THE MARINE GEOLOGY AND SEDIMENTOLOGY OF HAWAII KAI, KUAPA POND, AND ADJACENT MAUNALUA BAY

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ABSTRACT

The marine geology and sedimentology of the Hawaii Kai area were studied. Physical oceanographic characteristics studied included salinity/temperature values and turbidity. During fair weather, temperature and salinity values in the marina are stable and do not vary much, reflecting good interchange with ocean water and good vertical mixing. Salinity is reduced in the marina during rainstorms, especially where streams enter, but revert to near-normal concentrations within a day following rainstorm activity. Water is generally less turbid in the marina now than it was in the 1960s. However, the water still remains turbid and will remain so due to the suspended fine, clay-sized terrigenous and carbonate sediments, planktonic organisms, and terrigenous materials brought in as runoff during storms.

Eighty-seven samples from the marina and bay were sampled and analyzed for grain size parameters and composition. The graphic mean categorizes the sediments into size groups and indicates their distribution. The inclusive graphic standard deviation points out the areas of poorly sorted and well sorted sediments. Inclusive graphic skewness values reveal a basic difference between sands from Paiko Peninsula and those from Portlock. The varying factor is the input of smaller grains of Koko Head tuff diluting the carbonate sands along Portlock which is located adjacent to Koko Head. Graphic kurtosis values show that, generally, muds are platykurtic, sediments on the reef flat leptokurtic, and sediments exposed to high energy mesokurtic. Percentages of carbonate, terrigenous, and organic material were found for the samples. Carbonate values are highest in the open ocean and decrease shoreward. Terrigenous values are highest toward the upper portions of the marina and decrease seaward. Organic percentages are not accurate due to the small amounts present.

X-ray analyses were conducted for the clay fractions of fifty-six terrestrial and forty-four marina and bay samples. Twenty-three terrestrial and sixteen marina and bay samples were X-rayed for bulk mineral content. Clay minerals in the terrestrial samples consist of kaolinite and montmorillonite with minor amounts of plagioclase. Bulk analysis reveals magnetite, hematite, and quartz. The marina and bay samples contain calcite, kaolinite, and montmorillonite in the clay fractions. The bulk fractions contain magnesium-rich and magnesium-poor calcite, aragonite, plagioclase, magnetite, kaolinite, and montmorillonite.

INTRODUCTION

OBJECTIVE OF STUDY

The objective of this thesis was to provide a study of the marine geology and sedimentology of the Hawaii Kai-Kuapa Pond area and adjacent Maunalua Bay, with emphasis on clay mineralogy and the nature and distribution of sediments. Early in Hawaii Kai's development history, in 1961, a study was conducted for the Hawaii Kai Development Company by Marine Advisers, Incorporated of La Jolla, California. The oceanographic aspects and water characteristics of the Hawaii Kai Marina and adjacent Maunalua Bay were studied for a brief period of time. Aspects investigated included surface and bottom currents, turbidity, bottom characteristics, and water density. The present study includes some of the aspects of the earlier study and attempts to detect any significant alterations that may have occurred within the past fourteen years.

GEOGRAPHIC SETTING

The study area, located in southeast Oahu (Figure 1), extends from the western slopes of Koko Head and Koko Crater across several ridges and valleys of the eastern Koolau Range, and terminates at Kuliouou Valley and Paiko Peninsula. Included within this area are Hawaii Kai, the Hawaii Kai Marina, which was formerly Kuapa Pond, and the adjacent eastern end of Maunalua Bay. Rainfall in this area averages

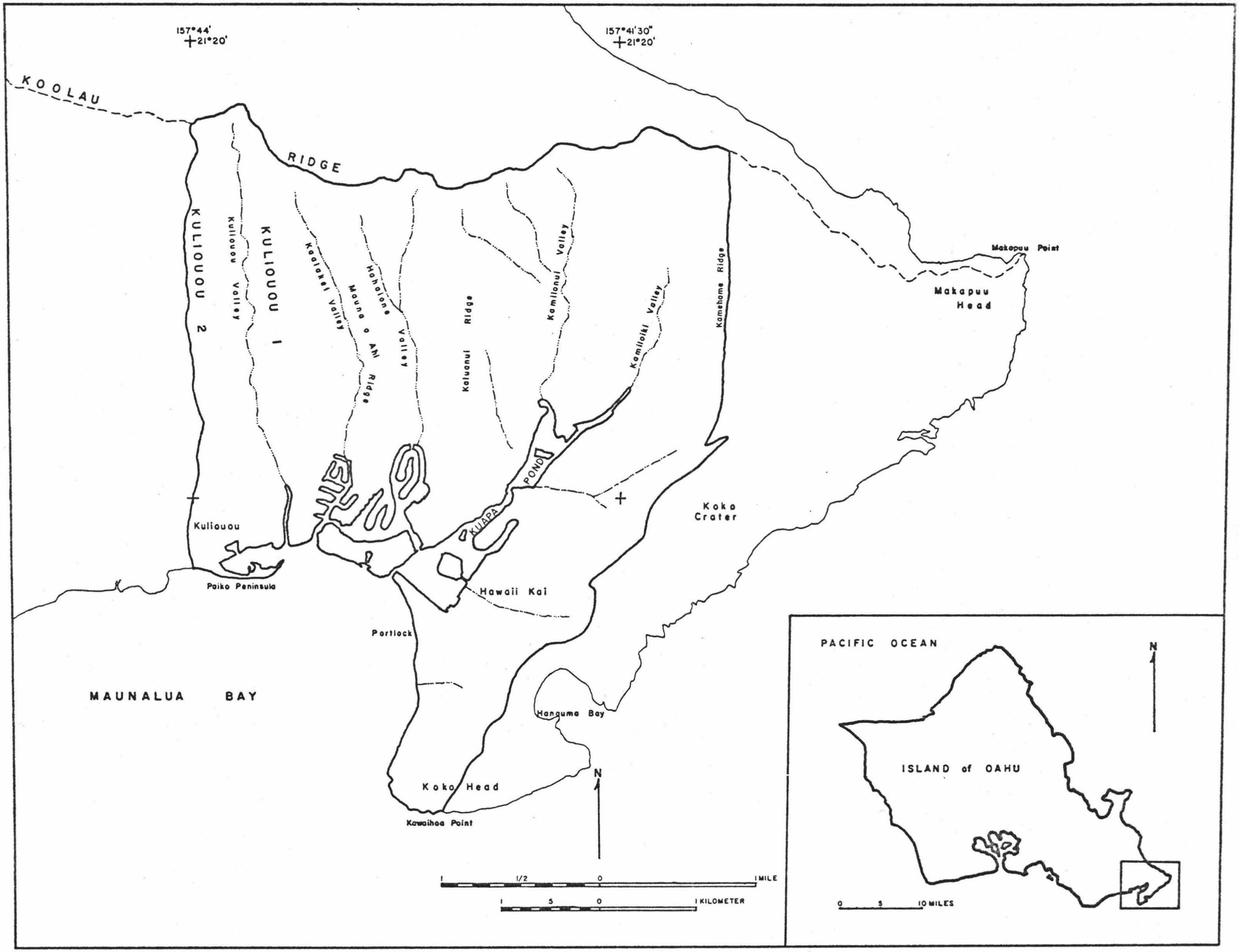

Figure 1. Map of study area.

approximately thirty inches per year.

GEOLOGIC HISTORY

The geologic history of the area reaches back 2.2 to 2.6 million years (for more information concerning ages of Hawaiian volcanic rocks as determined by the potassium-argon method see Table 17, Macdonald and Abbott (1970)), with the emergence and building of the Koolau volcano next to its already established neighbor the Waianae volcano. Following a lengthy period of dormancy and concurrent erosion, the outline of the area resembled Figure 2. From 0.1 to 0.9 million years ago volcanic activity was renewed with the eruptions of the Honolulu Volcanic Series. The outline of the area was altered as Koko Crater and Koko Head emerged along the Koko fissure and formed the prominent landmarks that they are today. Concurrently, as Koko Crater and Koko Head advanced seaward, they formed the eastern end of present day Maunalua Bay and built the area which is now Hawaii Kai.

GEOLOGIC SETTING

The Hawaii Kai area exhibits various stages in the geomorphic cycle. Koko Crater and Koko Head, very young features by the geologic clock, are in the youthful to submature stage of the erosion cycle. Though young geologically, they are relatively easily eroded and are notched with miniature v-shaped valleys. Flat areas between these valleys, planezes, are not very broad as in the characteristic youthful stage

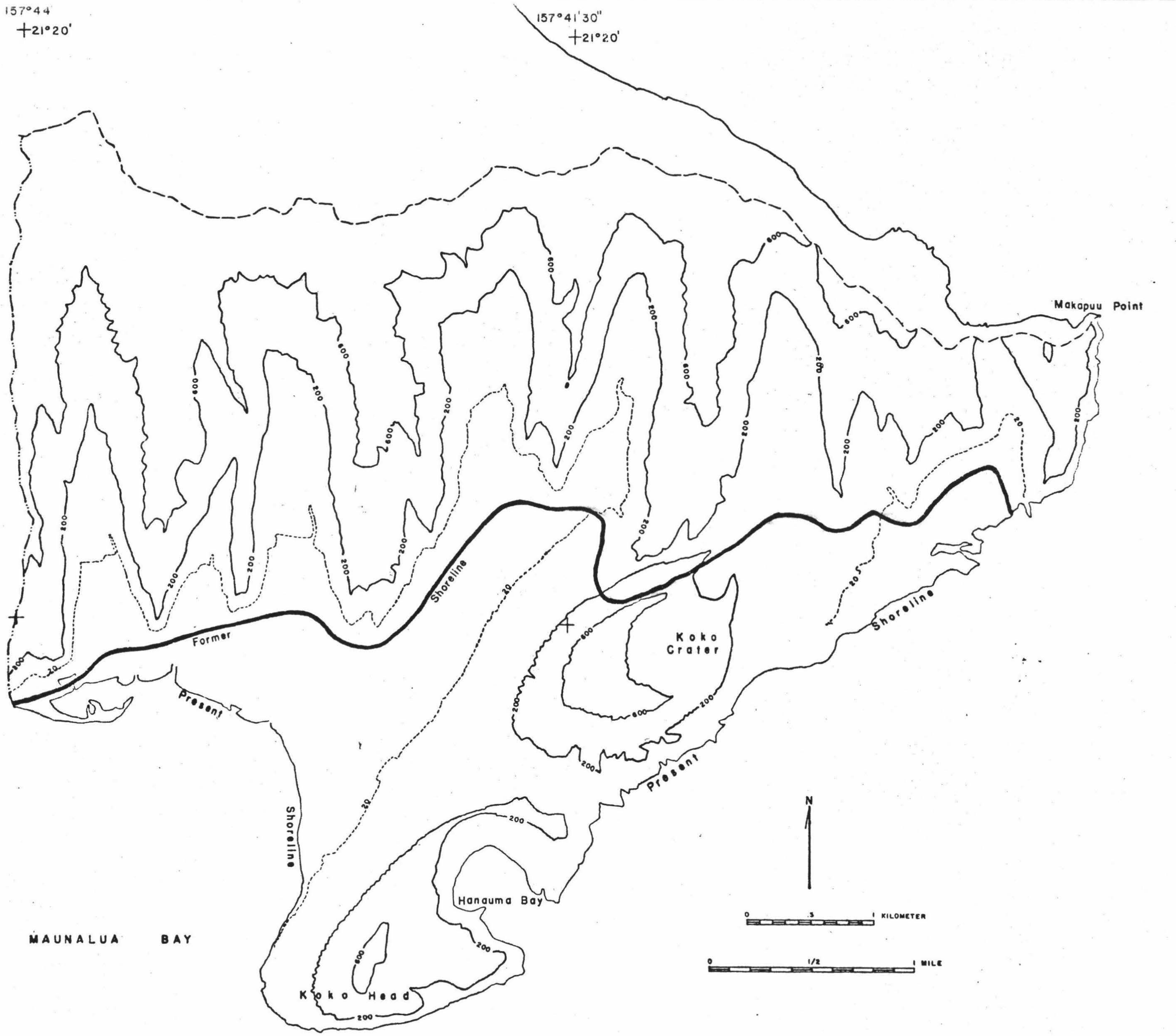

Figure 2. Map of study area prior to Koko fissure volcanics.

but they essentially mark the original slopes of the features. The Koolau ridges and valleys in the area are in the submature stage of the geomorphic cycle. Hahaione and Kamilonui valleys are seemingly mature with broad v-shaped valleys and flat floors, but are surrounded and separated by features which are submature. The flat floors are, in this instance, caused not by erosion of the valley bottoms but by alluvial and marine sediments that covered the valley floors during higher stands of the sea. Kaluanui Ridge, an eroded planeze in the submature stage, is situated between Hahaione and Kamilonui valleys. Also in the submature stage are Kaalakei Valley, Kuliouou Valley, and a small unnamed valley on the southeast slope of Kaluanui Ridge.

Streams in the area flow south, perpendicular to the east-west direction of the Koolau ridgeline. Presently, due to the low precipitation, approximately thirty inches per year, all streams in the area are intermittent, flowing only during infrequent periods of heavy downpours. In the past, however, when rainfall was higher, the streams were dynamic forces constantly shaping and reshaping the land. Though still present today, these forces are working at a less rapid rate. Evidences of past stream activity can be seen everywhere in the valleys and on the ridges in the area. There are good examples of dendritic streams in the valleys and there is one good example of stream piracy. On the unnamed ridge between Kamilonui and Kamiloiki valleys a captured stream valley enters Kamilonui Valley almost perpendicularly indicating that Kamilonui Stream had captured the adjacent smaller stream when the streams were more active.

There seems to be a discrepency in the erosional stages of some of the valleys in the area. Rainfall generally intensifies from east to west which should result in a similar increase in the maturity of the valleys from east to west. That is not the case. Going from east to west, Kamiloiki and especially Kamilonui and Hahaione valleys are broad, flat-floored valleys indicating a greater degree of maturity. In Kaalakei and Kuliouou valleys, further west, the valleys are narrower and more v-shaped indicative of less rainfall and submaturity. An explanation of this apparent discrepency is afforded by Macdonald and Abbott (1970) who believe that the Koolau crest was formerly about 6,000 feet above sea level and that reconstructing the former shield surface and probable belts of rainfall intensity would place the region of heaviest rainfall, and consequently deepest erosion, between Kaaawa and Waimanalo. Under such conditions, located at the flank of the region of heaviest rainfall, Kamiloiki, Kamilonui, and Hahaione valleys would have received more substantial amounts of rainfall than at present, while the valleys further west would have been shielded by the crest of the yet uneroded volcano, thereby receiving less rainfall.

Kuapa Pond is situated in the center of the study area and empties into Maunalua Bay. The formation of Kuapa Pond followed the emergence of the Koko Head and Koko Crater volcanics. Prior to these volcanics, the coastline was relatively straight (Figure 2). As the volcanics formed they added to the coastline forming the eastern end of what is now Maunalua Bay. The present pond was then probably an elongated bay opening to the southwest. With passing time the mouth of the bay was closed as a sand bar was built across it. Kuapa Pond, also known as Keahupua-o-Maunalua Fishpond, once covered 523 acres and was the largest "loco kuapa" in the Hawaiian Islands. A loco kuapa was an enclosed shore fishpond, or loco, made by building a wall, or kuapa, on the reef. The old wall was a sand embankment approximately 5,000 feet long faced on the top and seaward with lava and coral stones. McAllister, who conducted an archaeological survey of Oahu in 1930 recorded that the pond was built by Mahoe, the great-grandmother of his informant, Makea Napahi. According to legend, the pond was completed by menehunes who in one night finished the construction when the pond had only been partially built. The water was brackish and a brackish spring was located about 1,400 feet from the beach on the Honolulu end of the wall. Mullet was the principle fish kept in the pond. According to McAllister (1933), natives in the area claimed that the pond was connected by means of an underground tunnel with Kaelepulu Pond in Kailua, for from time to time great schools of mullet disappeared from Kuapa and were found in Kaelepulu and the awa that were in Kaelepulu would appear in Kuapa. When the mullet reappeared in Kuapa the awa disappeared. By 1921 the pond had reduced in size with a water area of 301 acres and 125 acres of swampland. According to the State Department of Agriculture and Conservation, Kuapa Pond was still being used commercially up to 1960.

DEVELOPMENT

The present development of Kuapa Pond and the Hawaii Kai area began in the early 1960s and has continued to the present. Prior to that time the land was used for pig farms, truck farms, and other agricultural uses. In 1961 dredging and filling operations began near the Honolulu end of the pond. The entrance to Marina Unit Number 1 was cleaned out and the present channel dredged to approximately nine feet at mean lower low water. The dredged material was used to extend the existing beach and added approximately 8.5 acres. By 1966, Marina Unit Number 1 was already fully developed and dredging and filling operations began on the remaining acreage of the marina. In 1967 the main bridge at the Koko Head end of the marina was rebuilt and a channel to the sea dredged. The channel served a dual purpose--as a boat access from the marina to the bay and to provide better drainage for the marina waters. Along with the development in and around the marina came the development of the adjoining areas. From the early 1970s rapid progress has been made in the development of Kamiloiki and Hahaione valleys and Kaluanui Ridge.

PHYSICAL OCEANOGRAPHY

GENERAL

Physical oceanographic parameters studied included salinity and temperature patterns, turbidity, and currents. These parameters were studied mainly to determine relationships, if any, to distribution of sediments and differences between the marina and bay environments.

