SAND AND AGGREGATE RESOURCES VAIUSU BAY, APIA, WESTERN SAMOA

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SOPAC Secretariat

September 1995 *SOPAC Technical Report 223*

Funding for this project came primarily from the European Union and the Government of Australia

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SUMMARY

To assess the sand and gravel resources in Vaiusu Bay mapping of bathymetry and drilling of 60 jetprobe holes to a maximum penetration depth of 5.0 metres was completed. From the jetprobing data a subsurface of impermeable reef pavement was encounted in the eastern portion of the survey area. This in part has controlled the direction of where the existing dredging has taken place.

Dry sieve analysis shows the sediments to be classified into three textural sub-groups, gravel, sandy gravel and gravelly sand. Examination of the composition indicates a dominance of coral rubble and detritus, shell fragments and whole gastropods, echinoid spines and some Halimeda present. Foraminiferal faunas usually a significant component of beach sands were noticeably few. Calculated volume of aggregate in the resource area is 3 million m^3 for water depths ranging between 0 and 3 metres.

The extent of the dredging causeways appear to be influencing the natural coastal process of Mulinu'u Peninsula and the flushing of Vaiusu Bay. Their current location was mapped by profiling along the exposed perimeter at mid tide. It was found that during a substantial period of both the flood and ebb tide the causeways are effective barriers which restrict the flushing of Vaiusu Bay. Turbid water conditions exist in the bay with visibility being no more than 1 metre, more often only tens of centimetres.

Abandoned dredge sites are craters with precipitous slopes lined with loose coral rubble and fine sediments and help maintain turbid water conditions that are most unfavourable for new coral growth or recolonization of seagrass beds. At present the area still under seagrass is estimated to be only 13 % of the area surveyed. Rehabilitation of the old dredge sites should be encourage to regenerate coral growth in what are at present aesthetically unattractive barren areas that are often a breeding site for ciguatera poison commonly found in reef fish.

ACKNOWLEDGEMENTS

The major funding support for this study was from the European Union and Australia. The project had the support and assistance of the Government of Western Samoa through the Ministry of Agriculture Forests Fisheries and Meteorology.

OBJECTIVES

The objectives of the survey WS9501 carried out to fulfil the requirements of Task 95.WS11 were as follows:

1. identify and map alternative sand and aggregate resources in Vaiusu Bay, and
2. estimate potential volumes of resources within the identified area.

The location of survey area is shown in Figure 1, and the field survey study was completed over the period 9 to 24 May 1995 (Smith,R. etal. 1995).

This survey was carried out at the request of W.S. Government and is of particular interest to the Department of Lands and Environment, Division of Environment and Conservation, Public Works Department and the Ministry of Transport.

INTRODUCTION

In 1987, preliminary bathymetry and jetprobing was conducted in Vaiusu Bay by SOPAC but this data was not published in map form. Volume reserves were quoted but their derivation is unclear due to the lack of maps and accompanying sediment analyses (Mata'afa, M. etal 1988).

Aggregate extraction for sand is done from the lagoon areas of Vaiusu Bay by draglines operating from causeways constructed from the shoreline into the lagoon. A number of issues are of concern with this method of mining. (1) dredging nearshore may cause coastal erosion and interfers with the natural coastal processes in the area, (2) the presence of the causeways which behave as artificially constructed groins interfere with natural the circulation and flushing of the lagoon and bay, (3) the remains of old workings are often aesthetically displeasing, (4) the risk of promoting breeding areas of ciguatera by the transportation of microscopic algae in the fine sediments of the plume generated by dredging activity.

The Department of Lands and Environment, Division of Environment and Conservation has in place draft dredging guidelines which in the long term, if implemented, would minimise the impact of this activity on lagoon resources and the coastline and encourage rehabilitation of abandoned dredge sites. To support this initiative alternative resources need to be identified, mapped and the quality and quantity assessed. With such background data Government can best assist and encourage the private sector to move towards a more sustainable and environmentally friendlier approach to winning sand and gravel.

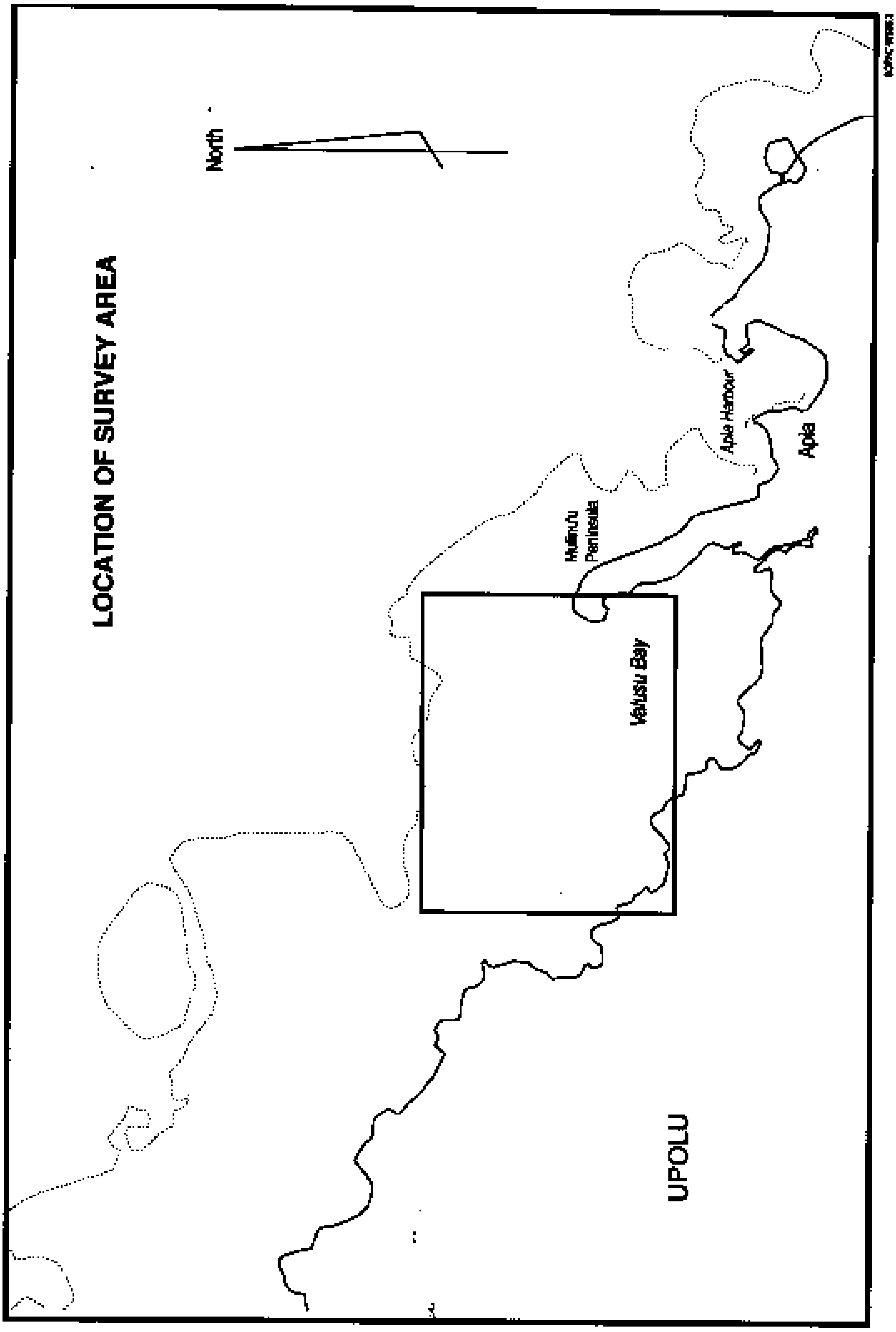

Figure 1. Location map of survey area.

Personnel Involved

Robert Smith	Marine Geologist	SOPAC
Simon Young	Senior Electronics Technician	SOPAC
Lameko Talia	Senior Scientific Officer	Apia Observatory
Vele Vatu	Seismologist Trainee	Apia Observatory

EQUIPMENT & METHODS

Navigation Control

Navigation control was accomplished with a Del Norte 1009 microwave/GPS digital distance measuring unit. Calibration for microwave navigation was done over a known range and the calibration factors recorded and checked daily throughout the course of the survey. Remote shore stations and descriptions of their location are in Appendix 1. Final reduced coordinates for the data sets are expressed in metres based on the Western Samoan Integrated Grid Datum specifications are:

Geodetic Datum: WGS 72
Projection: Transverse Mercator
First Eccentricity Squared: 0.006694317778
Semi Major Axis: 6378135
Central Meridian: 172 degrees west
Scale Factor at Central Meridian: 1.00000
Origin: Intersection of the central Meridian with the equator
False Origin: East 700 000; North 7 000 000
Zone width: 2 degrees

Bathymetry

An Odom echotrac precision echo sounder was used for profiling the seabed, the digital output logged and processed by the Del Norte 1009. Calibration of the sounder was by the bar check method. All bathymetric data collected are reduced to zero of the National Tidal Facility tide station sited at Apia Wharf.

Jet Probing

This diver controlled system to drill into the seafloor consisted of a 3 meter-long galvanised 2" ID pipe with a 1" ID jet nozzle connected to a diesel water pump (Figure 2).

Sediment Size Analysis and Composition

During this survey 60 jetprobe holes were drilled into the lagoon floor in the area surveyed (Figure 3) to confirm sediment thickness, obtain samples for grain size analysis, and determine sediment distribution and composition. The sample return was dependent on the nature of the substrate drilled. In loose to semi-consolidated sands there was a large sample return that could be collected in the return flow of water at the top of the hole. In semi-consolidated gravels with high porosity and permeability, as in a coral and rubble detritus deposit, the sample return was small. In addition ten surface sample were taken. A log of all sampling is in Appendix 2.

Sediment grain size distribution was determined by dry sieve analysis using the classification shown in Table 1. Sieve results for the 60 samples are in Appendix 3.

Table 1. Grain size classification as used in this report. Textural classification of the sediments (Figure 4) is based on Folk (1968).

