas, and flood deltas occur at the mouths of rivers and streams. Where discharge is particularly high or persistent, gaps in the adjacent reef may be present.

6. **Swamps and mangroves.** There is a widespread occurrence of swamps and mangroves in low-lying protected coastal areas. They are sites of fine sediment deposition and a valuable fisheries resource.

7. **Sediment transport.** Longshore and cross-shore transport of sediment is primarily controlled by the dominant east to west wind/wave circulation. Variations from this pattern are created by storms, local morphology/current interaction, and ENSO events.

8. **Sea level changes.** Available evidence suggests that Upolu is undergoing relative subsidence at a rate around 1 m/1000 yrs. There is no unequivocal evidence for a sustained higher than present Holocene sea level stand.

9. **Coastal stability.** Coastal erosion appears to be a widespread phenomenon on Upolu but it is severe in limited areas only. Widespread erosion of the shoreline may be related to the relative subsidence of the island enhancing wave attack, improperly designed coastal engineering structures, and sand and gravel mining.

10. **Placer minerals.** Potential economically viable placer mineral deposits are limited to those derived from basaltic rocks: magnetite (iron ore) and ilmenite and rutile (titanium). There are no ultramafic rocks on Upolu and no confirmed gold deposits.

11. **Construction materials.** The nearshore region is the site of abundant sand and gravel deposits which are composed of both carbonate and terrigenous materials. Extensive reserves occur in the Vaiusu Bay area and several promising prospects are located throughout the island, notably at: Mulifanua/Manono barrier reef, opposite Faleolo airport, Aleipata, and near Vaie'e Peninsula.

RECOMMENDATIONS

Construction Materials

1. There appear to be adequate nearshore resources of construction materials in presently mined areas to provide the needs of Upolu for at least a decade at present consumption rates. It also appears that additional supplies occur at numerous localities around the island. In order to meet future requirements and provide maximum protection to the environment it is recommended that:

    a) As much information as possible should be obtained regarding projected use of construction materials including locations, quality and quantity of material needed. This information would be used to facilitate planning strategies for future aggregate resources.

    b) A biological and physical environmental monitoring programme should be established to assess the effects of current mining operations.

    c) Existing mining technologies should be reviewed to suggest methods to improve current practices.

Placer Minerals

2. At present there is no coastal mining for placer minerals and although the general geology of the island is not encouraging, the potential is essentially unknown. A two-stage programme is recommended to provide an upto-date review

a) A complete literature review/bibliographic data base of the geology, and, if more encouraging information is found,

b) A detailed sampling programme focussing specifically on placer mineral resources.

Future changes in the economics of certain minerals could alter the economic viability of placer mining - a complete review of Western Samoa's potential would be valuable for future reference.

Coastal Stability

3. Coastal erosion in Western Samoa is a widespread phenomena that appears to be related to multiple causes. A historical shoreline analysis using aerial photographs, maps, charts, and interviews would provide background information regarding rates and potential causes of shoreline retreat. The Coastal Morphology Maps can be used to prepare relevant geohazard maps of the coast incorporating information on floods, tsunamis, and cyclone/storm overwash. In the event of continued shoreline retreat, areas should be prioritised in terms of shore protection works.

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APPENDIX I

Summary Sheet Descriptions for the 1:20,000 Coastal Maps

List of Appendix I Figures

SUMMARY SHEET DESCRIPTION

SHEET NUMBER AND NAME: 17/MULIFANUA

....

COASTAL MORPHOLOGY AND GEOLOGY :

Reefs: Extensive fringing and barrier reefs are developed around the entire western tip of Upolu and surrounding Manono Island. Blue holes are widespread and reach depths as great as 14 m. Numerous patch reefs border the reef between Manono Island and Mulifanua. Storm-derived rubble deposits occur on the outer reef flat opposite Si'ufaga.

Coastal Plain: Only a narrow coastal fringe borders the gently-doping Mulifanua Volcanics. There are a few scattered mangrove/swamp areas and limited beach development. A barrier spit and associated swamp deposits occur between Si'ufaga and Pata. No large rivers enter the area.

Sediments: Thin and patchy distribution of mostly carbonate sand along the beaches; some mud occurs along protected shorelines, in particular near the mangroves at Pata. Large areas of carbonate sand cover the back-reef lagoon floor. The deeper blue holes are tilled with carbonate mud.

....

COASTAL STABILITY:

Approximately 60-70% of the shoreline is armoured to protect the main coastal road, housing, and reclaimed land. The lee-side of the island and has a wide barrier reef but limited mangrove development indicates frequent exposure to westerlies.

....

MINERAL RESOURCES:

There is very little in regards to onland construction material deposits, however, extensive back-reef deposits are present. Conservative estimates of potential sand and gravel reserves are around 1.7 x 10 m (Richmond and Roy, 1989)

....

OTHER COMMENTS:

Dredging at the Mulifanua Ferry site uncovered lapita pottery shards from beach deposits at 2.5-3 m water depths.