SALINITY AND TEMPERATURE

Salinity and temperature were taken on two separate occasions utilizing a YSI Model 33 S-C-T Meter. Sampling on August 18, 1973, was conducted under normal conditions for Hawaii Kai with trade winds and partly cloudy skies. On November 29, 1973, however, conditions were the opposite. The National Weather Service recorded two inches of rain in the area during that twenty-four hour period. While sampling, it was heavy overcast with a constant light to moderate shower. The wind was slight and from the south. At each sample location measurements were taken at the surface, bottom, and approximate middle depth. The results (Figures 3 through 8) were then compared with measurements taken in another survey by Sunn, Low, Tom and Hara, Incorporated (1974). During periods of fair weather, temperature and salinity values are quite stable and do not vary much, reflecting good interchange with ocean water and good vertical mixing. During rainstorms salinity is reduced in the marina

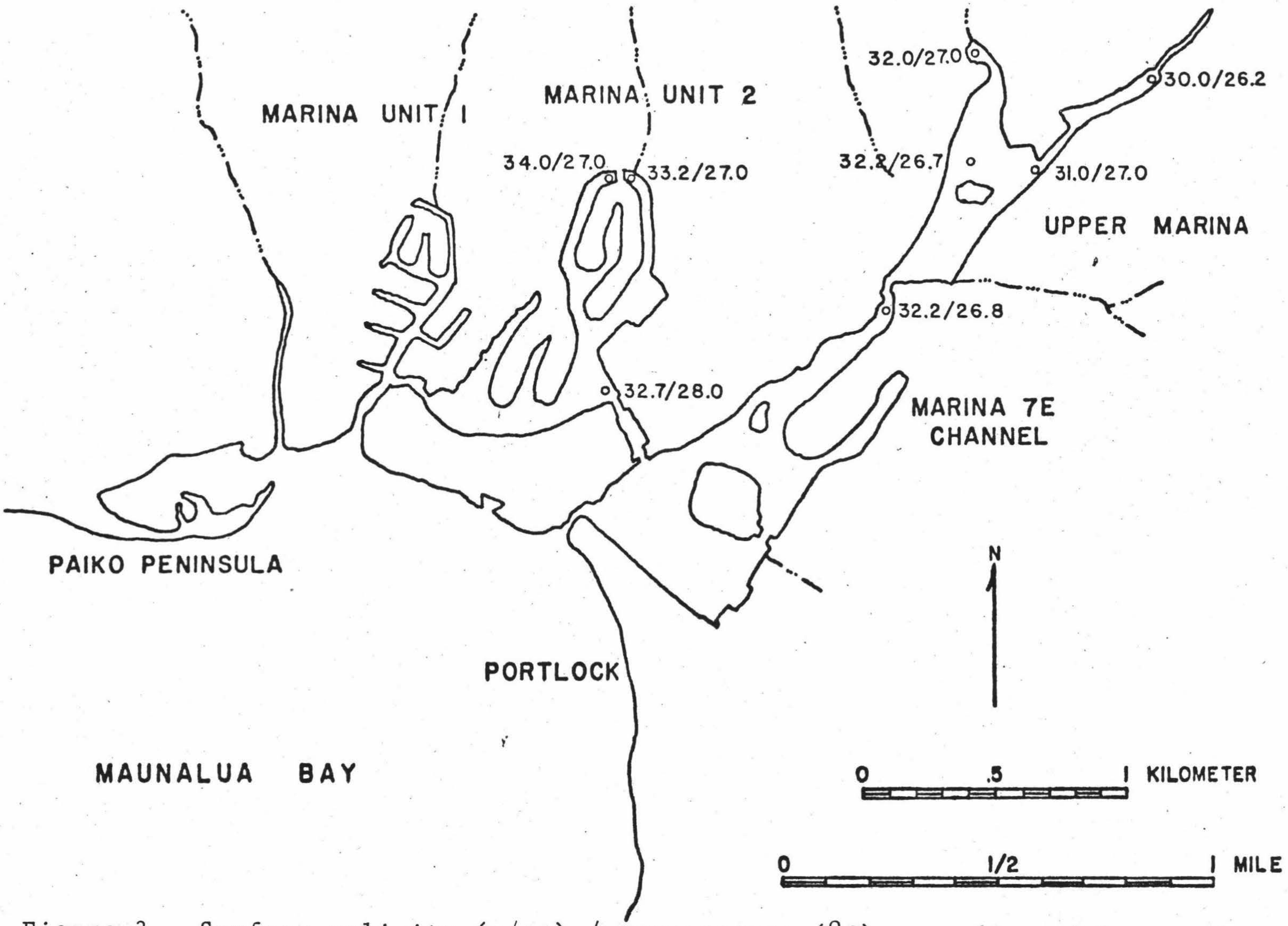

Figure 3. Surface salinity (o/oo) / temperature (^{o}C) recordings taken on August 18, 1973.

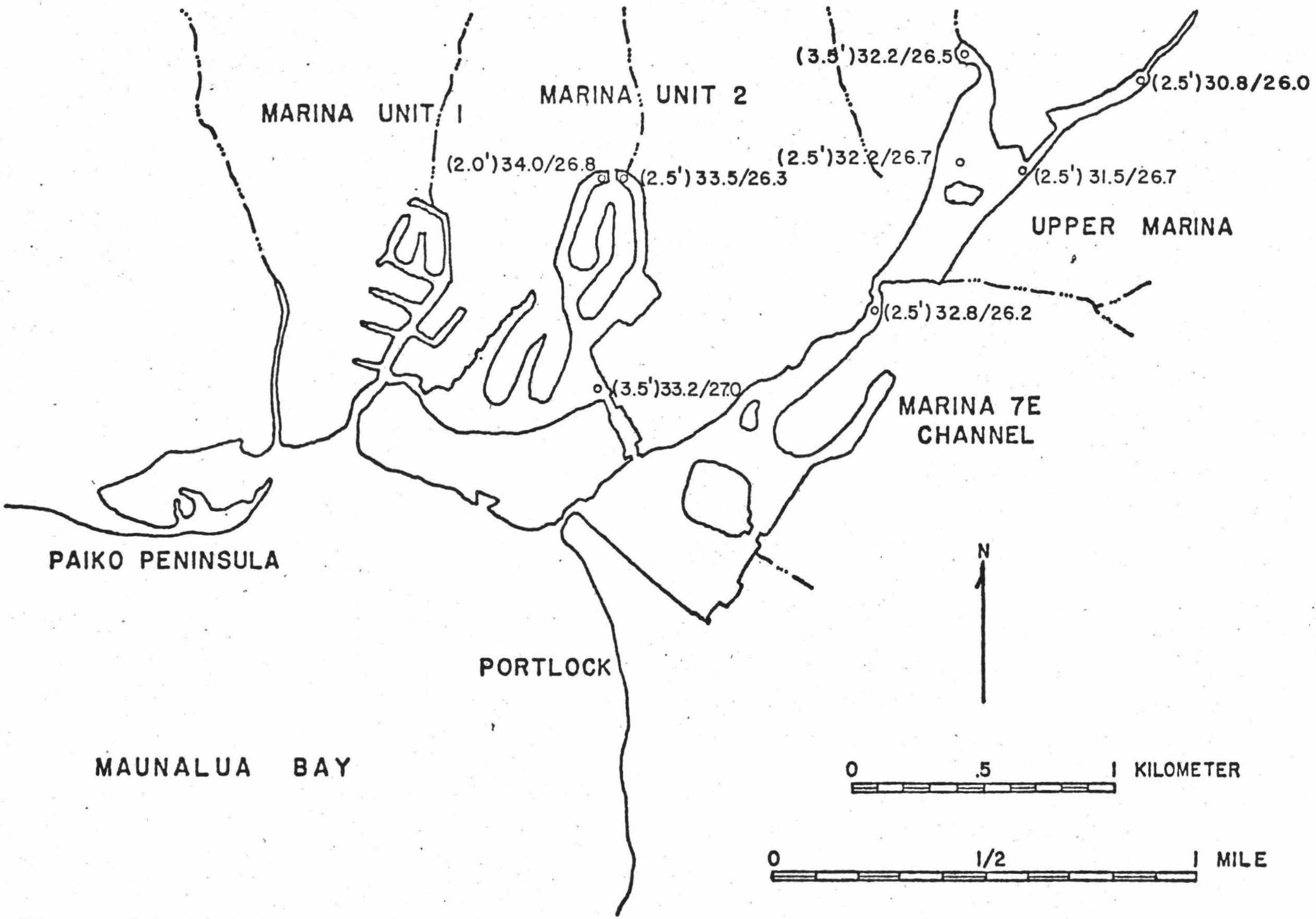

Figure 4. Middle depth salinity (o/oo) / temperature (°C) recordings taken on August 18, 1973.

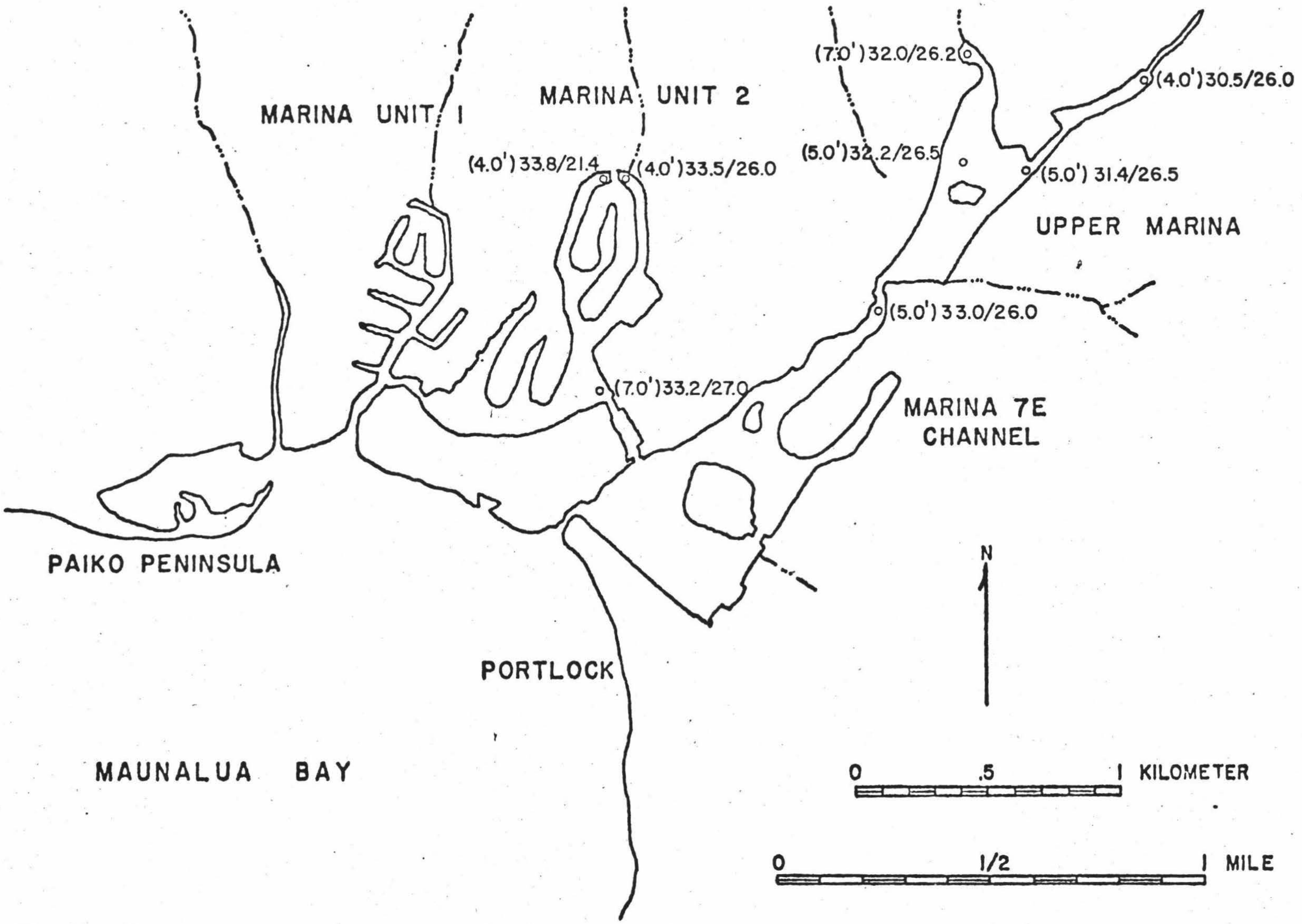

Figure 5. Bottom salinity (o/oo) / temperature (°C) recordings taken on August 18, 1973.

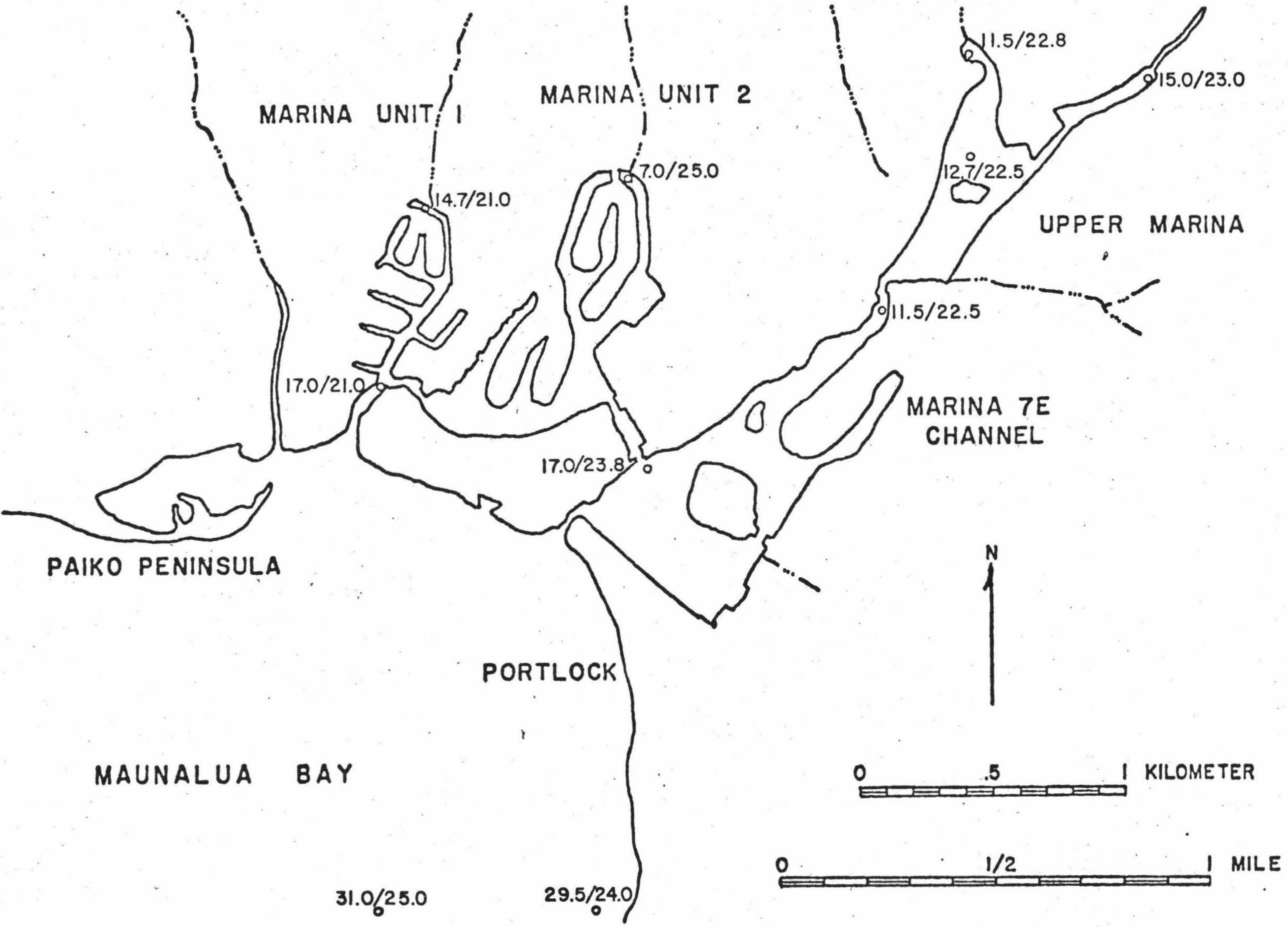

Figure 6. Surface salinity (o/oo) / temperature (°C) recordings taken on November 29, 1973.