Lower size limit(mm)	Phi Æ	Wentworth Size Class
64	-6	Cobble
16	-4	Pebble
4	-2	Pebble
2	-1	Very coarse sand
1	0	Coarse sand
0.5	1	Medium sand
0.25	2	Fine sand
0.125	3	Fine sand
0.0625	4	Very fine sand
pan		Silt

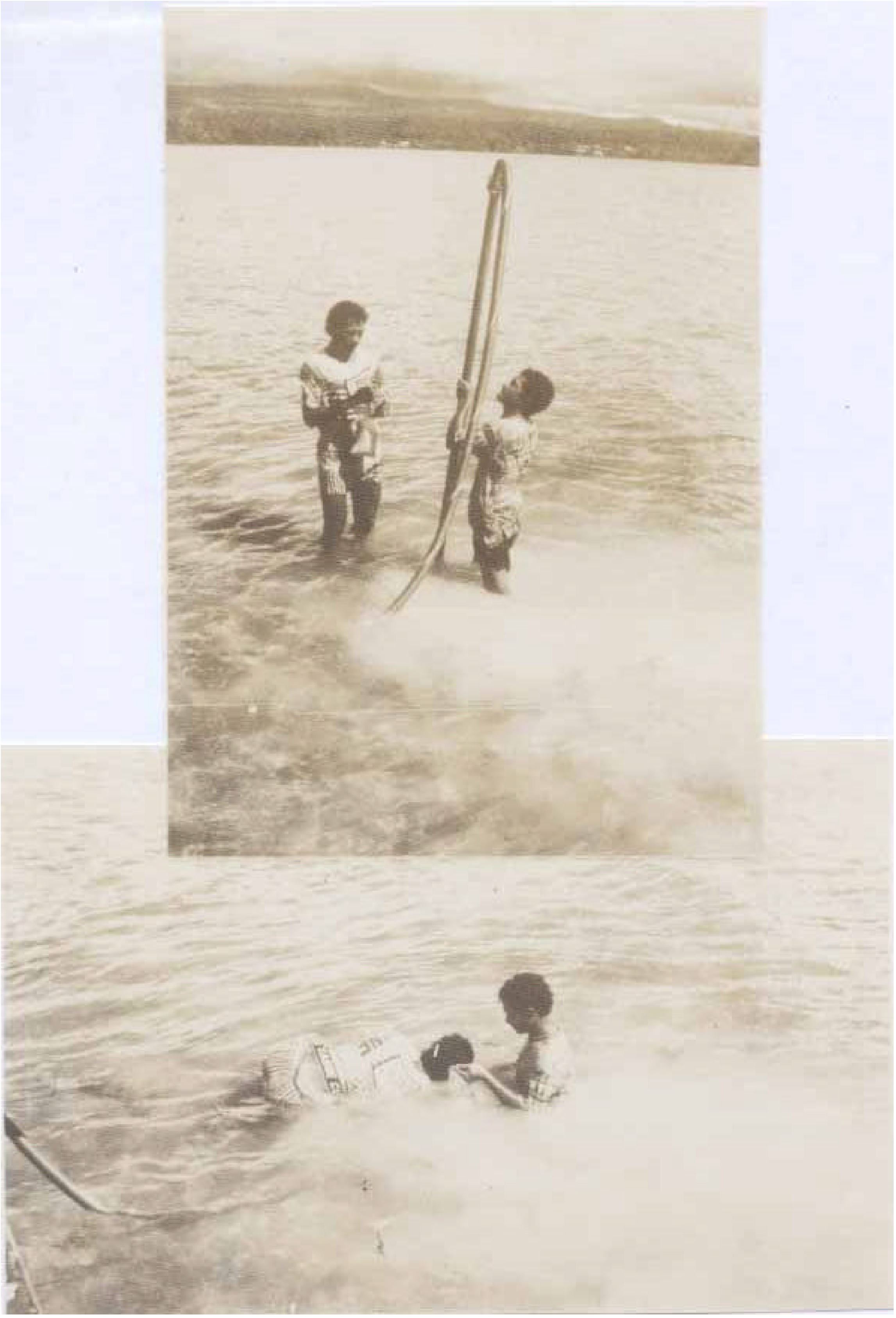

Figure 2. Jetprobing in Vaiusu Bay.

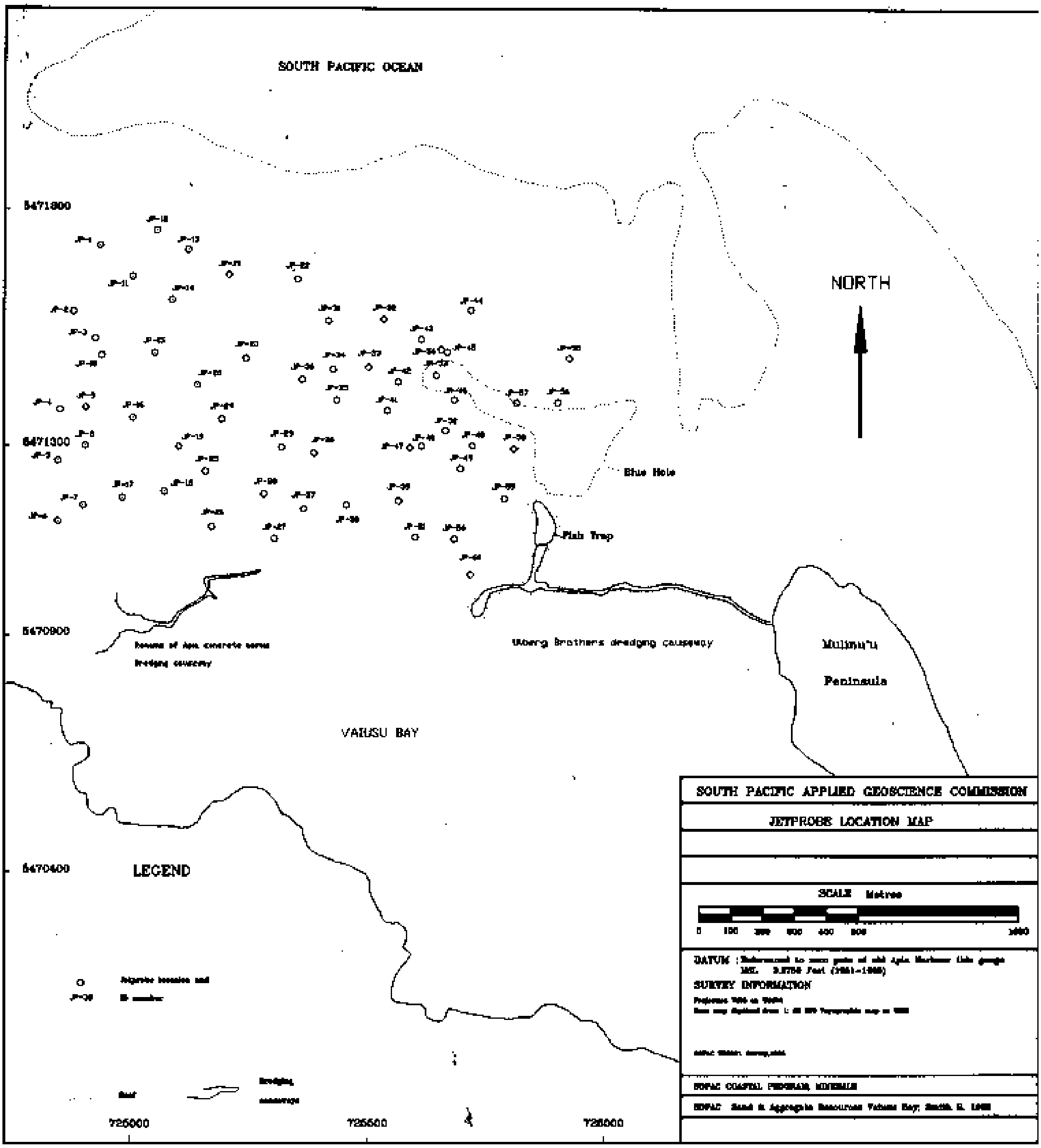

Figure 3. Jetprobe locations Vaiusu Bay.

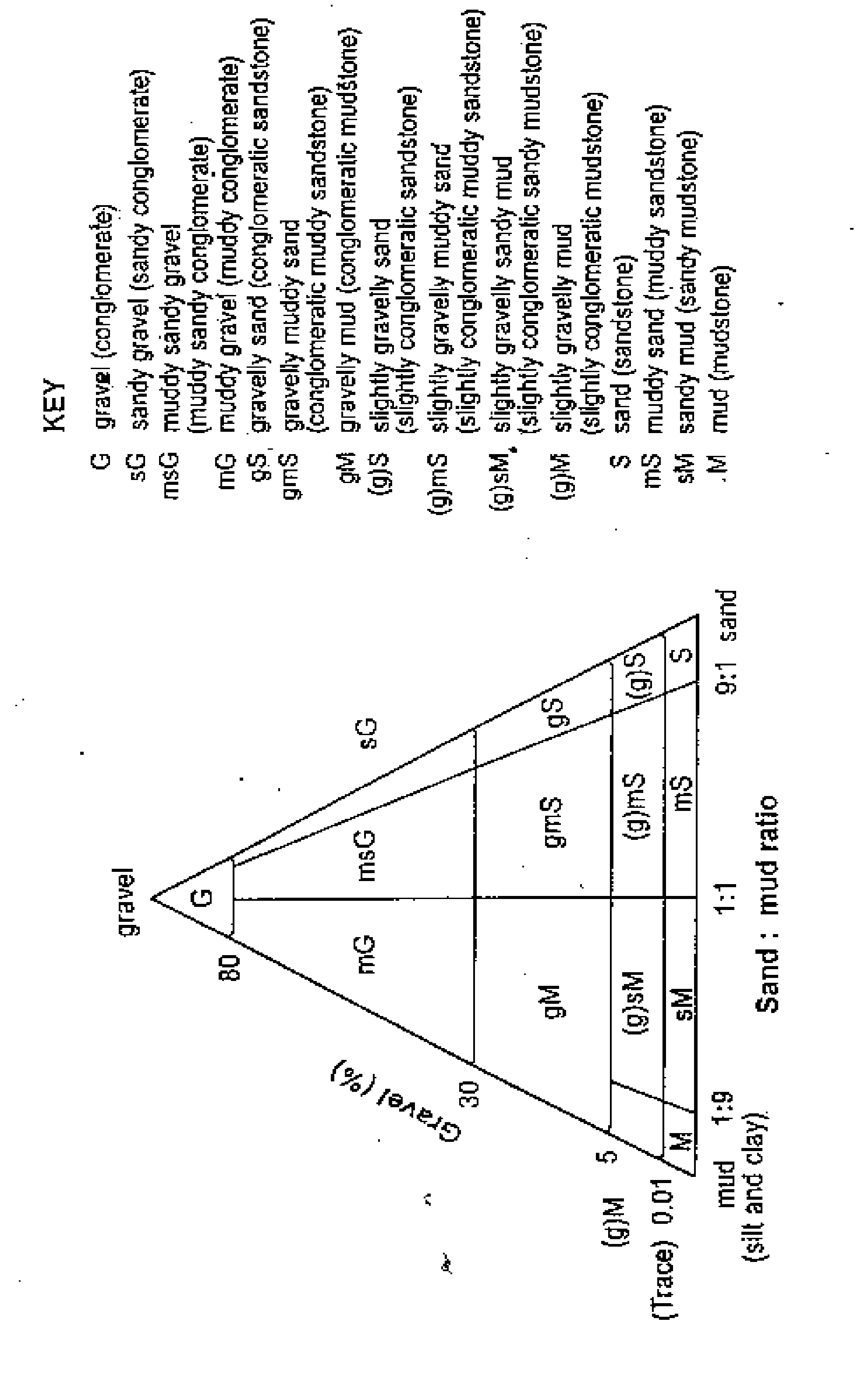

Figure 4. Textural sediment classification from Folk.