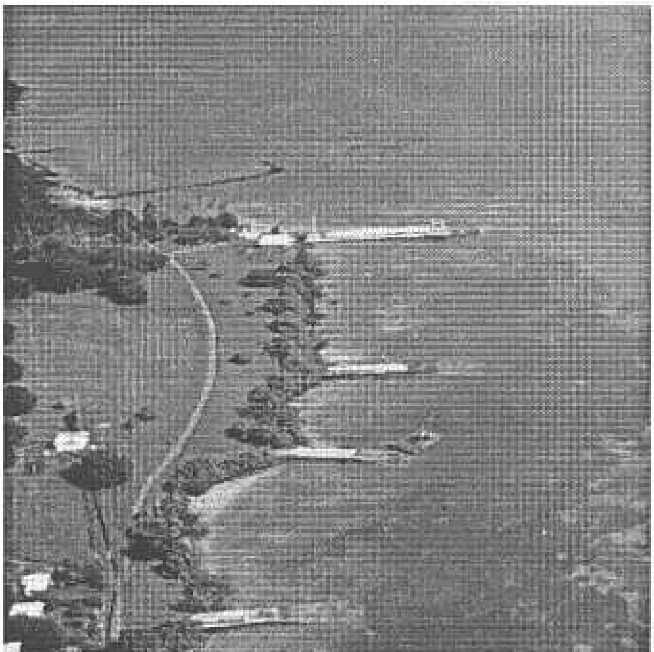

Figure AI/1. Top: a) Shoreline near Lalovi, Mulifanua showing eroded coconut palms on shore, basalt boulders (foreground) used in revetment to protect coast road, and reclaimed land with fale in centre. View to south. Bottom: b) Oblique aerial photograph near Toloa showing groins and dragline. Note the general lack of sediment on the beach; the groin at the bottom has trapped some carbonate sand on its eastern side indicating transport to the west. The darker areas on the reef flat is covered by marine flora. View to west.

SUMMARY SHEET DESCRIPTION

SHEET NUMBER AND NAME 18/NOFOALI'I

....

COASTAL. MORPHOLOGY AND GEOLOGY:

Reefs: There are wide fringing reefs (450 to 1800 m) approaching a barrier type to the west. Numerous blue holes are developed within the outer reef flats in the western half. The submarine terrace is well-developed extending as much as 800 m beyond the reef crest. Isolated patch reefs also are present.

Coastal Plain. The hinterland is composed mostly of gently-sloping Mulifanua Volcanics. Where Mulifanua rocks do not outcrop along the shoreline there are small pockets of Tafaugamanu Sand and alluvial deposits. Coastal depositional features are of very limited areal extent; the largest is the barrier beach backed by swamps at Fasito'otai - Uailu'utai. A mangrove fringe occurs along much of the shoreline.

Sediments: No large rivers or streams enter the coastline, therefore sediment is composed mostly of carbonate material. Thin sediment veneers **occur** along the inner reef flats and beaches. Extensive carbonate sand bodies occur in shallow lagoonal areas of the barrier reef.

....

COASTAL STABILITY:

Numerous basalt-rock seawalls occur along the shoreline to protect reclaimed land (mostly privately owned) and the main coastal road. Most of the time wave/current conditions are generally subdued, however, during northerly to westerly storms, conditions may be quite severe. The entire shoreline of FaleoloInternationalAirport is armoured.

....

MINERAL RESOURCES.

On-land1 construction material deposits are small and mostly covered by coastal housing. Reef deposits are extensive especially opposite Faleolo International Airport where some extraction has occurred (preliminary conservative estimate indicates 8 x 10 m of carbonate sand and gravel available).

....

OTHER COMMENTS

The coastline is similar to the western portion of sheet 19/Apia and the eastern part of sheet 17/Mulifanua. Nearshore dredging operations utilising draglines occurred opposite the airport.

Figure AI/2. Top: a) Remnant of coastal road near Vailu'utai School, Nofoali'i. The new coastal road was diverted inland; without shore protection structures the old road has eroded away. View to east. Bottom: b) Oblique aerial photograph of large sand body on the reef near Faleolo Airport. Former dredge sites are visible in the lower right. View to east.

SUMMARY SHEET DESCRIPTION

SHEET NUMBER AND NAME: 19/APIA

....

COASTAL MORPHOLOGY AND GEOLOGY :

Reefs: Combmation of fringing reefs and shallow barrier reefs. The reef is about 3000 m wide north of Malie. A large patch reef occurs north of Cape Tiapepe. Blue holes are developed north of Cape Tiapepe, to the northwest of Mulinu'u Peninsula, and near Pilot Point (Palolo Deep Marine Reserve).

Coastal Plain: Two types of coastline occur: 1) The Greater Apia area (Apia Harbour/Vaiusu Bay) consists of deltaic deposits, river channels, and the Mulinu'u barrier spit. Extensive mangrove communities are developed along the Vaiusu Bay shoreline. 2) West of Vaiusu Bay the coast consists of a gently seaward-sloping hinterland of Mulifanua Volcanics. The shoreline consists of either mangrove/swamp deposits or volcanic rock outcrops. Beaches are poorly developed.

Sediments: Mixture of carbonate and terrigenous beach sediment. They form very limited deposits except at Mulinu'u which is a nearly 2 km long barrier spit. Mud occurs within the mangrove/swamp areas.

....

COASTAL STABILITY:

The shoreline from Mulinu'u east to Moata'a is about 90 % armoured to protect the Apia waterfront. This includes the reclaimed sports field and the main wharf area. West of Vaiusu Bay there are numerous small-scale shoreline protection works to protect the main road and reclaimed land areas.

....