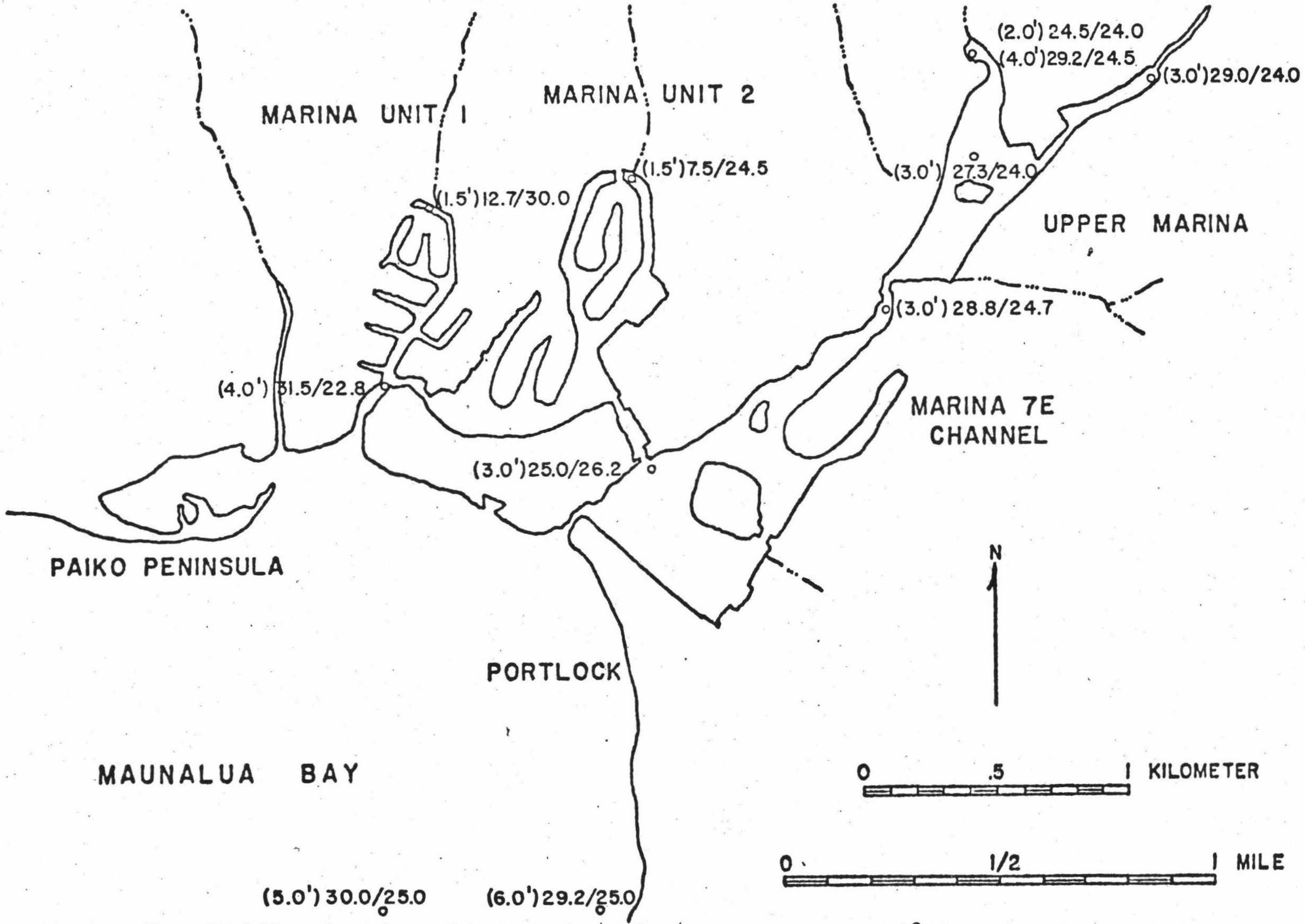

Figure 7. Middle depth salinity (o/oo) / temperature (°C) recordings taken on November 29, 1973.

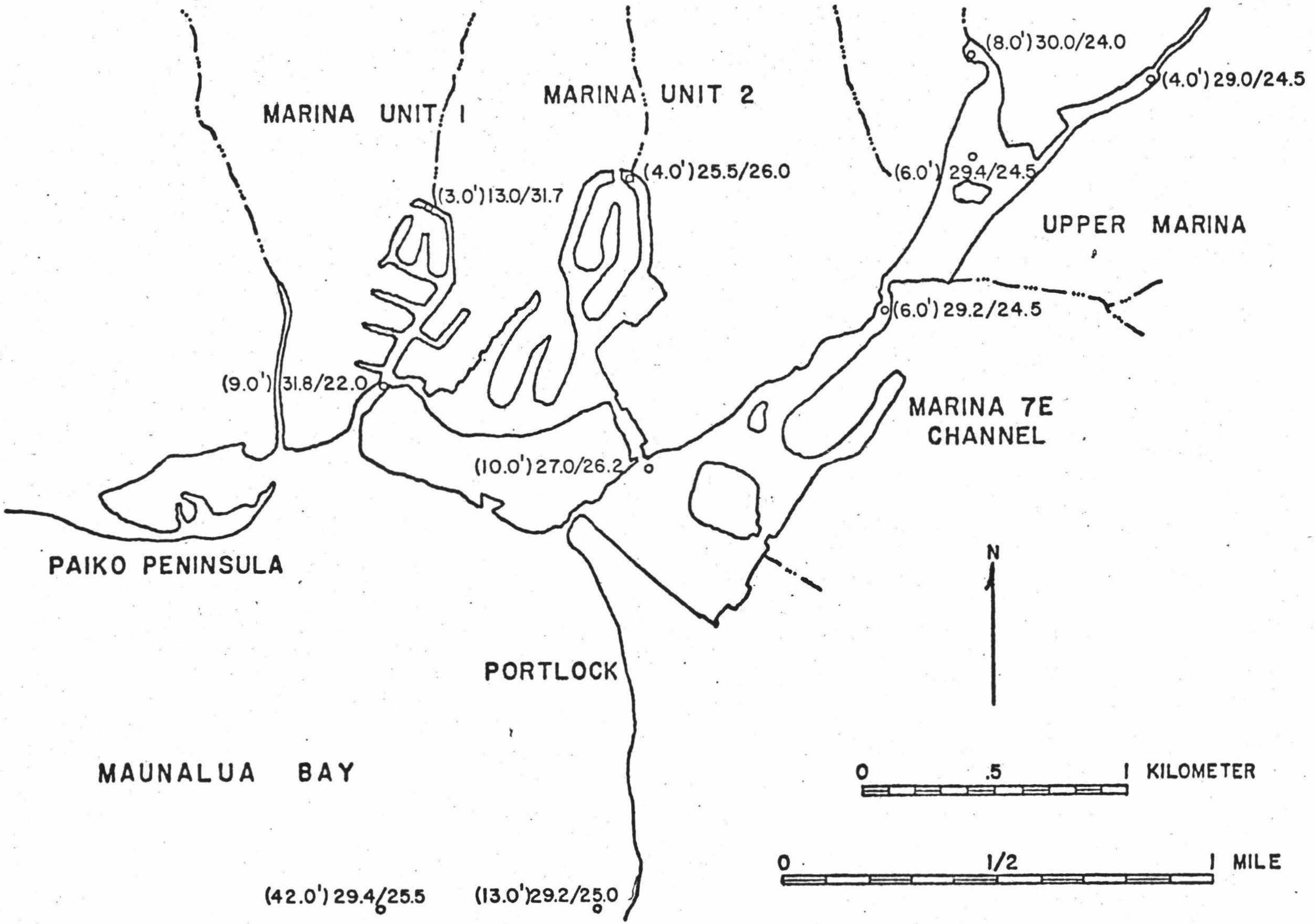

Figure 8. Bottom salinity (o/oo) / temperature (^oC) recordings taken on November 29, 1973.

especially at points where streams enter. Fresh water flowing into the marina may float above the denser marina water, as was observed during the rainstorm on November 29, 1973. It was noted at that time that water from Kaluanui Ridge, reddish-colored from its journey downslope through yet unfinished construction sites, entered the marina just above the upper marina bridge. The water, easily distinguishable from the marina water because of its color, formed a plume-like surface layer visually estimated at approximately six to ten inches deep and was drifting slowly toward the upper marina as it was pushed along by the slight south wind. Distinct layering such as this is short-lived, for wind and currents quickly mix the waters and salinities and temperatures soon return to normal, approximating values found in the open ocean during fair weather. This was shown by observations made by Sunn, Low, Tom and Hara, Incorporated (1974), who took salinity and temperature readings one, three, and five days after a storm on November 11, 1973 (Table 1). Their findings just one day after the storm were significantly closer to normal than the readings taken during the November 29th storm. There is the possibility that the storm on November 11th was less intense and therefore had less input of fresh water, but it is more likely that the one day difference was sufficient for enough mixing to occur to return the salinity and temperature values to near-normal.

TABLE 1.--Salinity/temperature changes following the storm of November 11, 1973 (modified after Sunn, Low, Tom and Hara, Incorporated, May 1974).

STATION		SALINITY (o/oo)			TEMPERATURE (°C)		
See Figure 11		Days after storm			Days after storm		
		1	3	5	1	3	5
M1	Surface	32.48	32.88	32.58	25.53	25.74	24.75
	Mid-depth	32.44	32.86	32.66	25.58	25.53	24.66
	Bottom	32.44	33.00	32.55	25.62	24.65	24.65
M2	Surface	31.00	31.85	31.65	25.70	24.98	24.36
	Mid-depth	---	---	---	---	---	---
	Bottom	31.20	31.76	31.35	25.70	24.98	24.53
M4	Surface	31.00	31.55	31.80	25.08	25.80	24.70
	Mid-depth	31.04	31.36	31.80	25.04	25.86	24.75
	Bottom	31.30	31.40	31.82	25.06	24.90	24.85
M9	Surface	31.21	32.64	32.93	25.20	25.65	25.18
	Mid-depth	31.30	32.70	32.96	25.18	25.30	25.15
	Bottom	32.66	33.00	33.08	25.15	25.10	25.02
M10	Surface	31.85	31.95	32.26	25.95	24.84	25.02
	Mid-depth	---	---	---	---	---	---
	Bottom	31.89	32.20	32.50	26.00	24.90	24.82
M12	Surface	31.00	32.30	32.60	26.00	26.00	26.00
	Mid-depth	31.35	32.34	32.83	26.00	25.95	25.13
	Bottom	31.60	31.42	32.58	26.00	24.80	25.10
M13	Surface	32.70	31.80	32.38	25.45	25.76	25.23
	Mid-depth	---	---	---	---	---	---
	Bottom	32.70	31.80	32.48	25.50	25.45	25.30

TURBIDITY

On April 30, 1961, the water clarity was measured by Marine Advisers, Incorporated (1961) at the weir between the pond and Marina Unit Number 1 and it was found that "the water flowing out of the pond was so turbid that the secchi disk (a white round plate eight inches in diameter) could be seen only six inches below the surface". At that time it was also recorded that the secchi disk could be seen at 1.5 feet in Marina Unit Number 1, all the way to the bottom (twelve to twenty-five feet deep) outside the reef, and only to 1.5 feet in shallow water over muddy bottom near shore. To see what changes, if any, had occurred in the years since then, more secchi disk measurements were taken and the reults shown in Figures 9 and 10. The most significant change can be seen in Figure 10 near the exit of Marina Unit Number 1. Where in 1961 the secchi disk could be seen only six inches below the surface, in 1973 it could be seen at a depth of 3.5 feet. The study by Sunn, Low, Tom and Hara, Incorporated (1974) cited the factors influencing turbidity in the marina as input from storm runoff, suspension of sediments due to wind and tidal mixing, and density of planktonic organisms. To that should be added the effects of boat motors stirring up the bottom, as has been observed many times while sampling in the field and as correctly predicted by the Marine Advisers' report of 1961. In attempting to identify the cause of the turbidity, Sunn, Low, Tom and Hara,

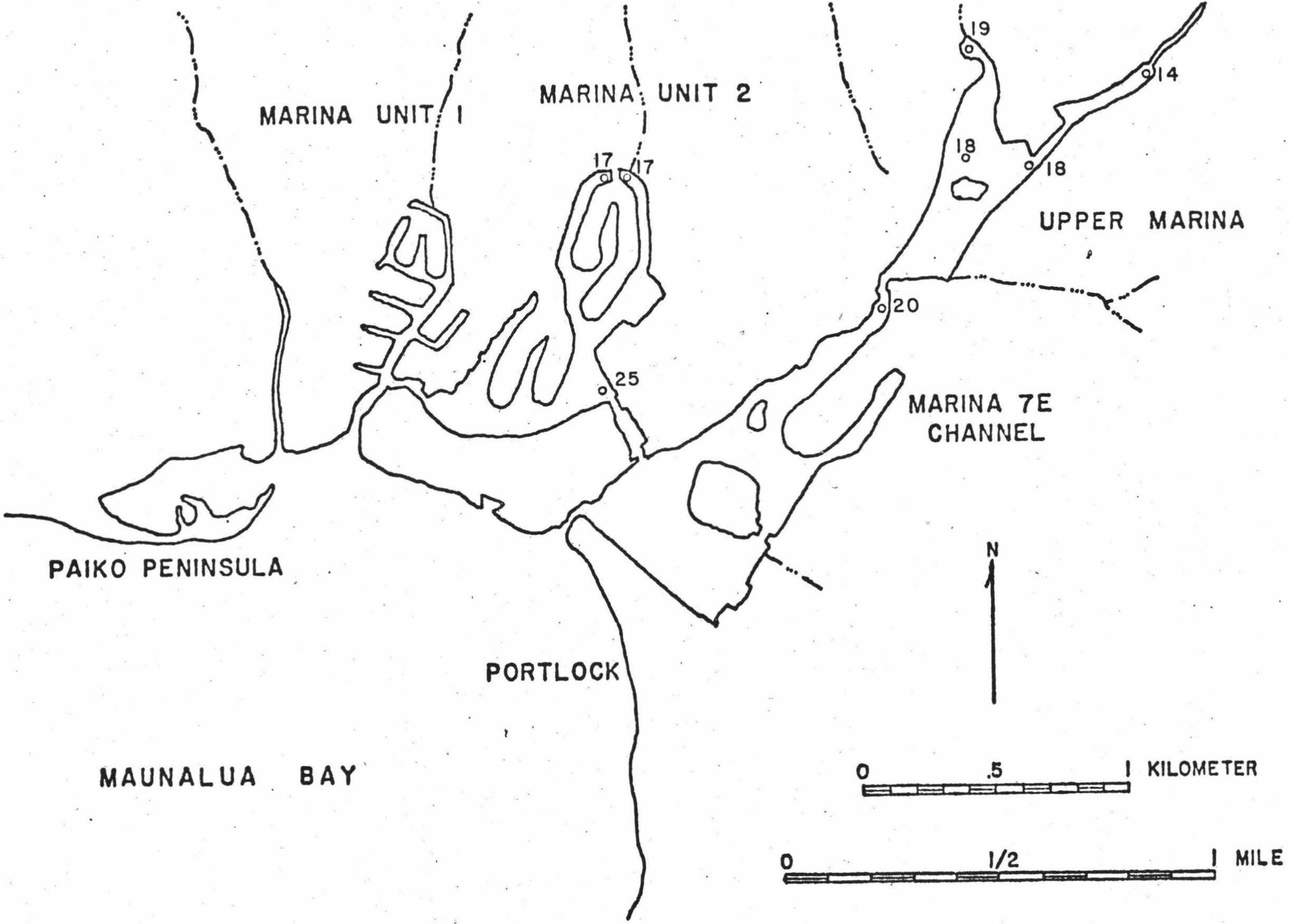

Figure 9. Secchi disk measurements (in inches) taken on August 18, 1973.

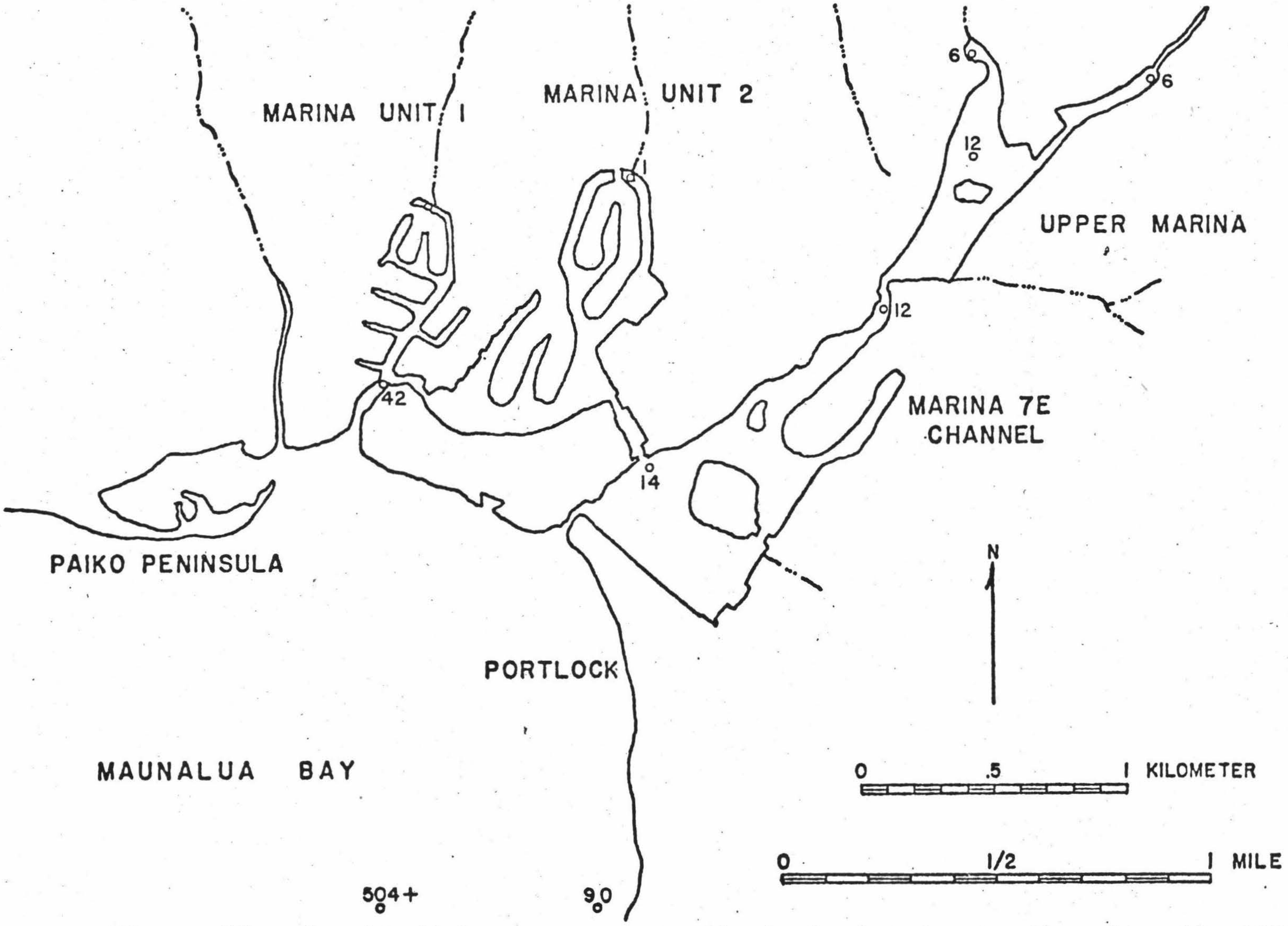

Figure 10. Secchi disk measurements (in inches) taken on November 29, 1973.