Resource Assessment

Computation of the potential resource volumes of the material identified was done using Autocad software by plotting the water depth and sediment thickness derived from the jetprobe data. The isopachs were derived by contouring the data using Quicksurf software. The calculations were performed on a volume defined by the upper and lower surfaces of the sediment body.

To convert the resource volume in cubic metres to tonnes, a value for sediment density is required. For carbonate sediments this figure can vary considerably, as shown in Table 2.

PRESENT SAND AND GRAVEL PRODUCTION

The current method employed at present for aggregate extraction from the lagoon areas of Vaiusu Bay by operating draglines from dredge causeways constructed from the shoreline into the lagoon (Figure 5). The location of the current extraction sites and active causeways are shown in Figure 6.

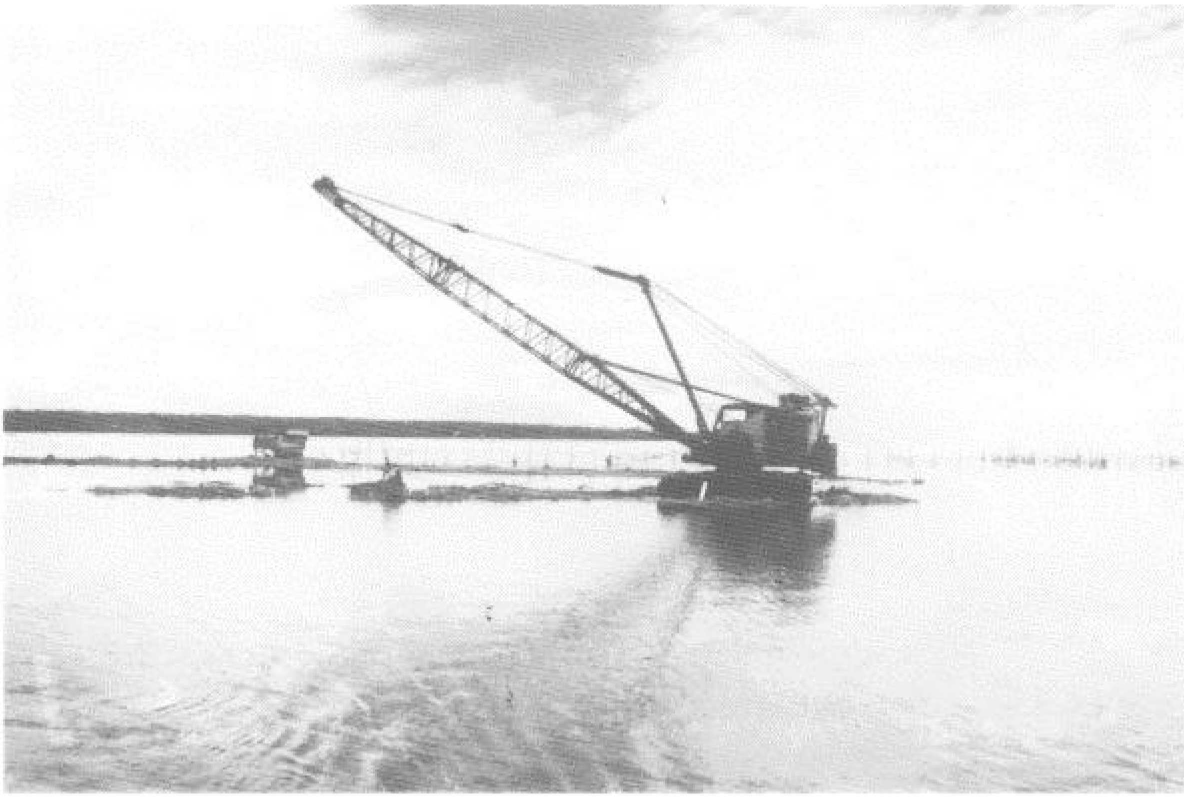

Figure 5. Dredging in Vaiusu Bay. Note fishtrap behind dredge.

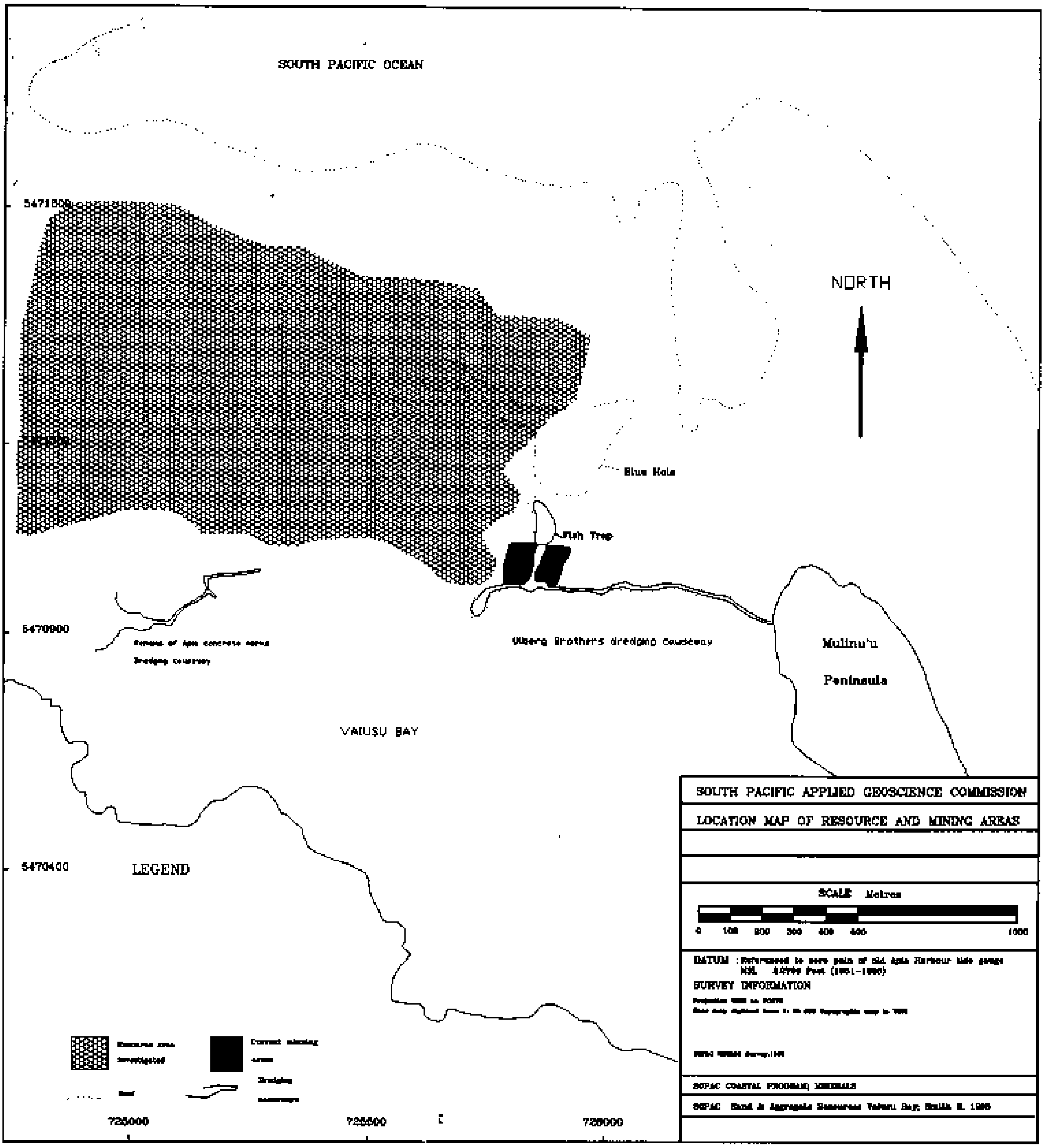

Figure 6. Location of the current extraction sites and active causeways.

Table 2. Examples of some conversion figures used for converting volume to tonnes.

SOURCE	*Tonnes per m^3*
Fiji Industries dredged coral sand (MRD, Fiji)	1.0
Tonga beach sands (Tappin. 1993)	2.05
Tonga, Fafa sand deposit dry (Smith & Gatliff. 1991)	2.48

Impacts of Current Dredging Methodology

Often the opening of a coral extraction site is governed by the need to satisfy immediate requirements and is chosen according to economic criteria. As a result a number of impacts both on the reef environment and socially are associated with this method of extracting aggregate:

- heavy turbidity of the water in the working area. As the workings are not from within an enclosed dyke which is elevated above Highest Astronomical Tide (HAT) or screened using modern geotextiles to prevent suspended fine sediment being distributed widely, the risk of degrading large portions of the reef and seagrass beds is high.
-
- at seabed level the problem of dredge workings producing a lunar landscape (craters) which complicates restoration of the area at a later date.

- pollution linked to the operation.

- increased shoreline erosion.

- modification of the hydrodynamic regime, poor flushing of semi enclosed bodies of water.

- risk of introducing ciguatera poisoning by promoting the spread of microscopic algae on the suspended fines.

- aesthetically displeasing remains of old workings , and associated rusting equipment. a common sight at old workings.

- the constant turbidity found in old working do nothing to help or encourage new coral growth thus these areas remain barren and unproductive. for very long or indefinite periods.

