SEDIMENTOLOGY OF KAHANA BAY, OAHU, HAWAII

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

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INTRODUCTION

Purpose of the Study

The objective of this study was to present a detailed description of the sedimentology of Kahana Bay, concentrating in particular on sediment transport within this littoral cell. Coastal embayments formed by existing streams are ideal configurations for this purpose, since the interrelationships between fresh and sea-water mixing, between detrital and reef-sediment deposition, and between brackish-water and marine microfaunal death assemblage accumulation, can be investigated. Embayments such as these are characteristic of the deeply indented windward or northeast coasts of the Hawaiian Islands.

Using Kapaa, Kauai as a study area, Inman *et al*. (1963) generalized the nature of littoral sedimentary process on windward coasts of subtropical islands. They concluded that rivers flowing on windward sides of such islands carry silt and clay size material, but only minor quantities of grains large enough to be classified as sand. Windward beaches were found to be mostly calcium carbonate, with only very minor fractions of detrital sediment. Their data also suggest that water circulation and sediment transport perpetuate submarine canyon locations; and that such features traversing reef flats constitute individual cells of water circulation and sediment transport. Under this study, these generalizations have been tested by making a detailed investigation of a single littoral cell.

For this study I chose Kahana Bay (Figure 1), an ideal area. The bay, a large coastal embayment formed by a substantial stream, is largely undeveloped, and is ecologically unspoiled by the intrusion of developers. It also has a ramp suitable for launching small boats.

Geologic Setting

Kahana Bay is located on the northeast (windward) coast of Oahu, Hawaii (Figure 1). Prior to this investigation, only general survey work has been done in the area. The coast between Laie and Kaaawa is described by Moberly (1963). A brief description of Kahana Beach is given in Moberly and Chamberlain (1964) with beach profiles (taken between March 1962 and September 1963), results of grain size analysis for several samples, as well as jet probe penetrations are presented in the appendix to their report. A general description of the Kahana Stream watershed is presented in Cox and Gordon (1970), and may also be found in the Oahu Water Plan (1963).

Kahana Bay is the coastal expression of the topography of Kahana Valley. Precipitous ridges, 1,000 to 1,800 feet high border both sides of the valley and are joined by a crescent-shaped beach that protects a flat, swampy, valley floor. The valley extends about 3.5 miles inland from the

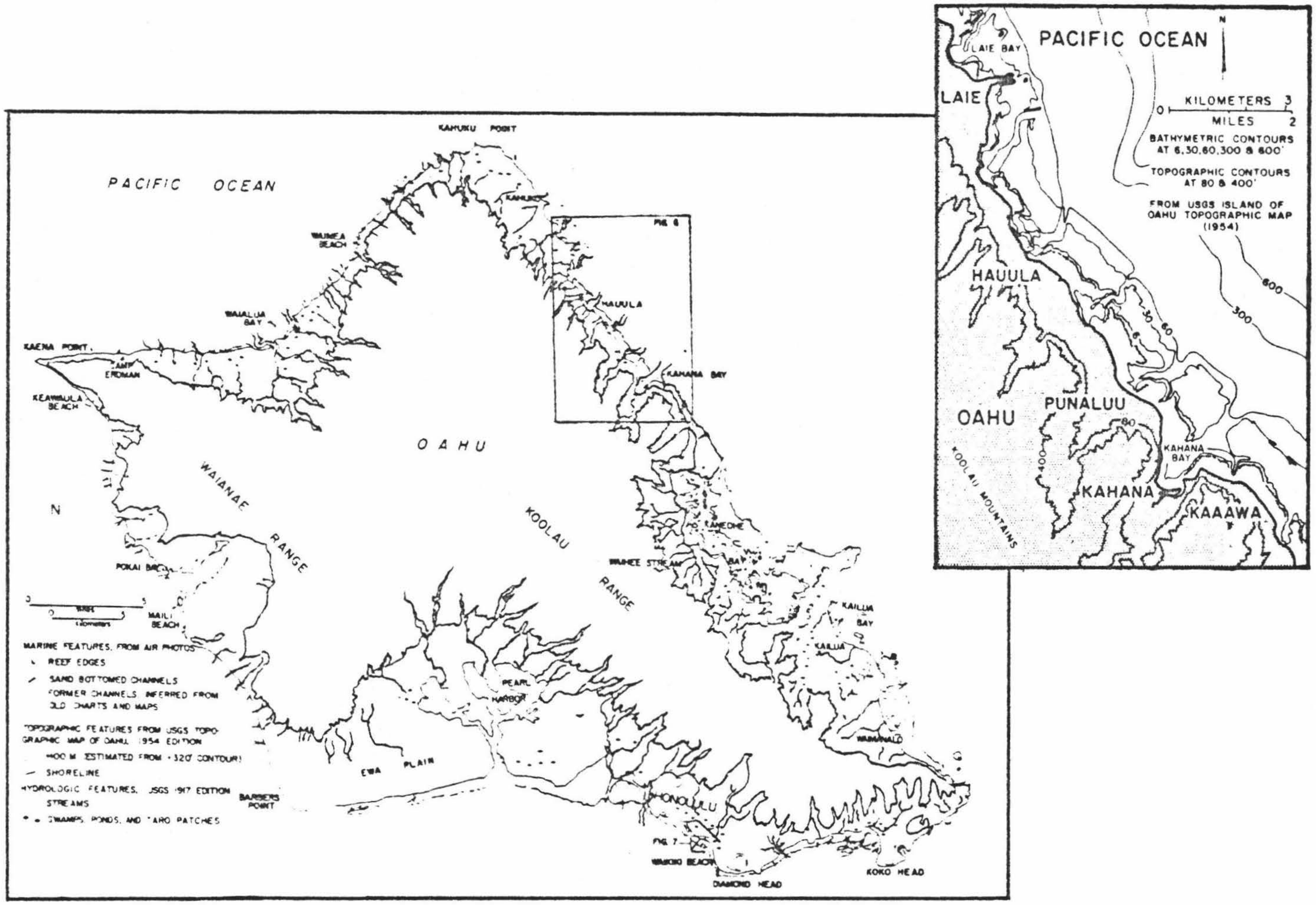


Figure 1. Location map for Kahana Bay (after Moberly, 1968).

coast to the source of Kahana Stream on the Koolau ridge. The upper stream course lies over a boulder bed and the stream is lined by dense tropical vegetation. In its lower course about 1.5 miles inland from the sea, the stream begins to meander over the swampy terrain of the lower valley. The stream channel here is bordered by high swamp grasses and in places is completely covered by hau trees. Two former beach ridges are located immediately inland of the present-day shoreline. These beaches are marked by sharp stream meanders and stands of ironwood trees. Ironwood trees also line the present-day beach. The sand of the fossil ridges is now consolidated, and this rock is plainly visible on the stream banks due to its light-brown color.

Rainfall over the watershed of Kahana Valley ranges from 75 inches per year at the bay shore, to 240 inches per year at the Koolau crest (Mink *et al.*, 1963). Kahana Stream flows throughout the year, reaching the sea through a permanent channel at the eastern corner of the bay. Floods resulting from heavy rains open an intermittent flood channel at the central part of the beach. Discharge across the beach at that location has occurred only once since November 1968, following the heavy rains of April 1971. A second small stream crosses the western end of the beach.

Huilua Pond, located in the southeast corner of the bay (Figure 2a), is the remnant of an old Hawaiian fishpond which has now deteriorated into a salt-water marsh. On its seaward sides, it is bordered by dilapidated boulder walls. A sand bar, shallow enough to be exposed at very low tides, extends from the seaward corner of the pond to a point about one third of the distance across the bay. The end of the bar is ill-defined since it gradually merges with the deeper bay floor toward the western side of the bay.

Extending out from the shoreline along the east and west periphery of the bay are fringing reefs whose depths range from a little over 10 feet at the outer reef edges to sea level, where blocks of coral along the eastern reef margin are exposed at low tides. The boundaries of the reefs as interpreted from aerial photographs are shown on Figure 2a as dashed lines. Except in nearshore areas, the reef edges are vertical cliffs, extending down 30 feet or more to the sandy bottom of the bay. A patch reef is in the northwest portion of the bay.

Relief is contoured on Figure 2a in 1-fathom intervals. These data were obtained using a Raytheon Portable Fathometer Depth Recorder (Raytheon Company, San Francisco, California) operated from a small boat along the tracks shown in Figure 2b. In addition to these records, spot soundings were taken at various stations. All positions were fixed by horizontal sextant angles to various shore points, and all depths were corrected to mean lower low water (mllw). Deeper water soundings were obtained from U.S.C. & G.S. Map Register No. 3252, "Kahana Bay to

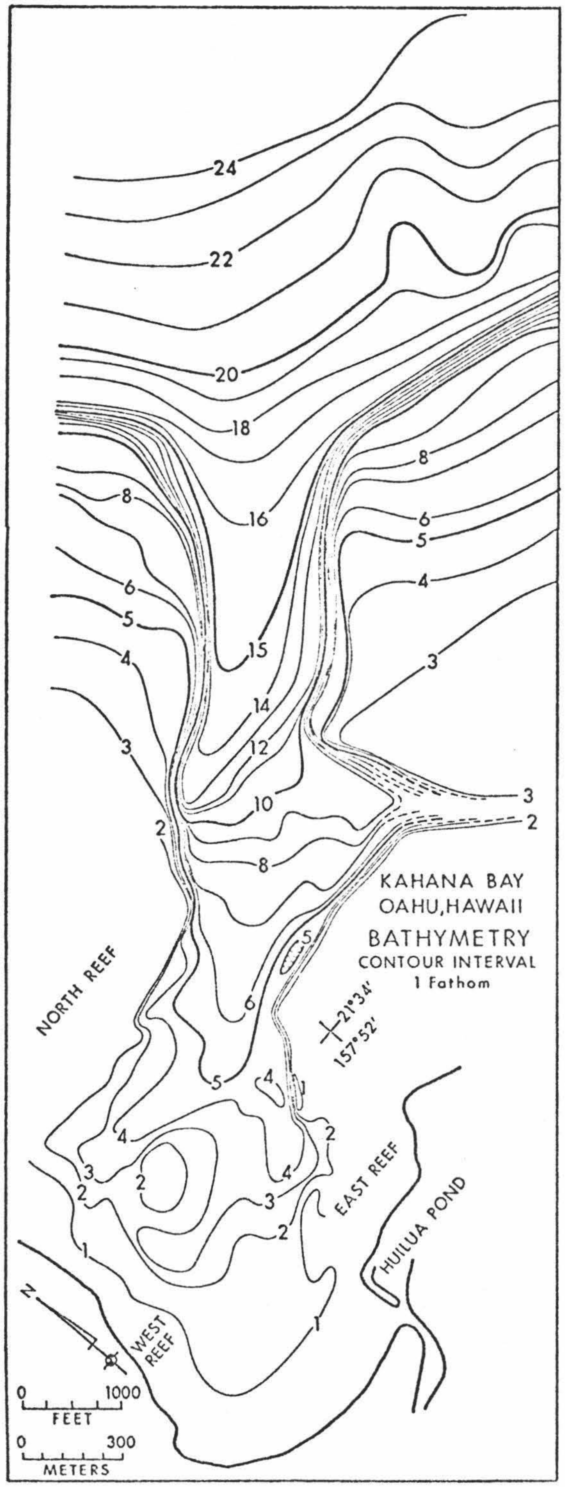


Figure 2a

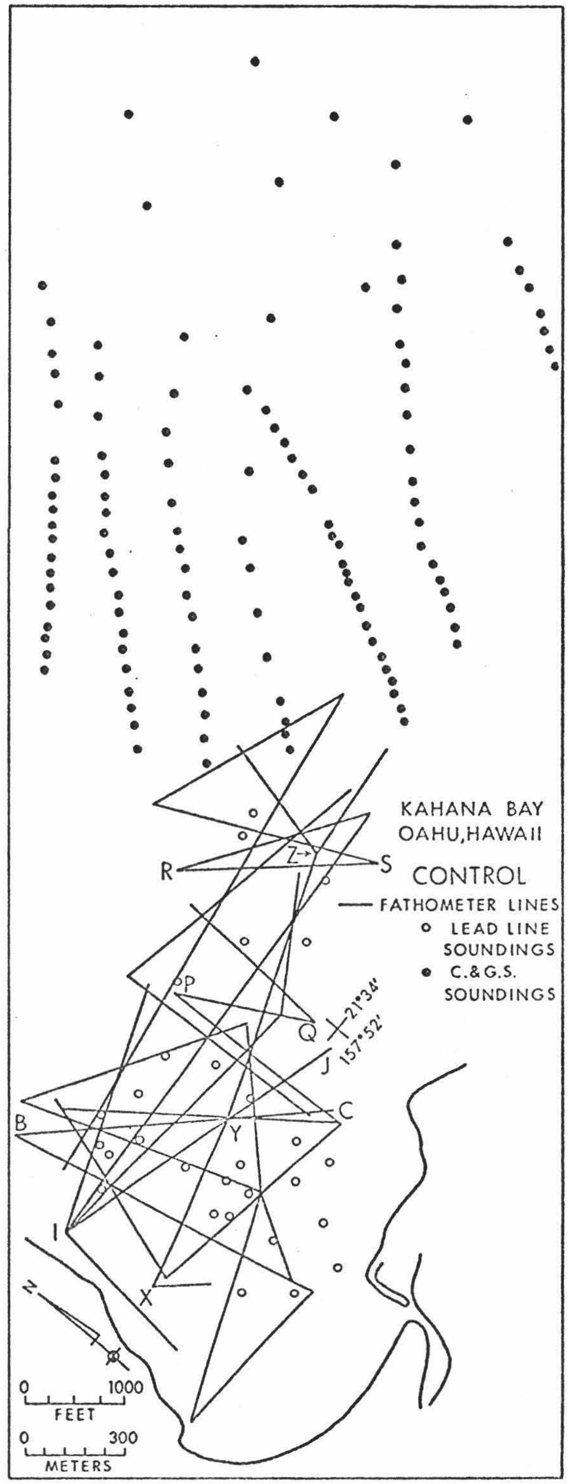


Figure 2b

Mokapu Point."

The data show that the sand channel floor is generally flat, and slopes gradually seaward (Figure 3, profile X-Y-Z). Visual observations during numerous SCUBA dives showed the sands on this portion of the floor to be rippled as far offshore as sample location 600-F (Figure 14). The crests of the ripple marks are aligned in a northwest to southeast direction. Contacts of the sandy bottom against the reef walls are quite abrupt, and generally consist of a 90° break in slope (Figure 3, profiles B-C, I-J, P-N, and R-S). There is a lack of talus accumulation at the base of the eastern reef margin, and depths actually increase near the reef walls. Roy (1970) found similar depressions surrounding patch reefs in Kaneohe Bay, and suggests that they are due to increased current velocity and turbulence... "related to the obstructive presence of the patch reefs." Similar depressions described by Emery _et al_. (1954) at Bikini Atoll are attributed to the geometry of acoustical reflection off coral knolls, whereas Lowenstam's (1950) investigation of Niagran reefs indicate that such marginal depressions are due to subsidence of these large reefs into underlying compressible sediments. If the sequence of reef limestone alternating with shallow water and subaerial sediments, described in Cores Ewa I and Ewa II (Resig, 1969), is analagous to that at Kahana Bay, it is possible that such reef settlement might be responsible for these 'moats'.

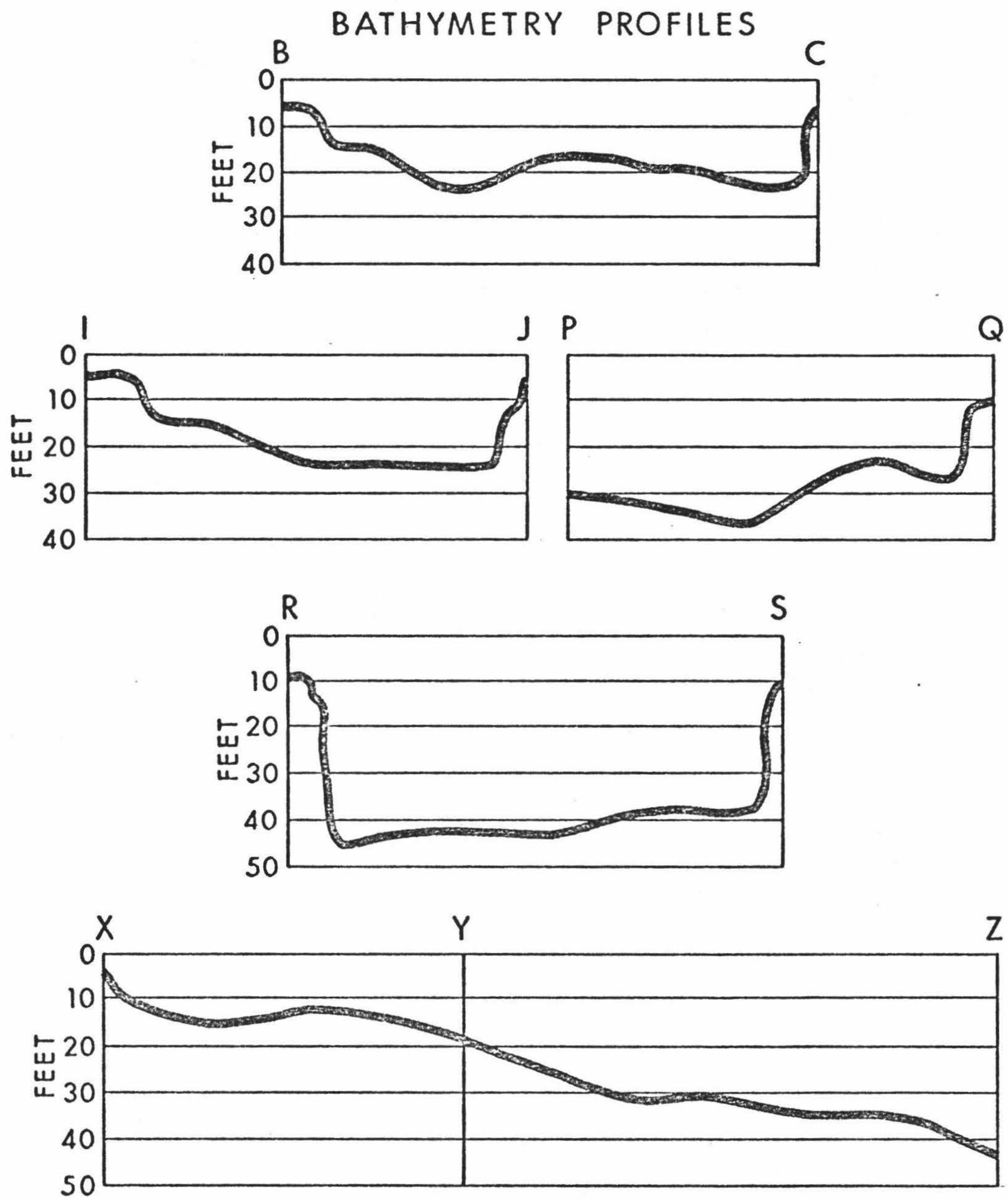


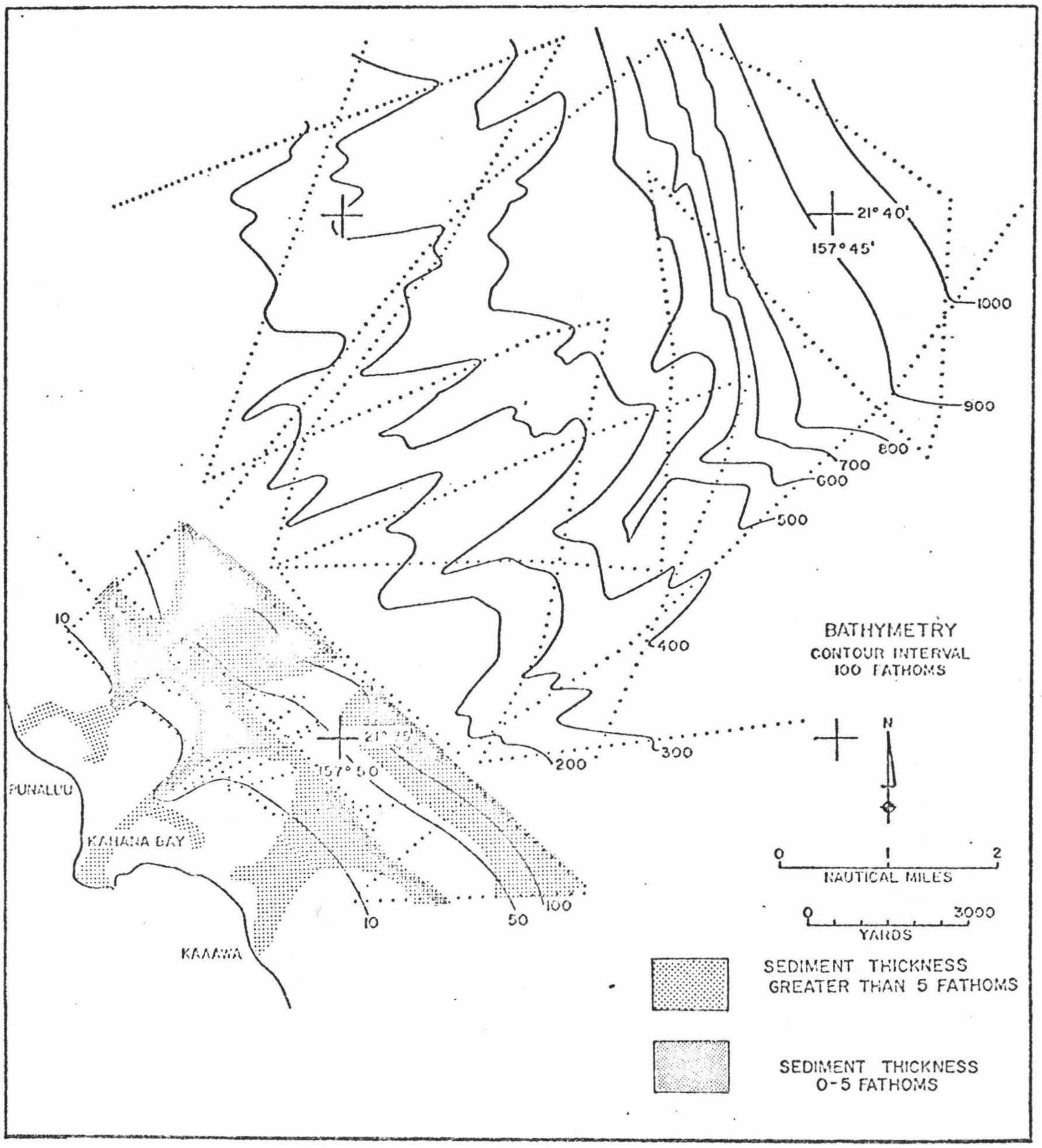
Figure 3

However, scouring of sediments during periods of high stream discharge seems to be a more likely explanation.

The border of the eastern reef is broken by a channel that runs approximately parallel to the shoreline. Aerial photograph interpretation suggests that this feature has a mixed sand and coral bottom, and that it extends eastward towards the town of Kaaawa with smaller tributary channels branching shoreward.

The data from U.S.C. & G.S. Map No. 3252 (Figure 2a) and survey work by Pararas-Carayannis (1965) both indicate that, physiographically, Kahana Bay resembles the head of a submarine canyon. The bathymetric expression of the canyon vanishes at a depth of 17 fathoms, and does not reappear until depths of 120 fathoms are reached. The steep contour gradients between 10 and 15 fathoms mark the reef foreslope.

Seismic reflection data at depths from 10 to 120 fathoms were obtained using a Uniboom (E.G. & G., Environmental Equipment Division, Waltham, Mass.) as a sound source. The quality of data obtained for this section of the shelf is excellent and sub-bottom reflectors are clearly visible. The portion of the shelf between 10 and 120 fathoms (Figure 4) is generally characterized by smooth sea-floor topography consisting of a thin veneer of sediment covering a more irregular basement. A similar smooth shelf extending to about 65 fathoms depth is shown on Mathewson's (1970) bathymetric map of windward Molokai. The record obtained



5 fathoms or greater sediment thickness

0 - 5 fathoms sediment thickness

Figure 4

from one track parallel the shore off Kahana Bay at about 30 to 40 fathoms depth was exceptional, because it revealed two sub-bottom reflectors. The deepest is assumed to be basement of basalt rock. The shallower reflector is horizontal and presumably represents an old reef surface, in turn blanketed by a sediment layer that is 5 to 10 fathoms thick.

Another very prominent feature between Kaaawa and Punaluu is the wedge of sediment at 30 to 40 fathoms. A distinct rock terrace at 40 fathoms depth is masked by this sediment. The work of Campbell et al. (1970) off the leeward Oahu coast shows that either there is no terrace at 40 fathoms, or, where present, the terrace is narrow or merges gradationally with the more common 50-fathom terrace. Stearns (1935) described a -300 foot (50 fathoms) Pleistocene shoreline for the Hawaiian Islands. Ruhe et al. (1965) named it the Mamala shoreline, and found that, for the 187 Oahu profiles they examined, this terrace depth ranges from 41 to 68 fathoms with a mean depth of 57.6 fathoms. Off Kahana the slope of the shelf noticeably increases at depths greater than 50 fathoms, suggesting that the break in slope is a product of the 300-foot lowerings of sea level during the Pleistocene.

Sediment accumulations are thin or entirely absent at depths between 40 and 50 fathoms (Figure 4). Wave energy during the -300 foot, Mamala stands probably transported much of this sediment offshore to depths beyond the 50-fathom contour.

At depths greater than 120 fathoms, bathymetric relief increases and the smooth shelf topography gives way to rugged ridges and canyons. Figure 4 shows three distinct submarine canyons aligned with their subaerial counterparts off Kaaawa, Kahana, and Punaluu valleys. Kahana canyon is the largest of the three and appears to merge with Kaaawa canyon between 400 and 500 fathoms depth. This canyon can be followed to 900 fathoms depth. Hamilton (1957) has traced the canyon to a sediment fan at depths between 1,000 and 1,500 fathoms.

Shepard (1948, p. 236) and Mathewson (1970) have shown a similar alignment of subaerial and submarine canyons along the windward Molokai coast. The work of Shepard and Dill (1965) off the Napali coast of northwest Kauai shows that submarine canyons are aligned with their subaerial counterparts off Honopu, Hanakoa, and Hanakapiai valleys. In both areas, as off Kahana, the subaerial and submarine portions of the same valleys are interrupted by the smooth nearshore shelf. Indentation of contours drawn from U.S.C. & G.S. Map Register No. 4719, "Kokole Pt. to Kailio Pt.," suggest that canyons off the northwest coast of Kauai head at about depths of 60 fathoms. The bathymetric map presented by Mathewson (1970) clearly shows that submarine canyons off windward Molokai also head at about 60 fathoms. However, Kaaawa, Kahana, and Punaluu canyons first appear distinctly between 120 and 160 fathoms. The absence of the bathymetric continuity of all these submarine canyons is attributed to the accumulation of sediment on a basement topography significantly modified during numerous lower stands of sea level. The sea level fluctuations leveled promentories, while coral growth filled the valleys. Expression of the heads of submarine canyons at different depths on different islands may result from varying rates of reef growth and sediment production on the nearshore shelves of these three islands.

Only after isopachs of the sediment thickness are plotted is it possible to prove the continuity of onshore river valleys with the submarine canyons. Of the three canyons shown in Figure 4, only Punaluu is clearly continuous. Sediment thicknesses in the axis of this canyon were found to be in excess of 10 fathoms for traverses made at depths of 30, 40, 50, and 120 fathoms. The combined effects of erosion and reef-building during the Mamala sea levels reduced the expression of the basement rock of Kahana canyon and erased all traces of Kaaawa canyon in the 40- to 59-fathom interval.

The presence of the sediment wedge at 40 fathoms depth off Kahana Bay, and of similar wedge-shaped deposits off leeward Oahu (Campbell *et al*., 1970) makes it clear that seaward transport of sediments is not confined exclusively to submarine canyons. Brock and Chamberlain (1968) also observed patches of sand on terraces off leeward Oahu. This evidence suggests that much of the sediment found offshore has never been on the beaches, but instead is transported seaward directly across the terraces.

This report will focus on the sedimentology shoreward of the 15-fathom contour line. The study area includes two terrestrial physiographic provinces and three aquatic environments which together comprise the geomorphic entity of Kahana Bay and Valley. On the land there is a sharp contrast between the flat valley-floor sediments and the surrounding steep ridges and cliffs that are their source. A brackish-water swamp and stream environment is separated from the sandy bottom environment of the channel by the present-day beach ridge. Flanking the channel is a shallow-water, reef-flat environment characterized by high salinity and surf agitation.

PHYSICAL OCEANOGRAPHY

Kahana Bay is exposed to prevailing northeast trade-winds and waves. Open-ocean swells on passing through the deep channel entrance must diverge across the width of the inner bay. The loss of energy associated with this phenomenon is responsible for the small wave-heights usually observed along the beach. Breaking waves rarely exceed two feet. The shoreline of the western half of the beach and the boat ramp have the greatest nearshore wave action. Frequently, surf forms over the patch reef. From this area seaward, swell height gradually increases and once beyond the shallow reef edges there is no protection from the open ocean swell and wind chop.

The physical oceanography of the bay was studied to obtain generalized and specific patterns of salinity and temperature distribution, in the event that a consistent relationship was found to exist between water properties and sediment type. However, the study was not intended to provide an exhaustive and precise survey of hydrographic properties and seasonal fluctuations, but merely to relate temperature and salinity patterns to various wind directions.

Methods

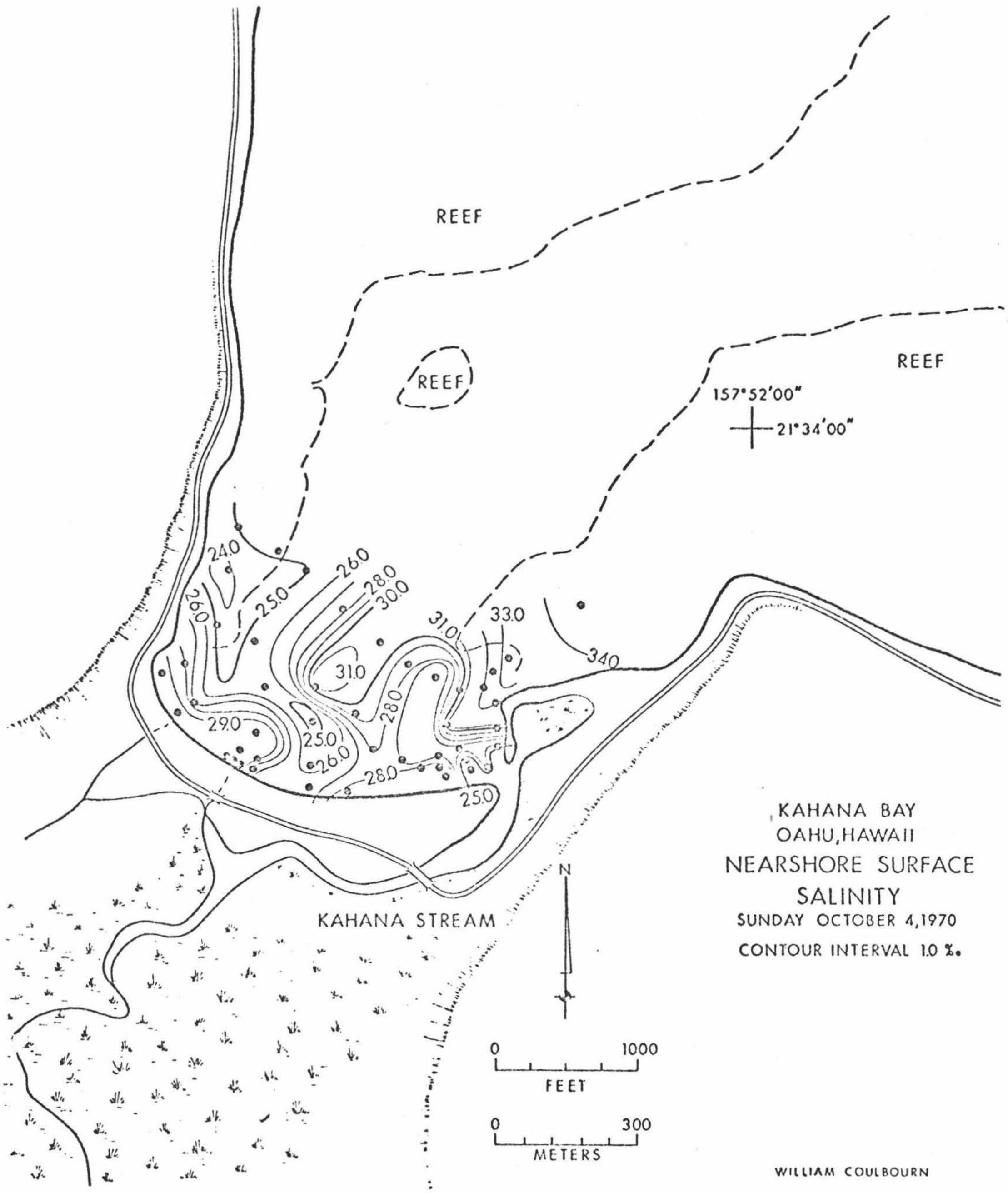
A variety of techniques was employed for taking data in the field. Salinity was measured in situ as a function of conductivity and temperature. A portable conductivity meter (RB3 - 3341 SOLU BRIDGE, Industrial Instruments Inc., Cedar Grove, New Jersey) was used. This portable self-powered unit was connected by a 55-foot cable to the sensor, making possible measurements at depths up to 50 feet. The instrument also contained a thermometer. However a more accurate instrument (MODEL M11 TCD, Martex Instruments Inc., Newport Beach, California) was available from which readings to the nearest .25°C could be estimated after an initial calibration with a mercury thermometer. The sensor for this portable instrument is mounted on a 30-foot-long cable.

The data obtained from this equipment were used to compile composite maps (see Figures 9 to 12), that represent surface and bottom salinity and temperature over the following dates: February 21, March 6, 11, 15, 22, and 28, 1970. None of the figures represent a synoptic picture of water properties in the bay, but each does show some generalized features, as discussed in the following section.

Nearshore data taken on October 4, 1970, and October 13, 1970, required that a large number of samples be taken quite rapidly so that a near-synoptic pattern might be obtained. This was done by utilizing a very portable device created at the University of Hawaii by Dr. L. Lepley. A Taylor Permax Hydrometer (No. H4807 astm 89H, Range .995 - 1.055 gm/cc, Taylor Instrument Companies, Rochester, New York) is placed in a clear tube, approximately 2 inches in diameter and about 18 inches long, corked at one end, and fitted with a disc-shaped thermometer at the other. Small "finger" holes, about 1/2-inch in diameter, are drilled in the tube sides at the top and bottom. Sampling is carried out by immersing the tube in the water until full. Placing fingers over the holes, the temperature is then read and recorded, and then nearly half the water is allowed to drain out. The level at which the hydrometer floats is recorded. Knowing the temperature and density makes a conversion to salinity possible. Data acquired by this method are shown in Figures 5 to 8. Tidal fluctuations certainly should affect these readings, since sampling generally took 5 hours or more, so that usually one high and low tide occurred. It is obviously not practical, within the capabilities of this project, to obtain simultaneous readings over the entire area, therefore tidal effects are ignored in the presentation and discussion of the data.

Daily Salinity and Temperature Patterns

Figures 5 and 6 show salinity and temperature patterns respectively under partly sunny skies, surf less than 1 foot in height, and tradewinds less than 15 knots. The preceding two days had periods of heavy rainfall from a southwesterly, or "kona," storm. The stream discharge was probably above the average of 7.2 million gallons per day reported by Cox and Gordon (1970) at the time these readings were taken. Figure 5 shows that less saline water is associated with the stream mouth and displaced to the west by more saline water from the shallow reef flat seaward of Huilua Pond. Some of the fresher stream water appears to cross the shallow sand bar built across the river mouth, while the remainder is confined shoreward of this barrier until the deeper water of the central bay is reached. At this point the discharge proceeds seaward across the western half of the bay. The surf zone of the western part of the bay is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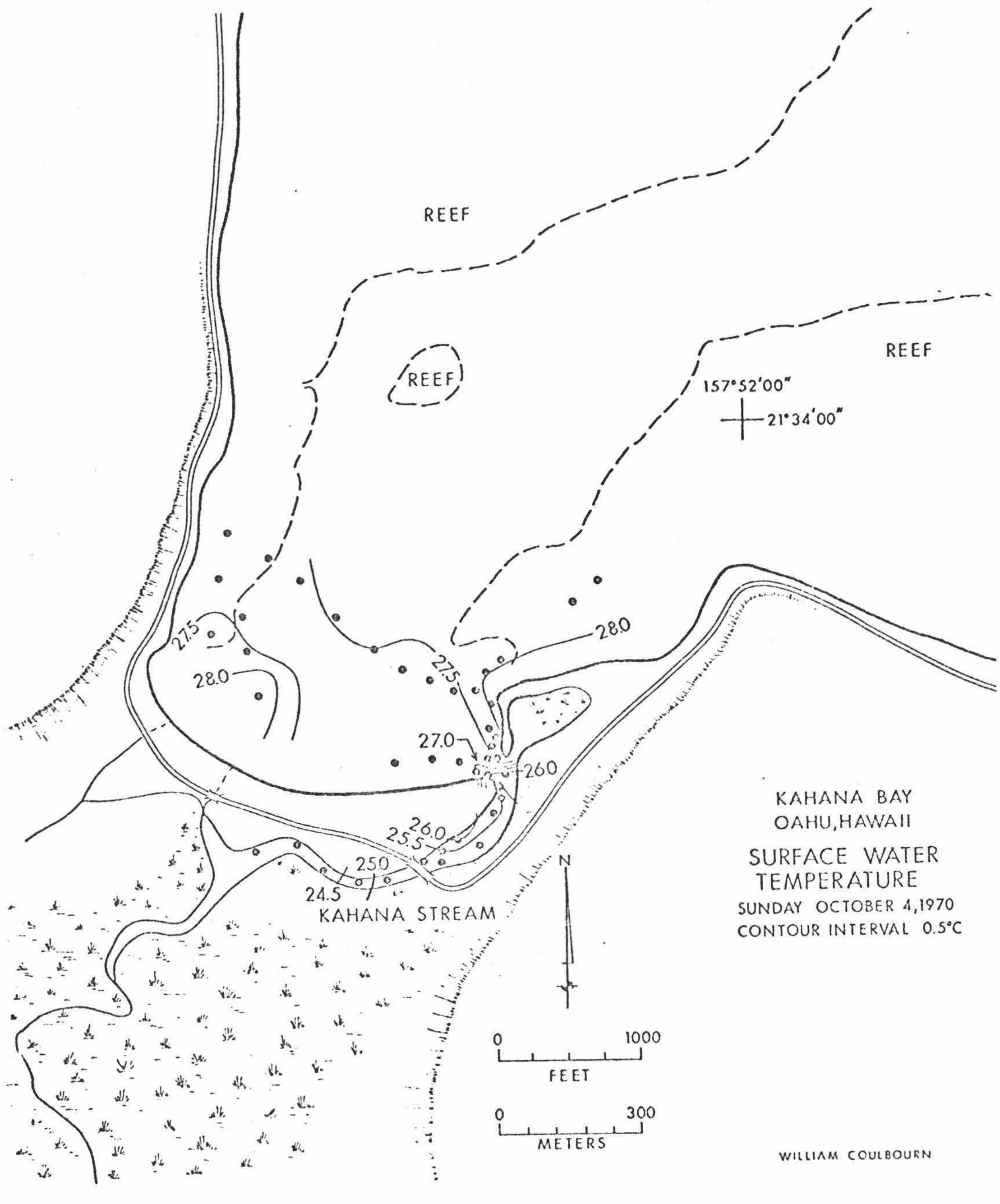
KAHANA BAY
OAHU, HAWAII
NEARSHORE SURFACE
SALINITY
SUNDAY OCTOBER 4, 1970
CONTOUR INTERVAL 1.0 ‰
WILLIAM COULBOURN

Figure 5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KAHANA BAY
OAHU, HAWAII
SURFACE WATER
TEMPERATURE
SUNDAY OCTOBER 4, 1970
CONTOUR INTERVAL 0.5°C
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METERS
WILLIAM COULBOURN

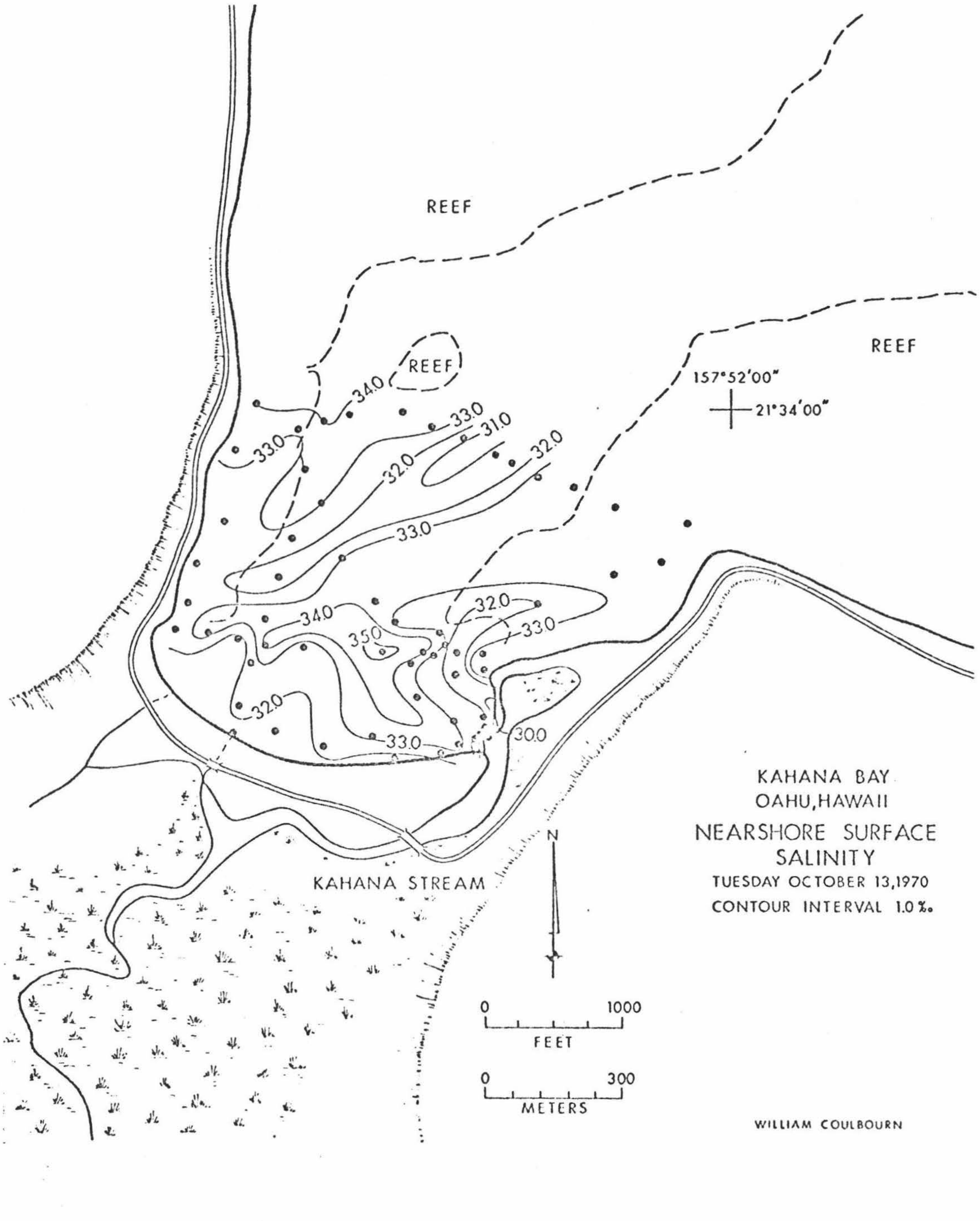
Figure 6

a pocket of relatively saline water. Strong temperature gradients, Figure 6, were found associated with the river mouth only on this day.

Figures 7 and 8 show the pattern of salinity and temperature on an overcast day, with intermittent showers and light offshore winds. The stream discharge then appeared to be directed over the shallow river-mouth bar and out onto the reef flat. Reduced salinity and temperature indicate seepage through the beach near the intermittent stream flood channel. There is a reduction of salinity in a southwest to northeast trending band across the center of the bay.