Incorporated conducted a microscopic survey on samples taken on February 26, 1974. They found the median turbidity particle size to be in the order of one to two microns. They observed that planktonic organisms made up only a small fraction of the particles, while the majority appeared to be small, single particles roughly spherical in shape. To further identify the particulate matter, two five-gallon water samples were taken on July 27, 1974, one from the vicinity of Station M9 and the other from Station M10. The M9 sample was the typical marina water with a slight greenish tinge while the M10 sample had a slight brownish tint. The samples were left to settle for approximately two weeks then most of the water poured off leaving the residue that was formerly held in suspension. Further settling by centrifuge and decanting left enough residue, approximately 0.2 grams per five gallons of water, to prepare a slide for X-ray analysis utilizing the same methods as those described in the section on clay-mineral analysis. Sample M9 contained 34 percent magnesium-rich calcite, 14 percent magnesium-poor calcite, 43 percent aragonite, and 9 percent kaolinite. Sample M10, the darker of the two, contained 29 percent magnesium-rich calcite, 14 percent magnesium-poor calcite, 33 percent kaolinite, and 24 percent plagioclase. The bulk of the M9 residue, then, consisted of calcareous particles in suspension with a minor amount of the clay mineral kaolinite. M10, closer to a source of terrigenous sediment, contained 57 percent terrigenous material (kaolinite and plagioclase) and only 43 percent calcareous material. Turbidity, then, is caused partly by planktonic organisms, at times by terrigenous material brought in as runoff during storms, and mostly from the suspension of sediments, both terrigenous and calcareous, due to wind, tidal, and boat-propeller mixing.

CURRENTS

Marine Advisers, Incorporated (1961) studied the currents in Unit Number 1 of the Hawaii Kai Marina and Maunalua Bay. It was observed that in the marina the upper few inches of water moved with the wind regardless of tidal direction. Below one to one and a half feet the current coincided with the direction of tidal flow. The currents in the bay were similar, with the surface layer of six inches or so flowing with the wind and the water below that depth flowing inward during rising tide and outward during falling tide. Longshore currents were found to move from Paiko Peninsula toward the marina and from Portlock toward the marina indicating that in the past these same currents formed Paiko Peninsula and the barrier that formed Kuapa Pond.

SEDIMENTS

SAMPLING PROCEDURE

Soil samples were collected from the ridges and valleys in the study area (Figure 11). Established residential areas were not sampled because it could not be determined whether or not soils from those areas were original or brought in from other locations on Oahu. Newly cleared construction sites, however, were sampled whenever possible. Soil sampling consisted of hiking to the heads of the valleys or along the ridges to the Koolau Ridge and simply collecting soil in plastic bags from locations that were easily marked or unusual in appearance such as soils of different colors or in distinct layers. Size analysis was not conducted for the soil samples. They are further discussed in the section on clay mineralogy.

Marina samples (Figure 11), mostly mud, were collected from a small boat utilizing a plastic core liner which was imbedded into the mud, plugged at the upper end with a rubber stopper to create a partial vacuum, and pulled out.

Samples from the bay (Figure 11) were collected in plastic containers at regular intervals while walking the beaches and shallow areas. On the reef flat, snorkeling gear was used from a small boat and in the deeper water outside the reef, scuba equipment was utilized to collect the sediment.

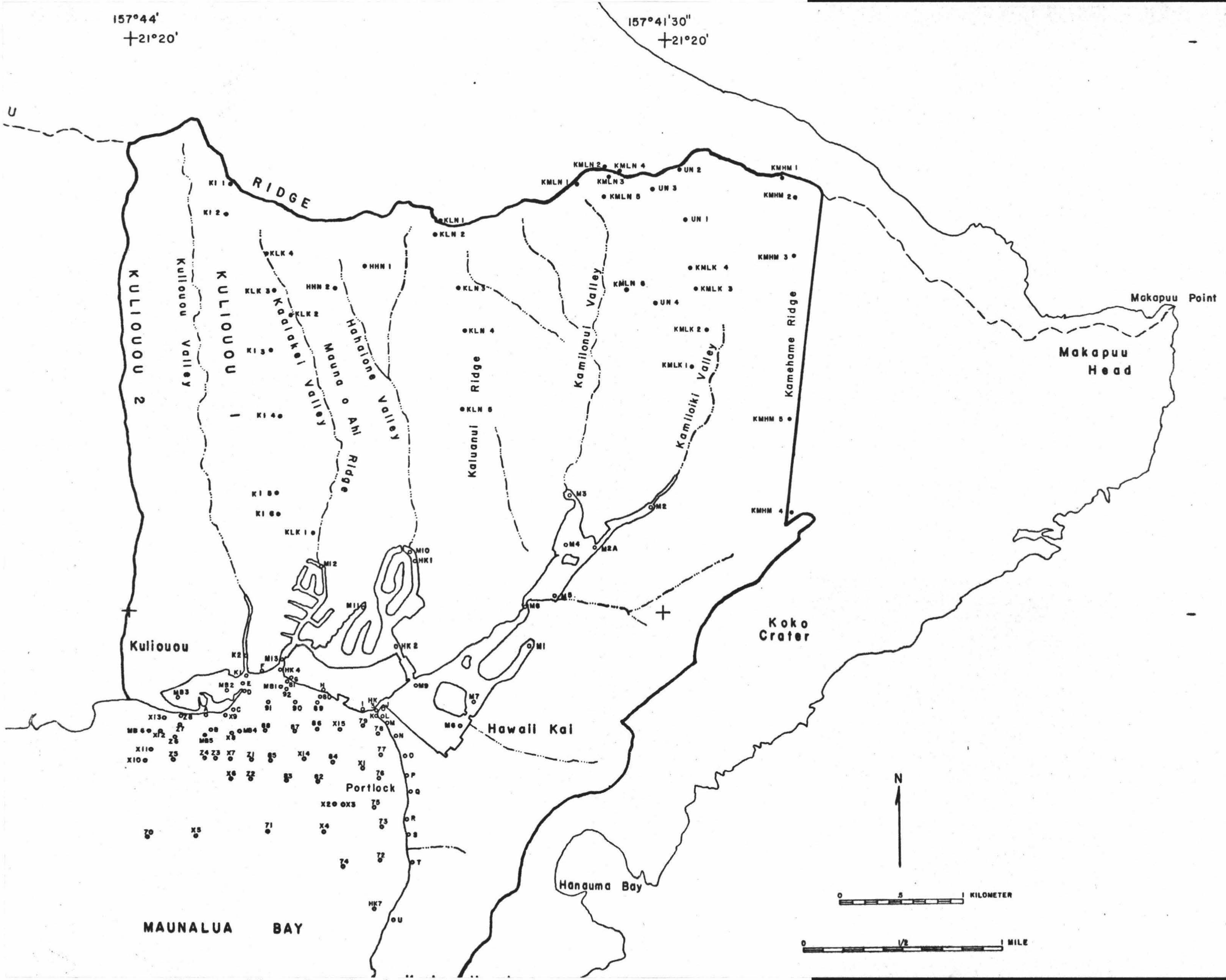

Figure 11. Sample location map.

LABORATORY PROCEDURES

Soil samples as well as other samples containing mud were prepared and X-rayed as discussed in the section on clay-mineral analysis. Samples containing sand and mud were prepared according to the methods of Folk (1972). Those with ten percent or more of mud were first wet-sieved to separate the sand from the silt and clay. The sand fraction was then dried and sieved at 0.5 phi intervals. The mud content was then determined by dispersing the mud, diluting it to exactly one liter, stirring well, then withdrawing 20 ml of suspension from a 20 cm depth after 20 seconds. When dried and weighed this 20 ml of suspension represented one-fiftieth of the total mud content, assuming that none of the mud was lost during the operation, that the particles upon stirring were so uniformly suspended that the 20 ml withdrawn contained one-fiftieth of the total mud content, and that the several weighings were essentially error-free especially concerning the absorption of moisture during weighing. The sample was then restirred and another portion of suspension removed for analysis of the silt and clay fraction which was conducted utilizing the photometric centrifuge and techniques of Woodruff (1972).

GRAPHIC MEAN (M_z)

The graphic mean (Folk, 1972) is given by the formula $M_z=(\phi16+\phi50+\phi84)/3$. The sediments were divided into four categories for comparison (Figure 12). Values greater than 4.00Φ containing the silt and clay-sized particles were categorized as mud; sediments with values from 2.00Φ to 4.00Φ as fine to very fine sand; those from 0.00Φ to 2.00Φ as coarse to medium sand; those greater than 0.00Φ as very coarse sand to gravel.

Sediments with graphic means ranging from very coarse sand to gravel were found along the reef flat on the edge of the boat channel connecting the main marina bridge to the open sea, in a sample near the center of the reef flat, in a sample seaward of the reef, and in a sample in semi-protected deep water behind the reef near Portlock (Figure 11). Samples on the reef flat and seaward of the reef flat were taken from pockets in the reef containing sediment. Consequently, in several of the samples, large coral chunks were included, thereby raising the average grain size of the samples. The sample from near Portlock, however, is a little different. Instead of coral chunks the sample contained coarse sand-sized grains of volcanic material eroded from Koko Head tuff and deposited in this relatively low-energy environment.

Coarse to medium sand was found on most of the reef flat and along all the beach areas along Maunalua Bay from the seaward side of Paiko Peninsula eastward past the marina and southward along Portlock.

Fine to very fine sand was found in eight of the bay samples. Four were from the deep-water channel, low-energy environment seaward of the mouth of Kuliouou Stream and

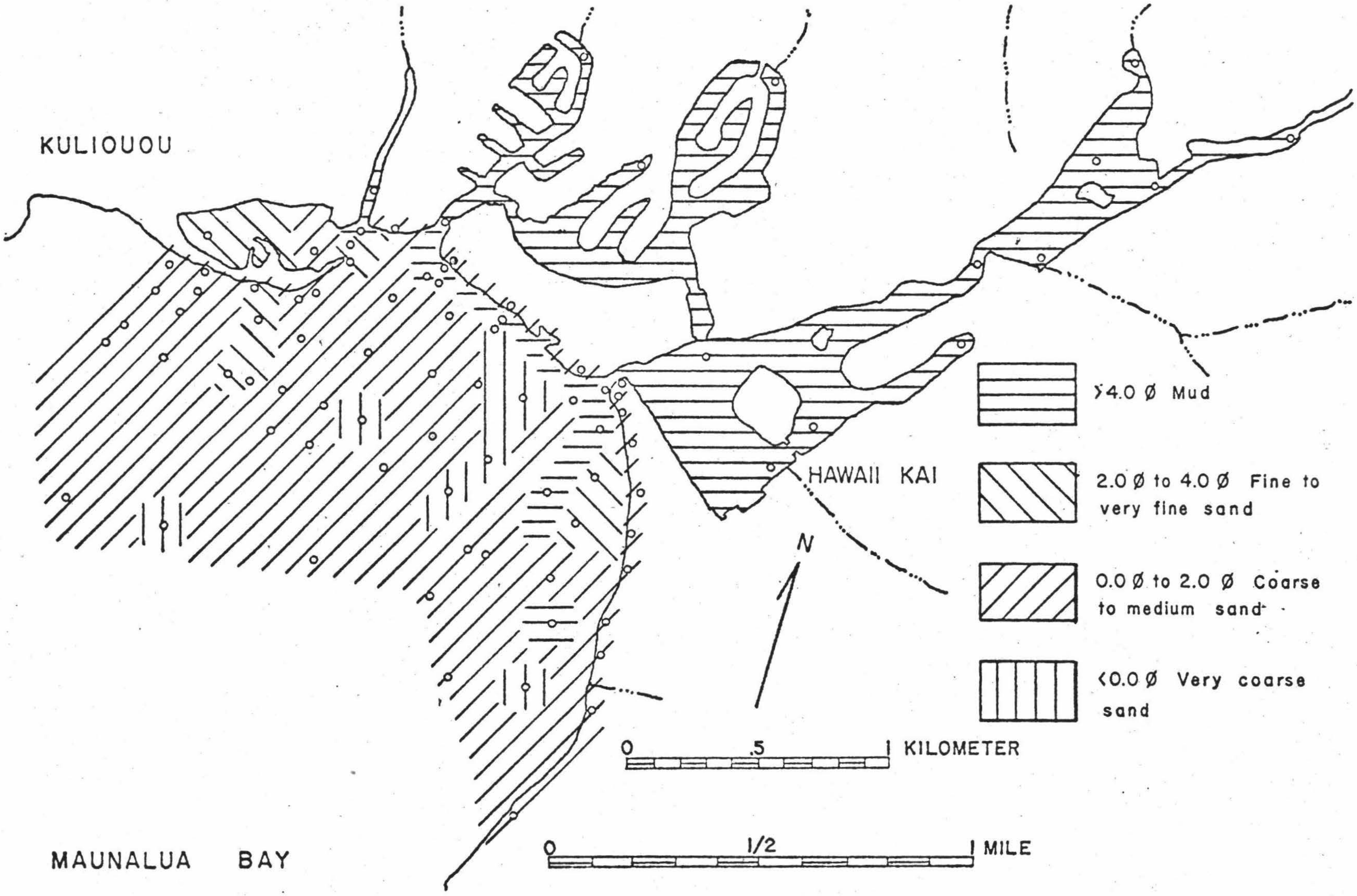

Figure 12. Graphic mean (M_z).

seaward of the main marina bridge. The other four were from the tidal flat inside Paiko Peninsula and an area just seaward of it. The energy is low in the area north of Paiko Peninsula because it is cut off from the open sea by the peninsula itself. Fine sediments are deposited in the area seaward of the peninsula because it is separated from the open sea by the extensive shallow reef flat and also because during low tide sandbars in that area stand above the water line, further restricting circulation with the open sea.

Mud was found in all samples in the marina, at the mouth of Kuliouou Stream, in the deep channels immediately seaward of both marina outlets, and in the deep channel connecting these two outlets. Mud is found in these areas because their waters are protected from the forces of the open sea and their depths are usually over six feet, both conditions of low energy that favor the deposition of fine sediment.

INCLUSIVE GRAPHIC STANDARD DEVIATION (σ_I)

The inclusive graphic standard deviation (Folk, 1972) measures the degree of sorting of the sediment and is given by the formula: $\sigma_I = (\phi 84 - \phi 16)/4 + (\phi 95 - \phi 5)/6.6$. Values less than 0.50$\phi$ are considered well to very well sorted; 0.50ϕ to 1.00ϕ, moderately well sorted to moderately sorted; 1.00ϕ to 2.00ϕ, poorly sorted; greater than 2.00ϕ, very poorly sorted. Generally the degree of sorting indicates the amount of time the sediment is exposed to various forces of nature, in this case the energy of waves and currents. The distribution of inclusive graphic standard deviation is shown in Figure 13. A cluster of well to very well sorted sediments was found toward the open sea near Portlock and also at various places on the beach along Portlock and on the sandbar at the end of Paiko Peninsula. Moderately well sorted to moderately sorted sediments were found along most of the reef flat and along the beaches that border Maunalua Bay. Sorting was poor to very poor in the dredged channels and in the protected area inside Paiko Peninsula where silt and clay are able to settle out of suspension and mix with the other sediment. There was also a larger than expected area of poorly sorted material leeward of and following the dredged channel and also a broad area extending onto the reef flat south-southwest of the Honolulu-side marina entrance. Sediments adjacent to the dredged channels were characterized by coarse coral rubble and some mud, indicating that these sediments are poorly sorted due to prior dredging in the area. The sediments on the reef flat south-southwest of the Honolulu-side marina entrance generally did not contain as much coral rubble but contained more mud, again indicating that dredging of the area and the resulting suspension of sediments and later deposition to the leeward side played a part in determining the character of the sediment.

