Mr Sione Tongilava
Superintendent
Ministry of Lands, Surveys
and Natural Resources
P. O. Box 5
NUKU'ALOFA, TONGA.

Subject: Sand Inventory Tongatapu

Dear Mr Tongilava

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11 September 1981

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Superintendent
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Dear Mr Tongilava

Enclosed please find my interim report on the above. It is hoped, that the conclusions and recommendations will prove helpful to you in continuing further coral sand exploration, for the benefit of the Kingdom of Tonga.

With warmest remembrances to our time together in Tonga and ALOHA 1982!

Klaus Duphorn

Copies to: CCOP/SOPAC, SUVA, FIJI
E C BRUXELLES, BELGIUM
E C SUVA, FIJI
Prof. Dr W. Schott, Hannover, Germany

INTERIM REPORT

ON APPLIED CORAL SAND INVESTIGATIONS IN AND OFF TONGATAPU

submitted by
Prof. Dr. Klaus Duphorn
Kiel, Federal Republic of Germany

Temporary consultant of the Institute of Marine Resources, The University of the South Pacific, Suva, Fiji, from July to September 1981.

Suva, Fiji, September 11, 1981.

Contents

1. Background and Objectives

According to a joint agreement between the commission of the European Economic Communities and the governments of Fiji, Tonga and Western Samoa in 1977 I had been appointed temporary consultant of the Institute of Marine Resources at the USP in 1981.

This is the interim report of the first working stage which included 4 weeks of field work in Tongatapu from August 4 to 31, 1981, and 2 weeks of initial studies of regional publications and of governmental and intergovernmental project documents, particularly from CCOP/SOPAC in Suva, Fiji.

According to a joint agreement between USP, CCOP/SOPAC and the Ministry of Lands, Survey and Natural Resources, Tonga, my initial survey should focus its attention to an applied investigation of coral sands in and off Tongatapu, because there is a strong and continuing demand for coral sands, suitable for road and construction purposes. Moreover coral sands are used as "patapata", that by tradition covers the grave of a Tongan.

This report is a follow-up to the advisory report submitted by Prof. W. SCHOTT, Hannover, Germany, to USP in 1978, and is made jointly to the USP, EEC, CCOP/SOPAC, the Government of the Kingdom of Tonga and to Prof. SCHOTT personally. I must apologise for being unable to complete the interim report by adding geological sketch maps and profiles, but the time available for elaboration was too short to do that. However, the interim report was urgently wanted by the Government of Tonga.

2. Present beach sand mining

The present sand requirements of approximately 8000 tons per year are satisfied by beach sand mining. The beaches, however, are very

small and narrow and their resources are limited. On the other hand, there is a strong and urgent demand for coral sands due to the growing population and the increasing tourist industry. Probably the demand could be twice of that from today in the very near future.

The active beaches are almost totally composed of calcareous sand. The composition of this sand varies slightly from beach to beach, but much of it usually consists of disc-shaped foraminifera that live in the shallow water of the adjacent fringing reef which surrounds the island. These most abundant components are followed by various amounts of calcareous algae and fragments of gastropods and echinoids also originating from the fringing reef. The percentage of coral is relatively low, but changing due to the wave action and erosion of the outer reef edges.

Sand cannot be transported by wash-over processes from further offshore to the beaches because of the abrupt drop-off in the water depth at the outer edge of the reef. There is also no lithic input from the limestone hinterland of the island, which is without any rivers. Thus most of the beach sands originate from the adjacent reef itself.

The broadness of the fringing reef is only 30m to 80m except for the northern coast off Nuku'alofa. Thus the catchment area of the reef is too small and narrow for sufficient sand supply and for the regeneration of the mined-out beach areas. Much of the scars left by the past mining operations are still apparent today. They confirm the statement based on the above observations, that a continuation of beach sand mining would deprive the island of one of its most beautiful and scenic natural landscapes and tourist attractions.