MINERAL RESOURCES:

Western Samoa's largest nearshore construction materials excavation site occurs in Vaiusu Bay near Mulinu'u Point. A gross estimate of the rate of extraction is about 28,000 m/yr or about 420,000 m during the 15 years of operation (conservative estimate). Preliminary estimate of reserves are 1,100,000 m. A second nearshore operation occurs at Apia Concrete Products in Vaitele. The material mined at both locations is a mixture of back-reef calcareous sand, rubble, in-situ coral colonies, and river-derived terrigenous sediment.

....

OTHER COMMENTS:

Because of the wide fringing/barrier reef and the northerly exposure most of the shoreline west of Mulinu'u exhibits features characteristic of a low-energy coast: extensive mangrove communities, muddy sediment, and limited beach development.

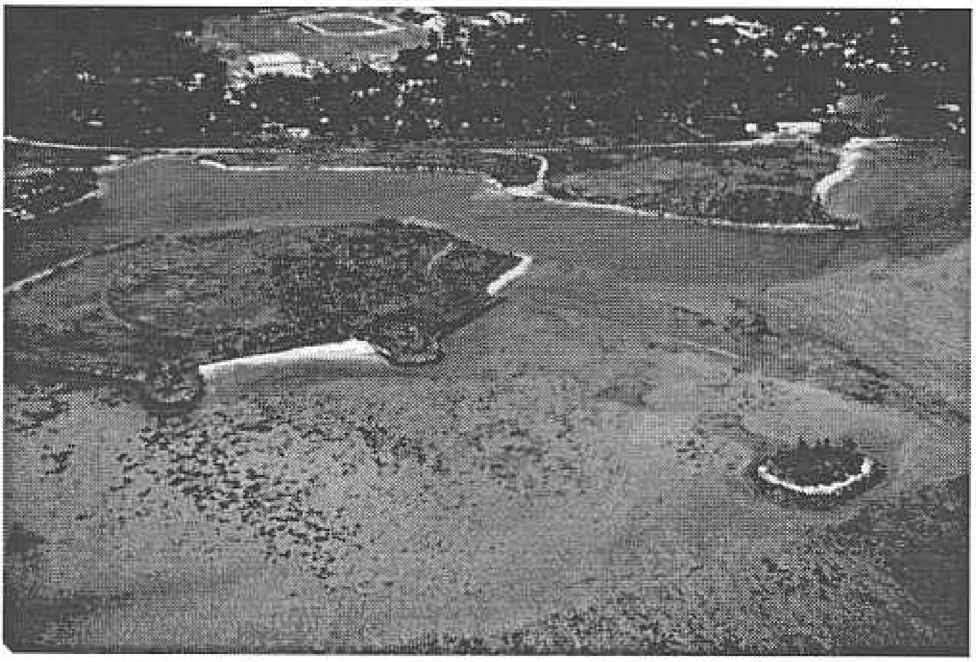

Figure AI/3. Top: a) Oblique aerial photograph of the Royal Samoan Hotel site showing the reef flat borrow pits and reclaimed land (island). The beach in the centre of the island indicates westward longshore drift as evidenced by sand buildup on the western (right) seawall. View to south.
Bottom: b) Distal end of Mulinu'u Peninsula showing the nearshore dredging operations, causeways, and rock groins. Sand buildup on the groins indicates westward drift. View to south.

SUMMARY SHEET DESCRIPTION

SHEET NUMBER AND NAME: 20/LUATUANU'U

....

COASTAL MORPHOLOGY AND GEOLOGY:

Reefs: The coast is bordered by fringing reefs and occasional patch reefs. Maximum fringing reef width is about 1200m near Vailele and it varies between 400 m and 1000 m wide from Cape Utusi'a to Falefa. The rest of the coastline has either a narrow fringing reef (<500 m) or the reef is absent due to fluvial drainage systems (ie. at Lauli'i, Vainamo Bay, Fusi). Large patch reefs occur opposite Letogo, Leusoali'i, andSaluafata Harbour.

Coastal Plain: An extensive barrier spit complex is developed around Matautu Point from material mostly derived from the Falefa River basin. Smaller spit complex's occur at Cape Utusi'a (carbonate sand) and Solosolo (volcanic sand and gravel). The remaining coastal plain deposits are primarily pocket beaches backed by beach ridges and swamps.

Sediments: Solosolo and the Falefa - Faleapuna area are predominantly terrigenous sand, the latter area composed of fine sand. The remaining coastal areas are either carbonate or mixed terrigenous/carbonate materials.

....

COASTAL STABILITY:

Discussions with elders at the Cape Utusi'a and Matautu Point areas indicate severe shoreline retreat (on the order of a 100 m, during the last 40-50 years). The coastal road is armoured at numerous locations to prevent erosion.

....

MINERAL RESOURCES:

Small-wale commercial beach mining has occurred at Solosolo. Potential nearshore deposits occur in the wide fringing reefs near Vailele and Falefa. Diving near river/stream mouths at Solosolo, Vainomo Bay, and Leusoali'i indicated that mostly fine-grained terrigenous sand occurs offshore.

....

OTHER COMMENTS

The hinterland is mostly steep Fagaloa and Salani volcanics. Wave energy on the reefs appears slightly higher than to the west of Apia. This is probably due to greater exposure to easterly fetches.