A number of impacts both existing and possible were noted during the course of the survey work in Vaiusu Bay. During the dredging operation the plume generated is not contained and is able to spread in a direction dependent on tidal and wind driven currents. This can, and is, resulting in degradation of the reef and seagrass beds. The random geometry of the current workings has resulted in exposure of the pits being open to circulating waters within the lagoon. The sediments exposed in the precipitous slopes generated by this dredging methodology contain a mixture of loose coral boulders, rubble and fine sediments which are not conducive to new coral growth. The resulting fines generated from mining at a site which has been abandoned continue to contribute to the turbidity of the water resulting in very low visibility which is not good for promoting coral growth. During jetprobing visibility was often less than a metre in 1.5 metres of water and in some areas only tens of centimetres. The mining operations do not employ the use of protective screens or restrict dredging to within an enclosed dyke. Therefore the risk of contaminating fine sediments with the microscopic algae *Gambierdisus toxicus* that generate ciguatera a toxic poison found in many species of reef fish is high. As there is a high level of subsistence fishing in the lagoon this could be a major health concern should an outbreak of ciguatera occur.

Rehabilitation of the current dredge sites is complicated due to the random nature of the dredging operations and the large area of workings. It is estimated that 22 - 30% of the bay has been degraded with dredging.

RESULTS OF THIS SURVEY

As an alternative to the present sites for mining aggregate, an area northwest of the current dredging areas was investigated (Figure 5). This area may satisfy the requirements for sustainable resource exploitation. Prior investigations east of this site encounted either hard substrate due to lack of penetration or inexperience in drilling into a gravelly sequence.

Bathymetry

Bathymetric soundings in this area are from the 60 jetprobe stations. Detailed profiling was prevented with the loss of the transducer on the coral reef. The area surveyed was characteristically shallow and of low relief with much of the area exposed at low tide. Figure 7 is the bathymetry shown with a contour interval of 0.25 metres.

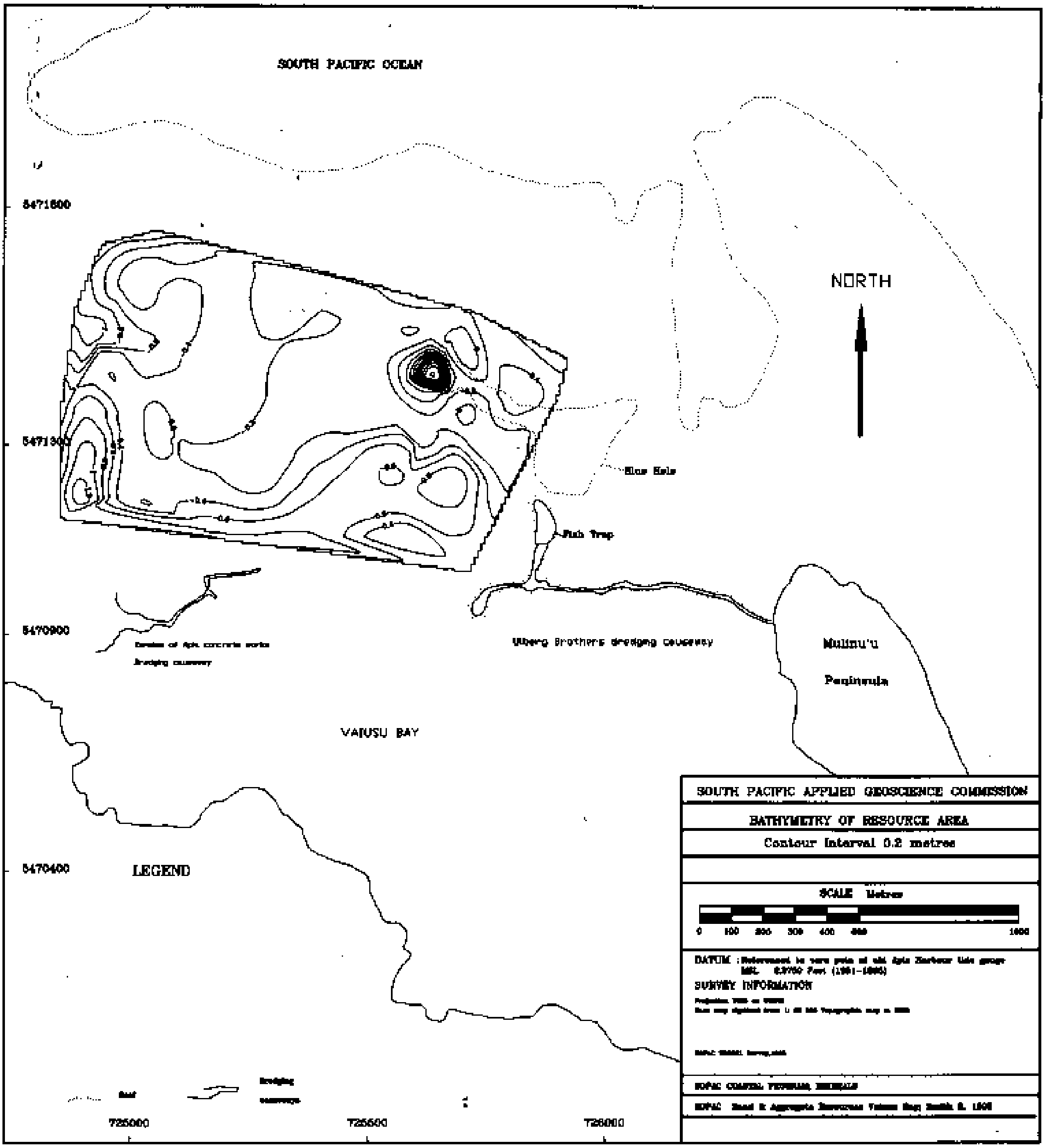

Figure 7. Bathymetry Vaiusu Bay.

Seabed Morphology

Figure 8 is an inventory of the different seabed morphological units interpreted from the jetprobe locations. In general the area is devoid of any significant coral growth and beds of seagrass. An area lying north of the current dredging site and close to the reef crest was the only area were seagrass was noted to be abundant. Of the total area shown in Figure 8 (1.6 million m^2) the area still under seagrass represents only 13 % coverage.

Potential Resource Volume.

From the jetprobe locations and depth of penetration data combined with the bathymetry data an isopach, a map of sediment thickness was generated to calculate the resource volume (Figure 9). For a water depth range between 0 and 3.0 metres there is a potential resource volume of 3 million m^3 available. This is a conservative figure based on proven thickness of sediment from the jetprobe data. In 1987 a borehole northwest of the area surveyed penetrated 17 meters of coral sands (JICA1987) terminating before reaching bedrock. In Figure 10, based on the jetprobing results is a map illustrating “buried reef pavement” , areas where a hard impermeable substrate interpreted to be reef pavement covered by a layer of sand between 0.5 and 2 metres thick. These areas were identified during the jetprobing, when the probe penetrated through the top sand layer and reached a resistive substrate. Due to the substrate’s impermeability the jetprobe bounced as a result of the hydraulic action of the water jet.

At location 53 at the western edge of an elongated depression in the reef, referred to as a blue hole, penetration of 5m was easily achieved in a clean carbonate sand. Digitized from a dyeline copy of the new 1:50,000 Western Samoan Integrated Grid of Vaiusu Bay the blue hole has areal extent of approximately 130,000 m^2. Assuming a constant sediment thickness of 5 metres a potential resource of 500,000 cubic metres of clean carbonate sand is present.

Sediment Analysis and Composition

Dry sieve data analysis data of the jetprobe samples were used to compile a ternary plot of sample texture based on three end components, gravel fraction, sand, and mud (Figure 11).

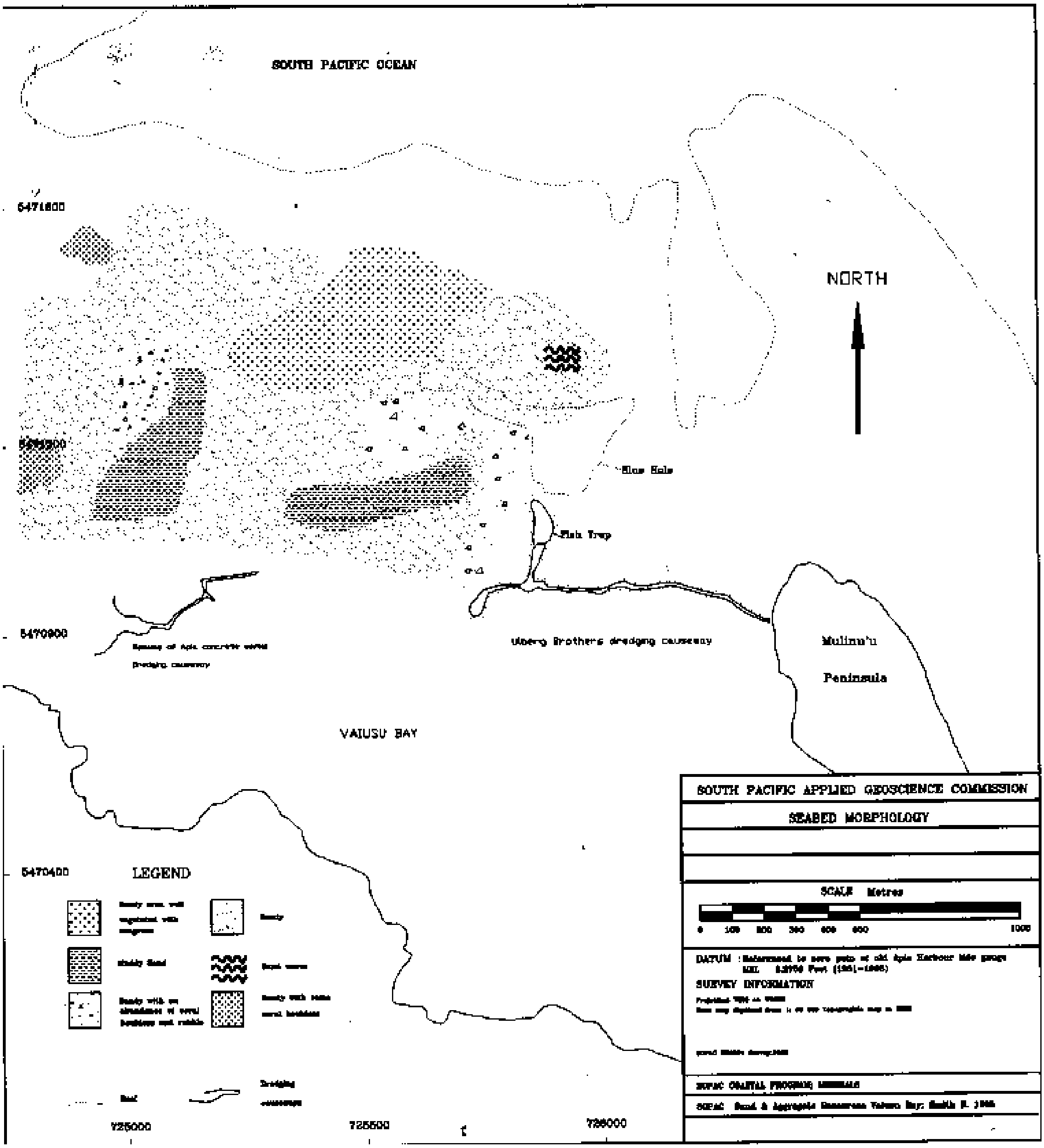

Figure 8. Seabed morphology interpreted from the jetprobe locations.