3. Previous work nearshore

Due to the above statement the need for other sand resources became apparent urgently. Therefore in 1978 CCOP/SOPAC took up the project CCSP - 1 TG6: "Reconnaissance inventory of beach and nearshore sand for landfill, construction and roading and determination of beach sand sources and renewal rates". The project commenced with two surveys for coral sand off Nuku'alofa in 1978 and 1980.

Results: An amount of 4 million m^3 sand has been located in a large embayment of the reef south of Fafa and Velitoa Islands, about 6 km north of Nuku'alofa. Considerable volumes of coral sands also occur in the southeastern part of the Nuku'alofa Lagoon south of Pangaimotu Island.

Technical testings of some sand samples undertaken by the Concrete Research Association of New Zealand revealed that the material, although not ideal, can be used as a concrete aggregate. According to the grain size analyses, however, much of these sands are rather fine grained and well sorted and therefore appear to be suitable as raw materials for cement and concrete only after sieving out the excessive amount of fine sand. For this reason an exploitation could not be recommended unless these fine sands could be mixed up with coarser sands from nearby.

In June 1981 CCOP/SOPAC proposed two other nearshore areas for sand exploration:

1) North of Nukunuku.
2) East of Niu Aunofo Point.

Additionally CCOP/SOPAC proposed to carry out "environmental studies, because it is obviously desirable to be able to predict the effects of the proposed sand dredging, before any potential site can be evaluated from a geological point of view."

4. Environmental aspects of coral sand dredging

I consciously should like to confirm this CCOP/SOPAC proposal for exploring both the living and non-living nearshore resources very sensitively because of two main reasons:

1) Nearshore dredging operations could lead to changes in currents affecting the island.

2) Moreover they could severely pollute the reefs and waste the complex and very sensible ecosystems of the marine environments, because much of the lagoonal sands off Nuku'alofa appear to contain a considerable amount of fine sand and muddy silt. The fine materials could be stirred up and pollute the coastal waters. Re-sedimentation may impede the growth of corals and reduce the productivity of fisheries by making the water turbid and by blanketing sea-grass areas, thus diminishing breeding and feeding environments (see below).

This confirmation and recommendation respectively is in close agreement with two governmental priorities:

1) Tongan waters are renowned for the variety of game fish and the coral reefs in Tonga are virtually untouched. In order to protect certain of these areas in their natural state, the Government of Tonga has legislated 5 marine reserves and 2 island parks under the National Parks and Reserves Act of 1976. These reserves contain representative examples of the marine environments of Tonga, which are of special scientific, educational, recreational or scenic interest.

2) The Tongans are heavily dependent on sea foods. In the future this problem will become still more serious, because the Tongan population is predominantly young and continues to grow at a rate which is well above the world average. Therefore the Government of Tonga has given high priority to the development of fisheries in the Kingdom, because imports of fish and fish products had to be made already in the amount of approximately Tongan Dollars 100.000/ year. For these economical reasons fish-farming in Tongan waters is seriously considered and should not be disturbed by any dredging or Hovercraft operation.

5. Preliminary results of the baseline study inshore

One of the most important conclusions to be drawn from the offshore collision between sand dredging, fisheries and preservation interests is, that the sand exploration should be extended from offshore to