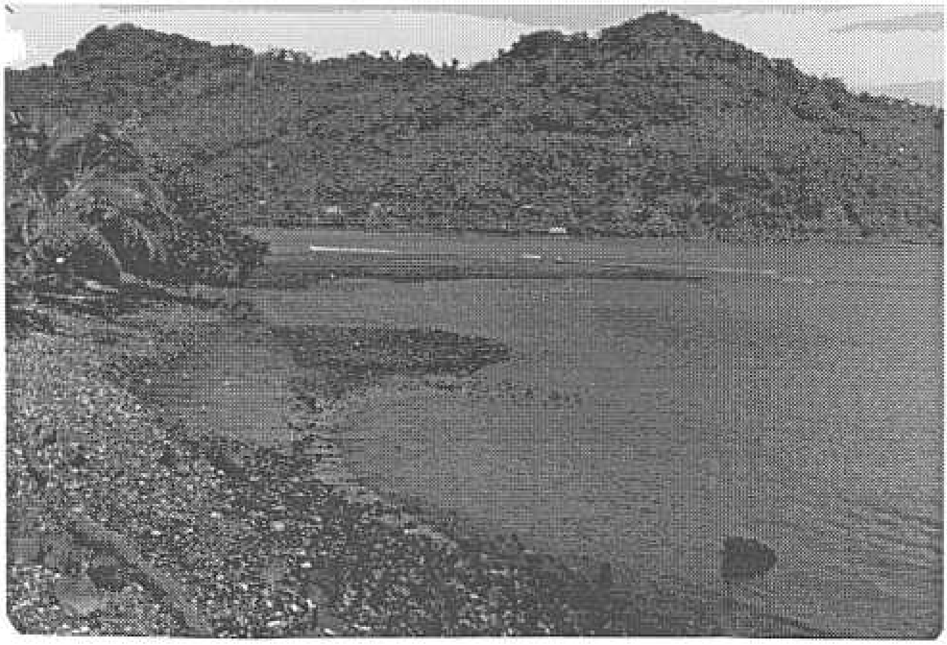

Figure AI/4. Top: a) Beach in east Lauli'i composed of mixed carbonate/terrigenous sediment (mostly gravel). Flood delta on the reef flat in centre of photograph. View to west.
Bottom: b) Narrow fringing reef (foreground) and gap in reef (centre) opposite Lauli'i Stream. View to east.

SUMMARY SHEET DESCRIPTION

SHEET NUMBER AND NAME: 21/LEFAGA

....

COASTAL MORPHOLOGY AND GEOLOGY:

Reefs: Fringing reefs characterise most of the coastline. Reef width varies from less than 100 m to over 2500 m south of Sa'anapu. A few small patch reefs are situated in a reentrant near Nu'uavasa Island.

Coastal Plain: Pocket beaches are the only depositional feature for much of the shoreline from Asia Point to Lefaga Bay. The pocket beaches may contain several beach ridges and are separated by cliffs of Fagaloa Volcanics. The Faleaseela River and several small streams drain into Lefaga Bay which is rimmed by mangroves. Swamps fronted by beach ridges occur at Matautu, Salamumu, and areas between Nu'uavasa island and Sa'anapu. From Faleaseela to Sa'anapu a carbonate sand (Tafagamanu Sand) beach ridge(s) backs much of the shoreline. Where volcanic rock platforms are present the sand is deposited by storms above the mean high tide level. Beach ridge elevation as much as 4 m above approximate mean sea level occurs at Salamumu.

Sediments: The pocket beaches are composed of dean carbonate sand. Terrigenous sand and mud predominate in Lefaga Bay. The narrow fringing reefs are irregularly covered by sand and gravel veneers except for the wide fringing reef south of Sa'anapu which contains extensive deposits of carbonate sand and gravel.

....

COASTAL STABILITY:

Protective coastal works are common between Faleaseela and Matautu and at Sa'anapu. Eroded coconut palms occur east of Salamumu and near Sa'anapu. Large segments of the coast are uninhabited.

....

MINERAL RESOURCES:

Beach ridges of Tafagamanu Sand in remote areas are a potential, although limited, resource. The large reef tract south of Sa'anapu probably contains large reserves of carbonate sand and gravel. Beach ridge mining of carbonate sand has taken place near Salamumu.

....

OTHER COMMENTS:

Basalt "terraces" along the Matautu - Salamumu coast appear to be constructional rather than erosional in origin. The upper surfaces of many of the flows have a primary ropy texture suggesting they are not erosional features formed during a presumed Holocene high sea level stand.

Figure AI/5. Top: a) Mined out beach ridge near Salamumu. View to east. Bottom: b) Narrow fringing reef and carbonate sand beach overlying a basalt terrace. Beachrock is exposed at the shoreline (centre). Near Leniu Point, view to south.

SUMMARY SHEET DESCRIPTION

SHEET NUMBER AND NAME 24/FAGALOA

....

COASTAL MORPHOLOGY AND GEOLOGY:

Reefs: Narrow fringing reefs and reefless coastline. The widest reefs (up to 400 m) occur within Fagaloa Bay.

Coastal Plain: Steep, cliff-forming Fagaloa Volcanics back most of the shoreline. Pocket beaches and limited alluvium/swamp deposits front most of the valleys. A large barrier-spit complex is developed on the western side of Falefa Harbour.

Sediments: The pocket beaches are mostly carbonate sand; terrigenous sediment occurs at Falefa and at Taelefaga near the head of Fagaloa Bay.

....

COASTAL STABILITY:

Moderate to severe coastal erosion at Falefa.

....

MINERAL RESOURCES:

Potential submerged delta deposits occur in Falefa Harbour and less-likely in Fagaloa Bay.

