United States Department of the Interior
Geological Survey

OFFSHORE SAND RESOURCES ALONG THE SOUTH SHORE OF TUTUILA ISLAND, AMERICAN SAMOA

by
John R. Dingler
Stephen C. Wolf
David Carlson

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This report is preliminary and has not been revised for conformity with U.S. Geological Survey editorial Standards.

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Statement of Problem

The residents of Tutuila Island, American Samoa need sand for construction and personal use. Traditionally, that sand came from the nearest beach, being taken as needed, usually in small quantities. However, the island's beaches do not contain enough sand to meet the present demands while still maintaining their integrity. Rather than having long stretches of coast with wide, sandy beaches, Tutuila Island has an irregular coastline that is characterized by small pocket beaches separated by rocky headlands (Fig. 1). Furthermore, the fringing reef tends to be narrow or missing, which limits the amount of coral available for reworking into sand.

If the needs of its residents are to be met, additional sources of sand have to be found near Tutuila Island. Because of the steep, volcanic nature of the island and its dense, vegetative cover, subaerial sources are unlikely. In places, sand collects in small coastal lagoons, but the extensive removal of such sand could have important sociological ramifications. Once sand has been deposited outside the reef, however, it is lost to the littoral system. Although the bottom drops off rapidly around the island, it is possible that some sand deposits occur in depths shallow enough to be dredged. If so, they could be a valuable source of sand.

The purpose of this study was to ascertain whether significant sand deposits exist outside the reef in water shallow enough to be dredged. At present, suction dredges can operate in depths less than about 20 m (U. S. Army Corps of Engineers, oral comm.). This depth limition occurs because the maximum vacuum that can be pulled is less than one atmosphere. Mechanical dredges can operate in deeper water, though costs increase and efficency decreases with increasing depth. Assuming that dredging technology will improve, a maximum depth of 30 m was chosen for this survey.

Both geophysical techniques—side scan sonar and seismic profiling—and scuba diving were used to search for shallow-water sand deposits. Diving enabled the survey team to inspect areas that looked interesting on the geophysical records and to collect sand samples that could be analyzed for grain size and composition. During the study, we searched for various types of sand, including siliciclastic-rich sand (herein, siliciclastic means pertaining to clastic, noncarbonate rocks), which could be used to make concrete (concrete made with siliciclastic sand is stronger than concrete made with carbonate sand), and carbonate sand, which could be used as beach fill.

Other Data Sources

Much of the existing information on the coastal zone of American Samoa is summarized in atlas form (Lam Yuen, Jr., 1981). Studies of coral reefs (U. S. Army Corps of Engineers, 1980) and of shoreline types (Sea Engineering Services, Inc./R. M.

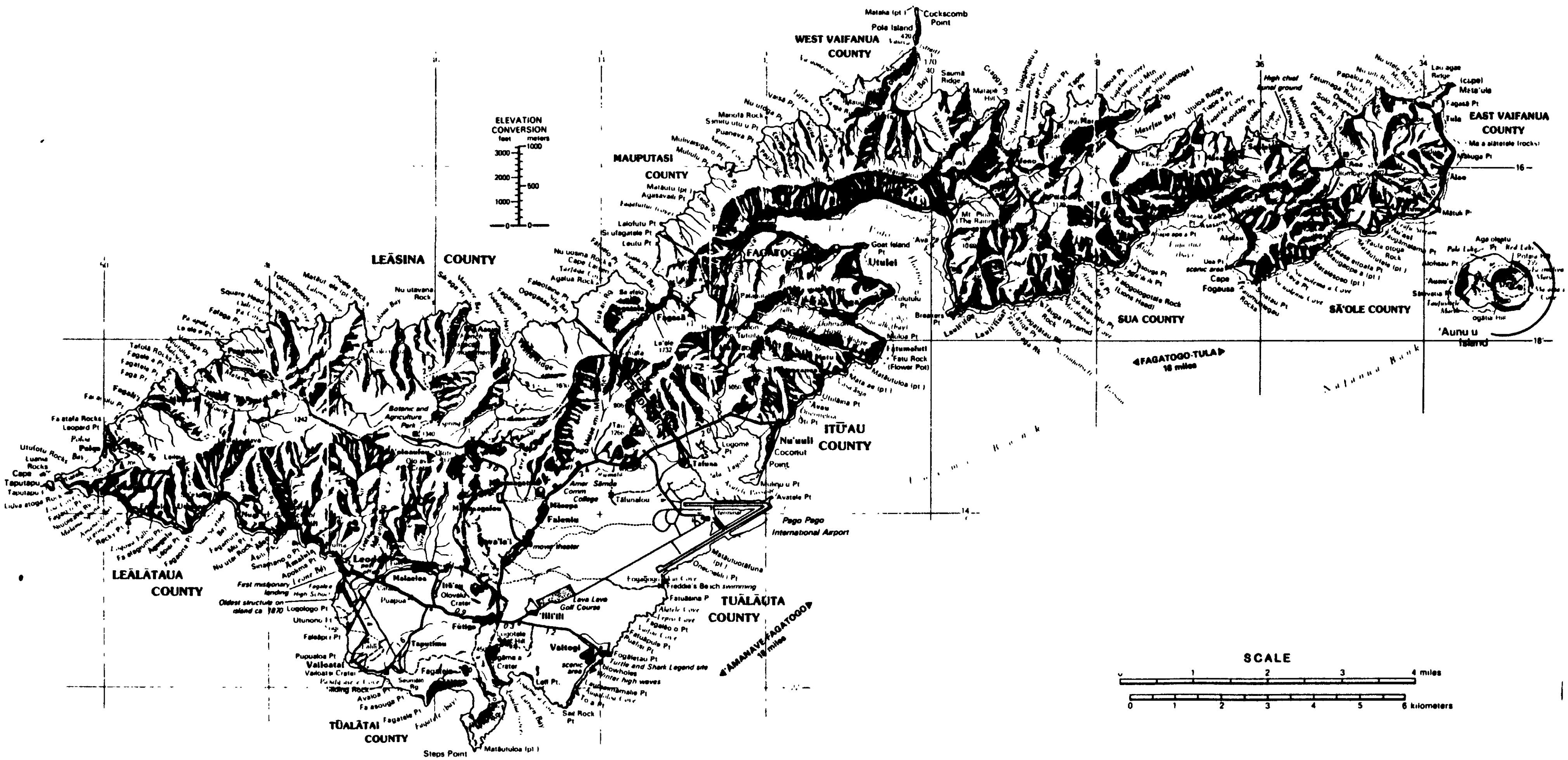

Figure 1. Tutuila Island, American Samoa [*adapted from* Bier, 1980].

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Towill Corp, 1980) in American Samoa contained background information pertinent to this study. Those reports helped delineate the most promising search areas, though neither of them had enough information on the mineralogic composition of the beach sands to locate beaches with high siliciclastic concentrations.

Hobbs, *et al* (1985) used similar geophysical techniques to search for nearshore sand bodies in southern Chesapeake Bay. They also collected cores throughout the study area to determine the sand composition below the bottom. From that study, they were able to define sand bodies that could be dredged by the local municipalities for beach fill.

Geologic and Oceanographic Setting

Tutuila Island consists primarily of Pliocene, Pleistocene, and Recent volcanic rocks (Stearns, 1944) with the Masefau volcanics being the oldest rocks and the Leone volcanics the youngest (MacDonald, 1944). A narrow, fringing reef grows along much of the island, and, south of the island, a submerged barrier reef extends to within about 5 m of the ocean surface. Stearns recognized several stages of island development, including (in chronological order);

1. Outpourings of olivine basalts that built up much of the island.

2. Vigorous stream and marine erosion that carved deep canyons and made wide coastal platforms.

3. Island submergence of 180 to 600 m.

4. Formation of a barrier reef around much of the island.

5. Rapid submergence of about 60 m that killed most of the barrier reef.

6. Emergence of about 6 m.

7. Outpouring of the Leone volcanics and formation of Aunuu Island. Lava from the Leone volcano built a platform onto the submerged barrier reef.

8. Emergence of another 2 m resulting in the present shape of the island.

This type of geologic activity, especially the large amount of subsidence, would produce a thick deposit of siliciclastic and calcareous sediments on the island's shelf, though most of the siliciclastic sediments may now reside in deep water.

Oceanography

The location of Tutuila Island at 170°41' west latitude and 14°18' south longitude (the location of Pago Pago; Fig. 1) puts it in the zone of the South Pacific Trade Winds. Year-around, the dominant winds blow from the southeast and east, though those winds weaken in both strength and duration during the months of December through April. Winds from other directions occur less frequently and are, on the average, slightly weaker than the trade winds. On a monthly average, the force of the trade winds is as high as 4 on the Beaufort Scale and as low as 2 (Defense Mapping Agency, 1981). Winds of Beaufort force 4 can produce offshore wave heights more than 2 m, if the wind duration were long enough; Beaufort force 2 winds, however, produce waves less than 1-m high.

American Samoa has semidiurnal tides with a mean range of 0.8 m and a spring-tide range of 0.9 m (National Ocean Service, 1985). The principal ocean current, the South Equatorial Current, flows to the west all year at speeds that average between 3 and 13 m/s (Defense Mapping Agency, 1981).

SURVEY METHODS AND DATES

Field work for this study commenced with a reconnaissance visit, where sand samples were collected, and ended with detailed geophysical and diving surveys. Locations for the latter surveys were based both on the observations and samples collected during the reconnaissance visit and on available maps and reports of the island.

Texture and Composition of Beach Sands

Texture refers to the size, shape, and roundness of the material making up a sedimentary deposit, and composition refers to its chemical or mineral makeup. Usually, sand is classified by size based on a scheme developed by Wentworth (1922). Table 1 gives that classification scheme.

Range (ϕ)	Range (mm)	Wentworth Class
4 - 3	0.0625 - 0.125	very-fine sand
3 - 2	0.125 - 0.250	fine sand
2 - 1	0.250 - 0.500	medium sand
1 - 0	0.500 - 1.000	coarse sand
0 - -1	1.000 - 2.000	very-coarse sand

Table 1. Wentworth (1922) classification scheme for sandy material.

The equation

$$D_{mm} = (1/2)^{D_\phi} \qquad (1)$$

relates grain size in phi units D_ϕ to grain size in millimeters D_{mm}.

Sand grains can vary considerably in shape depending on their original shape and their maturity (*i.e.*, the degree to which a sediment has evolved from its source material), which is a function of transport distance, time, and composition. Immature grains tend to have a wide range of shapes, but, with time, most sand grains become spherical and rounded, especially if they have traveled long distances.

The beach sands of Tutuila Island contain siliciclastic and calcareous grains in varying proportions. The source of the former is the volcanic rocks comprising the island and the sources of the latter are the fringing reef and shells. Because the fringing reef blocks the onshore migration of offshore sand, the siliciclastic fraction of a beach sand is principally terrigenous in nature (*i.e.*, it comes from subaerial sources rather than from the erosion of submarine outcrops). Because waves and currents will eventually move the beach sand offshore, the composition of a beach sand should indicate whether there is any siliciclastic material offshore. For that reason, we collected small samples of sand from many of the beaches on Tutuila Island and analyzed them for gross composition, shape, and grain size.

Bascom (1951) determined that grain size could be used to compare the slopes of various beaches if the grain-size samples came from a standardized part of each beach that he termed the "reference point". The location of the reference point, which is the section of beach subjected to waves at mid-tide level, is a function of both the astronomical tide and any local water-surface variations. Not only is beach slope directly proportional to grain size (the beach gets steeper as grain size increases), but beach slope also depends on the strength of the incident waves so that a beach of constant grain size will become steeper as the wave energy decreases.

Most beaches on Tutuila Island are steep and only a few meters wide, being confined to the area between the reef flat and the back-beach bluff. We collected our sand samples from the middle of the beach face, assuming that area would include the reference point; we made no attempt to establish the actual mid-tide level for the time.

Geophysical and Diving Surveys

Three types of geophysical surveys—side scan sonar, shallow seismic, and precision bathymetric—and scuba diving surveys were conducted during the second trip, in July 1985. The objectives of the geophysical surveys were (1) to determine the lateral distribution of sand in selected areas and (2) to determine, if possible, the sand thickness in those areas. The objectives of the diving surveys were (1) to verify the bottom types suggested by the geophysical records, (2) to collect surficial sand samples to determine size and composition, and (3) to probe into the bottom to measure the thickness of the unconsolidated material.

The geophysical surveys were conducted from the Office of Marine Resources vessel *Sausauimoana*. A Geodimeter Model 140 Total Station functioned as a precision navigation device to locate the geophysical tracklines. This device measures the round-trip time of an infrared beam reflecting off a target prism. For this study, the Geodimeter was set-up onshore, several known points surveyed in to establish the instrument's location, and the location of a prism on the *Sausauimoana* measured at one-minute intervals. Accuracy of the Geodimeter in the tracking mode is better than 1 cm, which is much higher than required for a survey of this type. The actual location of the geophysical instruments varied from the measured value, however, because:

1. There was sometimes a few-second delay between locating the vessel and marking the geophysical records. This error is less than 1 m per second of delay at the survey speeds used and is, consequently, insignificant in this type of survey. Also, the error was reduced by interpolating between shot points.

2. The geophysical instruments were separated from the prism by 10 m or more. The error produced by this offset was acceptable for the types of surveys being conducted, and the navigation lines can be corrected to account for such a constant offset, if necessary.

Side Scan Sonar

A side scan sonar transmits and receives electronic pulses at a prescribed frequency to produce an image of the bottom. The sonar consists of a torpedo-shaped unit, called a tow fish; a unit containing the signal electronics and recorder; and a connecting cable. The tow fish is pulled near the vessel at a selected depth above the bottom. On each side of the tow fish are transducers that transmit electronic pulses that travel sideways and downward through the water and receive the energy reflecting back off objects on the bottom. The return pulses are amplified and displayed on a continuous roll of paper as light and dark areas that correspond to shadow zones and strong reflectors respectively. The result, which is called a sonograph, is a continuous image of the bottom with dark areas representing surfaces facing the tow fish and light areas representing depressions or the backs of the high areas. Features too small to be detected by the sonar produce a constant hue on a sonograph.

A Klein Hydroscan Side Scan System was used throughout this study. The unit consisted of an electronics package, 100- and 500-kHz tow fish, and a power and tow cable that connected the electronics package with the tow fish. The electronics package contained the power source, signal formatter, amplifiers, and a wet-paper analog recorder. Each tow fish contained the appropriate transmitters/receivers for its specified frequency. Generally, the side scan can cover more of the bottom and is less sensitive to noise with the 100-kHz electronics and tow fish. However, in its 500-kHz mode, the side scan is able to resolve smaller objects.

We used the 500-kHz system throughout the study to maximize the chances of recording small undulations, which are called ripples, that form on the surface of sandy bottoms. In fine sand, the spacing (wavelength) between adjacent ripple crests is 10 to 20 cm, whereas in coarse sand, spacings may be over 1 m; ripple heights are about 15% of the wavelengths (Dingler and Inman, 1977). Because ripple size increases as the grain size increases, the presence on the sonograph of ripples gives a general indication of the coarseness of the sand.

Though the 500-kHz side scan sonar can theoretically resolve spacings of about 10 cm, our experience in other areas is that 30 cm to 1 m is the minimum resolvable wavelength because of ship motion, waves, and deviations from the ideal tow-fish-to-bottom height. Miller and Komar (1980) concluded that the maximum ripple spacing λ for a given grain diameter D was given by the relationship

$$\lambda = 0.028D^{1.68}$$

where λ is in centimeters and D is in microns (10^{-3} mm). Using this relationship, a spacing of 30 cm equals a grain size of 0.250 mm, which is the lower limit of the medium sand class. A 1-m ripple spacing equals a grain size of 0.513 mm, which is just above the lower limit of the coarse-sand class.