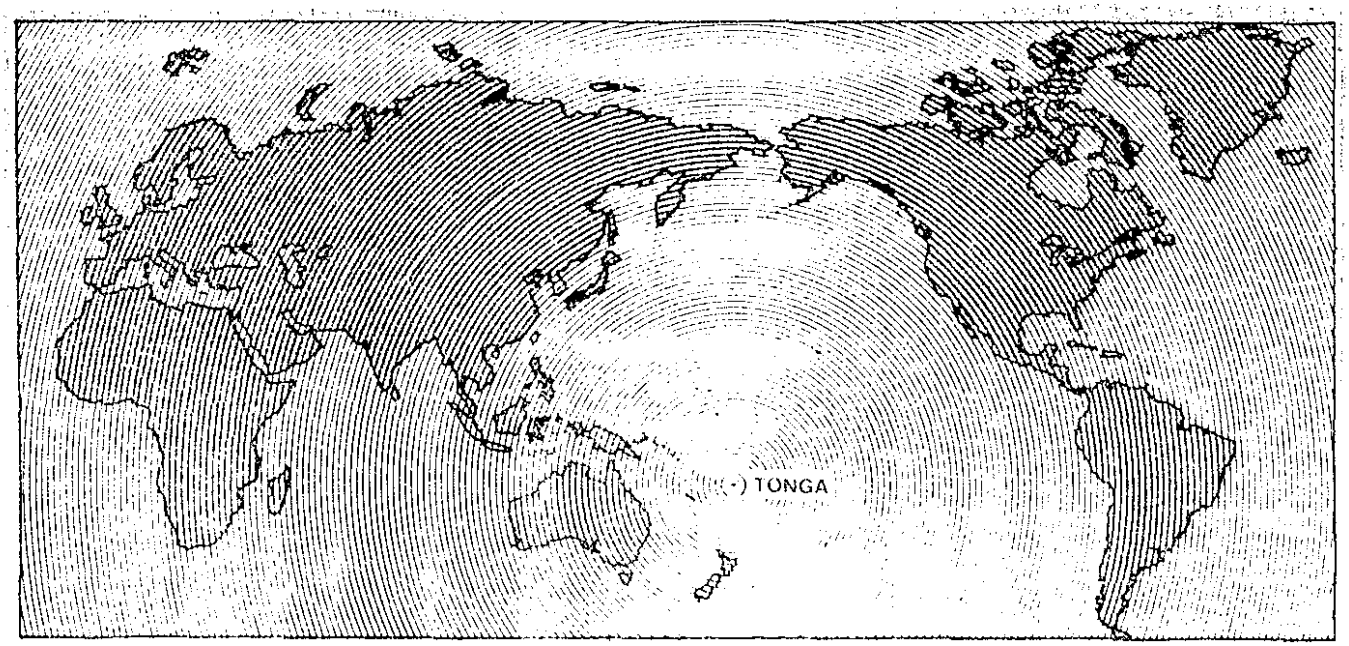


Fig. 1: Sketch map showing the central position of Tonga in the Pacific.

onshore, in order to find alternative potential sites which would not continue to be a significant environmental management problem.

One of the most serious handicaps of a prospecting geologist is, to start his field work without any geological map available. Therefore, in my own case the first task was to establish a geological baseline with special emphasis on the natural coastal development of Tongatapu during the Late Quaternary, that means during the past 130,000 years.

5.1 Coastal dynamics and morphology

Tongatapu, the largest Tongan Island, measures about 35 km by 20 km and has a coastline of approximately 95 km. The island rises up to an altitude of 61 m in the southeast and has a general downward slope gently inclined from south to north (see fig. 2).

Tongatapu is composed mostly of an uplifted coral limestone of Pliocene to Quaternary age. Its surface dipping appears to result from tectonical tilting to the north in Quaternary time (see 5.3).

Most of the coastline of Tongatapu consists of sea cliff and is surrounded by a fringing reef. However, the reef-protected shore shows different morphological features. The northern shore is flat, deeply embayed and fringed by mangrove swamps. Its adjacent reef extends until 10 km offshore and is separated from the shore line by the Nuku'alofa Lagoon, which is scattered by some small limestone islands and sand cays. 15 islands, surrounded with magnificent coral reefs, lie mainly within sight of Nuku'alofa, the Kingdom's capital (see fig. 2).

Unlike the northern coastline the other ones are steeply cliffed, primarily due to the stronger uplift. The fringing reef lies only

30 to 80m offshore and at some sites it even approaches the base of a nearly open cliff shore, which is subject to tremendous violent wave action and erosion.