INCLUSIVE GRAPHIC SKEWNESS (Sk_I)

Inclusive graphic skewness (Folk, 1972) is given by the

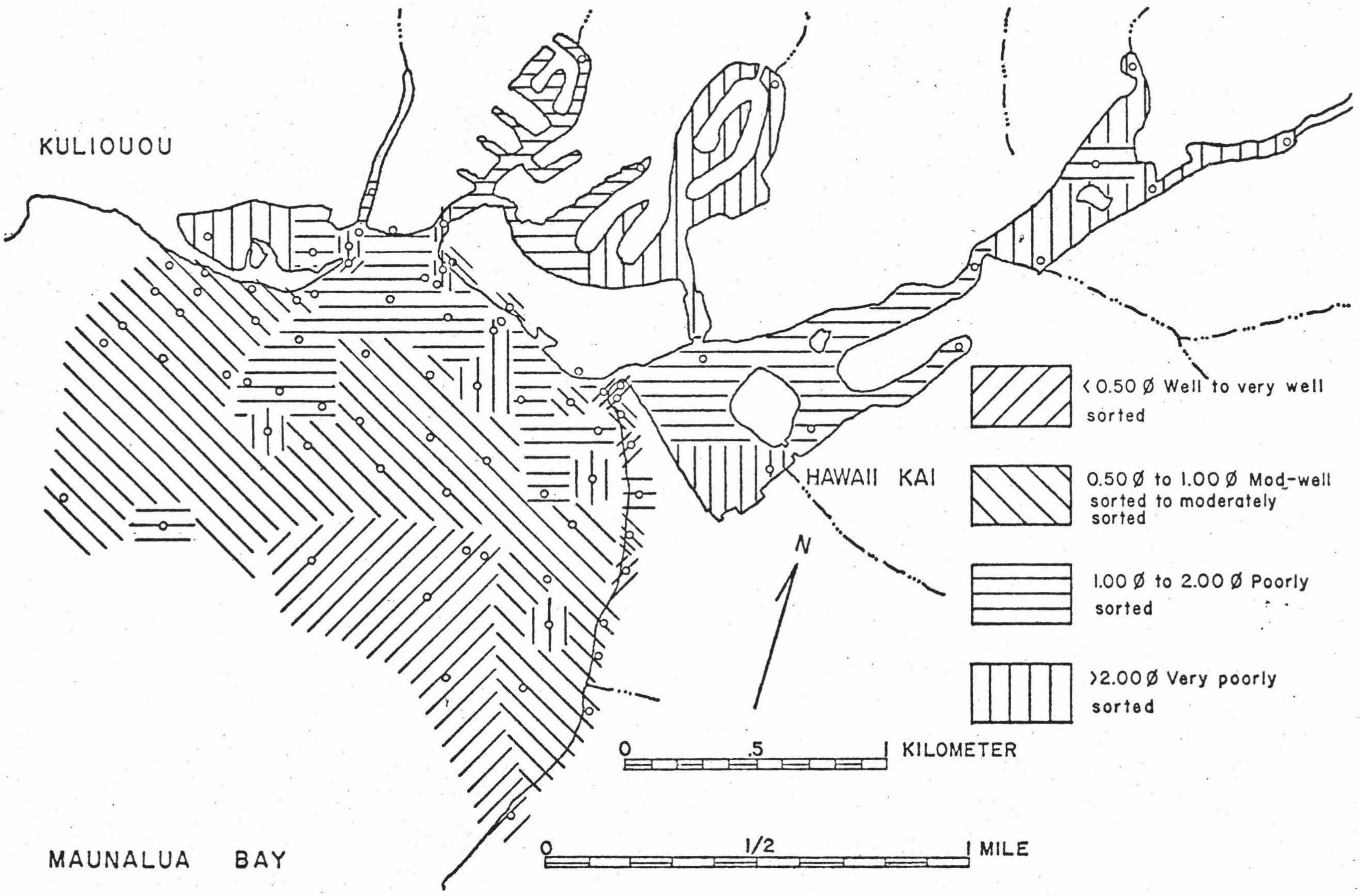

Figure 13. Inclusive graphic standard deviation (σ_I).

formula:

$$Sk_I = (\phi16+\phi84-2\phi50)/2(\phi84-\phi16) + (\phi5+\phi95-2\phi50)/2(\phi95-\phi5)$$

and measures the degree of asymmetry of the curves as well as the sign or direction of the asymmetric tail, whether it is to the right (positive or fine skewed) or to the left (negative or coarse skewed). The greater the departure from 0.00 the greater the asymmetry. The distribution of inclusive graphic skewness values is shown in Figure 14. It should be noted that the sign or direction of the number does not necessarily indicate corresponding grain size. As an example, many of the marina muds are strongly negative or coarse skewed. This merely indicates that the curves for these samples are asymmetric to the left, not that there is excess coarse material in the samples. Here the materials are coarse only in relation to the rest of the finer materials contained in the sediments. Beach sediments along Paiko Peninsula and between the two marina bridges were negatively skewed. Portlock beach sediments were near-symmetrical to fine skewed due to the fine-grained volcanic sediments introduced from the Koko Head volcanics. The muds were negatively to strongly negatively skewed having negative tails due to the excess of fine materials in the sediment. Sediments on the reef flat trended toward coarse to near-symmetric tails. Those that were positively skewed generally reflected the presence of mud intermixed in the sediments.

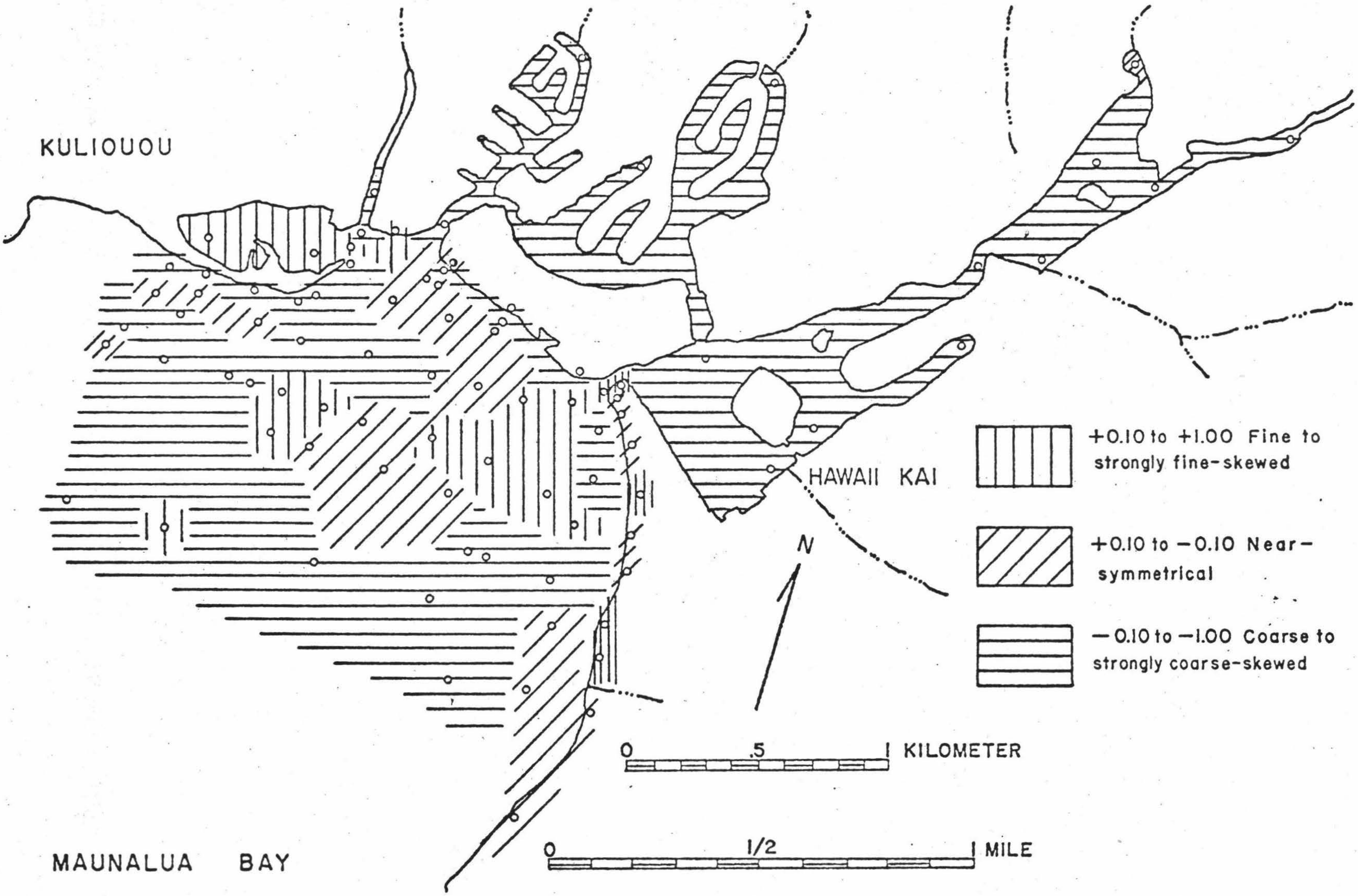

Figure 14. Inclusive graphic skewness (Sk_I).

GRAPHIC KURTOSIS (K_G)

Graphic kurtosis (Folk, 1972) is given by the formula: $K_G = (\phi 95 - \phi 5)/2.44(\phi 75 - \phi 25)$ and measures the ratio between the sorting in the "tails" of the curve and the sorting in the central portion. In a normal probability curve $K_G = 1.00$. If the central portion ($\phi 75 - \phi 25$) is better sorted than the tails ($\phi 95 - \phi 5$) the curve is excessively peaked or leptokurtic and the ratio is greater than 1.00. If the tails are better sorted than the central portion, the curve is flat-peaked or platykurtic and the ratio is less than 1.00. The distribution of graphic kurtosis values is shown in Figure 15. In general sediments composed mainly of mud ranged from mesokurtic to very platykurtic, indicating better sorting in the tails. Beach sediments along Portlock and Paiko Peninsula ranged from mesokurtic to leptokurtic, indicating a better sorted central portion. Reef flat sediments also ranged from mesokurtic to leptokurtic with the sediments exposed to the higher energy levels being more mesokurtic.

SUMMARY

The study of the grain size parameters indicated the various types of sediments in the study area. The graphic mean categorized the sediments into size groups and indicated their distribution. The inclusive graphic standard deviation, or degree of sorting, pointed out the poorly sorted sediments adjacent to the dredged channels connecting the

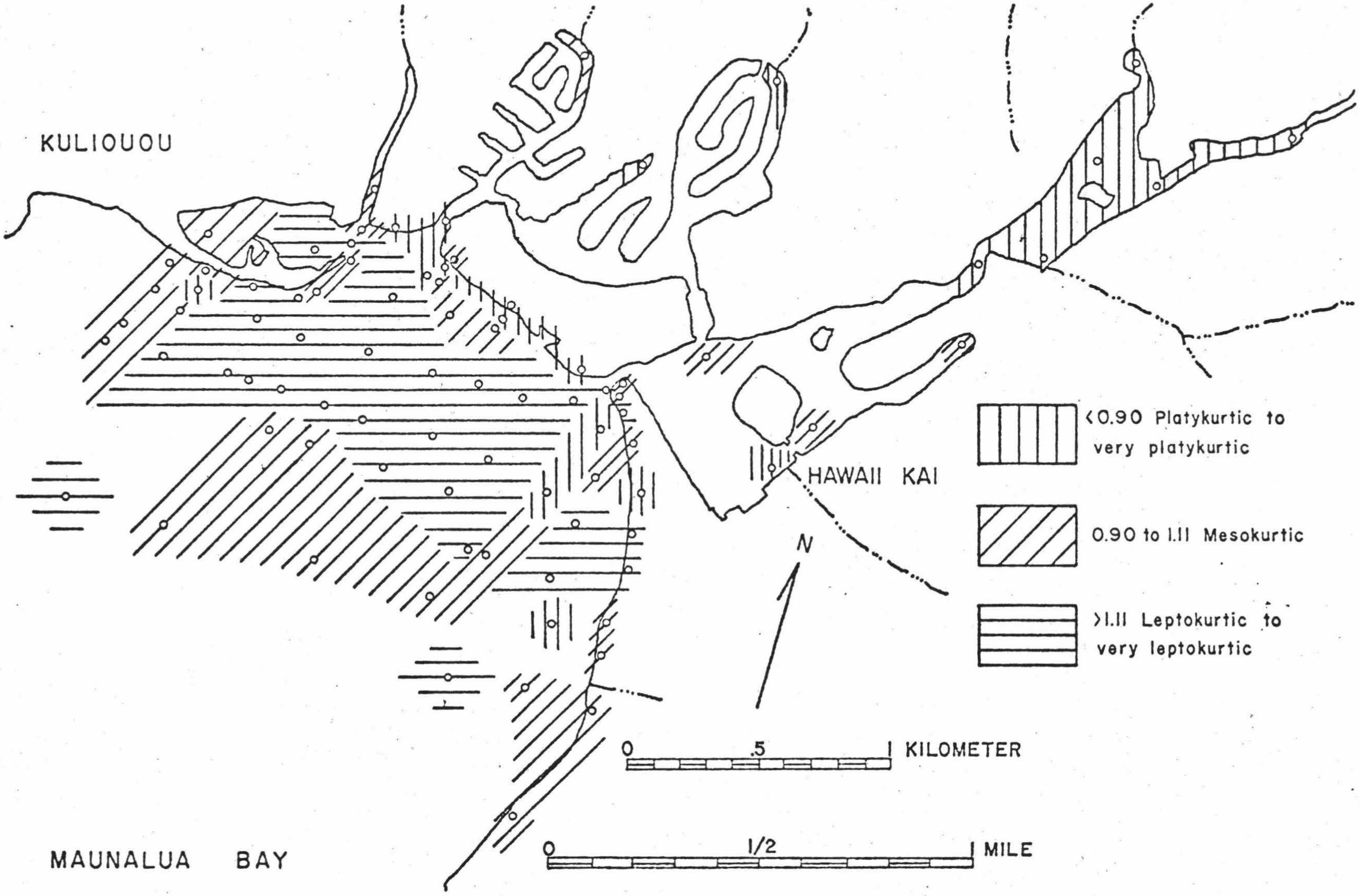

Figure 15. Graphic kurtosis (K_G).

two marine entrances then running out to sea and the area of poor sorting south-southwest of the Honolulu-side marina entrance. Inclusive graphic skewness values revealed a basic difference between the sands from Paiko Peninsula and those from Portlock. Further investigation determined that the Portlock sands were fine skewed due to the presence of smaller, more easily eroded grains of Koko Head tuff diluted with the carbonaceous sands. Graphic kurtosis showed that, generally, the muds were platykurtic, sediments on the reef flat leptokurtic, and those exposed to high energy mesokurtic.

COMPOSITION OF SEDIMENT

LABORATORY PROCEDURES

Samples from the marina and bay were analyzed to determine percentages of calcareous, terrigenous, and organic material. A small amount of each sample, approximately six grams, was placed in a pre-weighed 50 ml beaker, dried, then weighed. Hydrochloric acid was then added to the sample to dissolve the calcium carbonate fraction. Upon complete dissolution of the calcium carbonate fraction the sample was washed to remove the calcium chloride formed from the reaction of the hydrochloric acid with the calcium carbonate, dried, then reweighed. The weight loss indicated the amount of calcium carbonate in the sample. The sample was then oxidized with 30 percent hydrogen peroxide, again dried, and reweighed, the difference in weight indicating the amount of organic material in the sample. The weight of the insoluble residue remaining after the above steps was that of the terrigenous portion of the sample.

RESULTS

Percentages of calcium carbonate were found to be greater than 96 percent in most of the seaward Maunalua Bay samples (Figure 16). Samples in a relatively narrow band along the shoreline of the bay as well as in a patch seaward of Paiko Peninsula contained 66 to 96 percent calcium carbonate. In the bay, pockets of sediment with percentages

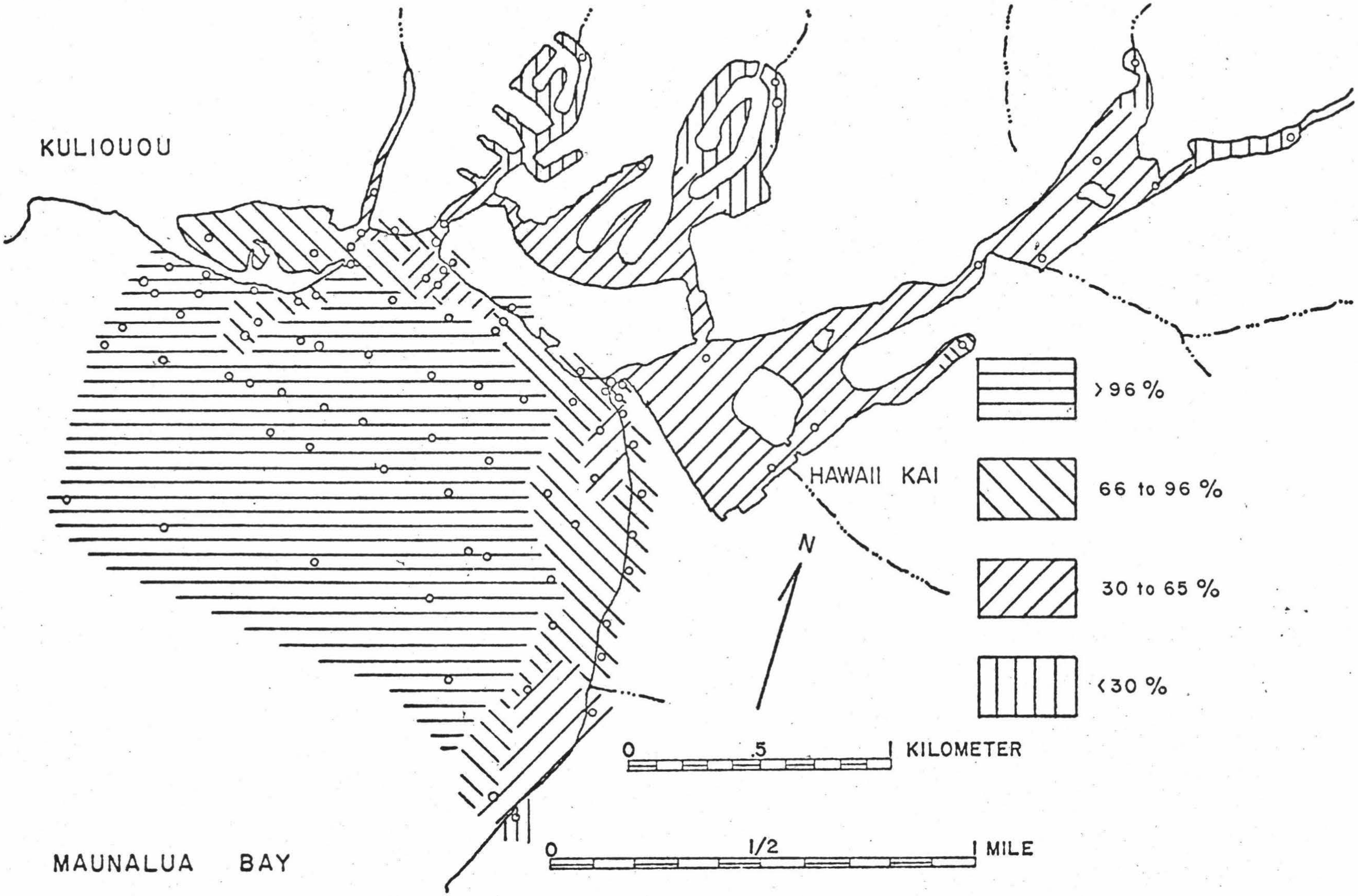

Figure 16. Percentages of calcium carbonate.

of calcium carbonate ranging from 30 to 65 percent were found at the mouth of Kuliouou Stream, at both entrances to the marina, and in the area located between Kui Channel and the shoreline adjacent to it along Portlock. Kuliouou Stream sediments and sediments from most of the marina ranged from 30 to 65 percent calcium carbonate. The areas of the marina containing less than 30 percent calcium carbonate included the upper portions of Marina Units Numbers 1 and 2, the left and right fingers of the upper marina and a small area in Marina 7E Channel.