When ripples appear on a sonograph, their spacing can be measured, and grain size estimated. A rippleless part of the record could represent several different bottom types, including:

- A sandless bottom. If there were no sediment at all, the bottom would probably be irregular enough that other patterns would appear on the sonograph. If the bottom consisted of silt and clay, the sonograph could be featureless.

- A very fine or fine sand bottom. Then ripple spacing would be too small to be seen and the sonograph would be featureless.

- A medium sand bottom where the survey conditions were such that ripples could not be resolved.

- A medium or coarse sand bottom that was not rippled. In wave dominated parts of the nearshore, this happens very close to the surf zone where the waves produce very strong bottom motions. In water depths pertinent to this study, ripples should exist, even if they were produced by earlier, more energetic waves.

Measuring the distance from the tow fish (the center, clear band on the sonograph) to each feature, converting those measurements to horizontal distances from the sides of the tow fish, and plotting those distances produced mosaic-like pictures of the survey areas. Features that were plotted included reefs, coral outcrops, and rippled bottoms with medium or coarse sand. The remaining, featureless areas were interpreted to be bottoms composed of finer sediment.

Shallow Seismic

For the seismic surveys, we used a ORE GeoPulse Seismic System, an EPC 3200S recorder, a Hewlett-Packard tape recorder, and a Benthos hydrophone. The GeoPulse System, which consisted of an acoustic receiver, power supply, and towed catamaran with an acoustic source (a transducer having a 30° beam width), had a power output of 100 to over 500 J over a frequency range of 1 to 7 kHz. The firing rate during the study was a pulse every one-eighth of a second. The hydrophone had a frequency response of 200 Hz to 10 kHz. Return signals with frequencies between 300 Hz and 10 kHz were recorded onto tape and the 1- to 3-kHz range displayed on the recorder for on-site evaluation.

Later, the seismic data were replayed through a swell filter, which removed wave noise. Also, frequencies below and above the range of the seismic system (1 to 7 kHz), which contained noise, were filtered out. Then the data were plotted again, using a bandpass filter to permit the display of only a part of the frequency range. Filtering out the high frequencies emphasizes reflectors at depth, but shallow reflectors are lost. Filtering out the low frequencies emphasizes near-surface features, but deeper reflectors disappear. Often a compromise range of frequencies is chosen to display both shallow and deep features; however, in this study, the low frequencies were filtered out because near-surface features were of most interest. Using this technique, resolution was about one-half meter starting one meter below the bottom. The uppermost meter could not be deciphered because the returns were mixed with the strong signal generated when the transmitted pulse reflected off the sea floor.

Bathymetry

The 200-kHz mode of a Ratheon RTT 1000 Bathymetric Survey System was used for precision depth recording. The transducer had an 8° beam width, which eliminated most of the side echos encountered, even though the areas surveyed were of variable bathymetry. The return signals, after amplification, were recorded on an EPC 1600 Recorder.

Later, waves were removed from the trace of the bottom and the data computerized. From that data, bathymetric maps were made using Surface Gridding Library and Surface Display Library routines developed by Dynamic Graphics, Inc. Because the surveys were concentrated in selected parts of the bays, the contouring routines did not completely reproduce the actual depths but did produce charts that show the general trend of the contours in the surveyed areas.

Scuba Diving

Standard scuba equipment was used during all the dives; that gear was supplemented by two underwater propulsion vehicles when large areas were to be traversed. Sand was collected in a cloth bag. A 3-m long, small diameter brass tube attached to an air tank was used as a probe. The force of the air was enough for the tube to penetrate unconsolidated sand; consolidated layers, though, readily stopped the probe.

RESULTS

Based on existing reports, direct observations, and samples of beach sands collected during the reconnaissance trip, Faga'itua Bay and the nearshore area between Leone and Nua-Se'etaga Bays were investigated in detail. Initial diving observations showed that the area immediately off Leone lacked sandy deposits, though there were scattered patches of coarse, platy calcareous material. Subsequently, detailed work on the western end of the island was restricted to Nua-Se'etaga Bay, though reconnaissance geophysical surveys were run off of Leone. The geophysical surveys produced records showing the distribution of sand and reef both on the bottom and in the subbottom. Diving observations confirmed the geophysical interpretations of surface distribution, probing suggested that there was a cemented layer just below the bottom, and sand samples indicated the texture and composition of the areas' surficial sediments.

Beach Sands

Between 22 and 25 April 1985 we collected sand from 55 beaches on Tutuila Island; 43 samples came from the south side of the island (between Cape Taputapu and Cape Mata'ula), and the rest came from the north side of the island. Figure 2 shows the locations and numbers of the samples. Because of its inaccessibility and ruggedness (which would also be reasons for not dredging there), only one sample came from the area between Leone and the airport. Video tapes, taken from a small airplane on 23 April 1985, showed that area to have a lower percentage of sandy beaches than other parts of the south coast. Also, Fagatele Bay is a newly created marine reserve, and dredging activities in its vicinity presumably would be discouraged, if not prohibited. The coast between Nu'uuli and Atuu was not sampled either because of its paucity of beaches. Following the example of Inman (1952), all the sand samples were sieved and median and mean grain sizes, sorting, skewness, and kurtosis calculated. A detailed description of the graphical parameters is also given in Dingler and others (1986). Figure 3 shows how the grain size data is typically plotted and gives the relationships between the grain size parameters. Tables 2 and 3 respectively list the statistical parameters calculated from the samples and class percentages for the sands.

For each sample, grain shape and the size of the siliciclastic fraction were approximated visually. Samples with a high concentration of siliciclastic material were also weighed, treated with hydrochloric acid to remove all the calcareous material, and reweighed. Table 4 gives the results of both the visual inspection and the percentages determined with acid.

Geophysical Surveys

Side scan and shallow seismic surveys were run separately to eliminate interference between the two instruments. The precision depth recorder ran during both types of surveys. Surveys using precision navigation exceeded 35 km in trackline distance, and additional reconnaissance surveys roughly covered another 15 km (Table 5). Navigation fixes were taken every minute, and intermediate points interpolated where necessary.

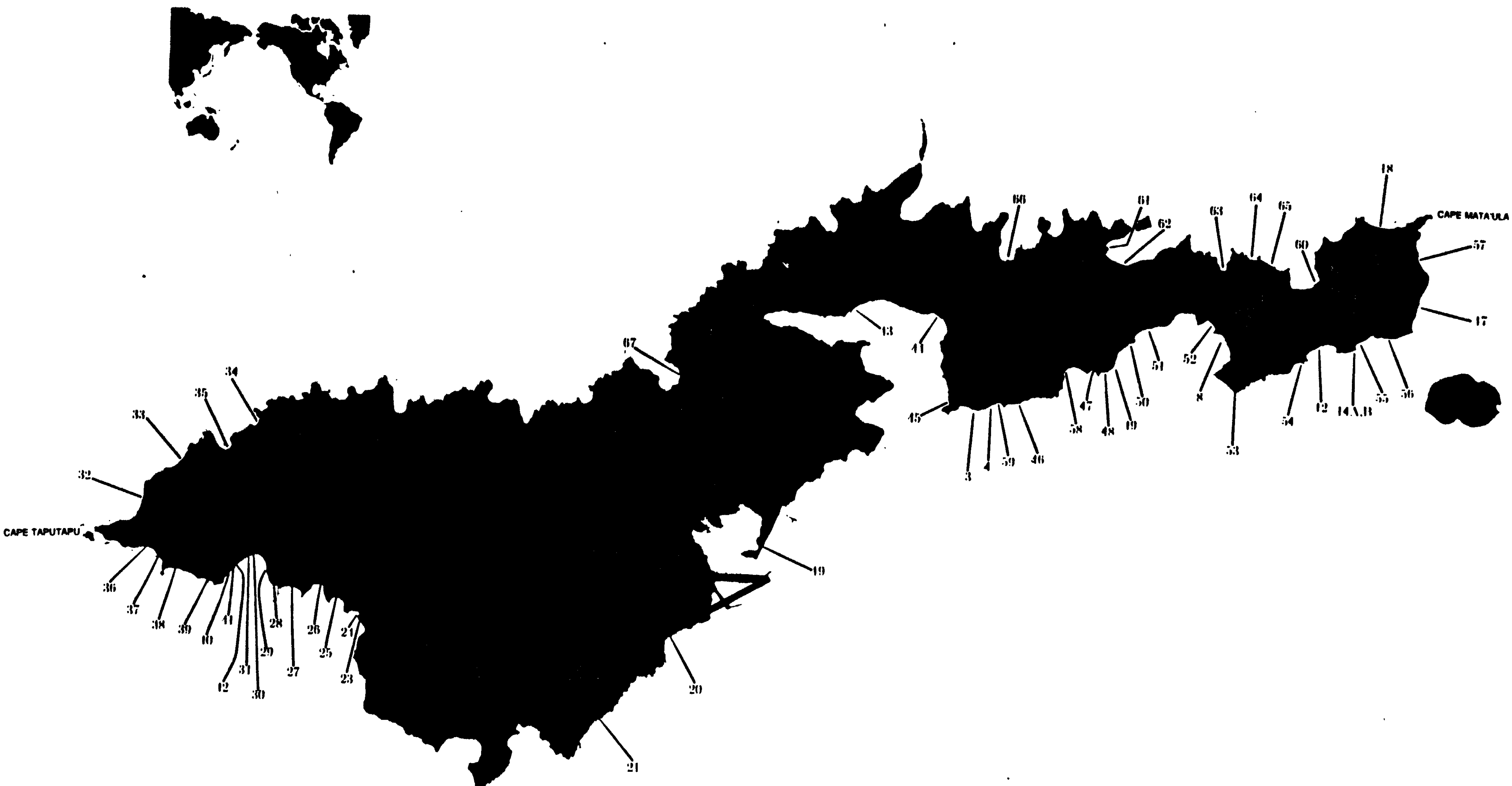

Figure 2. Location of sand samples collected from beaches on Tutuila Island during the last week of 2 April 1985.

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$$Md_\phi = \phi_{50}$$

$$M_\phi = \frac{\phi_{16} + \phi_{84}}{2}$$

$$\alpha_{\phi 2} = \frac{\frac{\phi_5 + \phi_{95}}{2} - Md_\phi}{\sigma_\phi}$$

$$\sigma_\phi = \frac{\phi_{84} - \phi_{16}}{2}$$

$$\beta_\phi = \frac{\frac{\phi_{95} - \phi_5}{2} - \sigma_\phi}{\sigma_\phi}$$

$$\alpha_\phi = \frac{M_\phi - Md_\phi}{\sigma_\phi}$$

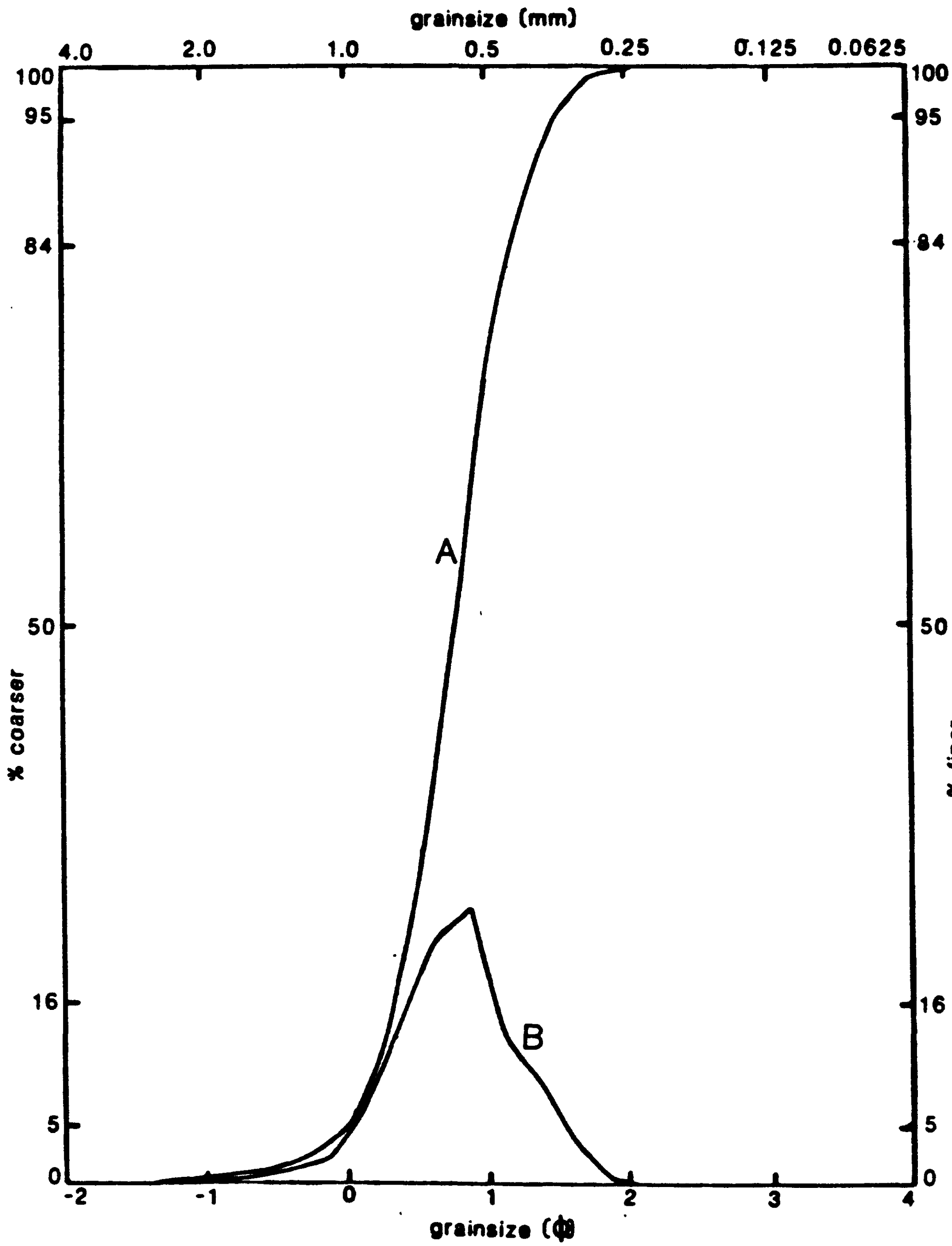

Figure 3. Cumulative (A) and frequency (B) curves for Beach Sample 30 (Se'etaga). Equations at the top give the relations for the graphical parameters discussed in the text.

