DEPARTMENT OF THE INTERIOR
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MISCELLANEOUS FIELD STUDIES
MAP MF—1875

MAP SHOWING LOCATIONS AND STATISTICAL PARAMETERS OF BEACH AND OFFSHORE SAND SAMPLES, TUTUILA ISLAND, AMERICAN SAMOA

By

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1987

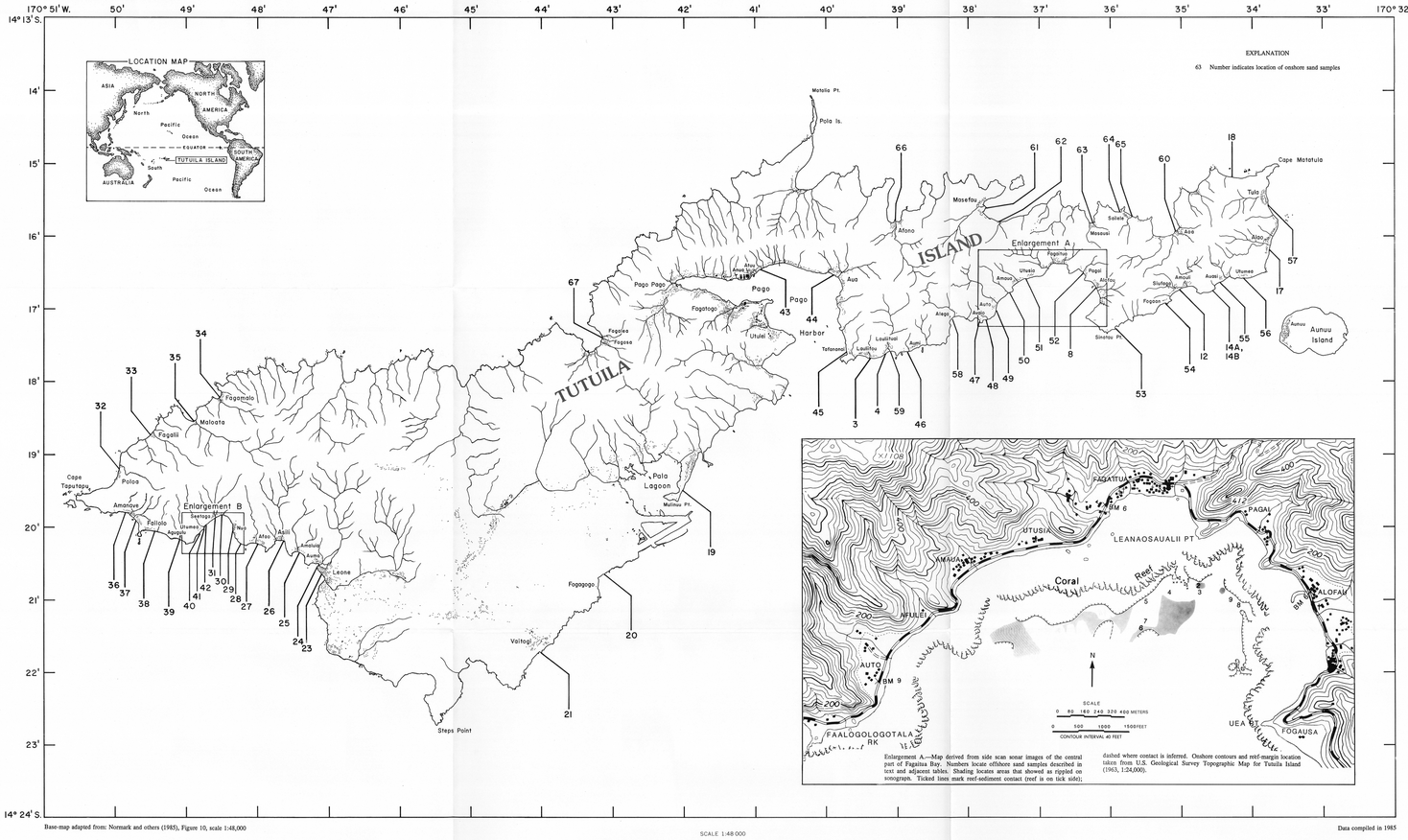


Table 2.—*Grain-size parameters for the samples from Tutuila Island, American Samoa. Listing starts at Leone and goes clockwise around the island*