General Salinity and Temperature Distribution Offshore

Figures 9 through 12 indicate that areas of lower salinity and temperature are associated with the reef margins. These areas are probably not as extensive in the field as the data suggest. For example, in Figure 11 low temperatures prevail along the western reef edge, while Figure 9 shows reduced salinity over the same area. Along the eastern border of the channel, areas of low salinity are quite localized. This distribution is the surface expression of fresh-water springs that are flowing out from the reef margins. These were very noticeable during SCUBA dives as areas of cold water. In the course of a dive along the reef wall one would pass through several such cold and warm patches attesting to the spotty distribution of the



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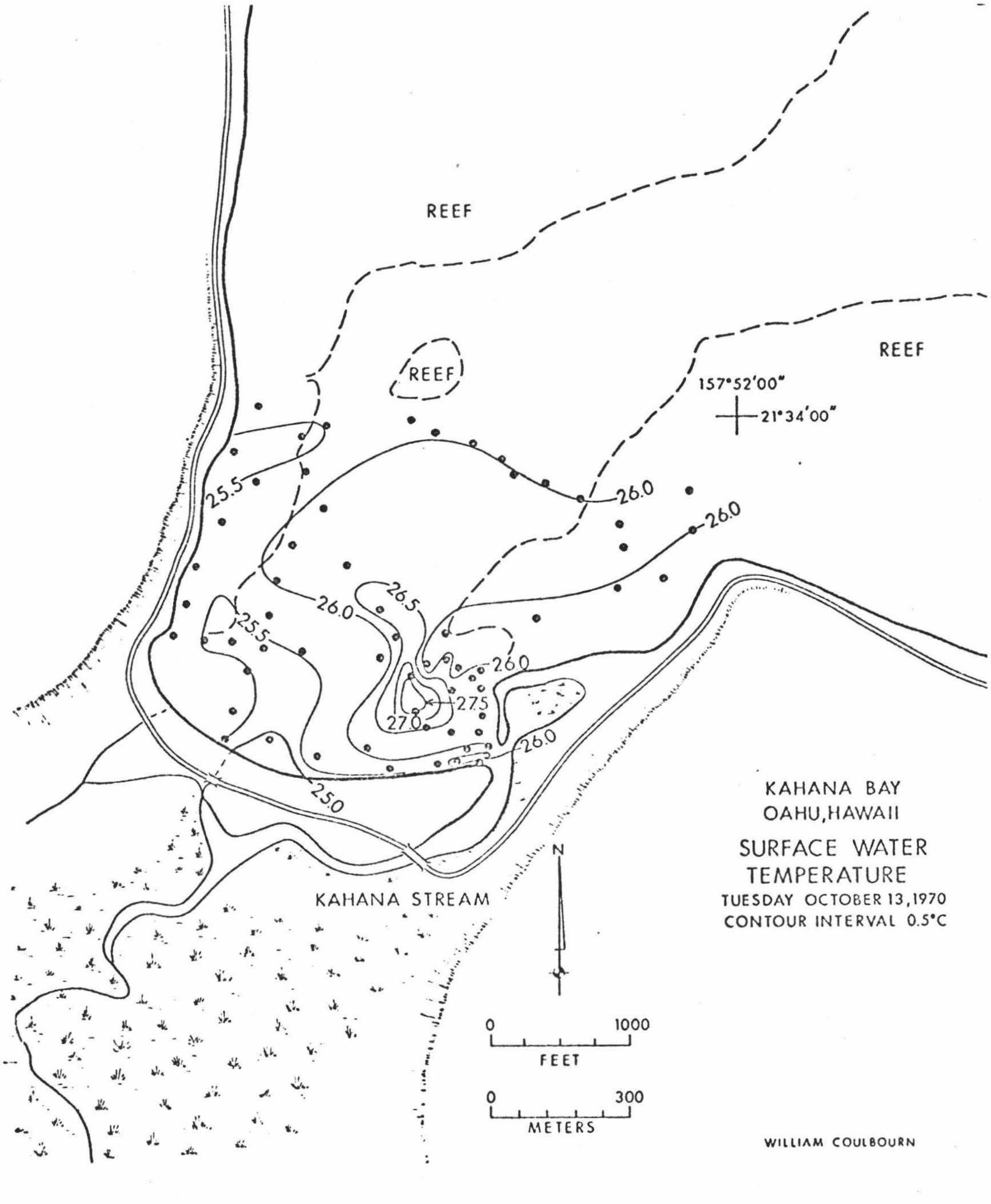
KAHANA BAY
OAHU, HAWAII
NEARSHORE SURFACE SALINITY
TUESDAY OCTOBER 13, 1970
CONTOUR INTERVAL 1.0 ‰
WILLIAM COULBOURN

Figure 7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OAHU, HAWAII
SURFACE WATER
TEMPERATURE
TUESDAY OCTOBER 13, 1970
CONTOUR INTERVAL 0.5°C
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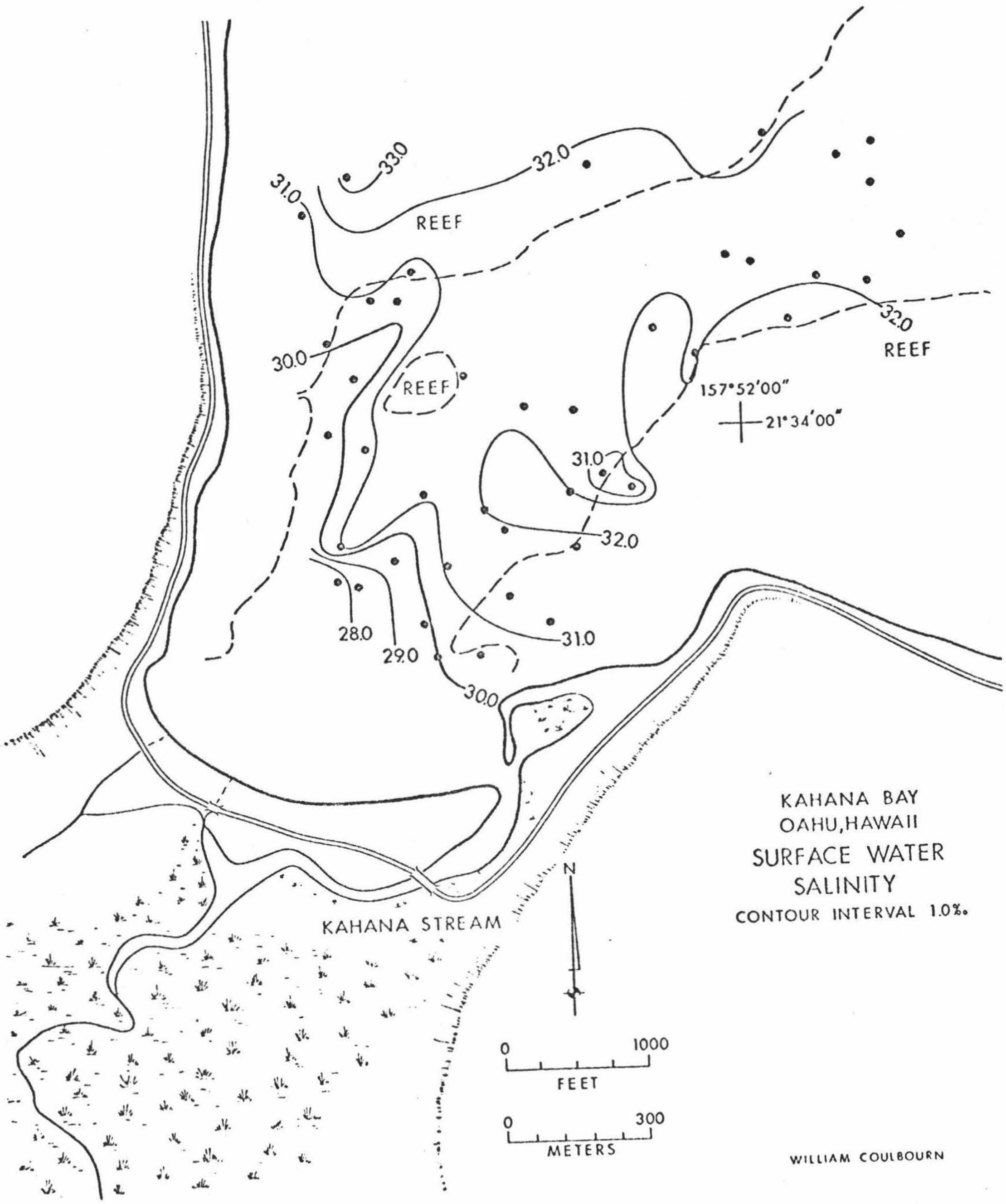
METERS
WILLIAM COULBOURN

Figure 8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KAHANA BAY
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SURFACE WATER
SALINITY
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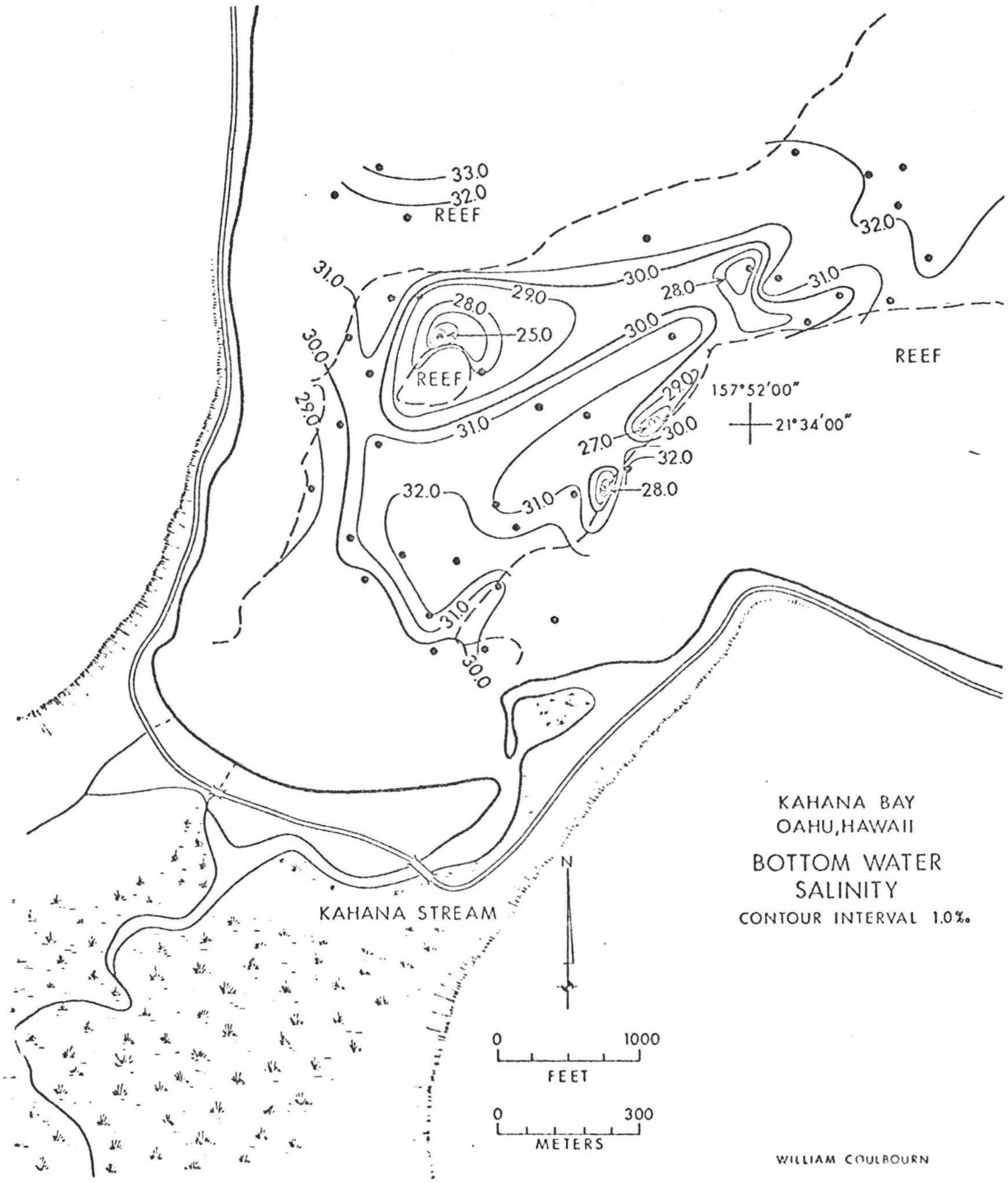
WILLIAM COULBOURN

Figure 9



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OAHU, HAWAII
BOTTOM WATER
SALINITY
CONTOUR INTERVAL 1.0‰
KAHANA STREAM
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WILLIAM COULBOURN

Figure 10

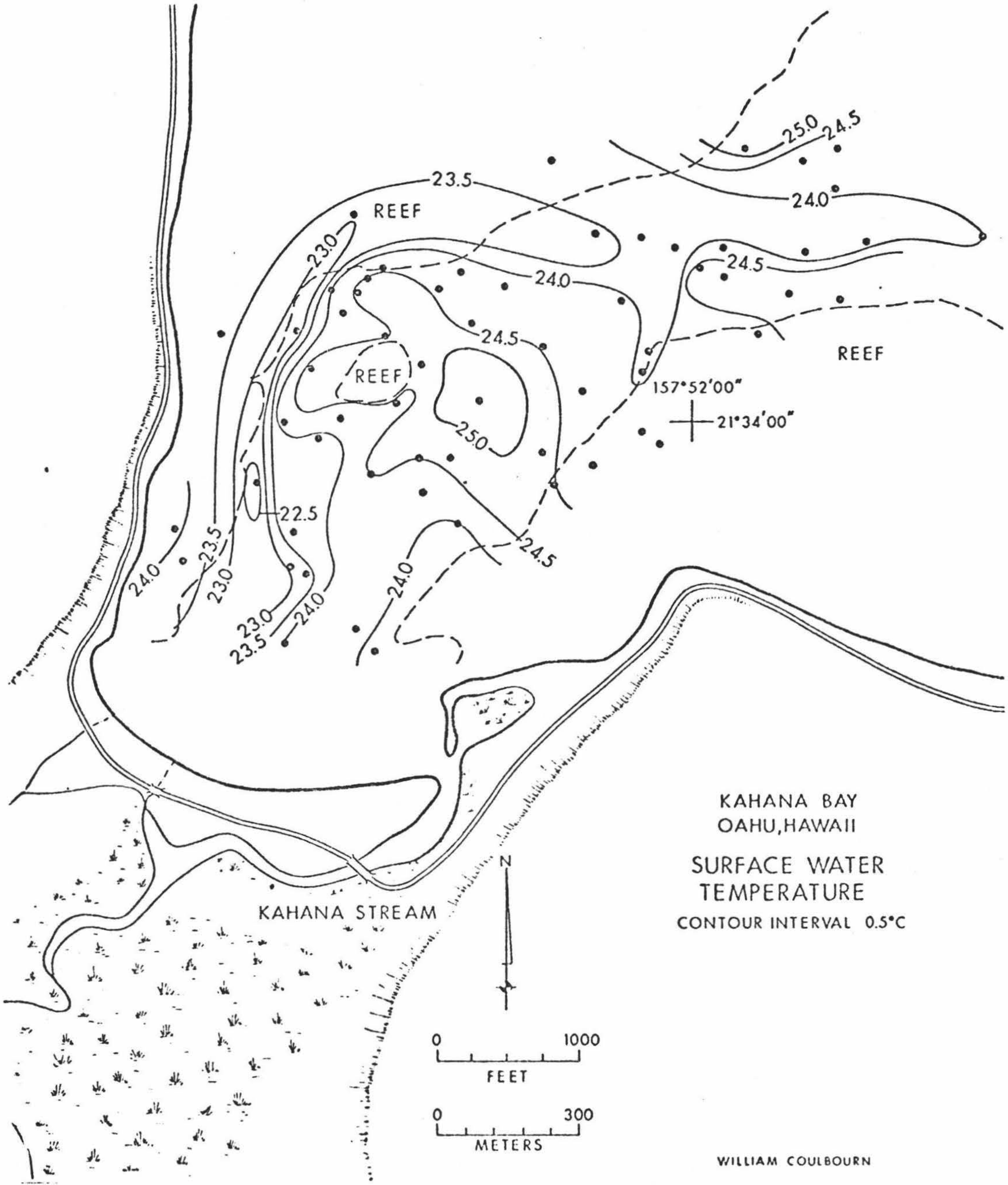
KAHANA BAY
OAHU, HAWAII
SURFACE WATER TEMPERATURE
CONTOUR INTERVAL 0.5°C
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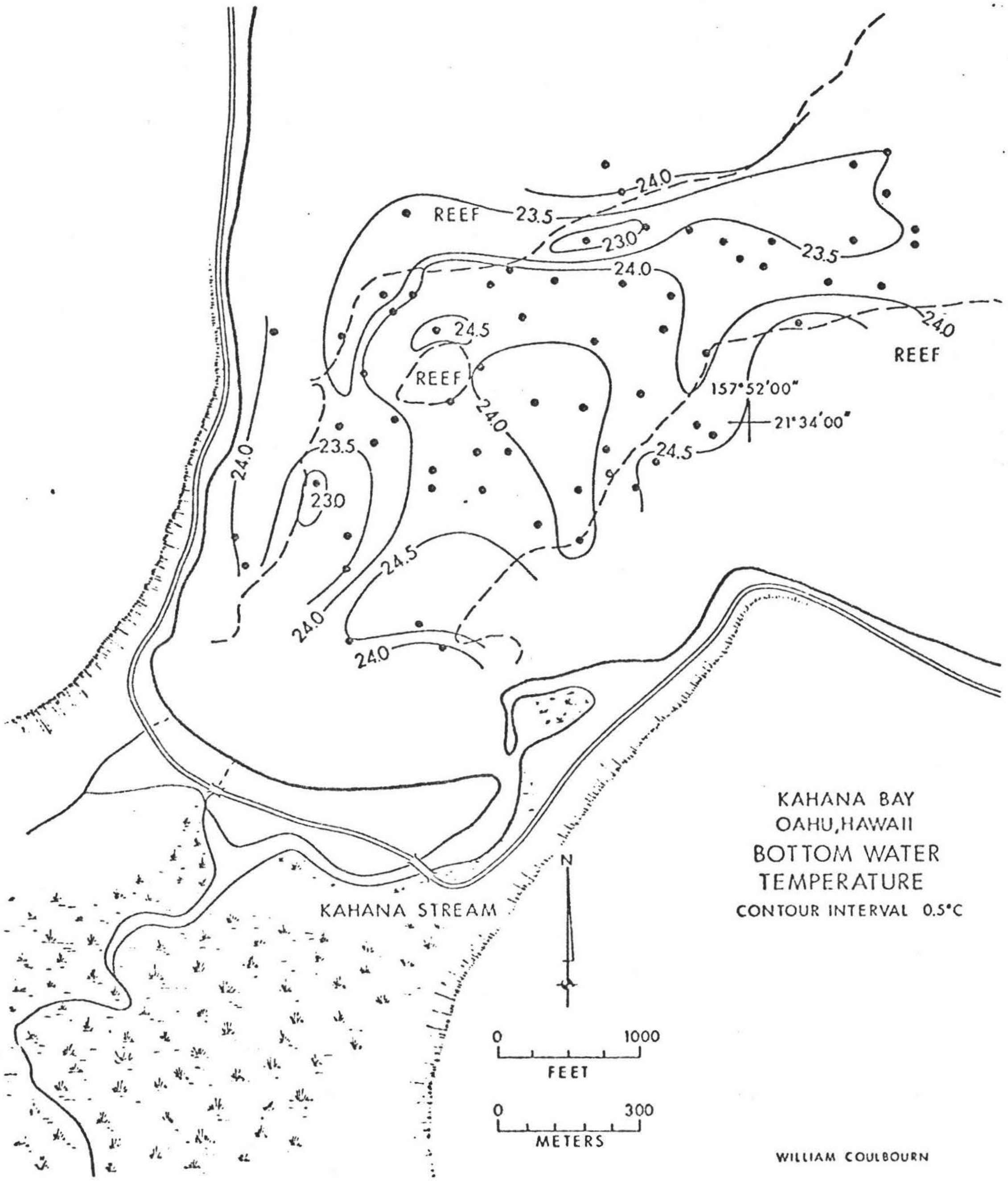
Figure 11



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OAHU, HAWAII
BOTTOM WATER
TEMPERATURE
CONTOUR INTERVAL 0.5°C
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METERS
WILLIAM COULBOURN

Figure 12

springs. Dives in the central part of the bay revealed no sharp variances in temperature.

Bottom Currents

A current meter (Model 501, Hydro-Products Division of Dillingham Corp., San Diego, California) was moored about 1 foot off the bottom at a point 50 feet west of station 606 (Figure 15) at a depth of about 30 feet. Data obtained between February 6, 1971, and February 10, 1971, indicate that bottom currents fluctuated between 0.1 and 0.3 knots and that water temperature was constant at 22°C. The directional component of the record was sporadic due to a faulty connection between the sensor and the recorder. The data received indicate the bottom water oscillates and is capable of 180-degree reversals in direction in a matter of seconds. During the process of mooring the meter, divers also observed this oscillating water motion, which is probably caused by waves passing around the sharp bend of the eastern reef margin. This type of meter was not suitable for measuring the net current.

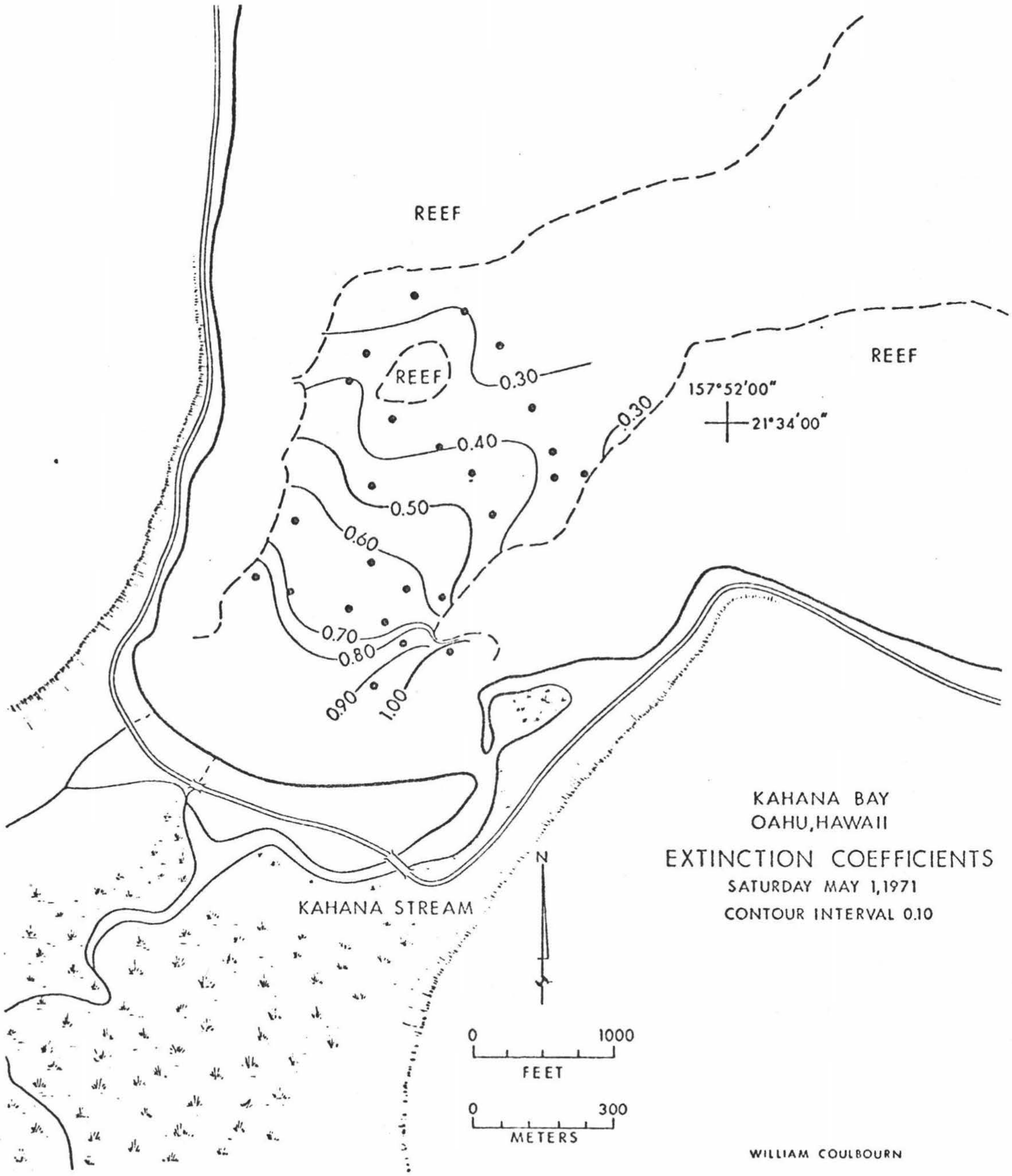
Turbidity

Kahana Stream water is characterized by a suspended load of fine, rounded basalt fragments, clay minerals, and organic material. After heavy rains, water far out into the bay is discolored by suspended sediment for several days. Aerial photographs, SCUBA dives, and turbidity measurements suggest that the eastern side of the bay is generally more turbid than other areas.

The border of the turbid water to the west is frequently marked by a line of floating debris, including leaves, branches, and grasses in the general area of the patch reef. Figure 13 shows the values of turbidity plotted in terms of the extinction coefficient, k:

$$k = 1.7 / D$$

where D is the maximum depth in meters at which a white disc 30 cm in diameter is visible from the surface (Pickard, 1963). Values of k greater than .70 are generally confined to the inner bay (Figure 13). Two turbid areas extend seaward on either side of the channel, the most prominent of which is located towards the eastern side of the channel, while the other, associated with the lee side of the patch reef, is due to an unusual breakthrough at the flood channel, allowing the stream to discharge across the beach. Thus, turbid water was being introduced at two major points along the shoreline. Clearer water near the eastern margin of the channel was due to water drifting from the shallow reef flat, driven by the northeast trade winds. The lower values of k in the northwest corner of the bay result from clearer ocean water off the reef flat that was forced there by high surf along the northern outer reef. This water is confined by the surf, northeast winds, and shoreline configuration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0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
157°52'00"
21°34'00"
KAHANA BAY
OAHU, HAWAII
EXTINCTION COEFFICIENTS
SATURDAY MAY 1, 1971
CONTOUR INTERVAL 0.10
KAHANA STREAM
N
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 13

of the western side of the bay so that it must flow back to sea through the channel of Kahana Bay, confirming for this local area one of the predictions of Inman *et al*. (1963), that water circulation tends to perpetuate canyon location, once the initial channel is established.

Summary of Water Data

Nearshore data show that the stream discharge is either directly seaward, or displaced towards the central part of the bay, depending on the presence or absence of trade winds.

Offshore data suggest that the stream is not the only source of low salinity and low-temperature water in the bay. Colder and fresher water flows from springs along the reef margins.

The configuration of the western shoreline, the high wave energy on the outer western reef, and the northeast trade winds, all unite to drive ocean water across the reef flat and into the channel where it meets the more turbid stream water that characterizes the eastern half of the bay.

SEDIMENTS

Aerial Photograph Interpretation

Aerial photographs of Kahana Bay show distinct patterns of light and dark areas on the sand channel floor. The best definition was seen on photograph 5234-2 taken by R. M. Towill Corporation, Honolulu. Borders of light and dark contrasts were traced from overlapping photographs using a Zeiss Standard NZ Mirror Stereoscope (Carl-Zeiss, 7082 Oberkochen/Wiirtt · West Germany), and are shown in Figure 14. Outstanding features of the channel sands include:

(a) A dark area in the central portion of the bay which continues seaward along the eastern reef margin.

(b) A light area surrounding all but the southeast corner of the patch reef.

(c) Light areas along the edge of the western fringing reef.

(d) A light area extending southwest from Huilua Fishpond across less than half the bay, darkening slightly near the beach.

The light area near the fishpond coincides with the sand bar across the mouth of Kahana Stream previously described. Correlations of the other patterns with the bathymetry brought out the following: Bathymetric contours

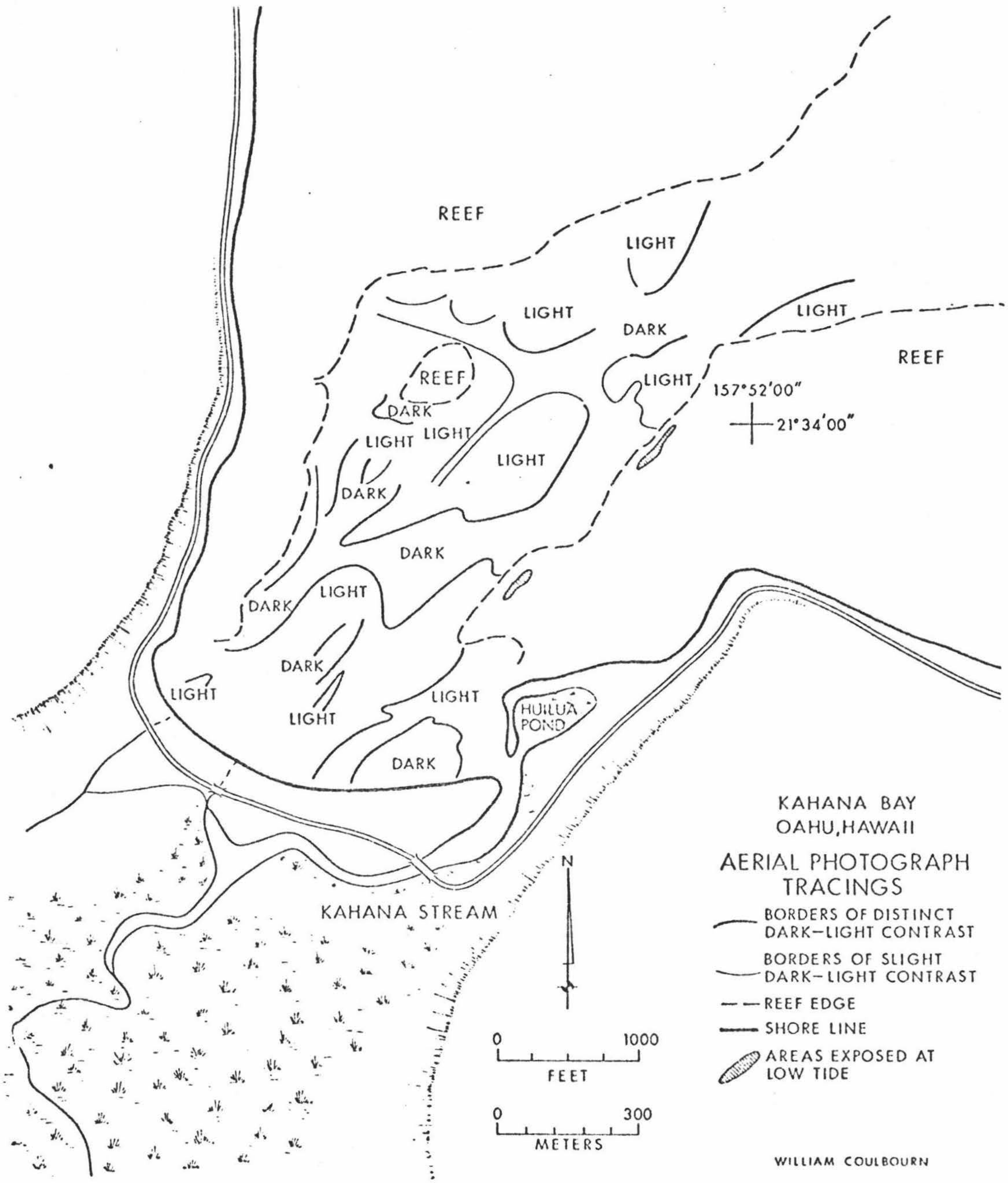

REEF
LIGHT
LIGHT
DARK
LIGHT
REEF
REEF
LIGHT
157°52'00"
21°34'00"
DARK
LIGHT
LIGHT
LIGHT
DARK
DARK
DARK
LIGHT
DARK
LIGHT
LIGHT
LIGHT
HUILUA POND
DARK
KAHANA STREAM
N
KAHANA BAY
OAHU, HAWAII
AERIAL PHOTOGRAPH TRACINGS
BORDERS OF DISTINCT DARK-LIGHT CONTRAST
BORDERS OF SLIGHT DARK-LIGHT CONTRAST
REEF EDGE
SHORE LINE
AREAS EXPOSED AT LOW TIDE
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 14

indicate some shoaling around the patch reef, coinciding with the aforementioned light area; and a depression near the eastern reef edge, matching that dark area. A comparison of Figure 2a and Figure 13 shows that other dark-light contrasts have no bathymetric expression. The data show that each light area is not uniformly shallower than adjacent dark areas and that breaks in slope associated with these borders are absent. The most likely conclusion is that tonal contrasts are due to differences in sediment reflectivity and not to bathymetric relief. Therefore differences in sediment composition and grain size must be responsible.

Other noteworthy features identified include numerous small sand channels on the reef flat, aligned perpendicular to the shore, and a cuspate sand bar along the western shore. Its tip extends toward the south, indicating that sediment transport along this shore is from north to south.

Sampling Procedure

As originally intended, one sediment sample was obtained for each pre-established 400-foot-square area over the entire inner bay. However, in many cases more than one sample per unit area was obtained due to errors in visual judgement of position. A Van-Veen grab sampler lowered from a small boat was used to obtain the samples. Positions of the stations, determined by horizontal sextant angles to shore points, are shown on Figure 15. Surface sediment samples for statistical counts of the microfaunal population were taken at random stations (indicated on Figure 15 by the suffix F) when diving conditions were favorable. In shallow water this was carried out by using a snorkel only, whereas SCUBA gear was required at depths greater than 15 feet. In either case the surface sediment was scraped into a plastic freezer container. These samples were then treated with a solution of rose bengal and ethyl alcohol to preserve the living protoplasm, while staining it red.

Laboratory and Statistical Procedures

Size analysis of each sample was carried out by dry-sieving the sand at $1/2\varphi$ intervals. Graphs of cumulative weight percent against grain size at each $1/2\varphi$ interval (Muller, 1967) were constructed for all the samples. From these, statistical parameters of Graphic Mean, Inclusive Graphic Standard Deviation, Inclusive Graphic Skewness, and Graphic Kurtosis were obtained according to the formulas of Folk (1968). For samples with more than 5% passing the 62-micron sieve (4φ), the silt and clay fraction was further analyzed by pipetting.

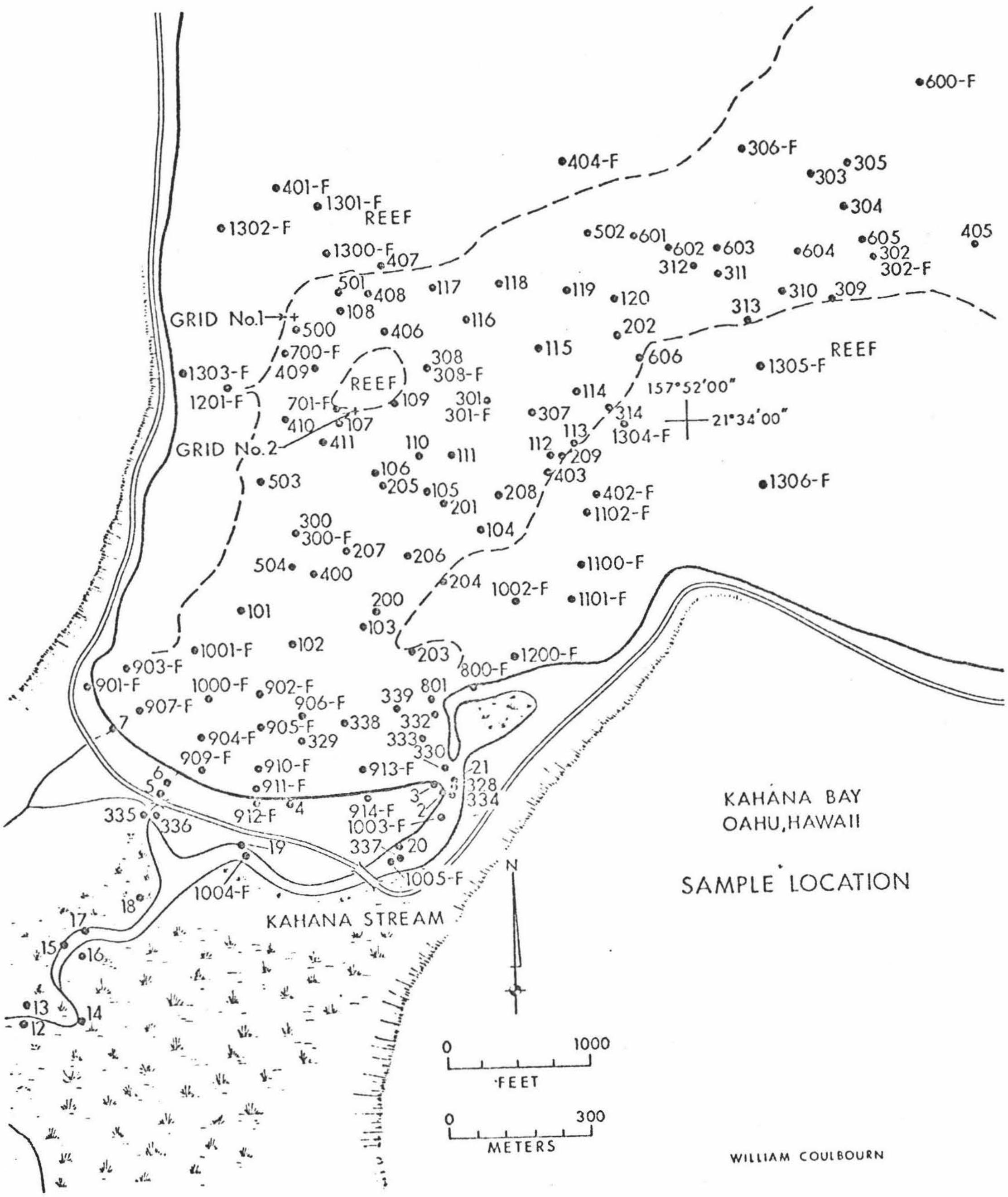

KAHANA BAY
OAHU, HAWAII
SAMPLE LOCATION
KAHANA STREAM
REEF
GRID No.1
GRID No.2
157°52'00"
21°34'00"
N
0 1000 FEET
0 300 METERS
WILLIAM COULBOURN

Figure 15

Results of Size Analysis Mean

The values for mean grain size determined graphically according to the formula: Mean = $\varphi 16 + \varphi 50 + \varphi 84/3$ are listed in Appendix I and have been contoured at 1/2φ intervals in Figure 16. Where sample distribution was sparse, allowing several possible interpretations, the contours were biased to trend along the borders of light-dark areas traced from the aerial photograph (Figure 14). The mean grain size ranges from about 1.0φ to 3.5φ over most of the sand channel. Sand of this size is classified as being medium to very fine sand (Folk, 1968). Stream samples have values greater than 2.0φ and are classified as fine to very fine sand. Samples 16 and 18, collected from the side of the stream bed where it crosses the old beach ridges, are coarser. Figure 16 shows that samples obtained from the reef flat are generally medium to very coarse sand, with values from 2.00φ to -0.50φ. The water flow from the reef flat to the deeper channel, the steep and abrupt walls of the channel, and the comparatively calm waves inside the bay, all indicate that sand transport is only from the reef flat down into the channel, and not visa versa. Areas where sand is introduced into the channel from the reef flat appear as bulges in the contours. Such transport accounts for the coarser channel sands found adjacent to the western reef edge, whereas the high gradient of contours associated with the eastern reef edge

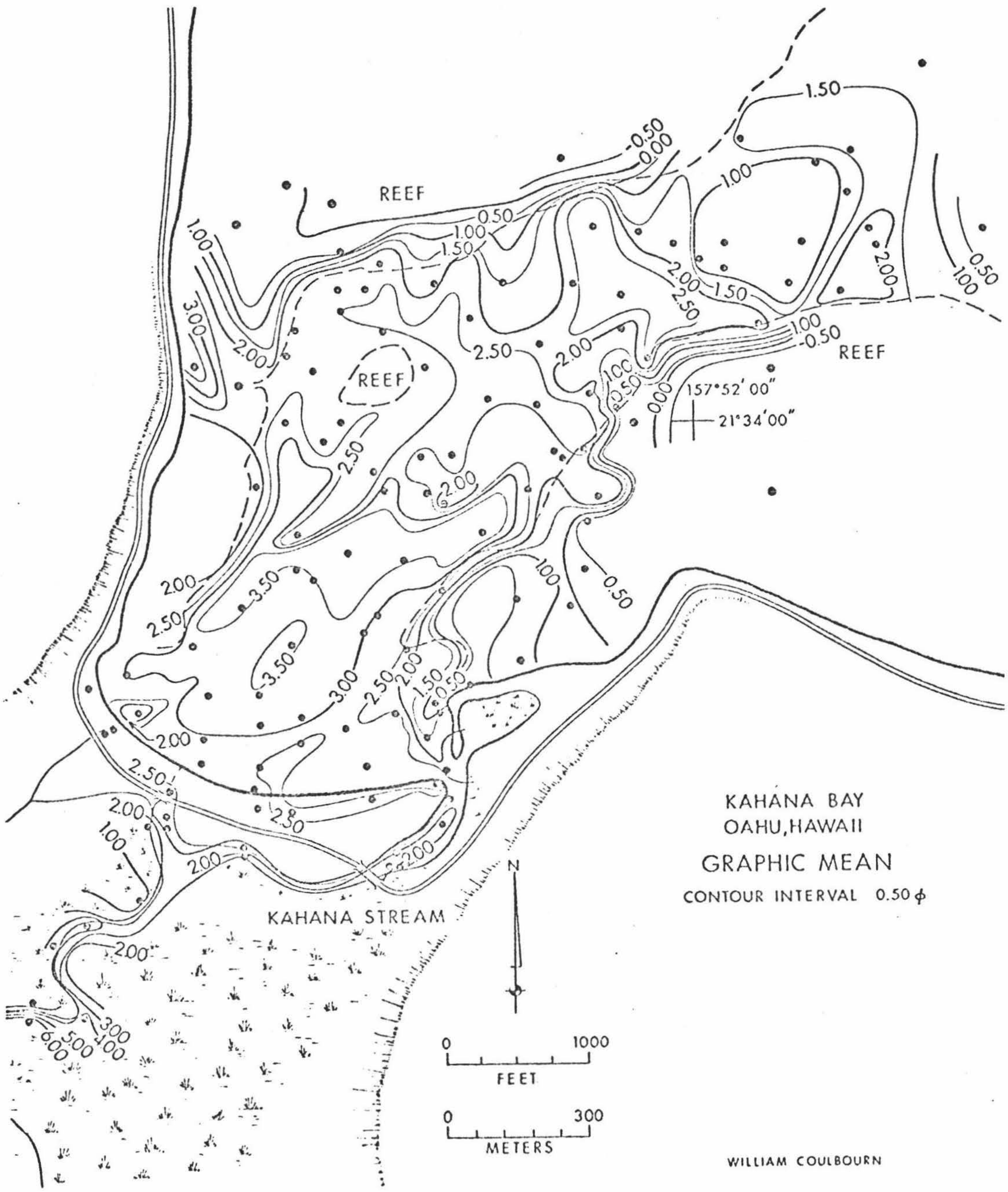

REEF
REEF
REEF
KAHANA STREAM
157°52' 00"
21°34'00"
KAHANA BAY
OAHU, HAWAII
GRAPHIC MEAN
CONTOUR INTERVAL 0.50 φ
0 1000
FEET
0 300
METERS
N
WILLIAM COULBOURN

Figure 16

suggests that not much sand is carried across that boundary. The exceptions are around the edge of Huilua Fishpond, and in the general vicinity of sample 314. There are two concentrations of very fine sand in the central sand channel where values are 3.50φ or greater. Both represent areas of minimal wave energy and current velocity. Diving observations have shown that large wave oscillations throw this sand into suspension. However the net component of sediment transport could not be determined visually.

Standard Deviation

Values of Standard Deviation were calculated graphically according to the formula: S.D. = $\varphi 84 - \varphi 16/4 + \varphi 95 - \varphi 5/6.6$. This parameter indicates the degree of sorting of the sample. For example, a value of 0.5φ means that two-thirds of the sediment grains fall within $\pm$ 0.5φ unit of the mean grain size of that sample. In Figure 17 values of standard deviation are contoured at 0.25φ intervals.