Sample	Md_ϕ	M_ϕ	σ_ϕ	α_ϕ	$\alpha_{2\alpha}$	β_ϕ
23	0.3324	0.1768	0.5182	-0.3003	-1.7754	1.7255
24	0.5240	0.5506	0.6213	0.0429	0.3325	1.2571
25	0.4866	0.3924	0.7131	-0.1320	-0.2381	0.7139
26	1.1626	0.4022	1.4194	-0.5357	-0.6310	0.5971
27	0.7703	0.6368	1.0358	-0.1288	-0.4119	0.9058
28	0.3003	0.2785	0.3652	-0.0597	-0.4660	0.7337
29	1.4616	1.4148	0.1721	-0.2718	-0.2721	1.4241
30	0.7639	0.7717	0.4285	0.0184	-0.0595	0.7265
31	1.2673	1.2720	0.2231	0.0208	-0.0386	0.4930
42	-0.3459	-0.0694	1.0950	0.2525	0.5929	0.9318
41	1.1349	1.0330	0.6210	-0.1640	-0.6249	0.9717
40	1.6622	1.6415	0.4422	-0.0469	-0.4571	0.8579
39	-0.3991	-0.4910	1.5090	-0.0609	0.1428	0.2037
38	0.8068	-0.1671	1.8329	-0.5314	-0.4474	0.0839
37	0.6436	0.4713	0.9867	-0.1746	-0.6006	1.0786
36	0.3010	0.3148	0.2281	0.0604	-0.0111	0.4878
32	0.9996	-0.2428	1.7572	-0.7070	-0.6174	0.0879
33	-0.4511	-0.7605	1.1433	-0.2706	-0.1406	0.2142
35	-0.0917	-0.2182	1.0890	-0.1161	-0.1266	0.6257
34	1.9518	1.9219	0.4596	-0.0650	-3.5582	4.0399
67	1.1203	0.8667	0.6336	-0.4003	-1.9621	1.9627
66	1.3543	1.3139	0.9766	-0.0414	-0.7559	1.0406
61	0.4848	0.4712	0.2856	-0.0476	-0.1950	1.0747
62	0.4462	0.3839	0.6613	-0.0941	-0.3785	1.1867
63	0.3783	0.4783	0.6282	0.1592	0.7793	1.5817
64	1.0846	0.9925	0.4885	-0.1885	-2.3423	2.6041
65	-0.1974	-0.2375	0.6024	-0.0666	-0.0843	0.8511
60	0.5806	0.4034	0.6205	-0.2857	-1.2181	1.9411
18	0.8848	-0.2866	1.7134	-0.6837	-0.6083	0.0754
57	0.5212	0.5543	0.3816	0.0866	-0.0619	1.0753
17	1.6536	1.7043	0.2082	0.2439	0.0731	1.0572
56	0.1474	-0.2251	1.3084	-0.2848	-0.1762	0.4651
55	0.3994	0.2897	1.0401	-0.1055	-0.2959	0.5466
14B	0.7081	0.7763	0.7661	0.0891	-0.0693	0.5896
14A	1.2144	1.1421	0.4810	-0.1505	-0.3442	0.6772
12	-0.2293	0.1323	0.9724	0.3718	0.4758	0.8447
54	-0.0966	-0.1477	0.3915	-0.1306	-0.1017	0.6802
53	0.0277	-0.4071	1.5206	-0.2859	-0.1505	0.1830
8	0.5533	0.5707	0.9152	0.0190	-0.1714	0.7793
52	0.1882	0.0306	0.7384	-0.2136	-0.6721	1.2914
51	-0.2549	-0.4982	0.6981	-0.3485	-0.8470	0.6528
50	0.0690	-0.5435	1.4565	-0.4205	-0.2686	0.1519
49	-0.6921	-0.8935	1.1065	-0.1820	-0.0128	0.1693
48	0.0693	-0.0134	0.5158	-0.1603	-0.2868	0.7396
47	0.2540	-0.2187	1.7374	-0.2721	-0.1354	0.1620
58	1.8846	1.8607	0.4193	-0.0572	-0.4355	1.0510
46	0.2379	0.0407	1.6189	-0.1218	-0.1130	0.2694
59	0.5929	0.4491	1.4181	-0.1014	-0.2807	0.5477
4	-0.3509	-0.4702	0.5004	-0.2384	-0.9423	1.3534
3	0.4374	0.4224	0.7351	-0.0204	-0.2054	0.7252
45	-0.7579	-0.9188	1.0811	-0.1488	0.0858	0.2347
44	0.6572	0.5913	0.6042	-0.1091	-0.2331	0.7396
43	0.0342	-0.0674	0.6135	-0.1656	-0.4380	0.7786
19	0.4583	0.1201	1.4445	-0.2341	-0.1427	0.5591
20	0.1239	0.1141	0.3530	-0.0278	-0.1345	0.8730
21	1.1344	1.1181	0.4292	-0.0379	-0.2437	0.7674

Table 2. Grain-size parameters for the samples from Tutuila Island, American Samoa. Samples start at Leone and go clockwise around the island.

Sample	> 2mm	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Pan
23	12.9	9.7	75.1	2.2	-	-	0.1
24	3.9	15.3	60.1	14.9	4.7	0.9	0.2
25	4.3	20.2	56.3	18.4	0.8	-	-
26	16.1	6.1	20.6	44.9	10.8	1.3	0.1
27	9.6	12.6	37.9	30.6	8.6	0.6	0.1
28	1.2	19.9	77.0	1.8	0.1	-	tr
29	0.1	0.1	4.9	94.1	0.9	-	tr
30	0.5	4.5	68.1	26.6	0.2	-	tr
31	-	0.2	12.4	87.0	0.5	-	tr
42	21.0	41.8	21.0	9.4	3.8	2.0	1.2
41	3.3	4.3	34.0	53.9	4.4	-	tr
40	0.5	1.1	8.7	68.4	21.2	-	tr
39	41.5	16.8	25.4	14.2	1.9	0.1	0.1
38	32.9	2.0	20.3	40.2	4.4	tr	tr
37	12.6	11.5	43.8	25.6	6.3	0.1	-
36	0.4	5.3	93.9	0.3	-	-	tr
32	31.9	0.1	18.1	47.1	2.8	0.1	tr
33	33.9	31.6	31.9	1.9	0.4	0.2	0.1
35	22.2	31.2	33.9	10.5	2.0	0.2	0.1
34	11.4	0.4	1.1	42.0	42.9	2.1	0.1
67	12.5	1.6	27.6	56.8	1.5	0.1	tr
66	6.1	4.3	26.2	37.3	24.5	1.7	tr
61	0.4	8.1	85.8	5.5	0.3	-	tr
62	6.0	17.7	58.8	14.5	2.7	0.3	-
63	3.2	17.7	61.8	7.6	8.9	0.8	tr
64	6.1	2.7	34.1	56.0	1.0	-	tr
65	11.5	48.2	36.5	3.6	0.1	-	tr
60	11.1	8.2	62.7	14.2	3.2	0.6	tr
18	21.9	4.3	30.6	42.2	0.9	-	0.1
57	1.1	8.5	77.2	12.8	0.4	-	-
17	0.2	0.1	1.6	86.6	11.5	-	tr
56	21.1	20.5	41.0	14.1	3.2	0.1	tr
55	11.6	22.0	39.7	25.1	1.5	-	tr
14B	1.8	13.8	48.1	33.5	2.8	-	tr
14A	0.7	1.9	33.5	61.4	2.5	-	-
12	11.7	50.7	20.9	11.3	5.3	tr	tr
54	2.1	55.8	40.6	1.4	tr	-	tr
53	29.9	18.8	33.0	17.5	0.7	-	tr
8	6.4	18.8	43.3	26.1	5.0	0.3	-
52	12.7	24.0	53.0	9.0	1.1	tr	0.1
51	20.3	45.9	33.5	0.2	0.1	-	0.1
50	36.3	12.3	38.7	11.8	1.0	tr	tr
49	44.8	28.8	24.8	1.5	tr	-	tr
48	4.7	39.6	52.8	2.7	0.1	-	tr
47	27.6	15.7	26.6	24.5	5.6	0.1	tr
58	0.2	1.0	4.7	52.7	41.1	0.2	tr
46	21.0	18.7	30.0	23.1	7.2	-	tr
59	15.7	16.0	30.2	25.1	12.7	0.3	tr
4	15.5	62.5	21.4	0.5	0.1	-	tr
3	4.9	21.6	52.2	20.7	0.6	-	-
45	43.6	33.0	21.4	1.7	0.1	0.1	0.1
44	1.0	15.4	58.0	24.3	1.2	tr	tr
43	9.4	38.3	49.5	2.8	-	-	tr
19	18.5	14.3	37.9	19.1	9.2	0.9	tr
20	1.7	31.4	65.3	1.4	0.2	-	tr
21	0.1	1.8	37.4	58.6	2.0	-	tr

Table 3. Wentworth groupings for the Tutuila Island beach samples. The symbol "tr" means that a trace of the indicated class was present on the sieves. Samples start at Leone and go clockwise around the island.

Sample	%Carbonate	%Siliciclastic visual	%Siliciclastic acid	Sample	%Carbonate	%Siliciclastic
BEACH SAMPLES						
23	2	98	90	18	95	5
24	1	99	88	57	100	tr
25	15	85	71	17	100	tr
26	75	25		56	100	none
27	50	50	49	55	100	tr
28	98	2		14B	100	tr
29	95	5		14A	100	tr
30	70	30		12	100	tr
31	20	80	78	54	99	1
42	3	97	92	53	98	2
41	93	7		8	100	tr
40	95	5		52	100	tr
39	80	20		51	99	tr
38	99	tr		50	99	1
37	95	5		49	98	2
36	100	tr		48	99	1
32	90	10		47	95	5
33	30	70	68	58	97	3
35	70	30		46	99	1
34	80	20		59	95	5
67	93	7		4	100	tr
66	75	25		3	99	1
61	99	1		45	99	1
62	97	3		44	99	1
63	99	1		43	85	15
64	100	tr		19	99	1
65	100	tr		20	93	7
60	100	tr		21	93	7
OFFSHORE SAMPLES						
10	100	none		1	100	tr
11	tr	100	93	2	100	none
12	60	40	54	3	100	tr
13	80	20	26	4	100	none
14	90	10	41	5	100	none
15	100	tr		6	100	none
16	75	25	28	7	100	tr
17	93	7		8	100	none
				9	100	tr

Table 4. Composition of beach and offshore sands. In the table, the beach samples start at Leone and proceed clockwise around the island. Samples in column two of the Offshore Section come from Faga'itua Bay, and those in column one from Leone Bay (#10) and Nua-Se'etaga Bay. Plate 0 shows beach locations, and Figures 8 and 9 offshore ones. The symbol "tr" means that a trace was noted in the sample.

Location	Trackline Distance (km) Side Scan Sonar Surveys	Shallow Seismic Surveys
Detailed Surveys		
Faga'itua Bay	6.7†	5.2†
Leone Bay	2.5†	
Leone to Fagaone Point		8.4†
Nua Se'etaga Bay	5.1†	7.0†
subtotals:	14.3	20.6
Reconnaissance Surveys		
Fageone Point to Niuolepava Rock		2.4
Logologo Point to Papualoa Point		4.8
Areas between Fagasa Point and Falase'eitoafa Point	8.0	
subtotal:	8.0	7.2
TOTAL:	22.3	27.8

Table 5. Trackline distances for geophysical surveys on the south side of Tutuila Island. Detailed surveys included precision navigation whereas reconnaissance surveys used local landmarks for navigation. Precision depth records were also gathered for surveys marked with a †.

Side Scan Sonar

Closely spaced side scan sonar tracklines were run in Faga'itua Bay, Leone Bay, and Nua-Se'etaga Bay. Additional side scan sweeps were made between Fagasa Point and Falase'eitoafa Point and between Anapeape'a Point and Vailoa Point. Trackline distances are given in Table 5. Figures 4, 5, and 6 show tracklines for Faga'itua Bay, Leone Bay, and Nua-Se'etaga Bay respectively. Tracklines for the reconnaissance side scan surveys are not plotted; in those areas, the vessel cruised just outside and parallel to the reef, and the tow fish flew near the surface to avoid hitting coral.

On the sonographs, patterns that represented three bottom types were identified. One pattern had irregular distributions of strong reflectors and shadow zones. Often, rapid fluctuations in water depth occurred in this area. This pattern was indicative of the reef, including both the front of the fringing reef and deeper areas where the bottom primarily is covered with broken coral. A second pattern was featureless with uniform shading and was associated with bottoms composed of fine-grained, unconsolidated sediments. The third pattern had closely spaced dark and light bands and represented areas with large ripples that form on a coarse-sand bottom. These rippled areas occur both as narrow patches within the reef and as broad zones adjacent to or within the featureless areas. Figure 7 shows a sonograph with these bottom types labeled; the variation in intensity between various ripple fields could be caused by size differences (suggesting differences in grain size) or differences in proximity to

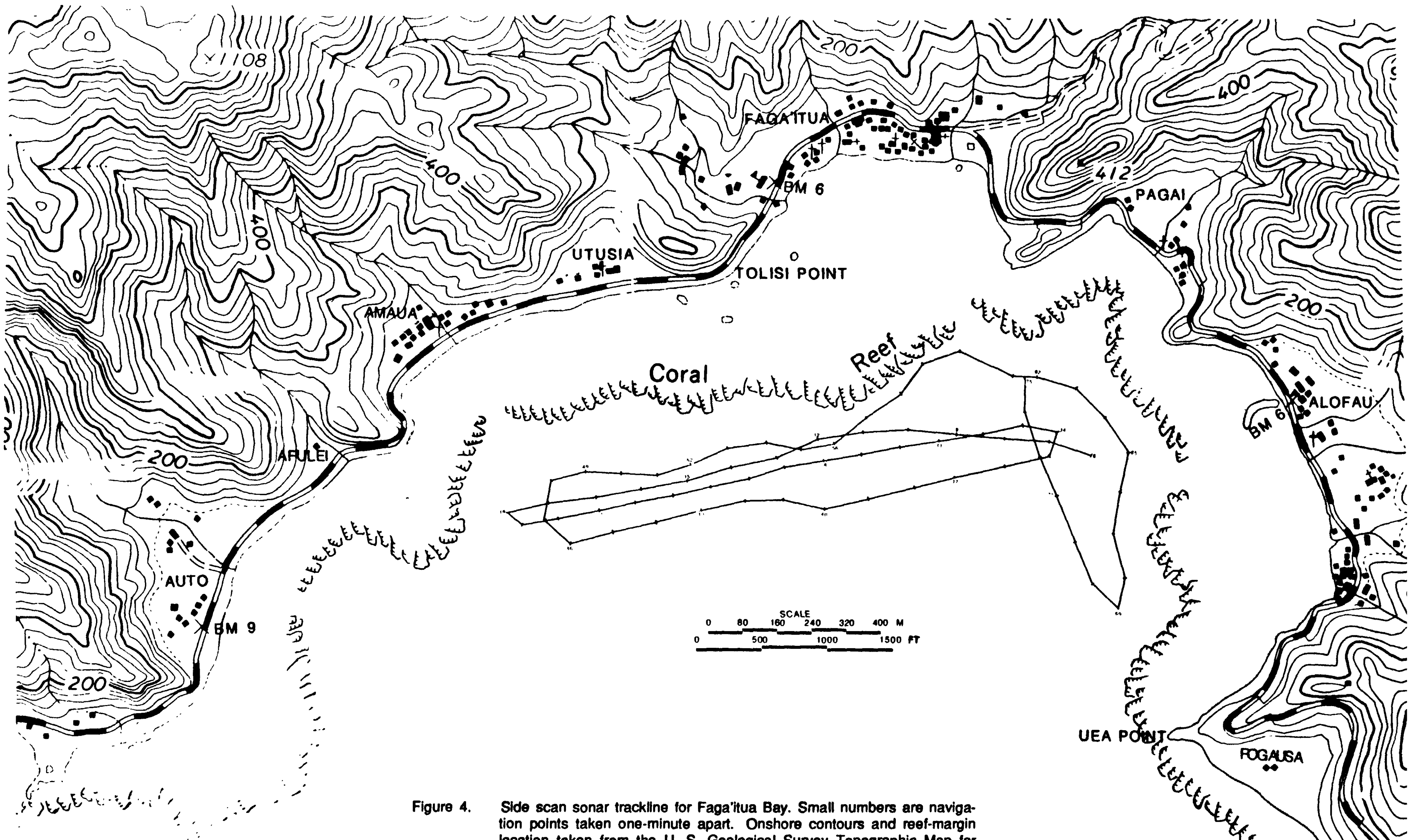

Figure 4. Side scan sonar trackline for Faga'itua Bay. Small numbers are navigation points taken one-minute apart. Onshore contours and reef-margin location taken from the U. S. Geological Survey Topographic Map for Tutuila Island (1963, 1:24,000).