[$M_d\phi$ is median diameter; M_ϕ, mean diameter; σ_ϕ, sorting parameter; α_ϕ and $\alpha_{2\phi}$, first and second skewness parameters respectively; and β_ϕ, kurtosis parameter]

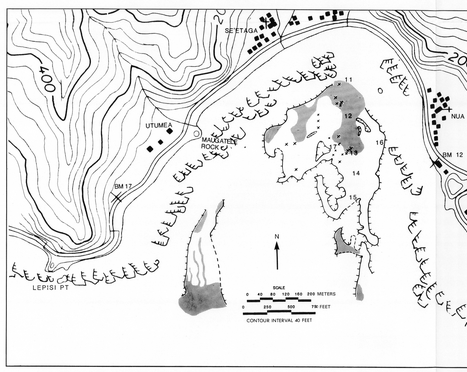
Sample	Md_ϕ	M_ϕ	σ_ϕ	α_ϕ	$\alpha_{2\phi}$	β_ϕ
23	0.3324	0.1768	0.5182	-0.3003	-1.7754	1.7255
24	0.5240	0.5506	0.6213	0.0429	0.3325	1.2271
25	0.4866	0.3924	0.7131	-0.1320	-0.2381	0.7139
26	1.1626	0.4022	1.4184	-0.5377	-0.6310	0.5971
27	0.7703	0.6368	1.0358	-0.1288	-0.4119	0.9058
28	0.3003	0.2785	0.5262	-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	0.7262
31	1.2673	1.2720	0.2231	0.0208	-0.0186	0.4930
32	-0.3459	-0.0694	1.0930	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	0.8379
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	0.9607	-0.1746	-0.6006	1.0786
36	0.3010	0.3148	0.2281	0.0604	-0.0111	0.4878
33	0.9996	-0.2428	1.7372	-0.7070	-0.6174	0.0879
33	-0.4511	-0.7605	1.1433	-0.2706	-0.1406	0.2142
35	-0.0917	-0.2182	0.6890	-0.1161	-0.1266	0.6257
34	1.9518	1.9219	0.4596	-0.0650	-3.5582	4.0399
67	1.1203	0.8667	0.8536	-0.4003	-1.9621	2.1627
66	1.6543	1.1339	0.9766	-0.4414	-0.7559	1.0406
61	0.4848	0.4712	0.2836	-0.0476	-0.1930	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	1.5812
64	1.0846	0.9925	0.4885	-0.1883	-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	0.3904	0.0891	0.0693	0.5896
14A	1.2144	1.1421	0.4810	-0.1505	-0.3442	0.6772
12	-0.2293	0.1323	0.9732	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	-0.3483	-0.8470	0.6528
50	0.0609	-0.5435	1.4560	-0.4205	-0.3666	0.1519
49	-0.6921	-0.8935	1.1065	-0.1820	-0.0128	0.1693
48	0.0693	-0.0154	0.5138	-0.1603	-0.2668	0.7396
47	0.2540	-0.2187	1.7374	-0.2721	-0.1354	0.1620
58	1.8846	1.8607	0.4193	-0.0572	-0.4555	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	0.0042	-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	0.9350	-0.0278	-0.1345	0.8730
21	1.1344	1.1181	0.4292	-0.0379	-0.2437	0.7674

Table 3.—*Wentworth groupings for the Tutuila Island beach samples. "tr" indicates trace of class present on sieves; -, no material present. Listing starts at Leone and goes clockwise around island*