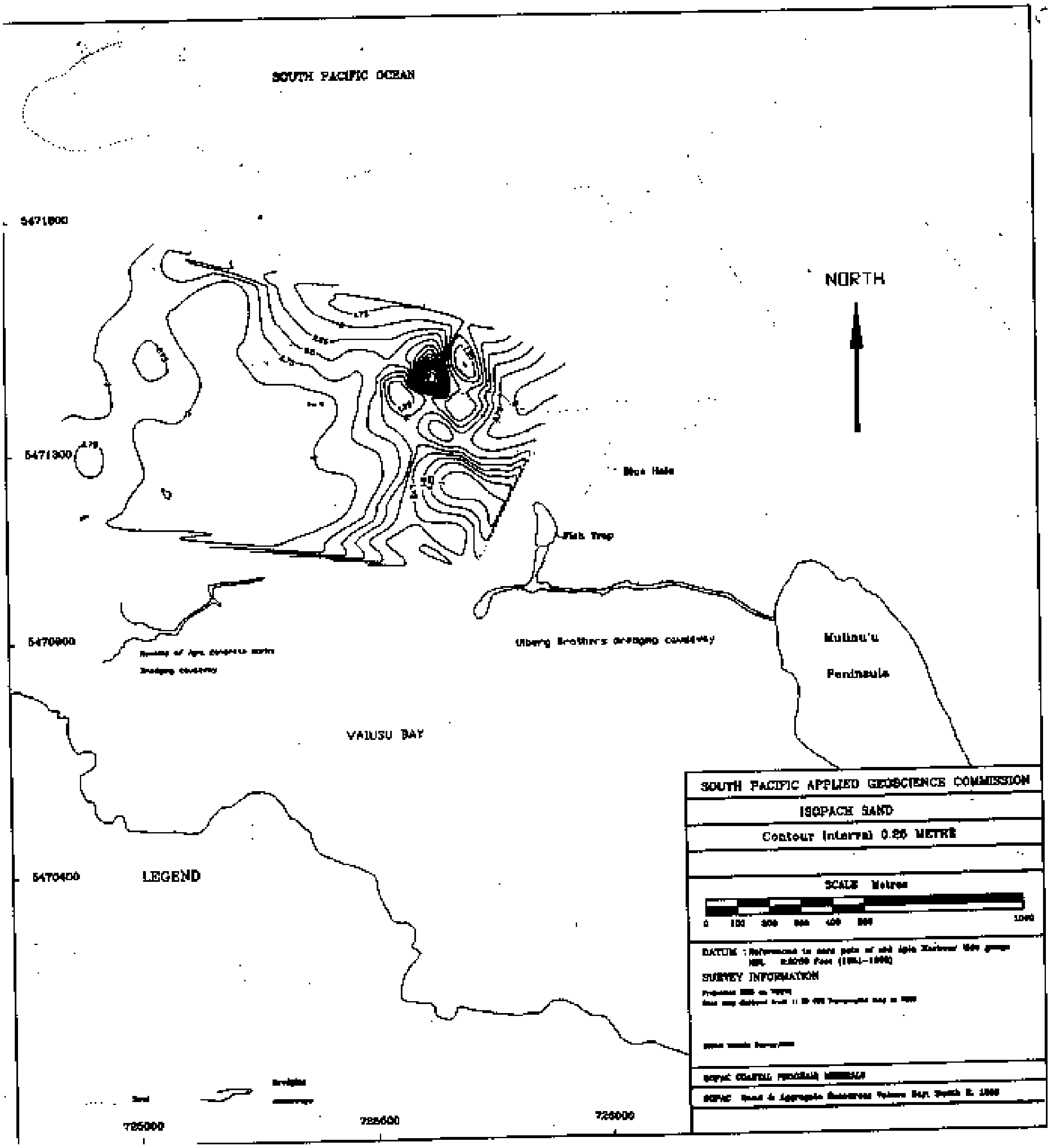

Figure 9. Isopach of sediment in resource area.

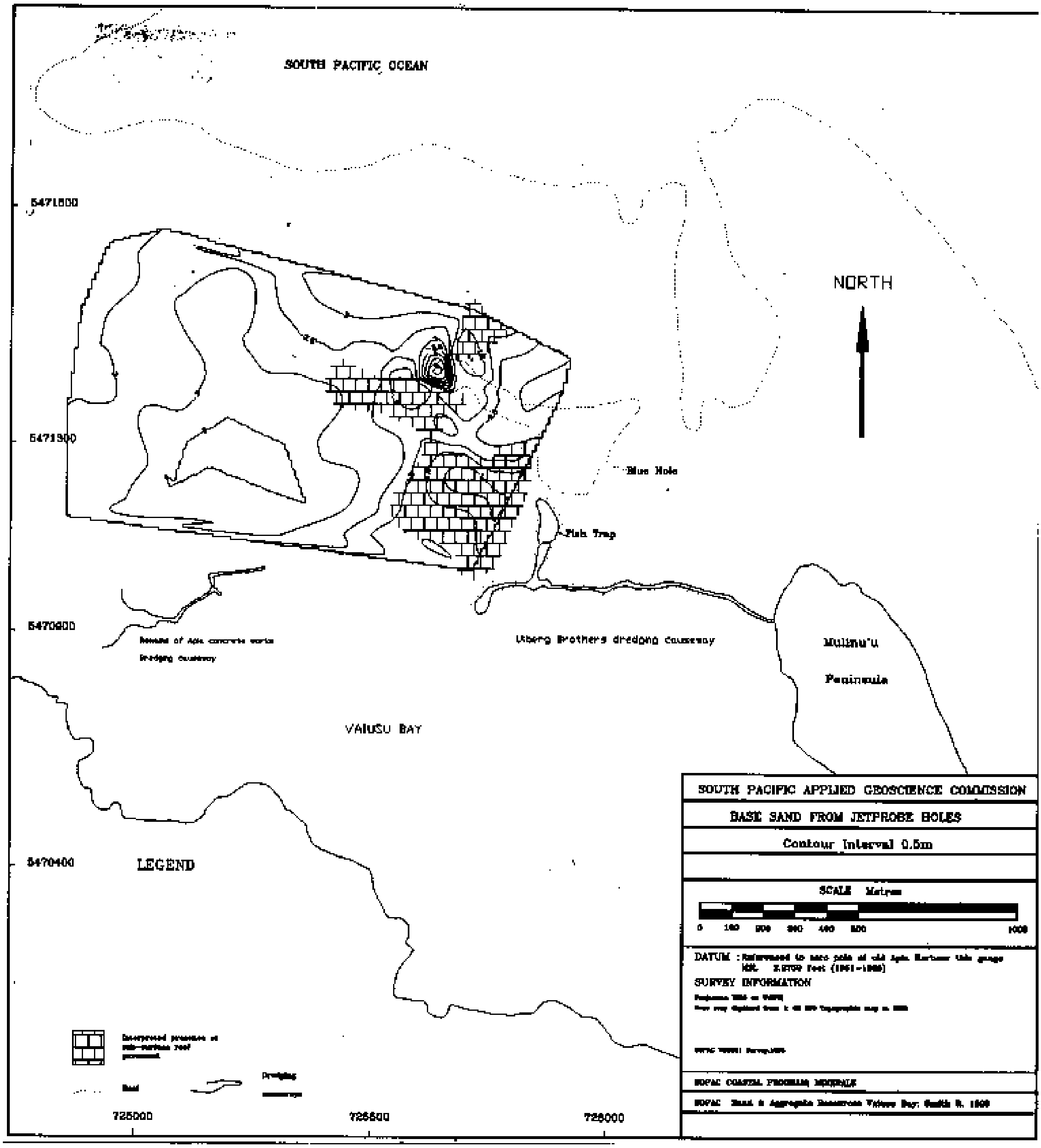

Figure 10. Base of sand from jetprobe data in resource area.