Percentages of terrigenous sediment (Figure 17) were generally found to be the reciprocal of those of the carbonate sediment. Samples with greater than 70 percent terrigenous material were found in the upper portions of Marina Units Numbers 1 and 2 and in the left and right fingers of the upper marina. The remaining portions of the marina, as well as the entrances to the marina and the area shoreward of Kui Channel, contained sediments with 35 to 70 percent terrigenous material. Sediments in the narrow band following the shoreline of the bay and the small area seaward of Paiko Peninsula contained between 10 and 34 percent terrigenous material. Samples in the remainder of the bay, as well as a few samples along the shore of the bay, contained less than 10 percent terrigenous material.

The organic material content of the samples (Figure 18) proved to be the least both in quantity and in accuracy. None of the samples contained more than 4 percent organic

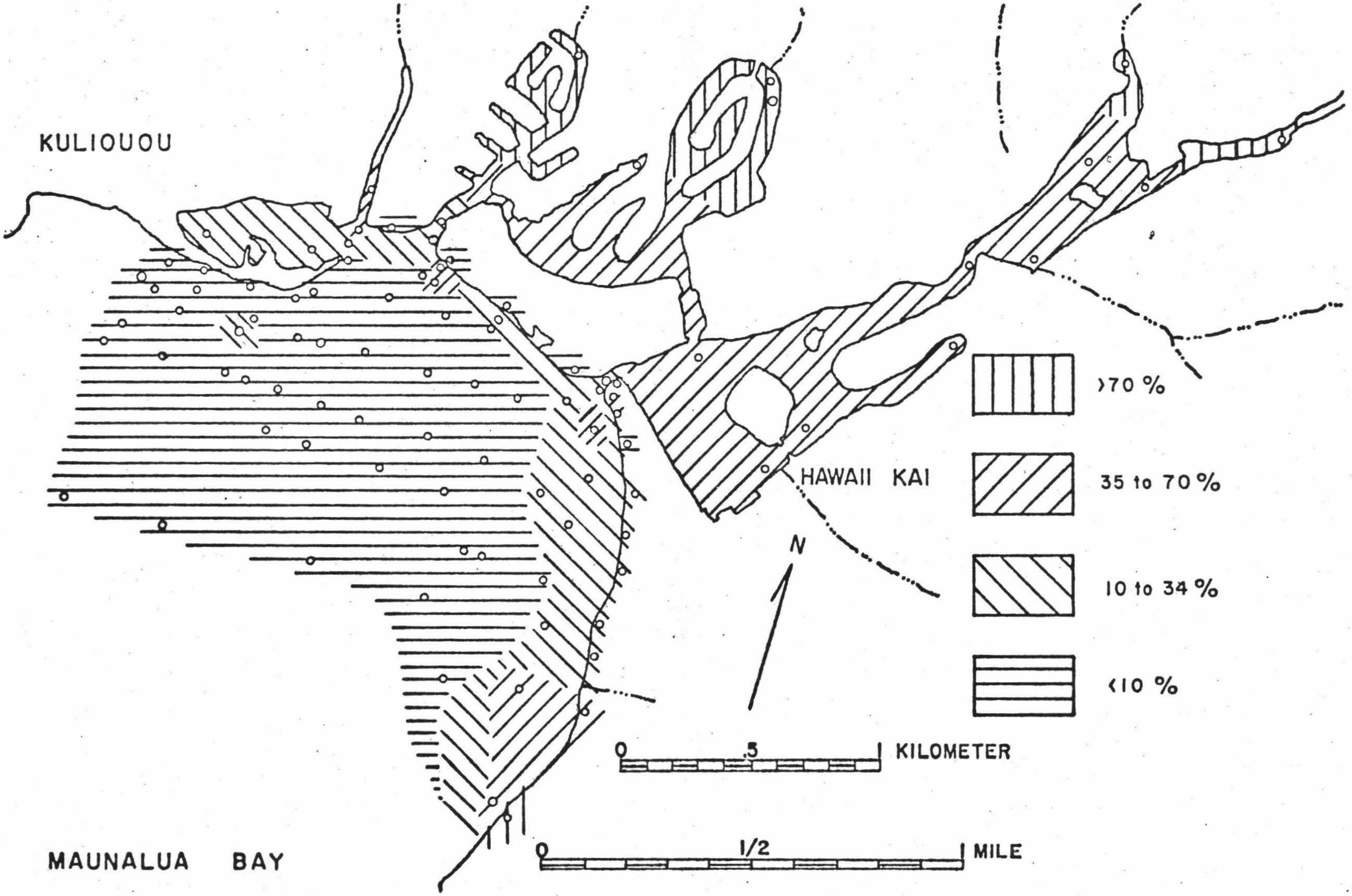

Figure 17. Percentages of terrigenous sediment.

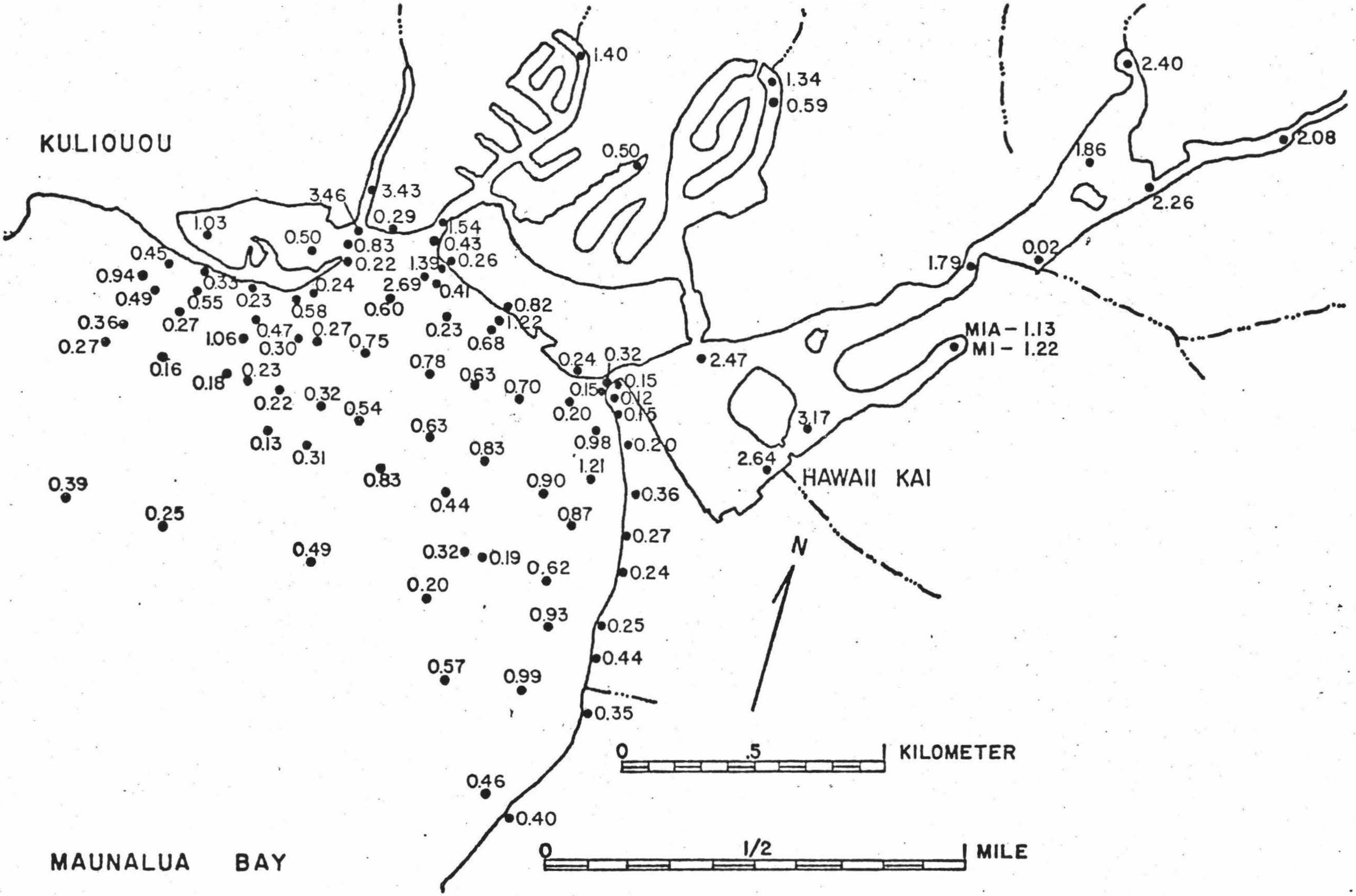

Figure 18. Individual percentages of organic material.

material. In a similar study by Coulbourn (1971) the experimental error using this procedure was calculated by performing ten analyses on one sample. It was found that the best agreement of values was for the calcium carbonate percentage which had a standard deviation of 3.7 percent, small compared to the total amount of carbonate. The terrigenous fraction standard deviation was found to be 4.6 percent which is less accurate but still small compared to the total amount. The organic content standard deviation was 4.0 percent, which is greater than the greatest amount found in any of the samples. Therefore the values of the organic content are less accurate than those for the carbonate and terrigenous content. No well-defined trend resulted when the organic percentage figures were plotted. About the only conclusion that could be drawn was that the sediments with higher organic content were usually associated with the bottom muds found in reducing environments.

SUMMARY

Samples with highest carbonate percentages were taken from beaches, pockets in the reef, and from other high-energy localities where wave action prevented mud from settling out and where the main input of sediment was from the abrasion of the reef and from transport of calcareous material along the shore. Carbonate percentages ranged from 66 to 96 percent in areas where wave energy was less, such as in the tidal flat behind Paiko Peninsula, in the deep channel at the mouth of Kuliouou Stream, at both entrances to the marina, and in the deep channel leading from the main channel bridge of the marina to the open sea. Values were also in the 66 to 96 percent range on the eastern end of Maunalua Bay, along Portlock, partly because the deep channel prevents full wave energy from reaching the sediments and partly because terrigenous sediments washed off of Koko Head have diluted the carbonaceous sands along the beach. The small area seaward of Paiko Peninsula also contained sediments with 66 to 96 percent carbonate. Sediments in this area are diluted with mud originating mainly from Kuliouou Stream during storms and secondarily from the marina. Trade winds and storm runoff transport the silt and clay-sized sediments toward the southwest where they are trapped by sandbars running generally perpendicular to Paiko Peninsula, some of which remain above the water line at very low tides and thereby prevent the fine sediments from being washed into the open sea.

Most of the marina, Kuliouou Stream, the deep channels adjacent to both marina entrances, and the area near Kui Channel contained sediments with from 30 to 65 percent calcium carbonate and from 35 to 70 percent terrigenous material. These sediments generally are grayish muds characteristically found in areas where oxygen is lacking, such as the marina bottom and at the bottom of the deeper channels in the bay where energy levels are low, allowing the sediments to settle and preventing them from being further transported.

Sediments containing less than 30 percent carbonate and more than 70 percent terrigenous material were found at the heads of Marina Units Numbers 1 and 2 and at the left and right fingers of the upper marina. These areas are the sedimentary basins for the intermittent streams that empty into the marina and therefore contain the most terrigenous material.

X-RAY ANALYSIS

LABORATORY PROCEDURES

Approximately twenty grams of dry sample were placed in a beaker to which 50 ml of a dispersant solution was added. The mixture was then agitated to place the clay-sized particles into suspension. It was then centrifuged at 600 rpm for eight minutes leaving only the clay-sized particles (less than two microns) in suspension. The solution was then poured off, calcium chloride added to flocculate the clays, and again centrifuged to separate the liquid from the clay particles. The clay residue was then mounted on a glass slide for X-ray analysis. Samples were run on a Norelco--Phillips Diffractometer from 2 degrees to 33 degrees at 1 degree per minute. Wet samples from the bay and marina were first washed several times with water to get rid of the salt, then the above procedures followed.

For bulk sample analysis approximately five grams of sample were hand ground with an agate mortar and pestle then further ground for two hours in a pulverizer. The sample was then pressed to 7,000 pounds per square inch in a hydraulic press, then X-rayed from 2 to 65 degrees on the same instrument mentioned above.

To obtain the relative percentages of minerals in the samples, the heights of the X-ray peaks were measured in centimeters, multiplied by the concentration factor (Fan and Rex, 1972), then converted into percentages.

RESULTS--TERRESTRIAL

A total of fifty-six soil samples (Figure 11) were X-rayed to determine the clay mineral content and of these fifty-six, twenty-five were selected and X-rayed to determine the bulk mineral content. Clay minerals in the soil samples (Table 2) consisted mainly of kaolinite and montmorillonite. Minor amounts of plagioclase were present in a few samples. Bulk analysis revealed other minerals such as magnetite, hematite, and quartz (Table 2).

Because of the very small amounts of other minerals present in the clay fraction only the percentages of kaolinite and montmorillonite were calculated. Percentages of both clay minerals ranged from 0 to 100 percent without any apparent pattern or distribution. As an example, on Kuliouou 1 Ridge, going from the Koolau ridge toward Maunalua Bay, the following was found: sample K1/1, 100 percent kaolinite; K1/2, no clay minerals present; K1/3, 100 percent montmorillonite; K1/4, 100 percent kaolinite; K1/5, 100 percent montmorillonite; K1/6, 6 percent kaolinite and 94 percent montmorillonite. This random distribution of minerals agrees with the findings of Saing (1968) who suggested that the combined effects of climate, vegetation, and drainage were more significant in the final outcome of the soil than was the parent material. Sherman and Uehara (1956), in their study of spheroidally weathered olivine basalt boulders, found that kaolin-type clays formed on the

TABLE 2

RESULTS OF X-RAY ANALYSIS OF TERRESTRIAL SAMPLES

Smpl No.	Description (Munsell Soil Color Chart)	Minerals in the clay fraction (relative percentages)	Minerals in the bulk fraction (relative percentages)
K1/1	10YR4/3 brn-drk brn	kaol(100)	
K1/2	7.5YR3/2 drk brn	---	
K1/3	10YR5/2 grysh brn	mont(100)	
K1/4	5YR3/4 drk rddsh brn	kaol(100)	
K1/5	10YR6/2 lt brnsh gry	mont(100)	
K1/6	10YR5/1 gray	kaol(6) mont(94)	
KLK 1	10YR4/2 drk grysh brn	kaol(6) mont(94)	
KLK 2	10YR3/1 vry drk gry	kaol(72) mont(28)	kaol(20) magn(39) hema(29) qtz(12)
KLK 3	10YR5/4 yllwsh brn	kaol(75) mont(25)	mont(76) magn(24)
KLK 3B	10YR3/3 drk brn	kaol(59) mont(41)	kaol(25) mont(21) magn(54)
KLK 4	10YR3/3 drk brn	kaol(100)	
HHN 1A	10YR3/2 vry drk grysh brn	kaol(100)	
HHN 1B	10YR3/2 vry drk grysh brn	kaol(100)	

TABLE 2. (Continued) RESULTS OF X-RAY ANALYSIS OF TERRESTRIAL SAMPLES

Smpl No.	Description (Munsell Soil Color Chart)	Minerals in the clay fraction (relative percentages)	Minerals in the bulk fraction (relative percentages)
HHN 1C	10YR4/3 brn-drk brn	kaol(100)	
HHN 1D	10YR4/2 drk grysh brn	kaol(100)	
HHN 2	10YR4/2 drk grysh brn	kaol(44) mont(56)	
KLN 1A	10YR4/2 drk grysh brn	kaol(9) mont(91)	
KLN 1B	10YR4/3 brn-drk brn	kaol(31) mont(69)	
KLN 1C	10YR5/2 grysh brn	kaol(8) mont(92)	
KLN 2	10YR4/2 drk grysh brn	kaol(31) mont(69)	
KLN 2B	10YR4/3 brn-drk brn	---	
KLN 3A	10YR3/3 drk brn	kaol(89) mont(11)	
KLN 3B	10YR5/4 yllwsh brn	kaol(100)	kaol(26) magn(52) qtz(22)
KLN 3C	10YR5/2 grysh brn	kaol(100)	kaol(19) magn(57) qtz(24)
KLN 3D	7.5YR5/4 brn	kaol(100)	kaol(16) magn(32) hema(41) qtz(11)
KLN 4A	10YR4/3 brn-drk brn	kaol(100)	
KLN 4B	7.5YR4/4 drk brn 2.5YR5.5/0 gray	kaol(100)	