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OTHER COMMENTS:

Generally a remote and very rugged stretch of coastline with only a few inhabited areas.

Figure AI/6. View to the east of Fagaloa Bay.

SUMMARY SHEET DESCRIPTION

SHEET NUMBER AND NAME: 25/SAFATA

....

COASTAL MORPHOLOGY AND GEOLOGY:

Reefs,: The 'O le Pupu' area is formed of Holocene Puapua lava flows which bury pre-existing reefs. It is bordered by a coral fringe and narrow submarine terrace. Situated cast of Si'umu, fringing reefs as much as 2800 m wide, protect the coast except where coral growth is inhibited by freshwater discharge. Small patch reefs are common in embayments of the fringing reef.

Coastal Plain: Two distinct coastal land forms are present: 1) From Sa'anapu to Si'umu major depositional features occur. This is highlighted by the 4 km long Vaie'e Peninsula barrier spit west of Tafitoala. Sandy shorelines and beach ridges fronting swamp deposits, and rivers and streams arc common. 2) A cliffed shoreline of Holocene lava flows from Si'umu to east of Cape Niuatoi where no major depositional landforms occur.

Sediments: The beaches and coastal plains are formed of a mixture of carbonate and terrigenous sand. Mud is characteristic of the back barrier and other protected environments.

....

COASTAL STABILITY.

Protective engineering works are limited to a few villages, notably Sataoa, Tafitoala, and Mulivai. Artificial beach nourishment was undertaken at the Hideaway Hotel. The source area was the adjacent reef flat.

....

MINERAL RESOURCES:

On-land beach ridge and barrier spit deposits contain potential sand reserves. Nearshore areas surrounding the Vaie'e barrier spit are a possible south coast counterpart to the extensive nearshore deposits around the Mulinu'u Peninsula, Apia.

....

OTHER COMMENTS:

Most spit orientations indicate a net longshore drift direction to the west, however, there are several spits indicating eastward drift (i.e. near Tafitoala, Mulivai, Si'umu). This may be related to complex wave refraction around the reefs and protection from southwest swells by Cape Nu'utoi. An impressive pocket beach of mixed volcanic/carbonate sand extends at least 3 m above sea level at the historic village of Sa'aga. It faces to the southwest and is not bordered by a reef.

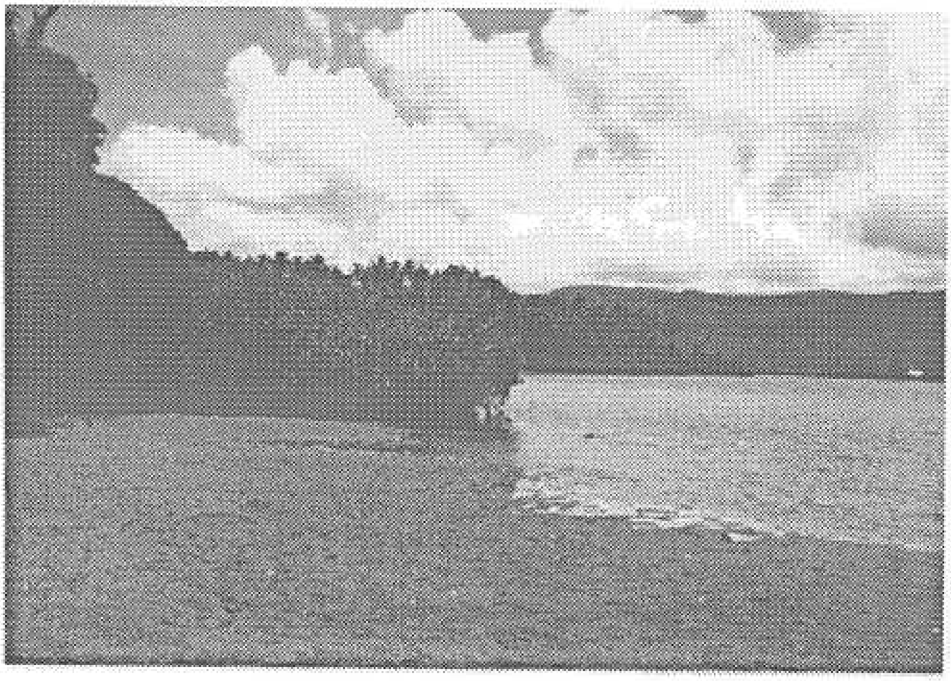

Figure AI/7. Top: a) Landward shoreline of Vaie'e Peninsula showing mangoves and muddy sediment. View to northwest. Bottom: b) Shoreline near Si'umu composed mostly of terrigenous sand; note eroded coconut palms on foreshore. View to east.

SUMMARY SHEET DESCRIPTION

SHEET NUMBER AND NAME: 26/FALEALILI

....

COASTAL MORPHOLOGY AND GEOLOGY.

Reefs: Predominantly a fringing reef. It is very narrow and borders steep cliffs west of Ili'ili. East of Ili'ili it widens and is up to 1500 m wide opposite Tafatafa where several blue holes exist. A fringing reef is also present around the small, offshore volcanic island of Nu'usafe'e. Reef passages occur opposite the major streams and rivers.

Coastal Plain: West of Ili'ili the coast is bounded by cliffs of Holocene Puapua lava flows. East of Ili'ili there are numerous streams and the Mulifagatoloa River, all of which have well-developed spits at their mouths. Beaches compose most of the shoreline, broken only by occasional basalt outcrops. The beaches are backed by a near-continuous strip of Tafagamanu sand.