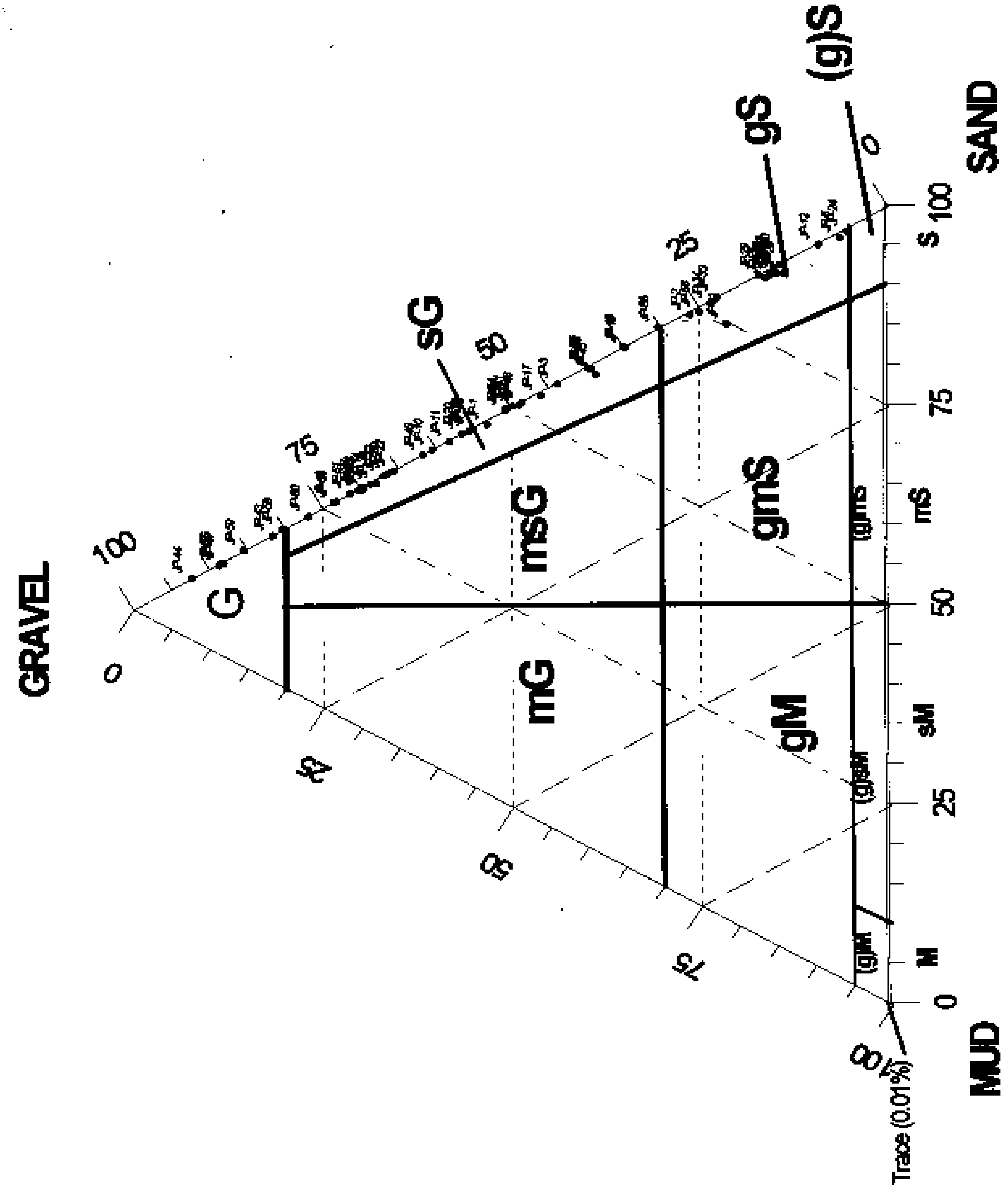

Figure 11. Textural nature of jetprobe samples based on Folks classification.

Following Folk's textural classification for sediments (Figure 4), the samples plotted in three categories, gravelly sand, sandy gravel and gravel. Based on this, the distribution of gravel, sand, and mud is shown in Figure 12, 13, 14 respectively.

A detailed composition analysis for each sample has not been completed, but a general overview is that the bulk of the sediments are carbonate in origin with very little terrigenous derived material. Magnetite a mineral resistant to weathering and derived from the volcanics was rare. For the carbonate fraction the typical composition is coral rubble and detritus, shell fragments, whole gastropods of varying size, echinoid spines and some Halimdea. A discolouration observed in the carbonate sand and detritus ranging from grey to black is staining resulting presumably from burial and organic content of the sand. Foraminiferal species a common component of beach sands (Todd ,1962) were notably absent.

Flushing of Vaiusu Bay

During the work in Vaiusu Bay it was noted that a strong ebb current developed at the end of the dredging causeway. On one particular occasion as very calm conditions prevailed the survey boat was used as a drogue with speed of drift and direction measured using the navigation system. The resultant drift velocity was 20 $cmsec^{-1}$. In addition, the exposed perimeters of the dredging causeways were profiled at mid tide to place in map form their size and extent from the shoreline. It was found that the causeways have extended far enough from the shoreline across the head of Vaiusu Bay to reduce the bay opening to only 650 metres width from an estimated original opening of 1.5 kilometres. The nett result is that the flushing of Vaiusu Bay has become quite restricted.

DISCUSSION

Dredge Site Rehabilitation

Figure 15 is an illustrative cartoon depicting a sequence to rehabilitate a mined area (Porcher M 1993). Rehabilitation of old workings is desirable not only for health reasons, encouraging new coral growth and recolonization of sea grassbeds it can impact in a positive manner on coastline stability, water circulation but is also aesthetically pleasing.

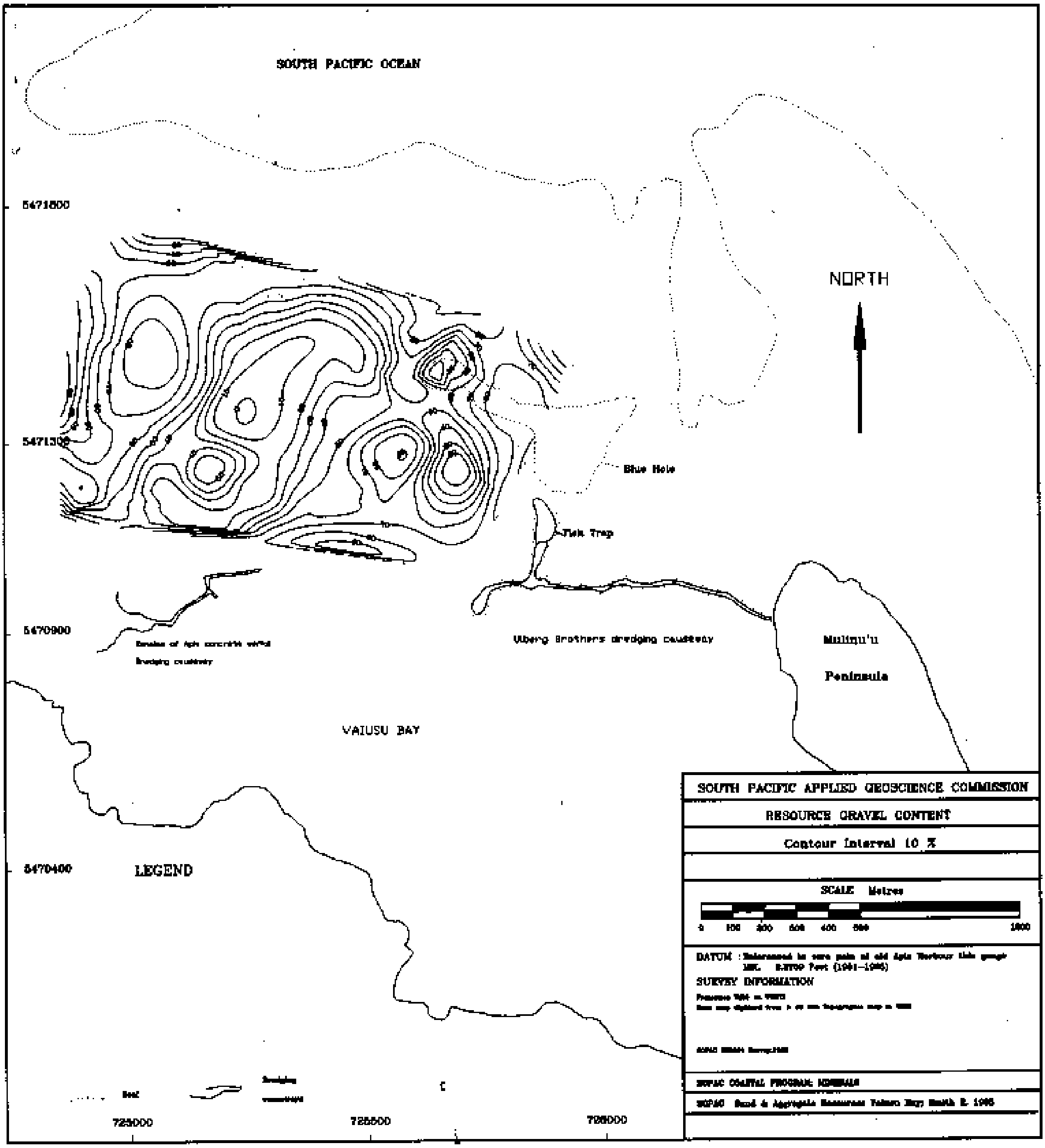

Figure 12. Resource gravel content.

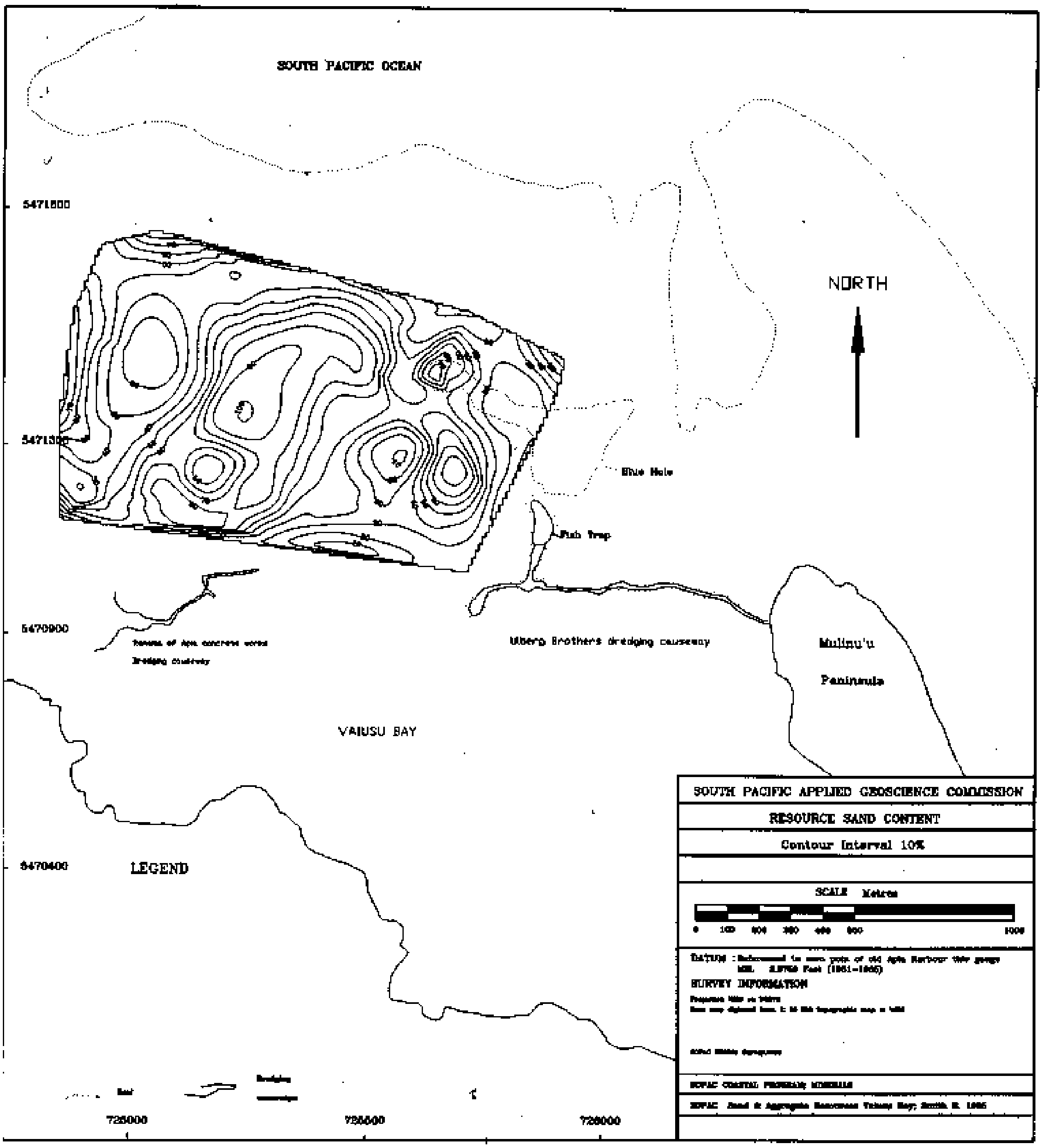

Figure 13. Resource sand content.