These erosional processes reach their most extreme form at the famous blow-hole coast in the southeast, which is well exposed to the prevailing SE Trade Winds. The waves of the ocean rush into the blow-hole caverns in the limestone reef and gush up geyserlike into the air.

One of the most important conclusions to be drawn from these morphological observations is, that a significant net accumulation of beach sands cannot take place in the south and east along the erosional blow-hole coast. Only the sheltered northern and north-western coasts, where the debris, eroded by wave action in the south and east, has been shifted, are undergoing significant net accumulation.

This statement is also valid for most of the Late Quaternary times. Emerged blow holes and solution notches, situated between 3 and 9 m above sea level, provide geomorphological evidence that the eastern and southern coasts were dominated by cliff erosion also in the past, when the sea level was higher than today (see 5.2).

5.2. Sea level changes

A second factor strongly influencing Tongatapu's coasts is the Late Quaternary sea level changes caused by global climatic variations. Only twice in the past 200,000 years, during the climatic optima of the Holocene ($\sim$ 6000 years before present) and of the last interglacial period ($\sim$ 120,000 years B.P.), the sea level was higher than today. Most authors estimate about +2-3 m and about +6 m for the high stand about 6000 and 120,000 years B.P. respectively.

One of the most important conclusions to be drawn from the sea-level history record of Tongatapu is, that three coastlines connected with beach sands, each of different age and altitude, can be recognized and must be distinguished for the sand exploration, what never happened before. These beach systems are:

1) The active beach.

2) The so-called "Pumice Terrace", 3-5 m above the high tide level, corresponding to the higher sea level 6000 years B.P. (see 6.1).

3) The so-called "Kolovai Terrace", 10-12 m above the recent sea level, corresponding to the higher sea level 120,000 years B.P. (see 6.2).

5.3 Tectonical Uplift

A third factor strongly influencing the shape of Tongatapu and also quite important for sand exploration is the tectonical uplift of the island. The discovery of the marine Kolovai Terrace, originating from the 6 m - sea level 120,000 years B.P., but now far inland and raised up to an altitude of +10 to 12 m, proves significant uplift in the last 120,000 years, with an average rate of 4 to 6 m (see fig. 3). These numbers were derived by subtracting the height of the former sea level (6 m) from the height of the marine beach terrace (10 to 12 m).

One of the most important conclusions to be drawn from this continuing uplift of Tongatapu is: Find the raised coastline and you might find raised coral sands!

6. Potential sand resources inshore

6.1 The Pumice Terrace

The Pumice Terrace surrounds the island in narrow benches and pockets very adjacent to the active beaches, but separated from them

by a morphological step 3 to 5 m high. In some mined-out areas the mining operations have been approached also the outer edge of the Pumice Terrace, which is without any geological connection to the active beach downslope and never could be renewed by recent wave action(see figure 3).

The beach sands of the Pumice Terrace, which reaches a broadness of 100 m at some places, have been deposited during the 2-3 m sea-level high stand 6000 years B.P. This age has been proved by radiometric dates, both by $^{230}Th/^{234}U$ and ^{14}C, at the corresponding reef of Tongatapu and Eua Islands (F.W. TAYLOR: Quaternary tectonic and sea-level history, Tonga and Fiji, Southwest Pacific.- Thesis Cornell University New York 1978). The Pumice Terrace, however, has not been dealt with and the Kolovai Terrace (see 6.2) even not been mentioned by TAYLOR.

The beach sands of the Pumice Terrace are partly reworked and overlaid by coastal dunes which are quite small and gentle. They are also almost composed of calcareous grains originating from the fringing reef, which obviously was much larger during the sea-level high stand 6000 years B.P. Unless the active beach sands, however, the beach sands of the Pumice Terrace have been blanketed by a dense layer of greyish black, andesitic pumice ash, which probably has been erupted about 6000 years B.P. Therefore I propose to call this lithostratigraphic unit "Pumice Terrace."