Sediments: The beaches are a mixture of terrigenous and carbonate sediment. Basalt gravels occur at the more energetic localities.

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COASTAL STABILITY:

Some shoreline protective works occur in the villages to guard roading and houses. The coastal plain is subject to overwash during major storms. Beachrock exposures along large segments of coastline suggest recent erosional trends.

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MINERAL RESOURCES:

The narrow coastal plain is near-continuous east of Ili'ili and a potential construction material resource for LIMITED operations. Nearshore back-reef deposits undoubtedly exist but because of the high wave energy commonly experienced along the south coast, mining operations could be hazardous. The reef passage channel floors are potential sites for mixed terrigenous/carbonate deposits with the passages in the lee of Nu'usafe'e Island appearing to be the most promising.

....

OTHER COMMENTS:

West of Vaovai the barrier spits indicate westward drift; east of Vaovai they indicate eastward drift.

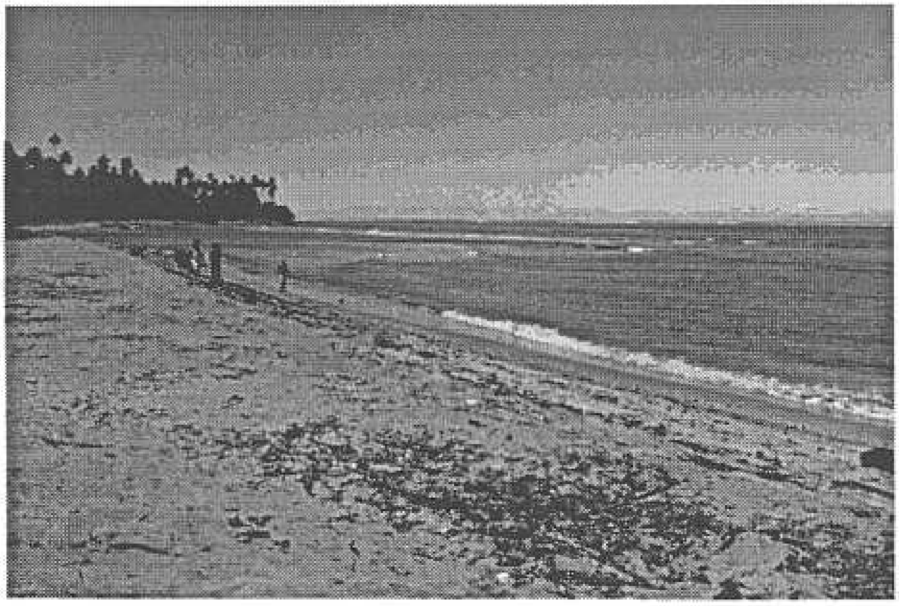

Figure AI/8. Top: a) Mouth of the Fagatoloa River near Salani; note the partially submerged flood-delta on the reef flat (centre). Beach is composed of mixed terrigenous/carbonate sediment. View to east. Bottom: b) Tafatafa Beach showing partially submerged beachrock (left centre) and small erosional backbeach scarp (right centre). View to west.

SUMMARY SHEET DESCRIPTION

SHEET NUMBER AND NAME: 27/LEPA

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COASTAL MORPHOLOGY AND GEOLOGY

Reefs: A narrow (maximum width 500 m) fringing reef borders almost the entire coast. The submarine terrace is also narrow except between A'ufaga and Lepa where it appears that a sand platform has expanded seaward.

Coastal Plain: Several streams enter the coast forming limited stream mouth deposits including small flood deltas and spits. East of Lepa an escarpment up to 250 m high is bordered by a large beach ridge(s) at its base. West of Lepa the shoreline alternates between rocky headlands with steep cliffs and beaches.

Sediments: East of Lepa the beach sand is nearly pure carbonate; west of Lepa it is a terrigenous/carbonate mixture except at Lotofaga which is mostly carbonate.

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COASTAL STABILITY:

Beachrock exposures are common along the coast but man-made shore protection works are nearly absent. The beach ridges, especially in the vicinity of Saleapaga, are prone to overtopping during major storms.

....

MINERAL RESOURCES:

Because of its narrowness, patchy veneer of sediment, and exposure to high-energy waves the fringing reef has low potential as a construction material deposit. On land resources are restricted to the narrow coastal plain which supports most of the housing in the area. Offshore deposits of the submarine terrace are possible resources particularly near A'ufaga.

....

OTHER COMMENTS

The beaches in the Saleapaga area are about 3 m above sea level and represent constructional features produced during storms. Their elevation is indicative of wave run-up heights.

Figure AI/9. Top: a) Coastal road on crest of beach ridge near Saleapaga. The road was recently overwashed by waves during a storm. View to west. Bottom: b) Oblique aerial photograph of the eastern Lepa coastline showing the coastal escarpment, narrow strip of carbonate sand, and fringing reef. The promontory in the centre is Cape Tuiolemu. View to west.

SUMMARY SHEET DESCRIPTION

SHEET NUMBER AND NAME: 28/ALEIPATA

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COASTAL MORPHOLOGY AND GEOLOGY:

Reefs: A barrier reef and shallow (<5 m) extend out to the offshore islands of Namu'a and Fanuatapu. Fringing reefs occur west of Cape Tapaga and northwest of Sagafoe Point. Reef passages are shallow and probably occur in paleo-stream channels.