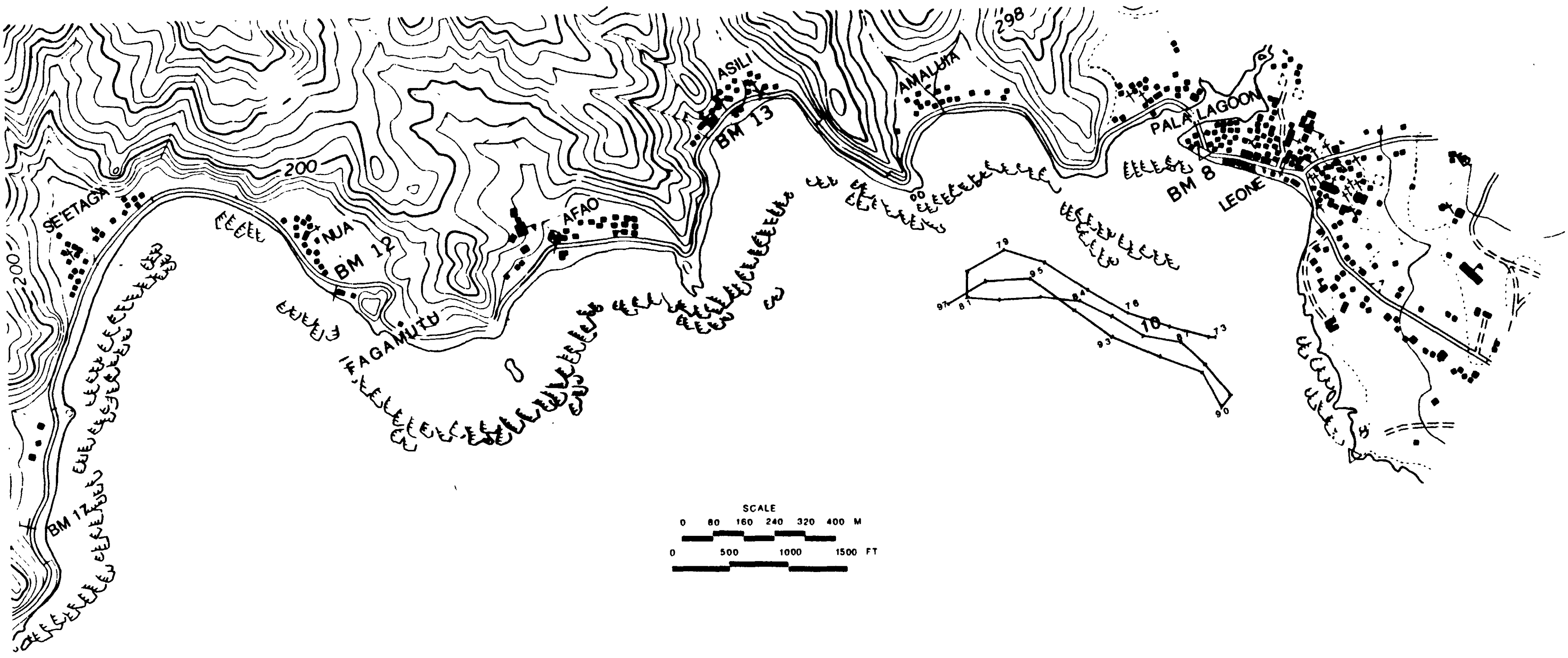

Figure 5. Side scan sonar trackline for Leone Bay. Small numbers are navigation points taken one-minute apart. Onshore contours and reef-margin location taken from the U. S. Geological Survey Topographic Map for Tutuila Island (1963, 1:24,000).

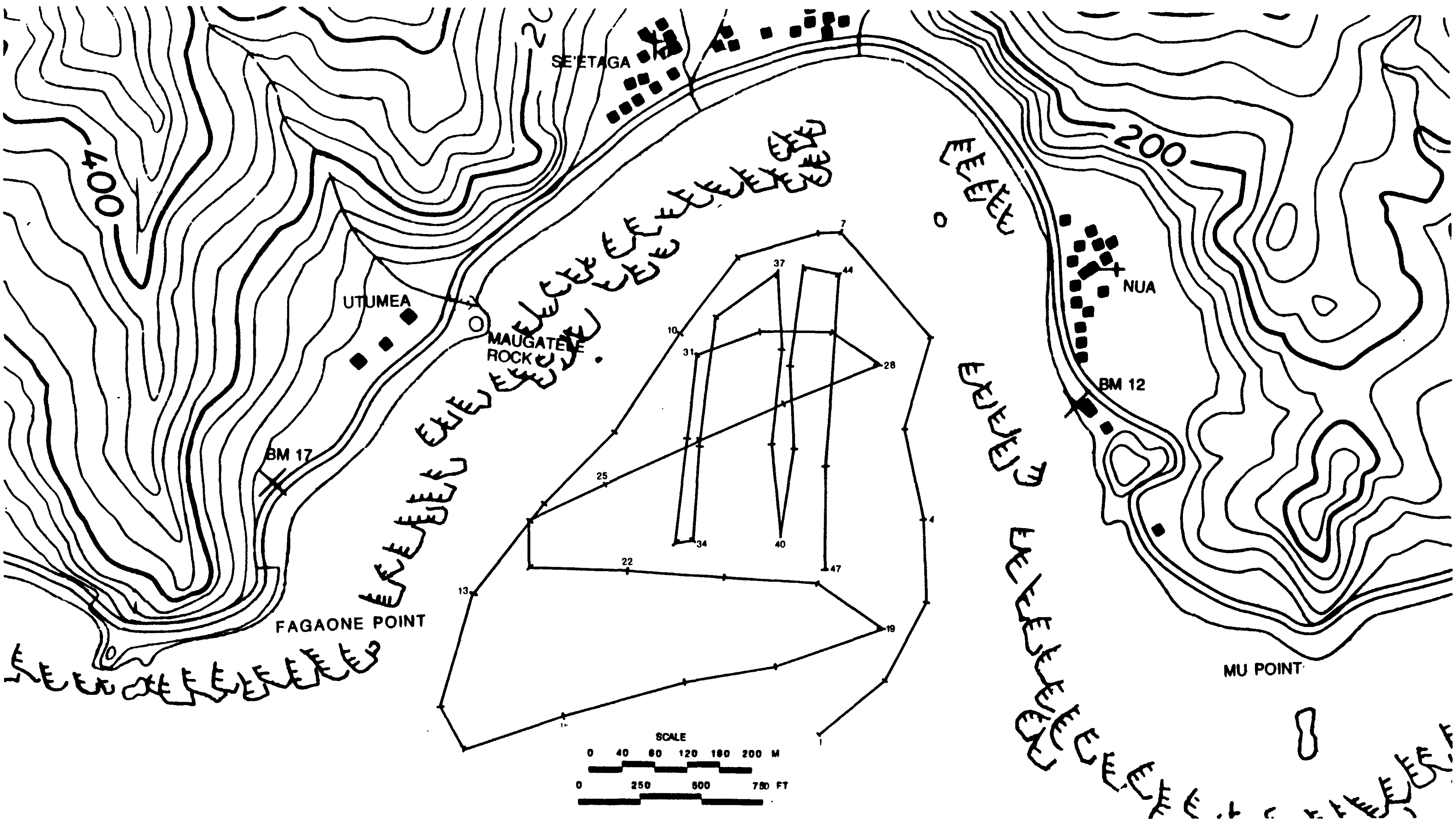

Figure 6. Side scan sonar trackline for Nua-Se'etaga Bay. Small numbers are navigation points taken one-minute apart. Onshore contours and reef-margin location taken from the U. S. Geological Survey Topographic Map for Tutuila Island (1963, 1:24,000).

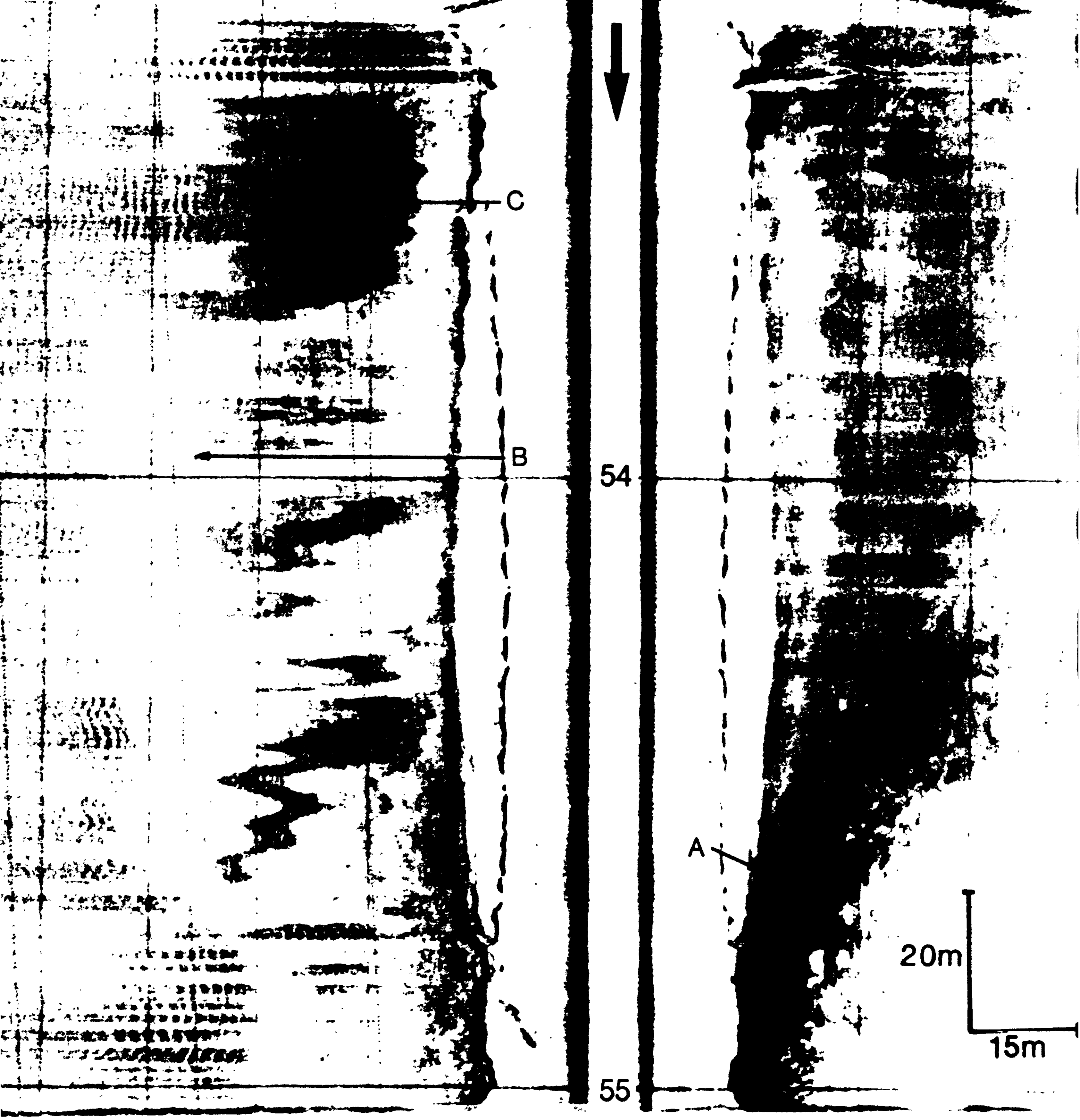

Figure 7. Sonograph of a section of the bottom in Faga'itua Bay, American Samoa. showing the three major bottom types: (A) reef, (B) featureless, and (C) rippled.

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the tow fish. Reflectors far away return less energy then those near the tow fish. The long, narrow ripple patches could be a result of the tow fish rolling in response to the waves, causing a temporary loss of bottom return. The patchy nature of the ripples in other areas, though, is real.

Reconnaissance Surveys

The sonographs from the reconnaissance side scan surveys were inspected, and interesting areas noted. Much of the bottom surveyed in this manner consisted of coral reef with occasional pockets of coarse sand. However, two areas—outside the fringing reef at Amouli and on the west side of Faga'itua Bay near the village of Auto—appeared to have wide expanses of sandy bottom in water depths of 30 m or greater. Rippled and featureless bottom types occurred in both those areas, and the former were extensive. Those areas should be investigated further if dredging below 30 m is feasible.

Detailed Surveys

Both Nua-Se'etaga Bay and the center and eastern side of Faga'itua Bay were side scanned in detail. In Faga'itua Bay, the trackline follows the outside of the fringing reef from Tolisi Point to Uea Point. For navigational safety and because the depth in the outer part of the bay was greater than 30 m, the survey was confined to the area between the fringing reef and an offshore bathymetric high in the center of the bay. Coverage in this area was complete (Fig. 4). Analysis of the sonograph resulted in the map shown in Figure 8.

In Nua-Se'etaga Bay, the trackline follows the outside of the fringing reef, and then turns into the central part of the bay, making closely spaced east-west and north-south transects. Therefore, the survey covers the area outside the fringing reef and inside of a line connecting Fagaone and Mu Points (Fig. 6). Analysis of the sonograph resulted in the map shown in Figure 9.

Shallow Seismic Profiling

Seismic profiling took place in Nua Se'etaga Bay and Faga'itua Bay and along the coast between Leone Bay and Mu Point. An additional reconnaissance line was run between Fageone Point and Niuolepava Rock, and four roughly shore-parallel lines run between Logologo Point and Pupualoa Point. Table 5 gives the trackline distances for all the seismic surveys. Figures 10, 11, and 12 show the tracklines for Faga'itua Bay, Leone Bay, and Nua-Se'etaga Bay respectively.