Sample	> 2 mm	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	-	-
32	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
33	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	10.1	2.0	0.2	0.4
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	-	-
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	32.5	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	17.1	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	-	-
48	4.7	39.6	52.8	2.7	0.1	-	-
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 4.—*Composition of beach and offshore sand. Listing of beach samples starts at Leone and goes clockwise around island. Samples in column two of the offshore samples come from Fagaitua Bay (enlargement A), and those in column one from Leone Bay (10) and Nua-seetaga Bay (enlargement B). The symbol "tr" indicates trace noted in sample*

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	tr
29	95	5	14A	100	tr	tr
30	70	30	12	100	tr	-
31	20	80	78	54	99	1
32	3	97	92	53	98	2
41	93	7	8	100	tr	tr
40	95	5	52	100	tr	-
39	80	20	51	99	tr	tr
38	99	tr	50	99	1	-
37	95	5	49	98	2	-
36	100	tr	48	99	1	-
33	90	10	47	95	5	-
33	30	70	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



Enlargement B.—Map derived from side scan sonar images of Nua-seetaga Bay. Numbers locate offshore sand samples described in text and adjacent tables. Shading locates areas that showed as rippled on sonograms. Ticked lines mark reef-sediment contact (reef is on tick side); dashed where contact is inferred. Onshore contours and reef-margin location taken from U.S. Geological Survey Topographic Map for Tutuila Island (1963, 1:24,000).

INTRODUCTION

In April 1985, sand samples were collected from many of the beaches on Tutuila Island, American Samoa, and in July 1985, three boys were surveyed using side-scan sonar and shallow seismic-profiling. During that second trip, scuba divers collected sand samples from the surveyed areas. Dingler and others (1986) describes the study; this report presents the grain-size and composition data for the onshore and offshore sand samples. Locations of the onshore samples are plotted on the map of the island, which is reproduced from Normark and others (1985); locations of most of the offshore samples and side-scan sonar interpretations made during the study are plotted on enlargements (A and B, respectively) of Fagaitua and Nua-seetaga Bays. Lam Yuen (1981), U.S. Army Corps of Engineers (1980), and Sea Engineering Services Inc. (1980) provide additional information pertaining to the island's beaches.

TEXTURE AND COMPOSITION OF BEACH SAND

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. In this report, sand is classified by its median or mean grain size based on a scheme (table 1) presented by Wentworth (1922).

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

Phi size (ϕ)	Grain size (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

The equation

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

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. The latter is the degree to which a sediment has evolved from its source material and 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 sand of Tutuila Island contains siliciclastic and calcareous grains in various proportions. The volcanic rocks comprising the island supply the siliciclastic grains, and the patch reef in the central part of the bay supplies the carbonate grains. Because the fringing reef blocks the onshore migration of offshore sand, the siliciclastic fraction of a beach sand is principally terrigenous in nature (that is, it comes from subaerial sources rather than from the erosion of submarine outcrops). Because waves and currents eventually move the beach sand offshore, the composition of a beach sand should provide a clue to the composition of the adjacent offshore sand deposits; however, offshore sand sources will not be reflected in the beach samples. Furthermore, the samples, strictly speaking, only represent the beach sand at the time they were taken; changes in wave conditions and variations in sediment supply can alter the composition of the sand over time. On Tutuila Island, temporal variability should be minimal because the beaches are small and the source areas close by.

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 middle level, is a function of both the astronomical tide and any local water-surface variations. Plotting measured beach slope at the reference point versus median grain size of sand collected at the reference point produces a relation (fig. 1), where not only is beach slope directly proportional to grain size (beaches get 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 the samples from the middle part of the beach, assuming that area would include the reference point; we made no attempt to determine the actual reference point.