Sand channel deposits at Kahana Bay fall in the range described as moderately well-sorted (Folk, 1968). Moderately to poorly sorted sediments are found along the northern edge of the sand channel and in the lower part of Kahana Stream. Poor sorting near the stream mouth is due to small pebbles in the riverbed load. Farther upstream values in excess of 3.00φ result from the presence of swamp silts and clays. Coarse, reef-derived material washed into

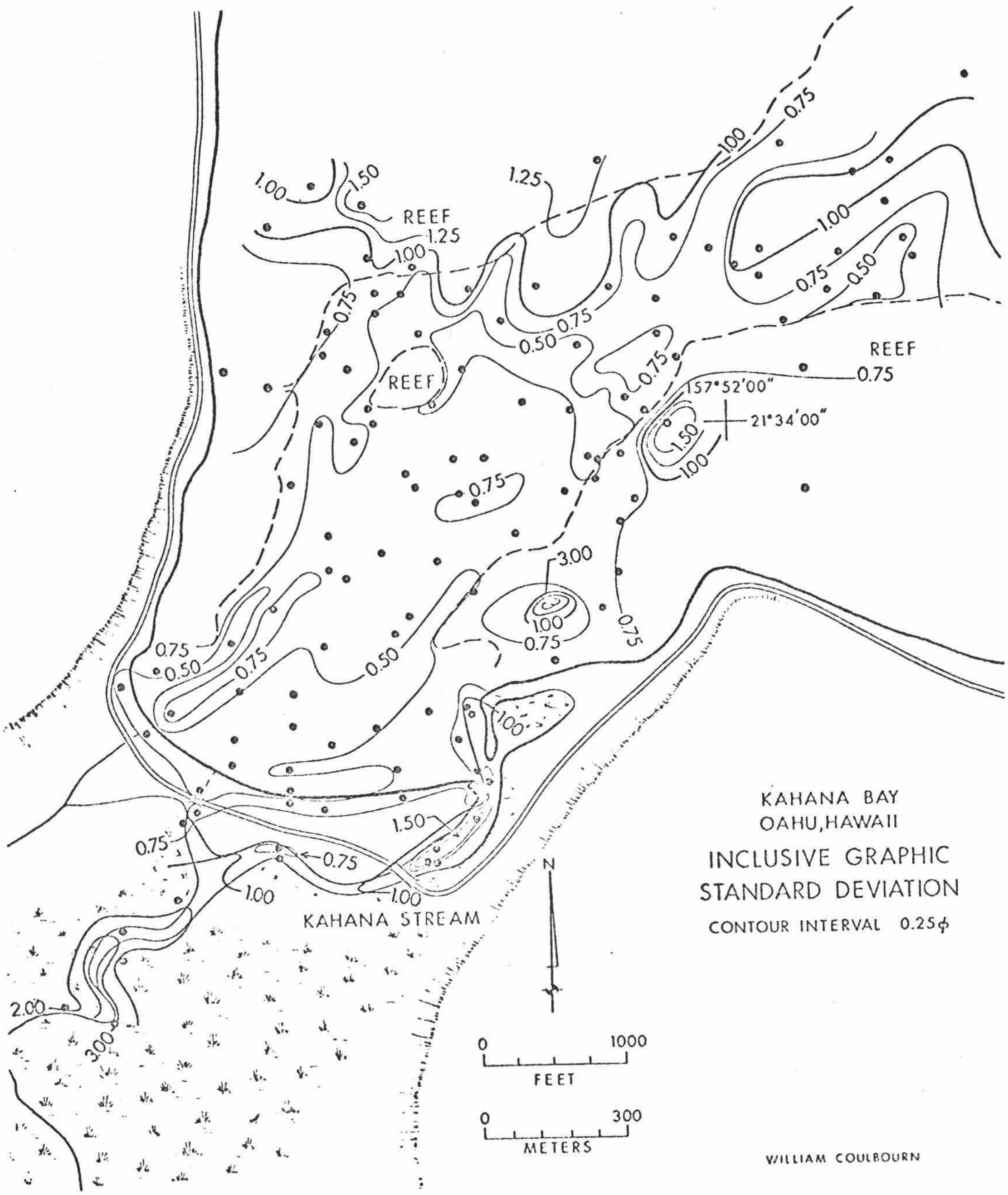

KAHANA BAY
OAHU, HAWAII
INCLUSIVE GRAPHIC
STANDARD DEVIATION
CONTOUR INTERVAL 0.25ϕ
REEF
KAHANA STREAM
157°52'00"
21°34'00"
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

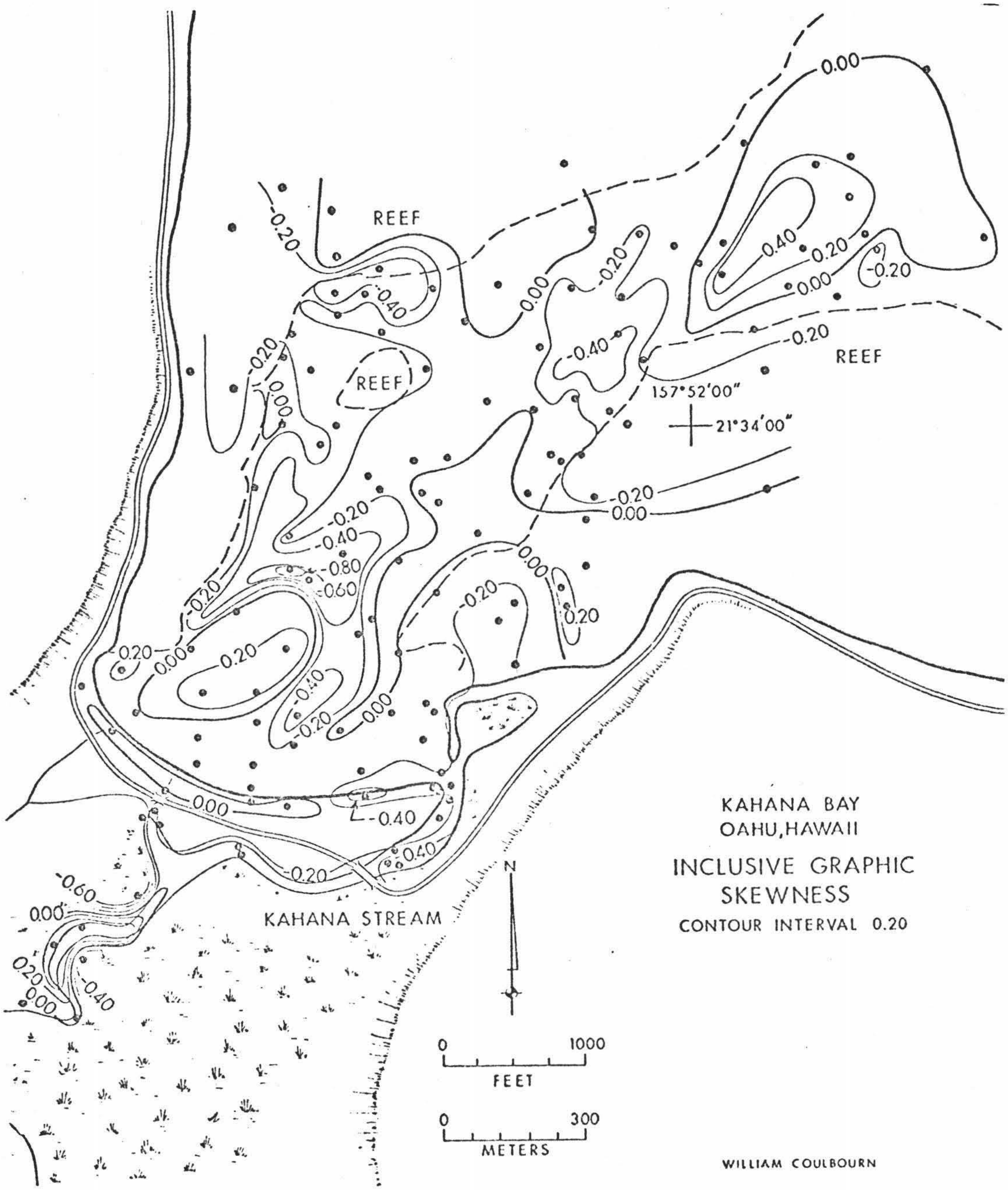
Figure 17

the channel and mixed with the finer sands there, results in local mixtures along the western and northern reef edges that are poorly sorted. A small area of very poor sorting on the eastern reef flat is due to a few large coral fragments collected in Sample 1002-F. Reef-flat samples were gathered by scraping sediment from very shallow and localized sand pockets. The type of material collected is variable, depending on the amount of sand or rubble in a particular depression. Therefore a wide range in values of statistical grain size parameters of reef sediments should be expected.

The most important information provided by standard deviation was the identification of the local sources of the coarse reef material that is introduced into the sand channel across the reef margin.

Skewness

The parameter skewness was calculated graphically from the formula: $sk = [\varphi 16 + \varphi 84 - 2(\varphi 50)]/(\varphi 84 - \varphi 16) + [\varphi 5 + \varphi 95 - 2(\varphi 50)]/(\varphi 95 - \varphi 5)$ and is contoured in Figure 18. Skewness, a unitless quantity, is a measure of the departure of actual grain size distribution from a curve symmetric about the mean. A symmetric curve has a skewness of 0.00. Positively skewed distributions have excess amounts of fine grains, that is the frequency curve has a tail towards the fines. Negative values of skewness



KAHANA BAY
OAHU, HAWAII
INCLUSIVE GRAPHIC SKEWNESS
CONTOUR INTERVAL 0.20
REEF
REEF
REEF
KAHANA STREAM
157°52'00"
21°34'00"
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 18

(i.e. coarse tails) are associated with most of the reef. Samples 202 and 314 could indicate areas of accumulation of fragments transported off the eastern reef flat into this deeper part of the channel. Positive values in the upper stream are due to silt and clay in the swamps.

Inland beach ridge sediments, as well as the part of the present-day shore protected by the stream-mouth sand bar, are negatively skewed. Samples collected from the western two-thirds of Kahana beach and the nearshore area across the entire width of the bay are not skewed. Few coarse grains are transported there, and the fine fraction is winnowed out, minimizing tails at both ends of the frequency distribution. The disparity of values across the beach front is caused by the protection from strong wave action afforded by the shallow sand bar across the eastern half of the bay. Farther offshore, where even larger volumes of very fine-grained sand can settle out of suspension, the shift of the mean grain size leaves a relatively coarser tail. Thus, as the wave energy on the bottom diminishes, skewness values change from positive to negative.

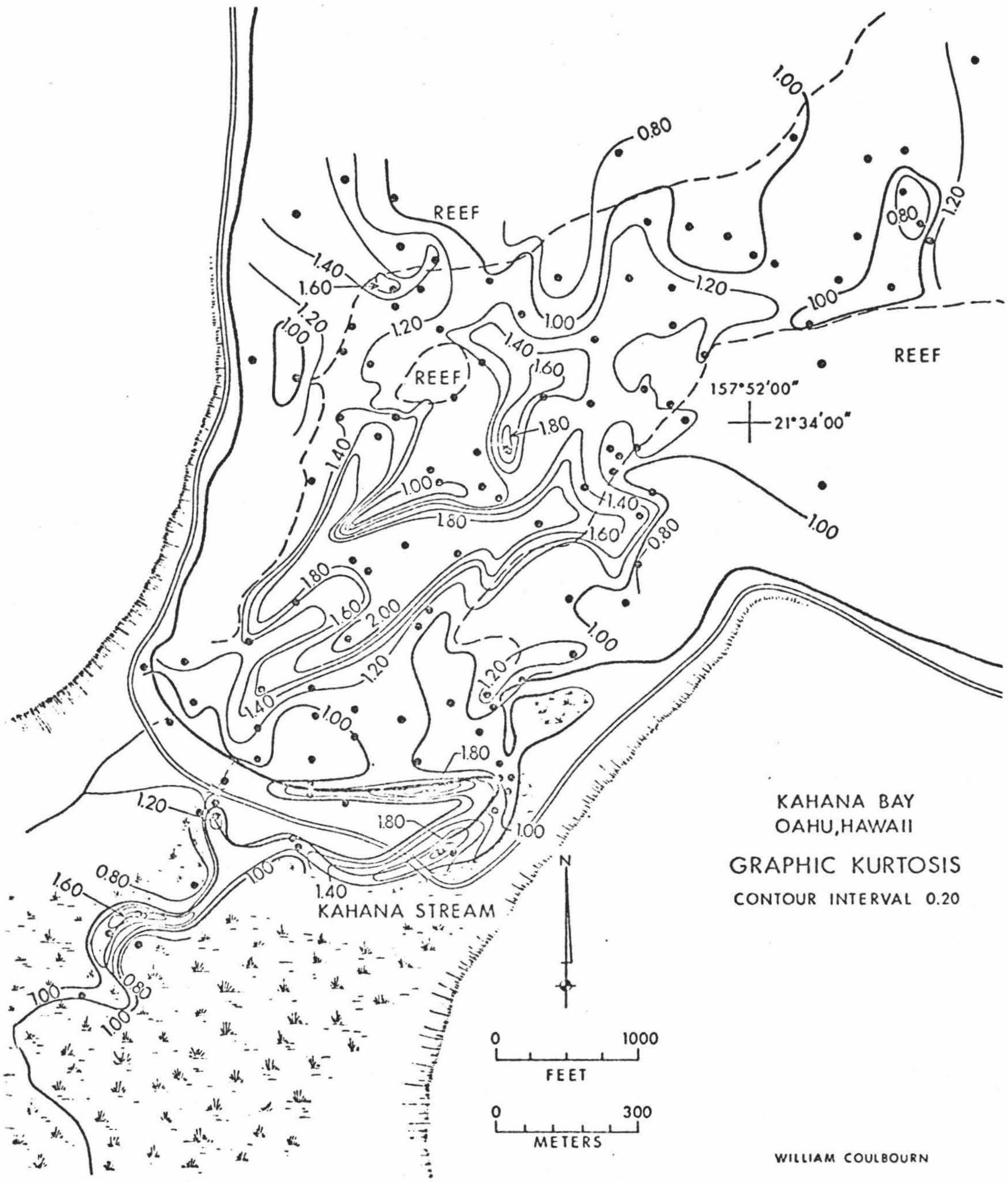
Kurtosis

Kurtosis is measured relative to a normal Gaussian, bell-shaped probability curve.

"It (Kurtosis) measures the ratio between the sorting of the 'tails' of the curve and the sorting in the central portion. If the central portion is better sorted than the tails, the curve is said to be excessively peaked or leptokurtic; if the tails are better sorted than the central portion, the curve is deficiently or flat-peaked and platykurtic." (Folk, 1968.) Contours shown in Figure 19 represent graphical calculations of kurtosis according to the formula: $K = \varphi 95 - \varphi 25/2.44(\varphi 75 - \varphi 25)$. Platykurtic distributions have values less than 1.00, while those of leptokurtic curves exceed 1.00.

Figure 19 shows that most samples from the sand channel have leptokurtic curves, that is the φ95 to φ5 interval is wide when compared to the φ75 to φ25 interval. Values are raised by introduction of material on either the coarse or fine extremes of the size range, or by excellent sorting of the material in the φ75 to φ25 range. Maximum values occur in the central sand channel area associated with sediment sizes of 3.50 φ or finer. High values demonstrate the excellent sorting of this fine material that settled out of suspension. Values in Kahana Stream mouth are high, due to the presence of pebbles in the stream sands. Values in excess of 1.20 in the upper stream reflect the wide size range of the swamp silts and clays.

Reef flat samples have values of 1.00 or less, indicating a spread in the φ75 to φ25 interval. This demonstrates a poorer sorting of the material comprising



KAHANA BAY
OAHU, HAWAII
GRAPHIC KURTOSIS
CONTOUR INTERVAL 0.20
REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA STREAM
N
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 19

the central part of the distribution. Low values along exposed sections of Kahana beach, and across the stream-mouth sand bar, result from surf agitation. Values of kurtosis, like skewness, show that the eastern half of the shore is protected from wave action by the sand bar, whereas the bar and the western half of the shore belong to the same sedimentary environment.

Summary

Statistical parameters of grain size show that reef-derived material is introduced into the sand channel at localized points. High values of mean grain size and kurtosis represent areas where very fine particles settle seaward of the surf zone. Low values of standard deviation and kurtosis, and near-zero value for skewness, are indicative of beach and nearshore sands.

NATURE OF SEDIMENT (Calcareous, terrigenous, organic)

Laboratory Procedure

The method used to determine the composition of sediment was chosen for simplicity and speed. Two to five grams of each sample were placed in a 20 ml. pre-weighed beaker, and the carbonate fraction dissolved in hydrochloric acid. The sample was pipetted and washed to remove the calcium chloride, dried, and then reweighed. The weight loss is attributed to the amount of $CaCO_3$ dissolved.

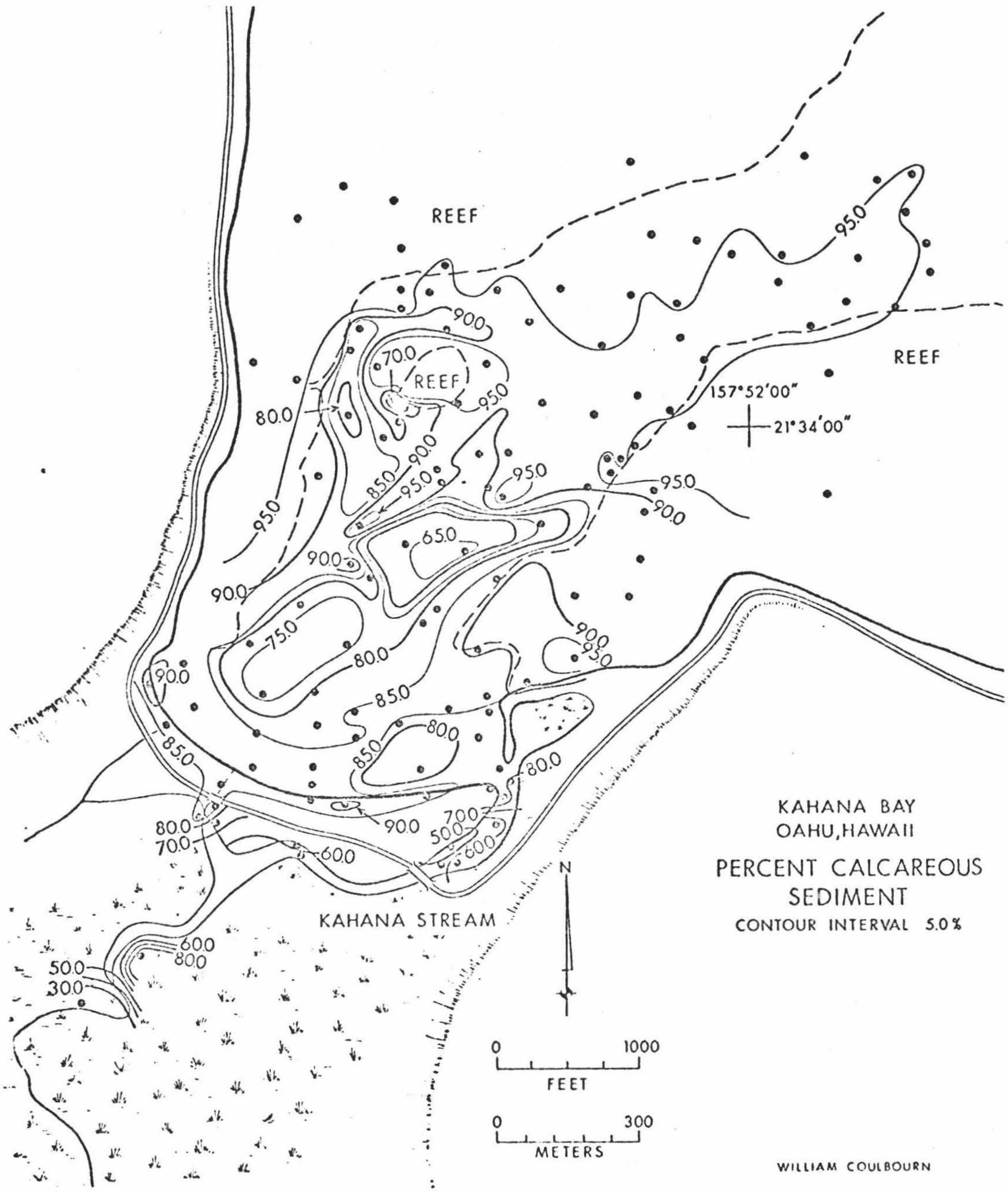
The insoluble residue was oxidized with hydrogen peroxide, removing organic carbon. The dried sample was again weighed and the difference termed organic material. The remainder was categorized as terrigenous material. Weight percents for the calcareous, organic, and terrigenous fractions are listed in Appendix I, and contoured in Figures 20 to 22.

Results

Figure 21 shows that the only large concentrations of organic material are to be found in the swampy sediments of the inland stream bed. Values in the bay are generally less than 2.0%. Concentrations of 8.0% on the eastern reef flat are due to marine plants and debris collected in pockets in the reef.

The low percentages of organic material indicate that Figures 20 and 22, for carbonate and terrigenous fractions respectively, will be approximately reciprocal to each other. Areas that appeared dark on the photograph (Figure 14) consistently have high percentages of terrigenous material, composed mainly of rounded basalt grains. Such areas are found in the center of the bay extending towards the eastern reef margin, as well as along the southern edge of the patch reef. Values generally increase toward the shore and the stream mouth. The contours in Figures 20 and 22

$CaCO_3$ vs. org. material



REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA BAY
OAHU, HAWAII
PERCENT CALCAREOUS
SEDIMENT
CONTOUR INTERVAL 5.0%
KAHANA STREAM
N
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 20

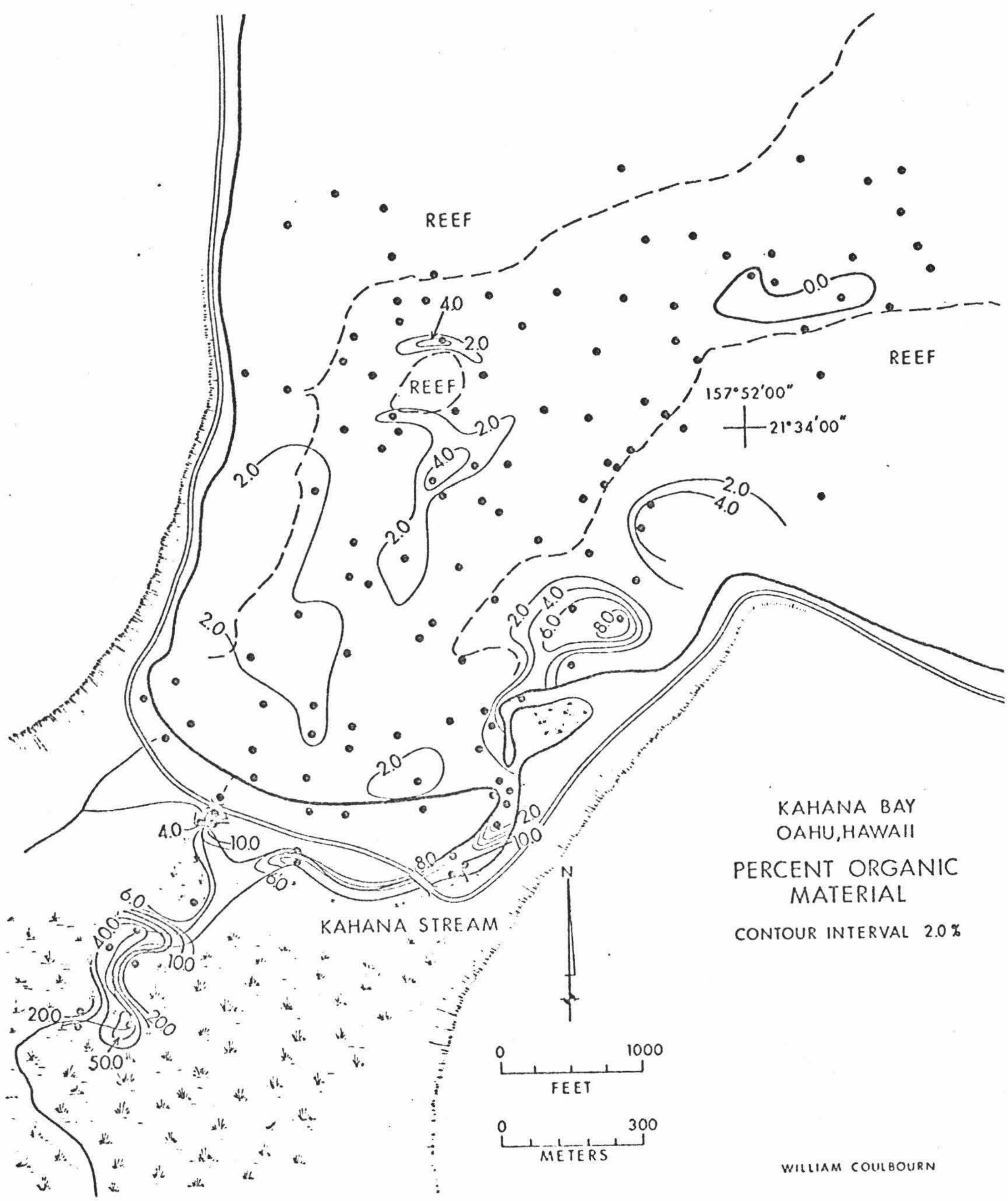

REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA STREAM
N
0 1000
FEET
0 300
METERS
KAHANA BAY
OAHU, HAWAII
PERCENT ORGANIC
MATERIAL
CONTOUR INTERVAL 2.0%
WILLIAM COULBOURN

Figure 21

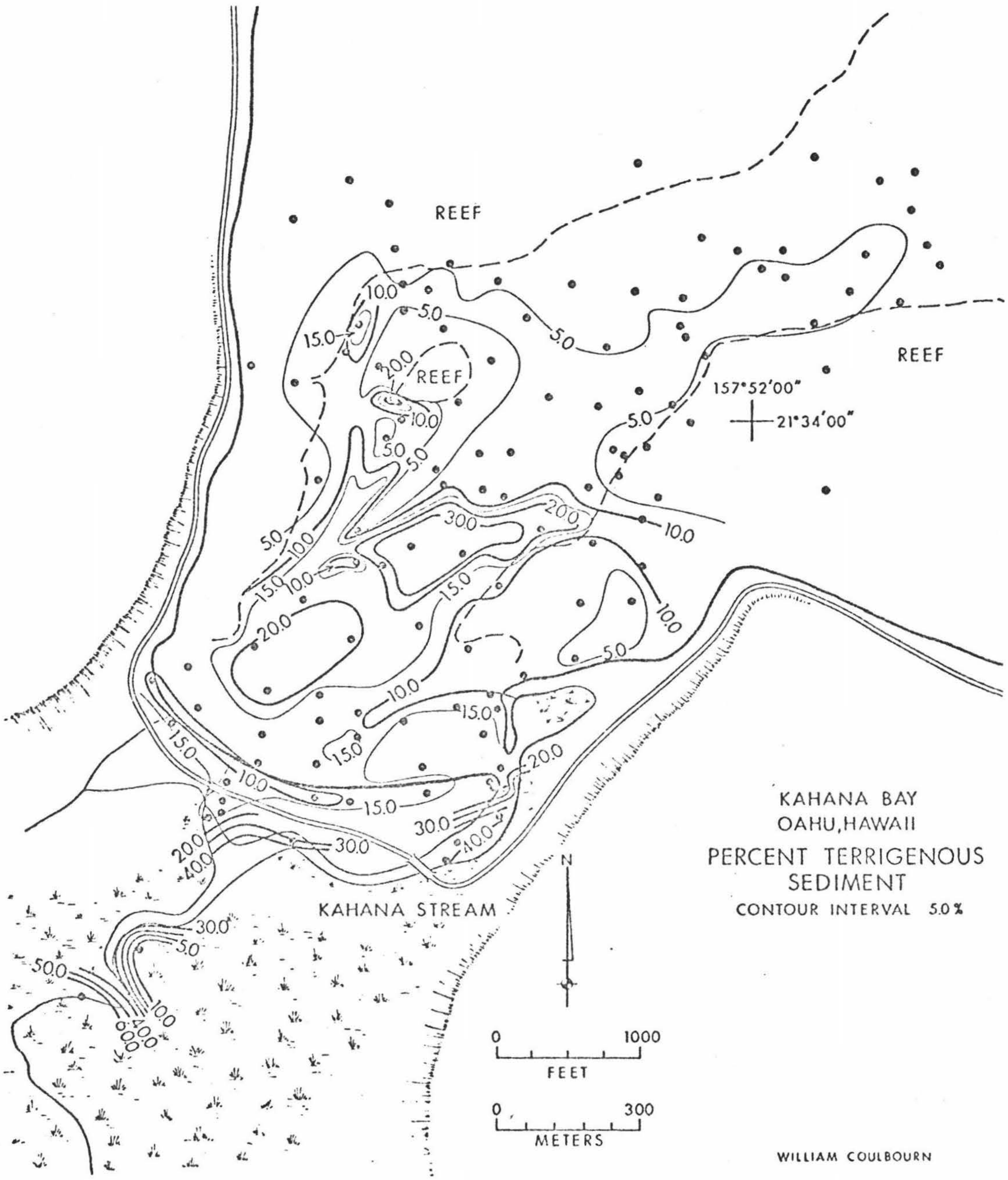

REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA STREAM
KAHANA BAY
OAHU, HAWAII
PERCENT TERRIGENOUS
SEDIMENT
CONTOUR INTERVAL 5.0%
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 22

were drawn using the light-dark aerial photograph contrasts (Figure 14) as a control wherever sample locations were sparse, or where several interpretations were possible.

Calcium carbonate is found in excess of 90% over nearly all of the reef-flat areas (Figure 20). Other areas of high concentrations are the outer channel, the patch reef, the western side of the channel, the beach, and the stream-mouth bar. A band of high carbonate concentrations extends south of the patch reef, and is associated with a distinct light area on the aerial photograph tracing (Figure 14). The gradient between this and the adjacent, comparatively low-carbonate sand to the east is quite sharp and coincides with a light-dark boundary (Figure 14).

Summary

Light-colored sands are found to have calcium carbonate concentrations in excess of 85% by weight. Dark-colored sands have terrigenous fractions greater than about 20% by weight. Organic carbon is present in the open bay sands only in small amounts.

The stream is the ultimate source of the terrigenous fraction and the data show that the part of the stream load that enters the bay is characterized by mean sizes of 3.00φ, or finer. Therefore, it is not surprising to find that this fraction accounts for less than 10% of the sediment in samples collected from the high-energy environment of the nearshore surf zone. Offshore concentrations are indicative of weak bottom currents that allow the fine detrital sand to be deposited. When Kahana Stream discharges across the middle of the beach during flood stages, the resultant jet flow transports an abundance of fine grains as far out as the middle of the bay.

Standard Deviation of the Results

Experimental error in the preceding data was determined by performing ten analyses on Sample 701-F (Table I). The laboratory procedure outlined at the beginning of this section was followed. The best agreement of values is for the percentages of calcareous material. Standard deviation of values increases for organic and terrigenous percentages due to the compounding of inaccuracies in successive weighings. Standard deviations for the percentages of calcareous and terrigenous fractions are small when compared to the values plotted. This is not true for the weight percent of organic material. Values over the Kahana Bay area are generally less than four per cent, or one standard deviation, and therefore Figure 21 probably is less accurate than Figures 20 and 22.

The analytical error is largely attributed to $CaCl_2$ remaining even after repeated washings of the sample. This compound is deliquescent, thus increasing the weight of the sample after drying as a function of the duration of

TABLE I

Percent Carbonate	$X - \bar{X}$	$(X - \bar{X})^2$
76.67	+5.12	26.21
71.53	-0.02	0.0004
74.71	+3.16	9.99
66.37	-5.18	26.83
73.64	+2.09	4.37
71.90	+0.35	0.12
65.32	-6.23	38.81
73.75	+2.20	4.84
72.02	+0.47	0.22
69.59	-1.96	3.84
715.50		115.23

$s^2 = 115.23/9$

$= 12.79$

$s = 12.79^{\frac{1}{2}}$

$= 3.7$

Percent Terrigenous	$X - \bar{X}$	$(X - \bar{X})^2$
19.57	-3.82	14.59
25.65	+2.26	5.11
20.23	-3.16	9.99
20.99	-2.40	5.76
16.90	-6.49	42.12
21.11	-2.28	5.20
32.55	+9.16	83.91
25.92	+2.53	6.40
27.62	+4.23	17.89
23.35	-0.04	.0016
233.89		190.97

$s^2 = 190.97/9$

$= 21.22$

$s = 21.22^{\frac{1}{2}}$

$= 4.6$

Percent Organic	$X - \bar{X}$	$(X - \bar{X})^2$
3.76	-1.30	1.69
2.82	-2.24	5.02
5.06	0.00	0.00
12.64	+7.58	57.46
9.46	+4.40	19.36
6.99	+1.93	3.72
2.13	+2.93	8.58
0.33	-4.73	22.37
0.36	-4.70	22.09
7.06	+2.00	4.00
50.61		144.29

$s^2 = 144.29/9$

$= 16.03$

$s = 16.03^{\frac{1}{2}}$

$= 4.0$

exposure to moisture in the air. Repeated decantings can reduce this error. However, after several washings, a point of diminishing returns is reached, since some of the finer suspended sediment may be removed with each pipetting. About one-half of the analyses were repeated, in those cases where sample-loss was observed.

SEISMIC REFRACTION

A portable Enhancement Seismograph (Model 1570, Bison Instruments, Inc., Minneapolis, Minnesota) was used on the foreshore at Kahana Beach to determine sand thickness, and to test the instrument's ability to function in the presence of surf-generated noise. Seismic refraction traverses consisted of a 150-foot, non-reversed line, originating at a point directly seaward of the western end of the bridge spanning the stream flood-channel; and a 300-foot reversed line originating at the western end of the beach. Both traverses roughly parallel the shoreline. Seismic energy was generated by striking a metal plate with a sledge hammer. The hammer was wired to the instrument so that impact started the recording sequence.

Results

The instrument was affected more by traffic on Kamehameha Highway than by surf noise, but neither were prohibitive to the operation. A minimum of three blows was required at each station to generate a sufficiently enhanced signal.

Travel-time plots (Figures 23(a) and 23(b)) show that apparent velocities for layer 1 are 1.45 km/sec, 1.45 km/sec, and 1.58 km/sec, giving an average value of 1.49 km/sec. This velocity is approximately that of seawater and represents the water-saturated sand layer. The arrival times give a linear best fit that does not intercept the origin. This deviation from the theoretical may be due to a much lower velocity of the thin surface-layer of dry sand.

Traverse C-D in Figure 23(b) shows that V_{2a}, the apparent down-dip velocity for the second layer, is 2.6 km/sec, and that the critical distance, X_c, is 217 feet. No second-layer refractions were registered for D-C, the east-to-west direction, therefore a minimum critical distance of 300 feet was used in the calculations. Assuming that layer 2 is composed of basaltic flows, corresponding to layer B (Furumoto et al., 1970), V_2 has been set equal to 4.0 km/sec making possible the calculation of V_{2b}, the apparent up-dip velocity. Once the appropriate velocities are calculated, a value for the minimum thickness of the layer can be obtained, according to the formula:

$$d = X_c/2\sqrt{V_2 - V_1 / V_2 + V_1}$$

The cross section inferred from C-D and D-C (Figure 23(d)) shows a second-layer dip of 10°08' towards the center of the valley. This section is dependent on the initial

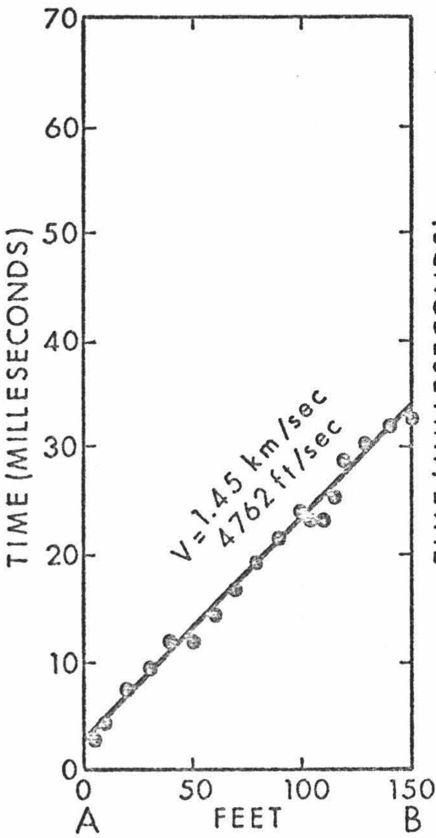


Figure 23a

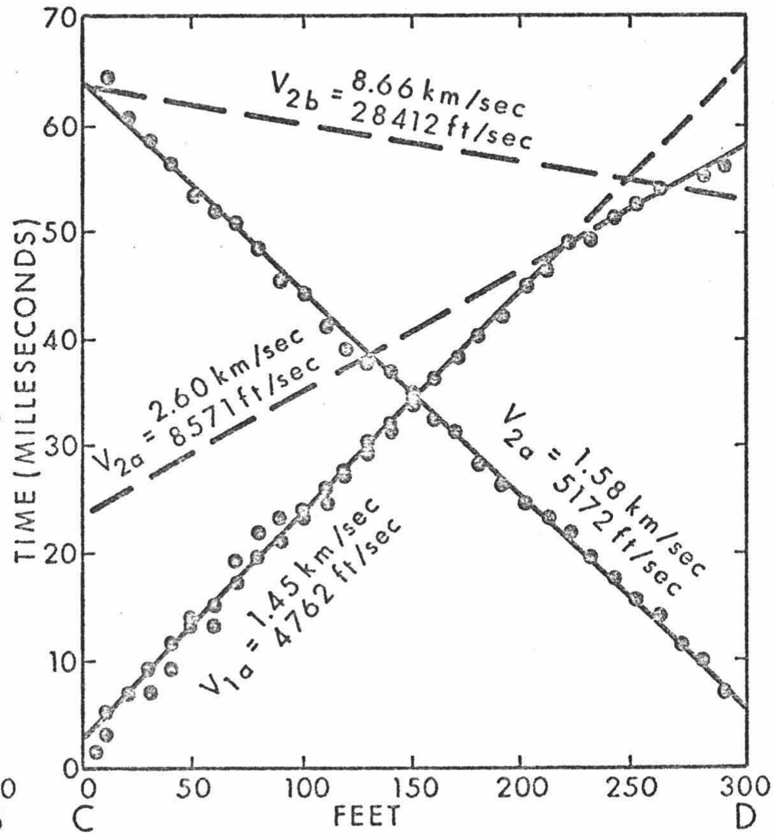


Figure 23b

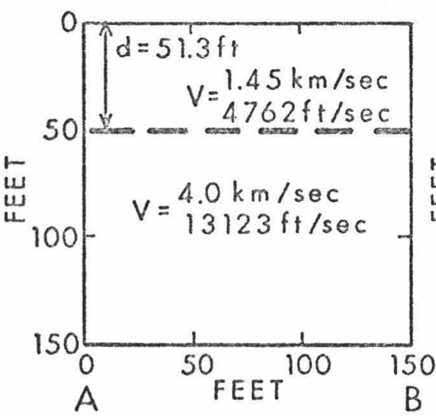


Figure 23c

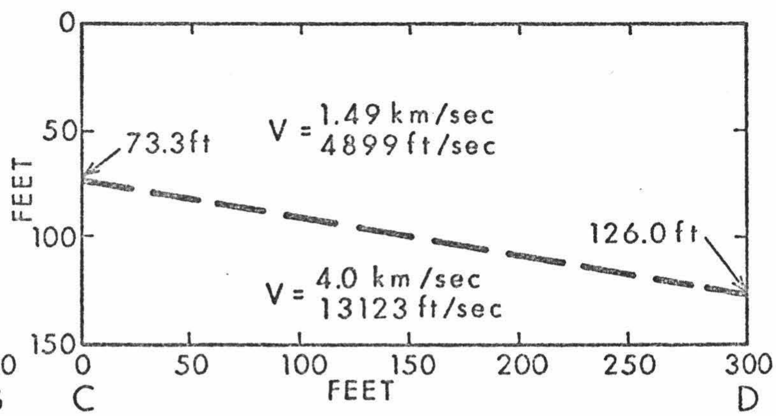


Figure 23d

assumptions that X_c equals 300 feet, and that layer 2 is composed of basalt flows having a velocity of 4.0 km/sec. The validity of these assumptions was checked by measuring the surface slope along a northeasterly extension of line C-D. The apparent dip from the ridge crest (1124 feet) to sea level is about 22°. However, the surface steepens at higher elevations and if the 200-foot-to-sea-level interval is considered separately, a dip of 10°01' is determined. This compares quite favorably with the section inferred from the refraction data.

Assuming a minimum critical distance (X_c) of 150 feet for traverse A-B and a second-layer velocity (V_2) of 4.0 km/sec, a minimum sediment thickness of 51.3 feet is calculated. Jet probes by Moberly et al. (1964) have demonstrated that the sand at Kahana Bay is at least 15 feet thick.

SAND TRACER EXPERIMENT

In order to determine the direction of sand transport within the channel of Kahana Bay, a sand tracer experiment was carried out. The two areas chosen for this experiment are labelled as Grid No. 1 and Grid No. 2 in Figure 15.

Field Work

At each location a grid of stakes was laid out in a pattern as shown in Figures 24 and 25 (after Kern, 1970).

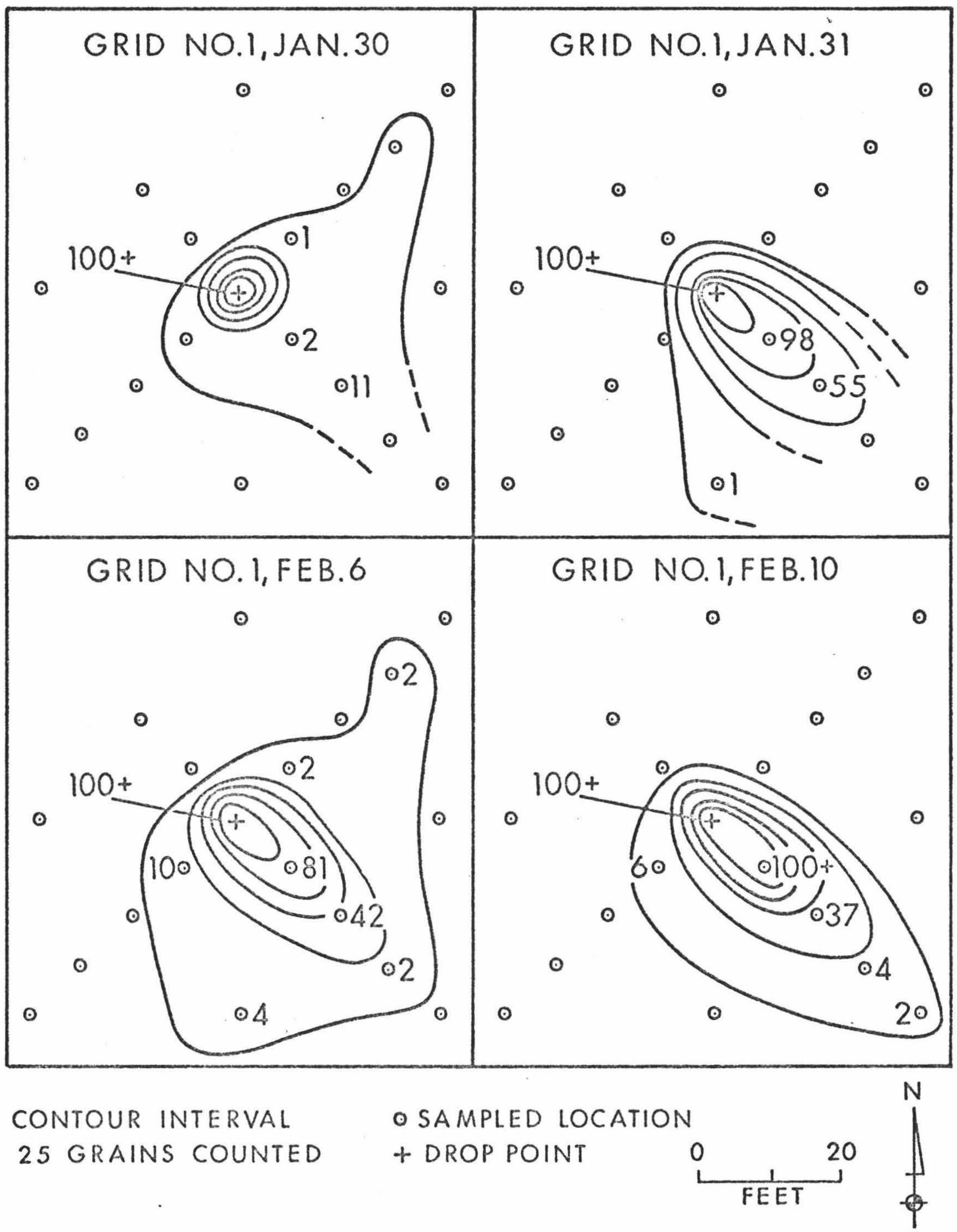

GRID NO.1, JAN.30
100+
1
2
11
GRID NO.1, JAN.31
100+
98
55
1
GRID NO.1, FEB.6
100+
2
2
10
81
42
2
4
GRID NO.1, FEB.10
100+
6
100+
37
4
2
CONTOUR INTERVAL
25 GRAINS COUNTED
SAMPLED LOCATION
+ DROP POINT
0
20
FEET
N

Figure 24

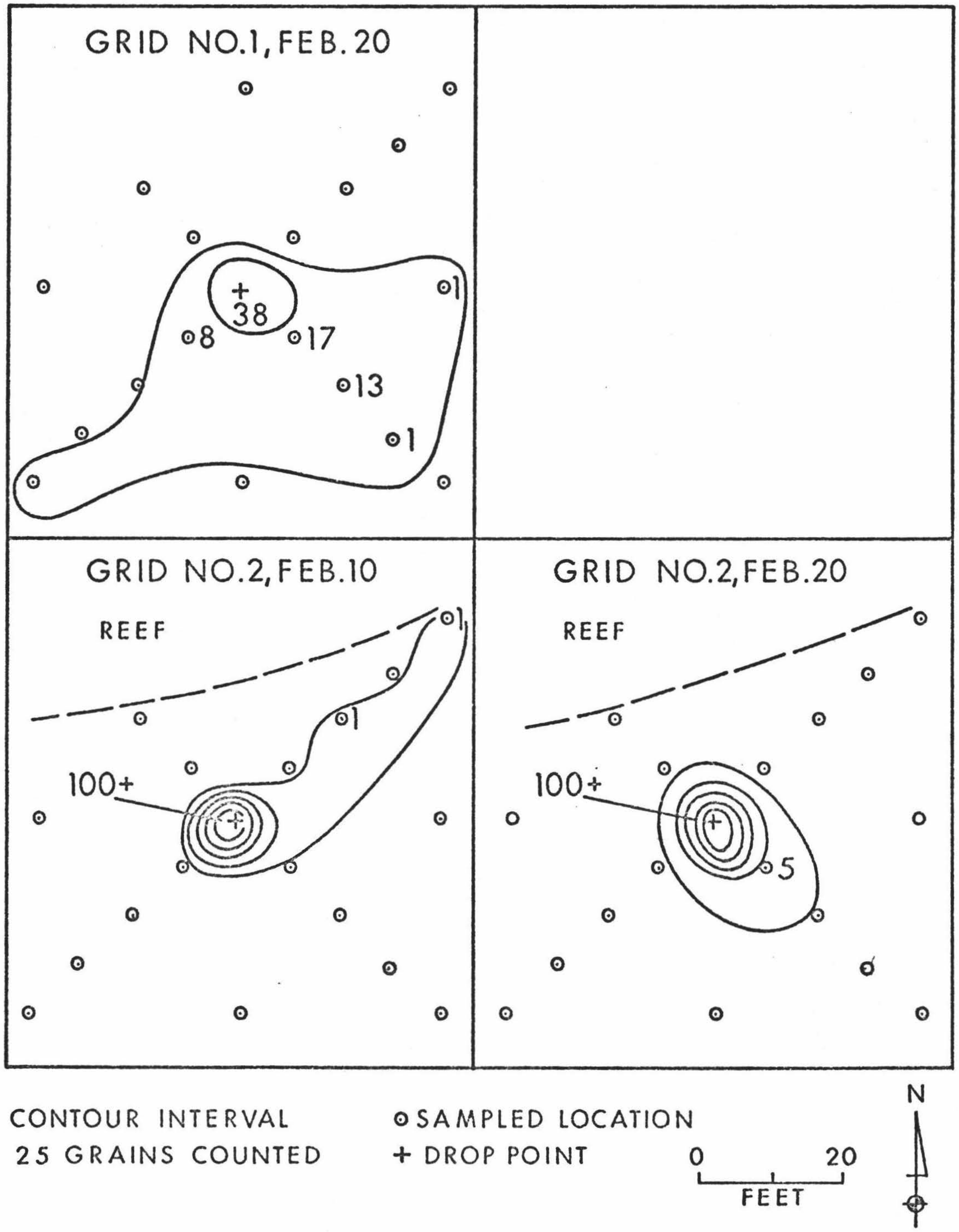

GRID NO.1, FEB. 20
38
8
17
13
1
1
GRID NO.2, FEB.10
REEF
100+
1
1
GRID NO.2, FEB.20
REEF
100+
5
CONTOUR INTERVAL
25 GRAINS COUNTED
SAMPLED LOCATION
+ DROP POINT
0
20
FEET
N

Figure 25

Grid stakes, each two feet long were cut from 1/2-inch diameter steel reinforcing rod. A larger pipe, 1 inch in diameter, was used as a center for the pattern. Stakes were driven into the sand with a hammer. Underwater locations were determined by compass and a rope knotted at 10-foot intervals. With clear diving conditions, laying out these patterns was a routine matter. However, a third site in the center of the bay was abandoned due to turbid water and the resulting difficulties thus presented in underwater orientation.