6.2 The Kolovai Terrace

Unless the Pumice Terrace, which surrounds the island along the recent beaches, the older and higher Kolovai Terrace is restricted to the central part of the northwestern "Tail of Tongatapu", which served as a natural sand trap during the last interglacial period. At this time, approximately 120,000 years B.P., all the area lower than +10m was inundated by the sea (see 5.2 and 5.3). Thus,

the backbone of the "Tongatapu Tail" was situated in the stream shadow of the higher mainland. The sands, eroded at the mainland in the southeast, were transported in a northwesterly direction by coastal drift (see 5.1) and deposited along the "tail's coastline". (See figs. 2 and 3).

The most extensive beach-ridge area developed near to the root of the "Tongatapu Tail", roughly midway between Kolovai in the north and the Good Samaritan Inn in the south. Figure 3 shows a sketch profile across this area.

The southern section of the profile cuts the fringing reef, the back-reef lagoon, the active beach sands and the adjacent beach sands of the Pumice Terrace (see 6.1). The Pumice Terrace ($\sim$ 6000 years B.P.) has an altitude of between 2 and 4m, the Kolovai Terrace of between 10 and 12m, due to the higher sea level $\sim$120,000 years B.P. and the additional tectonical uplift of Tongatapu (see 5.2 and 5.3).

The coastline of the marine Kolovai Terrace, situated just amidst of the cross profile, is indicated by a dense layer of broken and rounded coral rubble along a steep ridge, which is about 500m long, 100m to 150m broad and rises up to an altitude of between 15m and 20m above sea level and 8m to 10m above the Kolovai Terrace.

This Kolovai Ridge is covered by a dark brown, clayish soil, 2 - 3m thick and consisting of the so-called Terra fusca, which is the most abundant soil type developed on the coral limestone of Tongatapu. Three drillings, however, revealed that the core of the Kolovai Ridge is composed of calcareous sands. One drilling atop of the ridge reached a depth of nearly 7m, but did not reach the base of the sands, which rest on coral limestone.

According to the ridge and terrace morphology and to the above paleogeografical considerations, the base of the sand can be expected at a depth of 8m beneath the top of the Kolovai Ridge. Then the most favourable relation between soil overburden and sand would be 2-3m: 5-6m.

The sands of the Kolovai Ridge are fine grained and very well-sorted. Much of the grains have a rounded shape and a wind-polished surface pattern. Thus I interpret these sands to be originated from a buried beach system of the Kolovai Terrace and to have been reworked by wind action into a coastal dune ridge along the former beach.

7. Recommendations on future sand exploration inshore

According to the preliminary results described in this interim report, the future exploration efforts inshore should be centered to the Pumice Terrace and to the Kolovai Ridge, particularly to the latter one.

7.1 Kolovai Ridge

The present state of knowledge does not allow any valuable estimation about the amount of sand and soil and about the technical properties of the sand. Three drillings only and none of them finished really are too less for any geological prediction.

Nevertheless, despite this lack, the Kolovai Ridge appears to contain a substantial amount of sand which could be extracted without any significant environmental management problem. However, three geological handicaps must be taken into consideration:

1) The soil overburden, which is to be moved off and to refill after the sand exploitation is finished.

2) The grain size of the sands to be mined. In generally dune sands are fine grained and very well-sorted. However, perhaps the sands might become more coarse grained if the mining operations approach to the buried beach-sand source in the north and to the root of the "Tongatapu Tail" in the east. Otherwise the fine dune sands could be mixed up with coarser sands from the Pumice Terrace nearby.

3) The calcareous cementation of parts of the sands by weathering and solution processes. However, most of the sands mined from the active beach contain fragments of cemented beach rock too (for instance, please look to at the coral sands presently used for the construction of the new Police Office in Nuku'alofa!)