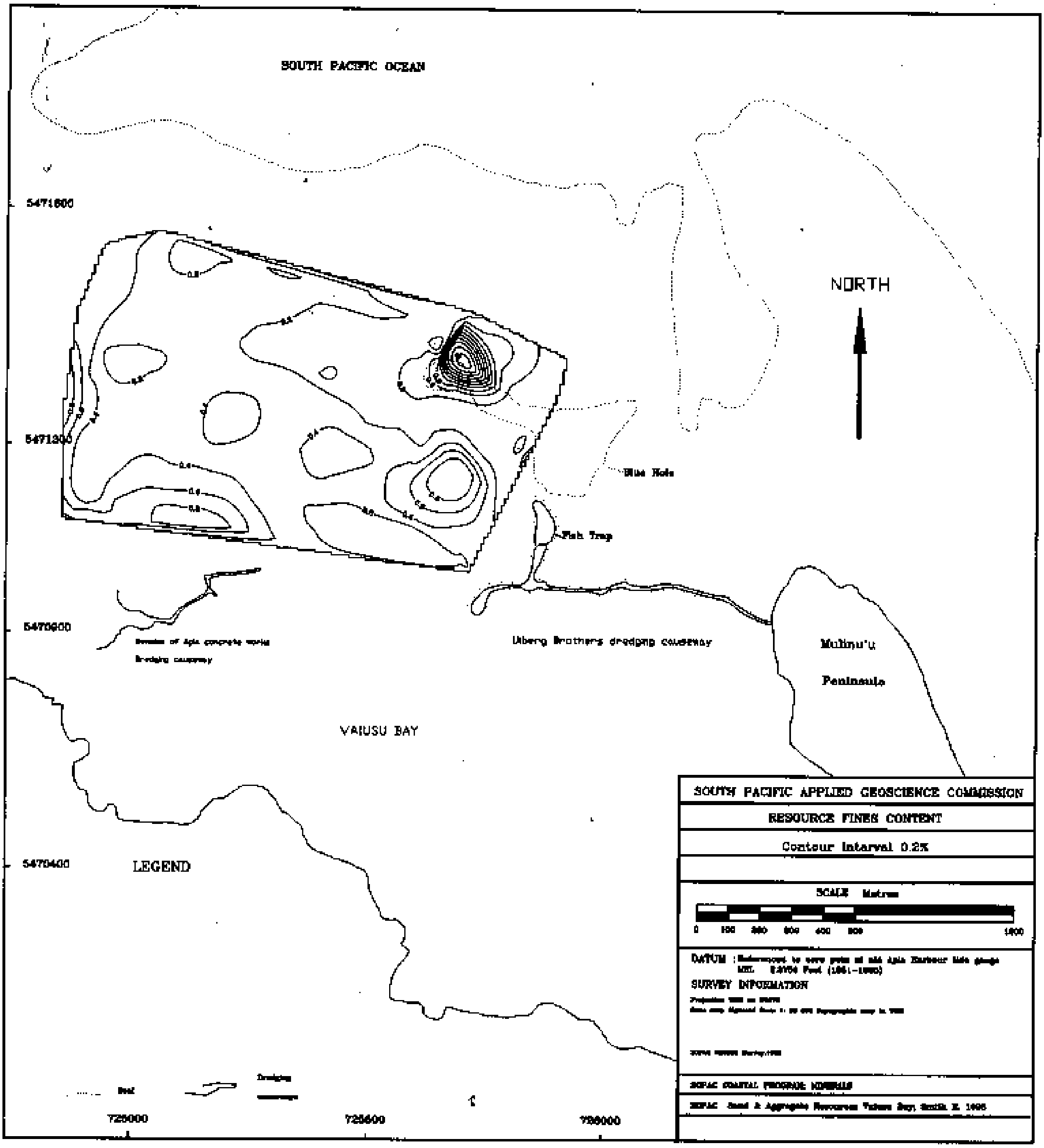

Figure 14. Resource fines content.

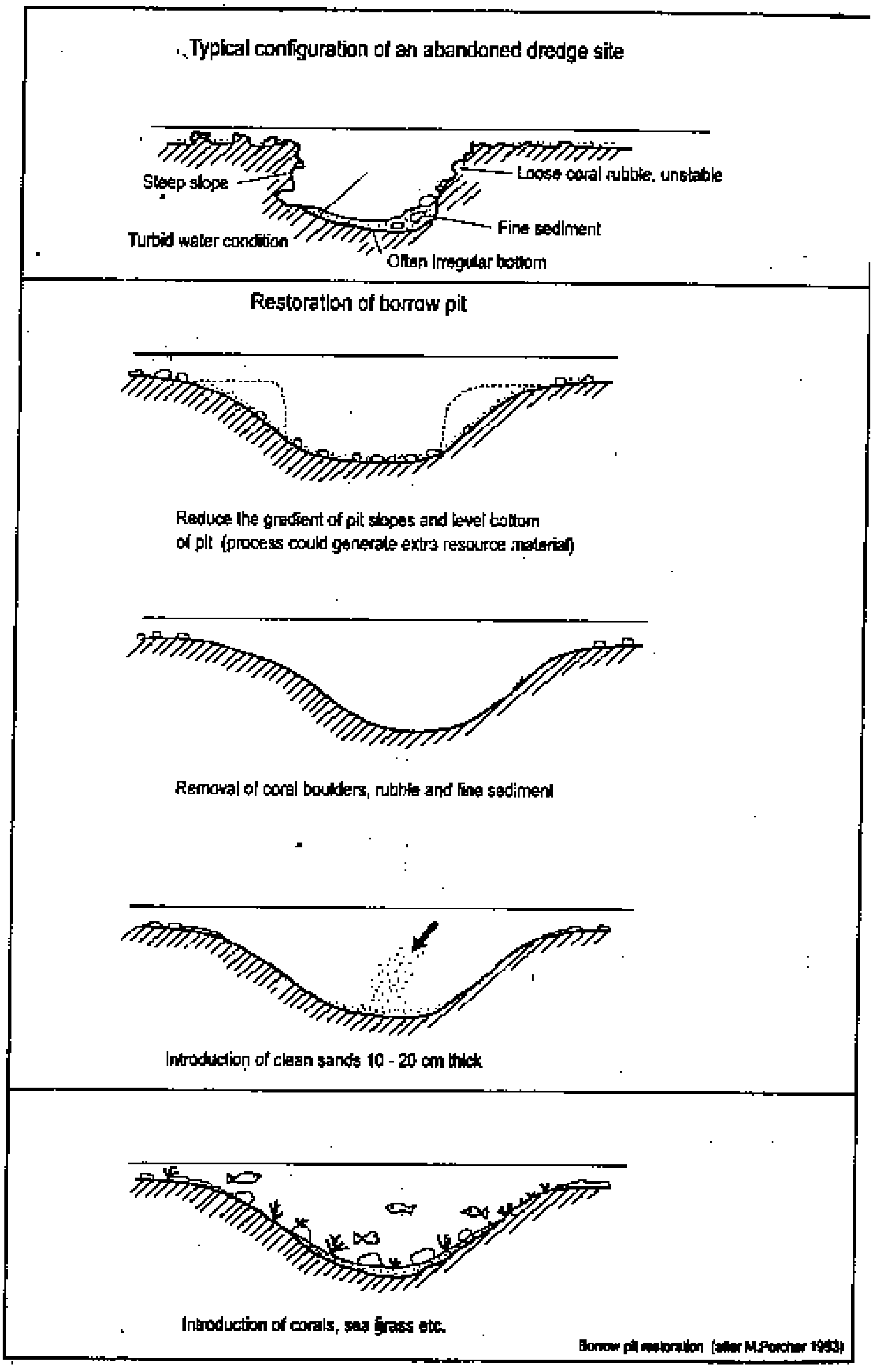

Figure 15. A cartoon illustrating a technique of dredge site reclamation.

Rehabilitation of the old workings west of Mulinu'u Peninsula would be large task and the pro and cons of attempting such an exercise would require a separate study, including one to examine in detail the state of the seabed resulting from blind dredging. Alone the resanding operation would require some 55 000 m^3 of clean sands. This could be sourced for example from the adjacent blue hole which has an estimated volume of 500 000m^3.

CONCLUSIONS

- For the sand and aggregate resources and bathymetry of Vaiusu Bay, results indicate a resource in excess of 3 million cubic metres in water depth ranging between 0 to 2 metres.
- Observations during the survey indicate that the dredging causeways are having an impact on the natural coastal processes in Vaiusu Bay, in particular the flushing of Vaiusu Bay. Around mid tide the causeways are exposed at which point they effectively form a dam stretching across 75 % of the head of Vaiusu Bay.
- The turbidity of the water is attributed in part to the continued suspension of fine sediments from old workings, and the effects of the extraction methodology used.
- Defining a method of extraction causing minimal impact is beyond the scope of this present study.

RECOMMENDATIONS

- Contain the dredging in an enclosed dyke or geotextile fence to prevent the escape of the dredging plume and turbid water.
- The enclosed dykes be constructed above HAT to prevent spillage into the lagoon.
- Dredging guidelines should include mandatory rehabilitation of the dredge sites.
- Remove the causeways where dredging has been discontinued to improve circulation in Vaiusu Bay.
- Investigate alternative methods of extraction, as distance from the shores increases.