Locations of the grids were determined by cross ranges to shore points as well as sextant angles, so that the patterns could be relocated for sampling.

Sand-Dyeing Procedure

Approximately 150 pounds of sand were collected in the area near Sample 106. The sand was then dyed with Rhodamine-B following the procedure outlined by Kern (1970). A small cement mixer, dye, urea formaldehyde resin, ammonium chloride catalyst, and a panel of four infrared heat lamps are required for this process. Difficulty was encountered by following the quantities of ingredients prescribed in Kern's Appendix - 2. It was found that reducing the amount of water by half greatly shortened the drying time. The following proportions are recommended:

Material	Quantity	
Sand	50	lbs.
Resin	8.5	lbs.
Ammonium chloride (20% solution)	500	cc.
Rhodamine-B extra dye	5	gm. (1 capfull)

After five hours of drying in the mixer, the sand was removed and oven-dried in bowls. A large portion formed pellet-like aggregates which were broken up with a mortar and pestle. This material was sieved through a coarse-mesh screen and residual aggregates discarded. The resulting histogram curves (Figure 26) for two of the dyed, dried, and disaggregated batches are compared to Sample 106, which is representative of the original grain-size distribution. The dyeing process quite obviously altered the original sample. Tracer Batch No. 1 is somewhat finer than Batch No. 2, but both are considerably coarser than the original sediment sample. Examination under the binocular microscope revealed that individual grains were stuck together in small aggregates.

Injection into the Environment and Sampling

The procedure outlined in Kern (1970) was followed, and found to be quite satisfactory. The dyed sand was placed in plastic bags, hand-carried to the central stake by divers where they were cut open. At each stake, samples

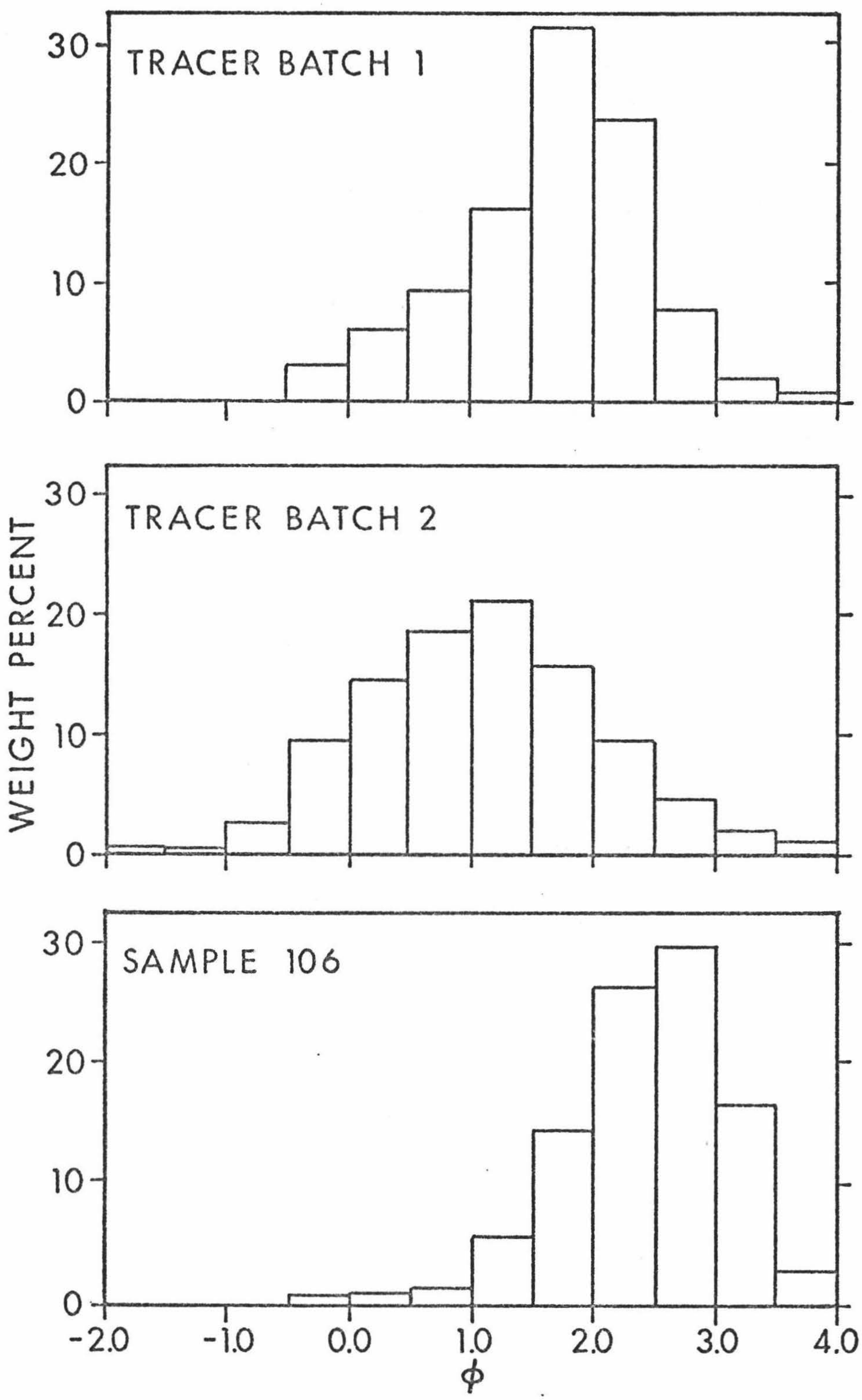

TRACER BATCH 1
TRACER BATCH 2
SAMPLE 106
WEIGHT PERCENT
30
20
10
0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
ϕ

Figure 26

were collected on 3-inch diameter jar caps coated with vaseline. The samples were examined under ultraviolet light and numbers of fluorescent grains counted. One-hundred is the maximum count and greater values are listed as 100+ (Figures 24 and 25).

Results

Figures 24 and 25 show the data obtained from both test sites. Dyed sand was dumped at Grid No. 1 and sampled two hours later. The results show that sand had already begun to disperse towards the southeast. A second sampling on the following day suggested that this was the dominant trend, and therefore two additional stakes were added at the southeast end of Grid No. 1 prior to sampling on February 6. Results show that over a 21-day period the dominant sand movement at Grid No. 1 was towards the southeast. After 21 days the number of grains counted significantly decreased, indicating that the sand either was being dispersed or had become partially buried. The direction of movement, parallel to the orientation of crests of ripple marks, and the symmetrical profile of the ripples show that the ripples are genetically related to wave oscillations.

After each sampling at Grid No. 1, attempts were made to sample at Grid No. 2. However, murky water made location of the stakes impossible, since visibility was restricted to less than three feet. On clear diving days there was no difficulty in finding the grid. Results for February 10 were obtained by sampling about two hours after Batch No. 1 of dyed sand was released, and are inconclusive. The sand at this time was concentrated in a pile at the central drop stake with only two grains scattered to the northeast. These grains may have been part of the material thrown into suspension by divers releasing the sand. Data from February 20 indicate that some sand had moved toward the southeast. Subsequent sampling was impossible due to the high surf and strong trade winds that prevailed throughout March 1971.

Summary

The data of Figures 24 and 25 clearly illustrate that sand movement at Grid No. 1 has a strong southeasterly component. Limited sampling at Grid No. 2 suggests a similar, but possibly slower, southeasterly transport. These results are in agreement with the circulation and turbidity patterns previously discussed. Coarser mean grain sizes (Figure 15) also indicate that reef sediments are entering this area of the bay from the west.

MICROFAUNA OF KAHANA BAY

Introduction

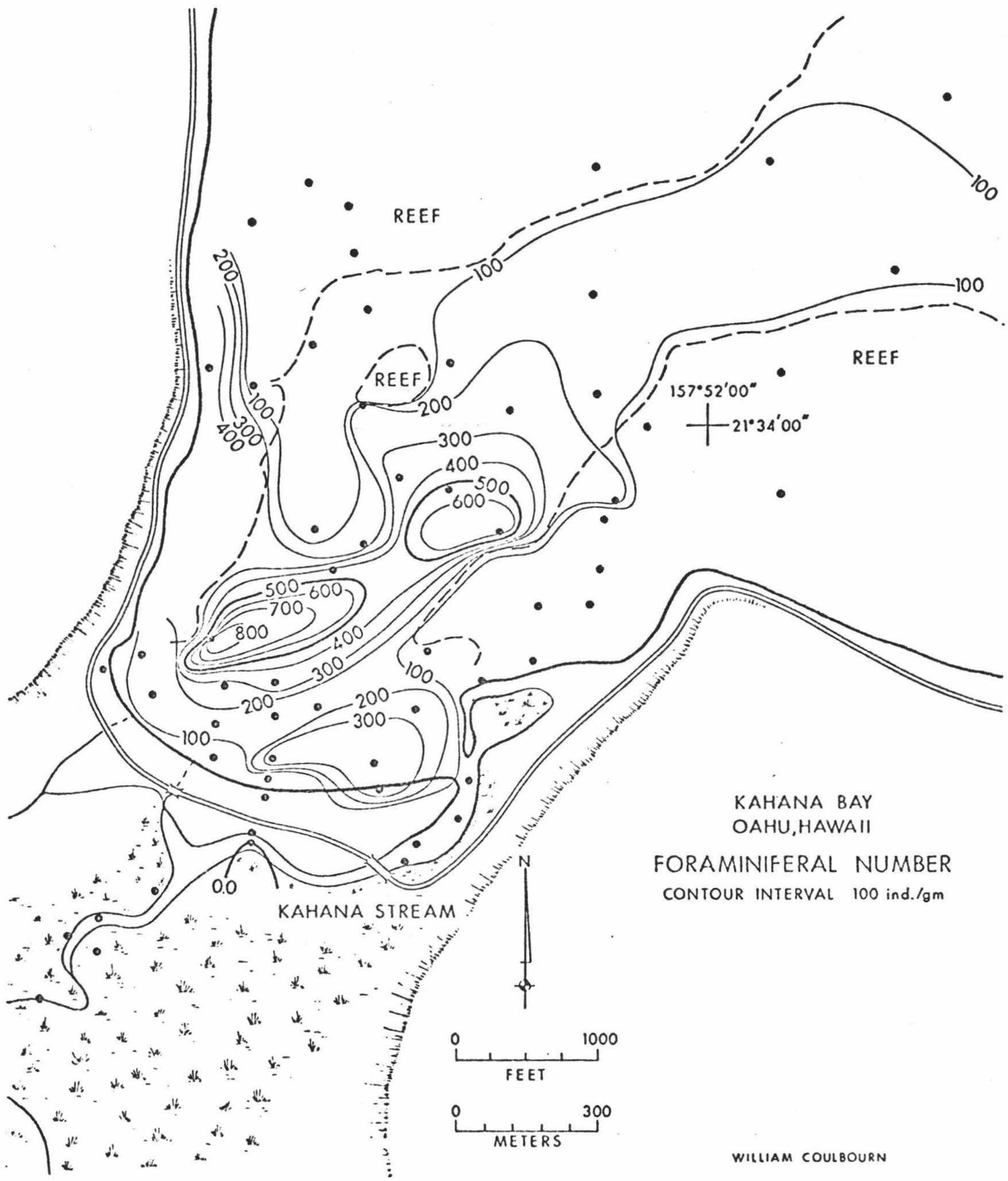
It was originally assumed that, in addition to the sediment parameters previously discussed, the distribution of tests from brackish-water species of foraminifera living in Kahana Stream would serve as a tracer for the course of stream-water discharge into the bay. Preliminary investigation of the samples showed that because of the small numbers of living individuals this approach would provide indecisive results. Therefore, an exhaustive statistical approach was taken, in which populations of individual species of gastropods, ostracods, and foraminifera were counted in samples from 59 locations. Altogether 59 species of foraminifera, 43 of gastropods, and 5 of ostracods were identified. Dr. J. Resig aided in the confirmation of the foraminiferal identifications, and Dr. A. Kay supplied identifications of the gastropods.

Laboratory Procedure

Approximately 50 grams of dried sample were mixed with perchloroethylene. Unbroken foraminifera tests generally are light enough to float in this heavy liquid, and so are concentrated on its surface. The floated portion was retained by pouring through filter paper and then reduced to about 300 individuals by microsplitter. Individuals were then counted with the exception of tests so badly broken that identification was impossible.

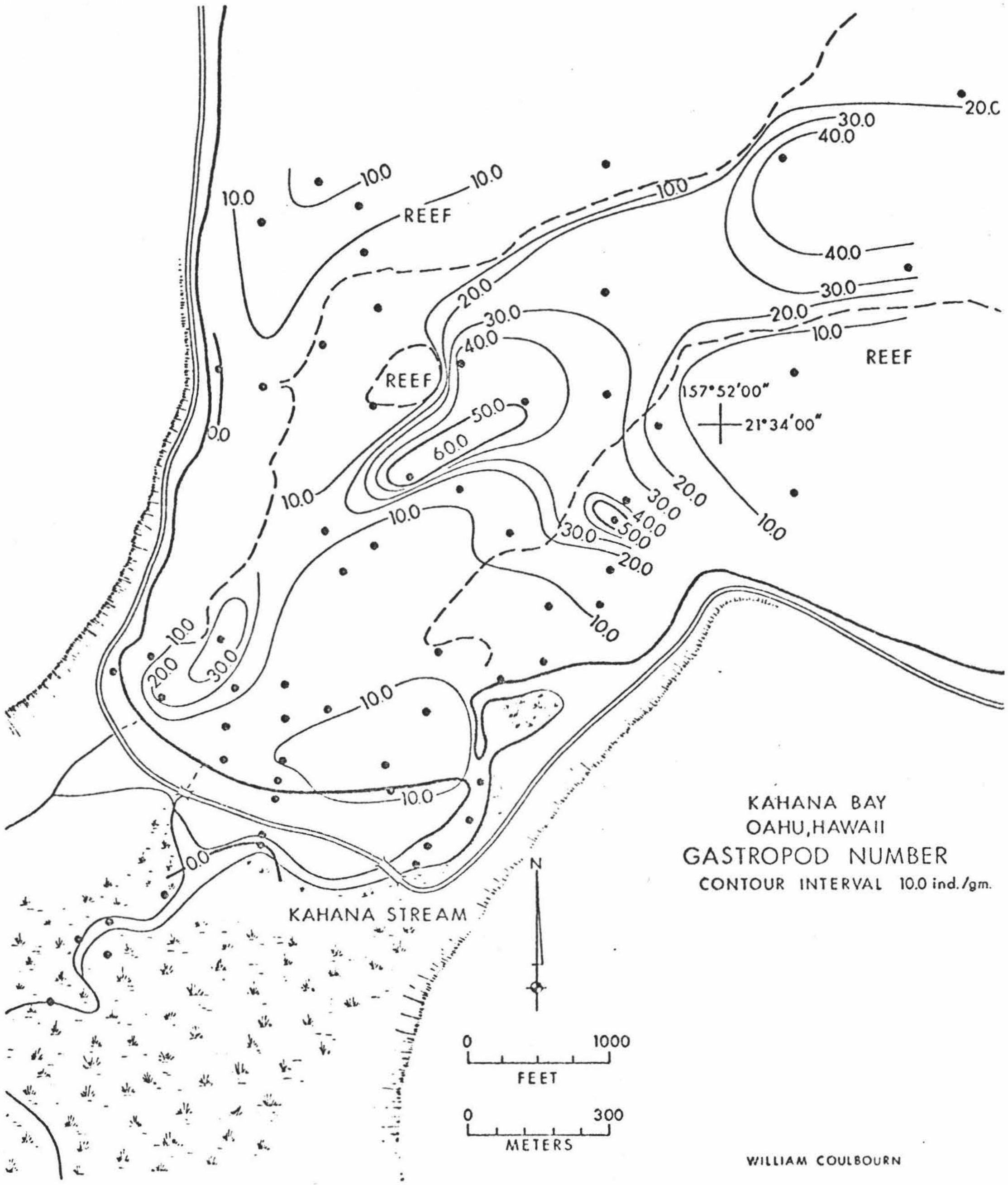
Results

Figures 27 and 28 show values for the total numbers of foraminifera and gastropods, respectively, per gram of sample. A comparison of Figures 26 and 15 show that high foraminiferal numbers correspond to fine grain sizes. Small values for the foraminiferal and gastropod numbers distinguish the reef-flat environment from the quieter wave and current regime of the channel. Values contoured for each species, in units of individuals per gram, more or less reproduced the patterns shown in these two figures. Because this particular format does not display relative concentrations of a species over an area of variable grain size, it was abandoned. The percentage of each foraminifer or gastropod species as compared to the entire population in the sample of foraminifers or gastropods respectively was calculated. The results were contoured and proved quite satisfactory, as the effects of a wide range in grain size were eliminated. Included here are those plots having the least ambiguous distributions.



REEF
REEF
REEF
KAHANA BAY
OAHU, HAWAII
FORAMINIFERAL NUMBER
CONTOUR INTERVAL 100 ind./gm
KAHANA STREAM
157°52'00"
21°34'00"
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 27



10.0
10.0
10.0
REEF
20.C
30.0
40.0
10.0
40.0
30.0
20.0
10.0
REEF
20.0
30.0
40.0
REEF
50.0
60.0
157°52'00"
21°34'00"
0.0
10.0
10.0
20.0
30.0
40.0
50.0
30.0
20.0
10.0
10.0
10.0
20.0
30.0
10.0
10.0
0.0
KAHANA STREAM
KAHANA BAY
OAHU, HAWAII
GASTROPOD NUMBER
CONTOUR INTERVAL 10.0 ind./gm.
N
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 28

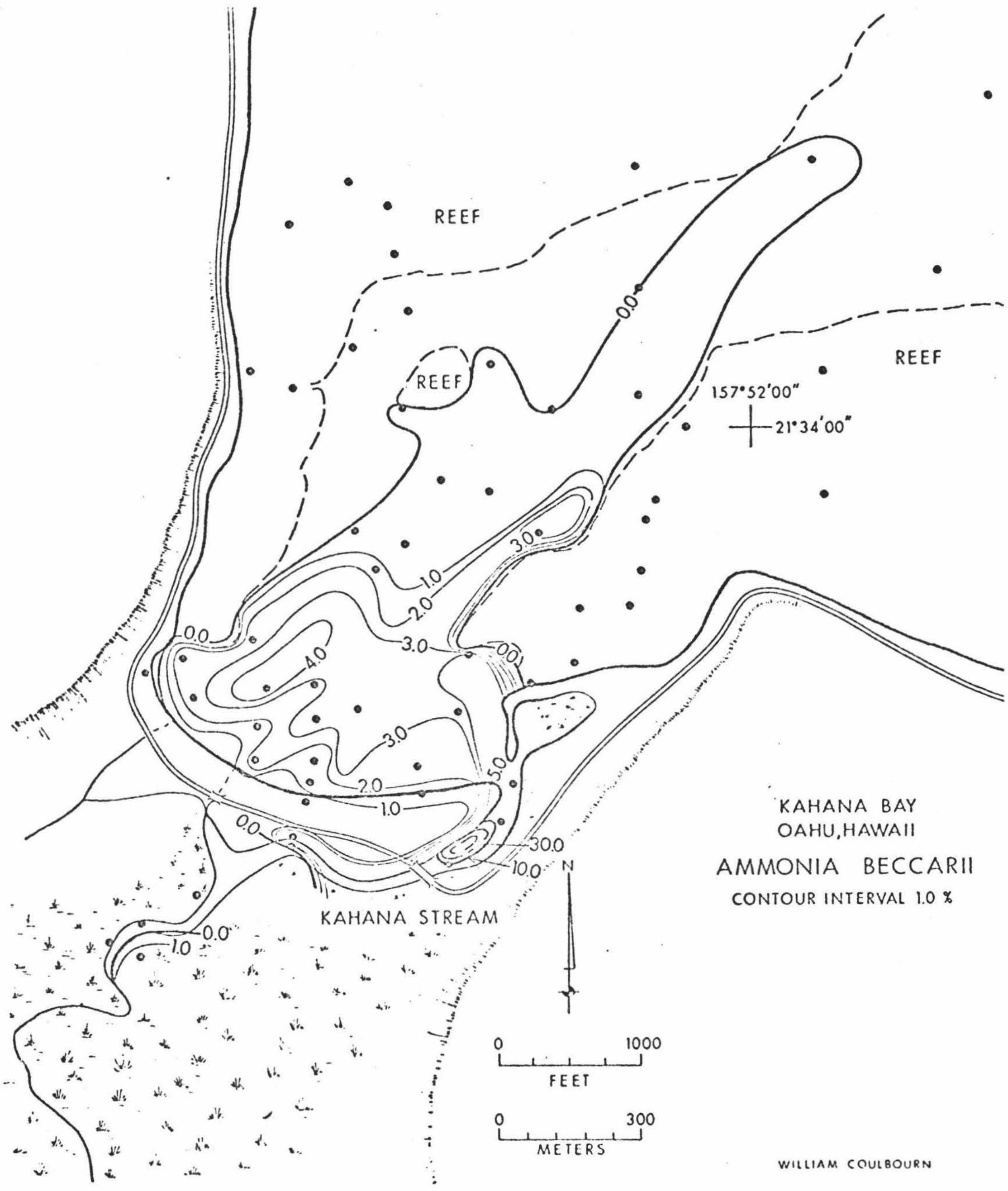
Foraminifera

Brackish-Water Species

Ammonia beccarii and *Elphidium* sp. (Figures 29 and 30) were found living in the estuary of Kahana Stream, and both have similar distributions in Kahana Bay. Accumulations of their empty tests occur in the bay along a southwest to northeast line, an area characterized by low reflectivity of sediments (Figure 14), fine grain size (Figure 16), and high percentages of terrigenous material (Figure 22). The absence of both species from the west side of the sand channel is significant. Because living individuals of each species were found only in the stream, it must be the primary source for tests found in the bay. Therefore the map of their dispersal very closely follows the map of the deposition areas of stream-derived sediment in the bay.

Very Small Species

Six species, *Bolivina rhomboidalis* (Figure 31), *Cibicides lobatulus* (Figure 32), *Elphidium hyalocostatum* (Figure 33), *Glabratella patelliformis* (Figure 34), *Rosalina vilardeboana* (Figure 35), and *Pateoris australis* (Figure 36) have distributions similar to that described for the species *Ammonia beccarii*, and *Elphidium* sp. However, no living specimens of the six were found in the stream bed. This implies that these species do not



REEF
REEF
REEF
157°52'00"
21°34'00"
0.0
1.0
2.0
3.0
4.0
5.0
10.0
30.0
KAHANA STREAM
KAHANA BAY
OAHU, HAWAII
AMMONIA BECCARII
CONTOUR INTERVAL 1.0 %
N
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 29

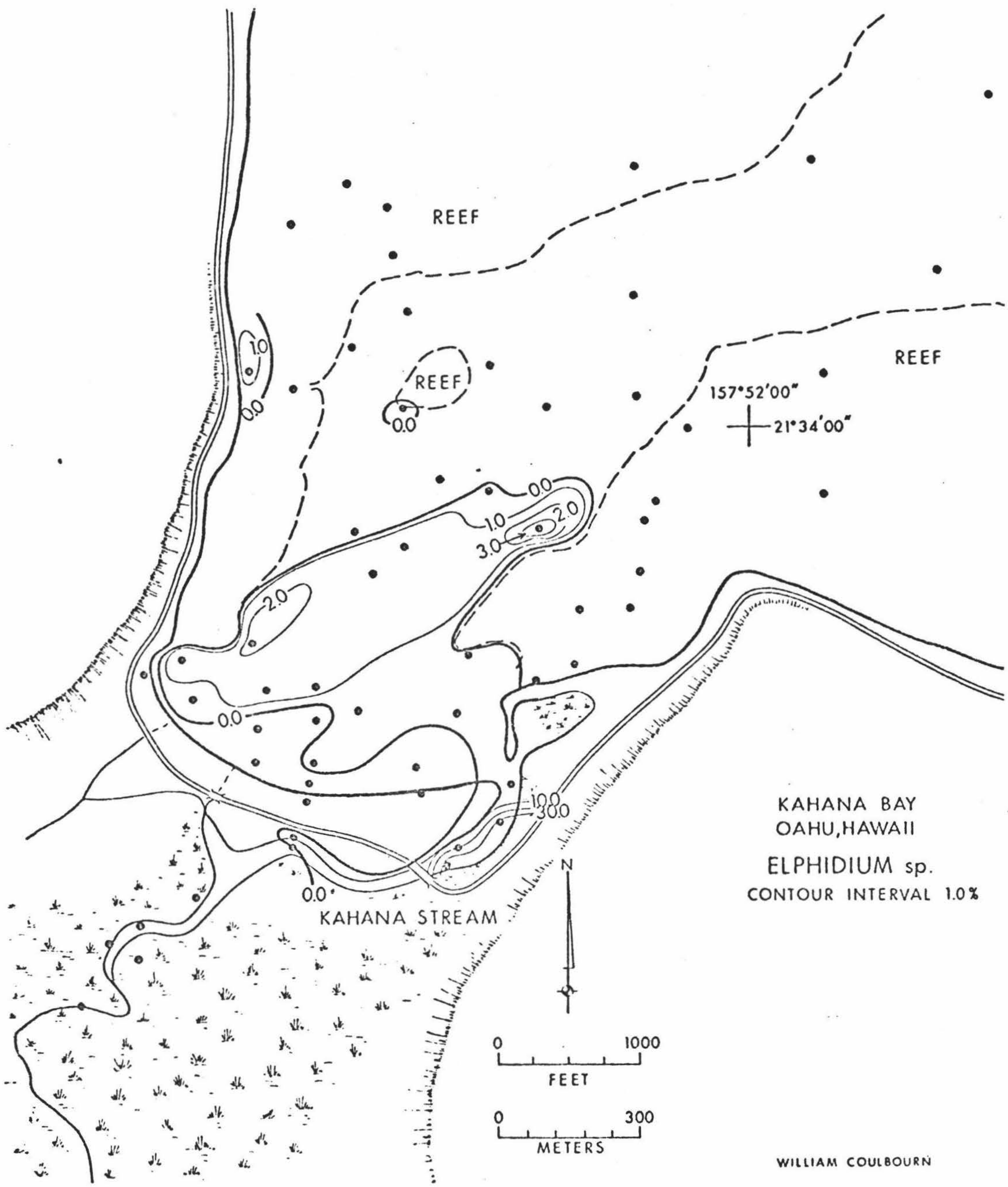

REEF
REEF
REEF
157°52'00"
21°34'00"
1.0
0.0
0.0
0.0
1.0
2.0
3.0
2.0
0.0
10.0
30.0
0.0
KAHANA STREAM
N
KAHANA BAY
OAHU, HAWAII
ELPHIDIUM sp.
CONTOUR INTERVAL 1.0%
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 30

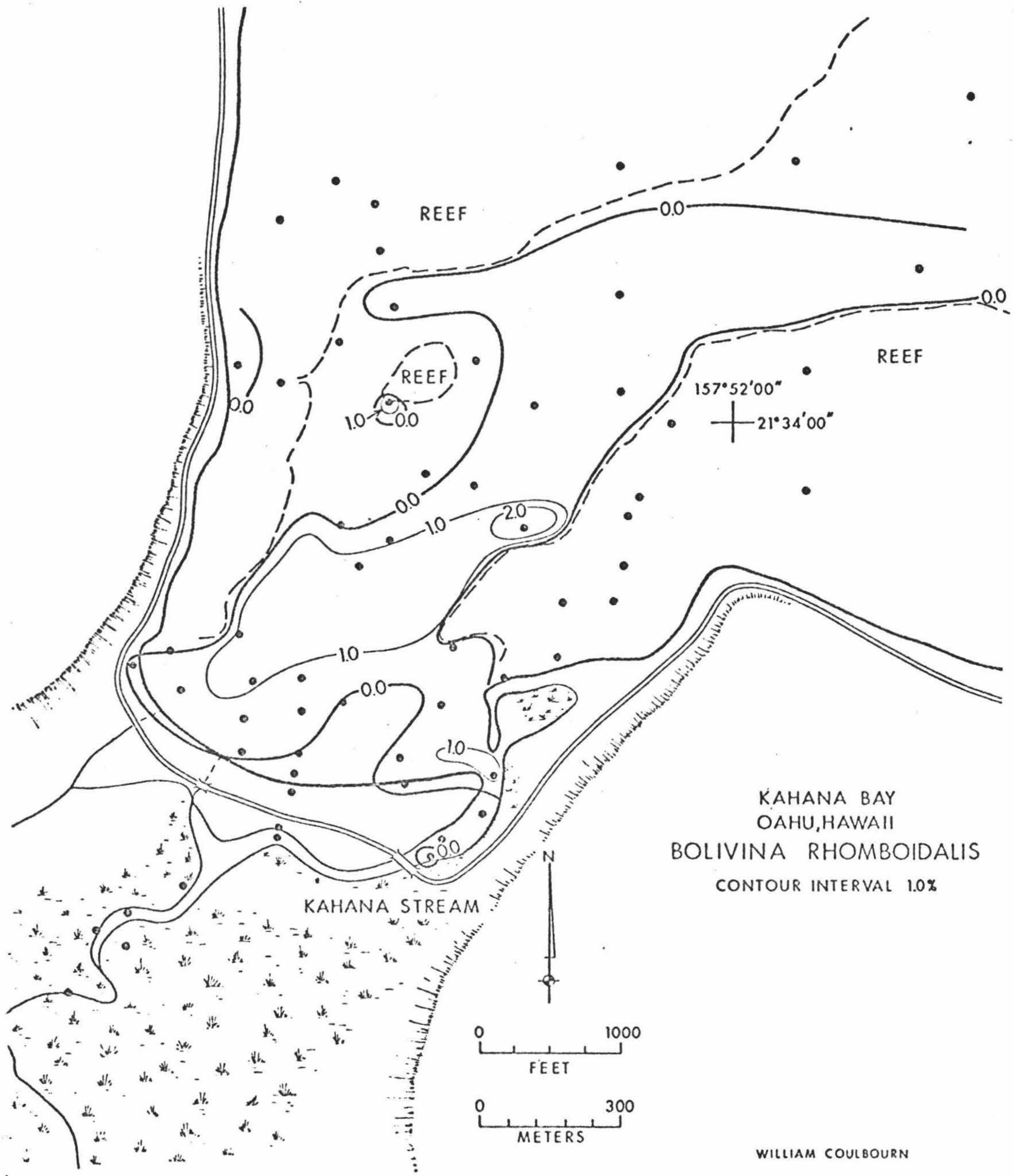
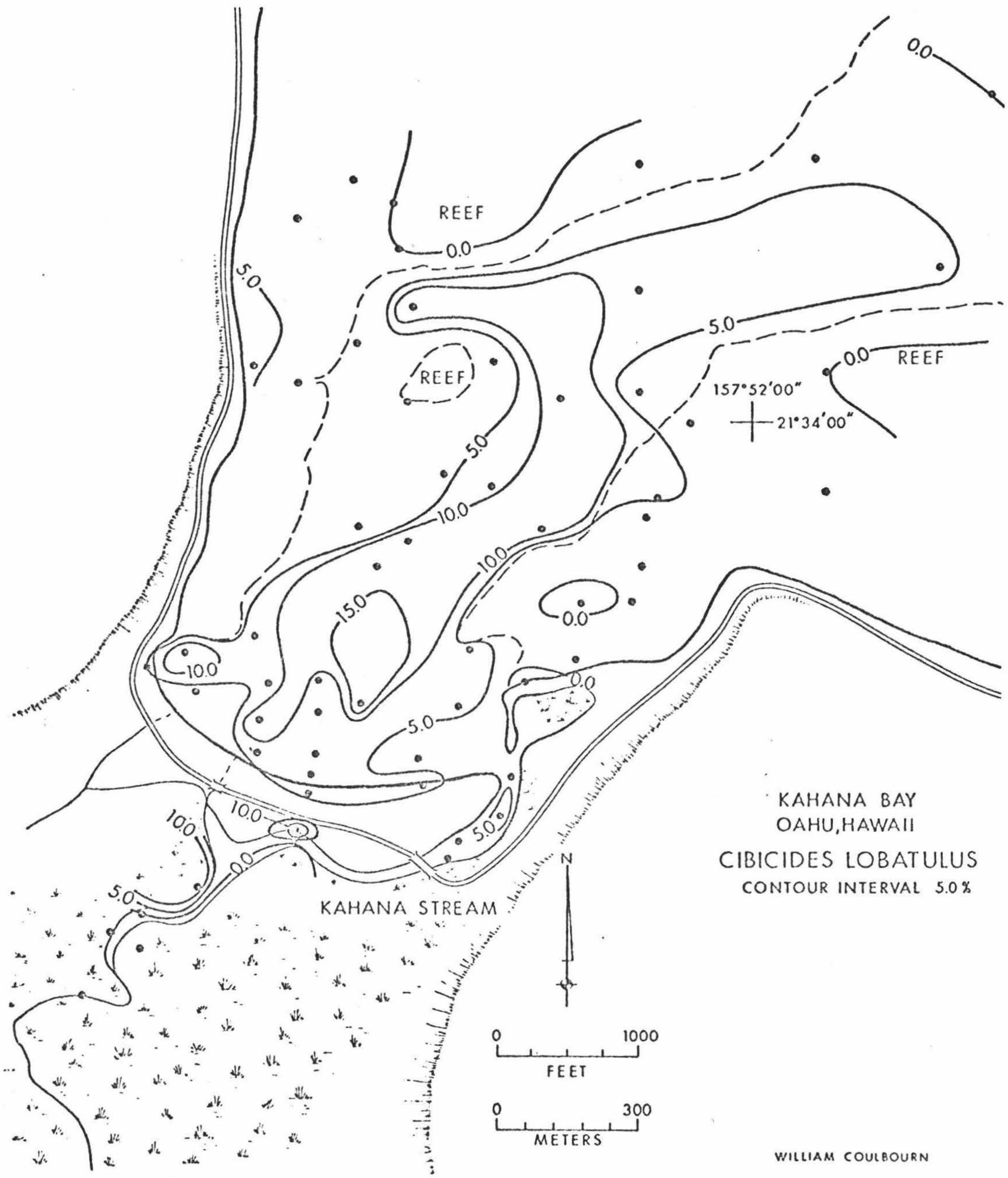

REEF
REEF
REEF
0.0
1.0
2.0
157°52'00"
21°34'00"
KAHANA STREAM
KAHANA BAY
OAHU, HAWAII
BOLIVINA RHOMBOIDALIS
CONTOUR INTERVAL 1.0%
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 31



REEF
0.0
5.0
REEF
5.0
0.0
REEF
157°52'00"
21°34'00"
5.0
10.0
10.0
15.0
0.0
10.0
0.0
5.0
10.0
10.0
5.0
0.0
5.0
KAHANA STREAM
N
KAHANA BAY
OAHU, HAWAII
CIBICIDES LOBATULUS
CONTOUR INTERVAL 5.0%
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 32

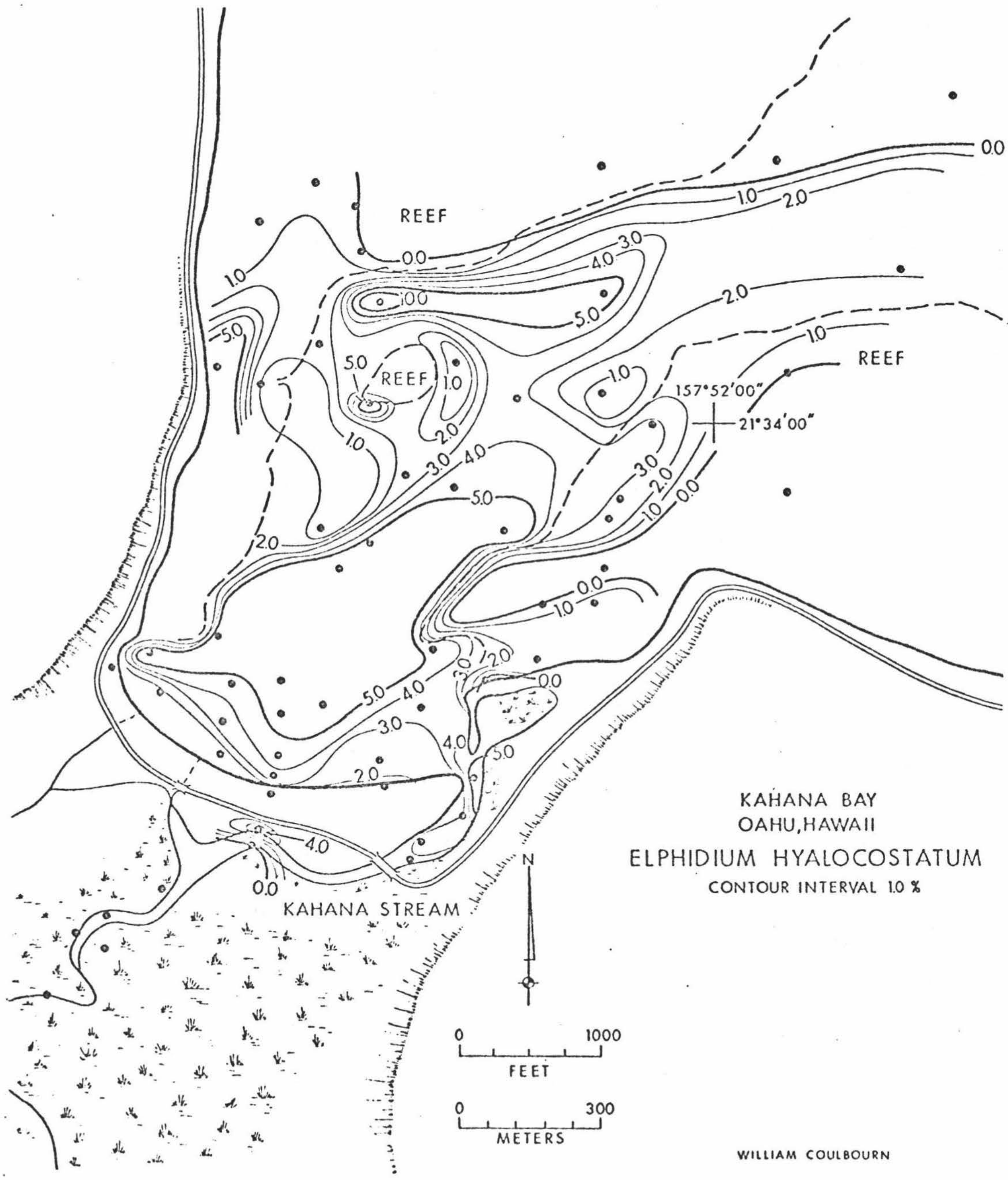
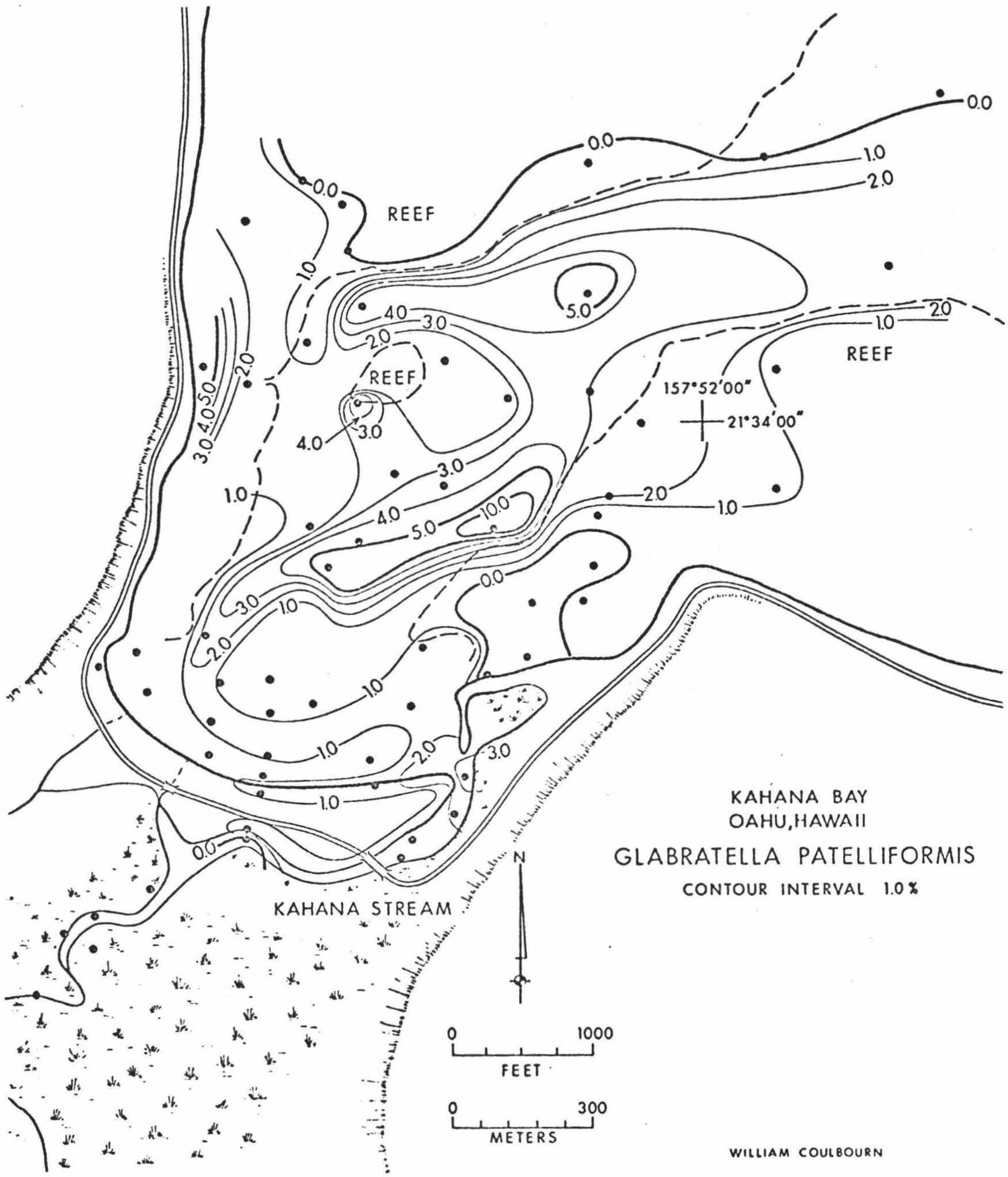

REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA STREAM
KAHANA BAY
OAHU, HAWAII
ELPHIDIUM HYALOCOSTATUM
CONTOUR INTERVAL 1.0 %
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 33



0.0
1.0
2.0
REEF
5.0
4.0
3.0
REEF
157°52'00"
21°34'00"
10.0
KAHANA STREAM
KAHANA BAY
OAHU, HAWAII
GLABRATELLA PATELLIFORMIS
CONTOUR INTERVAL 1.0%
N
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 34

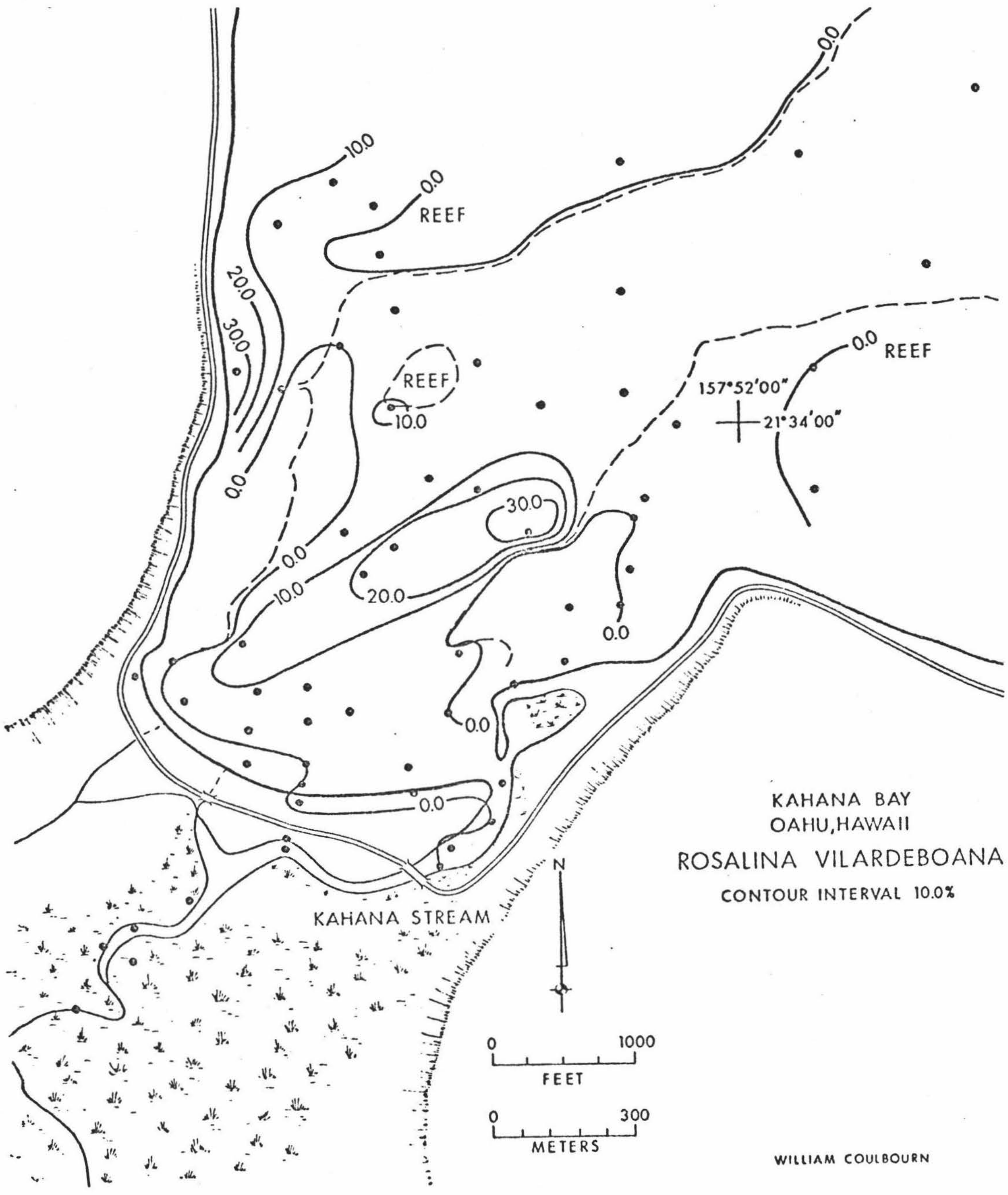

10.0
0.0
REEF
20.0
30.0
REEF
10.0
0.0
0.0
REEF
157°52'00"
21°34'00"
30.0
0.0
10.0
20.0
0.0
0.0
0.0
KAHANA BAY
OAHU, HAWAII
ROSALINA VILARDEBOANA
CONTOUR INTERVAL 10.0%
N
KAHANA STREAM
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 35

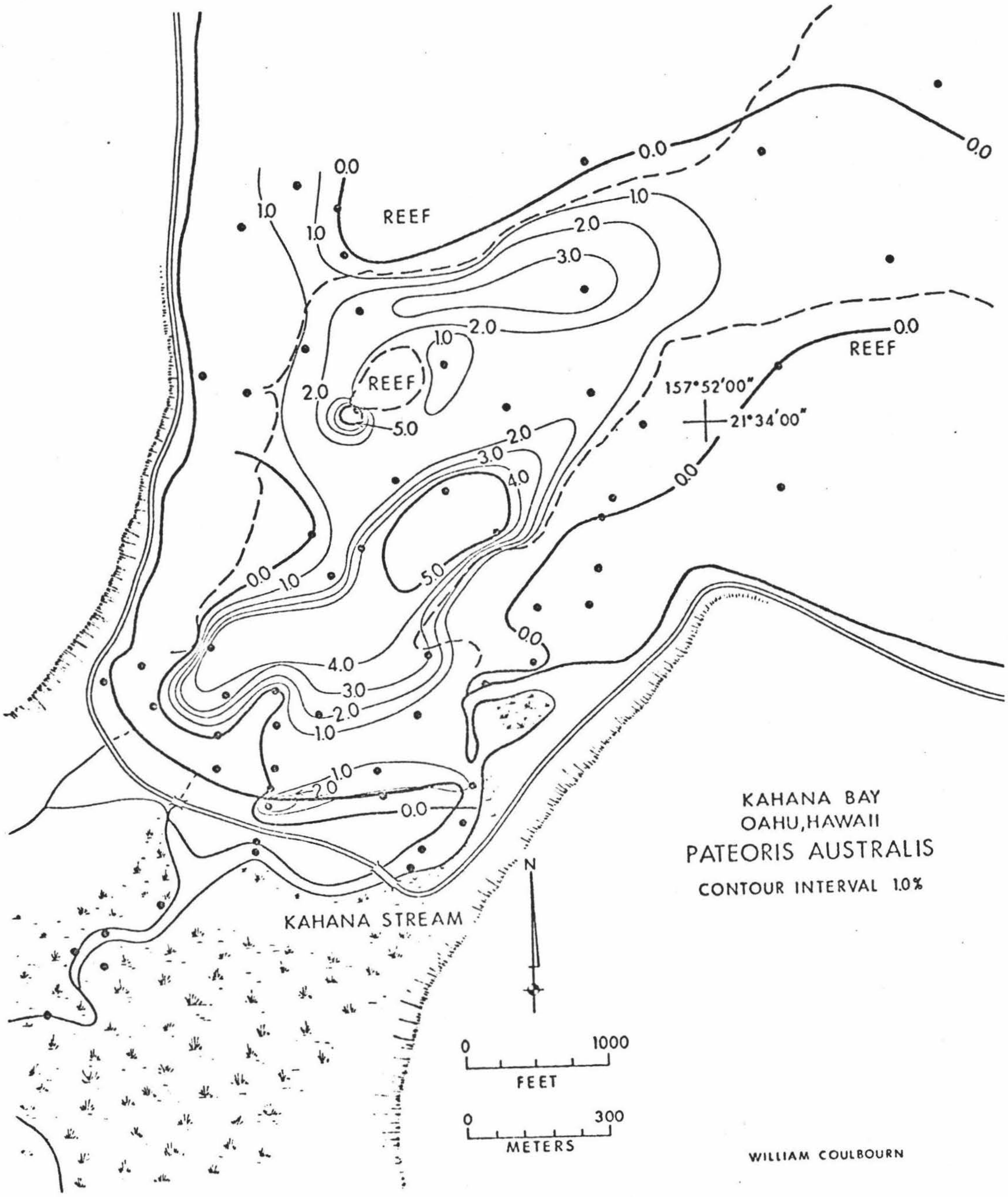

0.0
1.0
1.0
REEF
0.0
0.0
1.0
2.0
3.0
2.0
1.0
REEF
2.0
5.0
0.0
REEF
157°52'00"
21°34'00"
2.0
3.0
4.0
0.0
0.0
1.0
5.0
0.0
4.0
3.0
2.0
1.0
1.0
2.0
0.0
KAHANA STREAM
N
KAHANA BAY
OAHU, HAWAII
PATEORIS AUSTRALIS
CONTOUR INTERVAL 1.0%
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 36

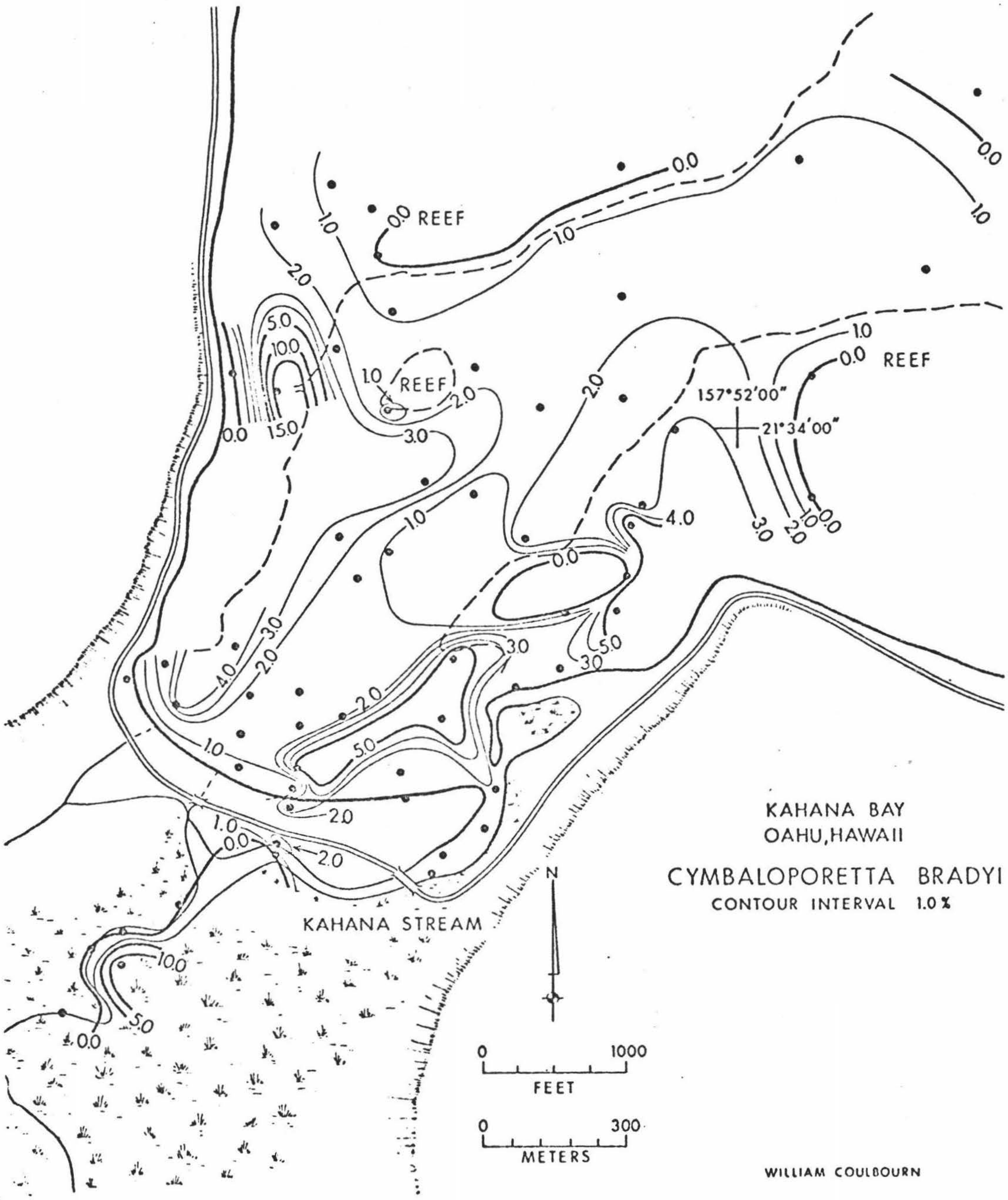
tolerate brackish-water, and that therefore accumulation of these tests in the bay is dependent on test size rather than environmental preference. A close correlation between large foraminiferal number and high percentages of the six species is evident when Figure 27 is compared with Figures 31 to 36. Even though each of the species occurs along the present-day beach in small quantity, the decrease in their percentages from east to west as wave energy increases, suggests that surf agitation effectively winnows out the tests. Elphidium hyalocostatum, Glabratella patelliformis, and Cibicides lobatulus are present in an eroding bank behind the present-day beach ridge (Sample 19), suggesting that the deposit accumulated under low energy conditions. An alternate explanation for relatively high percentages of these species, that of low species diversity, is thought to be responsible for the apparent 14.3% concentration of Cibicides lobatulus on the inland beach ridge (Sample 18).

All of these small species, except Bolivina rhomboidalis and Cibicides lobatulus, are concentrated locally at the southern edge of the patch reef (Sample 701-F). This area is on the lee side of the reef with respect to both wind and swell direction, and therefore it is not surprising that these small tests accumulate here, as energy sufficient for transport is lacking.

All of the small species occur along the northern side of the channel, but their low concentrations or complete absence in samples from the reef flat suggest that the source lies elsewhere. Furthermore, the western reef edge, an area where sand tracer studies have shown the sand to be moving into the channel, presumably off the reef flat, has minimal representation of these small species. It may be concluded that although some of the species might live in the reef sands, alternate sources of supply of these tests to the death assemblage of Kahana Bay are possible. These species may cling to algae or reef vegetation until death, at which time the inert small tests are rapidly transported across the reef flats. A less likely possibility is that channel sands are supporting a living population because, of all the tests counted, only one individual, of the species Rosalina vilardeboana from Sample 902-F was alive at the time of sampling.

Large Species

The distribution of large foraminifera that are generally either angular or disc-shaped is shown in Figures 37 to 44. All are characterized by significant concentrations on the reef-flat, the beach, and the nearshore high-energy environments. Spotty distributions over the reef-flat occur because most samples from this area have small foraminiferal numbers (Figure 27) so that



0.0 REEF
1.0
2.0
5.0
10.0
15.0
0.0
3.0
1.0 REEF
157°52'00"
21°34'00"
4.0
5.0
KAHANA STREAM
KAHANA BAY
OAHU, HAWAII
CYMBALOPORETTA BRADYI
CONTOUR INTERVAL 1.0 %
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 37

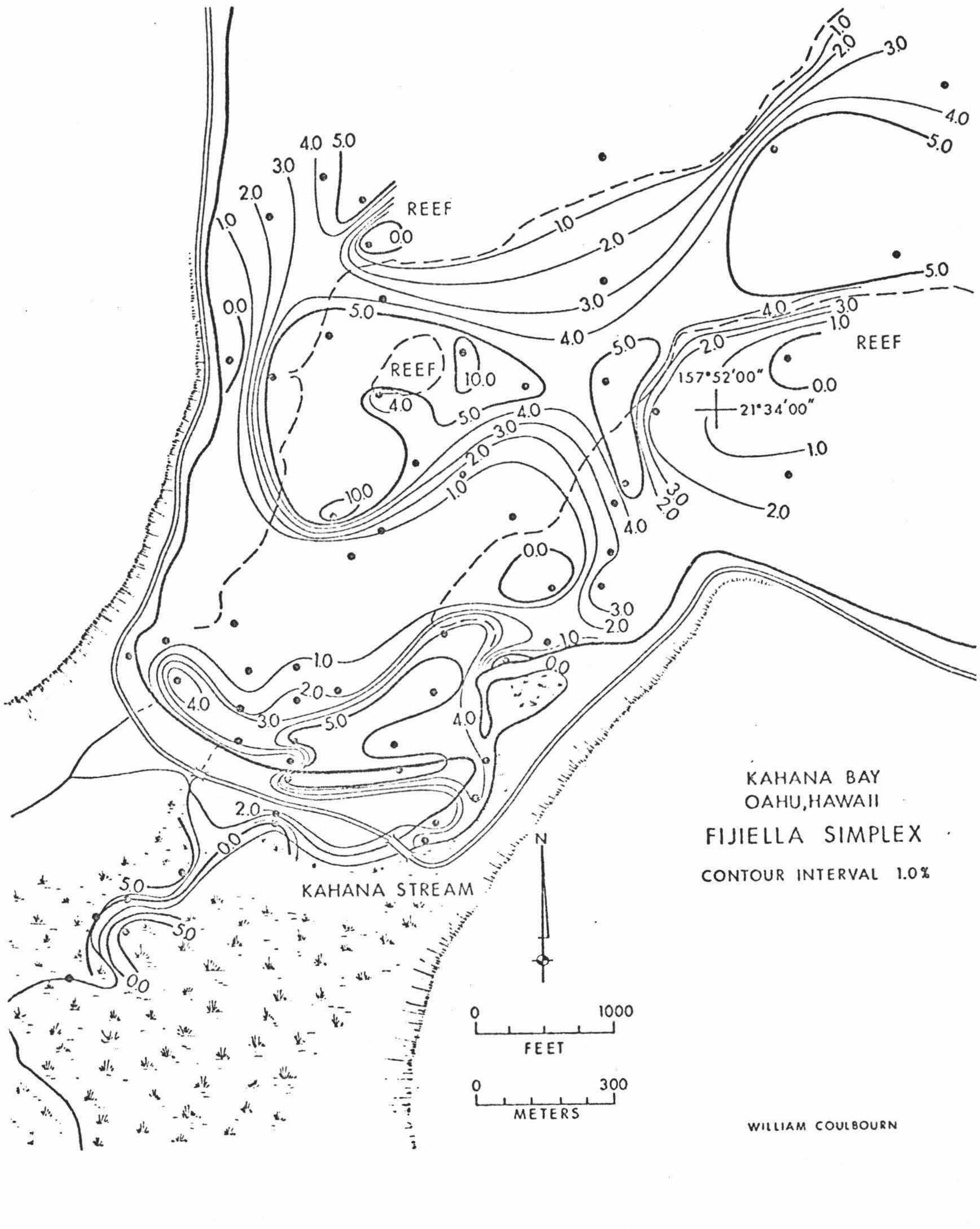

REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA STREAM
N
0 1000
FEET
0 300
METERS
KAHANA BAY
OAHU, HAWAII
FIJIELLA SIMPLEX
CONTOUR INTERVAL 1.0%
WILLIAM COULBOURN

Figure 38

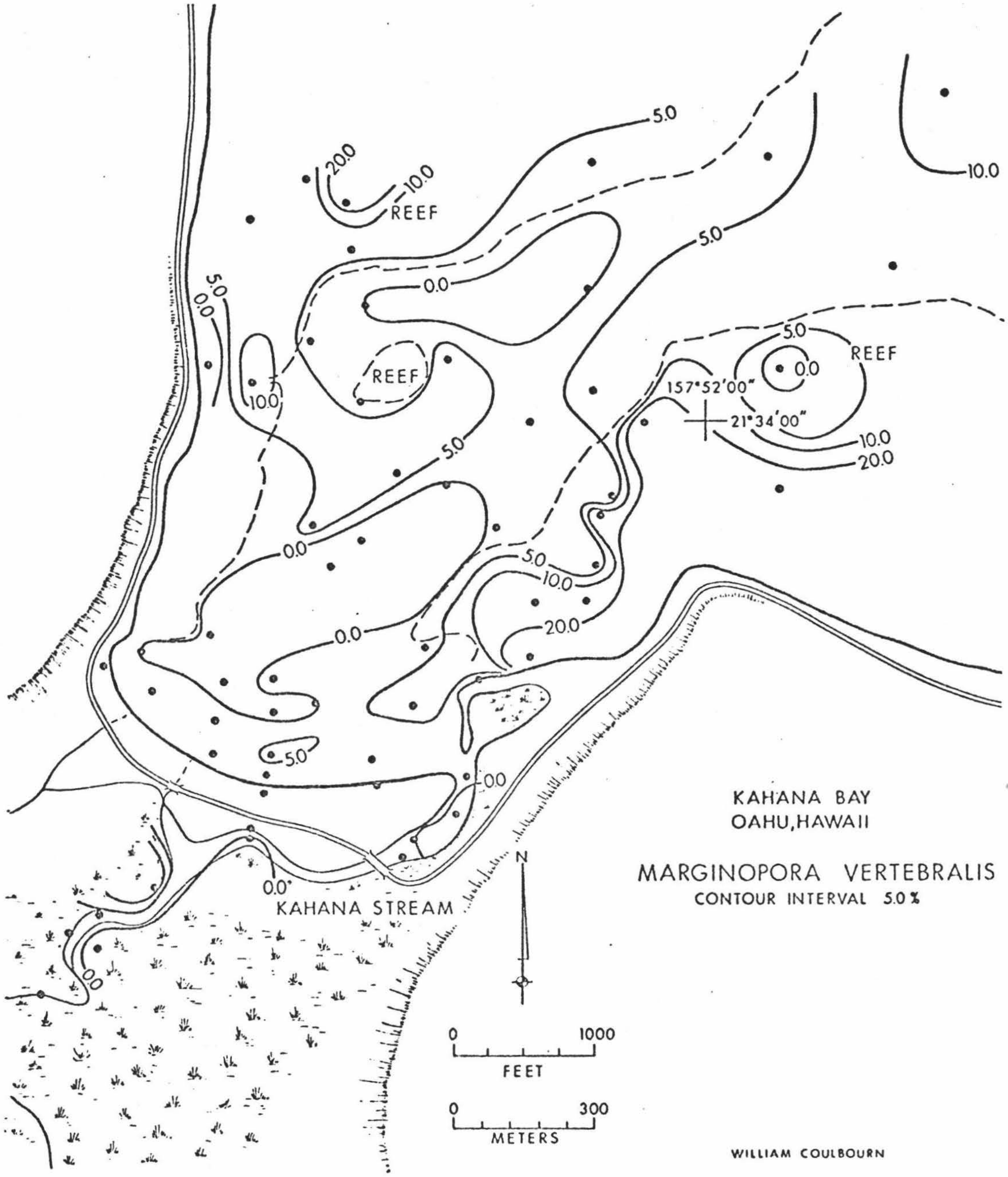

KAHANA BAY
OAHU, HAWAII
MARGINOPORA VERTEBRALIS
CONTOUR INTERVAL 5.0%
REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA STREAM
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 39

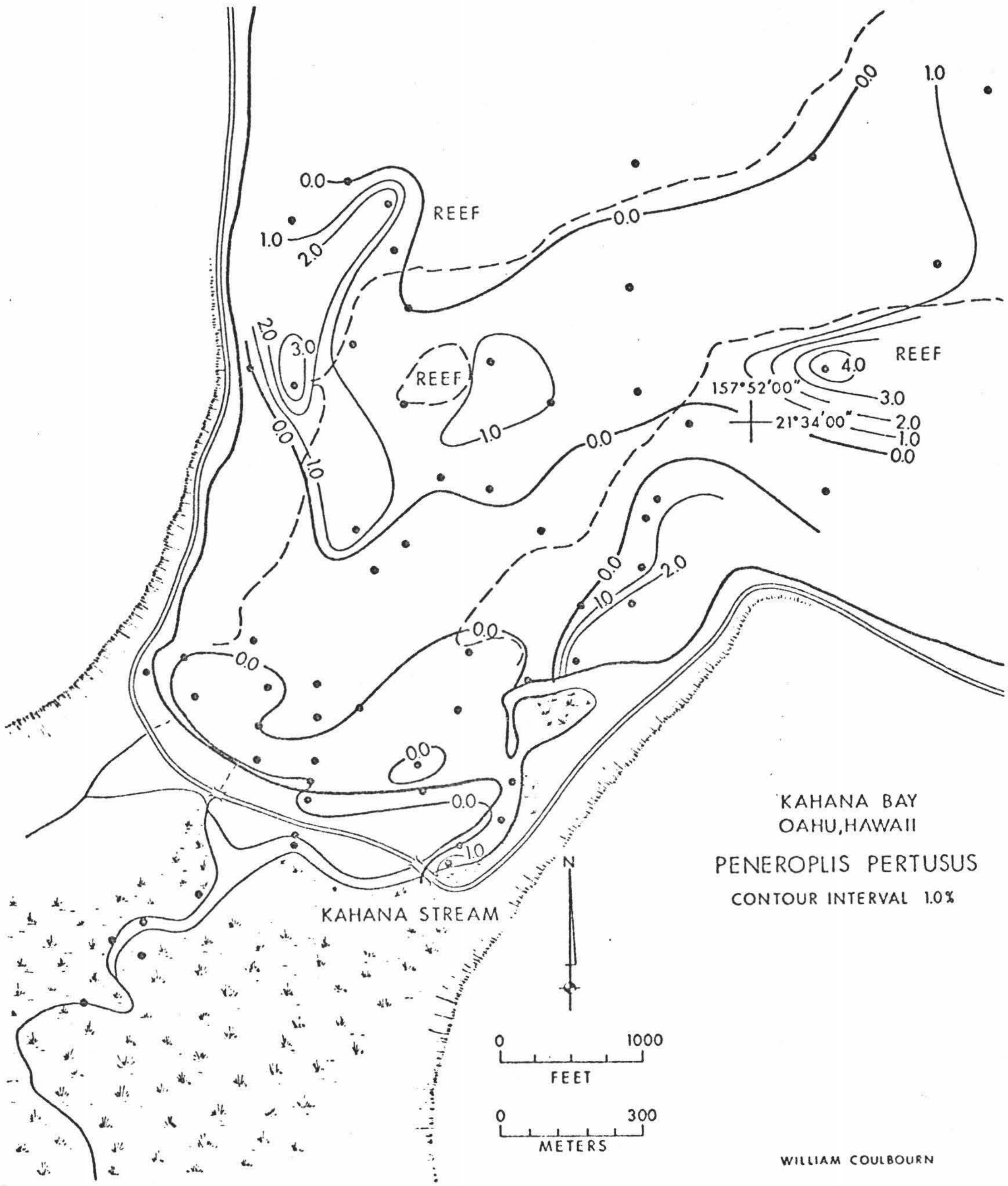
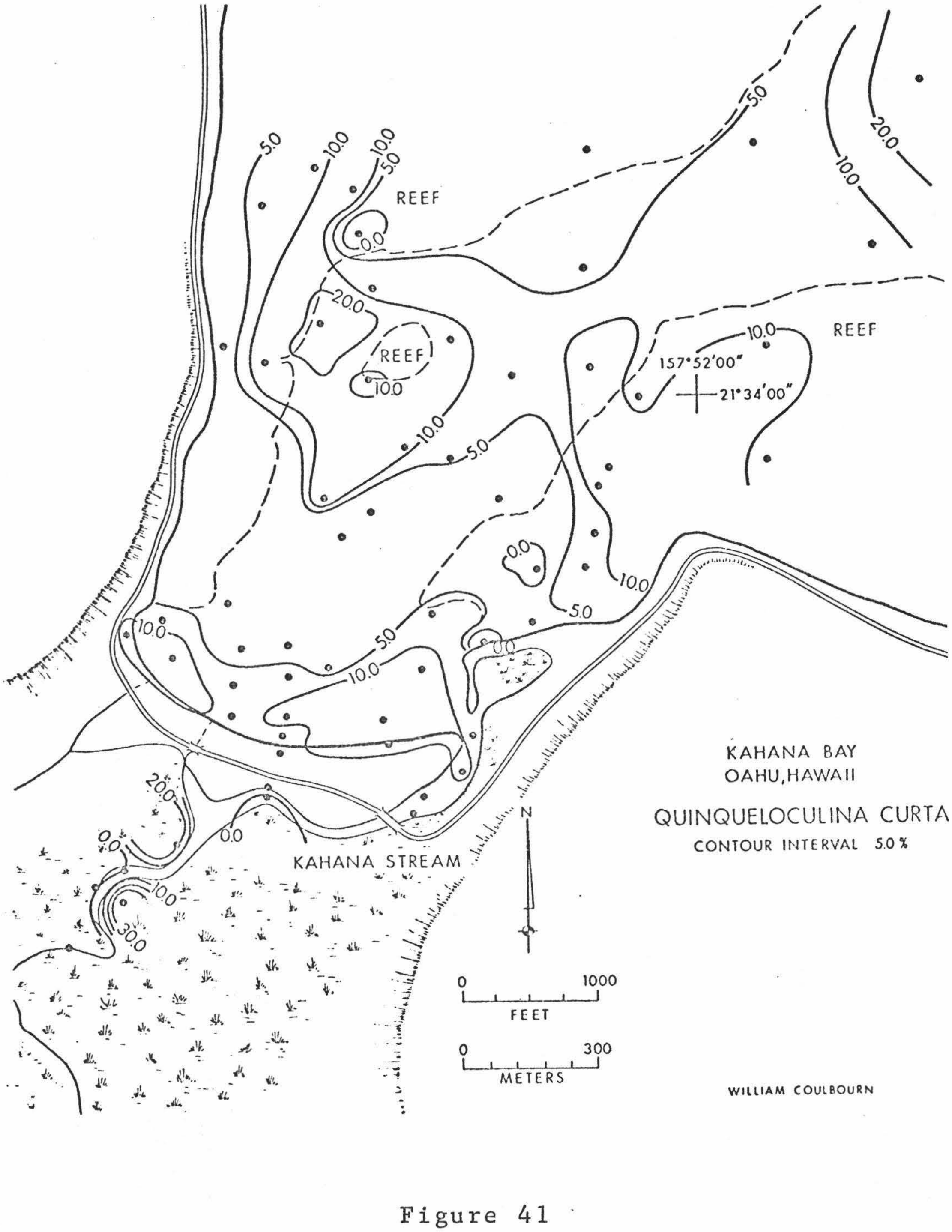

REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA BAY
OAHU, HAWAII
PENEROPLIS PERTUSUS
CONTOUR INTERVAL 1.0%
KAHANA STREAM
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 40



REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA STREAM
N
KAHANA BAY
OAHU, HAWAII
QUINQUELOCULINA CURTA
CONTOUR INTERVAL 5.0 %
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 41

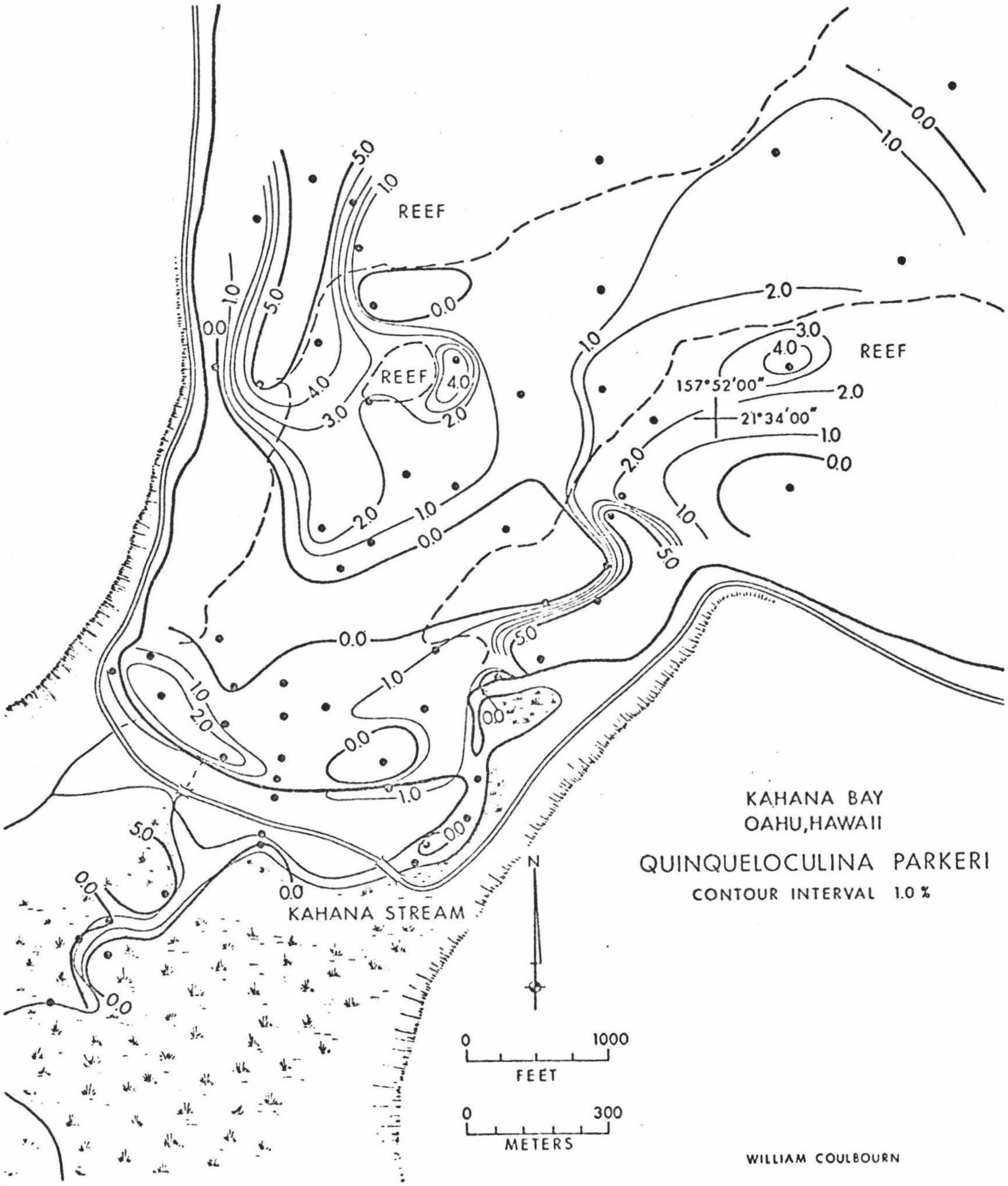

REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA BAY
OAHU, HAWAII
QUINQUELOCULINA PARKERI
CONTOUR INTERVAL 1.0 %
KAHANA STREAM
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 42

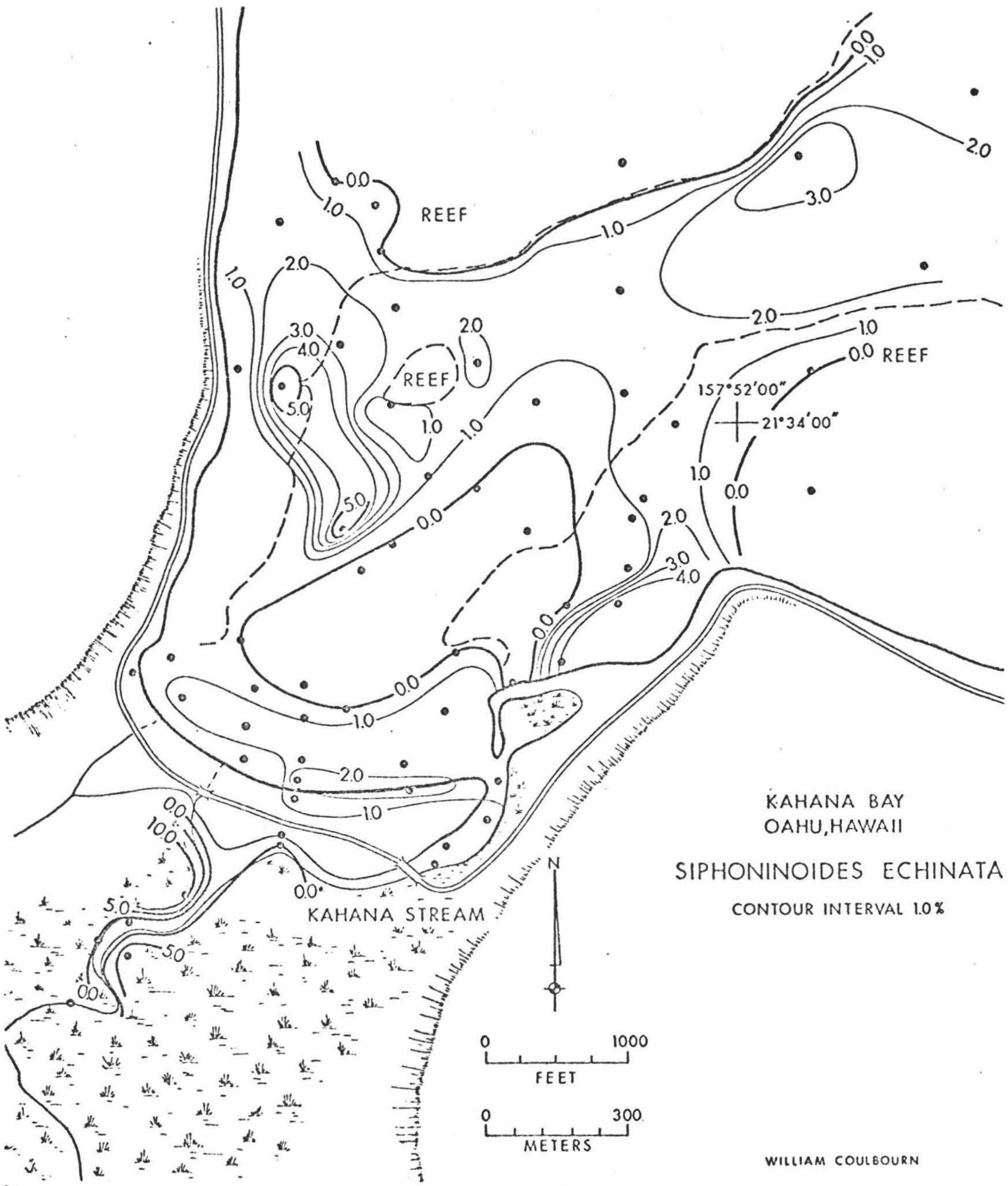

REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA STREAM
KAHANA BAY
OAHU, HAWAII
SIPHONINOIDES ECHINATA
CONTOUR INTERVAL 1.0%
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 43

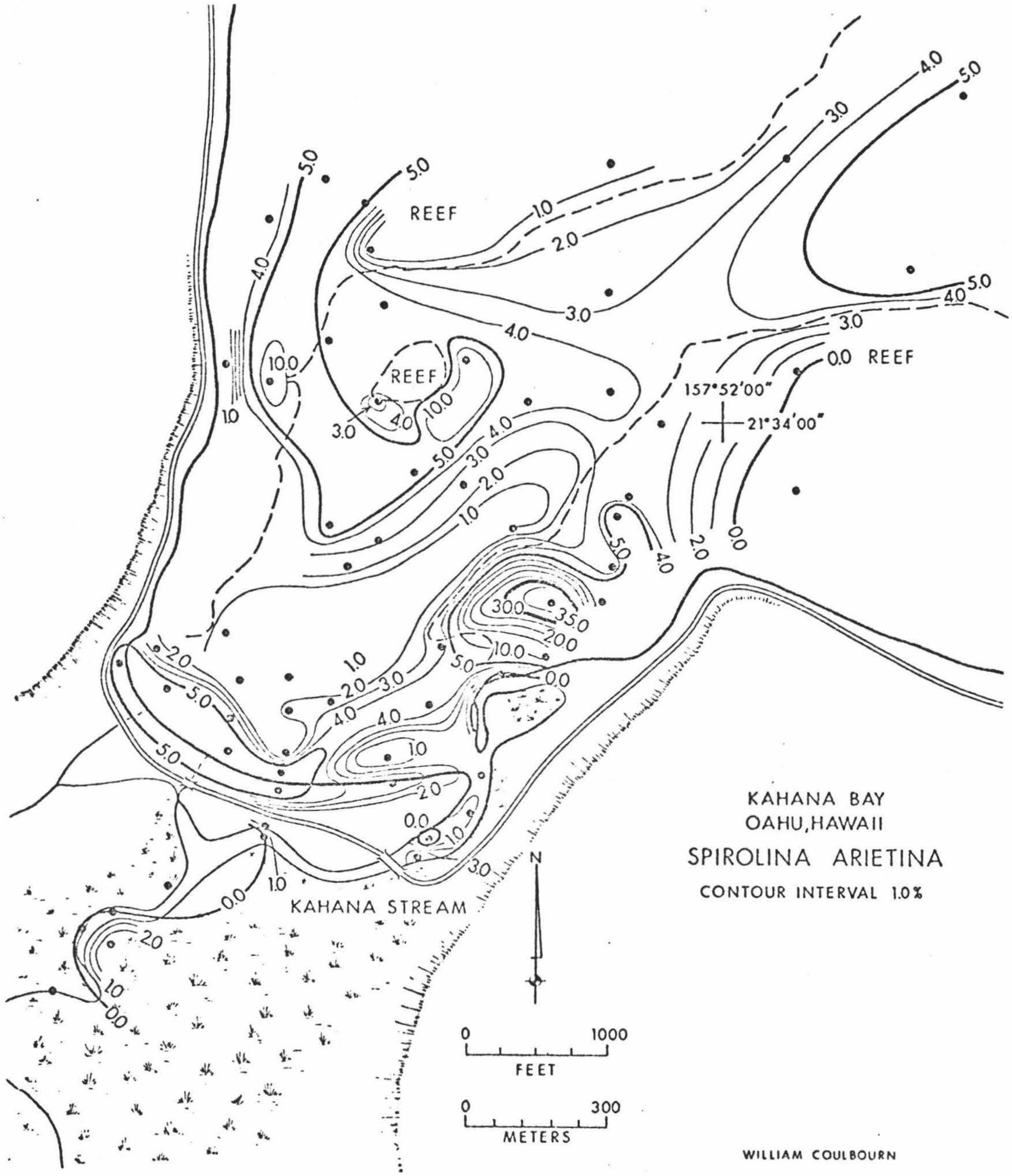

KAHANA BAY
OAHU, HAWAII
SPIROLINA ARIETINA
CONTOUR INTERVAL 1.0%
REEF
REEF
0.0 REEF
157°52'00"
21°34'00"
KAHANA STREAM
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 44

the chance recovery of minor constituents must be small. Minimal values occur in the central sand channel areas associated with fine sediment. This pattern compliments that previously described for Figures 29 to 36. It should be noted that significant percentages of all but Peneroplis pertusus are found in samples from the inland beach ridges, and that all are present in the high-surf areas of the bay, including the stream-mouth sand bar. The contours suggest that the eastern reef-flat is probably the source of these tests. The percentage contours of Marginopora vertebralis and Spirolina arientina (Figures 39 and 44) have high gradients along the eastern reef edge, indicating that little transport occurs across that boundary. This is further supported by a paucity of all the large species along most of the eastern sand channel. The distributions around the patch reef are particularly interesting. Low percentages found on the southeast, or downdrift, side of the patch reef, as well as the southeasterly drift of tracer sand at Grids No. 1 and No. 2 (Figures 15, 24, and 25) indicate that the tests are swept around the sides of the patch reef and moved into the bay. All species have relatively high percentage values on the western reef, but generally lower values in the very high energy zone of the northern reef-flat. There is also a noticeable absence of these species along the northern side of the channel, where the very small species accumulate. Quinqueloculina parkeri

(Figure 42), and Marginopora vertebralis (Figure 39) are totally absent from that area, a fact difficult to account for, since the mean grain size data (Figure 16) indicates that reef sediment is being introduced into that side of the channel. It seems that the dominant transport of microfauna living on the reef-flat may first be toward the west shore, then south, and finally eastward into the bay (at points such as Sample 1201-F) along the western reef margin. This movement corresponds to the pattern of water flow theorized in a preceding section, as well as with the Inman et al. (1963) hypothesis concerning sand movement across reef-flats. In a similar environment on Kauai, those workers found reef-dissecting sand channels with ripple marks aligned parallel to the shore, from which they deduced the dominant component of sand movement to be shoreward.