The main objective of the seismic analysis was to determine the parts of the sea floor underlain by sediment rather than by coral or volcanic rock. Once the sedimentary areas were delineated, the depth to the first major reflector was measured. That depth, however, may not represent only unconsolidated sediment thickness because the seismic-record patterns produced by adjacent consolidated and unconsolidated

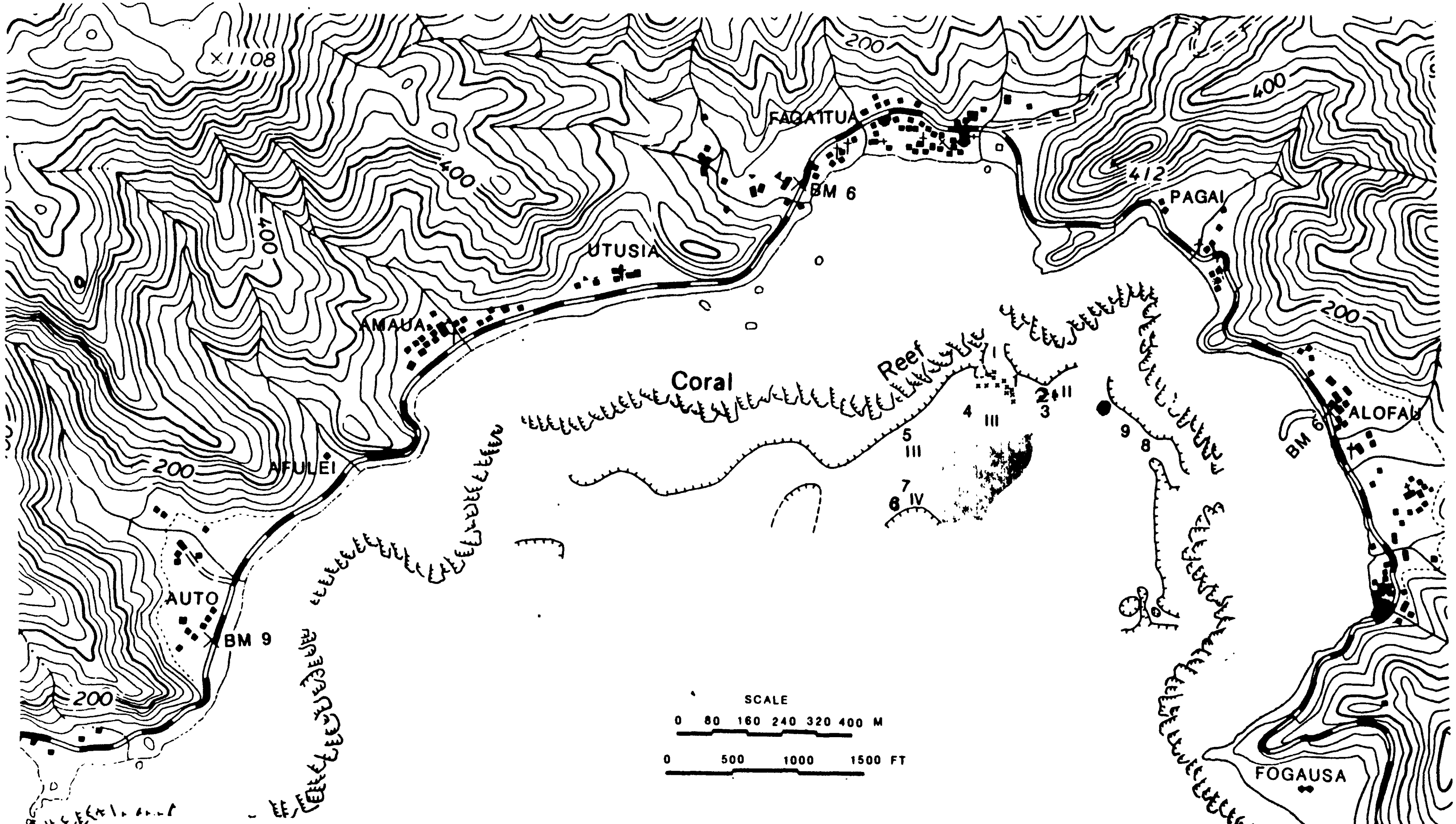

Figure 8. Side scan derived mosaic of the central part of Faga'itua Bay. Shaded areas suggest the presence of ripples on the sonograph. Numbers represent sand samples described in Tables 4 and 6. Ticked lines mark the reef-sediment contact (the reef is on the tick side); the line is dashed where the contact is inferred. Onshore contours and reef-margin location taken from the U. S. Geological Survey Topographic Map for Tutuila Island (1963, 1:24,000).

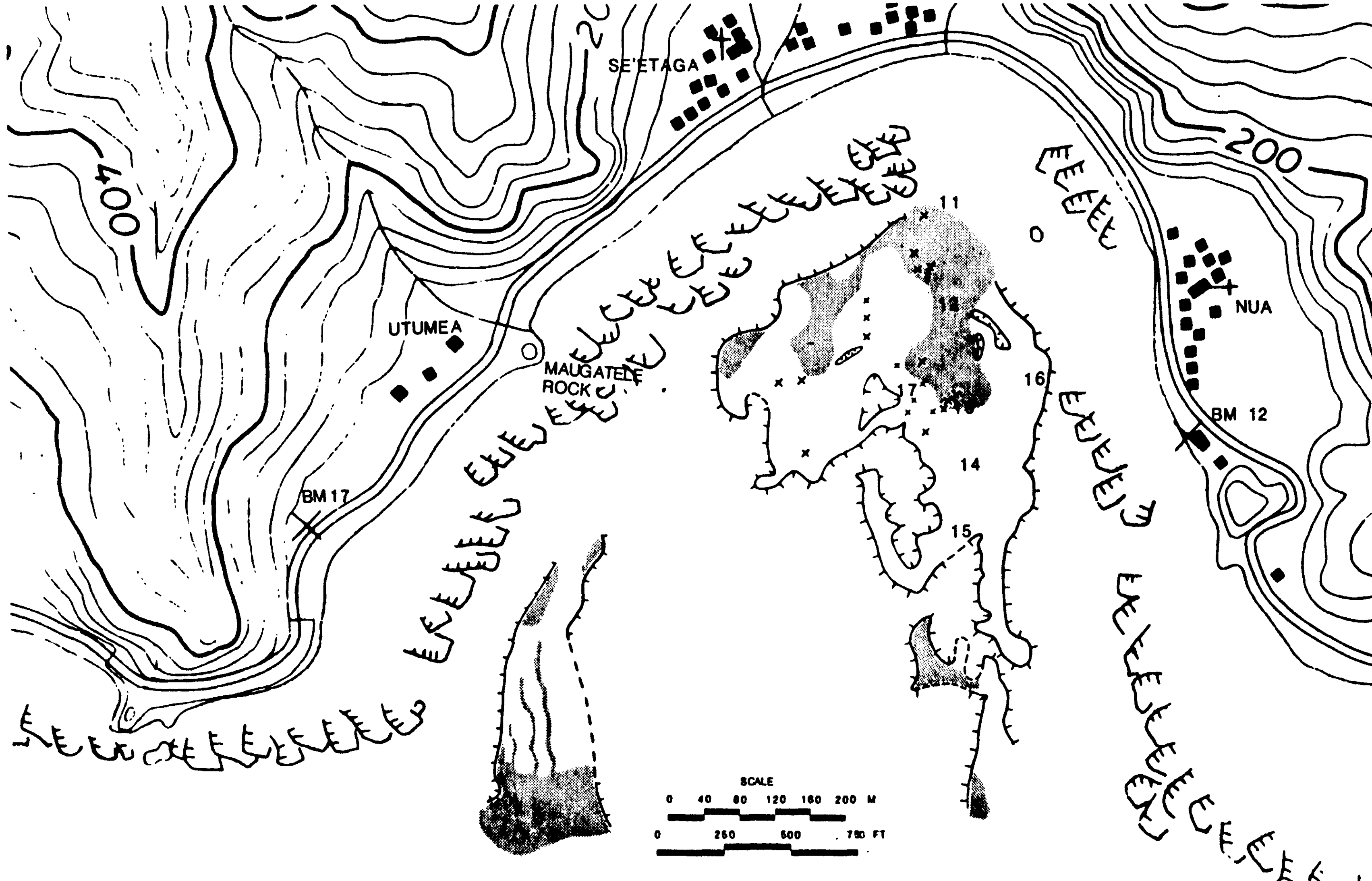

Figure 9. Side scan derived mosaic of Nua-Se'etaga Bay. Shaded areas indicate the presence of ripples on the sonograph. Numbers represent sand samples described in Tables 4 and 6. Ticked lines mark the reef-sediment contact (the reef is on the tick side); the line is dashed where the contact is inferred. Onshore contours and reef-margin location taken from the U. S. Geological Survey Topographic Map for Tutuila Island (1963, 1:24,000).

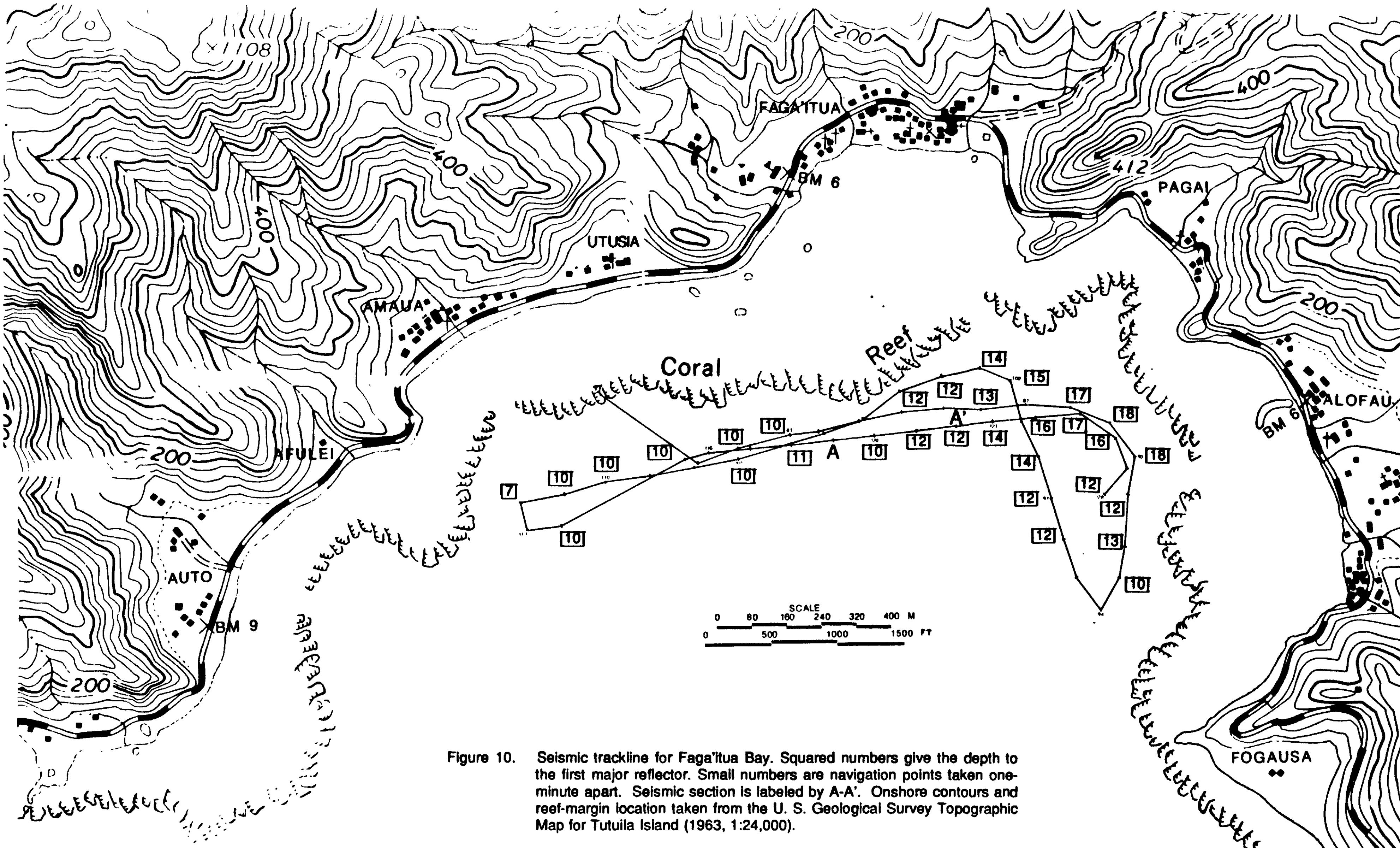

Figure 10. Seismic trackline for Faga'itua Bay. Squared numbers give the depth to the first major reflector. Small numbers are navigation points taken one-minute apart. Seismic section is labeled by A-A'. Onshore contours and reef-margin location taken from the U. S. Geological Survey Topographic Map for Tutuila Island (1963, 1:24,000).

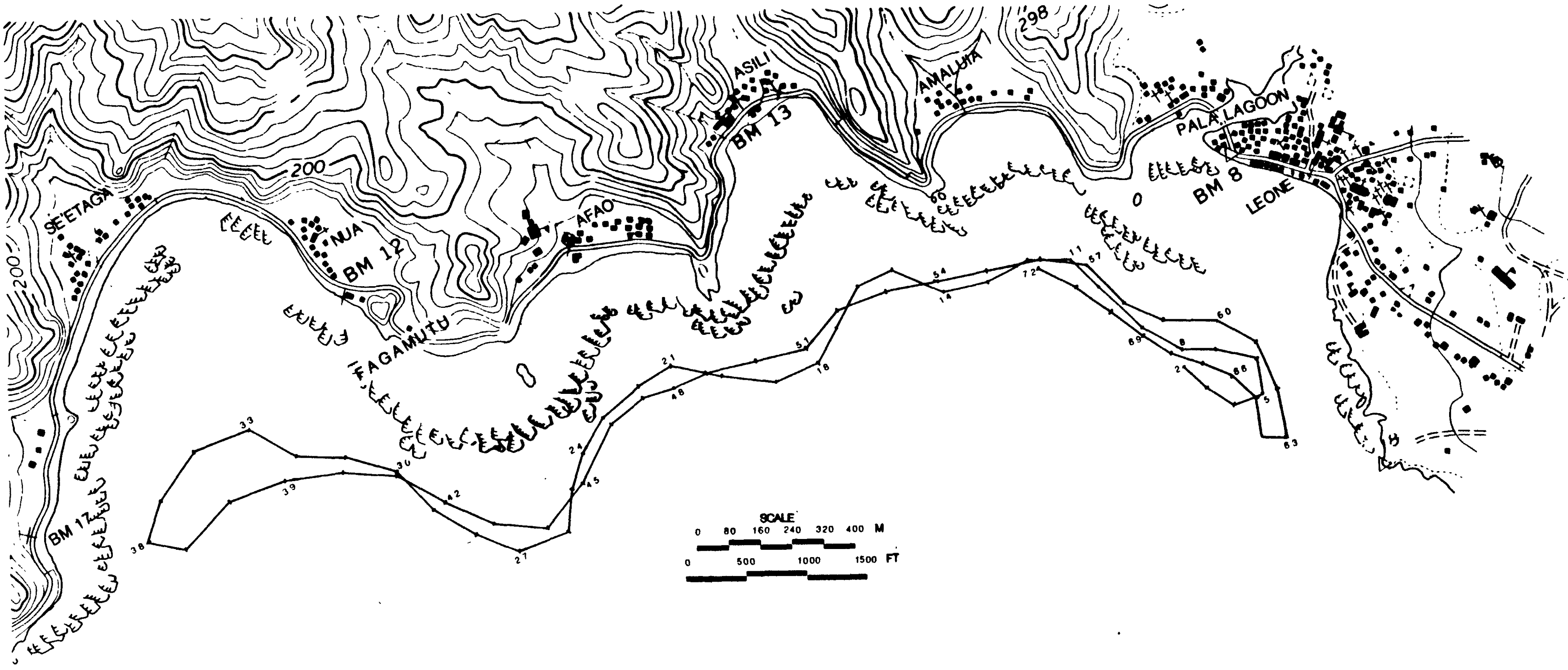

Figure 11. Seismic trackline for Leone Bay. Small numbers are navigation points taken one-minute apart. Onshore contours and reef-margin location taken from the U. S. Geological Survey Topographic Map for Tutuila Island (1963, 1:24,000).