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APPENDIX 1

Navigation Control Apia Harbour and Vaiusu Bay

Station	Easting (M)	Northing (M)	Elevation (m) wrt MSL	Remarks
Apia Yacht Club Pin III (5604)	724037.756	5471882.479	1.36	Land & Survey Control Position Remote 724 Harbour survey
Pin 5 Main wharf	725713.93	5470865.56	4 metres	Land & Survey Control Position Remote 764 Harbour survey
Rear Leading light	724938.8	5469139.4	Est 67 metres from Chart	Intersected this survey Position Remote 744 Harbour/Vaiusu Bay survey
Observatory tower platform Mulinu'u	723759.981	5472115.211	Est 19 metres	Surveyed in by Land & Survey Position Remote 724 Vaiusu Bay survey
Doppler station Apia Observatory	723686.43	5472143.389	0.91	Land & Survey Control Not used
Lemuta Bolt in Concrete path Apia Observatory	723719.437	5472123.784	1.148	Surveyed in by Land & Survey Not used
Pillar Faleula	718335.724	5474582.247	1.2	Land & Survey Control Not used

APPENDIX 2

Jet Probe Log Vaiusu Bay

Easting	Northing	water depth metres	Penetration Depth	Jetprobe Station #	Date	Time	Comments
721449.3	5473191	-1.75	3	JP-1	05/16/95	10.59.156	Hard initially substrate sandy with some rocks
721365	5472981	-1.8	3	JP-2	05/16/95	11.05.00	Very easy penetration
721434.9	5472896	-1.8	3	JP-3	05/16/95	11.13.557	sandy area Penetration difficult from 1.5 to 2.7 then easy after that took three attempts
721323.1	5472670	-0.9	3	JP-4	05/16/95	11.27.158	Sandy area Ist 2 metres easy last metre resistant
721316.3	5472509	-1.1	2.9	JP-5	05/16/95	11.37.359	Sandy area rubble very angular last 0.5 metre difficult
721315.7	5472318	-1.25	2.9	JP-6	05/16/95	11.51.360	sandy area 0-1 metre easy 1-2 very resistant 2-3 not as bad
721396.3	5472368	-1.7	3	JP-7	05/16/95	12.05.562	Sandy area adjacent to rocky reef 0-1 m easy 1-3 more resistant Surface sample taken
721403.4	5472557	-1.43	2.7	JP-8	05/16/95	12.19.263	Difficult hole pipe binding in hole due sand collapse
721405.6	5472678	-1.05	3	JP-9	05/16/95	12.37.164	Difficult hole from 1.7 to 3 metres Required 2 attempts very gravelly
721456.2	5472843	-0.6	3	JP-10	05/16/95	13.01.466	Substrate rocky penetration easy to 3.0 metres sandy
721552.9	5473093	-0.5	3	JP-11	05/16/95	13.21.268	In moat area behind reef crest rapid penetration to 3.0 m no effort Surface sample taken
721630.1	5473239	-1.2	3	JP-12	05/16/95	13.34.069	0-2 metres easy last metre difficult probe stuck Took consi-derable effort to remove fine sand on surface
721727.3	5473177	-0.67	2.5	JP-13	05/16/95	13.59.471	0-1 m easy 1-2.2 firmer 2.2 to 2.5 very resistant interpret compact sand
721677.2	5473019	-0.58	3	JP-14	05/16/95	14.17.173	0-2 metres easy, 2-3 some resistance a quickhole
721623.9	5472850	-0.7	2.7	JP-15	05/16/95	14.31.574	Rocky area on

							bathymetric high 3 attempts to reach 2.7 metres very gravelly
721553.6	5472645	-0.4	3	JP-16	05/16/95	15.02.177	gravelly 1.5 -2 m, 2.5- 3 m some resistance. Took surface sample
721520	5472391	-0.5	3	JP-17	05/16/95	15.16.078	0-1 metre easy 1-2m firmer some resistance at 2 m try 2 more location reached 3 m
721653	5472411	-0.55	3	JP-18	05/16/95	15.53.281	0-1 measly thereafter some resistance. Substrate muddy sand
721698.3	5472554	-0.44	3	JP-19	05/16/95	16.07.382	Substrate muddy sand surface sample taken coarse gravelly sand hole stands up well
721756.1	5472749	-0.6	3	JP-20	05/16/95	16.18.383	Substrate muddy sand drilled 3 m with some resistance from 0-1 m
721885	5473098	-1.32	3	JP-21	05/17/95	10.45.00	Easy drilling to 2.3 m then some resistance at 2.7 m
722070	5473083	-1.15	2	JP-22	05/17/95	10.55.00	Very difficult drilling,4 attempts. Very gravelly sample return. Substrate sandy.
721909	5472833	-1.2	3	JP-23	05/17/95	11.08.000	Very easy hole . Substrate sandy and well vegetated
721832	5472640	-1.2	3	JP-24	05/17/95	11.15.000	Relatively easy penetration in sandy area. No sea grass
721780	5472474	-1.1	3	JP-25	05/17/95	11.22.00	Easy drilling . Sample return coarse sandy gravel. Sandy substrate no vegetation
721801	5472298	-1.6	3	JP-26	05/17/95	11.27.00	As above but with some resistance 2-3 metres.
721998	5472261	-1.7	3	JP-27	05/17/95	11.35.00	Surface sample taken Halimeda noted for the first time. Probe sample shelly gravelly sand.
721965	5472402	-1	3	JP-28	05/17/95	11.45.00	Substrate sandy. Easy drilling.
722021	5472551	-0.9	3	JP-29	05/17/95	11.55.00	Sandy substrate no vegetation. 0-2 m easy drilling but 2-3 m was difficult
722085	5472764	-0.85	3	JP-30	05/17/95	12.05.00	Substrate sandy with sea grass .
722170.2	5472952	-0.9	2.1	JP-31	05/17/95	12.15.304	Gravelly resistance binding pipe at 2.1

722343.8	5472957	-0.78	2	JP-32	05/17/95	12.29.405	Sandy substrate well vegetated. 3 attempts max depth reached was 1.3 m. Solid resistance into an impermeable surface judging by the pipe bounce under its own water pressure.
722295.8	5472804	-0.7	2.7	JP-33	05/17/95	12.42.206	Sandy area well vegetated. Solid resistance at 2.0 m Same effect occurred a/a
722184.2	5472797	-0.5	2.7	JP-34	05/17/95	13.17.109	Substrate sandy w ith sea grass. 0-1.5 easy,1.5- 2.5 some resistance Solid at 2.7 m.
722195	5472700	-0.5	2.7	JP-35	05/17/95	13.29.410	Substrate sandy no vegetation. Solid resistance at 2.7 m.
722123.4	5472532	-0.65	3	JP-36	05/17/95	13.46.112	Substrate sandy no vegetation. Very easy drilling to 3.5 m. Water very turbid at this site.
722090.4	5472356	-0.94	3	JP-37	05/17/95	13.56.312	Easy drilling to 2.8 m. Last 20 cm resistance - gravels.
722226.7	5472369	-1	3	JP-38	05/17/95	14.04.313	Substrate muddy sand. Last 0.5 resistant - gravelly.
722391.6	5472381	-1	2	JP-39	05/17/95	14.14.314	Substrate muddy sandy. 0-1 m sand, 1-1.5 gravel .Solid resistance at 2.0 m. attempts at this location.
722463	5472555	-0.4	1.9	JP-40	05/17/95	14.28.115	Substrate sandy with scattered rocks. 4 attempts solid resistance at 1.9 m.
722355.3	5472667	-1.25	2.2	JP-41	05/18/95	08.59.310	Sandy substrate with scattered rocks no vegetation. Hit solid resistance at 2.2 m.
722390.8	5472758	-1.6	1.6	JP-42	05/18/95	09.09.211	Substrate coarse sand. Hit solid resistance at 1.6 m. 2 attempts at this location.
722463.2	5472893	-1.35	2.8	JP-43	05/18/95	09.17.012	Sandy substrate with sea grass mat. Resistance at 2.8 m - gravels ?
722620	5472986	-1.45	1.6	JP-44	05/18/95	09.28.013	As above with some scattered rubble. Solid resistance at 1.6 m. 2 attempts

							here
722545.7	5472852	-1.45	1.9	JP-45	05/18/95	09.37.414	As above. No vegetation. Hit solid resistance at 1.9 m
722568	5472701	-1.38	1.6	JP-46	05/18/95	09.53.415	Substrate sandy with detritus no vege-tation. Hit solid resistance at 1.6 m.
722427.5	5472550	-1.8	3.3	JP-47	05/18/95	10.01.416	Substrate sandy with rocks. Rapid pene-tration in last 0.5 m.
722625.9	5472556	-1.4	2.4	JP-48	05/18/95	10.13.317	Substrate sandy not vegetated. Easy drilling and hole does not stand up.
722587	5472483	-2	1	JP-49	05/18/95	10.22.518	Substrate sandy mud. Hit solid resistance at 1.0 m.
722567.1	5472260	-1.8	1.9	JP-50	05/18/95	10.34.419	Sandy substrate. Hit solid resistance at 1.9 m. Sample gravelly
722443.8	5472266	-1.45	1.55	JP-51	05/18/95	10.40.319	Sandy substrate - no vegetation barren. Easy drilling, hit solid resistance at 1.55 m.
722540.8	5472604	-1.35	2.6	JP-52	05/18/95	10.58.321	Substrate sandy and rocky. Hit solid resistance at 2.6 m.
722510.1	5472779	-3.3	5	JP-53	05/18/95	11.12.322	Sandy substrate . in Blue hole area. Very easy drilling to 5 m. Hole stood up well
722526.4	5472860	-1.4	3	JP-54	05/18/95	11.21.223	Substrate sandy with sea grass. 3.0 m penetration with some resistance.
722933.4	5472833	-1.1	3	JP-55	05/18/95	11.32.324	Sandy substrate with sand waves orien-tated E-W Drilled 3.0 m.
722896.7	5472692	-1.4	2.9	JP-56	05/18/95	11.42.424	0-1.5 easy penetration. 1.5 to 2 m firmer stopped at 2.9 m.
722766.4	5472692	-1.45	3	JP-57	05/18/95	11.52.125	Substrate sandy. Sample coarse sand some resistance to drilling
722756.8	5472546	-1	2.4	JP-58	05/18/95	12.02.526	Substrate sandy with coral rocks. Hit solid resistance at 2.4 m. Pump loaded down indicating no porosity causing back pressure.
722726.2	5472389	-1.15	1	JP-59	05/18/95	12.11.327	Easy penetration to 1.05 m. Hit solid substrate at 1.05. 3 attempts all the same result.

722618.7	5472148	-1.45	1.5	JP-60	05/18/95	12.21.128	4 attempts hit solid substrate at 1.5 m. This site adjacent to abandoned dredge area.

APPENDIX 3

Results Dry Sieve Analysis