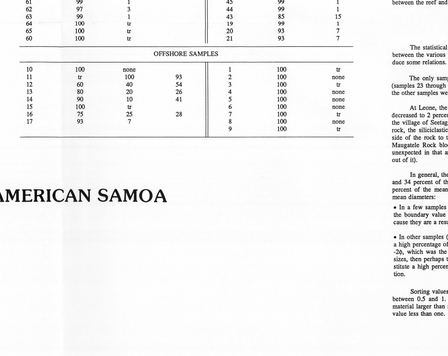


Figure 1.— Relation between beach slope and the median grain size at the reference point [from Wiegel, 1964, p. 359], showing average slope of different beach environments.

OFFSHORE SAND

Coastal waters around Tutuila Island are generally clear; however, it still would be very time consuming for scuba divers to conduct a detailed, systematic inspection and sampling program that encompasses the sandy, nearshore zone of the entire island. Much of that area, however, can be surveyed quickly with a side-scan sonar. Then, patterns shown on the sonographs could be ground truthed by divers. For example, shallow-water waves produce ripples on sandy bottoms. As the grain size increases, the ripple wavelength, or spacing, increases (Dingler and Inman, 1977). When the ripples are large enough, their image will appear on sonographs, indicating a sandy area and giving a gross indication of grain size.

Though the 500-kHz side-scan sonar used in the study can theoretically resolve spacings of about 10 cm (Klein and Associates, oral comm., 1985), our experience in other areas is that ship motion, waves, and deviations from the ideal tow-fish-to-bottom height make 30 cm to 1 m a more practical minimum resolvable wavelength. The grain sizes that correspond to those ripple wavelengths can be estimated from the relation

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

(Miller and Komar, 1980) where λ is the maximum ripple wavelength in centimeters for a given grain size D in microns (10^{-6} mm). Thus, a grain size of 0.250 mm, which is the lower limit of the medium-sand class, produces a ripple spacing of 30 cm, and a grain size of 0.313 mm, which is just above the lower limit of the coarse-sand class, produces a 1-m spacing.

When ripple images appear on a sonograph, their spacing can be measured, and grain size estimated. A ripplefree 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.

RESULTS

The sand samples were sieved, and graphical parameters calculated. Composition was determined by microscopic examination and, for samples high in siliciclastic material, by using hydrochloric acid to dissolve the calcareous material.

BEACH SAND

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 Matatula), and the rest came from the north side of the island (see map sheet for sample locations). Because of its inaccessibility and ruggedness, 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. The coast between Nuuuli and Atuu was not sampled because of its paucity of beaches. Following the example of Inman (1952), median and mean grain sizes, sorting, skewness, and kurtosi were calculated. Grain-size data were plotted in the standard manner to get the relations between the statistical parameters and grain-size values (fig. 2). Statistical parameters calculated from the samples and class percentages for the sands are given in tables 2 and 3.

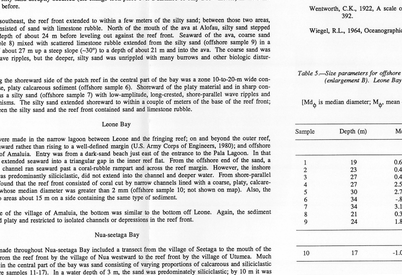


Figure 2.— Cumulative and frequency curves for beach sample 30 (Seetaga).

The graphical analysis procedure compares a sample with a normal ("bell-shaped") distribution where 68 percent of the grains fall between plus and minus one standard deviation of the mean and 95 percent fall between plus and minus two standard deviations. The median and mean diameters measure the central tendency of a grain-size distribution. The median diameter Md_ϕ (eqn. 2) is that grain diameter that divides a frequency curve into two equal areas; therefore, it equals the 50th percentile diameter on a frequency distribution.

$$Md_\phi = \phi_{50} \qquad (2)$$

The mean diameter M_ϕ (eqn. 3) is that diameter that represents the center of gravity of a frequency distribution.

$$M_\phi = \frac{\phi_{16} + \phi_{84}}{2} \qquad (3)$$

In a symmetrical distribution, the median and mean diameters are equal, but in an asymmetrical distribution they differ, except possibly in some unusual situations. The mean and median diameters can be converted to millimeters by equation 1.