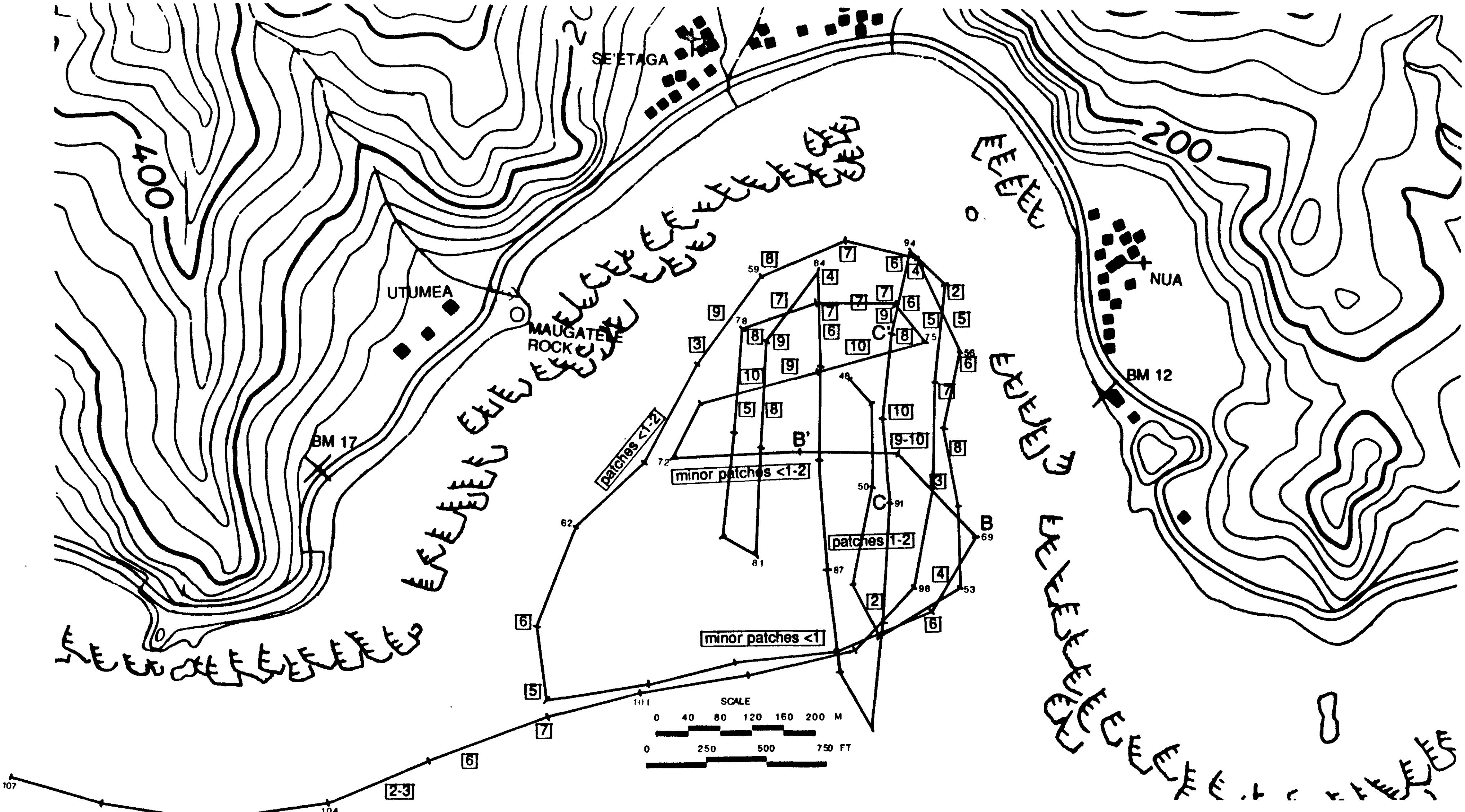

Figure 12. Seismic trackline for Nua-Se'etaga Bay. Squared numbers give the depth to the first major reflector. Small numbers are navigation points taken one-minute apart. Seismic sections labeled by B-B' and C-C'. Onshore contours and reef-margin location taken from the U. S. Geological Survey Topographic Map for Tutuila Island (1963, 1:24,000).

sediments are usually undifferentiable. A seismic record shows the total thickness of the sedimentary package; however, locating the contact between unconsolidated and consolidated beds requires that the sediment be probed or cored.

Reconnaissance Surveys

The reconnaissance seismic surveys were scanned for interesting features. Most of the areas covered in this manner consisted of coral reef with occasional narrow channels of sedimentary deposits. Sandy areas were noted between Logologo Point and Pupualoa Point, but they occurred in water depths greater than 30 m.

Detailed Surveys

The offshore area between Leone Bay and Mu Point consisted of coral reef with isolated channels containing sedimentary deposits. Much of the subsurface in Faga'itua Bay and Nua-Se'etaga Bay, on the other hand, contained reflectors suggesting sedimentary deposits. On some of the records, bedrock lay below more than 30 m of sediment, and the acoustic returns from the top several meters were similar, which suggests a constant depositional environment. The sediments between the sea bottom and the first major reflector comprise a sedimentary unit, though that unit may not be unconsolidated throughout its thickness. Figures 13 and 10 respectively show a seismic cross-section and its location in Faga'itua Bay; the latter figure also shows the sediment thickness of the first unit throughout the surveyed area. Figures 14 and 15 show cross-sections and Figure 12 their location in Nua-Se'etaga Bay; the latter figure also shows the sediment thickness of the first unit.

Bathymetry

Bathymetric contours were generated from the soundings taken throughout Faga'itua Bay and Nua-Se'etaga Bay. Because the surveyed parts of both bays were small and because of the contouring algorithm, the contours may not be correct in detail. However, the bathymetry conforms in general with the bathymetry shown on available maps and with the impressions gained during the surveys. The purpose of the bathymetric maps is to give a general idea of the bottom slopes in the bays and the relation of submarine features to the reef and shoreline. Figures 16 and 17 are the bathymetric maps for Faga'itua Bay and Nua-Se'etaga Bay respectively. The soundings that comprise the bathymetric contours were not corrected for tide; however, the tidal change between the start and end of each survey was small because of the short durations of the surveys and the small tidal range in the area.

Diving Observations

Scuba dives were made in Faga'itua Bay, Leone Bay, and Nua-Se'etaga Bay to verify the preliminary geophysical interpretations, collect sand samples, and probe for consolidated beds. The sand samples were analyzed in the same way as the beach sands; Table 6 gives the statistical parameters and Table 4 the gross compositions for

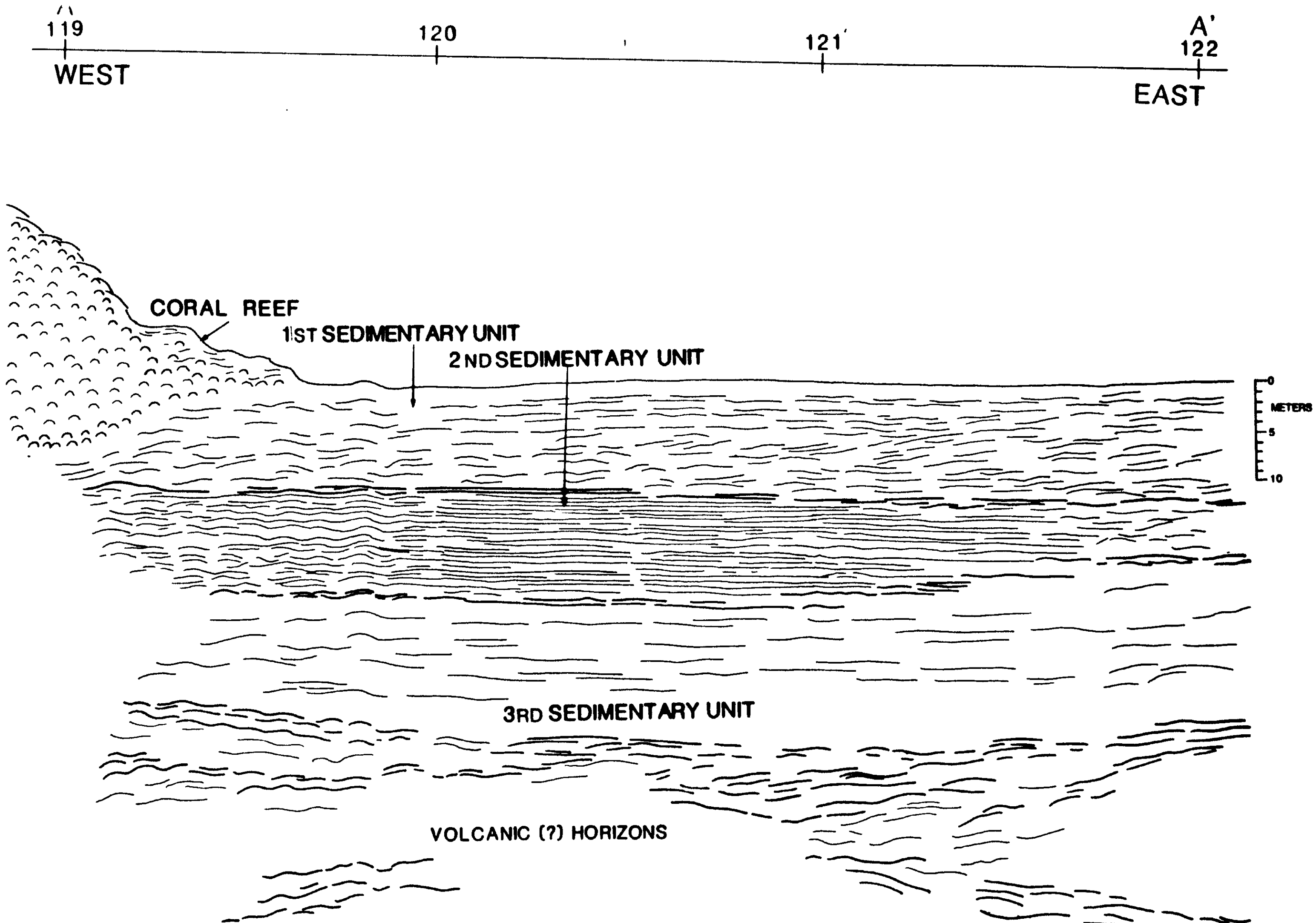

Figure 13. Seismic cross-section A-A' for Faga'itua Bay. Top numbers represent navigation marks shown on Figure 10.

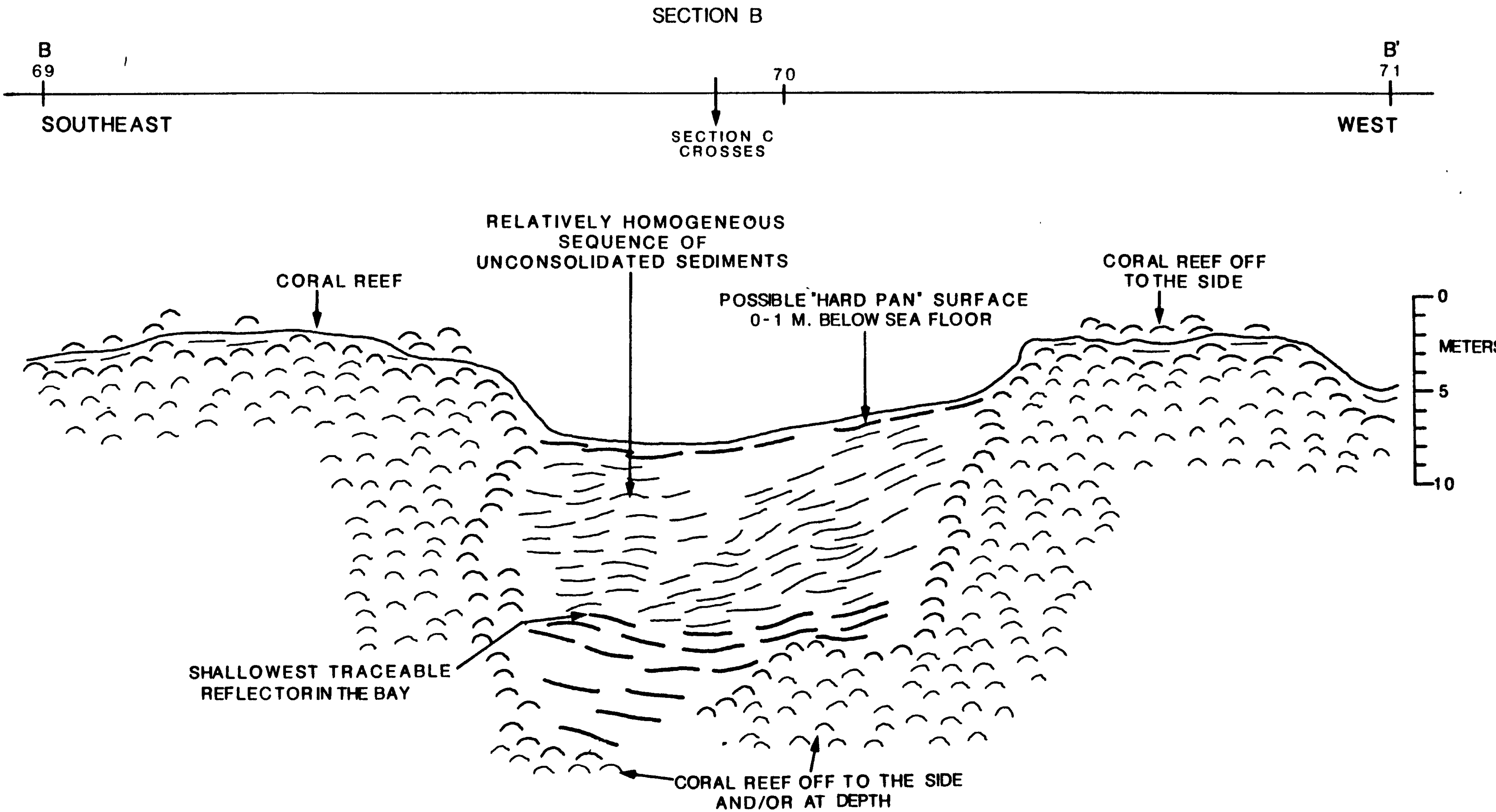

Figure 14. Seismic cross-section B-B' for Nua'Se'etaga Bay. Top numbers represent navigation marks shown on Figure 12.

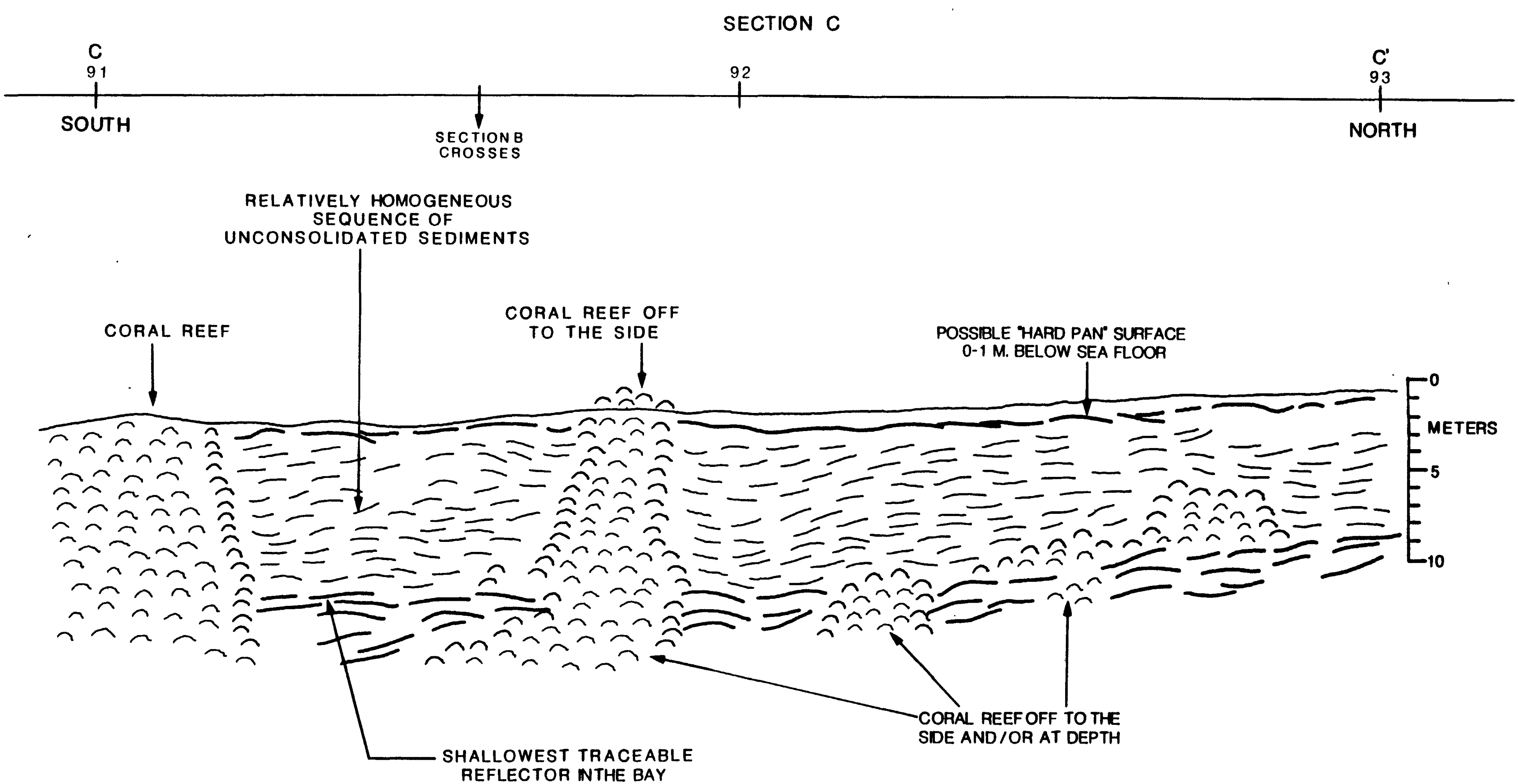

Figure 15. Seismic cross-section C-C' for Nua'Se'etaga Bay. Top numbers represent navigation marks shown on Figure 12.