Relatively high percentages of all six species correspond to areas labelled "light" on Figure 14, and show an abrupt termination at the border of light and dark in the center of the bay. This border represents the limit of southeasterly sediment transport within the sand channel.

Amphistegina madagascariensis

Very high percentages of this species in all of the reef samples (Figure 44) and significant numbers of living individuals indicate that in Kahana Bay as elsewhere

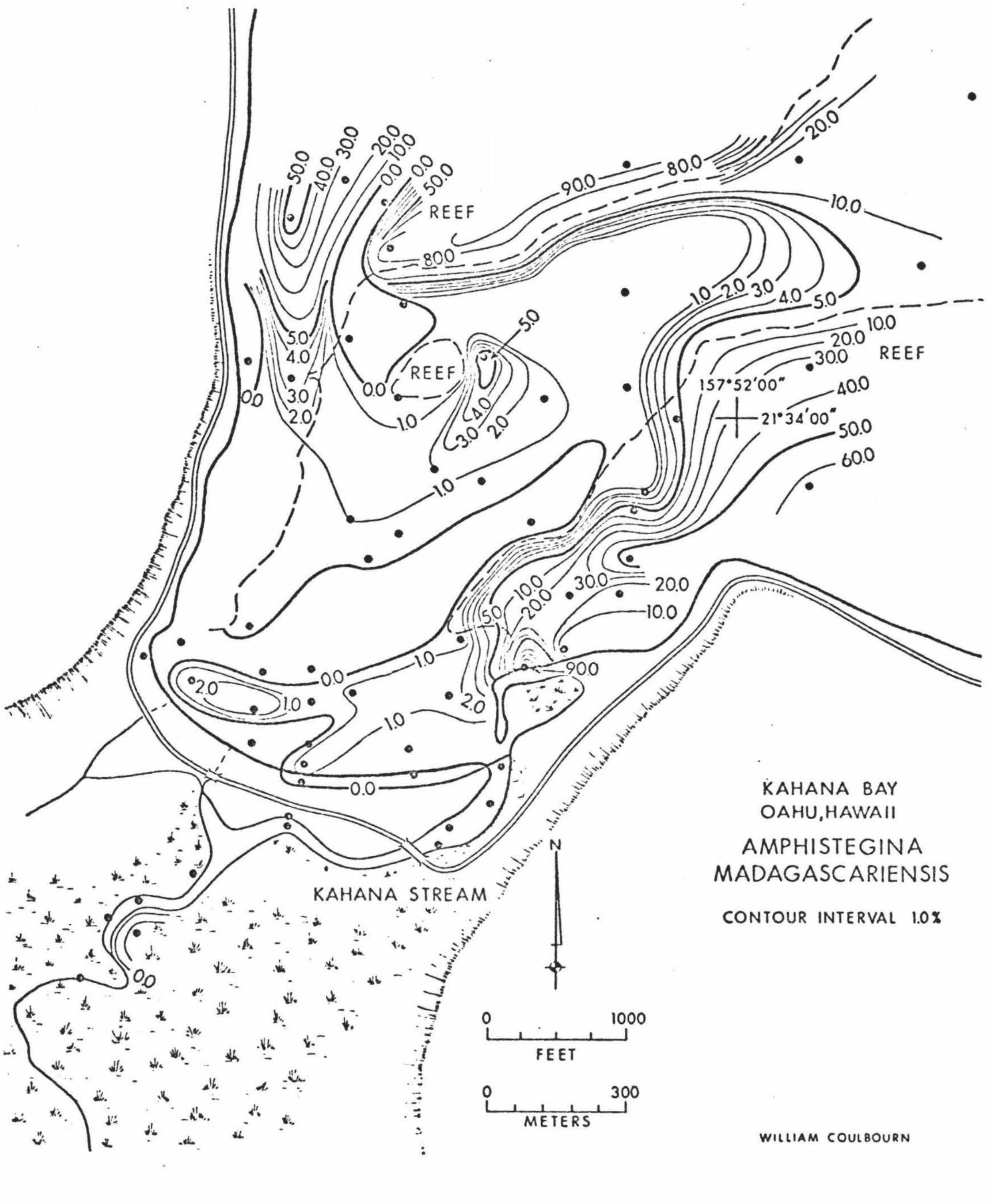

KAHANA BAY
OAHU, HAWAII
AMPHISTEGINA
MADAGASCARIENSIS
CONTOUR INTERVAL 1.0%
REEF
REEF
REEF
KAHANA STREAM
157°52'00"
21°34'00"
N
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 45

(Bandy, 1962), *Amphistegina madagascariensis* lives in the reef environment, either attached to the substrate and algae, or in the sand. The very large size, lenticular shape, and sturdy test construction enables this species to withstand breakage in environments having strong waves and currents.

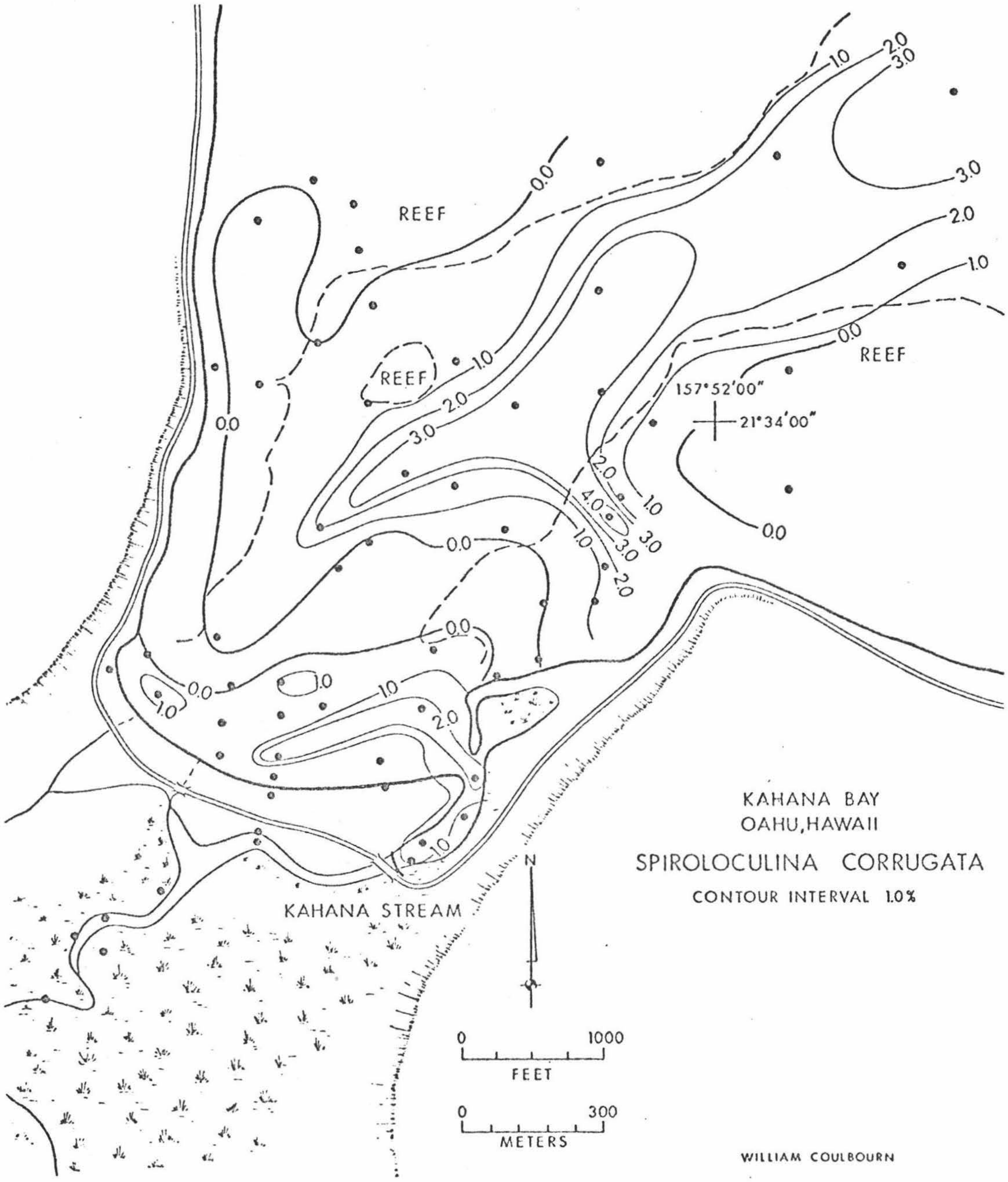
The low species-diversity and foraminiferal numbers (Figure 27) in reef stands where a few individuals can account for more than 90% of the population, are responsible for the sharp gradients of contours (Figure 45) along all the reef margins. This contrast may not represent a distributional barrier. Foraminiferal numbers in channel sediments are much higher than those on the adjacent reef. Therefore, the presence of even a small number of individuals in the channel samples is significant.

Apparently currents are not strong enough to transport the large tests of this species into the central bay area and portions of the beach. From the distributional pattern, it may be interpreted that this species is washed from the eastern reef across the stream-mouth bar, and concentrated in the surf zone at the western corner of the bay. There is a significant increase in percentages of *Amphistegina madagascariensis* in deeper water samples.

Spiroloculina corrugata

The distribution of this species (Figure 46) exemplifies one of the many patterns that are only of marginal use in illustrating sediment movements. This species is porcelaneous, large, and tabular-shaped. It is present in small quantity in areas of coarse, highly calcareous sand (Figures 16 and 20). The distribution suggests that Spiroloculina corrugata has no particular preference for either reef-flat or sand-channel habitats. No living individuals were found in the samples analyzed. Nearshore occurrences delineate areas of accumulation of reef-derived material. The concentrations in the stream mouth probably result from tidal ebb and flow, and do not indicate the presence of a living source population in the brackish-water environment. This is supported by generally abraded tests in the nearshore area, contrasted with the fresher appearing tests from reef-flat samples. High percentages in the central area of the channel are probably due to a living population as there is no indication that these tests are being brought in from the reef or nearshore areas.

Large size-range, wide salinity-tolerances, and adaptivity to various types of substrate are all factors contributing to unrestricted distributions. The species previously discussed, those with narrow size-ranges and ecological preferences, have proven to be the best indicators of transport.



REEF
REEF
REEF
0.0
1.0
2.0
3.0
4.0
157°52'00"
21°34'00"
KAHANA STREAM
N
KAHANA BAY
OAHU, HAWAII
SPIROLOCULINA CORRUGATA
CONTOUR INTERVAL 1.0%
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 46 .

Gastropods

The following figures show the percentage of each identifiable group of gastropods in the total gastropod population counted in each sample. The taxonomy of members of the family Vitrinellidae is uncertain and accordingly species described here are assigned the descriptive terms brown, lined, rough, and smooth. Each of these is recognizable as a distinct species.

Hipponix

The percentage distribution of juvenile forms of this genus (Figure 47) is similar to that of the very small species of foraminifera (Figures 31 to 36), presumably for the same reasons. The small size of these individuals and their high relative concentrations in areas of fine grain-size suggests that the distribution is dependent upon size-energy relationships.

Vitrinellid "lined"

This large species has a distribution (Figure 48) similar to that of the large species of foraminifers (Figures 37 to 44), suggesting that the species is a reef-dweller whose distribution in channel sediments is dependent upon size. Individuals of the species are probably introduced into lower Kahana Stream by tidal ebb and flow.

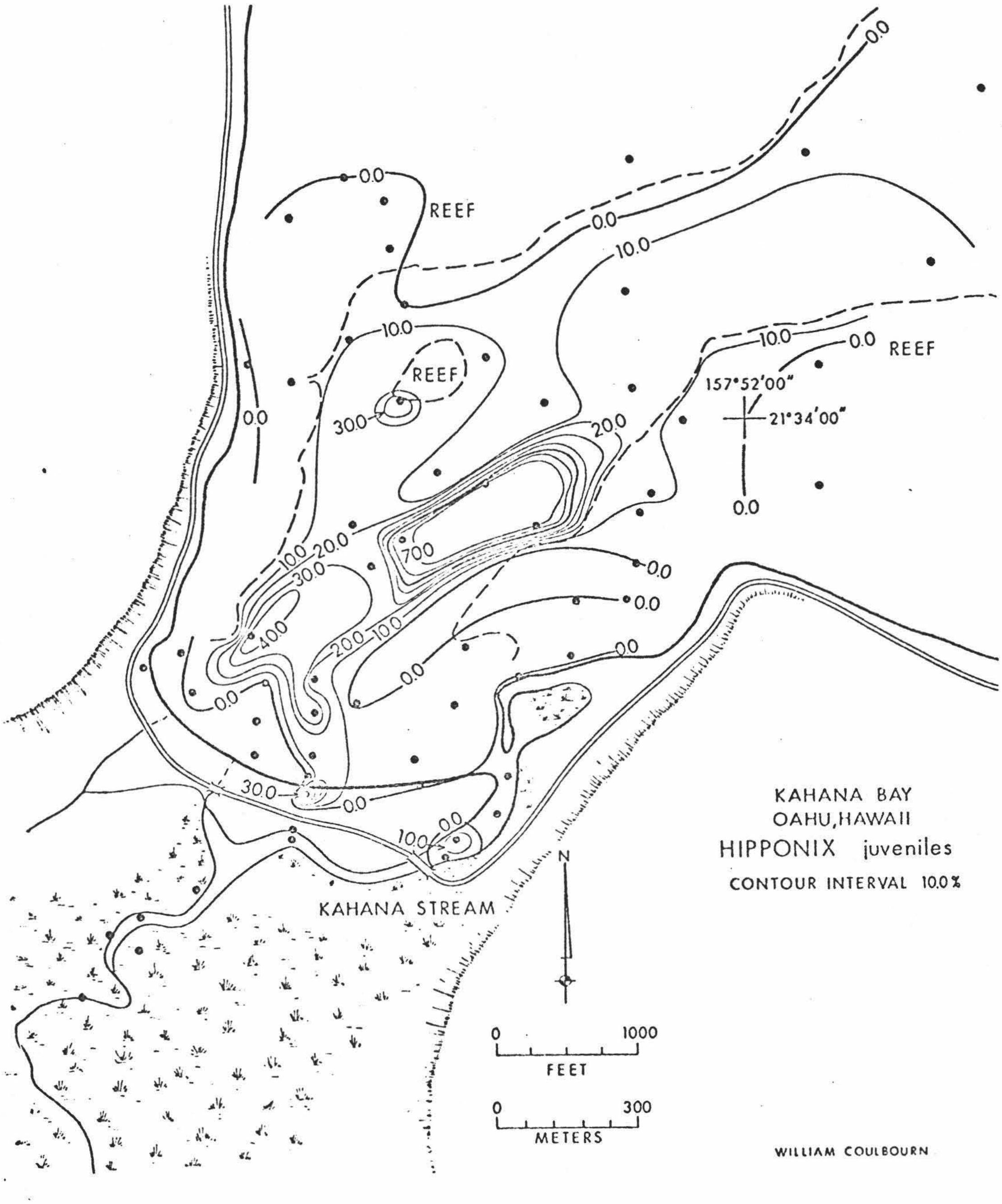
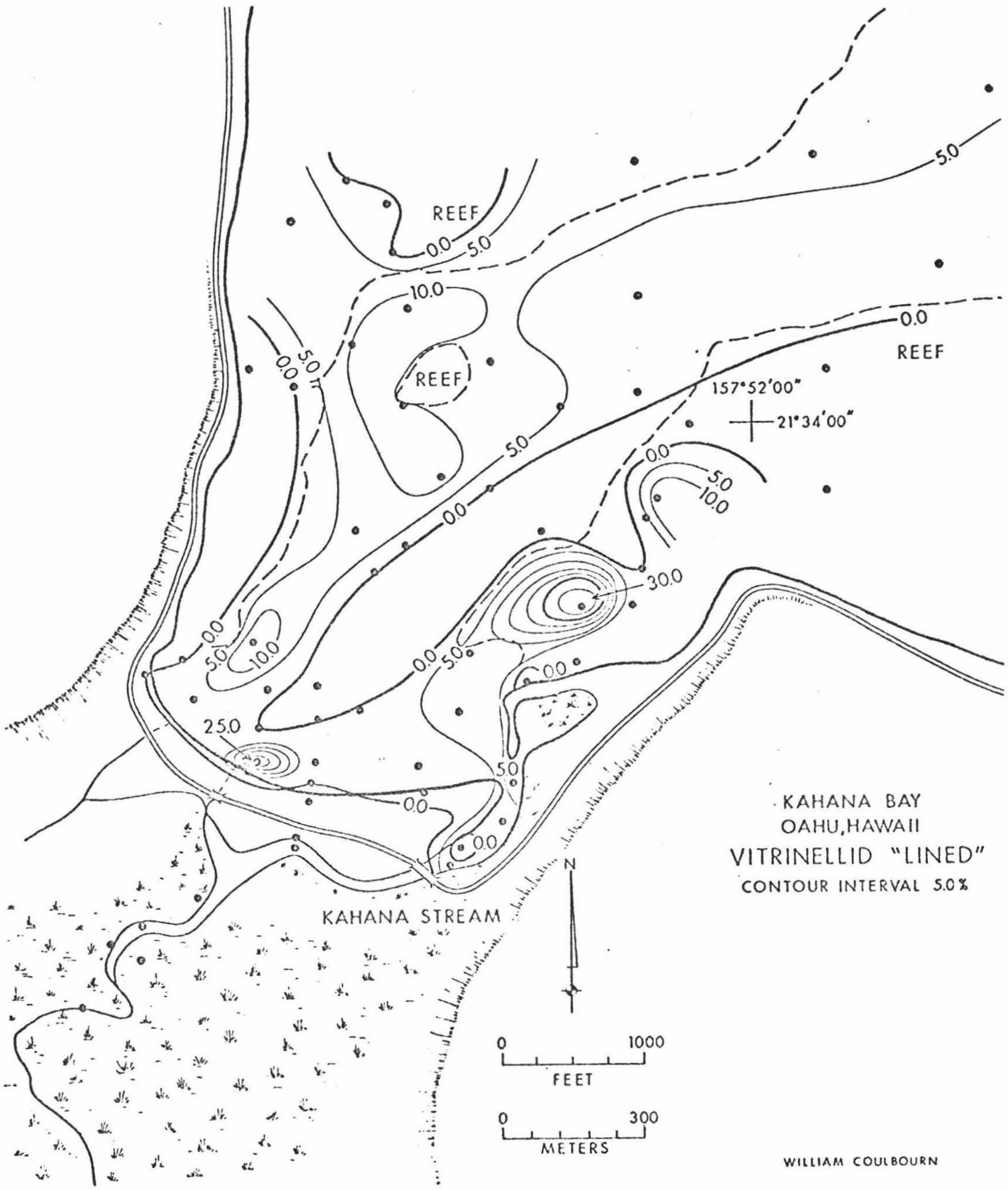

REEF
REEF
REEF
0.0
10.0
20.0
30.0
40.0
70.0
157°52'00"
21°34'00"
KAHANA STREAM
N
0 1000
FEET
0 300
METERS
KAHANA BAY
OAHU, HAWAII
HIPPONIX juveniles
CONTOUR INTERVAL 10.0%
WILLIAM COULBOURN

Figure 47



REEF
0.0
5.0
10.0
REEF
0.0
5.0
REEF
157°52'00"
21°34'00"
0.0
5.0
10.0
30.0
0.0
5.0
10.0
0.0
5.0
0.0
25.0
0.0
5.0
0.0
KAHANA STREAM
N
KAHANA BAY
OAHU, HAWAII
VITRINELLID "LINED"
CONTOUR INTERVAL 5.0%
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 48

Concentrations along the western side of the channel represent accumulations of shells from the western reef-flat.

Vitrinellid "rough"

There is a striking similarity between the distribution of the rough vitrinellid (Figure 49) and that of *Spirolina arietina* (Figure 44). Both exhibit high population percentages across the stream-mouth bar. This clearly indicates that these species, and therefore probably the calcareous fraction of nearshore sands, were derived from the eastern reef-flat.

Vitrinellid "smooth"

A comparison of Figures 50 and 16 shows that the spotty distribution of the smooth vitrinellid corresponds to areas of coarse grain size. The large size and thick walls of the species' shell allows them to resist surf abrasion. They are concentrated nearshore after the finer particles are winnowed out. It is difficult to distinguish whether environmental preference or restrictions imposed by size and test morphology exert the dominant control on the distribution pattern.

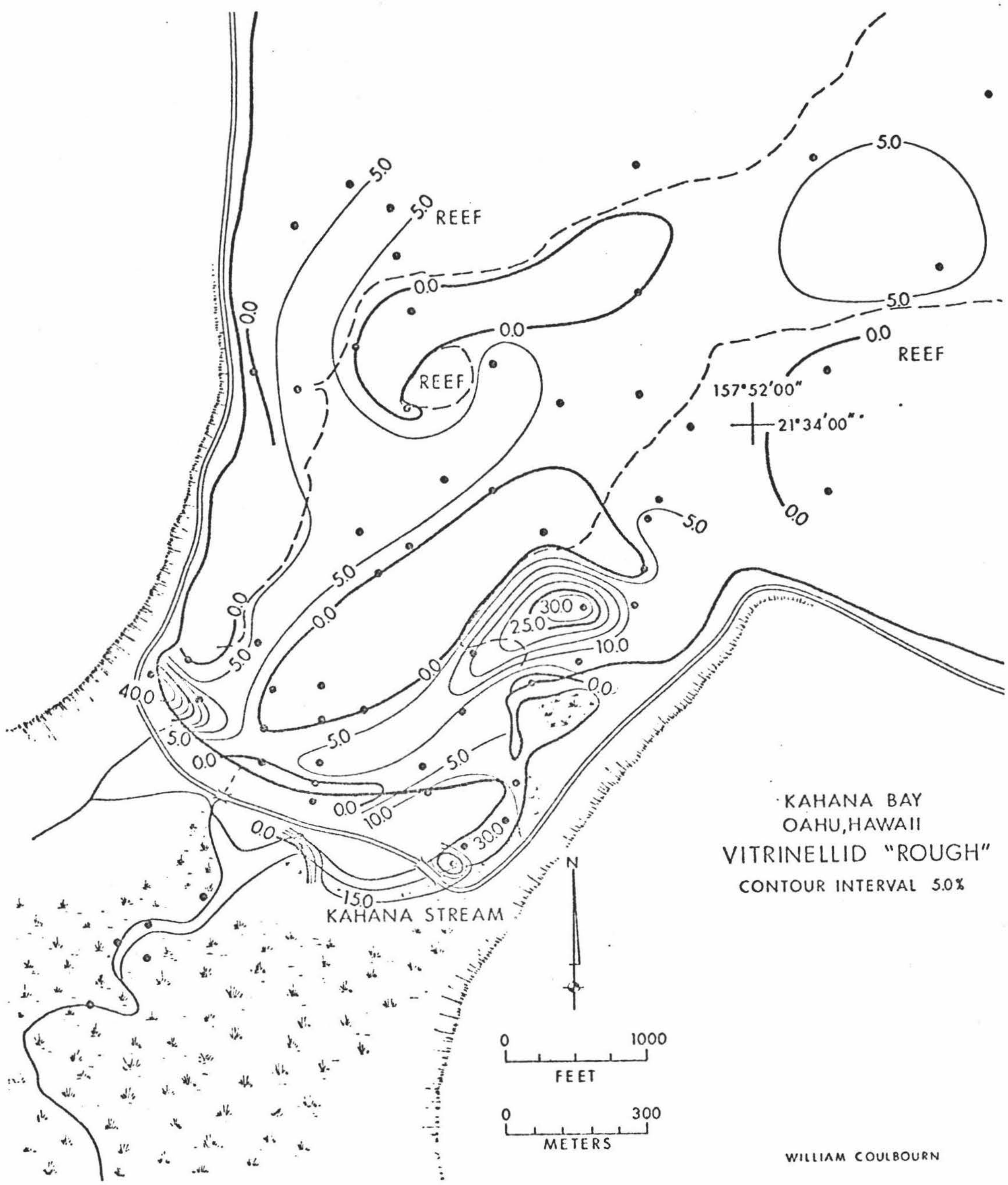

KAHANA BAY
OAHU, HAWAII
VITRINELLID "ROUGH"
CONTOUR INTERVAL 5.0%
REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA STREAM
N
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 49

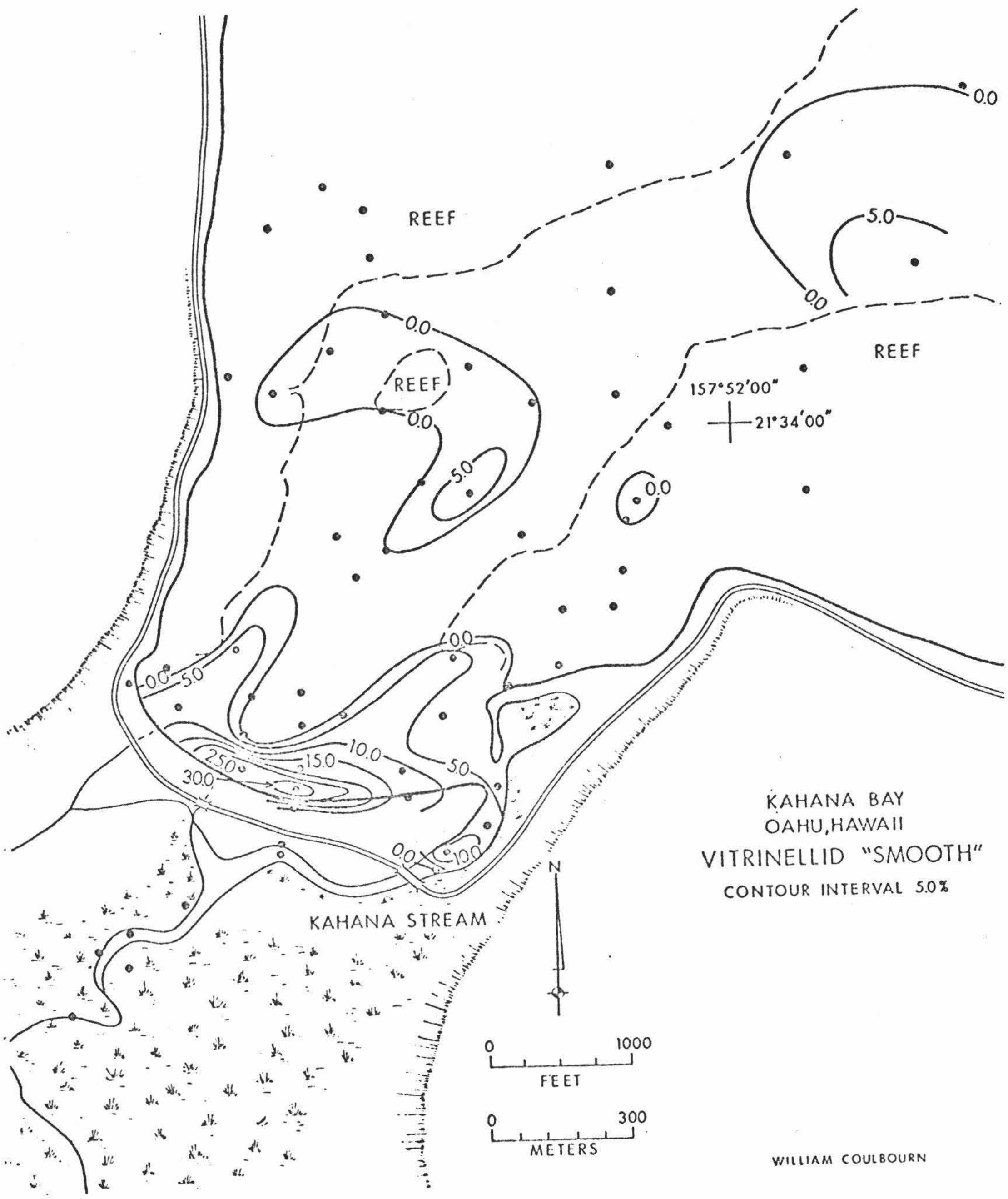

REEF
REEF
REEF
0.0
5.0
10.0
15.0
25.0
30.0
157°52'00"
21°34'00"
KAHANA STREAM
N
0 1000
FEET
0 300
METERS
KAHANA BAY
OAHU, HAWAII
VITRINELLID "SMOOTH"
CONTOUR INTERVAL 5.0%
WILLIAM COULBOURN

Figure 50

Cerithidae

Due to the number of juveniles present, this fauna is contoured as a family. The greater than usual variance in size and type probably accounts for the rather poorly defined pattern of Figure 51. High percentages in the western nearshore area reflect the lack of gastropod diversity in those samples rather than concentrations of members of this family. The individuals found nearshore are derived from the eastern reef-flat and were swept across the inner bay. The concentration in Kahana Stream is due to tidal reworking, and these specimens have a very worn appearance. Significant percentages occur in the northwest corner of the sand channel and probably represent specimens derived from the reef-flat. This family is generally associated with a reef and coarse-sand environment, and the distribution in channel sands is quite similar to that of the larger foraminiferal species.

Tricolia variablis

Figure 52 shows that the east and west fringing-reefs at Kahana Bay are source areas for accumulations of *Tricolia variablis* near the shore and around the patch reef. Concentrations in the stream are probably due to material derived from the subaerial eroding bank (Sample 19). The 30 per cent dominance of *Tricolia variablis* in the

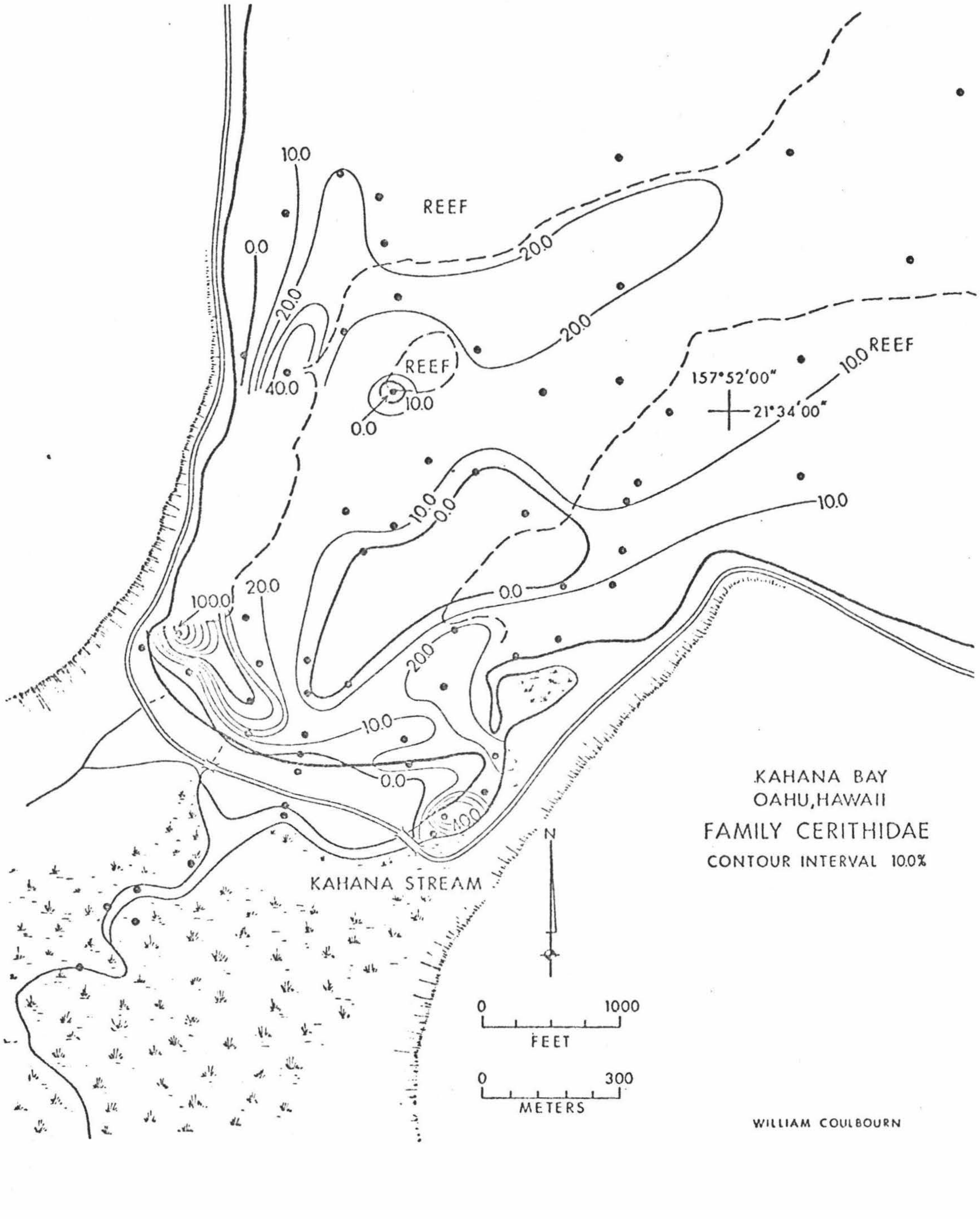

KAHANA BAY
OAHU, HAWAII
FAMILY CERITHIDAE
CONTOUR INTERVAL 10.0%
REEF
REEF
REEF
157°52'00"
21°34'00"
KAHANA STREAM
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 51.

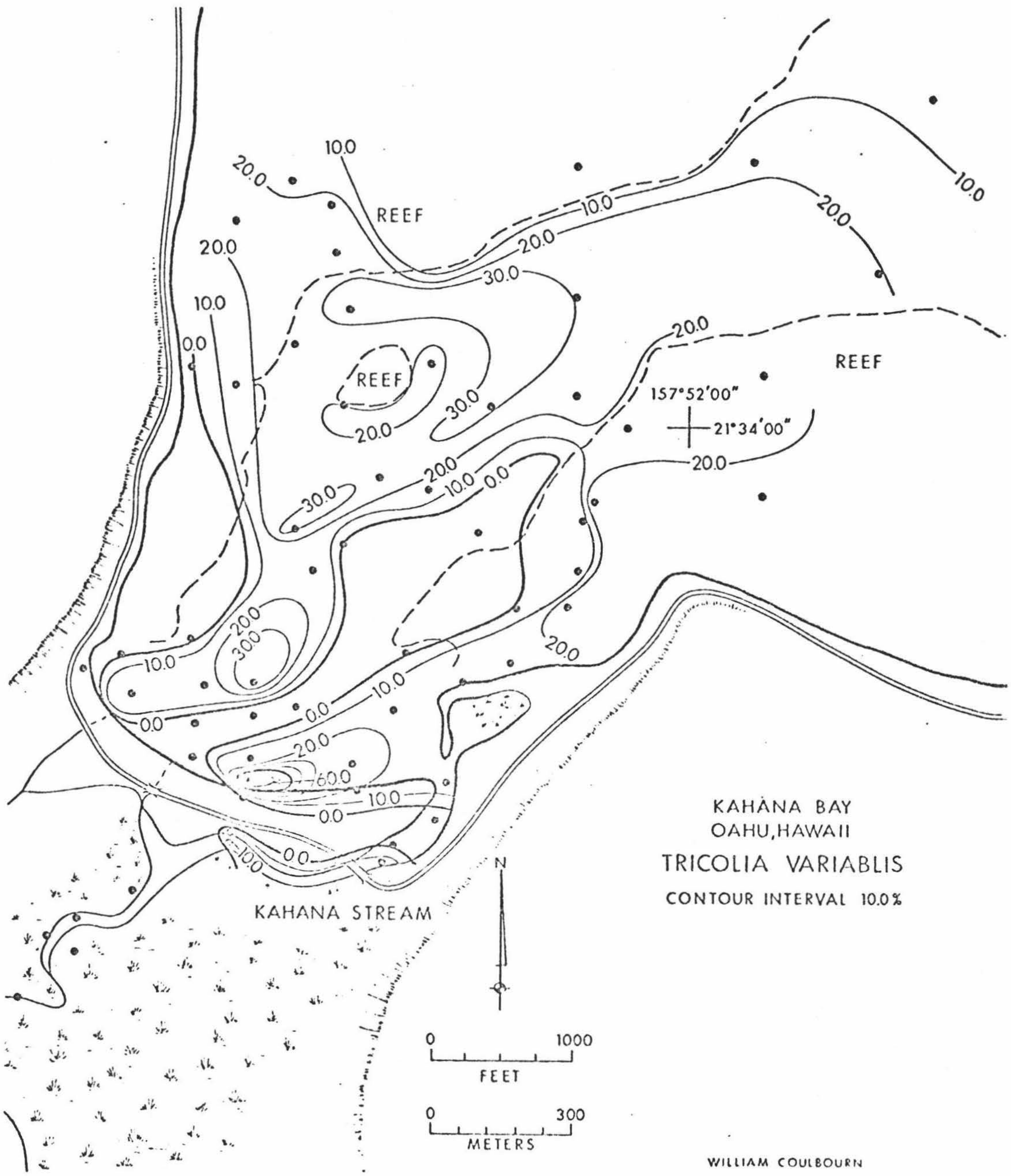

REEF
REEF
REEF
10.0
20.0
30.0
0.0
60.0
157°52'00"
21°34'00"
KAHANA BAY
OAHU, HAWAII
TRICOLIA VARIABLIS
CONTOUR INTERVAL 10.0%
KAHANA STREAM
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 52

central nearshore portion of the bay (Sample 902-F), and the 60 per cent dominance behind the stream-mouth sand bar (Sample 911-F), are due to the juvenile forms accumulated there and may represent loci of living populations. The wide size-range of this gastropod precludes association with a particular sediment type, causing this species to be an obscure indicator of transport directions.

Vitrinellid "brown"

The brown vitrinellids are small, planispiral gastropods found on the reef-flat, and in the sand channel, as well as in the lower-stream bed (Figure 53). Patchy occurrences are associated with fine sediments in the nearshore area. Exceedingly high percentages seaward of the stream-mouth bar may represent a living population. Accumulations there suggest that the species can tolerate brackish water. Concentrations around the patch reef are similar to those of the very small species of foraminifers and gastropods. These characteristics limit the usefulness of this species as a transport indicator.

Ostracods

Five different species of ostracods were recognized in the Kahana Bay and Stream samples. One brackish-water species, Cyprideis aff. beaconensis, was found living, in

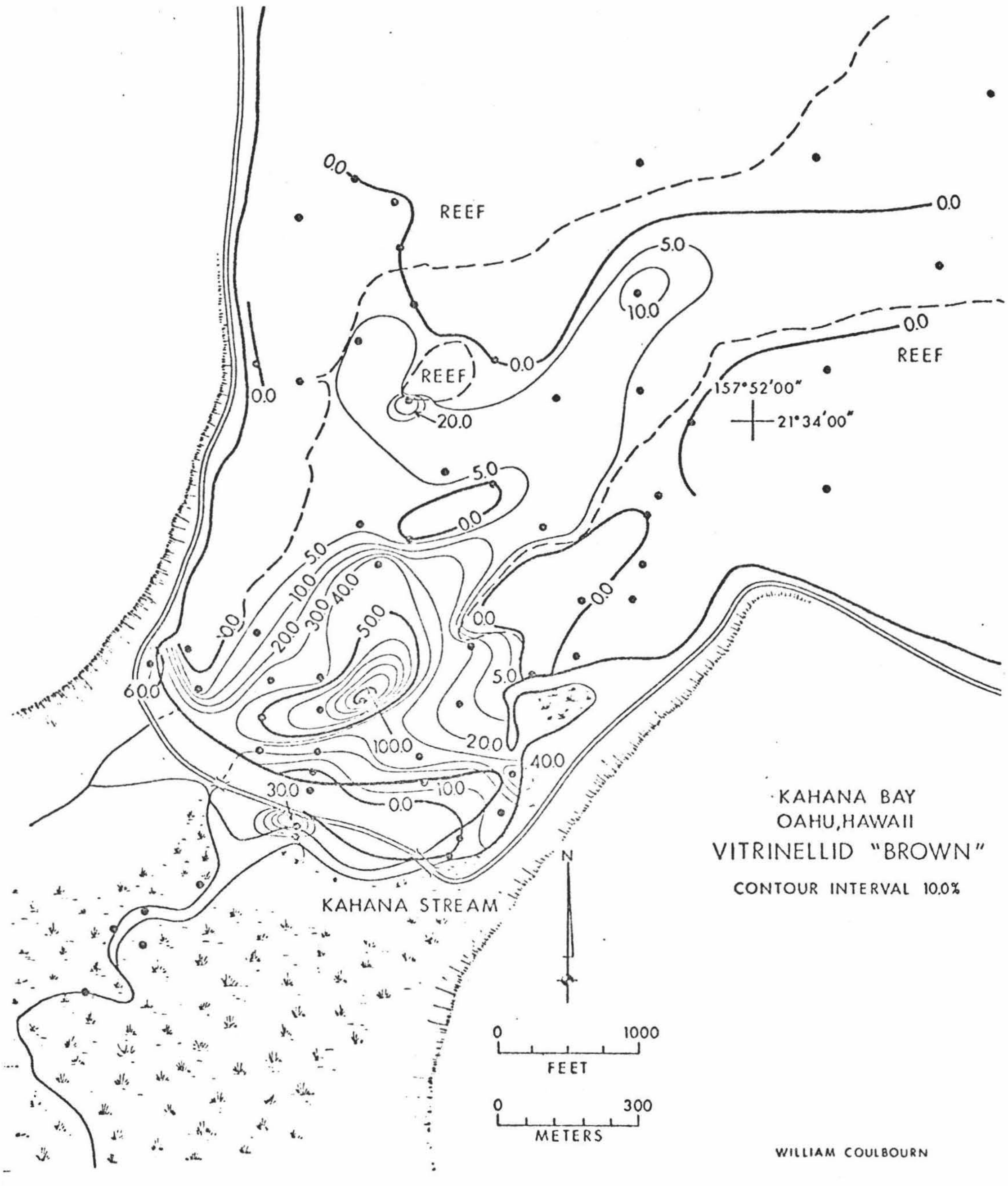

REEF
REEF
REEF
0.0
5.0
10.0
20.0
30.0
40.0
50.0
60.0
100.0
157°52'00"
21°34'00"
KAHANA STREAM
N
KAHANA BAY
OAHU, HAWAII
VITRINELLID "BROWN"
CONTOUR INTERVAL 10.0%
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 53.

abundance, only in Kahana Stream Sample 1005-F. The distribution pattern of Loxoconcha condyla and Loxoconcha longispina is shown in Figure 54 as individuals per gram. In spite of the size dependence introduced by this mode of expression, the species nevertheless is more abundant in the coarser, more highly calcareous sediments. A second species, Hermanites sp. (Figure 55) has a similar distribution. Nearshore accumulations of both probably result from material transported from the eastern reef-flat. The mid-channel population is represented by the accumulation of carapaces transported from the western reef and side of the bay, with possible contributions from an in situ living population. Freshness of appearance suggests that both species are indigenous to the reef-flat environment and are only transported into the channel environment after death or ecdysis. Nearshore deposits originate from the eastern reef-flat near Huilua fishpond.