My proposal is to complete the Kolovai Sand Inventory in successive working stages:

1) Continue digging holes in 8 profiles across the Kolovai Ridge parallel to the first one, 5 holes per cross profile, 100m distance between the profiles. That makes 40 holes totally.

2) Try to deepen the holes until the sand beneath the soil is reached. Then continue drilling with the equipment available as deep as possible.

3) Take sand samples for grain size analyses and technical testings, which could be carried out by the Concrete Research Association of New Zealand.

4) Since the sand mining is very urgent and of governmental top priority, take the risk to start the mining operation along the first profile if at least two of the drilling sites contain more than 3.5m sand and if also the adjacent profiles seem to be promising. In any case this risk would be restricted compared to the risk of a nearshore dredging operation to be started without having been preceded by long-term ecological studies of the complex marine environments.

5) In the case of starting mining operations, move off the soil overburden carefully in such a way that it can be refilled and be used as a valuable soil for re-cultivation. Thus, no environments would be wasted, no gaps would remain and the ridge, although more gentle, could be re-cultivated under a screen of coconuts, in rotational sequence with bananas, yams etc. The landscape cannot be hollowed out, because the hard bedrock of coral limestone beneath the sands of the Kolovai Ridge would serve as a natural defensive barrier and prevent that (see fig. 1).

6) The working stages 1 to 5 could be continued without my assistance. However, I myself hope to return to Tonga in July in 1982. Then the drilling holes should be deepened down to the base of the sand unit. Probably the Institute of Marine Resources can provide a new type of hand coring equipment, most suitable for sand exploration. By means of this equipment the network of drillings also could be densened, if necessary for the assessment of the total amount of sand and soil available.