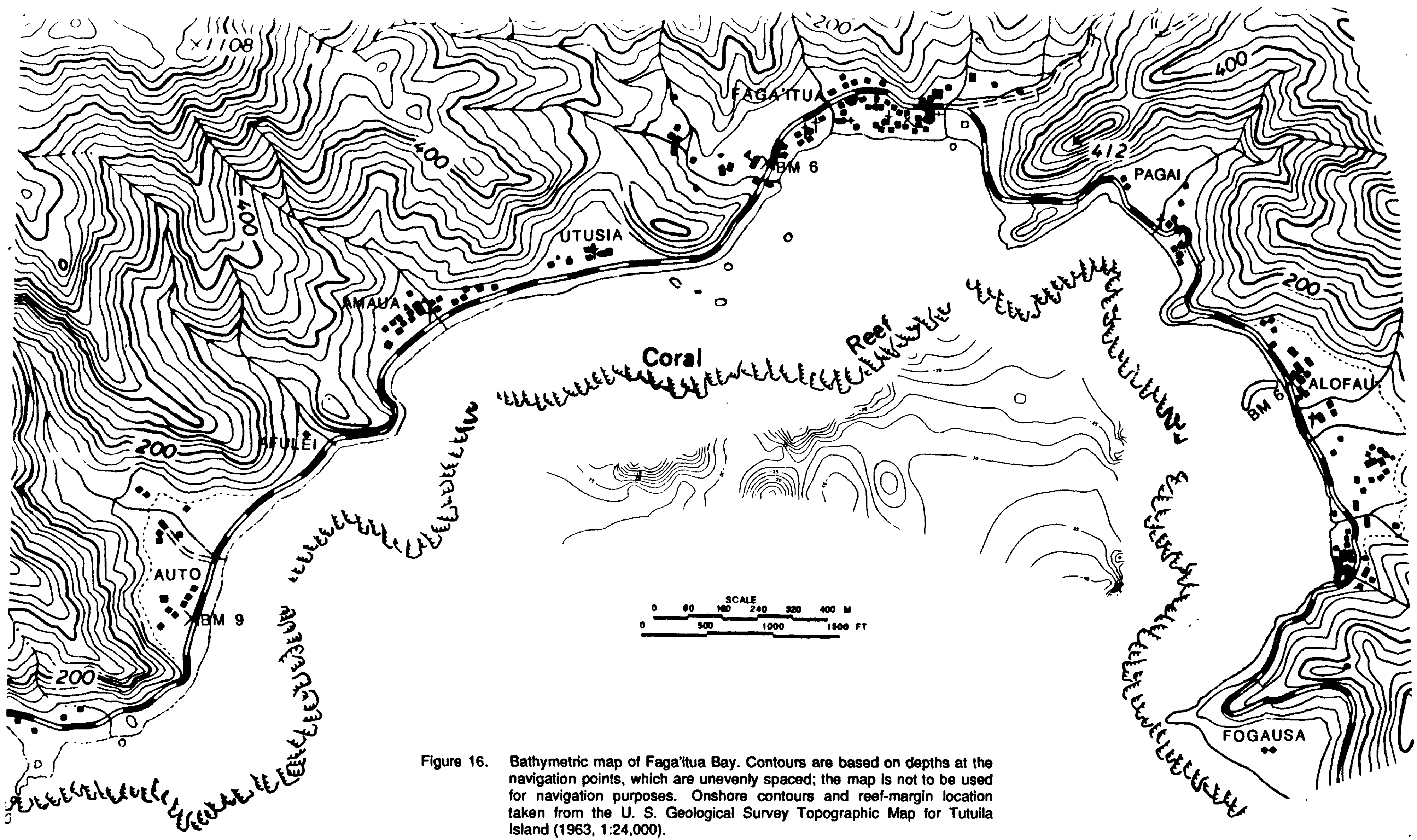

Figure 16. Bathymetric map of Faga'itua Bay. Contours are based on depths at the navigation points, which are unevenly spaced; the map is not to be used for navigation purposes. Onshore contours and reef-margin location taken from the U. S. Geological Survey Topographic Map for Tutuila Island (1963, 1:24,000).

Figure 17. Bathymetric map of Nua-Se'etaga Bay. Contours are based on depths at the navigation points, which are unevenly spaced; the map is not to be used for navigation purposes. Onshore contours and reef-margin location taken from the U. S. Geological Survey Topographic Map for Tutuila Island (1963, 1:24,000).

those samples.

Sample	Depth (m)	Md_ϕ	M_ϕ	σ_ϕ	α_ϕ	$\alpha_{2\phi}$	β_ϕ
			Faga'itua Bay				
1	19	0.6973	0.7025	0.6790	0.0076	-0.1006	0.8948
2	23	0.4393	0.4330	0.8993	-0.0070	-0.2524	0.7754
3	27	0.4428	0.5944	0.7653	0.1981	0.0266	0.7010
4	27	2.5060	2.4087	0.3896	-0.2496	-0.5994	0.9139
5	30	2.7079	2.5392	0.8449	-0.1997	-1.3991	1.6873
6	34	-.8913	-0.6046	1.1197	0.2561	0.5142	0.5020
7	34	3.1620	3.1727	0.6200	0.0173	-2.0366	2.3882
8	21	0.3204	0.4502	0.8844	0.1468	0.4209	0.8896
9	24	1.8047	1.5816	0.9691	-0.2302	-0.6143	0.8499
			Leone Bay				
10	17	-1.0197	-0.7551	0.8719	0.3034	0.5819	0.6610
			Nua-Se'etaga Bay				
11	3	0.9865	0.9633	0.3099	-0.0750	-0.6066	0.8073
12	7	1.2999	1.2105	0.3715	-2.2405	-0.5282	0.8087
13	10	1.7300	1.9104	0.4489	0.4018	0.3484	0.5883
14	12	1.6691	1.8840	0.3886	0.5531	0.5143	0.6998
15	15	1.8465	1.8967	0.3543	0.1417	0.1824	0.7549
16	9	1.9403	1.9923	0.4905	0.1059	0.1008	0.5828
17	12	2.9366	3.0867	0.8050	0.1865	0.0039	0.3171

Table 6. Size parameters for offshore sand samples from Faga'itua Bay, Leone Bay, and Nua-Se'etaga Bay. Locations for the Faga'itua Bay and Nua-Se'etaga Bay samples are shown on Figures 8 and 9 respectively. The Leone Bay sample came from the area south of the small ava leading into the lagoon.

Faga'itua Bay

Several dives were made in the central part of Faga'itua Bay. The first dive started in the lagoon adjacent to the village of Faga'itua, went out the ava (channel), and ended seaward of the reef front. Later dives covered the bottom adjacent to the reef front between the avas at Faga'itua and Alofau and between the reef front and the patch reef in the central part of the bay. The principal materials found on the bottom of the ava at Faga'itua were coarse, calcareous sand and limestone rubble. Usually, the sand and rubble were mixed, though there were occasional small patches of clean sand along the ava walls and next to coral mounds in the channel. The ava ended at the base of the reef front in a water depth of about 14 m. Beyond the ava, the bottom sloped gently seaward. To both sides and seaward the bottom was the same mix of coarse sand and limestone rubble. At a depth of about 27 m, the bottom leveled and the sediment was a fine, calcareous sand with a silty component that extended seaward beyond the limits of visibility (~15-20 m). Offshore Sample 1* came from this area.

Eastward on the sloping bottom between the reef front and the fine sand, coarse sand replaced the sand-rubble mix (Offshore Sample 2). Waves had shaped the sand into long-crested ripples that also appeared on the sonographs. Probing into the sand revealed hard surfaces about 0.5 m beneath the surface; digging exposed small, flat pieces of limestone rubble. The zone of coarse sand extended at least as far as the indentation in the reef at Pagai. Offshore, the transition from coarse sand to silty sand was sudden, occurring in the same water depth as before, and spanning a distance of only a few meters.

Farther to the southeast, the reef front extended to within a few meters of the silty sand; the intervening bottom consisted of sand with limestone rubble. North of the mouth of the ava at Alofau the silty sand stepped upward to a depth of about 24 m before leveling out against the reef front. Seaward of the ava, coarse sand (Offshore Sample 8) with scattered limestone rubble extended from the silty sand (Offshore Sample 9) in a water depth of about 27 m up a steep slope (~30°) to a depth of about 21 m and into the ava. The coarse sand was shaped into wave ripples, but the deeper, silty sand was unrippled with many burrows and other biologic disturbances.

Abutting the shoreward side of the patch reef in the central part of the bay was a 10-to-20-m wide zone containing a coarse, platy calcareous sediment (Offshore Sample 6). Shoreward of the platy material and in sharp contact with it, was a silty sand with low-amplitude, long-crested, shore-parallel wave ripples and tracks (Offshore Sample 7). The silty sand extended shoreward to within a couple of meters of the base of the reef front; the zone between the silty sand and the reef front contained sand and limestone rubble.

Leone Bay

Dives were made in the narrow lagoon between Leone and the fringing reef; on and beyond the outer reef, which dips seaward rather than rising to a well-defined margin (U. S. Army Corps of Engineers, 1980); and offshore of the village of Amaluia. Entry was from a dark-sand beach just east of the entrance to the Pala Lagoon. The sand extended seaward into a triangular gap in the inner reef flat. From the offshore end of the sand, a poorly defined channel ran seaward past a coral-rubble rampart and across the reef margin. However, the inshore sand, which was predominantly siliciclastic, did not extend through the channel and into deeper water. Shore-parallel traverses showed that the reef front consisted of coral cut by narrow channels lined with a coarse, platy, calcareous sediment whose median diameter is greater than 2 mm (Offshore Sample 10). Also, the divers saw two areas about 15 m on a side containing the same type of sediment.

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*The composition and textural parameters of the offshore samples discussed in this section are given in Tables 4 and 6 respectively.

Offshore of the village of Amaluia, the bottom was similar to the bottom off Leone. Again, the sediment was coarse and platy and restricted to isolated channels or depressions in the reef front.

Nua-Se'etaga Bay

Dives were made throughout Nua-Se'etaga Bay including a transect from the village of Se'etaga to the mouth of the bay and a transect from the reef front by the village of Nua westward to the reef front by the village of Utumea. Much of the bottom in the central part of the bay consisted of calcareous sand with varying amounts of siliciclastics (Offshore Samples 11-17). In a water depth of 3 m, the sand was predominately siliciclastic; by 10 m it was around 20%, and at the seaward limit of the sand it was predominately carbonate. Everywhere, the sand was shaped into long-crested wave ripples. Seaward, the sand decreased in grain size from coarse sand with scattered limestone rubble in the ava, to medium sand in a water depth of 10 m, to fine sand in 15 m; both the ripples and the grain-size trend suggest a nearshore, wave-dominated environment. As at the patch reef in Faga'itua Bay, there frequently was a narrow zone (a meter or two wide) of coarse, platy calcareous sediment between the reef and the sand. During the east-west transect, the sand was probed in several places to determine the thickness of the unconsolidated sediment. At every site, a hard layer was hit 0.7 to 2 m below the sea bed. The solid ringing sound made by the probe striking that layer suggested that the layer was a solid horizon rather than limestone rubble.

DISCUSSION

Before a decision to mine offshore sand can be made, the location, size, and texture and composition of existing sand bodies must be known. Location and areal extent were determined from side scan sonar records and diving observations, which showed that sand existed outside the reef in water depths less than 30 m. Some of the sandy areas were small, which makes it unlikely that they would be considered for mining; others, however, were large enough to warrant further consideration. The seismic records showed that sedimentary deposits extended deep into the subsurface in places, but the thickness of unconsolidated sand could not be determined from those records. In the few areas probed, a solid substratum was encountered within two meters of the sea bottom. Texture and composition were determined from small sand samples collected on the dives, and both varied with location, giving a variety of sand types to consider.

Beach Sands

The statistical grain-size parameters in Table 2 show no systematic pattern. No readily discernible correlation between the various parameters can be seen, though factor analysis might turn up some relationships. Some general patterns do appear, and those are enough for the scope of this study.

The only samples with a high siliciclastic content came from beaches between Leone and Maugatele Rock, on the west side of Nua-Se'etaga Bay, and four pocket beaches just north of Cape Taputapu. All other samples were predominately calcareous.

At Leone, the sand was greater than 90% siliciclastics; to the west, the siliciclastic concentration decreased to 2% just east of Mu Point and 5% at the village of Nua, but then increased to 30% at the village of Se'etaga and to greater than 90% on the east side of Maugatele Rock. On the west side of the rock, the siliciclastic concentration dropped to 7%. The large difference in percent siliciclastics from one side of the rock to the other is consistent with having the primary source of siliciclastic sediment to the east and Maugatele Rock blocking the eastward drift of calcareous sediment into Nua-Se'etaga Bay (westward drift would not be expected in that area because the incoming waves would drive the sand toward the head of the bay rather than out of it).

In general, the beach sediments would be classified as coarse or very coarse sands; 18% of the median and 34% of the mean grain diameters fell in the very coarse class, while 57% of the medians and 48% of the means were coarse. Two factors contribute to the difference in percentages between median and mean diameters:

- in a few samples (*e.g.,* Nos. 12, 43, 48, 56, 64, and 67) the values fall at the boundary between classes with one parameter being slightly lower than the boundary value and the other being slightly higher. Such differences are artificial, because they are a result of the arbitrary nature of the grain-size classification.
- in other samples (*e.g.,* Nos. 18, 26, 32, 38, and 50) the mean is skewed toward higher values because of a high percentage of material larger than sand size. Often the frequency distribution has a separate peak (mode) at -2ϕ, which was the largest sieve used in the analysis. If the frequency curve has an "∫ " shape within the sand sizes, then perhaps the coarser material should be eliminated from the analysis. One or two large clasts could constitute a high percentage of the sample weight but would not be part of the sand-size distribution.