Coastal Plain: Lalomanu to Sagafoe point is mostly carbonate sand teach backed by a coastal plain up to 500 m wide. The coastal plain is formed by swamps, beach ridges, and possible aeolian deposits. Small pocket beaches occur northwest of Sagafoe Point. A large beach ridge(s) forms the coastal plain from Matautu west.

Sediments: Reef-derived carbonate sand with minor amounts of gravel.

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COASTAL STABILITY:

Widespread but moderate erosion occurs from Lalomanu to Utufa'alalafa evidenced by eroding and fallen coconut palms and shoreline revetments.

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MINERAL RESOURCES

An extensive back-reef carbonate sand deposit occurs between Fanuatapu Island and Sale'a'aumua.

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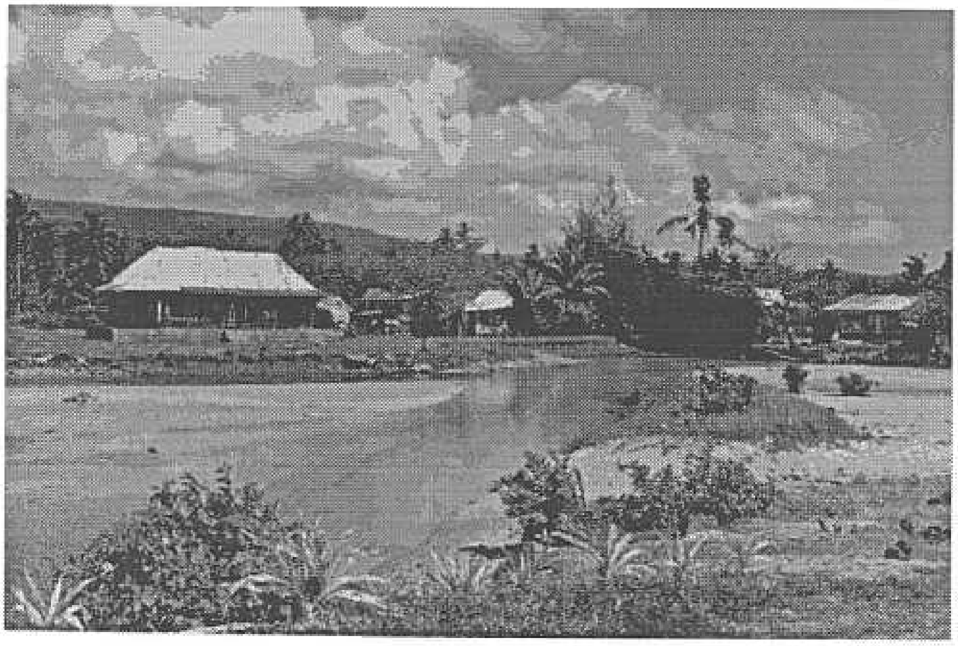
OTHER COMMENTS

Pocket beaches north of Amaile serve as construction material resources for private landowners in the area. The Aleipata area is a potential National Marine Park.



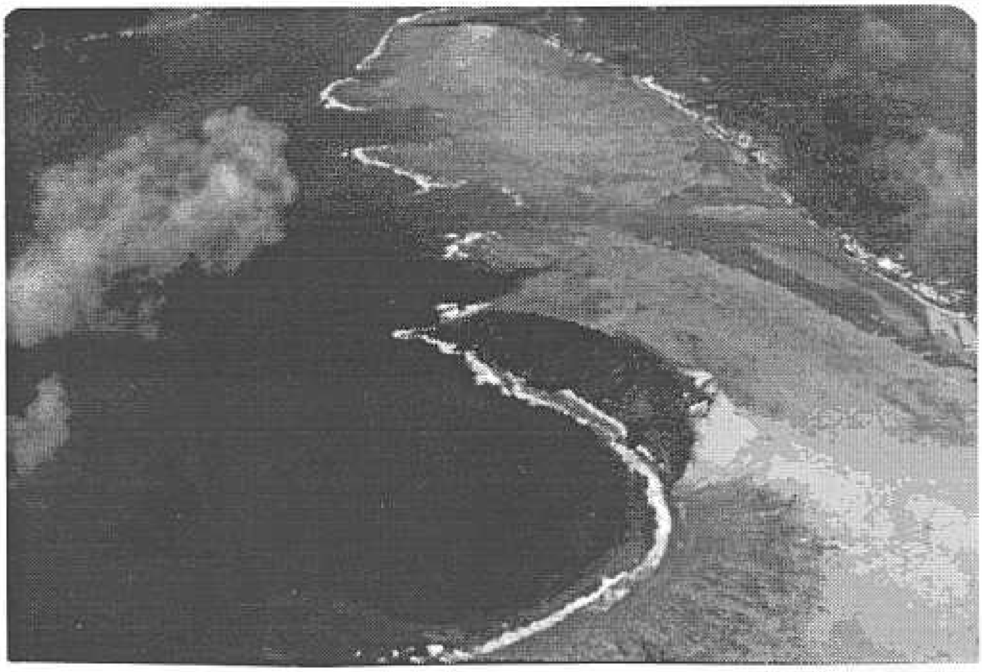


Figure AI/10. Top: a) Low-lying swampy area landward of the beach ridge near Mutiatele. View to west. Bottom: b) Oblique aerial photograph of the Aleipata coastline showing the reef and submarine terrace. View to southwest.