The degree of sorting of a sample σ_ϕ (eqn. 4) is the standard deviation in the phi (ϕ) notation.

$$\sigma_\phi = \frac{\phi_{84} - \phi_{16}}{2} \qquad (4)$$

The larger that σ_ϕ is, the more poorly sorted the sample is. A sorting parameter value of 1.0 means that the distribution between the 16th and 84th percentiles spans two Wentworth classes.

The degree of asymmetry in the cumulative distribution is represented by the first and second skewness parameters, α_ϕ (eqn. 5) and $\alpha_{2\phi}$ (eqn. 6) respectively.

$$\alpha_\phi = \frac{M_\phi - Md_\phi}{\sigma_\phi} \qquad (5)$$

$$\alpha_{2\phi} = \frac{\phi_5 + \phi_{95}}{2} - Md_\phi \qquad (6)$$

Both parameters are zero for symmetrical distributions, greater than zero if the distribution is skewed toward finer diameters, and less than zero if it is skewed toward coarser diameters. The first skewness parameter emphasizes the grain sizes in the bulk of the distribution, and the second parameter is sensitive to skewness in the tails of the distribution. Normally, the ratio of the second skewness parameter to the first is about 2.7.

Kurtosis is a measure of the peakedness of a distribution, and the kurtosis parameter β_ϕ (eqn. 7) measures the spread between percentiles on both ends of a cumulative distribution.

$$\beta_\phi = \frac{\phi_{95} - \phi_5}{\sigma_\phi} - \sigma_\phi \qquad (7)$$

A value of the kurtosis parameter equal to 0.65 is normal; a value less than 0.65 means that the distribution has tails shorter than normal, and one greater than 0.65 means that the tails are longer than normal.

For each sample, the fraction of siliciclastic grains was 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. The results of both the visual inspection and the percentages determined with acid are given in table 4.

OFFSHORE SAND

Scuba dives were made in Fagaitua Bay, Leone Bay, and Nua-seetaga Bay to collect sand samples and probe for solidified, subsurface strata. The sand samples were analyzed in the same way as the beach sands; gross compositions are shown in table 4, and the statistical parameters of the samples in tables 5 and 6.

Fagaitua Bay

Several dives were made in the central part of Fagaitua Bay. On the first dive, the divers started in the lagoon adjacent to the village of Fagaitua, swam out theava (channel), and ended seaward of the reef front. Later, divers covered the bottom adjacent to the reef front between the ava at Fagaitua and Alofau and between the reef front and the patch reef in the central part of the bay. The principal sediment found in the ava at Fagaitua was coarse, calcareous sand with limestone rubble. Occasionally, small patches of clean sand adjoined the walls and coral mounds in the ava. The ava ended at the base of the reef front at a water depth of about 14 m. Beyond the ava, the bottom, which sloped gently seaward, was the same mix of coarse sand and limestone rubble. Offshore sample 1 came from this area. At a depth of about 27 m, the bottom leveled and the sediment was a fine, calcareous silty sand that extended seaward.

Eastward along the reef front the surface rubble disappeared, leaving coarse sand (offshore sample 2). The zone of coarse sand extended at least as far as an indentation in the reef at Pagai. Waves had shaped the sand into long-crested ripples large enough to appear on the sonographs. Probing into the sand revealed an obstruction about 0.5 m beneath the surface; digging exposed small, flat pieces of limestone rubble. Offshore, the transition from coarse sand to silty sand abruptly occurred (the change took place over a distance of only a few meters) in the same water depth as before.