Summary on Microfauna as Indicators of Sediment Transport

Distribution patterns of the species of foraminifera, gastropods, and ostracods indicate that some may be useful as indicators of sediment transport. Restricted environmental preference of a species is the most important prerequisite. Four general distributional patterns are:

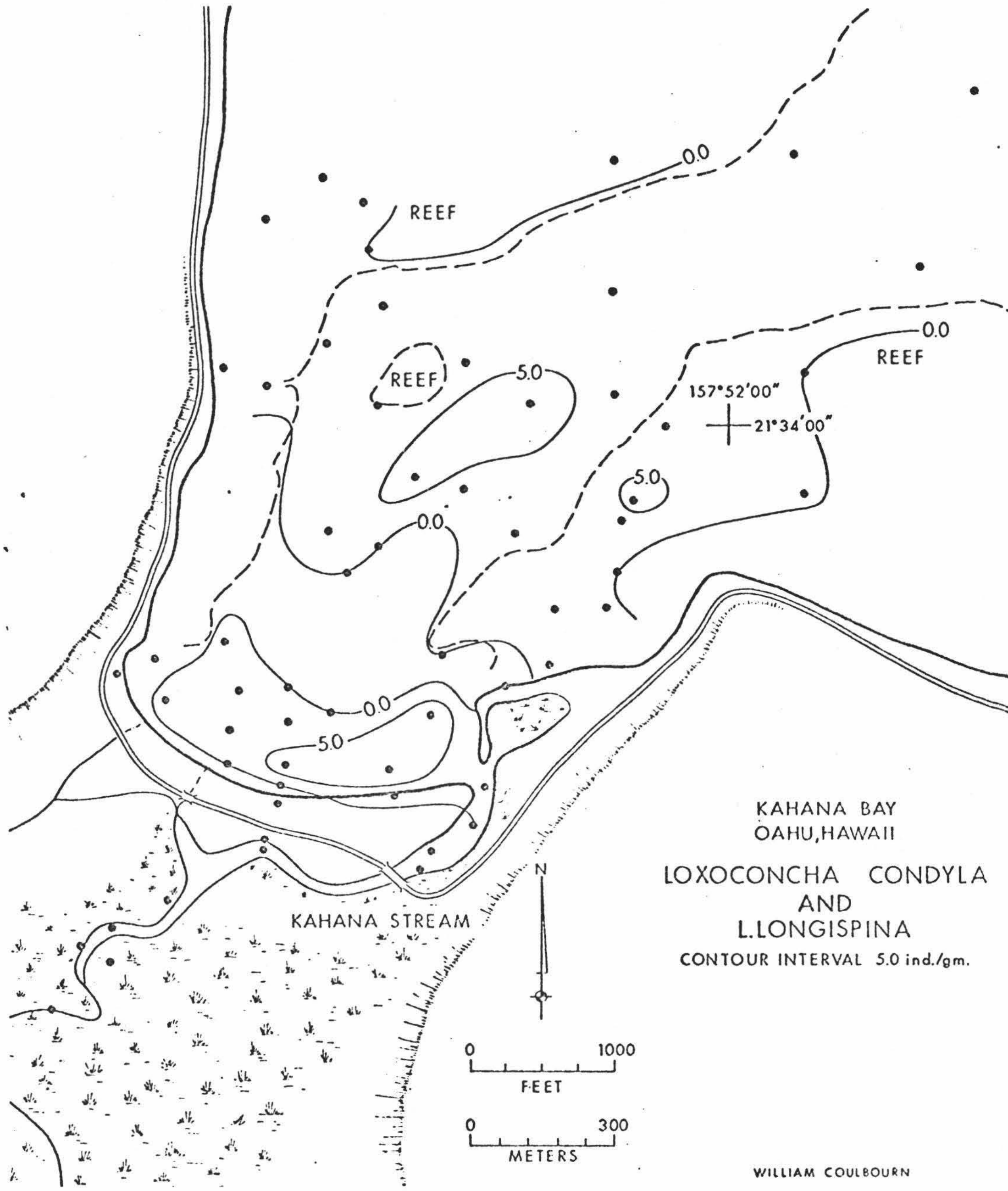

0.0
REEF
5.0
0.0
REEF
157°52'00"
21°34'00"
5.0
0.0
0.0
5.0
KAHANA STREAM
N
KAHANA BAY
OAHU, HAWAII
LOXOCONCHA CONDYLA
AND
L. LONGISPINA
CONTOUR INTERVAL 5.0 ind./gm.
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN

Figure 54

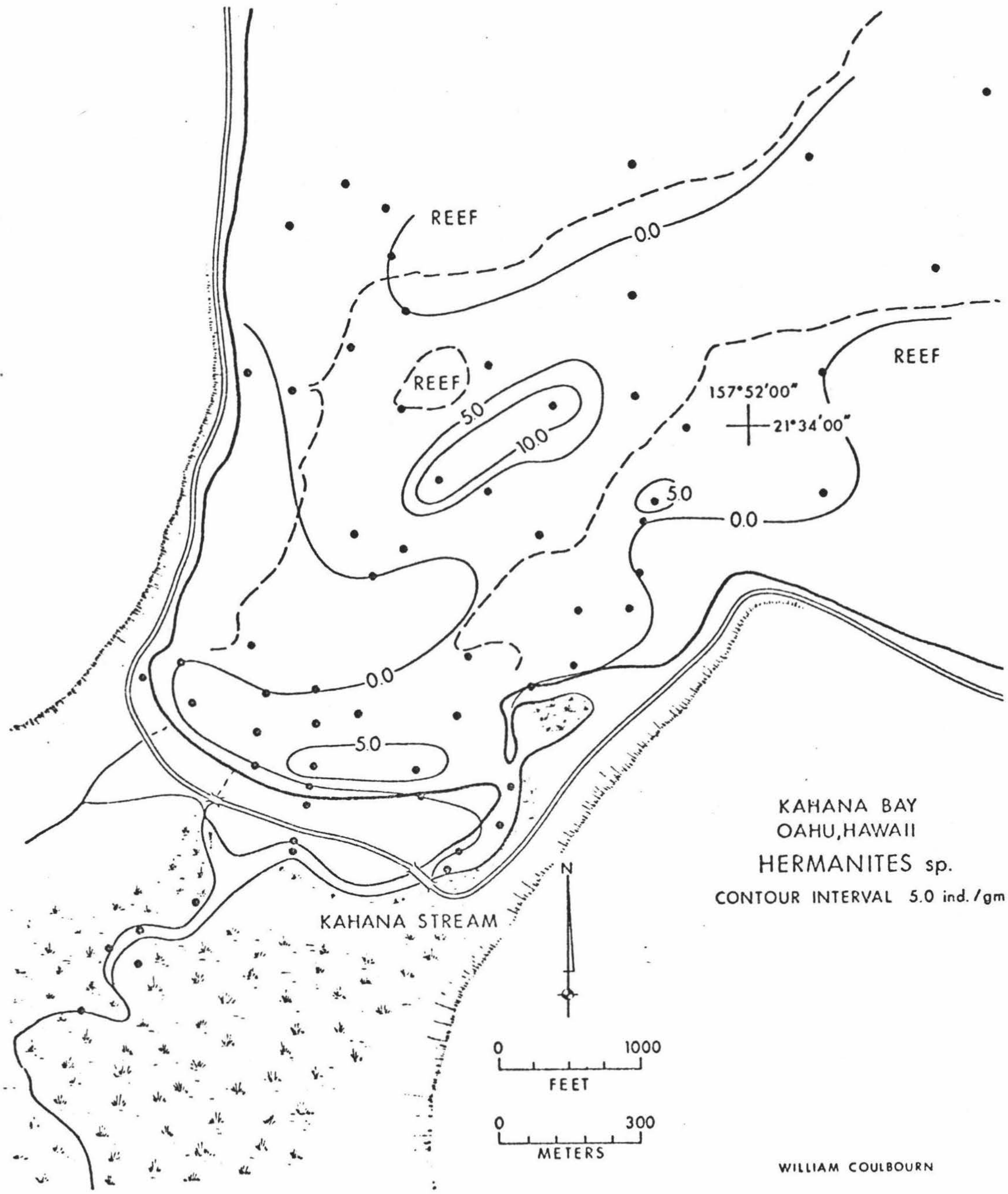

REEF
0.0
REEF
5.0
10.0
REEF
157°52'00"
21°34'00"
5.0
0.0
0.0
5.0
KAHANA STREAM
KAHANA BAY
OAHU, HAWAII
HERMANITES sp.
CONTOUR INTERVAL 5.0 ind./gm
N
0
1000
FEET
0
300
METERS
WILLIAM COULBOURN

Figure 55

1) Brackish water species.

2) Small species that accumulate only in areas of corresponding sediment size.

3) Large species that dwell primarily on the reef flat.

4) Species that have wide ecological and habitat ranges.

The first group consists of Ammonia beccarii, and Elphidium sp. Both species provide an excellent tracer of the distribution of sediment deposited in Kahana Bay from Kahana Stream.

The second group consists of the small species of foraminifera: Bolivina rhomboidalis, Cibicides lobatulus, Elphidium hyalocostatum, Glabratella patelliformis, Rosalina vilardeboana, and Pateoris australis, as well as the juveniles of the gastropod genus Hipponix. These have patterns largely governed by size-sorting, and are concentrated in areas of fine-sediment size.

The group of reef-dwelling species includes foraminifera of the species: Cymbaloporetta bradyi, Fijiella simplex, Marginopora vertebralis, Peneroplis pertusus, Quinqueloculina curta, Quinqueloculina parkeri, Siphoninoides echinata, Spirolina arietina, and Amphistegina madagascariensis, as well as the gastropods vitrinellid "lined" and vitrinellid "rough," and of the family Cerithiidae. The distribution pattern of these species can be used to interpret the movements of reef-derived material into the sand channel.

The remaining species have such wide environmental tolerances, or such ubiquitous distribution that they are not very useful in deciphering sediment transport.

X-RAY ANALYSIS

Laboratory Procedure

X-ray analysis was performed of the smallest available size fraction of various sediment samples. This generally consisted of the pan fraction, although the 4.0φ and in a few instances the 3.5φ fractions of coarser samples were examined. Smear slides of each sample were X-rayed at one degree per minute from 20° to 35°.

Aragonite was identified by peaks at 26.3° and 27.4° whereas the 23.0° and 29.4° peaks were assumed to be representative of calcite. Areas under peaks were taken as the product of peak height and width at one-half the height. Conversion to percent calcite was made according to the formula: $\text{Log}\left(\frac{I_A}{I_C}\right) = -0.5 + 1.2\ \text{Log}\left(\frac{\%A}{\%C}\right)$ (Smith, 1970)

I_A = area of the 26.3° aragonite peak

I_C = area of the 29.4° calcite peak

Results

Values are plotted in terms of percent calcite (Figure 55). The size fraction analyzed is small enough to

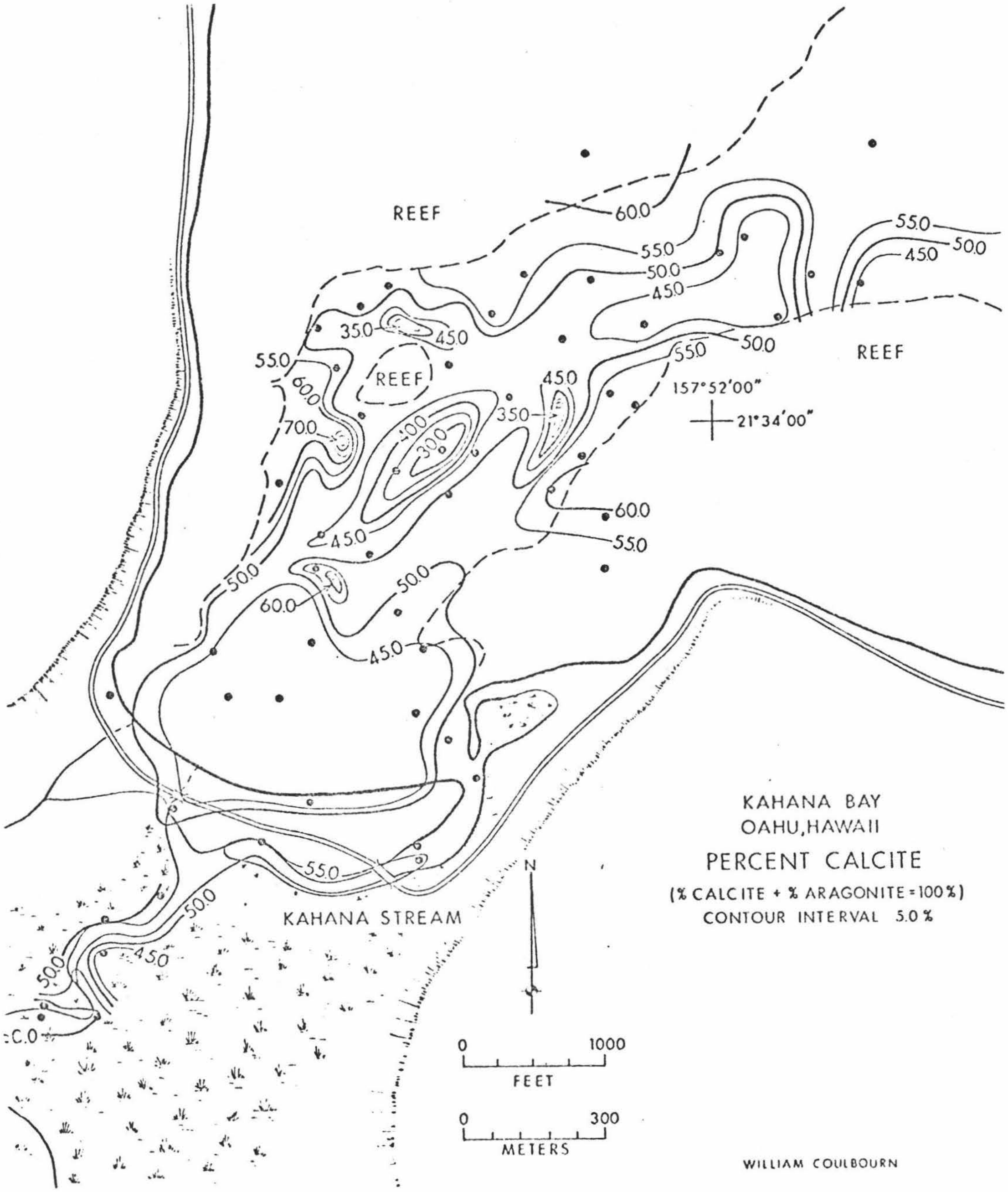

REEF
REEF
REEF
KAHANA BAY
OAHU, HAWAII
PERCENT CALCITE
(% CALCITE + % ARAGONITE = 100%)
CONTOUR INTERVAL 5.0%
157°52'00"
21°34'00"
KAHANA STREAM
N
0 1000
FEET
0 300
METERS
WILLIAM COULBOURN
60.0
55.0
50.0
45.0
35.0
30.0
70.0

Figure 56

be representative of the composition of the suspended load. This composition is determined by the relative amounts of aragonitic and calcitic organisms contributing to the sediment. Chave (1962) has demonstrated that foraminifera and ostracods are generally calcareous (some benthic foraminifers are aragonitic), whereas gastropods are aragonitic. Halimeda and reef coral fragments are aragonitic; coralline algae, echinoderms, and alcyonarian spicules are generally composed of calcite. All contribute to the total mass of the biogenic fraction of Kahana Bay sands. Figures 27 and 28 show that the loci of maximum foraminiferal and gastropod numbers respectively are oriented along a southwest to northeast line across the sand channel with highest gastropod numbers located slightly to the northwest of the maximum foraminiferal numbers. The only evidence of this relationship appearing on Figure 56 is a calcite minimum immediately southeast of the patch reef corresponding to gastropod numbers exceeding 60 at the same location. There is a difference of an order of magnitude between the foraminiferal and gastropod numbers (compare Figures 27 and 28). Even though gastropods are usually larger than foraminifers, it is evident that significant contributions of aragonite are introduced into the suspended sediment from sources other than the gastropod population alone. The lack of data on percentage abundance of coralline algae, coral fragments, and echinoderms, as well as the diversity of constituents in the total biogenic mass, prohibit a more explicit definition of the distribution shown in Figure 56.

GENERAL SUMMARY

Kahana Bay is a channel cutting through a shallow fringing reef, and having a flat floor of sand. The reef-sand channel border is marked physiographically by vertical cliffs and hydrographically by ground water springs. Stream discharge is directed seaward over the channel by the flow of ocean water driven across the fringing reefs. The usual combination of wind, and discharge rates, as well as the bathymetric configuration, directs the turbid stream outflow seaward along the eastern reef edge. Diving observations in the central and northwest corners of the bay, as well as current measurements near the eastern reef edge show that bottom currents are oscillatory. Moreover the oscillation ripple marks parallel the direction of advancing wave fronts.

Nowhere are large fractions of detrital sediment associated with coarse mean grain sizes. The detrital clay, silt and very fine sand, introduced from Kahana Stream settle to the bottom seaward of the surf break.

Reef-derived sand (Figure 57), identified by its coarser size and calcium carbonate content in excess of 90 percent, enters the deeper sand channel along the

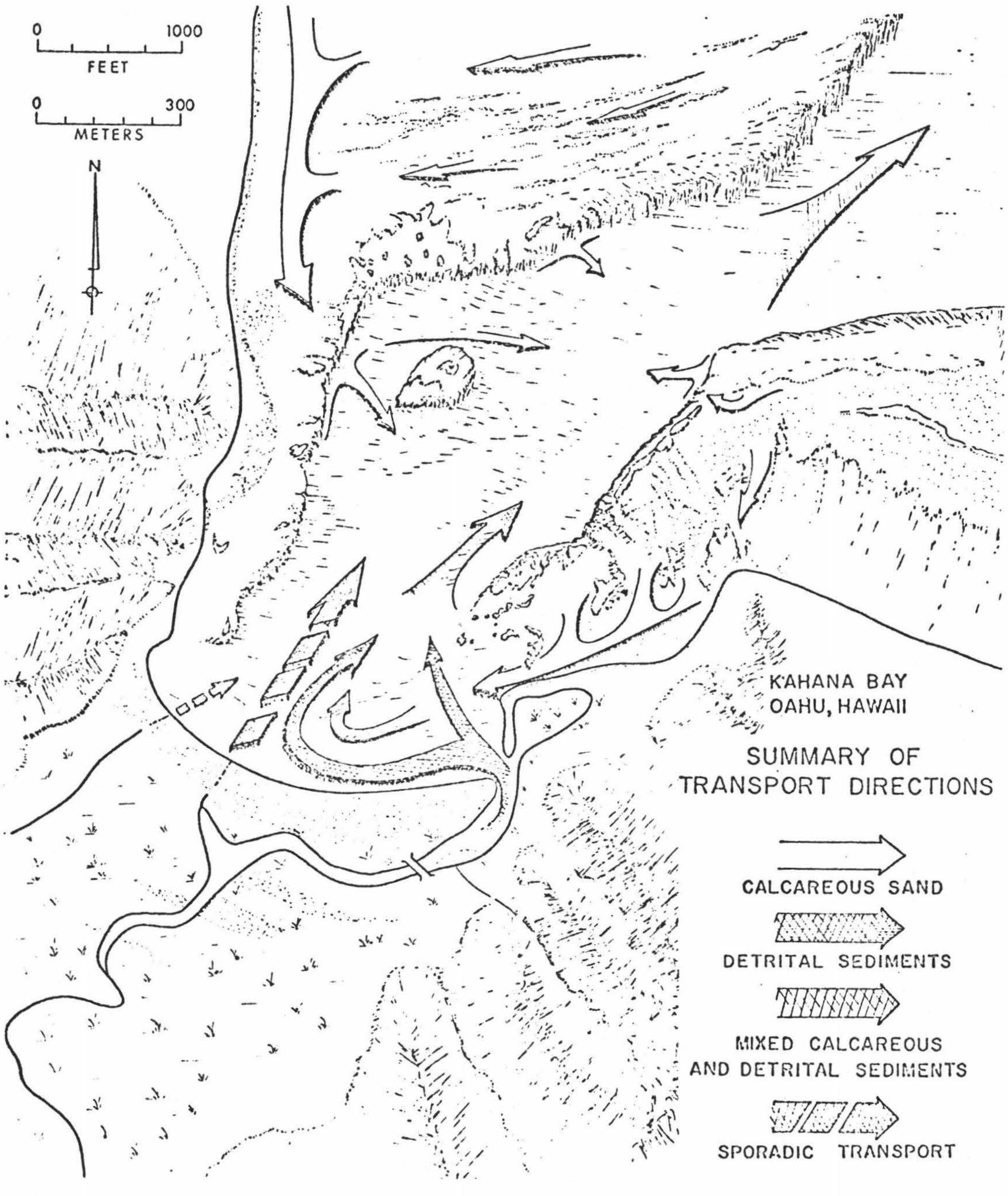

0
1000
FEET
0
300
METERS
N
KAHANA BAY
OAHU, HAWAII
SUMMARY OF
TRANSPORT DIRECTIONS
CALCAREOUS SAND
DETRITAL SEDIMENTS
MIXED CALCAREOUS
AND DETRITAL SEDIMENTS
SPORADIC TRANSPORT

Figure 57

western margin, in plumes from isolated sources along the northern edge, and at two points on the eastern reef. Organic carbon is a significant sediment constituent of swamp muds only, and generally comprises less than 4.0 percent of channel sands.

Brackish-water foraminifera inhabiting Kahana Stream are also associated with fine, highly terrigenous, channel sediments (Figure 57). These species provide an excellent tag for stream sediment distributed into Kahana Bay.

Dyed tracer sand and the distributions of reef-dwelling species indicate that the direction of sediment transport around the patch reef is towards the southeast. The same large species show that nearshore transport is from east to west. The distributions of several species are controlled by grain size, whereas the distributions of species with wide ecological tolerances have ambiguous patterns.

X-ray analysis indicates that the biogenic fraction of Kahana Bay sands generally consists of equal parts of calcite and aragonite. Diverse organisms contribute to the total bulk of calcareous material, so that interpretation of the data in terms of the foraminifera and gastropod populations exclusively is not possible.

CONCLUSIONS

The results of this investigation support the generalizations of Inman *et al*. (1963) regarding littoral sedimentary processes on windward coasts of subtropical high islands. The data suggest a probable future course of sedimentation in the bay.

Reef-sand channel borders (Figure 57) are inherited from the topography developed at lower sea-level stands and, as suggested by Inman *et al*. (1963), are perpetuated by present-day circulation. In this case the most important factor is the inability of corals to grow in areas of brackish groundwater outflow. Calcareous reef sediment is transported into the channel from two principal sources; one is the western reef, the other is the eastern reef near Huilua Pond. Lesser quantities are transported into the channel from offshore portions of the eastern reef, and therefore a greater relief is associated with this margin than that of the western side. Comparable relief of the latter develops only at points farther seaward. Water entering Kahana Bay from the northwest reef is assumed to be the driving force behind the observed southeasterly sediment transport. Somewhere across the channel width the water must return seaward. Aerial photographs show that the most turbid water flows in the eastern half of the channel and nearshore. Tests of brackish water species of foraminifera found in the bay are restricted to this same area, and are associated with high percentages of terrigenous material. Depths increase from west to east across the channel. All of the data suggest that seaward transport occurs along the eastern reef edge. Wave oscillations, present at depths of at least 30 feet, may be responsible for some lateral distribution of sediments, as well as seaward transport at depths exceeding the null point.

Kahana Stream sediments and calcareous sands from the eastern reef-flat are primarily responsible for the prograding stream-mouth sand bar. Combined stream and wave action will raise this deposit while extending it across the width of the bay. A history of accretion at present sea level is documented by the series of crescentic strands crossing portions of the valley. If the present rates of accretion remain in excess of erosion, the geomorphic expression of Kahana Bay should continue to diminish.

ACKNOWLEDGMENTS

This study was financed under the Sea Grant Program, grant No. GH 93, and space and equipment were made available by the Hawaii Institute of Geophysics. I would like to thank Dr. D. Gordon, Dr. F. Peterson, and Dr. L. Lepley for their assistance in the hydrographic aspects of this investigation, and Dr. P.-F. Fan for his help with the X-ray analysis. I am grateful to Dr. A. Kay for providing gastropod identifications.

Thanks go to Fred Casciano for his guidance on the sand-dyeing procedure, to Mr. J. T. O'Brien of Look Laboratory for the use of that facility and equipment, to Walter Lum for the seismic equipment, and to Maury Morgenstein who loaned his boat for the field work associated with the tracer experiment.

I am grateful to Joseph O'Donnell and Pierluigi Pozzi for assembling various portions of the current meter mooring, and to John Bell who kindly assisted in the launching.

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SEDIMENT PARAMETERS

SAMPLE NO.	MEAN	SORTING	SKEWNESS	KURTOSIS	PERCENT CARBONATE	PERCENT TERRIGENOUS	PERCENT ORGANIC
2	2.57	0.73	-0.32	1.14	81.61	18.07	0.32
3	2.60	0.66	-0.30	1.00	81.14	18.67	0.28
4	2.40	0.52	0.00	0.92	76.72	22.34	2.94
5	2.10	0.63	-0.22	0.91	87.61	11.12	1.26
6	2.50	0.41	0.00	0.95	85.23	-	-
7	2.60	0.41	0.00	0.96	88.18	10.32	1.49
12	6.20	-	-	-	-	-	36.48
13	2.20	1.45	-0.05	1.09	21.92	63.92	14.16
14	4.17	3.23	+0.15	0.75	-	-	55.60
15	3.33	3.17	+0.52	1.29	-	-	45.44
16	0.57	1.89	-0.53	0.68	82.97	2.61	15.62
17	3.56	2.56	+0.51	1.60	-	-	44.28
18	0.97	1.67	-0.60	0.73	-	-	5.35
19	2.60	0.55	-0.14	0.88	66.46	27.26	6.28
20	2.03	-	-	-	50.61	41.31	8.08
21	2.57	0.69	+0.04	1.43	75.69	15.86	8.45
101	3.67	0.76	+0.02	1.87	79.04	18.65	2.30
102	3.87	0.55	+0.32	2.05	74.85	24.60	0.55
103	3.00	0.58	-0.24	1.02	80.41	18.84	0.75
104	3.77	0.76	+0.11	1.87	79.82	16.95	3.23
105	2.90	0.75	+0.16	1.02	89.54	9.40	1.05
106	2.46	0.67	-0.11	1.18	90.76	4.24	5.00
107	2.07	0.65	-0.23	1.46	92.30	7.48	0.22
108	2.50	0.86	-0.08	1.23	95.92	4.00	0.07
109	2.36	0.45	-0.11	1.02	95.78	3.80	0.42
110	2.10	0.70	-0.02	1.05	87.48	9.72	2.50
111	2.70	0.52	-0.11	1.84	93.56	5.81	0.62
112	2.47	0.48	-0.14	1.16	95.62	4.13	0.24
113	2.53	0.63	-0.22	1.29	95.54	4.23	0.23
114	2.03	0.71	-0.15	0.98	94.39	5.09	0.51
115	2.37	0.50	-0.17	1.23	95.80	3.77	0.43
116	2.40	0.66	-0.02	1.19	93.98	5.78	0.25
117	1.70	1.13	-0.35	1.02	94.77	4.66	0.57
118	1.50	1.12	+0.12	0.61	97.75	1.61	0.63
119	2.47	0.88	-0.28	1.46	95.13	4.33	0.54
120	2.67	0.65	-0.19	1.28	96.80	2.87	0.33
200	3.00	0.60	-0.05	1.02	84.75	14.78	0.47
201	1.80	0.80	+0.13	1.23	96.00	2.84	1.16
202	1.90	0.85	-0.42	1.23	90.54	8.45	1.01
203	2.50	0.52	0.00	1.05	91.41	8.34	0.24
204	2.40	0.50	-0.18	1.64	96.28	10.27	1.09
205	3.03	0.63	-0.17	1.00	90.63	8.58	0.79
206	3.90	0.61	+0.13	1.84	64.46	34.90	0.65
207	3.83	0.66	-0.38	1.84	65.45	28.74	5.81
208	2.50	0.65	-0.15	1.35	94.58	5.11	0.31
209	2.40	0.49	-0.06	1.09	93.27	6.28	0.44

SAMPLE NO.	MEAN	SORTING	SKEWNESS	KURTOSIS	PERCENT CARBONATE	PERCENT TERRIGENOUS	PERCENT ORGANIC
300-F	1.93	0.69	-0.19	0.97	96.54	3.05	0.41
300	2.00	0.70	-0.18	1.05	90.64	-	-
301-F	2.67	0.58	-0.15	1.67	89.40	-	-
301	2.77	0.51	-0.13	1.30	92.92	6.41	0.68
302-F	2.03	0.62	-0.20	1.08	98.60	1.35	0.06
302	2.10	0.68	-0.26	1.28	91.75	3.32	4.93
303	0.77	0.85	+0.29	1.04	97.86	2.00	0.14
304	1.30	0.94	+0.27	0.79	97.37	2.27	0.36
305	1.75	1.06	+0.10	1.05	91.66	4.48	3.86
306-F	1.80	0.60	0.00	0.91	96.87	2.88	0.26
307	2.67	0.53	-0.03	1.37	92.35	7.09	0.56
308-F	2.27	0.45	-0.16	1.02	97.35	1.52	1.14
308	2.30	0.49	-0.32	1.39	94.07	5.63	0.29
309	2.20	0.41	0.00	0.96	95.00	4.53	0.48
310	0.53	0.57	+0.08	1.11	92.79	7.20	0.02
311	0.93	0.84	+0.48	1.01	93.28	6.52	0.21
312	0.70	1.03	+0.12	0.90	94.61	5.39	0.00
313	2.20	0.52	-0.06	0.92	91.38	7.94	0.69
314	1.07	0.98	0.00	1.23	94.61	5.02	0.37
328	1.60	1.49	-0.34	0.78	78.55	21.33	0.12
329	2.50	0.39	-0.03	1.06	84.25	15.10	0.65
330	2.23	1.00	-0.19	0.81	82.40	17.49	0.12
331	3.10	0.33	0.00	1.23	85.28	13.86	0.86
332	1.50	1.09	-0.02	1.05	82.59	13.45	3.94
333	1.46	0.88	-0.16	0.91	80.25	19.02	0.73
334	2.53	0.58	-0.15	0.97	81.78	17.64	0.58
335	1.76	0.61	-0.10	0.95	86.50	13.09	0.41
336	2.33	0.76	-0.16	1.23	78.49	2.53	18.98
337	2.30	1.34	-0.41	1.52	60.71	30.75	8.54
338	2.60	0.49	0.00	1.09	80.03	18.81	1.16
339	2.50	0.58	-0.02	0.97	85.53	14.23	0.24
400	3.37	0.51	-0.78	1.94	75.47	23.76	0.77
401-F	0.17	0.70	-0.14	1.28	96.52	3.01	0.47
402-F	2.40	0.53	-0.22	1.00	93.42	2.23	4.35
403	2.23	0.60	-0.18	1.02	96.69	2.95	0.37
404-F	0.90	1.25	0.00	0.84	86.34	-	-
405	0.40	1.04	+0.09	1.39	96.82	-	-
406	2.23	0.52	-0.16	1.05	88.05	11.29	0.65
407	2.27	0.77	-0.44	1.59	94.97	4.90	0.13
408	2.20	0.75	-0.29	1.28	93.32	5.96	0.72
409	2.40	0.78	-0.23	1.11	95.98	3.20	0.82
410	2.87	0.64	-0.05	1.41	79.54	19.92	0.54
411	2.30	0.77	-0.13	1.59	89.70	9.90	0.41
500	2.27	0.66	-0.38	1.23	84.02	15.40	0.58
501	2.17	0.80	-0.45	1.69	95.04	4.84	0.11
503	1.83	0.88	-0.31	1.23	94.28	3.46	2.26
504	2.60	0.66	-0.92	0.55	96.19	3.69	0.12

SAMPLE NO.	MEAN	SORTING	SKEWNESS	KURTOSIS	PERCENT CARBONATE	PERCENT TERRIGENOUS	PERCENT ORGANIC
600-F	0.47	0.48	-0.23	1.16	-	-	-
601	1.53	0.90	-0.20	0.96	95.75	2.89	1.36
602	1.70	0.50	-0.13	0.88	94.61	4.81	0.58
603	0.75	1.05	+0.10	2.41	96.61	3.03	0.36
604	0.80	0.86	+0.33	1.08	91.37	8.63	0.60
605	2.17	0.47	+0.07	0.76	95.09	4.54	0.36
606	2.77	0.47	-0.18	1.31	94.40	4.98	0.62
700-F	2.10	0.79	-0.10	1.23	85.53	7.50	6.97
701-F	-	-	-	-	71.55	23.39	5.06
800-F	0.27	0.37	-0.19	1.07	91.28	5.05	3.67
801-F	0.47	1.02	-0.03	1.23	89.48	10.34	0.18
901-F	2.80	0.43	-0.03	1.02	77.81	16.38	5.81
902-F	3.27	0.33	+0.25	1.23	82.61	15.02	2.37
903-F	3.00	0.52	-0.22	1.23	88.08	11.49	0.43
904-F	2.97	0.37	-0.11	1.07	88.84	10.46	0.70
905-F	3.10	0.36	-0.16	0.98	82.05	14.26	3.69
906-F	3.03	0.80	-0.42	1.15	88.59	10.71	0.70
907-F	1.87	0.77	-0.07	1.07	88.79	10.54	0.67
909-F	2.87	0.48	-0.09	1.16	89.36	10.16	0.48
910-F	2.47	0.61	-0.12	0.97	86.61	12.69	0.70
911-F	2.77	0.45	-0.09	1.02	88.82	10.73	0.44
912-F	2.57	0.51	-0.16	1.23	89.53	8.79	1.68
913-F	2.73	0.61	-0.19	1.00	79.06	17.17	3.77
914-F	2.27	0.67	-0.53	1.81	86.44	12.85	0.71
1000-F	3.47	0.50	+0.28	1.64	74.78	24.67	0.55
1001-F	3.47	0.47	+0.18	1.23	76.15	21.45	2.40
1002-F	0.67	3.07	-0.24	1.13	87.32	6.13	6.55
1003-F	-0.07	1.62	-0.03	1.11	54.66	45.09	0.26
1004-F	2.10	0.80	-0.10	1.15	54.03	45.16	0.81
1005-F	1.70	1.56	-0.49	1.81	58.67	41.09	0.24
1100-F	0.61	0.12	+0.06	2.21	85.63	13.54	0.83
1101-F	1.17	0.71	+0.26	0.90	87.73	3.68	8.59
1102-F	0.33	0.75	+0.04	1.43	86.36	8.35	5.29
1200-F	0.90	0.57	-0.02	1.23	98.41	1.10	0.49
1201-F	2.30	0.53	-0.28	1.00	93.15	6.39	0.46
1300-F	0.40	0.80	-0.28	1.28	98.22	0.81	0.91
1301-F	-0.33	1.57	+0.02	1.00	98.02	1.22	0.76
1302-F	0.20	1.05	+0.11	1.42	98.94	0.58	0.48
1303-F	3.70	0.30	-0.10	1.02	95.90	3.63	0.47
1304-F	0.30	1.53	-0.25	1.37	97.29	1.94	0.77
1305-F	-0.70	0.71	-0.31	1.09	98.18	1.02	0.80
1306-F	-0.70	0.82	0.00	1.04	98.47	0.90	0.63

APPENDIX C

FORAMINIFERA REFERENCES

Ammonia beccarii (Linnaeus) = Nautilus beccarii Linnaeus, 1758, Systema naturae, 10 ed., v. 1, p. 710, figure: Plancus Conch., pl. 1, fig. 1a-c; Gualtieri, Testas., pl. 19, figs. h-h, i-i.

Amphistegina madagascariensis d'Orbigny, 1826, Am. Sci. Nat., ser. 1, v. 7, p. 304. Fornasini, 1903, Le otto pretese specie di "Amphistegina" instituite da d'Orbigny nel 1826. R. Accad. Sci. Int. Bologna, n.s., v. 7, p. 143, pl. 2, fig. 5, 5a-b.

Bolovina rhomboidalis (Millet) = Textularia rhomboidalis Millet, 1899, Report on the Recent foraminifera of the Malay Archipelago collected by Mr. A. Durrand, Part VI. Roy. Micr. Soc. London Jour., p. 559, pl. 7, fig. 4a-b.

Cibicides lobatulus (Walker and Jacob) = Nautilus lobatulus Walker and Jacob, 1798, in Kanmacher, Adam's Essays on the Microscope, ed. 2, p. 642, pl. 14, fig. 36.

Cymbaloporetta bradyi (Cushman) = Cymbalopora poeyi var. bradyi Cushman, 1915, A monograph of the foraminifera of the North Pacific Ocean, Part V. Rotaliidae U. S. Nat. Mus. Bull., no. 71, p. 25, pl. 10, fig. 2a-c, pl. 14, fig. 2a-c.

Elphidium hyalocostatum (Todd), 1957, Smaller foraminifera, in Geology of Saipan, Mariana Islands, Part 3. Paleontology, U. S. Geol. Survey Prof. Paper No. 280-H, p. 300, pl. 88, fig. 19a-b.

Elphidium sp., Remarks: The identification or description of this species awaits electron microscope pictures.

Fijiella simplex (Cushman) = Trimosina simplex Cushman, 1929, The genus Trimosina and its relationships to other genera of the foraminifera. Washington Acad. Sci. Jour., v. 19, no. 8, p. 158, tf. 2a-b.

Glabratella patelliformis (Brady) = Discorbina patelliformis Brady, 1884, Report on the foraminifera dredged by H. M. S. Challenger, during the years 1873-1876. Rept. Challenger Exped., London, pt. 22, v. 9, p. 647, p. 88, fig. 3, pl. 89, fig. 1.

Marginopora vertebralis Blainville, 1830, Dict. Sci. Nat., v. 60, p. 377, 1834, in Blainville's Manual d'Actinologie ou de Zoophytologie, p. 412, pl. 69, figs. 6, 6a-c.

Pateoris australis (Parr) = Quinqueloculina australis Parr, 1932. Proc. Roy. Soc. Victoria, N.s., v. 44, pt. 1, p. 7, fig. in Brady, 1884, pl. 5, figs. 10, 11a-b.

Remarks: Initial chambers appear to be quinqueloculine, but final chambers are added in one plane, suggesting the generic classification Pateoris rather than Quinqueloculina, or Milliolinella (as appears in Brady, 1884), however, all specimens have an apertural flap rather than a tooth.

Peneroplis pertusus (Forskål) = Nautilus pertusus Forskål, 1775, Descriptiones animalium, p. 125, fig. in Brady, 1884, pl. 13, figs. 16-17, 23.

Quinqueloculina curta Cushman, 1921, U. S. Nat. Mus. Bull. 100, v. 4, p. 426, pl. 100, figs. 1-2.

Quinqueloculina parkeri (Brady) = Miliolina parkeri Brady, 1881. Quat. Jour. Micr. Sci., n.s., v. 21, p. 46, fig. in Brady, 1884, pl. 7, fig. 14a-c.

Rosalina vilardeboana d'Orbigny, 1839, Voyage dans l'Amerique Meridionale, Foraminifers, tome 5, pt. 5, p. 44, pl. 6, figs. 13-15.

Siphoninoides echinata (Brady) = Planorbulina echinata Brady, 1879, Notes on some of the reticularian Rhizopoda of the "Challenger" Expedition. Quart. Jour. Micr. Sci., v. 19, p. 283, pl. 8, figs. 31a-c.

Spirolina arientina (Batsch) = Nautilus (Lituus) arietinus Batsch, 1791, Conch. Seesandes, p. 4, pl. 6, fig. 15c.

Spiroloculina corrugata Cushman and Todd, 1944, The genus Spiroloculina and its species. Cushman Lab. Foram. Res., Spec. Pub. 11, p. 61, pl. 8, figs. 22-25.

APPENDIX D

PLATE I

FORAMINIFERA

MAGNIFICATION 50X

Figure		Text Page
	BRACKISH-WATER FORAMINIFERA	
1	Ammonia beccarii (Linnaeus). 1a, dorsal side; 1b, ventral side.	69
2	Elphidium sp. 2a, side view; 2b, apertural view.	70
	VERY SMALL SPECIES OF FORAMINIFERA	
3	Bolivina rhomboidalis (Millett).	71
4	Cibicides lobatulus (Walker and Jacob). 4a, dorsal side; 4b, ventral side; 4c, apertural view.	72
5	Elphidium hyalocostatus Todd. 5a, side view; 5b, edge view.	73
6	Glabratella patelliformis (Brady).	74
7	Rosalina vilardeboana d'Orbigny. 7a, dorsal side; 7b, ventral side; 7c, apertural view.	75
8	Pateoris australis (Parr). 8a, side view; 8b, apertural view.	76

DRAWINGS
specimens

Brackish H2O
1. Ammonia beccarii
2. Elphidium

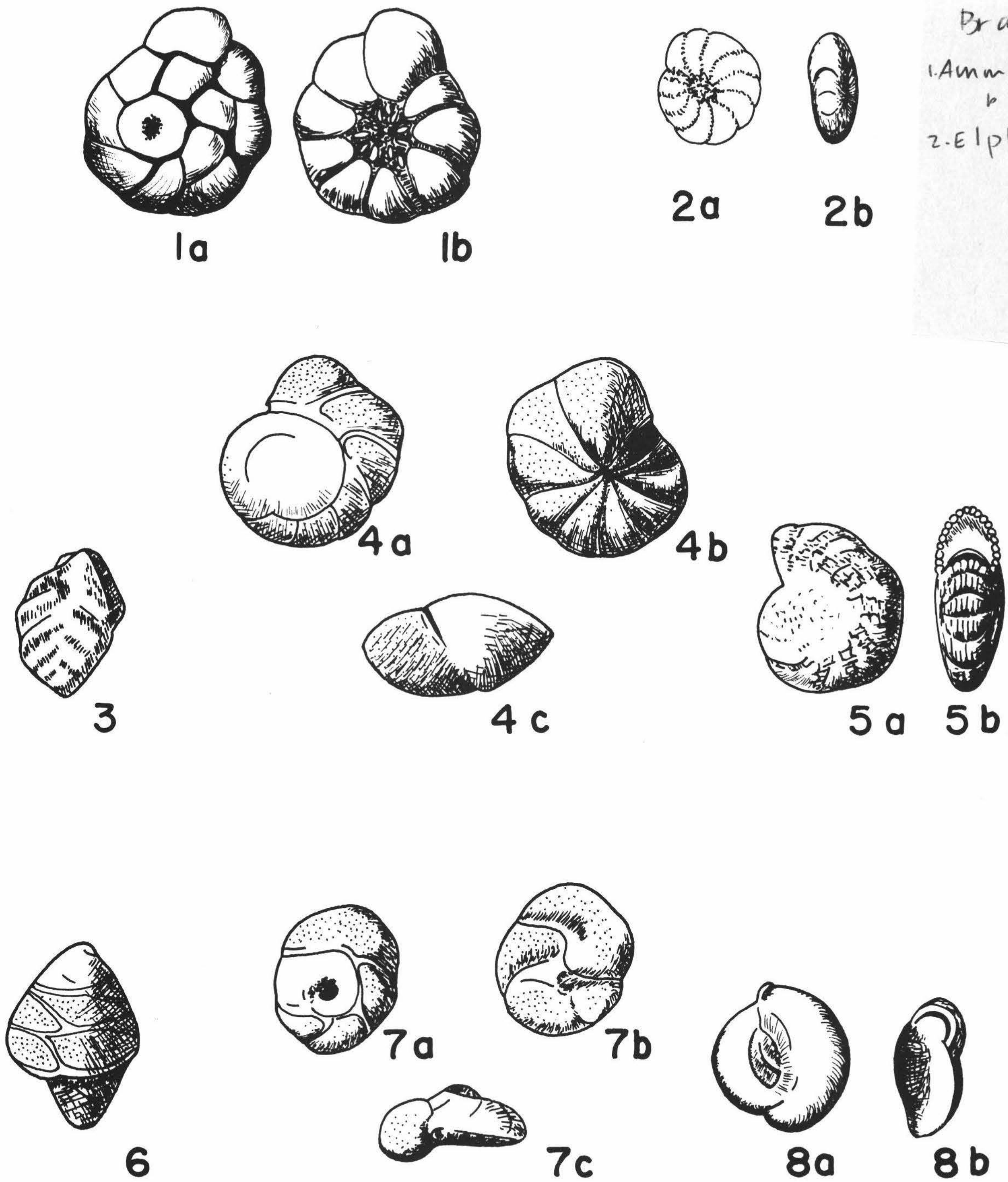


PLATE II

FORAMINIFERA

Figure		Text Page
	REEF-DWELLING FORAMINIFERA	
	MAGNIFICATION 50X	
1	*Cymbaloporetta bradyi* (Cushman). 1a, dorsal side; 1b, ventral side.	79
2	*Fijiella simplex* (Cushman).	80
	MAGNIFICATION 12X	
3	*Marginopora vertebralis* (Blainville). 3a, side view; 3b, edge view.	81
	MAGNIFICATION 25X	
4	*Peneroplis pertusus* (Forskål). 4a, side view; 4b, apertural view.	82
	MAGNIFICATION 50X	
5	*Quinqueloculina curta* (Cushman). 5a, 5b opposite sides.	83
6,7	*Quinqueloculina parkeri* (Brady).	84