APPENDIX II

Location, Depositional Environment, Sample Descriptions, and Remarks for Upolu Coastal Samples, 1987

SAMPLE NO.	LOCATION	ENVIRONMENT	SAMPLE DESCRIPTION *	SAMPLE COLOUR #	REMARKS	EXPOSURE $
1	Mulinu'u	Beach	MWS/CS-VCS	Black + orange	Eroded shore	HE
2	W Mulinu'u	Lagoon fill	PS/FS-VCS+G	Grey	Oredge spoils	MP
3	Vaisigano R, Apia	River bank	MPS/MS-VCS	Brown		
4	Fagali'i	Beach	WS/FS	Brown	Eroded shore	ME
5	Lauli'i	Beach	PS/FS-VCS	Brown	Eroded shore	ME
6	Leusoali'i	Beach	MWS/MS	Black + cream	Gravel on beach	ME
7	Namo R	Beach/river mouth	MPS/MS-VCS	Brown	Near Solosolo, gravel	E
8	SW Cape Utusi'a	Beach	MWS/MS-VCS	Cream/orange	Former sand mining site	MP
9	Mata'utu Pt.	Beach	MPS/MS-VCS	Black	Eroded shore	MP
10	Sauago Pocket	Beach	WS/MS-CS	Orange	Some basalt boulders	E
11	Fagaloa	Beach/river mouth	MWS/CS-VCS	Cream + black	Reworked river deposits	P
12	Satitoa	Beach	VWS/MS	Cream	Some erosion	ME
13	Mata'utu, Aleipata	Beach	WS/MS	Cream	Exposed beachrock	ME
14	Saleapaga	Beach	WS/MS-CS	Cream	Exposed beachrock	ME
15	Lepa	Mountainstream	VPS/FS-VCS + g	Black	Dry stream bed	
16	Salani	Beach/River mouth	WS/MS	Cream + black	Submerged flood delta	ME
17	Tafatafa	Reef flat (2mWD)	MS/MS-VCS	Cream + black	Sandy reef flat	ME
18	Tafatafa	Beach	WS/MS	Cream + black	Some beachrock	ME
19	si'umu	Beach/stream mouth	MWS/MS-CS	Brown	Muddy reef flat	MP
20	Mulivai	Beach	MPS/MS-VCS	Cream + black	Artificial beach nourishment	ME
21	Mulivai (W)	Beach/flooddelta	PS/MS-VCS	Brown	E facing spit	ME
22	Safata	Lagoonside, spit teach	MPS/FS-CS	Cream	Mangrove area	P

SAMPLE NO.	LOCATION	ENVIRONMENT	SAMPLE DESCRIPTION *	SAMPLE COLOUR #	REMARKS	EXPOSURE 5
23	Safata	Beach	MS/MS-CS	Cream + black (10%)	Exposed beachrock	ME
24	Safata	Beach scarp	WS/FS-MS	Lt. gray	Windblown (?)sand	ME
25	Safata	Beach	PS/CS-VCS + g	cream + black	Exposed beachrock	ME
26	Tafitoala	Beach	MWS/VCS	Cream + black	Exposed beachrock	ME
27	Sataoa	Beach/stream mouth	PS-WS-VCS	Brown	Small flood delta	ME
28	Sataoa	Beach	MS/MS-VCS	/=/brown + cream	Distal end of spit	ME
29	Matauta, Lefaga	Reef flat	WS/MS	Cream	Pocket beaches	E
30	Lotoso'a, Apia	Beach	WS/FS-MS	Cream + black	Thin veneer, erosion	ME
31	Tauo'o	Beach	MWS/FS-MS	Cream + black	Thin veneer, erosion	ME
32	Fagalepolu	Beach	WS/FS	Cream	Thin veneer, erosion	ME
33	Cape Fatuosofia	Reef flat	WS/VFS	Gray/cream	Thin veneer	ME
34	Cape Fatuosofia	Pocket beach	WS/FS	Cream	Thin veneer	ME
35	Pata	spit beach	MS/MS-CS	Cream + orange	Erosion	ME
36	Vaiala, Apia	Beach	WS/MS	Cream + black	Seawall	HE
37	Vaisigano R	Beach/river mouth	WS/MS	Brown	Seawall	ME

* ABBREVIATIONS USED:

SORTING TERMS

WS	=	well sorted
MWS	=	moderately well sorted
MS	=	moderately sorted
PS	=	poorly sorted
VPS	=	very poorly sorted

GRAIN SIZE TERMS

FS	=	fine sand
MS	=	medium sand
CS	=	coarse sand
VCS	=	very coarse sand
G	=	gravel
Z	=	silt
VFS	=	very fine sand

EXAMPLES OF USAGE

MWS/M-VCS moderately well-sorted medium to very coarse sand

Colour - Colour of the damp sediment. In general, the cream colour is indicative of pure, clean, carbonate sands. The orange colour is attributed to the tests of a benthic foraminifera. The grey, brown and black shades are caused by either the presence of organic matter or terrigenous sediment, primarily volcanics.

$ Exposure - Relative exposure to waves and currents at the sample site.

E	=	Exposed; generally an open coastline with no fringing reef
ME	=	Moderately Exposed; A high energy coastline fronted by a fringing reef
MP	=	Moderately Protected; A low energy coastline or an area with a very wide fringing reef
P	=	Protected; shorelines with low wave and current activity except during major storms