To the southeast, the reef front extended to within a few meters of the silty sand; between those two areas, the bottom consisted of sand with limestone rubble. North of the mouth of the ava at Alofau, silty sand stopped upward to a depth of about 24 m before leveling out against the reef front. Seaward of the ava, coarse sand (offshore sample 8) mixed 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 zone 10-to-20-m wide containing a coarse, platy calcareous sediment (offshore sample 6). Shoreward of the platy material and in sharp contact with it was a silty sand (offshore sample 7) with low-amplitude, long-crested, shore-parallel wave ripples and tracks of organisms. 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 Amalsia. Entry was from a dark-sand beach just east of the entrance to the Pala Lagoon. In that area, 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 considerable impact and across the reef margin. However, the inshore sand, which was predominantly siliciclastic, did not extend into the channel and deeper water. From shore-parallel traverses, we found that the reef front consisted of coral sand in narrow channels lined with a coarse, platy, calcareous sediment whose median diameter was greater than 2 mm (offshore sample 10; not shown on map). Also, the divers saw two areas about 15 m on a side containing the same type of sediment.

Offshore of the village of Amalsia, 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-seetaga Bay

Dives made throughout Nua-seetaga Bay included a transect from the village of Seetaga to the mouth of the bay and one from the reef front by the village of Nua seaward to the reef front by the village of Utumea. Much of the bottom in the central part of the bay was sand consisting of varying proportions of calcareous and siliciclastic grains (offshore samples 11-17). In a water depth of 3 m, the sand was predominately siliciclastic; by 10 m it was around 20 percent siliciclastic, and at the reef front it was predominately carbonate. Everywhere the sand was shaped into long-crested wave ripples. Seaward, the sand decreased in grain size from coarse sand containing scattered limestone rubble in the ava, to medium sand at a water depth of 16 m, to fine sand at 15 m; both the ripples and the grain-size trend suggest a nearshore, wave-dominated environment. As at the patch reef in Fagaitua Bay, there frequently was a narrow zone (a meter or two wide) of coarse, platy calcareous sediment between the reef and the sand.

DISCUSSION

Beach sand

The statistical grain-size parameters (table 2) show no systematic pattern. No readily discernible correlation between the various parameters can be seen, though a statistical analysis procedure, like factor analysis, might produce some relations. Some general patterns do appear, however, and those are discussed here.

The only samples with a high siliciclastic content came from beaches between Leone and Maugatele Rock (samples 23 through 31 and 43) and four pocket beaches just north of Cape Taputapu (samples 32 through 35). All the other samples were preponderantly calcareous.

At Leone, the sand contained greater than 90 percent siliciclastics; to the west, the siliciclastic concentration decreased to 2 percent just east of Mu Point and 5 percent at the village of Nua, but then increased to 30 percent at the village of Seetaga and to greater than 90 percent on the east side of Maugatele Rock. On the west side of the rock, the siliciclastic concentration decreased to 7 percent. 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-seetaga Bay (westward drift would unexpected 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 percent of the median and 34 percent of the mean grain diameters fell in the very coarse class, while 57 percent of the medians and 48 percent of the means were coarse. Two factors contribute to the difference in percentages between medians and mean diameters:

- In a few samples (for example, nos. 12, 43, 48, 56, 64, and 67), one parameter has a value slightly lower than the boundary value for a size class and the other has a value slightly higher. Such differences are artificial, because they are a result of the arbitrary nature of the grain-size classification.
- In other samples (for example, 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 "j"- 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 meaningful with respect to the sand-size distribution.

Sorting values ranged from 0.17 to 1.83 with 30 percent being less than or equal to 0.5 and 36 percent being between 0.5 and 1. All of the samples with sorting values greater than 1.1 had greater than 8 percent 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 percent of the α_ϕ values and 71 percent of the $\alpha_{2\phi}$ values were negatively skewed, while only 5 percent and 9 percent 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 sandy beach would tend to produce negative skewness.

Using a range of 0.55 to 0.75 as normal, 48 percent of the samples had longer tails than normal, and 25 percent 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.

OFFSHORE SAND

Central Fagaitua Bay

The lack of siliciclastics in the beach sands suggested that the offshore sand would be predominately calcareous; the offshore samples confirmed this. In the surveyed areas along the center and east side of Fagaitua Bay, the unconsolidated, calcareous sediments that we found fell into four groups: