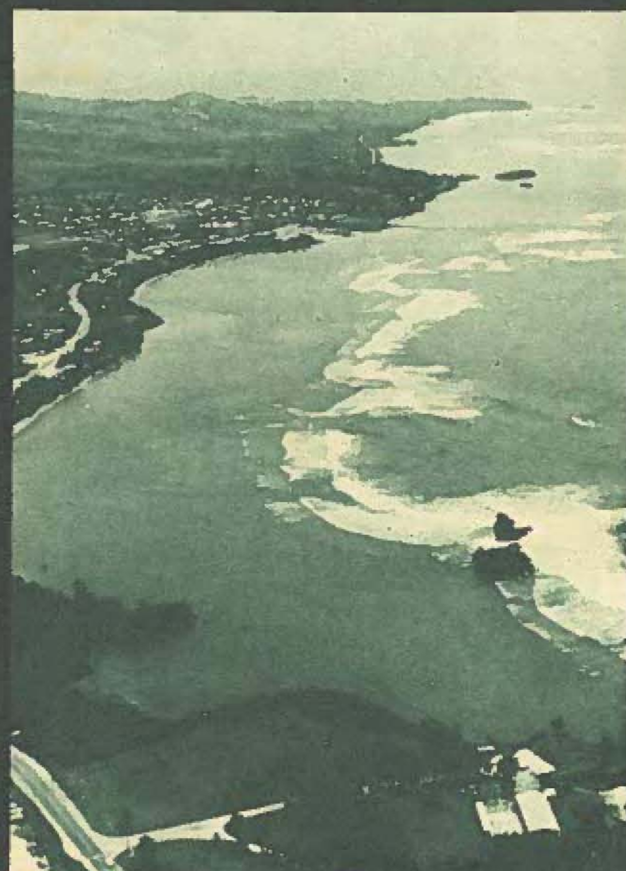
MARINE SURVEY OF AGAT BAY

Edited By

L. G. Eldredge, R. Dickinson, and S. Moras



UNIVERSITY OF GUAM MARINE LABORATORY

Technical Report No. 31

January 1977

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Submitted to

Guam Oil and Refinery Co., Inc.

University of Guam, Marine Laboratory

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INTRODUCTION

The Guam Oil and Refinery Co., Inc. (GORCO), in planning a major expansion in its petroleum refining operation in Guam, propose to construct and operate a sea-island mooring facility to accommodate tankers of at least 250,000 DWT. Van Houten and Associates, Inc., consulting engineers, determined that Agat Bay would be the most suitable location for such a facility.

In order to acquire the necessary permits for construction and operation, GORCO would need to submit required environmental impact statements which would include detailed marine studies.

To this end, GORCO requested that the University of Guam Marine Laboratory carry out the marine survey. A contract was negotiated and signed by representatives on March 26, 1974. The contract was for the study to be carried out over a fifteen-month period. A two-month extension request was granted.

This report is based on information provided by GORCO.

Scope of Work

The University of Guam Marine Laboratory was requested to provide the following:

1. A catalog of marine organims of Agat Bay,
2. An annual ocean current study of Agat Bay,
3. An evaluation of the potential environmental impact of the proposed facility's construction.
4. An evaluation of the potential environmental impact of operational emergencies, such as major oil spills; and the use of sea water for industrial cooling.

Acknowledgements

The authors wish to express special thanks to GORCO and to F. Cochran, W. Asper, and F. Santos for making this study possible and for providing available engineering information. The authors also wish to thank Bob Steth, Captain of the Yacht "Havaiki," and Arthur Mercereau, Captain of the Yacht "New World," for making these vessels available for this study.

We are particularly grateful to Mr. and Mrs. C. Marple who allowed us to use their house as a landmark and their electricity for a night navigational marker. Naval Station Security is also to be acknowledged for allowing us efficient access to Dadi Point.

We are also grateful to graduate, undergraduate, and high school students and staff members at the Marine

Laboratory who assisted us through the long 24-hour current surveys. Special thanks are extended to W. J. Tobias and D. Wooster. This research could not have been carried out without our marine technicians--F. Cushing, P. Beeman, M. Brown, and M. Salas--and our chief marine technicial T. Tansy who regularly organized the trips. Thanks are also extended to D. Hotaling who made some of the aerial photographs available.

Thanks are also extended to R. S. Jones, presently at the Harbor Branch Foundation, Rt. 1 Box 196, Ft. Pierce, Florida 33450, who initiated the project and whose encouragement helped carry it through.

We also thank our secretaries--Teresita C. Balajadia and Mary Mariano who typed all our records and reports and our office manager, A. S. Terlaje, who kept us within our budget and assisted in all our acquisitions.

PHYSIOGRAPHIC SETTING

R. H. Randall

The marine survey of Agat Bay provides a general description of that region. More specifically the study details the area from high intertidal zones to the offshore reef terraces. The coastal zone itself is defined as the sea and the land areas bordering the shoreline. In a landward direction it includes the beach zone to the top of the first major change encountered in topographic structure. The landward geologic setting of the Agat Bay area is detailed in Appendix I. In general the coastal zone of Agat Bay is described as the northern part of Sector X (Randall and Holloman, 1974). The seaward marine survey follows:

BEACHES

Much of the shoreline along Agat Bay consists of beach deposits. Dadi Beach borders the argillaceous limestone and alluvial land along the northeast part of the bay, Rizal and Togcha Beaches border the Alifan limestone the middle part of the bay, and Salinas Beach borders the alluvial land along the southern part of the bay, except for a small argillaceous limestone outcrop along the shore at Agat (Figs. 1 and 2). Although a developed beach is absent along the cliffed shoreline of the Mariana limestone at the northern part part of the bay, the cliff is buttressed by blocky boulder rubble and thin scattered patches of finer beach materials.

The shoreline south of Salinas Beach to Bangi Point is bordered for the most part by a mixture of much alluvium and some beach deposits (Figs. 1 and 2).

Two distinct provinces are found along Agat Bay. The smaller of these is located at the northern end of the bay where beach deposits are white to buff colored and are comprised mostly of bioclastic materials of reef origin; a condition caused primarily by the lack of stream development on the porous limestone land bordering this region. The second and larger province consists of the region south of Rizal Beach where the beach deposits are darker in color, caused primarily by the presence of various amounts of detrital material brought to the shore by the rivers and streams which drain the nearby volcanic slopes along this region and by the presence of alluvial deposits along much of the shoreline.

Emery (1962) collected a few beach samples from both provinces -- the southern province at high tide position (sample no. 54) and the northern province at both high and low tide positions (sample no. 55).

The characteristics of the sand at those two sample locations point out many of the differences between the two provinces. Characteristics of Emery's samples from the northern province (Dadi Beach) show that they have a low insoluble residue fraction (detrital material) of 8 per cent, a median grain diameter of 0.22 mm for the high tide and 1.16 mm for the low tide position samples, a Trask sorting coefficient of 1.17 for the high tide and 2.32 for the low tide position samples, and a beach slope of 8° for the high tide and 5° for the low tide position samples. The sample from the southern province has a much higher insoluble residue fraction of 39 per cent, a median grain diameter of 0.15 mm (high tide sample position), a Trask sorting coefficient of 1.58 (high tide sample position), and the beach slope was not measured.

The contribution of nonbioclastic detrital material to the beach deposits in the southern province is evident, both from Emery's analysis and from general observations made along the beaches of the bay. In general the samples at high tide are coarser than those from the low tide position. Emery (1962) explains this difference as the effect of wave action on the foreslope and upper beach which has either comminuted the coarser grains or winnowed out and redeposited there the finer ones from the reef flat. His belief is supported by the progressively better sorting values from the reef flat to high tide zone. Median grain size is somewhat smaller for the beaches with a higher detrital fraction which means that the detrital grains are finer than the bioclastic ones. The beach slope along the northern beaches of Agat Bay are moderate for the high tide position, when compared to other beaches around the island, which range from 3.3° to 15°, and high for the low tide position which range from 0.0° to 5.1° (Emery, 1962). Emery made several beach slope measurements at the northern end of Agat Bay before and after Typhoon Hester (Dec. 31, 1952) and Typhoon Nina (Aug. 10, 1953) and found that the beaches were cut by more than 30 cm during each. Typhoon Hester cut the beach to about 12 meters inland at Dadi Beach. Typhoon Nina cut Dadi Beach to a depth of 0.7 meters.

Composition of the bioclastic fraction of the beach materials along Agat Bay is mostly shells, coral, and red algae fragments, Halimeda debris, fine sand and silt, and foraminiferans. Feldspar, serpentine, hornblende, olivine, and rock fragments make up most of the composition of the detrital beach fraction.

The fringing reef descriptions follow an outline of biotopes and associated facies. Four fringing reef biotope units were recognized in the Agat Bay region (Figs.4 and 5). In a shore to seaward sequence these are the reef-flat platform, reef margin, reef front, and upper seaward slope (including associated submarine terraces) biotopes. Each of these biotopes can be further subdivided into several facies as given in the following descriptive outline.

Biotope I - Fringing Reef-Flat Platform and Associated Facies A-D

The flat, shallow, upper reef platform which extends seaward from the shoreline to the inner edge of reef margin. All or part of its surface is commonly exposed during low tides.

Facies A - Inner Reef Flat. The shoreward part of the reef-flat platform which retains water during low spring tides. The area of the retained water mass is referred to as the moat.

Facies B - Outer Reef Flat. The seaward part of the reef-flat platform which is slightly emergent during low or low spring tides.

Facies C - Reef-Flat Holes or Tide Pools. Isolated holes or depressions on the reef-flat platform which retain water during low or low spring tides, but not including those near the reef margin which communicate via cavernous surge channels or holes to the open sea.

Facies D - Reef-Flat Re-entry Channels. Shallow channels which cut through the reef margin into the reef-flat platform.

Biotope II - Reef Margin and Associated Facies A-D

The extreme seaward edge of the reef-flat platform which is immersed during high tide and awash during low or low spring tides, including associated surge channels and algal ridge features, if developed; a region of strong translatory currents and water agitation coinciding generally with the zone of breaking waves and surf.

Facies A - Upper Reef Margin Slope. Shallow seaward dipping slope of the reef margin, including the upper buttress surfaces and algal ridge features when developed.

Facies B - Open Surge Channels. Walls and floors of open surge channels, large cracks, and fissures which partly or completely bisect the reef margin.

Facies C - Cavernous Surge Channels. Cavernous parts of surge channels, tunnels, and holes, including the ceilings of overhanging surge channel walls and projecting ledges.

Facies D - Reef Margin Holes. Large open holes, usually located on the inner shoreward facing part of the reef margin which are connected to the open sea by surge channels, tunnels, or holes.

Biotope III - Reef Front and Associated Facies A-E

The steeply dipping seaward face of the shallow reef platform which extends downward and outward to the point where the submarine buttress and channel system terminates; a region always submerged and in a zone of strong oscillating currents located just seaward of the breaking waves and surf.

Facies A - Upper Reef Front Slopes. General reef front slope and upper buttress surfaces, including associated coral-algal knobs, pinnacles, and bosses, when developed.

Facies B - Submarine Channels. Walls and floors of submarine channels, cracks, grooves, and fissures which partly or completely bisect the reef front slope.

Facies C - Cavernous Regions of the Reef Front. Cavernous regions of submarine channels and grooves, holes, and submarine caves, and ceilings of overhanging channel walls.

Facies D - Reef Front Holes. Walls and floors of large open holes located on the reef front slope.

Facies E - Knolls, Knobs, Pinnacles, and Patch Reefs. Prominent relief structures developed upon the outer reef front slope.

Biotope IV - Upper Seaward Slopes, Shallow Submarine Terraces, and Associated Facies A-D

Seaward reef slopes below the reef front boundary, including intervening submarine terraces.

Facies A - Rocky Submarine Terraces. Shallow terraces consisting of rocky substrates located immediately seaward of the reef front.

Facies B - Unconsolidated Submarine Terraces. Shallow terraces consisting of unconsolidated substrates located immediately seaward of the reef front.

Facies C - Upper Seaward Slopes. Steeply dipping outer slopes located at the seaward margin of the shallow rocky and unconsolidated submarine terraces.

Facies D - Knobs, Knolls, and Pinnacles. Prominent relief structures developed upon the surface of the submarine terraces and outer seaward slopes.

Biotope I - Fringing Reef-Flat Platform and Associated Facies A-D

The entire shoreline of Agat Bay is bordered by a continuous fringing reef-flat platform (Figs. 5 and 6). The platform has a maximum width of 685 meters at the southern end of the bay between the tip of Bangi Point and Alutom Island (Figs. 6 and 7) and a minimum width of 100 meters near Neye Island at the north end of the bay (Fig. 2). The average reef flat width along Agat Bay is 300 meters. In a north to south direction the platform widens from 100 meters at Neye Island to 250 meters along the mid-part of Dadi Beach, then narrows to 120 meters along Rizal Beach, then widens again to about 275 meters along Togcha and Salinas Beaches, and finally widens to its maximum width of 685 meters south of Agat Village. This variable reef flat width is caused by the irregularity of both the shoreline and outer seaward edge of the platform. Major irregularities of the seaward edge of the platform are found at Pelagi Islets where a broad curving indentation and a reentry channel cut the reef margin, at a broad indentation along the length of Salinas Beach, at another reentry channel at Agat Village near Gaan Point, and at a sudden constriction of the reef flat north of Alutom Island (Figs. 2, 5, 7, 8 and 9). Major irregularities along the shoreline occur at the north end of the bay where the cliffed plateau land along Orote Peninsula is slightly undulatory, at Rizal Beach where a broad point of limestone projects seaward, and at Apaca and Gaan Points (Figs. 2, 6 and 8). Four rocky limestone islands rest on the outer edge of the reef-flat platform at various locations. The two largest of these are Neye Island (Figs. 2 and 58) situated at the north end of the bay and Alutom Island (Fig. 7) at the south end of the bay. A small pair called the Pelagi Islets (Figs. 6 and 10) are more centrally located opposite Apaca Point. Two others, Bangi and Yona Islands, are situated on the inner part of the reef-flat platform near the mouths of the Gaan and Auau Rivers (Fig.7). Several minor supratidal structures have been built on the reef flat at a sewer outfall line at Gaan Point (Figs. 4 and 9).

Much of the reef flat is exposed during low tide, depending on the magnitude of the low tide range, wind direction, and height of the surf at the reef margin which tends to pile water upon the reef flat platform. In general the outer seaward part of the reef flat is slightly elevated in respect to the inner shoreward part and at places retains a shallow moat of water. Along Agat Bay the inner reef flat (Facies A) is poorly developed and irregular in distribution, depending upon slight differences in elevation and topography and during low spring tides much of its surface is also exposed, like the outer reef flat (Facies B). The outer reef flat is bisected slightly where reentry channels (Facies D) south of the Pelagi Islets and opposite Gaan Point are located (Figs. 4,6 and 9). Here the outer reef flat is deeper than the inner part and the bottom gradually shoals toward the shore. During high tide the water depth on the reef-flat platform ranges from 0.5 to 1.5 meters, depending upon local topography and how well the inner reef flat depression or moat is developed.

Waves at the reef margin surf zone are transformed into translatory waves on outer reef-flat platform (Fig. 8). The water motion in these waves is mostly in a horizontal direction normal to the reef edge and oscillatory but generally with a shoreward movement. Upon reaching the inner reef-flat platform this shoreward moving water mass is deflected into currents which parallel the shoreline until reentry channels or other depressed reef margin zones are encountered where they then turn seaward and the water returns to the ocean. Sometimes noticeable rip currents are observed at these depressed zones and reentry channels as shown in Figures 6 and 8. The reef flat current direction and speed is dependent upon the volume transport of water over the reef-flat platform, reef flat topography, and location of reentry channels or depressed reef margin zones. Aerial photographs clearly show the patterns of sediment movement which correlate very well with observed current patterns.

Based upon composition, two reef-flat-sediment environments are found at Agat Bay. The first and smaller of these is the reef-flat platform along the northern part of the bay, between Neye Island and Rizal Beach, which lacks surface drainage from the bordering land. These reef flat sediments are light colored and mostly (90%) composed of calcareous organic remains (bioclastic sediments) of reef origin. A more extensive second environment consists of the reef-flat platform south of Rizal Beach which receives considerable surface drainage from the bordering land. These reef flat sediments are darker in color and composed of a mixture of bioclastic sediments of reef origin and nonbioclastic detrital sediments of volcanic origin. In the northern part of the bay, the mainly bioclastic sediments consist of mollusc shells, fine sand and silt, foraminiferan tests, Halimeda debris, coral, and red algal fragments. The southern reef-flat platform sediments consist of, in addition to the same above bioclastic materials, a volcanic detrital fraction which ranges up to nearly 50 per cent of the sediment composition. The composition of the detrital fraction consists of small rounded volcanic boulders, coarse sand and gravel, mud, silt, and some limestone material derived from calcareous fragments incorporated into the basal part of the bordering alluvial lowland. The detrital fraction is quite variable in distribution depending upon the nearness of the reef flat location to river and stream mouths which are the sources of these sediments and to the distance from the shoreline. In general the outer reef-flat platform contains a greater fraction of bioclastic material because the net current movement there is toward the shore. Exceptions to this distribution pattern are found where reentry channels cut through the platform, and reef flat currents are predominately toward the sea. It is through these channels where most of the reef flat sediments are moved seaward to the forereef seaward slope and submarine terrace environments (see Appendix II for special section on sediments).

At most places the outer reef flat is composed of relatively flat barren reef rock, except where scattered small holes, cracks, and depressions (Facies C) trap and hold a thin veneer of poorly sorted sediments ranging from fine sand to boulder rubble. The outer reef flat is generally swept clean of most unconsolidated material by waves except for scattered boulder rubble and larger blocks of reef rock which have been eroded from the reef margin and transported shoreward onto the reef platform by storm and typhoon waves (Fig. 10). Except for the above larger boulders and reef blocks, most of the boulder rubble is transported farther shoreward onto the middle and inner parts of the reef-flat platform or in some instances all the way to the shoreline where it forms part of the beach material.

Much of the reef-rock platform is covered by a growth of benthic algae, forming a low mat-like turf several centimeters or more thick. This mat traps and holds a small amount of fine sediments. Locally numerous larger foraminiferans are found intertwined among the algal filaments of the turf. The empty tests of these foraminiferans are worked shoreward by translatory waves and contribute a small fraction to the reef-flat platform sediments and beach deposits.

The inner reef-flat platform generally contains more sediment, although in most places it only forms a thin veneer, mostly less than 30 cm thick, and local patches of bare reef rock are not uncommon. In general, regions where wider fringing reef platforms occur there is a greater abundance of unconsolidated material. Locally the root systems of the sea grass, Enhalus acoroides, tends to trap and retain sediments a few centimeters above the general reef flat elevation.

Biotope II - Fringing Reef Margin and Associated Facies A-D

This biotope consists of the shallow seaward margin of the fringing reef-flat platform which is completely submerged at high tide and awash during low tides (Figs. 4 and 5). It is located in a zone of strong surging currents and agitated water, coinciding more or less with the region of breaking waves and surf (Fig. 9). Except for brief periods when low spring tides coincide with periods of calm this area is constantly washed by waves and is not subject to desiccation as are parts of the reef-flat platform. Surge channel and buttresses are moderately well developed along parts of the reef margin but are absent or poorly developed along much of the bay. Algal ridge development is also lacking along much of the reef margin, which is not surprising, since Agat Bay is situated on a lee coast and not exposed to steady vigorous wave attack or refracted swell. The algal ridge consists of a low convex elevation, generally less than 30 cm high, where growth of calcareous red algae and certain corals are enhanced by wave action on the upper buttress surfaces.

Reef margin surge channels and associated buttresses are best developed at the northern end of Agat Bay between Neye Island and the middle part of Dadi Beach. Where developed, shallow surge channels up to 3 meters in depth, 0.5 to 1.5 meters wide, and 5 to 10 meters long bisect the reef margin platform. Irregular buttresses consisting of various sized bosses, knobs, and ridges form low rounded to flat-topped lobate structures between the surge channels, giving the margin an irregular appearance along this stretch of shoreline (Fig. 8). The upper surfaces of the buttresses support a rich to moderate growth of encrusting and modular forms of calcareous algae and some scattered corals. The surge channel floors are relatively flat and smooth and contain some rounded boulders and coarse sand and gravel. The greater width of the floor and lower walls of these channels in relation to that of the upper margin is evidence that erosion is occurring there while accretion appears to be restricted more or less to the upper walls and margin. Locally horizontal shelves protrude outward over the upper surge channel walls and at places are partly to completely roofed over forming cavernous channels below. A honey-combed network of small interconnecting holes a few centimeters in diameter sometimes connect these cavernous parts with the upper reef margin surface. Some surge channels are enlarged into open pools and holes at their shoreward end and contain a more diverse assemblage of corals than the upper buttress surfaces or surge channel walls and floors.

Between the middle part of Dadi Beach and the reentry channel south of the Pelagi Islets, surge channel and buttress features are poorly developed (Figs. 10 and 11). Here the reef margin consists of a gentle seaward-dipping surface with irregular low knobs, ridges, holes, and troughs developed on the surface. The relief of these features is generally less than 40 cm, although occasional holes and channels 1 to 2 meters deep and wide are encountered. The remainder of the reef margin to Alutom Island has a moderately well-developed surge channel and buttress system except for a short area opposite of Salinas Beach near Agat Village where these features are poorly developed.

Vigorous wave action keeps the reef margin relatively free of sediments, except for the floors of surge channels, pools, and holes which contain a poorly sorted mixture of boulders and sand and gravel-sized sediments. During storms and typhoons increased wave action creates considerable movement of these loose sediments, causing abrasion along the floors and lower walls of these features which prevent coral settlement or erode away those which happen to have settled during normal reduced wave activity.

Biotope III - Fringing Reef Front and Associated Facies A-E

The reef front consists of the steeply dipping seaward edge of the fringing reef platform which is always covered with water (Figs. 4 and 5). Structurally it is principally a seaward extension of the reef margin surge channel and buttress system which is here called a submarine channel and buttress system. In general the degree of physiographic relief and development of the reef front channel and buttress system follows somewhat the same degree of such development exhibited by the contiguous surge channel and buttress system in the reef margin.

The submarine channels generally widen and the floor deepens from the outer reef margin to the seaward margin of the reef front. The lobate or flat-topped submarine buttresses form long ridge-like structures which have their greatest relief where they join the contiguous structures in the reef margin. In a seaward direction the relief of the buttresses gradually diminishes, sometimes very gently and sometimes more steeply. Generally, the downward slope is less pronounced along their inner part and more steep at their terminus where they sometimes continue rather ill-defined as shallow irregular troughs and ridges across the adjacent submarine terrace or seaward slope. Some channels are 4 to 6 meters wide at their outer ends while others may be only slightly wider than at their inner ends. Some widen into large flat-floored holes up to 50 or more meters across. Southwest of the Pelagi Islets one such hole is about 15 meters deep and a 100 meters across at its widest point.

The seaward boundary of the reef front is limited to the depth at which the submarine channels can be maintained, a factor more or less controlled by the depth to which storm and typhoon waves can abrade the lower channel walls and floors. Here along Agat Bay the outer depth of the reef front varies from 5 to 10 meters.

The width of the reef front is quite variable and depends for the most part on the degree of downward dip of the forereef slope. When the dip is considerable the reef front is rather narrow, possibly only 20 to 30 meters wide, and where the dip is more gentle it may be up to 100 or more meters wide.

In the reef front the downward dip of the submarine channel floors are much less than that of the surge channels in the reef margin and, consequently, contain more boulders and other various-sized sediments. The channels may be V- or U-shaped or wider at the bottom than at the upper margin, depending upon the amount of erosion along the lower walls and floors and the amount of growth along the upper walls and margins. Generally there is less outward shelving along the upper margin of the channels than along those of the reef margin, but locally the lower walls may be undercut up to a meter or more forming an overhanging region with much reduced light intensity.

Along the entire bay the reef front is bordered on the seaward side by submarine terraces of various widths and substrates (Figs. 4 and 5). At some locations these terraces are composed of consolidated reef rock, whereas at other places they consist of unconsolidated substrates.

A rather conspicuous feature of the outer reef front along Agat Bay is the presence of many knobs, knolls, and pinnacles which rise up from the general level of the reef front slope (Figs. 12 and 13). Some of these reach within a meter or two of the low tide level. Most prominent of these relief features are several reef patches (knolls or knobs which reach the upper surface at low tide) located on the outer reef front at the north end of Dadi Beach (Figs. 4 and 5). The largest of these reef patches is about 20 meters in diameter, the upper surface of which is awash during low spring tides. Aside from the relief imposed upon the reef front slope by the submarine channels, the upper surface of the buttresses are also very irregular because of the presence of many knobs, knolls, and ridges. Toward the reef margin boundary these relief features grade into flat-topped bosses which are awash during low tide (Fig. 14).

From the eastern end of Neye Island to the north end of Dadi Beach, a prominent channel and buttress system is developed along the reef front. The reef front is very irregular in width along this section, ranging from 10 to 20 meters immediately east of Neye Island to about 100 meters or more at the north end of Dadi Beach.

From the middle part of Dadi Beach to the Pelagi Islets the reef front channel and buttress system is poorly developed and irregular in width; about 50 to 120 meters wide. The outer buttress ridges are irregularly separated by lobate tongues of sand from the adjacent submarine terrace.

From the Pelagi Islets to the south end of Agat Bay the reef front is also very irregular in width. At places long ridges extend out over the adjacent sandy terraces and at other places the sandy terrace has made reentry zones into the reef front, particularly at the broad indentation of the reef margin at Salinas Beach and south of Gaan Point. The depth of these reentry zones range from 6 to 10 meters. At other places the reef front grades out onto consolidated reef rock terraces, but even here the width is irregular and appears to be influenced much by the topography of the surface. Development of the reef front submarine channel and buttress system is moderate to prominent at some places along this section while at other places it is poor. In general the development is less pronounced at the sandy reentry zones described above. Another poorly developed area is found at the reef margin indentation located immediately south of the Pelagi Islets, where several sandy-floored reentry channels and a large sand-floored hole about 15 meters deep borders the region.

Biotope IV - Upper Seaward Slope and Associated Facies A-D

This biotope includes the deeper reef areas located seaward of the reef front which were investigated to about 30 or more meters depth at places. Submarine terraces of various widths and substrates border the reef front along the entire length of Agat Bay (Figs. 4 and 5). Along the northern part of the bay, between Neye Island

and the middle part of Dadi Beach, the terrace is composed of reef rock and slopes downward rather gently to about 15 to 20 meters depth where the degree of slope abruptly increases at the seaward slope. Coral growth is scattered and irregular in development with small knobs, pinnacles and mound scattered over the surface (Fig. 15).

Along the southern part of Dadi Beach and Rizal Beach a broad submarine terrace composed mostly of unconsolidated substrates slopes gently seaward from the reef front. The break between the terrace and the seaward slope is less pronounced along this stretch than along those to the north or south. Near the reef front the terrace substrate is composed mostly of coarse sand-sized sediments intermixed with coral rubble. The only coral development in this area was restricted to many low mounds and knobs which protrude upward through the sandy terrace floor a meter or so high. Many of these mounds of hard substrate possessed Pocillopora, Goniastrea, Porites, and Favia species, although many are rather barren of living coral growth or only have a few small colonies scattered over their surface. Occasional low mounds or outcrops of reef rock were encountered where the sand substrate grades into rocky terraces to the north and south.

A broad rocky terrace borders the reef front between Apaca Point and the reentry channel south of the Pelagi Islets (Figs. 4 and 5). This terrace slopes very gently seaward to about 10 to 15 meters depth near the outer part, where the slope then increases slightly for a short distance to about 20 meters depth, at which point it breaks rather sharply downward at the steep seaward slope. Overall, the terrace relief is rather flat, but several large mounds rise up from the floor to within 5 meters of the surface and several large holes as deep as 15 meters are found along the inner part near the reentry channel south of the Pelagi Islets (the reef front borders the shoreward side of the larger hole). Aside from these major relief features the terrace topography is undulatory with 1 to 2 meters relief, studded randomly with pinnacles and mounds up to 3 meters high (Fig. 16).

From the above terrace south to Alutom Island the rocky submarine terrace gradually narrows but is irregularly cut at places by pockets of unconsolidated substrate. Sandy zones are particularly well developed along stretches opposite of Salinas Beach and south of Gaan Point. Here the water was very murky and turbid compared to other parts of the bay. In a seaward direction these sand-floored terraces generally grade into reef rock substrates near their outer margin where the degree of downward slope abruptly increases at the seaward slope. At other places, long lobate intrustions of the reef front grade into flattened ridges somewhat shallower than the adjacent sand-floored regions. In general the sand-floored zones were ripple marked in shallow areas with deeper pockets of finer material of a more silty plastic nature. Worm mounds were conspicuous where fine plastic sediments prevailed. Relief along this part of Agat

Bay is quite irregular. Knobs, mounds, and pinnacles of coral reef rock commonly rise up from the general level of both the sandy-floored and rocky terraces (Fig. 16). Along the outer part of the terraces the surface has less topographic relief but is quite undulatory with low ridges and shallow channels which grade into steep seaward slope margin. Many of these shallow channels appear to be the main route by which sediments are transported seaward from the sandy pockets described above to the deeper seaward slope region.

The seaward slope consists of an abrupt increase in the degree of downward slope at the outer edge of the more gentle dipping adjacent submarine terraces (Figs. 4 and 5). The steep slopes were investigated directly by SCUBA diving to 30 or more meters at scattered locations along the bay. Towing sled observations though, showed that a steep slope was present along all but the region opposite southern Dadi and Rizaï Beaches, where a broad and mostly unconsolidated terrace is bordered by a less pronounced sharp break in the degree of slope at its outer boundary with the seaward slope. At the proposed mooring location (Site A) the seaward slopes were investigated more thoroughly to depths of 50 meters. Here the slope is locally very steep (45° to 75°), and from the depth of 50 meters it could be seen to continue downward to at least 70 or more meters. In general where hard reef-rock surfaces prevail, a diverse coral community was observed on the seaward slope surfaces. A few prominent knobs and mounds were observed at places on the slope. These topographic relief features were particularly noticeable on the upper seaward slope, but they may be present on deeper slopes as well.

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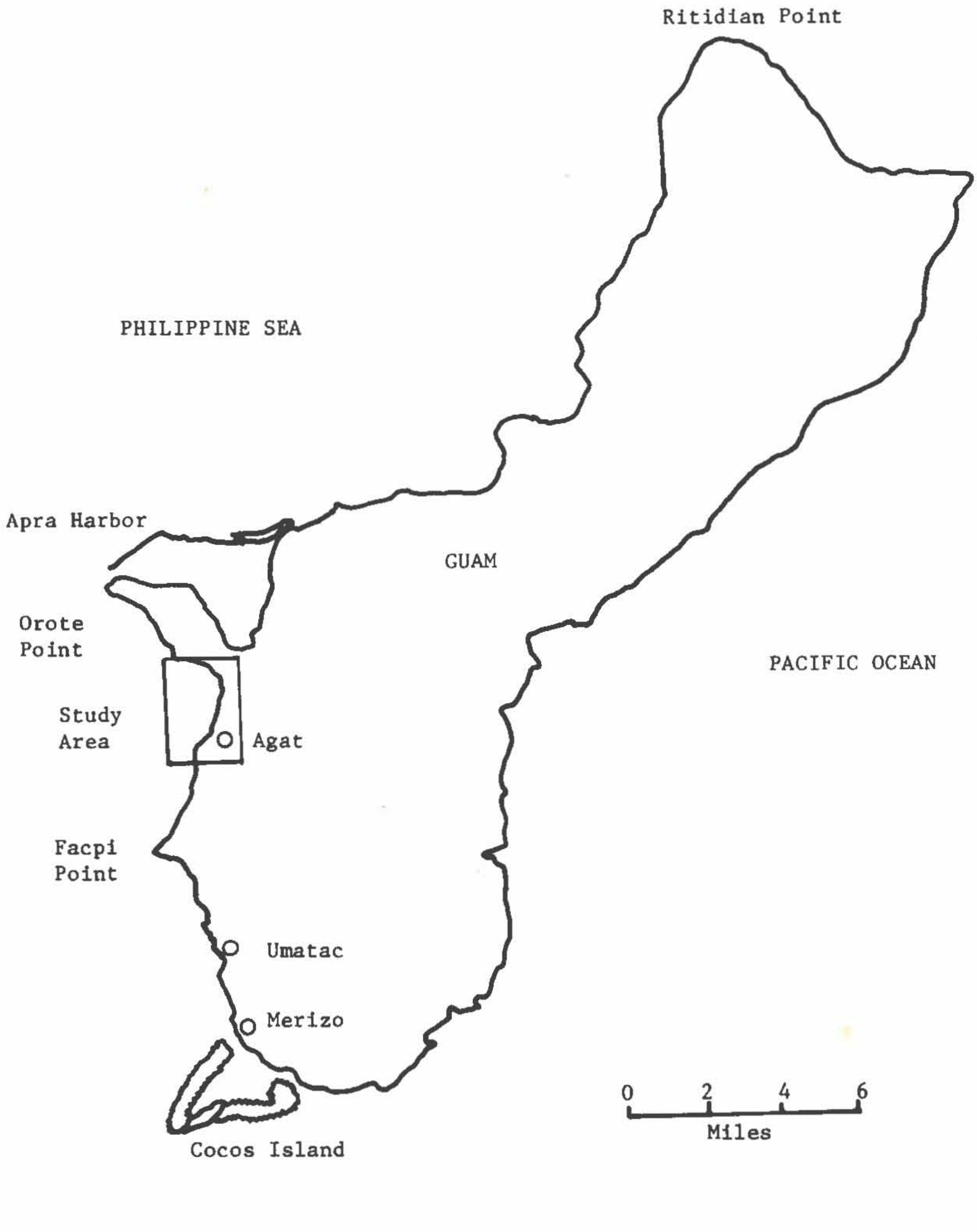

Fig. 1. Map of Guam showing the location of the Agat Bay study area.

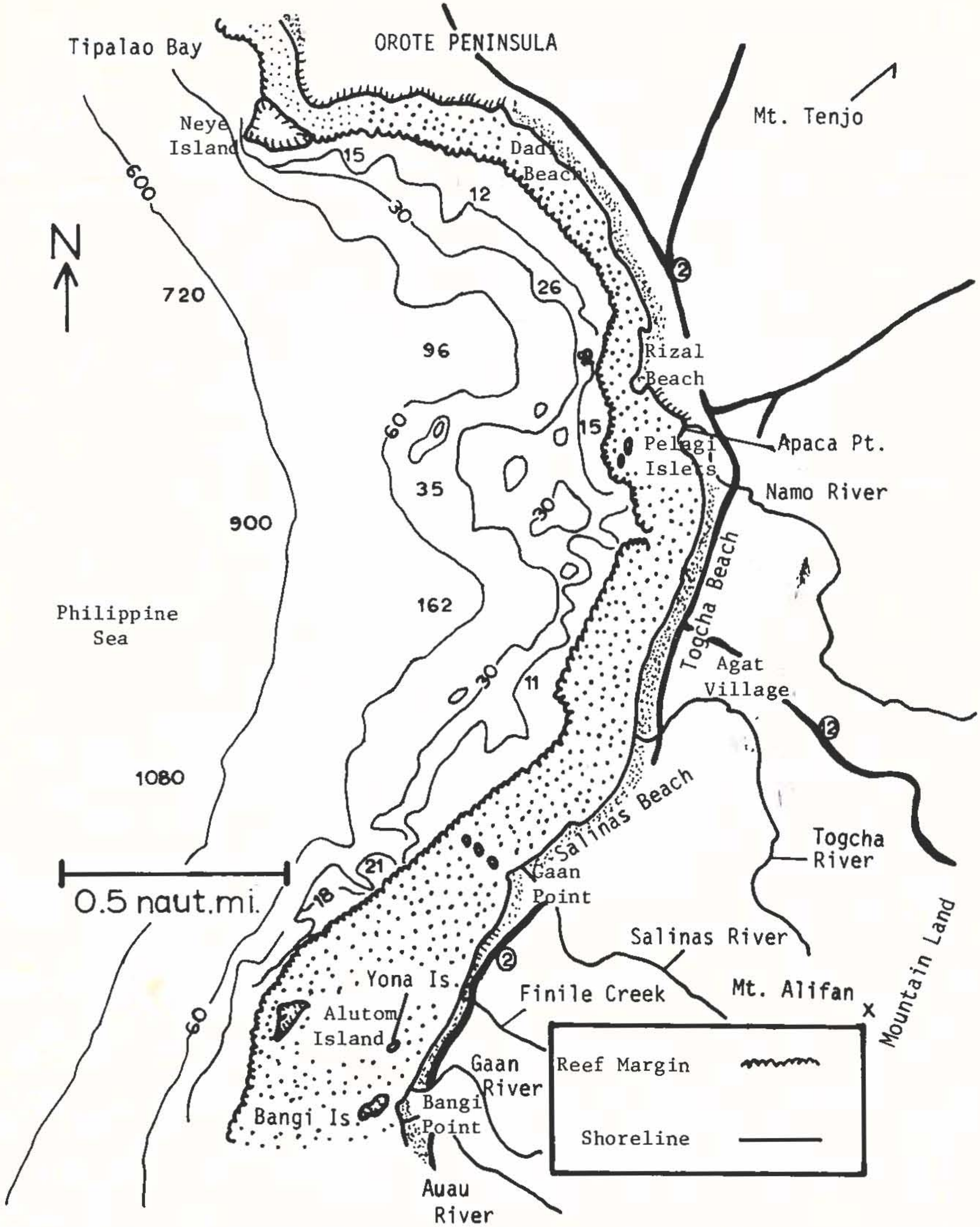

Fig. 2. General location map for the Agat Bay study area. Submarine contour depths are given in meters and the reef flat platform is stippled.

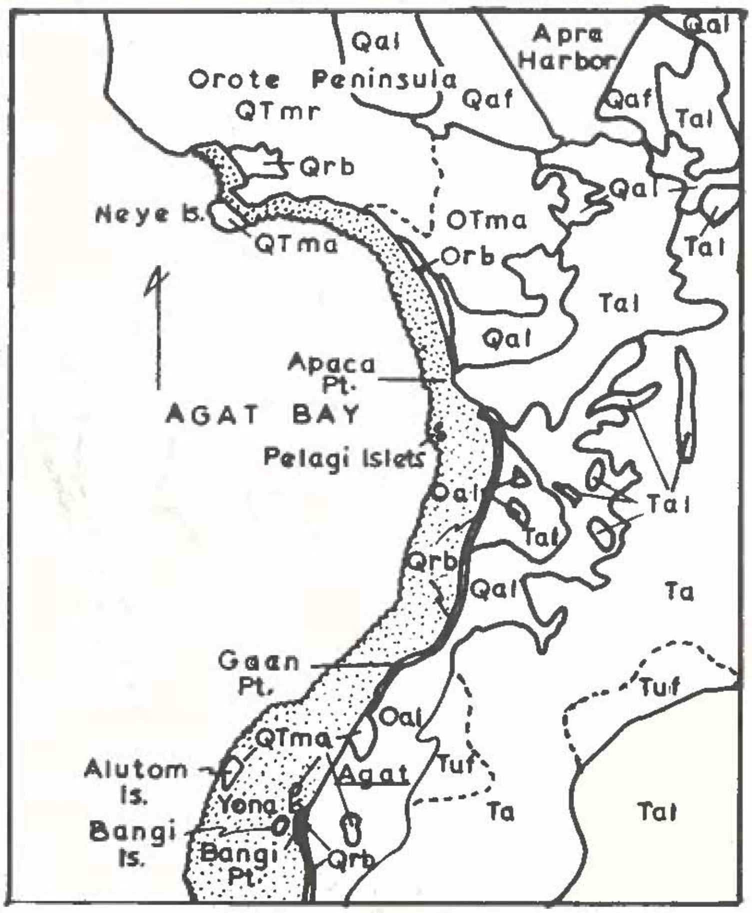

Fig. 3. Geologic map of the Agat Bay area showing the distribution of the various rock units described in the text. Reef-flat platform is stippled. (Map modified from Tracey <u>et al</u>., 1964).

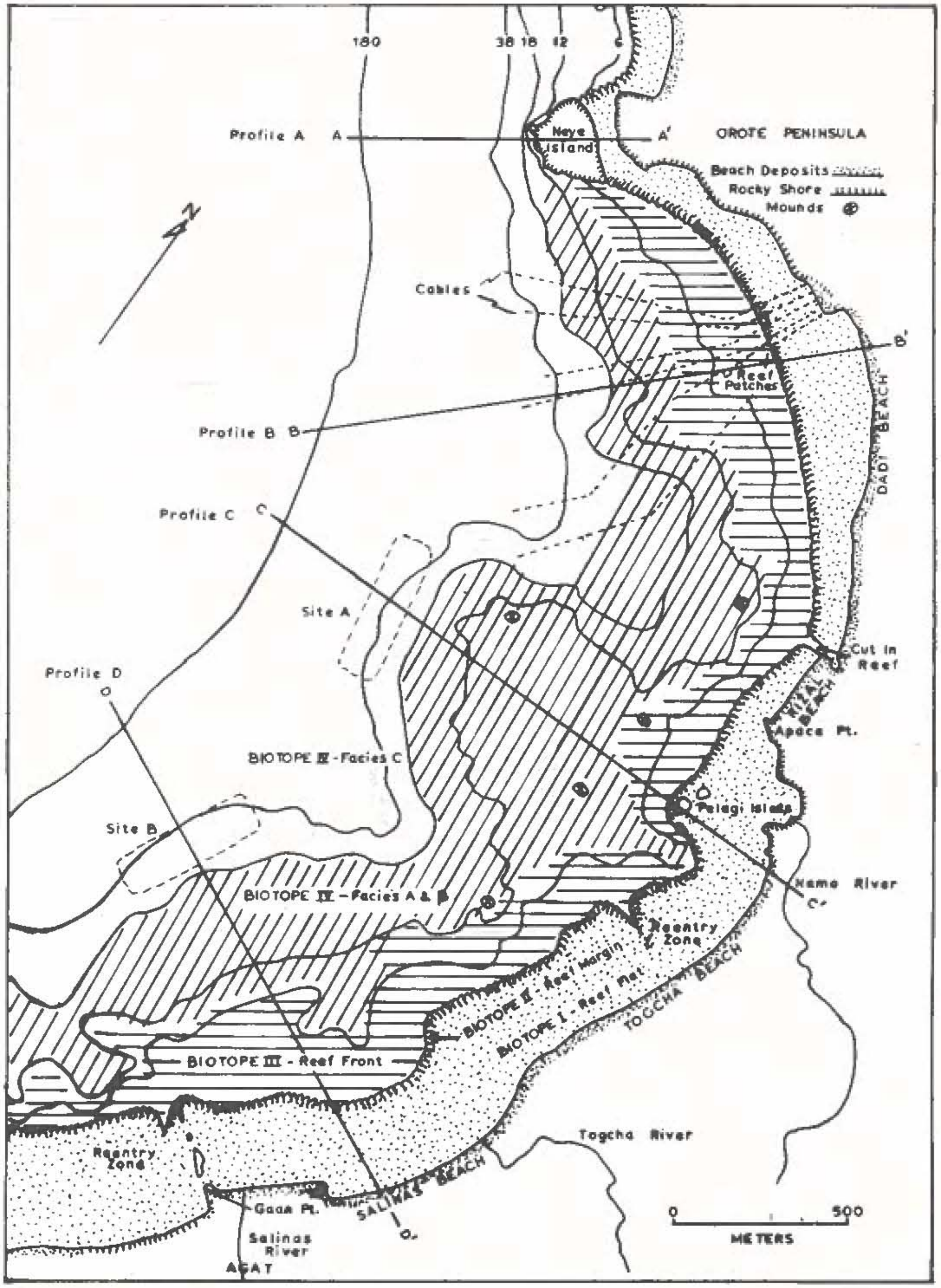

Fig. 4. Map showing the distribution of biotopes at Agat Bay. Submarine contours are given in meters and Profiles A-D are shown in vertical section in Fig. 5.

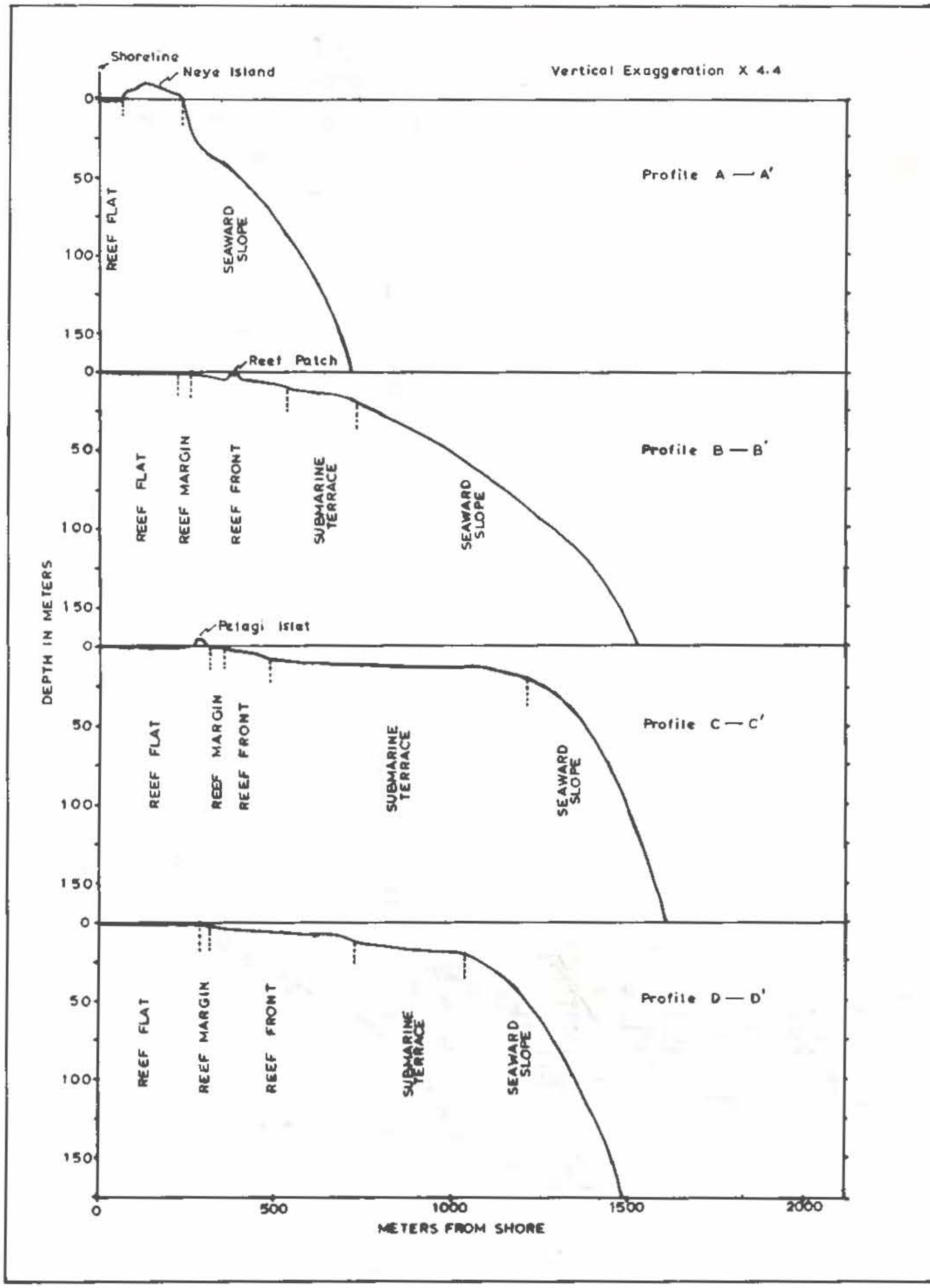

Fig. 5. Vertical profiles of the fringing reef and offshore slopes at Agat Bay. (For location of the profiles see Fig. 4.)

Fig. 6. Aerial view of Agat Bay, looking south from Rizal Beach. Agat village and highway Route 2 occupy the low coastal plain at the left and Bangi Point on the background. The Pelagi Islets are shown in the foreground on the outer reef flat opposite a small embayment along the shoreline at the Namo River mouth. Two rip-current zones at the reef margin are visible south of the Pelagi Islets.

Fig. 7. Aerial view of the wide reef-flat platform at the southern end of Agat Bay, showing Alutom Island at the seaward edge of the reef-flat platform and Yona and Bangi Islands near the shoreline. Agat village occupies the low coastal plain at the upper left and the broad reef margin indentation south of Gaan Point is visible at the left.

Fig. 8. Aerial view of Rizal Beach (background) and southern Dadi Beach (foreground). An old pier structure projects out onto the reef-flat platform in the left foreground. Facilities of the Naval Station on Orote Peninsula are visible at the left. The reef margin buttress and surge channel system is exposed at two places in the foreground (dark areas) as large wave troughs approach the seaward edge of the reef platform. A pronounced rip current is noticeable opposite the reef flat structures.

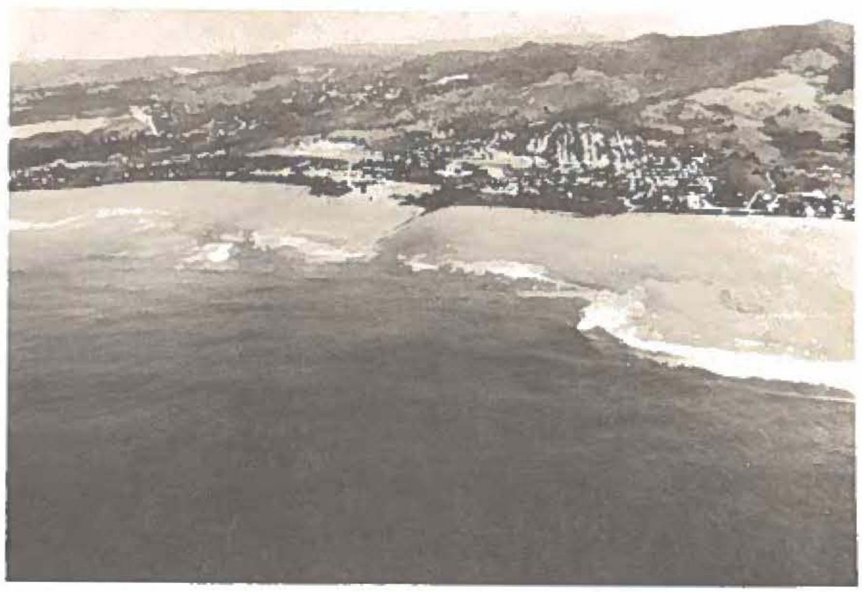

Fig. 9. Aerial view of Agat Bay from Salinas Beach on the left to the wide reef-flat platform south of Agat village. The irregularity of the outer reef platform edge is visible as well as some supratidal reef structures along an old sewer line and a reentry zone at the reef margin. Swells are causing a pronounced surf zone at the reef margin.

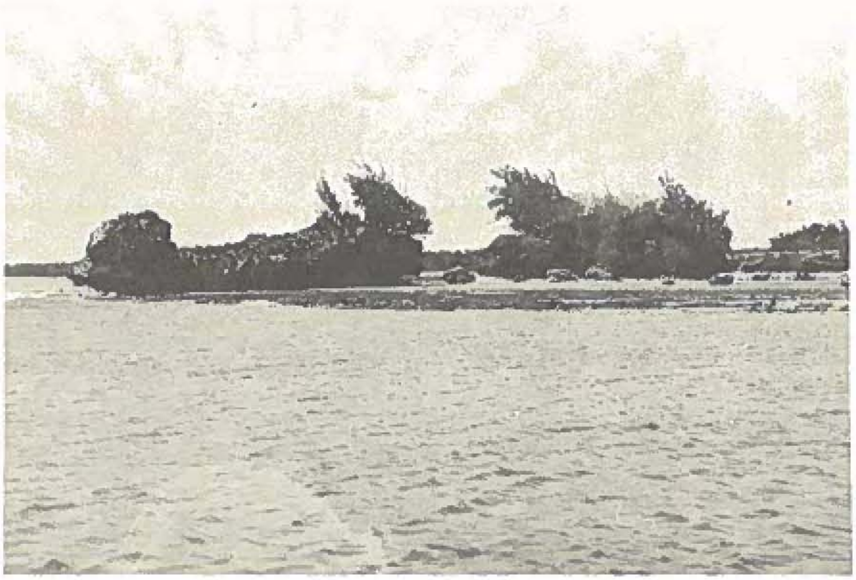

Fig. 10. Sea-level view of the Pelagi Islets and exposed outer reef-flat platform. Note the flat pavement-like nature of the platform and scattered reef blocks resting on its surface near the islets. The inner part of the reef margin is also visible (Biotope II, Facies A).

Fig. 11. Sea-level view of the outer reef-flat platform (Biotope I, Facies B) opposite Togcha Beach and the wave washed upper reef margin surface (Biotope II, Facies A).

Fig. 12. Small pinnacle about two meters high located on the outer reef front (Biotope III, Facies E). Millepora platyphylla growth forms most of the pinnacle. The depth is about 10 meters.

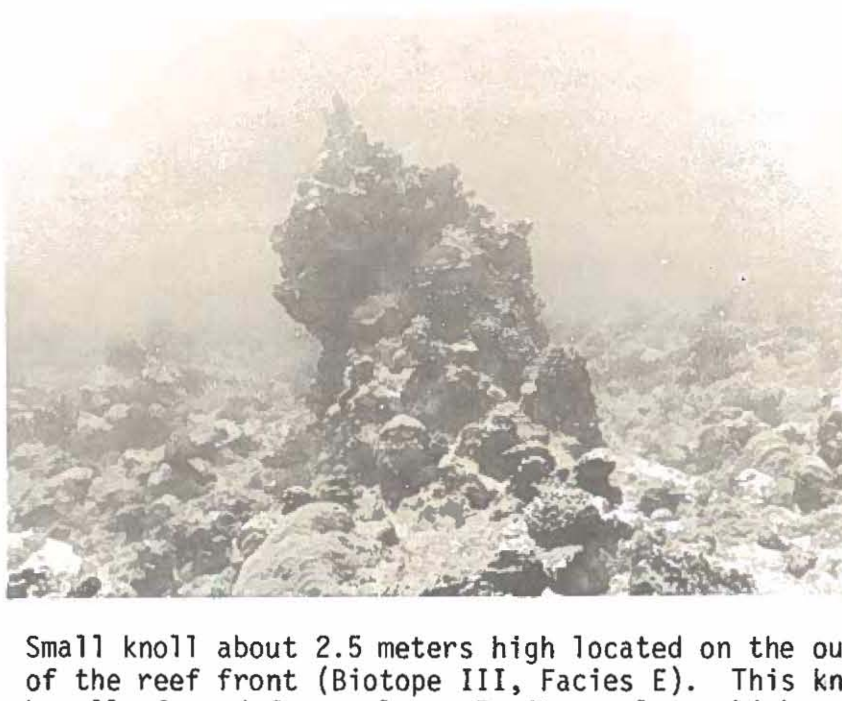

Fig. 13. Small knoll about 2.5 meters high located on the outer edge of the reef front (Biotope III, Facies E). This knob is basally formed from a large Porites colony which now supports a mixed community of corals. The depth is about 8 meters.

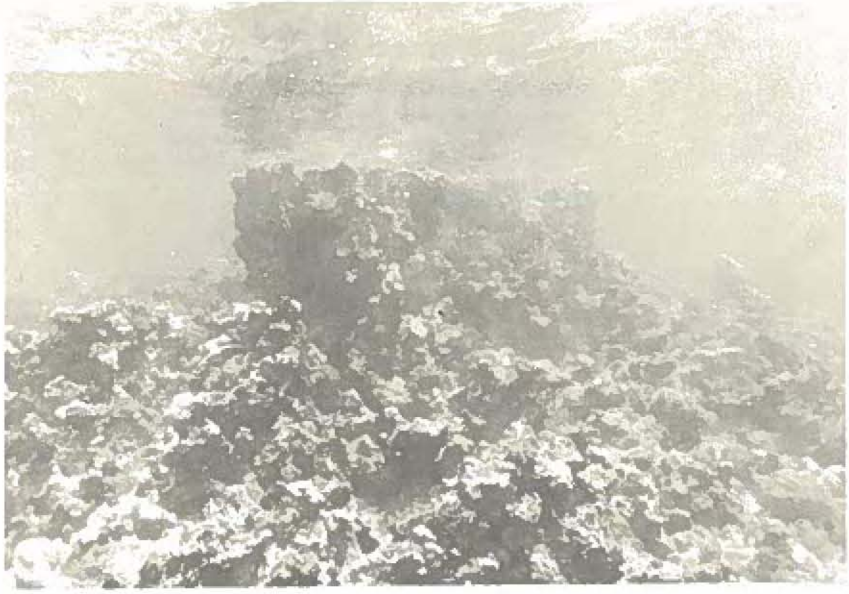

Fig. 14. Flat-topped boss arising from the upper surface of a buttress on the inner reef front (Biotope III, Facies A). The downward sloping seaward part of the buttress (foreground) supports a variety of corals giving it a rough irregular surface. The depth is about one meter at the base of the boss and about three meters in the foreground.

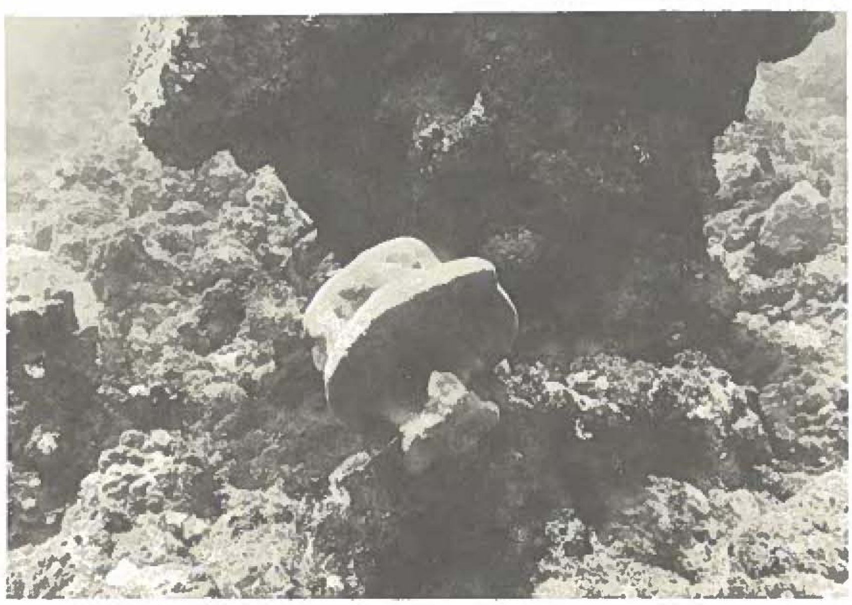

Fig. 15. Cuneate Pavona clavus colony growing at the base of a mushroom-shaped knob on the submarine terrace at the northern end of Agat Bay (Biotope IV, Facies A). The depth is about 15 meters.

Fig. 16. Large dead Pocillopora colony growing on a low convex-shaped mound on the submarine terrace (Biotope IV, Facies D) near the proposed mooring at Site A. Mixed living and dead coral growth gives the mound and adjacent terrace surface an irregular relief. The depth is about 12 meters.

STATION DESCRIPTIONS

Richard Dickinson and L. G. Eldredge

The study area was sampled at twenty-nine stations (Fig. 17), and descriptions of each station follow. The stations were used as reference points for field sampling. The location of each was chosen primarily because of some unique feature of a particular area, allowing more intense study of it. These descriptions do not include every species found at each station. The organisms and geologic features noted indicate only the most prominent aspects of that station and taken together provide a broad survey of Agat Bay. The various species are described in detail in their respective sections. Each group of organisms contains the names of all the species studied.

Station 1

This station was the northermost sampling area and was located on the submarine terrace south of Neye Island. This terrace was covered with coral rubble and scattered algal growth composed mostly of Padina jonesii.

The reef terrace had numerous patch reefs and pinnacles, especially closer to the reef margin. There were many long buttresses extending outward along the terrace from the reef front. Isolated ridges were also common. These buttresses and ridges were covered with consolidated dead coral and loose rubble, but there were many small living corals attached to this substrate.

Organisms noted here included the gastropods Drupa ricinus, Drupella cornus, Vasum turbinellus, Conus miles, Lambis truncata, and Strombus urceus. The starfish Linckia multifora and Acanthaster planci, the urchins Heterocentrotus mammillatus, Echinometra mathaei, and Echinostrephus aciculatus, and the holothurian Thelenota ananas were also observed.

Station 2

Station 2 covers the shoreline north of Dadi Beach to Neye Island. The beach is narrow, 5-10 m wide, with limestone cliffs rising steeply behind it. In places the cliffs rise from the water's edge and, in the nips formed there, large individuals of Nerita plicata were noted. Another high intertidal gastropod, Nerita albicilla, was very common with 3-4 individuals on a single small rock. Other common gastropods observed were Cerithium morus, Conus ebraeus, Cantharus fumosus, Nassarius margaritiferus, and

Strigatella literata. Also, found were the hermits crabs Calcinus latens and Coenobita sp. and the xanthid crab Eriphya sebana.

Industrial debris, apparently bulldozed over the cliffs from the Naval housing area above the beach, was also found scattered along the shoreline and on the reef flat. Additionally, many small freshwater rivulets cutting across the beach were noted, indicating seepage from the porous limestone (Figs. 18 and 19).

Station 3

This station extends from a cliffed headland southward including Dadi Beach. The headland was used as an artillery emplacement during World War II, and the cement foundation and cave still exist.

The reef flat is approximately 100-150 m wide with a well developed moat. It is covered with white sand of bioclastic origin and is distinctly different from the thick, muddy sediment characteristic of Stations 18, 19, 21, and 22.

The most common corals are Acropora spp., massive Porites spp., and the blue coral Heliopora coerulea. Common gastropods noted here included Vasum turbinellus, Morula uva, Nassarius margaritiferus, and Drupa ricinus. Also noted were the echinoderms Echinometra mathaei, Echinotrix sp., Heterocentrotus mammillatus, Linckia multifora, and L. laevigata.

Station 4

Station 4 is located offshore, approximately 1.25 km (0.75 mi) northwest of Rizal Beach and 0.4 km (0.25 mi) from the raised reef. The reef terrace has some algal cover with Padina jonesii as the most obvious. However, only small blades and no large thalli of this species were observed. There were some smaller algae in clumps, including Dictyota bartayesii, Halimeda discoides, and Lobophora variegata. Most of the substrate is composed of large, nonliving corals, but a few large species were noted--Favites sp. and Heliopora coerulea. Many broad, sandy patches, 2-5 m in diameter, were found at this station, and the entire area was covered with a fine detrital layer. The sea urchin Echinometra mathaei and the starfish Acanthaster planci and Linckia perplexus were observed. The large gastropod Cypraea tigris was also noted.

Station 5

Station 5 begins at the southern end of Dadi Beach and extends southward along the shore to a high fence which marks the border between the U. S. Naval Station and the beginning of public land. The beach is narrow, 12-15 m wide, with a gentle slope. There were numerous freshwater rivulets crossing the beach, similar to those found in Station 2. Dense floral cover begins immediately adjacent to the beach, but there were no steep cliffs. A highway borders the jungle approximately 500 m from the water line. Between the shore and highway old cement foundations and crumbling ruins of older construction were observed.

The reef flat, between 75 and 100 m wide, had the same general appearance found at Station 3. However, there was a boulder breakwater extending perpendicular to the shore. It was approximately 30-35 m long and slightly above the water line during high tides. This structure was believed to have been built to form a swimming area. Its function now is obsolete and serves only to disrupt the normal along-shore water movement. The alga *Galaxaura* sp. was very common in the moat area, and the holothurian *Stichopus chloronotus* was observed.

Station 6

Stations 6 through 8 were made close together because the proposed pipeline will run through the causeway (Station 7), and it was felt that an intense study should be made here.

Station 6 is located north and immediately adjacent to an old causeway at the north end of Rizal Beach. The entire reef flat from the causeway to Navy boundary fence (approximately 30-35 m) is exposed during low tides. It is composed of rubble with only didemnid and other encrusting ascidians and sponges on the undersides of the rubble. A profile was made, showing the contour of the reef flat (Fig. 20).

Station 7

This station includes the area between the cement walls of the old causeway on Rizal Beach. The causeway is 5 m wide and extends 70-75 m from shore toward the reef margin. The sides are approximately 1.5 m above the high water line. A depth profile was made (Figs. 21 and 22).

The substrate is mostly rubble with the alga *Padina tenuis* comprising approximately 50 per cent of the cover. Also present but scattered and sparse were *Halimeda opuntia* and *H. macroloba. Caulerpa racemosa* was also noted. Near the margin, 80 m from shore, the algae *Turbinaria ornata* and *Galaxaura fasciculata* were found. *Lobophora variegata* with epiphytic *Jania capillacea* were also observed. This station is virtually devoid of live coral.

A few small colonies of Pocillopora damicornis, Acropora sp., and a single colony of Porites lobata were found. The most common gastropods were Cerithium pfefferi, C. ravidum, Morula granulata, and Morula sp. (cf. M. fiscella). Also noted on the walls of the causeway and adjacent areas were Littorina scabra, L. coccinea, L. undulata, Nerita plicata, Strombus mutabilis, and Natica sp. The holothurians Holothuria leucospilota and H. atra were noted.

High waves from Tropical Storm Mary (August 12-13, 1974) washed large amounts of debris and rubble through this channel.

Station 8

This station comprised the reef flat along the south side of the causeway and had a development similar to Station 6 but was not completely exposed at low tides (Fig. 23). The alga Padina tenuis was common, although not as abundant as at Station 7.

Some of the organisms noted include the holothurians Holothuria atra and Actinopyga echinites and a hermit crab Dardanus megistos. The only live coral were some small colonies of Porites lobata. The gastropods Trochus niloticus, Drupa grossularia, Cymatium pileare, and Morula uva were observed (Figs. 24 and 25).

Station 9

Station 9 comprises the reef flat along Rizal Beach. There were large deposits of rubble, mostly fragments of Porites spp. and Acropora spp. A gridded quadrat was used to quantify the cover on the reef flat. More than 60 per cent of the total cover on this part of the reef flat was rubble. These fragments have been broken from large colonies growing in the deeper water on the reef front and then washed up and onto the reef flat during periods of heavy wave action. A search of the area revealed no living coral on the outer reef flat, and only two small specimens of Acropora were found on the margin (Figs. 26 and 27).

Padina tenuis was the only prominent alga of this station but with an occasional Halimeda opuntia. Also, the sponge Cinachyra australiensis was found scattered across the reef flat. The only other invertebrates were isolated individuals of Holothuria atra and a few molluscs including: Morula uva, Cerithium nodulosum, Cymatium pileare, Chicoreus brunneus, Trochus niloticus, Conus chaldeus, Drupa morum, Vasum turbinellus, and Tridacna maxima. The urchin Echinometra mathaei was also noted (see Fig. 28).

Station 10

This station was located on the reef front at Rizal Beach and at a depth between 1 and 4 m. A search of this area revealed large amounts of rubble but also many massive living colonies of Porites spp. and Acropora spp. (Fig. 29).

The alga Galaxaura oblongata was very common, forming large (0.4 m diameter) bushy patches on the rubble substrate. The algae Actinotrichia fragilis was abundant, and Padina tenuis, Halimeda discoidea, Udotea argentia, and Symploca hydnoides (=Schizothrix mexicana) were noted. The parthenopid crab Daldorfia horrida and the molluscs Tridacna maxima, Drupa ricinus, D. rubisidaeus, Vasum ceramicum, Drupella cornus, Coralliophyllia violacea, and Conus miles were observed. Echinoderms included Echinometra mathaei, Echinothrix calamaris, and Eucidaris metularia.

The most striking feature at this station was the large broken coral heads scattered through the surge channels and along the reef terrace. Some of these were recent damage, but many were old and were covered with encrusting organisms and small colonies of corals. It is believed that this site experiences periodic strong wave action. The largest coral colonies are constantly being fractured, and either washed up into the surge channels and onto the reef flat or remain in broken piles along the reef front and terrace.

Station 11

This station includes the reef flat and shore between a high bluff at the southern end of Rizal Beach and the mouth of the Namo River.

A well developed nip has formed at the base of the bluff. Many limpets, Patella spp. and the gastropods Morula granulata, Morula sp., Siphonaria guamensis, Cerithium morus, Strigatella sp. (cf. S. litterata), and Conus sp. were noted there (Fig. 30).

Toward the mouth of the Namo River, the shoreline was rocky with scattered boulders along the high water line. The beach was narrow, 1-3 m wide, and composed of dark brown sands. The beach sands from there and south to Bangi Point are of a different origin than those to the north. For a complete analysis and description of this refer to the physiographic section of this report. Few organisms were found along this stretch and among them were the xanthid crab Eriphya sebana and molluscs Nerita plicata, N. polita, Cerithium morus, Quidnipagus palatam, Cantharus fumosus, and Latirus sp.

The Namo River carries a heavy sediment load during the rainy season and the entire reef flat is covered with a layer of thick mud approximately 10-15 cm thick. Beneath the top layer the muck grades into a mixture of coarser sediments and a dense accumulation of mollusc fragments including the bivalves Arcopagia scobinata and Quidnipagus palatam and the gastropods Strombus sp. and Natica sp. The only living gastropod found during a thirty-minute search was Strombus mutabilis (Fig. 31).

There was virtually no macroalgal cover on the reef flat, although small, isolated clumps of Enhalus acoroides were noted.

Schools of Kuhia sp. and Gambusia sp. and many Periophthalmus koelreuteri were seen along the river near the mouth. There was much litter and debris scattered along the adjacent beach, probably washed down the river during heavy rains and flooding.

Station 12

Station 12 is located on the first submarine terrace at a depth of 15-20 m and approximately 0.28 km (.17 mi) east of the raised reef near Rizal Beach. A thin layer of fine sediments covered the entire substrate. Pinnacles, 1-3 m in height, were sparsely scattered over the terrace and coral rubble covers the substrate. The alga Padina jonesii was common. The prevalent rubble cover and large blocks of corals found tipped over or broken off is believed to indicate the great wave action this area has experienced. Large swells approaching the shore rise abruptly as they reach this terrace creating pressures and surge great enough to fracture and break up reef structures which rise above the terrace floor. This area was also heavily damaged by Acanthaster planci as were most of the corals from Pelagi Islets to Neye Is. [Tsuda, 1971, Mar. Lab. Tech. Rep. No. 2].

Stations 13 and 14

These two stations were located at the permanent mooring site used for the current studies, approximately 1.2 km (0.5 mi) east of the Pelagi Islets at a depth of 20-25 m (65-82 ft).

The terrace was rubble with occasional small sand patches and numerous small living coral colonies. The algae included scattered Halimeda sp. and Padina jonesii. Echinoderms observed were Holothuria edulis, Echinostrephis aciculatus, and Macrophiothrix longipeda.

Stations 15 and 16

Station 15 was located approximately 0.71 km (0.4 mi) east of the Pelagi Islets at a depth of 10-15 m (32-50 ft) and on the first submarine terrace. Station 16 was located closer to the raised reef about 0.2 km (0.1 mi) east of Station 15 and also on the first submarine terrace. The depth at Station 16 was 9-10 m (28-32 ft).

Both stations were similar. The substrate was covered with loose coral rubble much like that noted for Station 12 but more than at Stations 13 and 14. The rubble cover was thicker at Station 16 and is more evidence that corals in shallower water have experienced greater wave pressures and when broken off are slowly worked down the sloping reef terrace. The substratum was also covered with a fine layer of silt.

There was a dense growth of Padina jonesii scattered over the terrace. Additionally, algal clumps composed of many species were common. The algae in the clumps included: Halimeda discoidea, H. incrassata, Amphiroa fragilissima, Microcoleus lingbyacesus with epiphytes Chondria ripens and Jania capillacea, Dictyota bartayresii, Botryocladia scotsbergi, Zonaria sp., and Gelidiopsis sp. These clumps are scattered over the entire substrate in addition to small coral colonies especially Pocillopora spp., Acropora spp., and Heliopora coerulea. There were numerous nonliving coral colonies which might indicate Acanthaster planci predation as mentioned in Station 12. Between the coral colonies and algal clumps, are small deposits of bioclastic sands--foraminiferans, Halimeda sp. plates, mollusc shells, and degraded corals.

The bivalve Tridacna maxima was common. The echinoids Echinometra mathaei and Echinostrephus sp. were noted as well as the asteroid Culcita novaeguineae.

Station 17

This station was on the reef flat and reef front, just south of the Pelagi islets and just north of a narrow, deep channel that cuts through the reef flat. The cut serves as the major reef flat drainage for this area as well as a launching site for small boats, but usually only during high tides.

The outer reef flat was a relatively smooth limestone pavement, being exposed during low tides. Only a few organisms were noted including Holothuria atra, Echinometra mathaei and a few crustaceans, all living in cracks and small holes in the reef flat. The gastropods Chicoreus brunneus, Lambis lambis, Conus lividus, C. ebraeus, Thais armigera, Drupa ricinus, D. morum, and Vasum turbinellus were noted. On the reef margin, many Tridacna maxima and Echinometra mathaei were observed on large Porites sp. boulders. Aggregations, 5-10 individuals, of hermit crabs (Calcinus spp.) were found on the tops of boulders where there was no live coral. The reef front and the beginning of the first submarine terrace were covered with a thick layer of silt, probably carried out through the channel during heavy rains. Field work done during rainy weather confirms the presence of vast sediment plumes originating there, as well as at the Namo River mouth (Station 11) and at the stream which empties into the causeway at Rizal Beach (Station 7). The gastropods Drupa rubisidaeus, D. grossularia, Coralliophyllia violacea, Quoyula madreporarum, and Vasum ceramicum were found there.

Station 18

Station 18 was on the inner reef flat, south of the Pelagi Islets and immediately east of the channel mentioned in Station 14. The substrate was a thick, 5-10 cm (2-4 inches), muddy-ooze layer covering a denser sublayer composed mostly of mollusc shell fragments. These included fragments from Ctena divergens, Cerithium ravidum, Natica marochiensis, Otopleura sp., Strombus sp., Pyramidella sp., and Ctelina sp. Random samples of the substrate mud were sifted using 1.3 cm (0.5 in.) mesh sift boxes to locate any mud dwelling organisms (Fig. 32). Organisms found included an individual of the mollusc family Ctelinidae, an opisthobranch. Also, various burrowing polychaet annelids were found. The flora noted were a few small patches of Enhalus acoroides and Halimeda macroloba (Fig. 33), and Avrainvillea obscura, Padina tenuis, and Sargassum polycystum. The blue-green alga Schizothrix calcicola was present in the form of mats covering the mud.

Station 19

This station was located south of Station 18. A small creek empties onto the reef flat there and much organic debris and garbage were strewn along the shore. The reef flat drains in a southerly direction during low tides.

The inner reef flat is mostly sand and gravel and not as muddy as Station 18, but with a thick mollusc fragment sublayer. A burrowing shrimp, a species of Callianassa, was common and the holothurians, Actinopyga echinites, Holothuria atra and Holothuria sp. were noted. The alga Halimeda macroloba was found in widely scattered patches across the reef flat and broad mats of the blue green alga Schizothrix calcicola were observed. The outer reef flat was characterized by turtle grass beds, Enhalus acoroides, with epipytic Microcoleus lyngbyaceus. Numerous rabbitfish Siganus spinus were noted in the grass. The corals Pocillopora damicornis and Porites lobata were also found. The reef margin had large amounts of rubble with Nerita albicilla, Patella sp., and a chiton attached. The xanthid crab Eriphya sebana was common under larger boulders and in holes.

Station 20

This station was approximately 100 m south of Station 19 and was composed mostly of coral rubble and bivalve shells forming a broad elevated strand. It was completely exposed during low tides and no living organisms were found on it. It extended perpendicular to shore for 60 m (200 feet) and was from 20-25 m (65-82 feet) wide.

Station 21

This station was on the reef flat, 100 m south of Station 20, and due west of the U. S. Marine Corps monument which was erected along the highway. This station was also the site for one of our electric night lights used as a navigational point for plotting drift drogue movements during the 24-hour current studies.

The inner reef flat was not exposed at low tides and was covered by extensive beds of Enhalus acoroides (Fig. 34). Siganus spinus (rabbitfish) were found there also. The mud-sand bottom had numerous mounds, probably constructed by sipunculans. The gastropod Trochus niloticus was common and Nerita albicilla was found on larger boulders. Two different sponges species were found--one black and the other purple.

The outer reef flat was mostly coral rubble and large limestone boulders. Echinometra mathaei and Trochus niloticus were found there.

The reef front, 4-6 m (15-20 feet) depth was typical of the reef front and terrace studied Stations 10 and 17, where there were many dead corals, much rubble, and a layer of silt covering everything. The molluscs Vasum turbinellus, Drupa ricinus, Tridacna maxima, Cypraea tigris, and Latirus sp. were found there. The asteroids Culcita novaeguineae and Linckia laevigata were also noted.

Station 22

Station 22 was located on the reef flat opposite the Agat Village Community Center. The substrate did not have the thick muck layer found at Stations 11 and 18 but did have the typical sublayer of mollusc shell fragments. The shoreline was littered with all manner of refuse including tin cans, corrugated roofing, lumber, wrecked cars, glass bottles, and paper trash. There were small patches of Enhalus acoroides ($1 m^2$) on the inner reef flat and at the base of these patches were the algae Dictyota bartayresii and Halimeda opuntia. Also at the base was the bivalve Gafrarium pectinatum. Two hermit crabs, Calcinus latens and Clibinarius humilis were noted, and the ghost crab Ocypode ceratophthalmus was found along the shore (Fig. 35).

Station 23

This station was located south of the Agat Community Center and included a large out cropping of limestone boulders, a feature unique for the study area. There were various attached molluscs including Cerithium morus, Cantharus fumosus, Nerita plicata, and Isognomon sp. The hermit crab Calcinus latens was also found. The inner reef flat substrate was a mud-silt mixture also typical of Stations 21 and 22. No live coral was noted, and patches of Enhalus acoroides were scattered. A large concrete box standing on the inner reef flat was noted with two littorines Littorina scabra and L. undulata attached to it. The shoreline was littered with domestic trash (see Fig. 36).

Station 24

Station 24 was located on the north side of a peninsula which extended 92 m (100 yds) across the reef flat toward the reef margin at Gaan Point. This peninsula was approximately 1-2 m (3-7 feet) above the high water line and was composed mostly of coral rubble. The rubble was more heavily deposited and generally less consolidated than the southern side (Station 26). Much of it was blue coral Heliopora coerulea and some blocks of it weighed more than 13 kg (30 lbs) (Fig. 37).

The substrate on the reef flat was similar to that of Stations 21-23. There was a high density of the intertidal gastropods Cerithium morus. Also noted were Planaxis sulcatus, P. decollatus, and Cerithium sp. The marine insect Halobates sericeus was observed along the shore, and the sponge Spirastrella vagabunda was found on the reef flat.

Station 25

This station was located on the south side of the Gaan Point peninsula described under Station 24. This side is more consolidated, though with much rubble and had a much greater diversity of marine life. There was a deep, 2.2-5 m (6.5-8 feet), and wide channel parallel to the peninsula and extending seaward. It appeared to be the major drainage for the reef flat between Gaan Point and Bangi Point (southern end of study area). Field work during both high and low tides confirmed this observation (Fig. 38).

Massive Porites spp. microatolls were found scattered throughout the broad channel and the remaining substrate was sand with Acropora spp. rubble. The Acropora rubble is significant because there was no Acropora growing adjacent to the channel, that is, up on the nearby reef flat. This was further evidence indicating this site as a major drainage and that currents must at times be exceedingly swift. Storm waves passing over the reef margin near Alutom Island, would break up the Acropora sp. thickets living there. This water, piling up on the reef flat, would generate strong longshore currents and would push the broken branches towards Gaan Point and the drainage channel. This side of the peninsula yielded significantly more invertebrates than any of the reef flat stations to the north. Twenty species of gastropods were found during a one-half hour search, though the shore area did not have the high densities of Cerithium morus found at Station 24. Among the more common gastropods were Lambis lambis, Coralliophyllia violacea, Trochus niloticus, Cypraea moneta, Conus rattus, Tridacna maxima, and Cantharus sp. Among the more common echinoderms were Linckia laevigata, Actinopyga echinites, Holothuria hilla, Eucidaris metularia, Echinometra mathaei, and Echinothrix sp. The dominant coral on the adjacent reef flat was Heliopora coerulea.

Station 26

This station was located on the reef terrace just seaward of Gaan Point and at the present site of the Agat Village Sewer Outfall.

Very few organisms were noted though there was some algal cover and is discussed under the algae section of this report.

The blue coral, Heliopora coerulea was common, but most corals were nonliving and there were large amounts of rubble.

Station 27

Station 27 was located along the shore between Gaan Point and south to the mouth of the Finile Creek. The beach is narrow, composed of loose boulders and a high backshore at the northern end then grading to a sandy area leading to the stream (Fig. 39).

The gastropods recorded here included Nerita plicata, N. polita, Cerithium morus, Littorina coccinea, L. undulata, and a bivalve Donax sp. The ghost crab Ocypode laevis was also noted. There was much refuse along the shore and on the inner reef flat.

Station 28

This station was located on the broad reef flat between Gaan Point in the north to Bangi Point and Alutom Island in the south. It had, by far, the most diverse flora and fauna of any of the reef flat stations in the study area.

The inner reef flat had a well developed moat with a sand and rubble bottom. The gastropods Strombus luhuanus, Cerithium nodulosum were common. Others included Trochus niloticus, Vasum turbinellus, Strombus mutabilis, Conus lividus, C. rattus, Cypraea moneta, and Lambis lambis. The outer reef flat and front had diverse coral growth and there was no silty layer covering them as noted for

Station 10, 12, 16, 17, and 19. Gastropods there included *Drupa ricinus*, *D. grossularia*, *Morula uva*, *Cypraea caputserpentis*, and *Thais armigera*.

Station 29

Station 29 was our southermost station and was located on the reef flat, north of Autom and Yona Islands.

The outer reef flat was covered by rubble and sand with many large overturned coral heads. There was very little live coral though some isolated patches of *Psammocora* sp. and *Acropora* spp. thickets were noted. The alga *Turbinaria ornata* covered 20 per cent of the substrate along the extreme outer edge of the reef flat. Among the more common gastropods were *Morula uva*, *Drupa ricinus*, *D. morum*, *Trochus maculatus*, *T. niloticus*, and *Cypraea caputserpentis*. The banded shrimp, *Stenopus hispidus* was also noted.

The inner reef flat was similar to Station 28, but considerably broader. Over fifteen species of holothurians were found and among them *Holothuria atra*, *Actinopyga echinites*, and *Bohadschia bivittata* were common. A plankton sample taken from the reef front on May 22, 1975, contained a high density of harpacticoid copepods.

SAND CHANNEL

This channel was composed of a broad sand area extending from the reef front near Rizal Beach and covered a roughly oval-shaped region approximately 500 m (0.3 mi) long and 350 m (0.2 mi) wide (Fig. 17).

Dredge hauls were made using a 1.27 cm (0.5 in) nylon mesh bag protected by heavy canvas sides. The first dredge haul was 200 m (218 yd) long and extended from the seaward perimeter of the channel, 18-20 m depth (59-65 ft), toward the reef margin. The dredged material was removed and another haul was made closer to the reef front at a 7-10 m (23-32 ft) depth and over a circular course for approximately 200 m.

The dredge during both hauls became clogged with material composed mostly of three species of blue green algae. Most of this mat-like cover was *Microcoleus lyngbyaceus* with the epiphyte *Calothrix crustacea*. The third blue green alga was the reddish colored *Schizothrix calcicola*. The alga *Dictyota bartayresii* was noted but in immature form, and the monocot *Halophilia minor* was present.

The deeper terrace had a higher percent cover of the blue green algae mat and a small amount of *Halophilia minor*. The shallower dredge revealed more *Halophilia minor* but very little blue green alga on the substrate. Most of the substrate in the shallower area was sand and devoid of algal growth.

A series of SCUBA dives to sample the substrate were made beginning at the seaward perimeter of the sand channel and moving in the direction of the reef margin. The substrate of the seaward perimeter at a depth of 27.4 m (90 ft) was covered with a thin layer of coarse materials composed mostly *Halimeda* sp. plates and small coral rubble. Beneath this layer was a clay-like deposit approximately 0.75 m (2.5 ft) thick and still deeper the substrate became impenetrable. The substrate at a 16.8 m (55 ft) depth was mostly sand deposits (beneath the algal cover, if present) greater than 1 m (3.2 ft) deep and composed of dregraded coral, *Halimeda* sp. plates, and a high density of mollusc shells. Closer inshore at 14.3 m (47 ft) there was the same sand deposit but with several clay-like tabloid buttresses extending across parts of the terrace. The sampling at 11.6 m (38 ft) showed the same sand cover, greater than 1 m thick but with virtually no algal growth. The final sample made at a 9 m (30 ft) depth was also totally sand and devoid of algal cover.