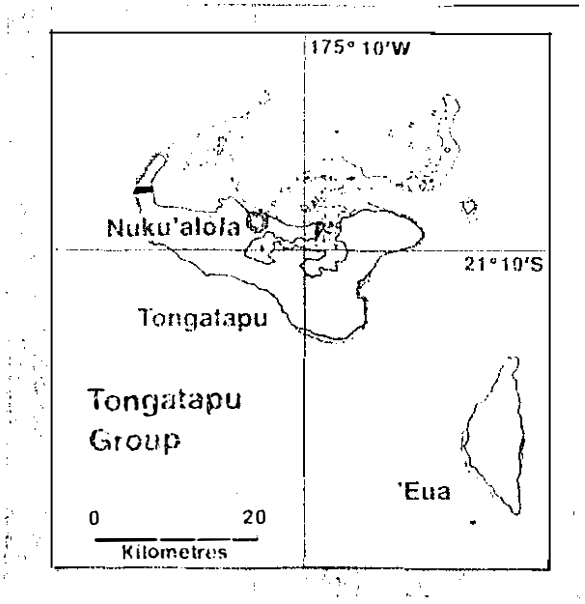
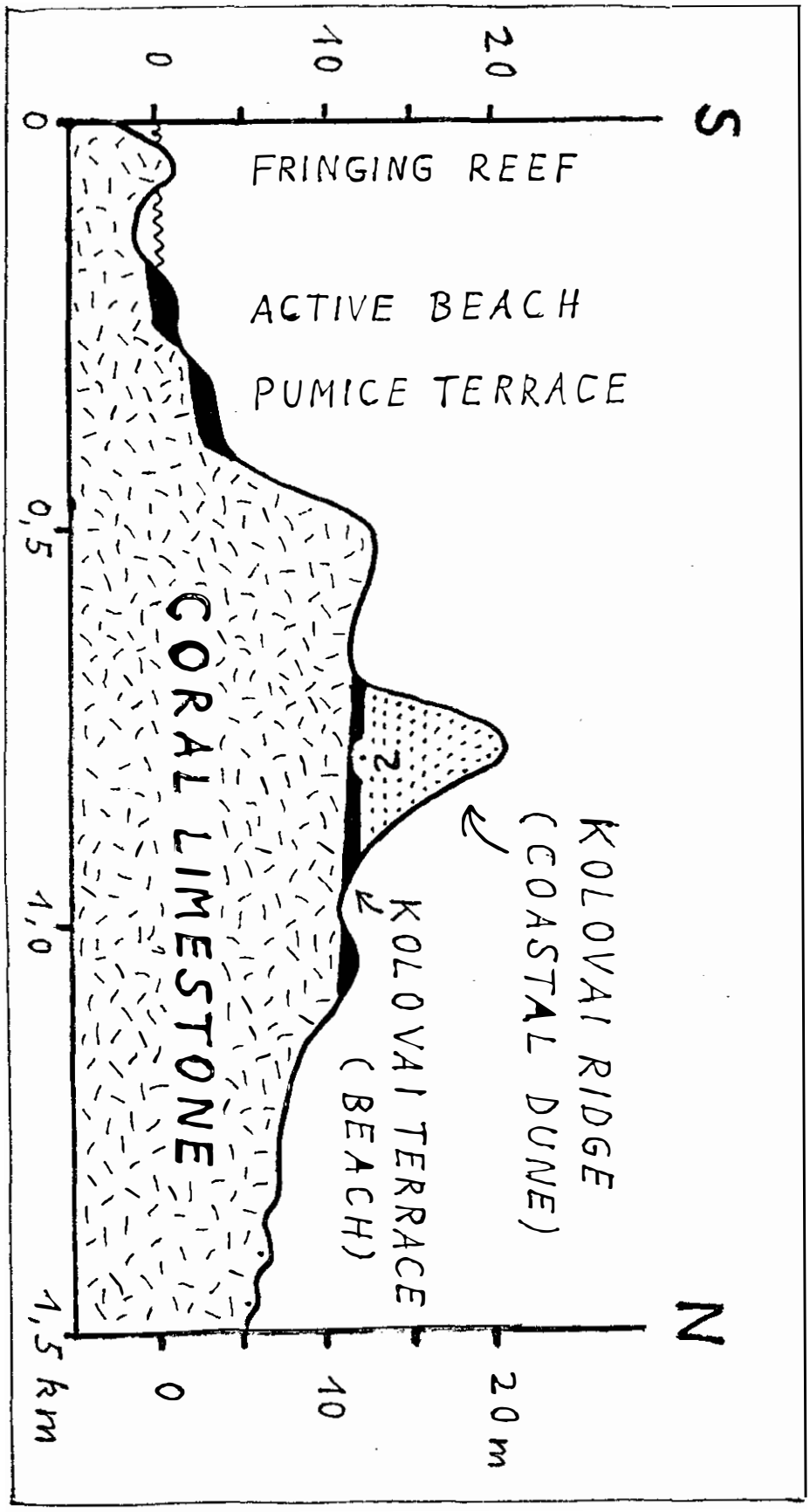


Figure 2: Sketch map showing position, size and shape of Tongatapu's coastline. The black line across the "Tail of Tongatapu" indicates the position of the profile shown in Fig. 3.

Fig. 3 : Sketch profile across the northwestern part of Tongatapu, roughly between Kolovai in the north and Good Samaritan Inn in the south and showing the positions of the three beach systems of Late Quaternary age.



7.2 The Pumice Terrace

Only little is known about extent and thicknesses of the emerged beach sands of the Pumice Terrace. Probably the broadness of the terrace does not exceed 80 to 100m and the thickness of the sand 2 to 3m. An accurate estimation of the amount of sand, however, only could be made on the base of a geological mapping by means of hand coring.

My proposal is, to map only the largest benches of the Pumice Terrace along the northwestern coastline, near to the Kolovai Ridge, and to mix up both sands if necessary (see 7.1).

8. Recommendations on future sand exploration nearshore

Before going into details, I should like to remember the ecological and economical nearshore priorities of chapter 4.

8.1. Nuku'alofa Lagoon and outlying islands

Under the premise of these priorities I support the working proposals made by CCOP/SOPAC in June 1981, to explore the nearshore areas 1) north of Nuku'alofa and 2) east of Niutan ofo Point (see chapter 3).

According to my own field observations I would prefer the second location. The first one seems to be less favourable, because the sands occur in small and thin patches, are very muddy and surrounded both by mangrove mud and by hard coral limestone. In any case a detailed geological mapping should be carried out at Low Tide, when the flats are dry land, before any mining operation can be started.

3) Moreover I recommend, not to finish the Fafa/Velitoa Survey from 1978 (see chapter 3) without adding a few deeper test drillings reaching the so-called prograded sands beneath the lagoonal fine sands. Due to the progradation*) these sands might be coarser and then could be mixed up with the fine sands above.

4) Only little is known about the erosion and accumulation patterns of the outlying limestone islands and sand cays. Nearly nothing is known about their geological history, their age, their development of formation. And absolutely nothing is known about the distribution and thicknesses of their sands, suitable for road and construction purposes as well as for "patapata" (see chapter 1).

I propose to continue the "Island Mapping Program" with top priority. It can be handled with a simple hand coring equipment and the expenses are extremely low compared to most of the other nearshore surveys. Even if some of the islands remain under governmental protection (I hope so!) and cannot be mined, their geological investigation with special emphasis on their sand inventory would serve as a valuable scientific baseline for all geological and ecological nearshore studies to be carried out off Tongatapu.

The tasks 1, 2 and 3 should be continued by CCOP/SOPAC, the task 4 by USP in close co-operation with the Ministry of Lands, Survey and Natural Resources, Tonga, and with my own assistance.

*) Progradation: process of building outward toward the sea (in front of a river delta) or inward to the land (during a marine transgression or by wash-over processes backreef) by deposition of sediment.

8.2 Fanga Uta Lagoon

Geological and soil studies carried out in some artificial holes in Nuku'alofa confirmed TAYLOR's suggestion, that most of the capital occupies the site of a former inlet that 6000 years B.P., when the sea level was 2-3m higher than today (see 5.2), connected Fanga Uta Lagoon with the sea (see fig. 2).

The tidal currents channelled in this inlet apparently were strong enough to erode the reef platform and to shift the erosional debris into the lagoon. A few meters of erosional deepening can be estimated, because most of the former Terra fusca soil, traditionally known as "kelekeleumea" and once covering the whole area, has been removed by the transgression, except for a few deeper karst caves filled with "kelekeleumea" and found beneath "Sanft's Theatre" at the main road of the town.

According to these observations and considerations I propose to take some samples from the bottom of the Fanga Uta Lagoon, which seems to be remarkably shallow and sandy at some parts. In joint agreement with Dr. Uday Raj and Dr. Zann, USP Suva, the sampling will be involved into the Fanga Uta Lagoon Project to be started by the Institute of Marine Resources, USP Suva, already next week.

9. Acknowledgement:

I should like to express my gratitude to the University of the South Pacific and to the European Economic Communities for sponsoring my trip to the South Pacific region and the survey carried out. In particular I should like to thank Dr. Uday Raj, Director of the Institute of Marine Resources, USP Suva, for kindly introducing me into his institute and for holding useful discussions. Special thanks to

Mr. Cruz Matos, Project Manager, CCOP/SOPAC, Suva, and to Mr. S. Tongilava, Superintendent, Ministry of Lands, Survey and Natural Resources, Nuku'alofa, Tonga, and to their staff for being so helpful and making my trip so enjoyable, Last, but not least, special thanks also to Miss Karen Anscombe, "His Majesty's Alllround Geologist", Tonga, for kind co-operation on sea and on land.

Suva, Fiji, September 11, 1981 Klaus Simpson