Sorting values ranged from 0.17 to 1.83 with 30% being less than or equal to 0.5 and 36% being between 0.5 and 1. All of the samples with sorting values greater than 1.1 had greater than 8% of their material larger than sand sizes. Conversely, only samples 4, 37, and 60 had that much large material and a sorting value less than one.

Most of the samples were negatively skewed in both the bulk and tails. Using values less than -0.1 for negative skewness and greater than 0.1 for positive, 55% of the α_{ϕ} samples and 71% of the $\alpha_{2\phi}$ samples were negatively skewed, while only 5% and 9% respectively were positively skewed. This pattern means that most of the sample distributions are skewed toward coarser diameters. Komar (1976, p. 344) cites several studies that found that beach sands are commonly negatively skewed, and he points out that adding a few coral fragments or shells to an otherwise sand beach would produce a tendency for negative skewness.

Using a range of 0.55 to 0.75 as normal, 48% of the samples had longer tails, and 25% had shorter ones. Again, there was no obvious correlation between kurtosis and the other parameters, though the samples with the most material larger than -2ϕ generally had the lowest kurtosis values or longest tails. This also suggests that those samples could be reanalyzed with the large material removed.

Central Faga'itua Bay

We surveyed Faga'itua Bay because both its shape and the existence of large sandy lagoons suggested a high probability of offshore sand deposits. Because there were no siliciclastics in the beach samples from the bay, we expected to find only calcareous sand offshore. Detailed surveys covered the central part and eastern side of the bay because those areas were more protected and were adjacent to the largest lagoons. Particularly interesting was a seaward bulge in the contours just offshore of the ava at the village of Faga'itua. Reconnaissance surveys at the end of the study, however, revealed a sandy bottom on the west side of the bay. The offshore zone adjacent to the village of Auto, where the reef swings shoreward and the bottom contours swing seaward toward an offshore bathymetric high, could be a sand trap similar to the one off the village of Faga'itua described below.

In the center and along the eastern side of Faga'itua Bay, the unconsolidated, calcareous sediments that we found fell into four groups:

I. A mixture of coarse sand and limestone rubble,
II. Coarse sand,
III. Fine sand with silt, and
IV. A platy sand.

The coarse sand and limestone rubble (area I, Fig. 8) lined the bottom of the ava off of the village of Faga'itua. Seaward of the ava, the zone of mixed sand and rubble lay between the reef front on the north and west, silty sand on the south (seaward), and coarse sand on the east. At the outside of the reef, the water depth was about 14 m and, at the contact with the silty sand, was about 27 m. Due to a high concentration of rubble, sand dredging in this area would be difficult.

Area I graded into coarse sand (Area II, Fig. 8) over a distance of several meters. Continuing eastward, the coarse sand followed the reef front toward the village of Pagai. In a seaward direction, it also ended in sharp contact with the silty sand in a water depth of about 27 m. The sand in Area II was shaped into large, long-crested ripples by the waves; those bedforms were large enough to show up on the sonographs. At one spot, the diver-held probe penetrated ~0.5 m before hitting something solid; digging there produced two tabular limestone pieces. At a nearby spot, the probe stopped after penetrating ~1 m into the sediment. Because limestone rubble is prevalent nearby (Area I), it is highly probable that rubble underlies the sand in Area II. Incident waves will move the sand more readily than they will move the rubble. Combined with strong, seaward flowing currents in the ava, the waves may transport sand into Area II at a high enough rate to bury the rubble. Digging, coring, or probing could verify the existence of buried rubble throughout Area II. Estimating the size of Area II from the sonographs is hard because the survey vessel was always turning in that area. However, the widespread distribution of ripples corresponds with a similar distribution of medium and coarse sand.

South of the indentation in the reef at Pagai, the coarse sand ended and the bottom consisted of silty sand except for a narrow zone adjacent to the reef front, which contained coarser sand and rubble. Silty sand also extended seaward from the fringing reef west of the Faga'itua ava to the patch reef in the central part of the bay. It may also have extended farther offshore, but the water was too deep for divers to explore. On the north side of the patch reef, silty sand lay in sharp contact with patches of the platy sand. Those patches were poorly sorted, having both platy, large-diameter grains and a high concentration of sand-size material. Waves had shaped the platy material into large ripples. Combining the sonographs and the diving observations suggests that the ripples formed in the platy sand produce darker reflectors than the ripples formed in the coarse sand. However, variations in gain caused by the side scan sonar operator or the automatic gain control could make it impossible to differentiate between the two sediments on the sonographs. In those cases, divers would have to verify the sediment type.

In Area III, the bottom slope is close to zero, and the sediment is a fine, silty sand. This area lies between the fringing reef, the patch reef, and rippled sand. This is an area the fine material settles into after being moved seaward by waves. The divers saw ripples on the bottom that had been degraded by benthic animals. Large waves would readily reform the ripples, but the ripple size would be too small to detect with side scan sonar because of the fineness of the sediment. The silt content of the sediment in Area III could limit its usefulness onshore. There should be some way to separate out the sand, but that process could lead to increased turbidity in the dredge zone.

Concentrations of platy fragments 1 to 2 mm in diameter (Areas IV) occur between the patch reef and the silty sand. These platy patches may be the result of selective sorting by waves and currents, but the organism producing that type of grain probably occurs locally. Folk and Robles (1964) described beaches principally composed of *Halimeda* algal fragments of about the same size and shape as those found in Faga'itua Bay (and also found in the Leone area). In their study, a combination of distinct grain-size modes, which were derived from the local plant and animal species, and physical processes produced beach sediments high in the platy fragments.

Of the four sandy areas, only the one with mixed sand and rubble seems inappropriate for dredging unless the sand could be separated from the rubble. The rest of the surveyed area would yield fine sand, coarse sand, and platy sand, all of which would be calcareous. The sonographs show ripples throughout the area, suggesting that medium and coarse sand are widespread. Estimating the surface area occupied by each sediment type is difficult because of the uncertainty involved in measuring the ripple distribution on the sonograph. Ripples formed in coarse sand cannot be readily distinguished from those formed in platy sand. Also, there is no way to separate Area I (coarse sand and rubble) from the fine-sand area because both areas look similar on the sonograph. However, the total surface area covered by unconsolidated sediments was measured using a digitizing table. The volume of sand available can then be calculated once the thickness of the unconsolidated, rubble-free sand has been determined. Within the survey area in central Faga'itua Bay, about 400,000 m^2 of the bottom were covered with unconsolidated sediment, and at least 35% of that area was rippled. Because the reef front effectively separates sandy areas from the shore and because the sand is in water depths greater than 14 m, removing sand by dredging should not alter the characteristics of the incident waves enough to affect the shoreline adversely.

Leone Bay

The beach sands between Leone and Maugatele Rock were predominantly siliciclastic in composition except near Mu Point, Nua, and Se'etaga. Because the sand extended into the lagoon on the shoreward side of the fringing reef at Leone, we had hoped to find deposits of siliciclastic sand offshore. However, all we found were patches of platy sand amongst the coral on the reef front. Even the small channel that crossed the reef at the village of Leone did not have a sandy bottom. Either the beach and lagoonal sands do not reach deeper water, we missed their area of deposition, or the less steep nature of the reef front encourages sand movement into deep water.

Nua-Se'etaga Bay

Except for the west side, where the fringing reef is wide, most of Nua-Se'etaga Bay (water depths less than 15 m) has a sandy bottom. From the beach seaward, the sand follows a fining seaward pattern, which is typical in the coastal zone. Furthermore, the sand ranges from 99% siliciclastics in a water depth of 3 m to around 20% in the middle of the bay. Probing in the central part of the bay gave sand thicknesses between 0.7 and 2.2 m; the response of the probe when it struck a solid object suggested that the surface was a continuous, solid surface rather than rubble. However, that deduction was not confirmed by digging. Based on the side scan interpretation, there are roughly 80,000 m^2 of sand with about 75% of it in the large area at the head of the bay. The bottom would have to be cored to determine whether the unconsolidated sediment is sandy in the subsurface.

Unlike Faga'itua Bay, where the sand deposits are in deep water, the deposits in Nua-Se'etaga Bay are in shallow water (0 to 15 m) close to shore. Furthermore, in places the reef is narrow, and at the head of the bay there is a large gap in the reef. The rippled nature of the bottom throughout the area shows that waves interact strongly with the bottom. Therefore, part of the feasibility study for Nua-Se'etaga Bay should be an determination of the amount that dredging will alter the characteristics of the incident waves.

Other Areas

The most promising areas seen while acquiring the reconnaissance geophysical lines were on the west side of Faga'itua Bay (see the discussion above) and seaward of the village of Amouli. The latter area is less protected than the sandy areas in Faga'itua and Nua-Se'etaga Bays, which may make dredging more difficult. Water depths in the sandy areas are around 30 m, which is near the limit for today's dredges. However, much of the area adjacent to the reef front was rippled on the sonographs, suggesting that the sand was coarse and, perhaps, that the amount of rubble was low (the latter supposition is based on the observation that the sonographs from Faga'itua Bay showed ripples where the bottom consisted of coarse sand but not coarse sand and rubble).

The Coral Reef Inventory (U.S. Army Corps of Engineers, 1980) mentions offshore sand deposits near Logologo Point. The only bedded deposits recorded on the seismic records, though, were in water depths greater than 30 m, so we did not dive on them. However, it is possible that the *Sausauimoana* could not survey close enough to shore to locate a shallow-water extension of those sands.

CONCLUSIONS

The beaches on the south side of Tutuila Island, American Samoa are small and consist of coarse sand. Between Leone and Maugatele Rock, the beach sands have a high siliciclastic composition, but elsewhere the beach sands are predominantly carbonate. The size and composition of the beach sands reflect the composition of the nearshore sand in Faga'itua Bay and Nua-Se'etaga Bay, though other grain sizes and shapes occur offshore. The fine, silty sand found in water depths greater than 27 m in the central part of Faga'itua Bay does not have a counterpart on the beach. Waves are strong enough to move any fine material offshore where it settles to water depths not strongly affected by the waves. The platy sand found in the offshore is probably derived from nearby sources and concentrated by the physical processes.

Coarse sand and limestone rubble, coarse sand, silty sand, and platy fragments occupied separate niches seaward of the reef front in central Faga'itua Bay. Dredging should be feasible throughout the area with the exception of the zone of mixed coarse sand and rubble. Unconsolidated sediment covers about 400,000 m^2 of the sea bottom in the area surveyed.

In depths shallower than 15 m, much of the bottom in Nua-Se'etaga Bay consisted of medium sand with a siliciclastic composition ranging from 99% to 0%. The area covered by sand is greater than 80,000 m^2, and 75% of that area is located in the head of the bay. The shallow depths and absence of limestone rubble means that dredging should be easy throughout the bay.

In the probed parts of Faga'itua Bay and Nua-Se'etaga Bay, unconsolidated sand extended at least one meter below the sea bottom but may not have extended to the limit of the sedimentary reflectors seen on the seismic records. Because the top meter on the seismic records was obscured by the sea-bottom return, it was not possible to identify a reflector that could be correlated with the top of the consolidated sediment that were determined by probing. However, seismic studies in other areas have shown that the acoustical differences between unconsolidated and consolidated sediments of similar composition are too subtle to differentiate. Usually the only way to determine the thickness of the unconsolidated sediment, and also its composition and texture at depth, is to core. It will be necessary to know the thickness and composition of the sediments before a feasibility study can be completed.

RECOMMENDATIONS

The sand bodies described in this report need to be cored to determine the composition and thickness of the unconsolidated sediment. If, as is suggested by a few probings, there are only a couple of meters of unconsolidated sediment, hand-driven cores could be used. Otherwise, hydraulic coring techniques will be necessary. Neither of these methods will penetrate solid substratum, which would have to be drilled. However, for dredging purposes, it will be necessary only to know the thickness of the unconsolidated sediment.

On the sonographs, ripples composed of coarse sand could not be easily differentiated from those composed of platy sand. Divers should inspect the rippled areas to determine the composition of the sand. With more direct observations, the sonographs could probably be interpreted more accurately.

A systematic sampling program in the offshore would help define the distribution of each sediment type. Either a grab sampler could be used, or divers could collect the samples. The former technique should be faster, but the latter will lead to a better knowledge of the bottom types throughout the area.

Limited funding and several days of unworkable sea conditions prevented us from covering all the south side of Tutuila Island in detail. Though we investigated two offshore areas with sand, reconnaissance surveys showed that other areas exist. Though it may be too expensive to survey those areas with the array of geophysical equipment used in this study, the areas should at least be examined by divers and, if possible, cored and probed.

This report does not address the environmental impacts related to removing sand from outside the reef. Although the sand is lost to the nearshore zone, removal will deepen the water depths outside the fringing reef, which could alter the incident waves adversely. The feasibility study should estimate the effect of dredging on the wave climate as well as on the biota.

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REFERENCES

Bascom, W. N., 1951, The relationship between sand size and beach-face slope: Transactions, American Geophysical Union, v. 32, no. 6, p. 868-874.

Bier, J. A., 1980, Islands of Samoa: Honolulu, The University Press of Hawaii, 2 p. of maps.

Defense Mapping Agency, 1981, Atlas of Pilot Charts, South Pacific Ocean, Pub. 107, 12 p.

Dingler, J. R. and Inman, D. L., 1977, Wave-formed ripples in nearshore sands: Proceedings, 15th Coastal Engineering Conf. American Society of Civil Engineers, P. 2109-2126.

Dingler, J. R., Carlson, D., and Sallenger, Jr., A. H., 1986, Tutuila Island American Samoa: Locations and statistical parameters of beach and offshore sand samples: U. S. Geological Survey, Misc. Field Map 86- (in prep.).

Folk, R. L. and Robles, R,. 1964, Carbonate sands of Isla Perez, Alacran Reef Complex, Yucatan: Journal of Geology, v. 72 p. 255-292.

Hobbs, C. H., Byrne, R. J., Gammisch, R. A., and Diaz, R. J., Sand for beach nourishment in lower Chesapeake Bay: Proceedings, Coastal Zone '85, American Society of Civil Engineers, v. 1, p. 791-811.

Inman, D. L., 1952, Measures for describing the size distribution of sediments: Journal of Sedimentary Petrology, v. 22, no. 3, p. 125-145.

Komar, P. D., 1976, *Beach Processes and Sedimentation*: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 429 p.

Lam Yuen, Jr., T., 1981, *A Coastal Zone Management Atlas of American Samoa*: Development Planning Office, American Samoa Government.

MacDonald, G. A., 1944, Petrography of the Samoan Islands: Bulletin of the Geological Society of America, v. 55, p. 1333-1362.

Miller, M. C. and Komar, P. D., 1980, Oscillation sand ripples generated by laboratory apparatus: Journal of Sedimentary Petrology, v. 50, no. 1, p. 173-182.

National Ocean Service, 1985, Tide Tables (for the) Central and Western Pacific Ocean and Indian Ocean: Rockville, Md., National Oceanic and Atmospheric Administration, 381 p.

Sea Engineering Services Incorporated/R. M. Towill Corporation, 1980, American Samoa shoreline inventory: Honolulu, U. S. Army Corps of Engineers, Pacific Ocean Division.

Stearns, H. T., 1944, Geology of the Samoan Islands: Bulletin of the Geological Society of America, v. 55, p. 1279-1332.

U. S. Army Corps of Engineers, 1980, American Samoa coral reef inventory: Honolulu, Pacific Ocean Division, 314 p. + 1 atlas.

Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, p. 377-392.