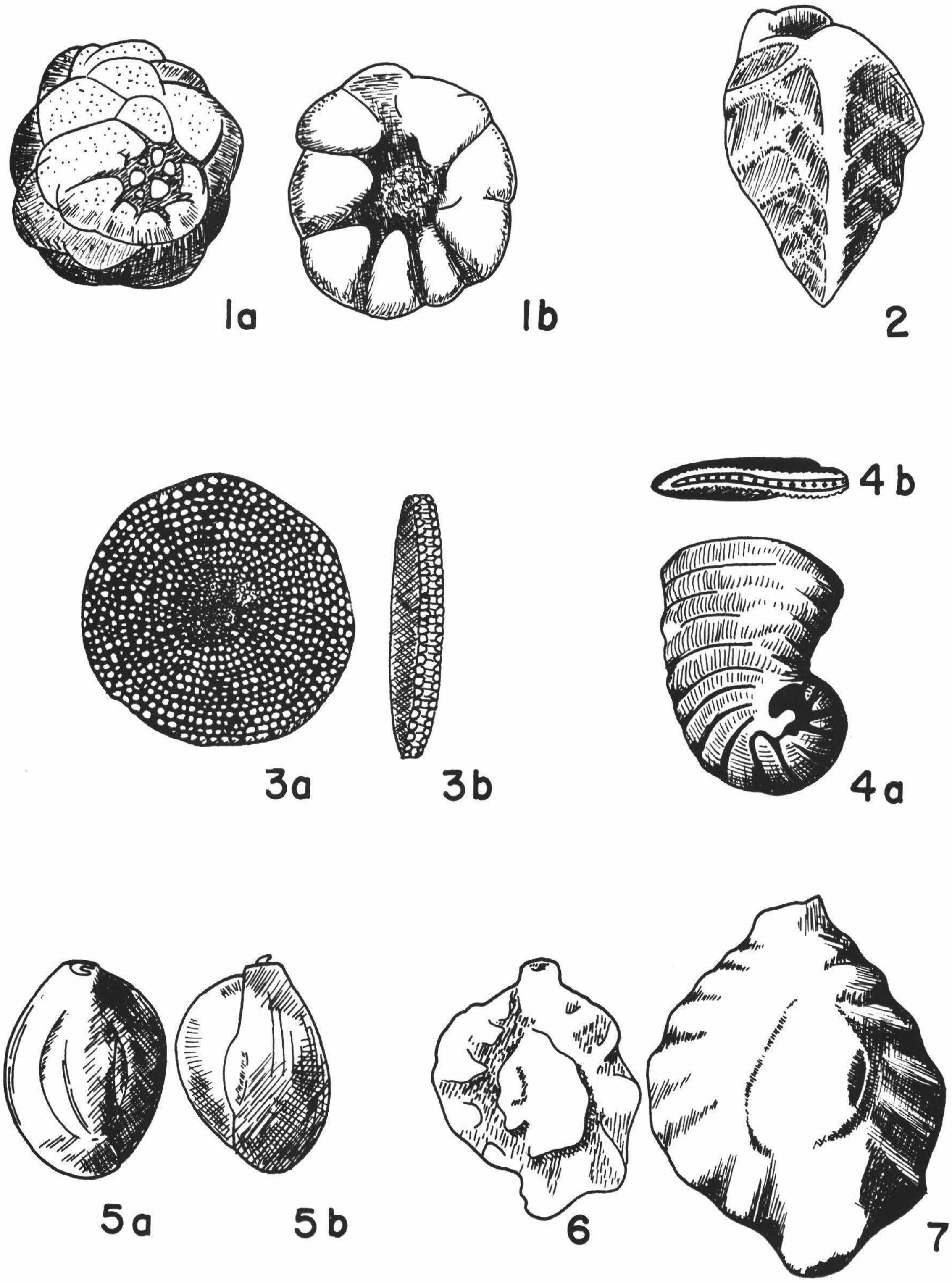

1a
1b
2
3a
3b
4b
4a
5a
5b
6
7

PLATE III

FORAMINIFERA

MAGNIFICATION 50X

Figure		Text Page
1	*Siphoninoides echinata* (Brady).	85
2	*Spirolina arietina* (Batsch). 2a, side view; 2b, apertural view.	86
3	*Amphistegina madagascariensis* d'Orbigny. 3a, dorsal side; 3b, ventral side; 3c, edge view.	89
4	*Spiroloculina corrugata* Cushman and Todd. 4a, side view; 4b, edge view.	92
	GASTROPODA	
	MAGNIFICATION 50X	
5	*Hipponix* juveniles	94
6	Vitrinellid "lined"	95
7	Vitrinellid "rough"	97

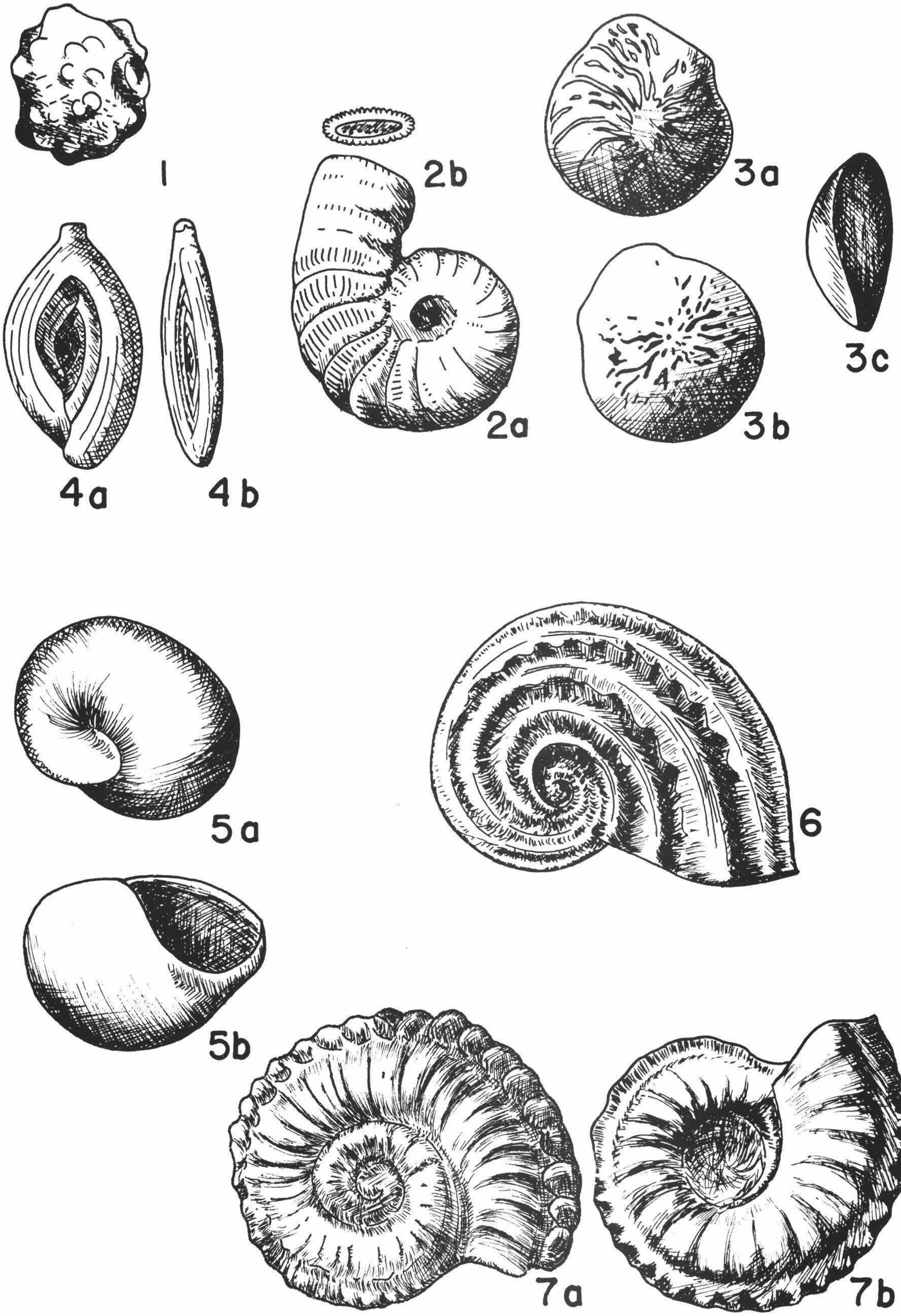
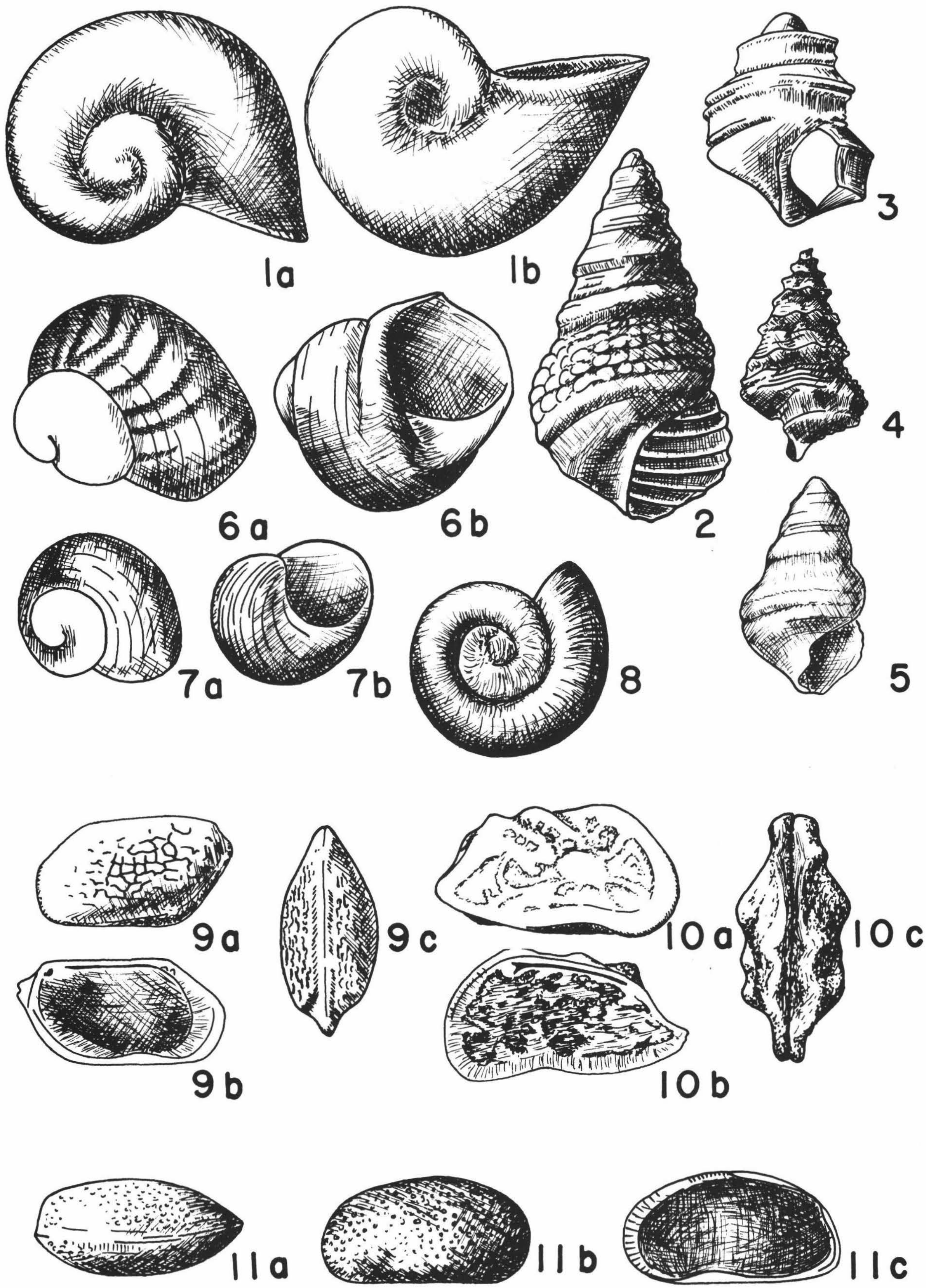

1
2b
3a
2a
3b
3c
4a
4b
5a
6
5b
7a
7b

PLATE IV

GASTROPODA

MAGNIFICATION 50X

Figure		Text Page
1	Vitrinellid "smooth"	98
	MAGNIFICATION 25X	
2,5	Family Cerithiidae	100
	MAGNIFICATION 50X	
3	Family Cerithiidae	100
	MAGNIFICATION 12X	
4	Family Cerithiidae	100
	MAGNIFICATION 50X	
6,7	Tricolia variablis (Pease)	101
8	Vitrinellid "brown"	103
	OSTRADODA	
	MAGNIFICATION 50X	
9	Loxoconcha condyla Holden	105
10	Hermanites sp. of Holden (1967)	106
11	Cyprideis sp. aff. beaconensis	102


1a
1b
3
4
6a
6b
2
7a
7b
8
5
9a
9c
10a
10c
9b
10b
11a
11b
11c

APPENDIX E

SAMPLE NO.	NO. of GRAMS	NO. of SPLITS	TOTAL NO. of INDIVIDUALS gram	AMMONIA beccarii		AMPHISTEGINA madagascariensis		BOLIVINA rhomboidalis		CIBICIDES lobatulus		CYMBALOPORETTA bradyi		ELPHIDIUM hyalocostatum		ELPHIDIUM sp.	
				ind./gm.	%	ind./gm.	%	ind./gm.	%	ind./gm.	%	ind./gm.	%	ind./gm.	%	ind./gm.	%
13	52.7	0	x	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	40.1	0	1.9	x	1.3	x	1.3	0.0	0.0	0.0	0.0	0.2	10.7	0.0	0.0	0.0	0.0
18	55.0	0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	x	14.3	0.0	0.0	0.0	0.0	0.0	0.0
19	35.1	3	91.4	2.1	2.2	0.0	0.0	0.0	0.0	10.3	11.2	2.1	2.2	4.3	4.7	3.9	4.2
20	56.0	1	8.2	2.9	35.7	0.0	0.0	0.0	0.0	0.3	3.0	0.2	2.6	0.3	3.9	2.2	27.0
21	52.1	4	94.3	5.5	5.9	0.0	0.0	1.2	1.3	4.3	4.6	2.8	2.9	6.1	6.5	0.6	0.7
104	43.8	6	100.2	2.8	4.4	0.0	0.0	14.6	2.3	81.9	12.9	14.6	2.3	49.7	7.8	19.0	3.0
105	58.0	6	516.5	3.3	0.6	2.2	0.4	3.3	0.6	48.6	9.4	3.3	0.6	25.4	4.9	1.1	0.2
106	41.3	5	389.8	0.8	0.2	7.7	2.0	0.0	0.0	18.6	4.8	12.4	3.2	8.5	2.2	0.0	0.0
108	61.2	5	79.5	0.0	0.0	0.0	0.0	0.5	0.7	10.4	13.1	0.5	0.7	9.9	12.4	0.0	0.0
114	48.1	5	173.5	0.7	0.4	1.3	0.8	0.7	0.4	7.3	4.2	4.0	2.3	1.3	0.8	0.0	0.0
119	49.4	5	141.2	0.0	0.0	0.7	0.5	1.3	0.9	11.0	7.8	2.6	1.8	9.1	6.4	0.0	0.0
203	49.7	4	96.2	4.2	4.3	0.3	0.3	0.6	0.7	6.1	6.4	4.8	5.0	4.5	4.7	0.3	0.3
207	62.6	5	116.0	0.5	0.4	0.5	0.4	1.0	0.9	12.8	11.0	1.0	0.9	7.2	6.2	1.0	0.9
300	52.4	4	93.2	0.0	0.0	0.9	1.0	0.0	0.0	1.2	1.3	2.1	2.3	0.3	0.3	0.0	0.0
301-F	46.9	5	281.8	0.0	0.0	4.1	1.5	0.7	0.2	30.0	10.7	4.1	1.5	8.9	3.1	0.0	0.0
302-F	44.2	4	129.5	0.0	0.0	11.2	8.7	0.7	0.6	6.5	5.0	2.2	1.7	2.5	2.0	0.0	0.0
306-F	45.1	5	119.3	0.7	0.6	14.9	12.5	0.0	0.0	5.0	4.2	2.1	1.8	0.0	0.0	0.0	0.0
308-F	43.9	4	139.9	0.4	0.3	8.0	5.7	0.0	0.0	3.3	2.3	2.2	1.6	0.7	0.5	0.0	0.0
339	40.2	4	281.5	9.2	3.3	4.4	1.6	1.2	0.4	17.1	6.1	22.7	8.1	8.8	3.1	0.4	0.1
400	51.6	5	461.9	5.0	1.1	1.9	0.4	6.8	1.5	65.1	14.1	7.4	1.6	37.2	8.1	3.1	0.7
401-F	45.2	0	2.4	0.0	0.0	0.6	22.5	0.0	0.0	0.1	2.7	x	0.9	x	0.9	0.0	0.0
402-F	51.0	5	259.0	0.0	0.0	2.5	1.0	0.0	0.0	21.3	8.2	7.5	2.9	6.9	2.7	0.0	0.0
404-F	44.2	0	6.5	0.0	0.0	6.0	90.7	0.0	0.0	x	0.3	0.0	0.0	0.0	0.0	0.0	0.0
600-F	50.0	0	1.2	0.0	0.0	0.2	15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
700-F	42.7	3	32.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.2	0.8	2.3	0.6	1.7	0.0	0.0
701-F	48.9	4	244.9	2.3	0.9	0.3	0.1	2.6	1.1	9.8	4.0	1.3	0.5	16.4	6.7	1.3	0.5
800-F	51.1	1	3.2	0.0	0.0	3.0	95.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
901-F	51.2	0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	x	0.8	0.1	1.2	0.0	0.0
902-F	50.4	5	321.9	8.9	2.8	0.0	0.0	0.0	0.0	30.5	9.5	5.1	1.6	25.4	7.9	4.4	1.4
903-F	50.8	5	132.1	3.1	2.4	0.0	0.0	0.0	0.0	15.7	11.9	3.1	2.4	6.9	5.2	2.5	1.9
904-F	52.3	4	115.3	1.5	1.3	3.4	2.9	0.9	0.8	13.5	11.7	1.5	1.3	4.0	3.4	0.0	0.0
905-F	46.3	5	172.1	6.2	3.6	0.0	0.0	0.7	0.4	13.1	7.6	2.8	1.6	13.8	8.0	0.0	0.0
906-F	46.0	5	175.5	5.6	3.2	2.1	1.2	0.0	0.0	26.4	15.1	3.5	2.0	11.1	6.3	0.7	0.4
907-F	50.7	4	149.5	5.1	2.7	1.9	1.3	0.3	0.2	7.3	4.9	6.0	4.0	2.8	1.9	0.3	0.2
909-F	52.5	4	55.3	1.2	2.2	0.0	0.0	0.3	0.5	4.6	8.2	0.6	1.1	0.9	1.6	0.0	0.0
910-F	52.2	5	307.6	0.6	0.2	0.0	0.0	0.0	0.0	20.8	6.8	16.6	5.4	13.5	4.4	0.6	0.2
911-F	51.0	3	39.3	0.6	1.6	0.5	1.2	0.0	0.0	2.0	5.2	0.3	0.8	1.4	3.6	0.0	0.0
912-F	53.0	3	56.4	0.3	0.5	0.3	0.5	0.0	0.0	3.2	5.6	1.8	3.2	1.1	1.9	0.0	0.0
913-F	52.0	5	306.5	6.8	2.2	0.6	0.2	1.8	0.6	11.7	3.8	8.6	2.8	7.4	2.4	0.0	0.0
914-F	49.4	5	358.2	5.8	1.6	1.9	0.5	1.3	0.4	18.1	5.1	6.5	1.8	3.9	1.1	0.0	0.0
1000-F	52.0	5	293.5	12.3	4.2	0.0	0.0	3.1	1.0	20.3	6.9	5.5	1.9	13.5	4.6	3.9	1.3
1001-F	52.7	6	805.0	19.4	2.4	1.2	0.2	8.5	1.1	72.9	9.0	37.6	4.7	51.0	6.3	20.6	2.6
1002-F	50.2	3	1.3	0.0	0.0	0.3	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1003-F	49.9	0	5.7	x	6.1	0.0	0.0	0.0	0.0	0.5	7.0	0.3	4.9	x	3.0	2.1	31.4
1004-F	51.5	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1005-F	50.8	2	22.6	1.9	8.5	0.0	0.0	0.1	0.4	0.7	3.2	1.7	7.8	0.5	2.1	7.1	31.9
1100-F	42.8	0	4.5	0.0	0.0	2.4	55.8	0.0	0.0	0.1	1.1	0.0	0.0	0.0	0.0	0.0	0.0
1101-F	49.8	1	18.5	0.0	0.0	3.0	16.1	0.0	0.0	0.2	0.9	1.1	6.1	0.2	1.1	0.0	0.0
1102-F	46.2	2	9.7	0.0	0.0	0.7	7.1	0.0	0.0	0.3	3.5	0.5	5.3	0.3	2.7	0.0	0.0
1200-F	59.5	1	5.8	0.0	0.0	0.6	10.3	0.0	0.0	0.1	2.3	0.2	2.9	0.1	1.7	0.0	0.0
1201-F	57.2	3	58.6	0.0	0.0	2.1	3.6	0.0	0.0	0.6	1.0	11.0	18.9	0.6	1.0	0.0	0.0
1300-F	55.1	1	25.4	0.0	0.0	22.6	89.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1301-F	67.6	3	14.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.8	0.0	0.0	0.0	0.0
1302-F	71.8	3	52.8	0.0	0.0	29.9	56.5	0.0	0.0	0.6	1.1	1.0	1.9	0.3	0.6	0.0	0.0
1303-F	46.1	7	480.3	0.0	0.0	0.0	0.0	2.8	0.6	27.8	5.8	0.0	0.0	47.2	9.8	8.3	1.7
1304-F	55.9	3	23.4	0.0	0.0	1.0	4.3	0.0	0.0	0.9	3.7	0.7	3.0	0.7	3.0	0.0	0.0
1305-F	62.9	0	0.8	0.0	0.0	0.3	34.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1306-F	69.8	0	0.9	0.0	0.0	0.6	60.8	0.0	0.0	x	1.4	0.0	0.0	0.0	0.0	0.0	0.0

SAMPLE NO.	FIJIELLA simplex ind./gm.	%	GLABRATELLA patelliformis ind./gm.	%	MARGINOPORA vertebralis ind./gm.	%	PATEORIS australis ind./gm.	%	PENEROPLIS pertusus ind./gm.	%	QUINQUELOCULINA curta ind./gm.	%	QUINQUELOCULINA parkeri ind./gm.	%	ROSALINA vilardeboana ind./gm.	%	SIPHONINOIDES echinata ind./gm.	%	SPIROLINA arietina ind./gm.	%
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.1	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	36.0	x	1.3	0.0	0.0	0.2	8.0	0.1	2.7
18	x	7.1	0.0	0.0	x	7.1	0.0	0.0	0.0	0.0	0.1	21.4	x	7.1	0.0	0.0	x	14.3	0.0	0.0
19	1.8	2.0	1.1	1.3	0.9	1.0	0.0	0.0	0.0	0.0	7.3	8.0	1.1	1.3	0.0	0.0	0.2	0.3	1.1	1.3
20	0.1	1.3	0.1	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.5	6.5	0.0	0.0	0.1	0.9	0.1	0.9	0.0	0.0
21	3.4	3.6	3.1	3.3	0.6	0.7	0.9	0.8	0.6	0.7	5.1	6.2	0.6	0.7	3.1	3.3	1.5	1.6	0.9	0.8
104	2.9	0.5	112.6	17.7	1.5	0.2	32.2	5.1	0.0	0.0	14.6	2.3	0.0	0.0	210.7	33.2	0.0	0.0	10.2	1.6
105	9.9	1.9	17.7	3.4	0.0	0.0	27.6	5.3	1.1	0.2	26.5	5.1	6.6	1.3	86.1	16.7	0.0	0.0	14.3	2.8
106	17.8	4.6	10.1	2.6	20.9	5.4	7.0	1.8	0.8	0.2	41.1	10.5	5.4	1.4	6.2	1.6	3.9	1.0	22.5	5.8
108	2.6	3.2	3.6	4.6	0.0	0.0	2.1	2.6	0.0	0.0	6.8	8.5	0.0	0.0	5.2	6.5	1.0	1.3	3.6	4.6
114	10.6	6.1	5.3	3.0	12.5	7.2	2.6	1.5	1.3	0.8	23.8	13.7	4.0	2.3	2.0	1.1	2.0	1.1	7.9	4.6
119	5.2	3.7	7.1	5.0	0.0	0.0	4.5	3.2	1.3	0.8	5.2	3.7	1.3	0.9	6.5	4.6	2.6	1.8	3.9	2.8
203	3.9	4.0	1.6	1.7	2.9	3.0	2.9	3.0	0.6	0.7	8.4	8.7	1.0	1.0	2.9	3.0	0.0	0.0	3.2	3.3
207	1.5	1.3	5.1	4.4	0.0	0.0	4.6	4.0	0.0	0.0	3.6	3.1	1.0	0.9	31.7	27.3	0.0	0.0	3.6	3.1
300	13.4	14.4	0.9	1.1	6.1	6.5	0.0	0.0	1.2	1.3	18.6	19.9	2.1	2.3	0.3	0.3	5.5	5.9	6.7	7.2
301-F	17.7	6.3	4.8	1.7	12.3	4.4	4.1	1.5	2.7	1.0	23.9	8.5	2.0	0.7	6.8	2.4	1.4	0.5	12.3	4.4
302-F	10.5	8.1	3.6	2.8	9.0	7.0	1.1	0.8	0.7	0.6	12.7	9.8	2.2	1.7	0.7	0.6	2.9	2.2	12.3	9.5
306-F	7.1	6.0	0.0	0.0	2.8	2.4	0.7	0.6	0.0	0.0	7.8	6.5	1.4	1.2	5.7	4.8	4.3	3.6	3.6	3.0
308-F	15.3	10.9	2.2	1.6	12.4	8.9	0.4	0.3	1.8	1.3	25.1	18.0	5.8	4.2	0.4	0.3	4.7	3.4	22.2	15.9
339	18.7	6.6	3.6	1.3	17.5	6.2	2.4	0.8	1.2	0.4	33.8	12.0	4.4	1.6	0.0	0.0	4.4	1.6	12.7	4.5
400	1.2	0.3	36.0	7.8	0.0	0.0	8.1	7.1	0.0	0.0	14.3	3.1	1.2	0.3	100.4	21.7	0.0	0.0	10.5	2.3
401-F	0.1	4.5	0.0	0.0	0.2	9.9	x	1.8	0.0	0.0	0.2	9.0	0.2	8.1	0.2	9.0	0.0	0.0	0.2	6.3
402-F	15.7	6.1	5.6	2.2	6.3	2.4	1.9	0.7	1.9	0.7	48.9	18.9	3.1	1.2	3.8	1.5	5.0	1.9	9.4	3.6
404-F	x	0.7	x	0.3	x	0.7	0.0	0.0	0.0	0.0	0.1	2.4	x	0.3	0.0	0.0	0.0	0.0	0.1	1.0
600-F	x	3.4	0.0	0.0	0.1	10.3	0.0	0.0	x	1.7	0.3	24.1	0.0	0.0	x	1.7	x	1.7	0.1	5.2
700-F	2.3	7.0	0.2	0.6	1.1	3.5	0.4	1.2	0.2	0.6	8.3	25.6	1.5	4.7	0.0	0.0	0.9	2.9	1.3	4.1
701-F	8.5	3.5	11.8	4.8	1.6	0.7	12.4	5.1	1.0	0.4	21.0	8.6	1.0	0.4	44.9	18.3	1.0	0.4	6.5	2.7
800-F	0.0	0.0	0.0	0.0	0.2	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
901-F	x	0.4	x	0.8	x	0.4	0.0	0.0	0.0	0.0	0.1	18.2	0.1	1.9	0.0	0.0	x	0.8	0.3	6.7
902-F	4.4	1.4	1.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	11.4	3.6	1.9	0.6	8.3	2.6	0.0	0.0	1.9	0.6
903-F	0.6	0.5	0.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	7.6	5.7	1.3	1.0	0.0	0.0	0.6	0.5	3.8	2.9
904-F	1.5	1.3	1.2	1.1	0.9	0.8	0.0	0.0	0.0	0.0	8.6	7.4	0.9	0.8	0.6	0.5	1.8	1.6	4.9	4.2
905-F	4.1	2.4	0.7	0.4	0.0	0.0	0.7	0.4	0.0	0.0	9.0	5.2	0.7	0.4	2.8	1.6	1.4	0.8	4.8	2.8
906-F	2.1	1.2	0.7	0.4	0.0	0.0	3.5	2.0	0.0	0.0	7.7	4.4	1.4	0.8	4.9	2.8	0.0	0.0	3.5	2.0
907-F	6.6	4.4	0.9	0.6	3.5	2.3	0.0	0.0	1.3	0.8	18.6	12.4	4.1	2.7	0.3	0.2	2.8	1.9	7.6	5.1
909-F	1.8	3.3	0.3	0.5	0.6	1.1	0.0	0.0	0.3	0.5	5.2	9.3	1.2	2.2	0.0	0.0	0.3	0.5	3.0	5.5
910-F	15.9	5.2	4.9	1.6	18.4	6.0	1.2	0.4	0.6	0.2	46.0	14.9	1.2	0.4	0.0	0.0	3.7	1.2	4.9	1.6
911-F	0.3	0.8	0.2	0.4	0.9	2.4	0.0	0.0	0.0	0.0	2.8	7.2	0.3	0.8	0.0	0.0	1.1	2.8	2.7	6.8
912-F	3.6	6.4	0.6	1.1	1.5	2.7	1.7	2.9	0.2	0.3	5.0	8.8	0.0	0.0	0.3	0.5	0.8	1.3	5.4	9.7
913-F	13.5	4.4	1.8	0.6	8.6	2.8	3.7	1.2	0.0	0.0	42.5	13.9	0.0	0.0	0.6	0.2	3.1	1.0	2.5	0.8
914-F	22.0	6.1	6.5	1.8	13.0	3.6	2.6	0.7	1.3	0.4	64.8	18.1	4.5	1.3	1.9	0.5	9.1	2.5	13.0	3.6
1000-F	0.6	0.2	2.5	0.8	0.0	0.0	9.2	3.1	0.6	0.2	9.2	3.1	0.0	0.0	22.2	7.5	0.6	0.2	2.5	0.8
1001-F	3.6	0.5	21.9	2.7	0.0	0.0	36.4	4.5	0.0	0.0	12.1	1.5	0.0	0.0	144.5	17.9	0.0	0.0	6.1	0.8
1002-F	0.0	0.0	0.0	0.0	0.2	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	37.5
1003-F	0.3	4.2	0.1	2.1	0.0	0.0	0.0	0.0	x	0.3	0.8	11.4	0.1	0.9	0.0	0.0	0.1	0.9	0.1	0.9
1004-F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1005-F	0.7	3.2	0.2	1.1	0.2	1.1	0.0	0.0	0.3	1.4	1.4	6.4	0.2	0.7	0.0	0.0	0.1	0.4	0.7	3.2
1100-F	0.1	2.2	0.0	0.0	0.1	1.7	0.0	0.0	x	0.6	0.4	8.3	0.0	0.0	0.1	1.7	x	0.6	0.2	3.9
1101-F	0.6	3.3	x	0.2	3.5	18.9	0.0	0.0	0.5	2.8	1.7	9.1	1.0	5.4	0.0	0.0	0.9	4.8	1.7	9.3
1102-F	0.3	3.5	0.1	0.9	1.2	12.4	0.0	0.0	0.1	0.9	1.4	14.2	0.5	5.3	0.0	0.0	0.1	0.9	0.8	8.0
1200-F	0.1	1.7	0.0	0.0	1.7	28.7	x	0.6	0.2	2.9	0.1	2.3	0.6	10.3	0.0	0.0	0.2	4.0	0.6	10.3
1201-F	4.2	7.2	0.8	1.4	5.9	10.0	0.1	0.2	2.1	3.6	7.3	12.4	3.1	5.3	0.0	0.0	3.1	5.3	6.4	11.0
1300-F	0.0	0.0	0.0	0.0	2.0	7.7	0.0	0.0	0.1	0.3	0.1	0.4	x	0.1	0.0	0.0	0.0	0.0	0.2	0.9
1301-F	0.9	6.4	0.1	0.8	3.7	24.8	0.0	0.0	0.4	2.4	1.9	14.8	0.5	3.2	0.1	0.8	0.1	0.8	0.9	6.4
1302-F	1.1	2.1	0.7	1.3	4.0	7.6	0.1	0.2	0.4	0.8	3.2	6.1	0.6	1.1	0.1	0.2	0.8	1.5	1.9	3.6
1303-F	0.0	0.0	44.4	9.2	0.0	0.0	2.8	0.6	0.0	0.0	5.5	1.2	0.0	0.0	172.1	35.8	2.8	0.6	2.8	0.6
1304-F	0.4	1.8	0.6	2.4	4.9	20.7	0.1	0.6	0.0	0.0	2.1	9.1	0.6	2.4	0.1	0.6	0.3	1.2	0.9	3.7
1305-F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	x	4.1	0.1	10.2	x	4.1	0.0	0.0	0.0	0.0	0.0	0.0
1306-F	x	1.4	x	1.4	0.2	20.3	0.0	0.0	0.0	0.0	x	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SAMPLE NO.	SPIROLOCULINA corrugata ind./gm.	%	PERCENT of TOTAL FORAMINIFERA POPULATION	LOXOCONCHA condyla and L. longispina ind./gm.	HERMANITES sp. ind./gm.
13	0.0	0.0	-	0.0	0.0
16	0.0	0.0	66.6	0.0	0.0
18	0.0	0.0	71.3	0.0	0.0
19	0.0	0.0	39.7	0.0	0.0
20	0.1	1.7	84.8	0.0	0.0
21	2.1	2.3	45.9	1.2	0.3
104	4.4	0.7	94.0	4.4	4.4
105	8.8	1.7	55.1	2.2	3.3
106	15.5	4.0	51.3	9.5	13.8
108	0.5	0.7	59.1	1.0	0.0
114	5.3	3.0	53.3	2.0	2.0
119	4.5	3.2	47.2	1.3	2.6
203	0.6	0.7	50.8	0.0	1.6
207	0.0	0.0	64.8	0.0	0.5
300	1.8	2.0	65.7	0.3	1.2
301-F	8.9	3.1	51.5	8.2	13.0
302-F	2.2	1.7	62.8	1.8	1.1
306-F	2.8	2.4	49.6	1.4	0.7
308-F	1.1	0.8	76.0	2.6	1.8
339	5.6	2.0	59.7	6.4	3.2
400	0.0	0.0	64.7	0.0	0.0
401-F	0.0	0.0	73.8	x	0.1
402-F	3.1	1.2	55.2	6.3	9.4
404-F	x	0.3	96.7	0.0	0.0
600-F	x	3.4	67.0	0.1	x
700-F	0.0	0.0	55.4	1.3	0.7
701-F	2.3	0.9	59.6	2.3	1.6
800-F	0.0	0.0	100.0	0.0	0.0
901-F	x	0.8	32.0	0.0	0.0
902-F	3.2	1.0	33.4	0.0	0.0
903-F	0.0	0.0	34.9	0.0	0.0
904-F	0.3	0.3	39.4	0.6	0.9
905-F	0.7	0.4	35.6	2.1	0.7
906-F	1.4	0.8	42.6	0.0	0.7
907-F	1.9	1.3	46.9	3.5	1.9
909-F	0.3	0.5	37.0	0.0	0.0
910-F	6.7	2.2	50.7	6.7	8.6
911-F	0.3	0.8	34.4	0.0	0.0
912-F	0.3	0.5	45.9	0.0	0.0
913-F	2.5	0.8	37.7	8.6	5.5
914-F	1.3	0.4	49.5	1.3	0.0
1000-F	0.0	0.0	35.8	0.6	0.0
1001-F	6.1	0.8	55.0	1.2	0.0
1002-F	0.0	0.0	75.0	0.2	0.5
1003-F	0.1	0.9	74.0	0.1	x
1004-F	0.0	0.0	-	0.0	0.0
1005-F	0.2	1.1	79.5	0.0	0.2
1100-F	0.1	1.7	77.6	0.0	0.0
1101-F	0.3	1.5	72.5	0.3	0.4
1102-F	0.4	4.4	69.1	0.2	0.0
1200-F	0.0	0.0	78.0	0.1	x
1201-F	0.1	0.2	81.1	0.4	0.1
1300-F	0.0	0.0	98.4	0.0	0.0
1301-F	0.0	0.0	59.2	0.4	0.4
1302-F	0.1	0.2	84.8	1.7	0.7
1303-F	0.0	0.0	65.9	2.8	0.0
1304-F	0.1	0.6	57.1	0.4	0.7
1305-F	0.0	0.0	53.1	0.0	0.0
1306-F	0.0	0.0	89.4	x	x

SAMPLE NO.	NO. of GRAMS	NO. of SPLITS	TOTAL NO. of INDIVIDUALS gram	FAMILY CERITHIDAE ind./gm.	FAMILY CERITHIDAE %	TRICOLIA VARIABLIS ind./gm.	TRICOLIA VARIABLIS %	HIPPONIX (juveniles) ind./gm.	HIPPONIX (juveniles) %	VITRINELLID "brown" ind./gm.	VITRINELLID "brown" %	VITRINELLID "lined" ind./gm.	VITRINELLID "lined" %	VITRINELLID "rough" ind./gm.	VITRINELLID "rough" %	VITRINELLID "smooth" ind./gm.	VITRINELLID "smooth" %	PERCENT of TOTAL GASTROPOD POPULATION
13	52.7	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
16	40.1	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
18	55.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
19	35.1	3	1.4	0.0	0.0	0.2	16.7	0.0	0.0	0.5	33.3	0.0	0.0	0.2	16.7	0.0	0.0	66.7
20	56.0	1	0.3	0.1	44.4	0.0	0.0	x	11.1	0.0	0.0	x	11.1	x	11.1	x	11.1	88.8
21	52.1	4	7.7	1.8	24.0	1.2	16.0	0.0	0.0	3.1	40.0	0.0	0.0	0.6	8.0	0.3	4.0	92.0
104	43.8	6	19.0	0.0	0.0	0.0	0.0	14.6	76.9	1.5	7.7	0.0	0.0	0.0	0.0	0.0	0.0	84.6
105	58.0	6	12.1	0.0	0.0	2.2	18.2	7.7	63.6	0.0	0.0	0.0	0.0	0.0	0.0	1.1	9.1	90.9
106	41.3	5	63.4	10.8	17.1	14.7	23.2	2.3	3.7	5.4	8.5	6.2	9.8	3.9	6.1	0.0	0.0	68.4
108	61.6	5	75.0	1.0	25.0	1.6	37.5	0.0	0.0	0.0	0.0	0.5	12.5	0.0	0.0	0.0	0.0	75.0
114	48.1	5	32.7	6.0	18.4	8.6	26.5	4.0	12.2	0.7	2.0	0.7	2.0	0.7	2.0	0.0	0.0	63.1
119	49.4	5	25.8	7.1	27.5	7.8	30.0	4.5	17.5	2.6	10.0	0.6	2.5	0.0	0.0	0.0	0.0	87.5
203	49.7	4	4.9	1.0	20.0	0.0	0.0	0.3	6.7	1.0	20.0	0.3	6.7	1.0	20.0	0.3	6.7	80.1
207	62.6	5	4.6	0.5	11.1	0.0	0.0	3.1	66.7	0.0	0.0	0.5	11.1	0.0	0.0	0.0	0.0	88.9
300	52.4	4	15.8	2.1	13.5	5.2	32.7	2.4	15.4	0.6	3.8	0.9	5.8	0.9	5.8	0.0	0.0	77.0
301-F	46.9	5	47.8	8.2	17.1	15.0	31.4	2.7	5.7	4.1	8.6	3.4	7.1	1.4	2.9	0.7	1.4	74.2
302-F	44.2	4	37.8	6.2	16.3	7.6	20.2	4.0	10.6	0.4	1.0	0.7	1.9	3.3	8.7	2.2	5.8	64.5
306-F	45.1	5	43.8	7.8	17.7	8.5	19.4	1.4	3.2	0.0	0.0	3.5	8.1	2.1	4.8	2.1	4.8	58.0
308-F	43.9	4	44.1	9.5	21.5	8.0	18.2	5.1	11.6	0.0	0.0	2.9	6.6	3.3	7.4	0.7	1.7	67.0
339	40.2	4	34.0	8.0	23.5	7.6	22.4	2.4	7.1	4.4	12.9	3.2	9.4	1.6	4.7	1.2	3.5	83.5
400	51.6	5	4.3	0.0	0.0	0.6	14.3	1.2	28.6	1.9	42.9	0.0	0.0	0.0	0.0	0.0	0.0	85.8
401-F	45.2	0	1.1	0.2	20.0	0.1	12.0	0.0	0.0	0.0	0.0	0.0	0.0	x	4.0	0.0	0.0	36.0
402-F	51.0	5	35.2	6.3	17.9	8.8	25.0	5.6	16.1	1.3	3.6	4.4	12.5	1.3	3.6	0.6	1.8	80.5
404-F	44.2	0	6.3	0.9	13.8	0.4	6.5	0.0	0.0	0.0	0.0	0.4	6.2	x	0.4	0.0	0.0	26.9
600-F	50.0	0	19.5	0.9	4.7	0.7	3.6	x	0.2	0.0	0.0	1.3	6.7	x	0.2	0.0	0.0	15.4
700-F	42.7	3	7.5	1.5	20.0	1.7	22.5	0.7	10.0	0.6	7.5	0.7	10.0	0.0	0.0	0.6	7.5	77.5
701-F	48.9	4	6.6	0.0	0.0	1.0	15.0	2.3	35.0	1.3	20.0	0.7	10.0	0.0	0.0	0.0	0.0	80.0
800-F	51.1	1	1.1	0.1	10.7	0.1	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.4
901-F	51.2	0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	60.0	0.0	0.0	x	40.0	0.0	0.0	100.0
902-F	50.4	5	6.4	0.1	9.1	2.5	36.4	1.3	18.2	2.5	36.4	0.0	0.0	0.0	0.0	0.0	0.0	100.0
903-F	50.8	5	1.2	0.6	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
904-F	52.3	4	1.2	0.6	50.0	0.0	0.0	0.0	0.0	0.6	50.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
905-F	46.3	5	2.1	0.0	0.0	0.0	0.0	0.7	33.3	1.4	66.7	0.0	0.0	0.0	0.0	0.0	0.0	100.0
906-F	46.0	5	1.4	0.0	0.0	0.0	0.0	0.0	0.0	1.4	100.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
907-F	50.7	4	23.3	1.3	5.4	4.4	18.9	1.9	8.1	0.6	2.7	0.6	2.7	3.8	16.2	1.9	8.1	62.1
909-F	52.5	4	1.2	0.3	25.0	0.0	0.0	0.0	0.0	0.3	25.0	0.3	25.0	0.0	0.0	0.3	25.0	100.0
910-F	52.2	5	21.6	2.5	11.4	3.7	17.1	2.5	11.4	4.3	20.0	0.6	2.9	1.8	8.6	3.7	17.1	88.5
911-F	51.0	3	0.5	0.0	0.0	x	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	x	33.3	100.0
912-F	53.0	3	2.0	0.0	0.0	0.0	0.0	0.6	30.8	0.0	0.0	0.0	0.0	0.0	0.0	0.3	15.4	46.2
913-F	52.0	5	23.3	1.8	17.9	5.5	23.7	1.2	5.3	7.4	31.6	0.6	2.6	0.6	2.6	2.5	10.5	84.2
914-F	49.4	5	18.6	3.2	17.2	1.9	10.3	0.0	0.0	3.2	17.2	0.6	3.4	2.6	13.8	2.6	13.8	75.7
1000-F	52.0	5	17.3	3.7	21.4	2.5	14.3	0.0	0.0	6.2	35.7	0.6	3.6	1.2	7.1	0.0	0.0	82.1
1001-F	52.7	6	32.7	8.5	25.9	0.0	0.0	14.6	44.4	2.4	7.4	3.6	11.1	0.0	0.0	2.4	7.4	96.2
1002-F	50.2	3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	33.3	0.2	33.3	0.0	0.0	66.7
1003-F	49.9	0	0.4	0.1	15.8	0.0	0.0	0.0	0.0	0.1	15.8	x	5.3	x	10.5	x	5.3	52.7
1004-F	51.5	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1005-F	50.8	2	2.6	0.5	18.8	0.4	15.6	0.1	3.1	0.0	0.0	0.2	6.3	0.8	31.3	0.0	0.0	75.1
1100-F	42.8	0	16.0	0.9	5.4	1.5	9.4	0.0	0.0	0.6	3.7	0.0	0.0	0.0	0.0	0.0	0.0	18.5
1101-F	49.8	1	13.2	1.7	13.0	3.2	24.1	0.0	0.0	0.2	1.5	0.1	0.9	0.8	6.3	0.0	0.0	45.8
1102-F	46.2	2	59.0	7.8	12.4	5.2	8.9	2.4	4.1	0.0	0.0	0.3	0.4	3.1	5.3	0.0	0.0	31.1
1200-F	59.5	1	3.9	0.6	14.8	0.3	7.8	0.1	1.7	x	0.9	0.1	1.7	0.3	7.8	0.0	0.0	34.7
1201-F	57.2	3	8.8	4.3	49.2	1.7	19.0	0.3	3.2	0.3	3.2	0.0	0.0	0.6	6.3	0.1	1.6	82.5
1300-F	55.2	1	7.1	1.2	17.3	1.9	26.4	x	0.5	0.0	0.0	0.0	0.0	0.1	1.0	0.0	0.0	45.2
1301-F	67.6	3	16.2	1.7	10.2	3.6	21.9	0.5	2.9	0.1	0.7	0.1	0.7	0.9	5.8	0.0	0.0	42.2
1302-F	71.8	3	11.8	1.0	9.0	2.5	22.0	0.2	2.0	0.2	2.0	0.7	6.0	0.1	1.0	0.0	0.0	42.0
1303-F	46.1	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1304-F	55.9	3	13.6	3.0	22.1	2.6	18.9	0.3	2.1	0.0	0.0	0.0	0.0	0.4	3.2	0.0	0.0	46.3
1305-F	62.9	0	0.8	0.1	11.8	0.1	17.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.4
1306-F	69.8	6	1.0	0.1	5.6	0.2	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.8