TABLE 2. (Continued) RESULTS OF X-RAY ANALYSIS OF TERRESTRIAL SAMPLES

Smpl No.	Description (Munsell Soil Color Chart)	Minerals in the clay fraction (relative percentages)	Minerals in the bulk fraction (relative percentages)
KLN 5A	5YR4/4 rddsh brn	kaol(100)	
KLN 5B	5YR3/3 drk rddsh brn	kaol(100)	
KMLN 1	2.5Y3/2 vry drk grysh brn	kaol(29) mont(71)	kaol(7) mont(13) magn(18) plag(62)
KMLN 2	2.5Y6/3 lt brnsh gry-lt yllwsh brn	mont(100)	mont(17) magn(16) plag(67)
KMLN 3	10YR4/3 brn-drk brn	kaol(20) mont(80)	
KMLN 4	10YR6/2 lt brnsh gry	mont(100)	mont(13) magn(19) plag(50) hema(18)
KMLN 5	10YR4/2 drk grysh brn	kaol(31) mont(69)	
KMLN 6	2.5Y4/2 drk grysh brn	kaol(39) mont(61)	
UN 1	10YR4/2 drk grysh brn	kaol(56) mont(44)	mont(15) magn(19) plag(66)
UN 2	10YR4/1 drk gry	mont(100)	mont(26) magn(13) plag(61)
UN 3A	10YR6/8 brnsh yllw	---	magn(100)
UN 3B	2.5YR3/4 drk rddsh brn	kaol(100)	kaol(34) magn(47) hema(19)
UN 4	10YR4/2 drk grysh brn	kaol(36) mont(64)	kaol(8) mont(17) magn(13) plag(62)

TABLE 2. (Continued) RESULTS OF X-RAY ANALYSIS OF TERRESTRIAL SAMPLES

Smpl No.	Description (Munsell Soil Color Chart)	Minerals in the clay fraction (relative percentages)	Minerals in the bulk fraction (relative percentages)
KMLK 1	10YR3/1 vry drk gry	kaol(23) mont(77)	
KMLK 2	10YR3/2 vry drk grysh brn	kaol(24) mont(76)	mont(28) magn(18) plag(40) hema(14)
KMLK 3	10YR5/2 grysh brn	mont(100)	mont(56) magn(21) hema(23)
KMLK 4	10YR3/2 vry drk grysh brn	kaol(17) mont(83)	mont(100)
KMHM 1A	10YR3/2.5 drk-vry drk grysh brn	kaol(100)	
KMHM 1B	5YR3/3 drk rddsh brn	kaol(100)	
KMHM 1C	10YR4/3 brn-drk brn	kaol(100)	
KMHM 2	5YR4/4 rddsh brn	kaol(68) mont(32)	
KMHM 3A	10YR6/2 lt brnsh gry	kaol(73) mont(27)	
KMHM 3B	10YR5/3 brn	kaol(25) mont(75)	mont(72) magn(28)
KMHM 3C	10YR5/4 yllwsh brn	kaol(22) mont(78)	
KMHM 4A	5YR5/3 rddsh brn	kaol(32) mont(68)	mont(35) magn(21) plag(26) hema(18)
KMHM 4B	5Y4/3 olive	---	

TABLE 2. (Continued) RESULTS OF X-RAY ANALYSIS OF TERRESTRIAL SAMPLES

Smpl No.	Description (Munsell Soil Color Chart)	Minerals in the clay fraction (relative percentages)	Minerals in the bulk fraction (relative percentages)
KMHM 5	10YR5/4 yllwsh brn	kaol(82) mont(18)	mont(27) magn(12) plag(61)
D1	5YR4/4 rddsh brn	kaol(100)	magn(15) plag(60) hema(25)
D2	10YR4/1 drk gry	kaol(100)	mont(5) magn(22) plag(73)

tops and sides of the boulders where drainage was good and montmorin-types of clays formed on the underside of the boulders where drainage was poorer.

The colors of the soil samples were recorded using the Munsell Soil Color Chart to determine whether or not there was any correlation between soil color and clay mineral composition. Though sampling was not extensive enough to establish hard and fast rules concerning the relationship of color to clay mineral content, a few observations should be noted. Of the fifty-six soil samples taken, twenty contained 100 percent kaolinite and eight had greater than 50 percent kaolinite. Six samples contained 100 percent montmorillonite and eighteen had more than 50 percent montmorillonite. Of the twenty samples with 100 percent kaolinite, six samples were reddish brown, two were gray, five were grayish brown, and the rest of the twenty were some shade of brown. Of the six samples with 100 percent montmorillonite, none were reddish, four were gray, and two were grayish brown. The majority of the samples with 50 percent kaolinite or greater were brown while the eighteen with greater than 50 percent montmorillonite tended to be more grayish brown. It can be stated from the data that reddish soils tend to be higher in kaolinite while grayer soils favor montmorillonite. Similar results have been noted elsewhere in the Hawaiian Islands as well as in other tropical areas such as in Australia, India, South Africa, and Indonesia. Sherman (1952) and Sherman and Uehara (1956) describe red and black earths with the black soils having clays of the montmorillonite type and the red soils having the kaolinite type clays. Uehara and Sherman (1956) further classified the soils of the red and black complex into four types: "The first type consists of black soils forming under low rainfall at low elevations adjacent to red soils forming under higher rainfall on upper elevations. Type II black soils may form under heavier rainfall than type I, but are stabilized by seepage waters from adjacent red soils. Type III comprises a number of black soils developing under restricted drainage, as a result of a high water table, near soils having better internal drainage. Type IV consists of several profiles of alluvial and ash material, where a red top soil rests upon a black subsoil. In every case, except in a red and black profile from Molokai, kaolin was found to be the dominant clay mineral in the red soil and montmorillonite in the black soil, with a kaolin-montmorillonite mixture in the transitionary zones. Under intense leaching and oxidation, kaolin formation was favored. In situations where retention of bases and silica was favored, montmorillonite formation occurred."

At several sample locations, multiple samples were taken, such as KLN 3A to 3D and KMHM 1A to 1C, to see if clay mineral content varied within a small area. Of the seven multiple samples taken, all except one set, KMHM 3A to 3C, contained either all of one clay mineral or similar proportions of each type. For example, in one of the sample locations, KLN 3A to 3D, samples were taken from a single soil bank which had four separate layers distinguished by different colors. The results were as follows: KLN 3A, 89 percent kaolinite and 11 percent montmorillonite; KLN 3B, 100 percent kaolinite; KLN 3C, 100 percent kaolinite and a trace of montmorillonite; KLN 3D, 100 percent kaolinite and a trace of montmorillonite. A possible explanation for the greater amount of montmorillonite in the top layer of the soil bank could be because the top layer contained roots while the layer below did not. The roots may have affected the soil through release of acids and exchange of cations or simply by retaining moisture which decreased drainage thereby favoring the formation of montmorillonite. In the KMHM 3A to 3C samples, the results were as follows: KMHM 3A, 73 percent kaolinite and 27 percent montmorillonite; KMHM 3B, 25 percent kaolinite and 75 percent montmorillonite; KMHM 3C, 22 percent kaolinite and 78 percent montmorillonite. In the latter case, the three samples were also from different layers distinguished by different colors. In this case the mineralogy reflects the sequence of weathering as stated by Sherman (1952). The primary materials of the parent material weather to montmorillonite then to kaolinite and finally to the free oxides. KMHM 3A, being the farthest away from the parent material has weathered to a greater degree than either 3B or 3C and therefore contains more kaolinite.

Minerals in the the bulk fraction included kaolinite, montmorillonite, plagioclase, magnetite, hematite, and quartz. Kaolinite and montmorillonite have already been discussed. Plagioclase is present in significant quantities due mainly to the fact that it is one of the most abundant minerals in Hawaiian lavas. Magnetite is common along with some hematite. Though its scarcity makes it difficult to make any statements regarding the occurrence of quartz in some samples, Rex and others (1969), through the study of the particle-size distribution and oxygen-isotopic composition of quartz from Hawaiian soils, concluded that virtually all the quartz in Hawaiian soils is of eolian origin.

RESULTS--BAY AND MARINA

Forty-four samples from the Hawaii Kai Marina and Maunalua Bay were analyzed for their clay mineral content (Figure 11). Minerals in the clay fraction (Table 3) included calcite, kaolinite, and montmorillonite. Forty-one of the forty-four samples contained calcite and twenty-seven of the forty-four contained both kaolinite and montmorillonite. In the samples with both, the percentage of montmorillonite was always greater than that of kaolinite. The greater than 4.0 phi fractions of sixteen of the forty-four samples were run for bulk mineral analysis. Minerals identified (Table 3) included magnesium-rich and magnesium-poor calcite, aragonite, plagioclase, magnetite, kaolinite, and montmorillonite.

TABLE 3

RESULTS OF X-RAY ANALYSIS OF BAY AND MARINA SAMPLES

Smpl No.	Minerals in the clay fraction (relative percentages)			Minerals in the greater than 4.0 phi fraction (relative percentages)
M1	kaol(12)	mont(15)	ca(73)	
M1A	(15)	(20)	(65)	
M2	(35)	(65)		
M2A	(29)	(71)		
M3	(34)	(66)		mg-poor ca(15) arag(47) plag(32) magn(6)
M4	(33)	(45)	(22)	
M5	(35)	(58)	(8)	
M6	(21)	(43)	(36)	
M7	(14)	(27)	(59)	
M8	(16)	(23)	(61)	mg-rich ca(19) mg-poor ca(20) arag(48) magn(13)
M9	(39)	(54)	(7)	
M10	(33)	(60)	(7)	mg-poor ca(45) plag(24) magn(16) kaol(6) mont(9)
M11	(20)	(41)	(39)	
M12	(29)	(67)	(4)	mg-rich ca(10) arag(35) plag(26) magn(13) mont(16)

TABLE 3. (continued) RESULTS OF X-RAY ANALYSIS OF BAY AND MARINA SAMPLES

Smpl No.	Minerals in the clay fraction (relative percentages)			Minerals in the greater than 4.0 phi fraction (relative percentages)
M13	kaol(24)	mont(36)	ca(40)	mg-rich ca(16) arag(84)
HK1	(26)	(61)	(13)	
MB1	(27)	(39)	(34)	mg-rich ca(19) arag(73) plag(6) magn(2)
MB2	(22)	(53)	(25)	mg-rich ca(27) arag(73)
MB3	(26)	(44)	(30)	mg-rich ca(29) arag(71)
MB5	(33)	(38)	(29)	
K1	(30)	(53)	(17)	mg-rich ca(10) arag(84) plag(6)
K2	(32)	(51)	(17)	
Z1			(100)	
Z3			(100)	
X1			(100)	mg-rich ca(33) arag(67)
X6			(100)	
X7			(100)	
X8			(100)	
X15			(100)	

TABLE 3. (Continued) RESULTS OF X-RAY ANALYSIS OF BAY AND MARINA SAMPLES

Smpl No.	Minerals in the clay fraction (relative percentages)			Minerals in the greater than 4.0 phi fraction (relative percentages)
73	kaol(--)	mont(--)	ca(100)	
76			(100)	mg-rich ca(19) arag(81)
77	(17)	(22)	(61)	mg-rich ca(17) arag(83)
78	(16)	(25)	(59)	mg-rich ca(23) arag(77)
79			(100)	
80	(15)	(29)	(56)	mg-rich ca(21) arag(79)
81	(17)	(36)	(47)	mg-rich ca(11) arag(63) plag(8) kaol(18)
86			(100)	
89			(100)	
90			(100)	
91			(100)	
92			(100)	
B			(100)	
C			(100)	
E	(24)	(48)	(28)	

Relative percentages of calcite, kaolinite, and montmorillonite were plotted (Figures 19 to 21) to determine the distribution of the clay minerals. Calcite was found to be most abundant in samples taken from the bay and decreased with distance shoreward. In samples exposed to the open ocean there was usually 100 percent calcite. In more protected areas such as behind Paiko Peninsula and in the deep dredged channels at the mouth of Kuliouou Stream and at both entrances to the marina, the calcite was mixed with kaolinite and montmorillonite. In the marina, samples M1, M1A, M7, and M8 contained high percentages of calcite. This is because the land adjacent to samples M1 and M1A was filled with mostly calcareous material and during the filling operations large amounts of fine calcareous material settled in the vicinity of M1 and M1A and spread downwind with the currents to sites M7 and M8. The middle portions of the marina units had varying proportions of calcite and the extreme fingers of the units had the least calcite and the most kaolinite and montmorillonite. Kaolinite and montmorillonite were especially abundant where intermittent streams enter the marina.

In the X-ray analysis of the greater than 4.0 phi fraction (Table 3) of those samples that had sufficient material to work with, it was noted that there were two different calcite peaks, high-magnesium and low-magnesium, as well as an aragonite peak. According to Chave (1954), aragonite is not chemically stable and dissolves or

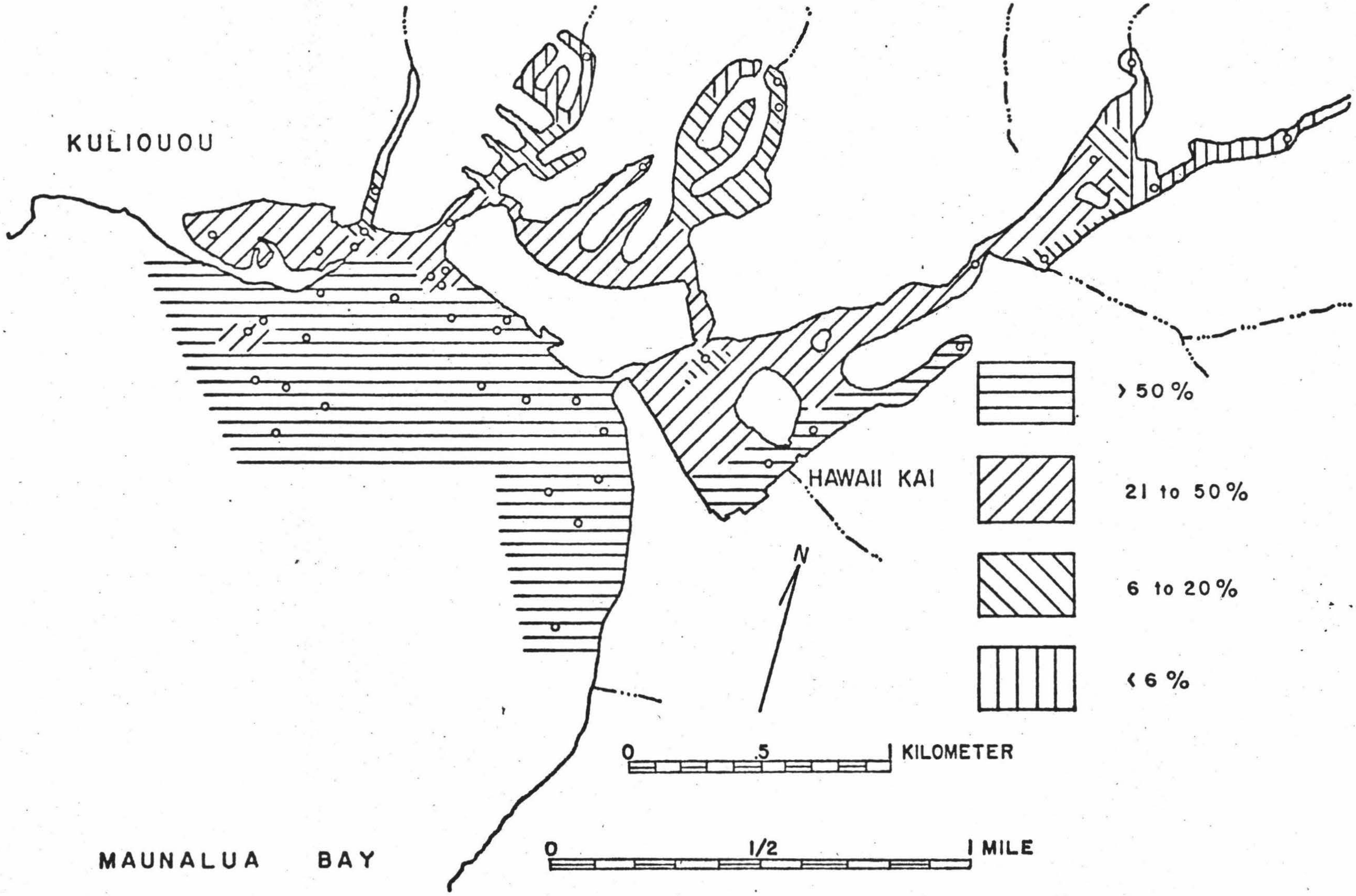

Figure 19. Relative percentages of calcite in the clay fraction.

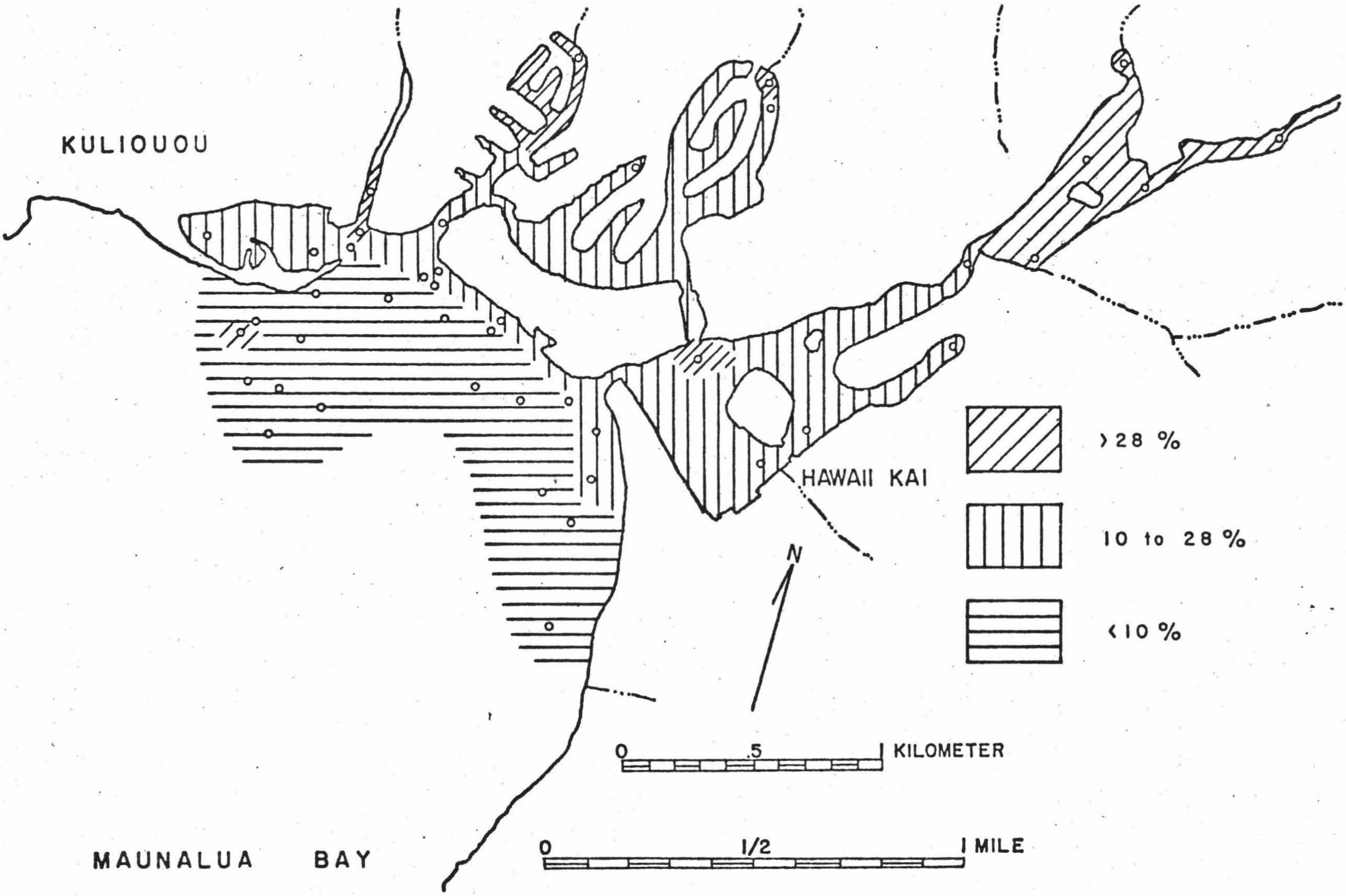

Figure 20. Relative percentages of kaolinite in the clay fraction.

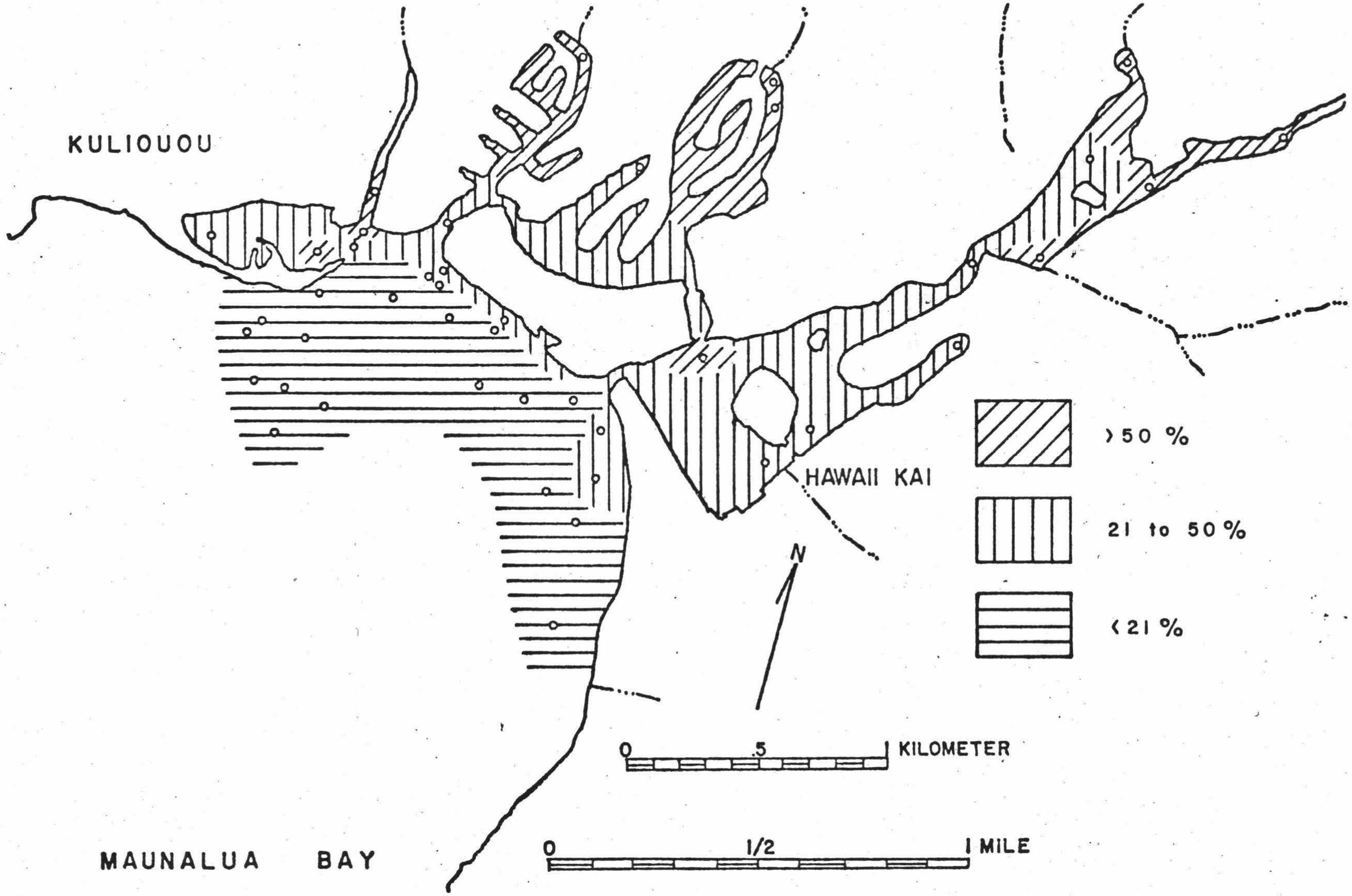

Figure 21. Relative percentages of montmorillonite in the clay fraction.

converts to calcite with the passage of time. High-magnesium calcite in turn changes to low-magnesium calcite with time. The presence of aragonite and high-magnesium calcite indicate fairly recent sediments. Because the low-magnesium calcite is found only in samples taken from within the marina it is possible that the source of the low-magnesium calcite is either from organisms composed of low-magnesium calcite living only in the marina or from older sediments. Most likely the low-magnesium calcite comes from older sediments introduced from other sources during filling operations or dredged from older reef formations in the area. Aragonite and magnesium-rich calcite composed the bulk of the carbonate fraction, as was found by Inman, Gayman, and Cox (1963) in their study of Kauai sediments.

SUMMARY

Because the parent materials are essentially the same in the study area, the clay mineral content of the terrigenous sediments must depend largely on environmental factors such as climate, vegetation, and drainage.

Of the twenty-three soil samples that were run for bulk mineral analysis twenty-one contained magnetite, fifteen had montmorillonite, eleven had plagioclase, eight had kaolinite and hematite, and quartz was found in four samples.

Clay-mineral distribution for the bay and marina was according to the source of the sediments. Calcite predominated in most of the samples from the bay while kaolinite and montmorillonite were more abundant closer to the upper fingers of the marina where intermittent streams deposit most of the terrigenous material.

Of the sixteen bay and marina sediments whose greater than 4.0 phi fractions were run for bulk mineral analysis fourteen contained aragonite, thirteen had magnesium-rich calcite, plagioclase and magnetite were found in six samples each, magnesium-poor calcite was found in three samples, montmorillonite in two, and kaolinite in one sample.

GENERAL SUMMARY AND CONCLUSION

The Hawaii Kai area was studied in three sections; the ridges and valleys, the marina, and the bay. The ridges and valleys, the source of the terrigenous sediments, were found to contribute mainly the clay minerals kaolinite and montmorillonite along with lesser amounts of other minerals. Terrigenous sediments are transported down valleys and ridges into intermittent streams and finally into the marina where they are deposited. Under normal conditions only small amounts of sediments are transported because natural vegetation keeps surface runoff to a minimum. Following landslides and other natural mass movements of materials or land clearing operations by man, the amount of sediments washed away from these areas increases greatly.

The marina is the sedimentary basin for the Hawaii Kai area. When sediments reach the marina deposition occurs, with the larger particles settling first. The finest clay particles may remain in suspension in the marina for long periods of time. Sediment-transporting forces in the marina consist of tidal currents, wind-induced currents, and turbulence caused by boat propellers. These forces constantly work on the sediments, sometimes resuspending them and displacing them to other portions of the marina. Sediments of a different nature are introduced into the marina from Maunalua Bay. Fine, clay-sized, carbonate material enters the marina with the tide and some of the material settles in the sedimentary column of the marina.

Maunalua Bay is the parent of the marina, supplying it with life-supporting seawater without which the marina would soon die. Energy levels are higher in the bay than in the marina. Wave action constantly sorts and reworks sediments and transports them shoreward. Longshore currents also displace sediments from the ends toward the center of the bay. Several areas of the bay have acquired sediments similar to those in the marina. These include the deep dredged channel at Kuliouou Stream, both marina entrances and the channel that connects them, the channel leading from the main marina bridge to the open sea, and the areas near Kui Channel. Fine, clay-sized, calcareous material placed into suspension by wave action settles in these low-energy areas as well as in the marina. Likewise, sediments from the marina, resuspended by tidal and wind mixing, and sediments from infrequent severe rainsrorms, are deposited in these areas and remain there while those deposited in higher-energy environments are winnowed away.

The Hawaii Kai area has undergone many changes since development began in the early 1960s. Expansion is still in progress and will continue into the future. The Hawaii Kai Marina is no longer a brackish pond with swampland surrounding it. It has been reshaped into a 258 acre recreational marina. Pollutants do not enter the marina except for surface runoff, which is exceptionally heavy in newly-cleared construction sites, and the inevitable runoff from the streets and lawns during heavy rains. Circulation between the marina and the bay is good, and water is generally clearer in the marina now than it was in the early 1960s. However, the water is still turbid and will remain so under the present conditions due to the suspended fine, clay-sized sediments which are continually resuspended by tidal, wind, and boat-propeller induced currents. Though storm runoff is presently another source of turbidity, it will be less of a factor when the newer construction sites are fully developed and the soil held in place with lawns and other forms of vegetation and ground cover. Another factor contributing to the turbidity of the marina waters as well as the bay waters is the clay-sized carbonate materials suspended in the water in the higher energy environment of the outer bay and transported by the tide and wind to other areas of the bay and into the marina. There have been no severe adverse effects during the course of development in the area. The dredging of the channels has caused excess amounts of silting on some areas of the reef flat and has also produced low-energy environments where muds can accumulate, but the channels also serve to circulate the marina water, keeping it from stagnating.

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APPENDIX A

SEDIMENT PARAMETERS

SAMPLE NO.	MEAN	SORTING	SKEWNESS	KURTOSIS	% CARB.	% TERR.	% ORGAN.
A	1.83	0.68	-0.18	1.66	98.17	1.60	0.23
B	2.61	0.67	+0.08	1.57	97.25	2.28	0.47
C	1.44	1.24	-0.19	0.95	98.64	1.13	0.24
D	2.39	0.41	-0.18	0.99	98.76	1.02	0.22
E	2.72	2.11	+0.49	1.86	87.90	11.27	0.83
F	1.20	1.47	+0.32	0.68	95.54	4.18	0.29
G	1.37	0.90	+0.01	0.96	93.53	6.21	0.26
H	1.78	0.94	-0.36	0.87	96.36	2.82	0.82
I	1.80	1.12	-0.42	0.74	93.41	6.34	0.24
J	1.75	0.47	+0.13	1.08	70.65	29.20	0.15
K	1.36	0.33	+0.12	1.31	69.79	30.06	0.15
L	1.88	0.74	+0.01	0.78	58.43	41.44	0.12
M	0.98	0.52	+0.07	1.15	62.00	37.85	0.15
N	0.61	0.26	-0.09	1.07	92.11	7.69	0.20
O	0.88	1.18	+0.47	0.82	86.39	13.25	0.36
P	1.38	0.67	+0.07	1.26	74.75	24.98	0.27
Q	1.33	0.39	+0.01	1.17	89.54	10.21	0.24
R	0.28	0.66	+0.13	1.11	80.52	19.23	0.25
S	0.16	0.89	+0.17	1.20	79.56	20.00	0.44
T	0.69	0.62	-0.03	1.02	48.76	50.89	0.35
U	1.49	0.38	+0.04	1.05	18.88	80.72	0.40
Z1	1.47	1.95	+0.27	1.12	97.99	1.69	0.32
Z2	0.56	0.59	-0.08	0.96	99.35	0.35	0.31
Z3	2.21	1.83	-0.14	1.27	97.94	1.83	0.23
Z4	2.52	0.72	-0.37	1.72	99.10	0.72	0.18
Z5	1.54	0.59	-0.22	1.24	99.52	0.32	0.16
Z6	0.96	0.63	-0.25	1.02	99.40	0.33	0.27
Z7	1.40	0.82	-0.08	0.85	98.77	0.68	0.55
Z8	1.14	0.53	-0.25	1.04	99.06	0.62	0.33
X1	5.67	1.52	+0.21	0.80	71.57	27.53	0.90
X2	1.42	0.36	-0.24	1.28	98.47	1.21	0.32
X3	1.23	0.38	-0.14	1.04	98.15	1.66	0.19
X4	1.49	0.34	-0.19	1.10	97.59	2.20	0.20
X5	-0.29	1.25	+0.18	0.98	99.35	0.40	0.25
X6	1.55	2.06	+0.42	1.05	97.68	2.19	0.13
X7	1.02	1.62	+0.51	1.60	98.91	0.87	0.22
X8	1.56	1.83	-0.13	1.25	97.75	1.95	0.30
X9	1.77	0.84	-0.18	1.46	94.35	5.08	0.58
X10	1.18	0.62	-0.09	1.05	99.07	0.66	0.27
X11	1.18	0.67	-0.11	1.00	98.81	0.82	0.36
X12	1.05	0.94	+0.04	1.34	97.50	2.01	0.49
X13	0.60	0.66	-0.12	0.97	98.68	0.86	0.45
X14	0.67	0.86	+0.26	1.74	97.03	2.34	0.63

APPENDIX A (Continued) SEDIMENT PARAMETERS

SAMPLE NO.	MEAN	SORTING	SKEWNESS	KURTOSIS	% CARB.	% TERR.	% ORGAN.
X15	-0.52	1.58	+0.18	1.25	98.33	0.97	0.70
MB1	6.14	1.54	-0.01	0.69	49.73	47.58	2.69
MB2	1.72	1.81	+0.24	1.49	93.56	5.93	0.50
MB3	2.80	2.52	+0.65	0.99	82.34	16.63	1.03
K1	6.49	1.52	-0.24	1.01	44.83	51.71	3.46
K2	--	--	--	--	40.06	56.51	3.43
M1	7.20	1.18	-0.27	1.09	77.07	21.71	1.22
M1A	--	--	--	--	57.55	41.33	1.13
M2	6.04	2.37	-0.35	0.65	24.34	73.58	2.08
M2A	--	--	--	--	32.39	65.35	2.26
M3	4.37	2.64	+0.09	0.75	27.39	70.21	2.40
M4	6.37	1.77	-0.21	0.76	36.08	62.05	1.86
M5	5.61	2.22	-0.23	0.85	64.45	35.53	0.02
M6	7.57	1.12	-0.39	0.82	45.01	53.20	1.79
M7	7.38	1.07	-0.30	0.99	60.94	35.89	3.17
M8	5.58	2.57	-0.54	0.76	46.92	50.44	2.64
M9	7.01	1.25	-0.25	1.02	49.85	47.68	2.47
M10	5.61	2.19	-0.30	0.83	21.34	77.32	1.34
M11	6.57	1.37	-0.17	0.81	59.01	40.49	0.50
M12	6.29	1.89	-0.42	1.02	18.32	80.28	1.40
M13	5.40	2.64	-0.48	0.71	65.78	32.68	1.54
70	1.19	0.50	-0.23	1.37	99.14	0.47	0.39
71	1.20	0.38	-0.16	1.09	98.71	0.80	0.49
72	-0.25	0.88	+0.03	1.08	63.09	35.92	0.99
73	4.14	2.88	+0.09	0.63	80.65	18.43	0.93
74	1.04	0.32	-0.26	1.19	98.65	0.78	0.57
75	1.46	0.50	-0.17	1.44	98.22	1.16	0.62
76	3.61	0.86	+0.41	1.57	74.49	24.63	0.87
77	2.96	3.37	-0.11	1.10	79.41	19.38	1.21
78	6.00	1.62	-0.17	0.86	60.18	38.84	0.98
79	1.53	0.65	+0.13	1.13	89.05	10.75	0.20
80	5.65	1.90	-0.21	0.08	65.39	33.40	1.22
81	5.07	2.31	-0.18	0.70	60.87	37.74	1.39
82	-0.06	0.73	-0.09	1.89	97.19	2.38	0.44
83	0.72	0.66	+0.02	1.47	97.43	1.74	0.83
84	-0.36	0.86	+0.25	1.21	94.73	4.44	0.83
85	-0.09	0.69	+0.02	1.45	98.57	0.89	0.54
86	-0.57	2.15	+0.03	1.12	96.53	2.84	0.63
87	1.28	0.62	-0.22	1.15	97.76	1.46	0.78
88	0.74	1.00	-0.20	1.41	97.72	1.53	0.75
89	-0.93	2.18	+0.06	0.94	97.89	1.43	0.68
90	0.25	1.94	+0.10	0.90	97.54	2.23	0.23
91	0.15	1.36	+0.08	1.20	97.59	1.81	0.60
92	0.74	1.70	-0.10	0.96	95.59	4.00	0.41