Molluscs retrieved from the deeper dredging operations included *Strombus* sp., *Terebra* (*Hastula*) sp., and *Terebra* sp. The shallower dredge contained *Cerithium ravidum*, *Natica gualtieriana*, *Pollinices* sp., *Oliva* sp., and *Terebra* sp.

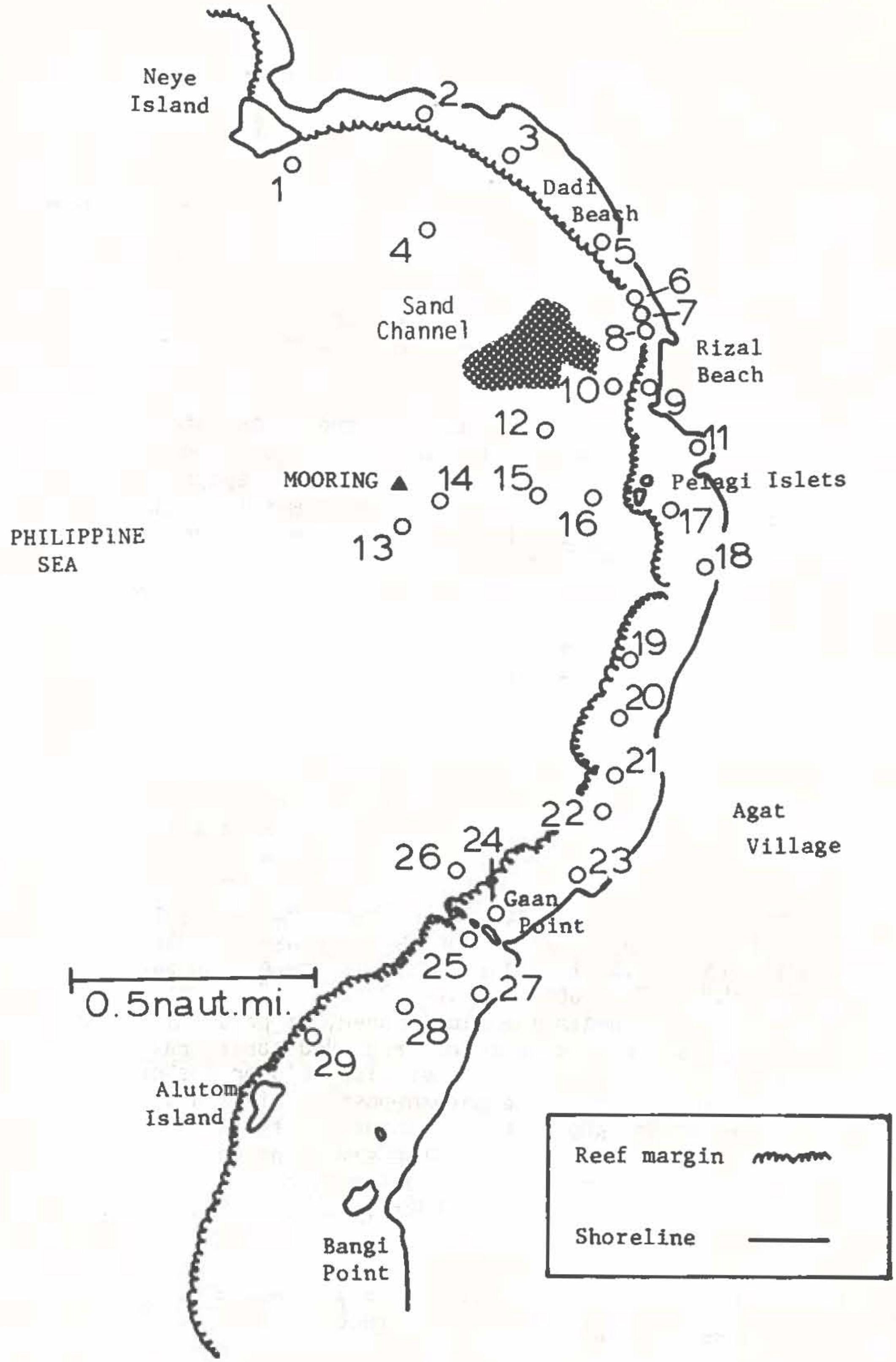

Fig. 17. Map of stations of Agat Bay.

Fig. 18. Shoreline along Station 2 during low tide. Note the high limestone cliffs with deep nips, and rocky, narrow beach.

Fig. 19. View of Station 2 showing gently the sloping beach with freshwater rivulets.

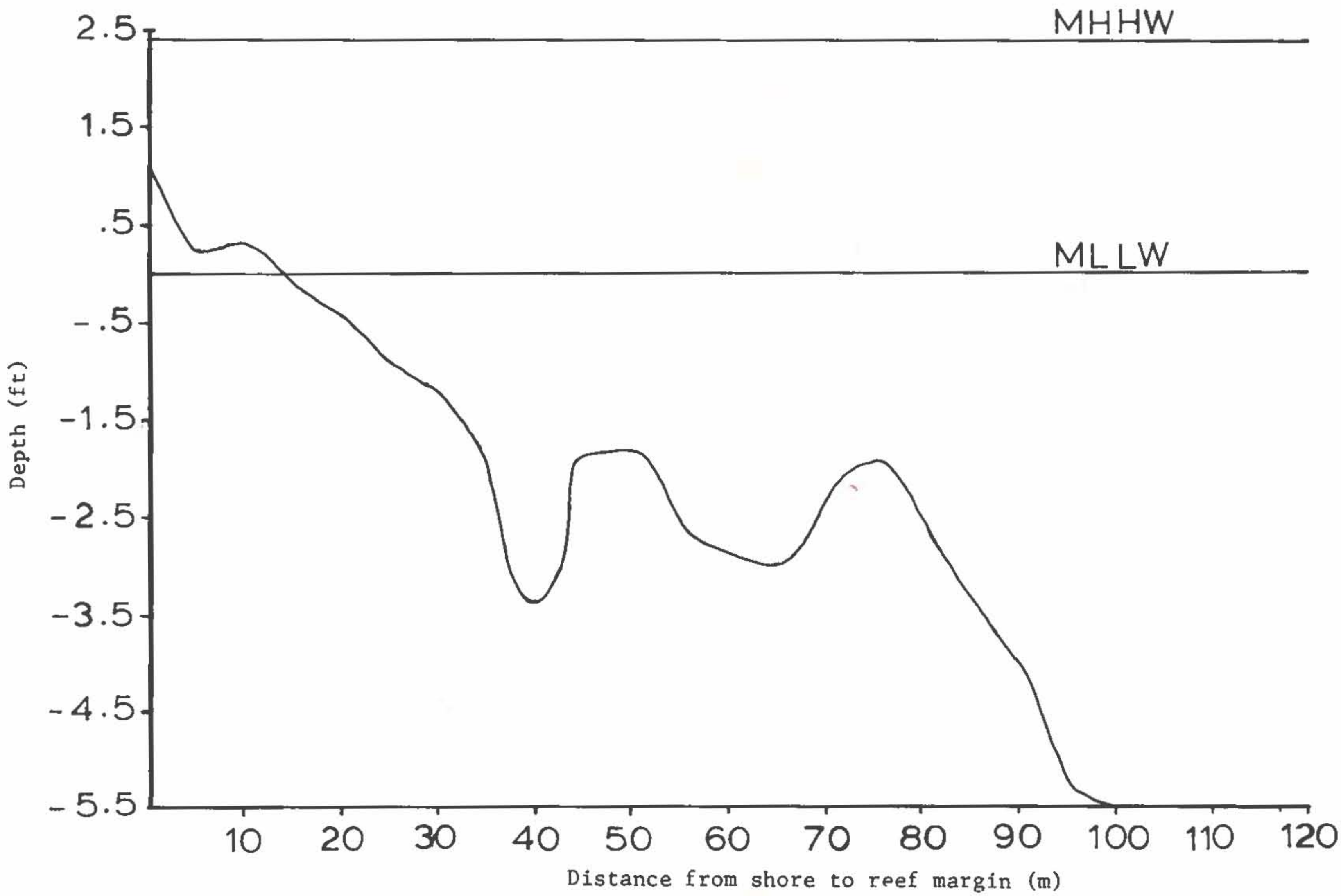

Fig. 20. Shows a vertical profile transect taken at Station 6. Profile is shown in relation to the MLLW and MHHW.

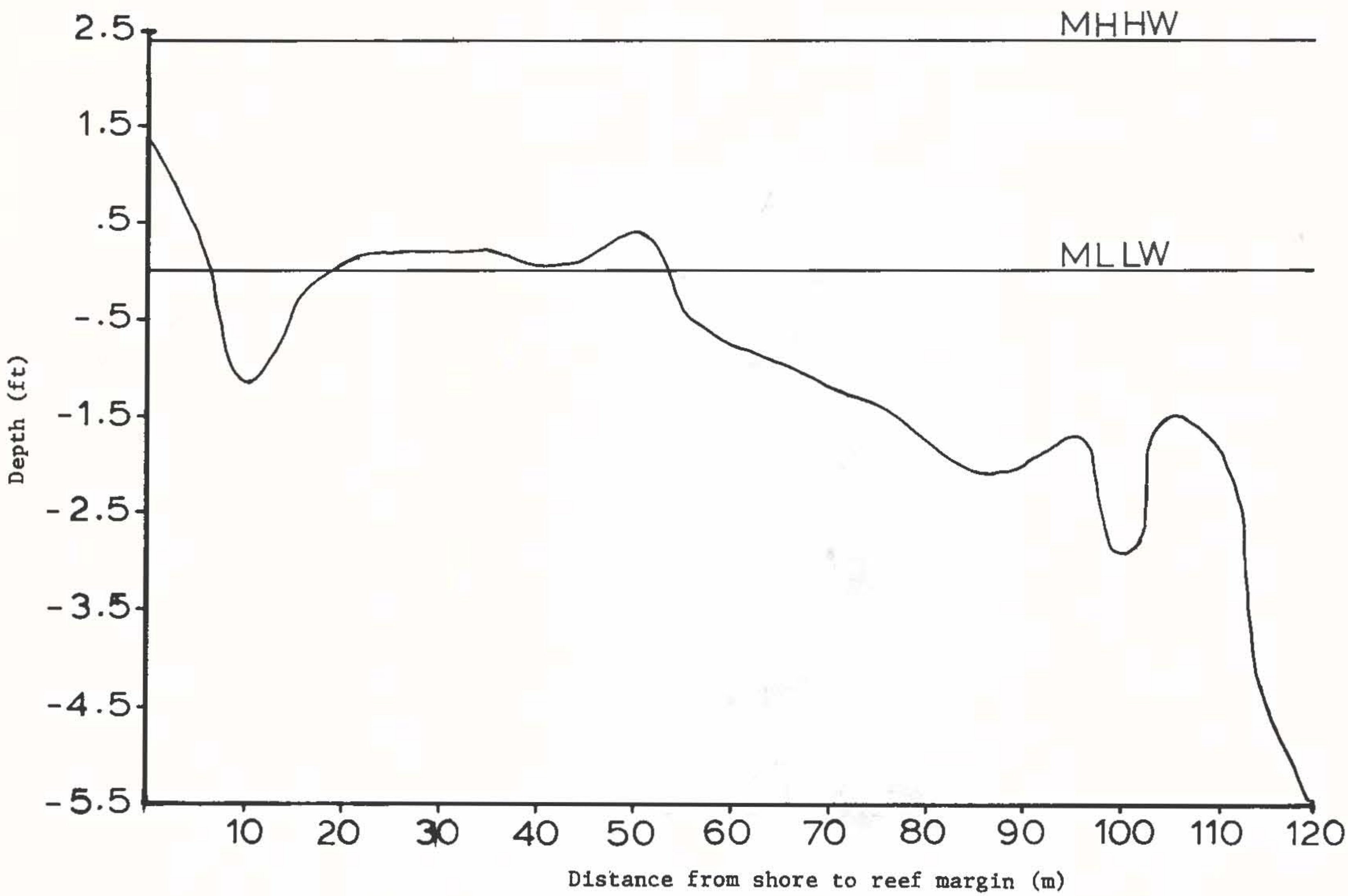

Fig. 21. Shows a vertical profile transect taken at Station 7. Profile is shown in relation to the MLLW and MHHW.

Fig. 22. Seaward view showing the causeway at Station 7.

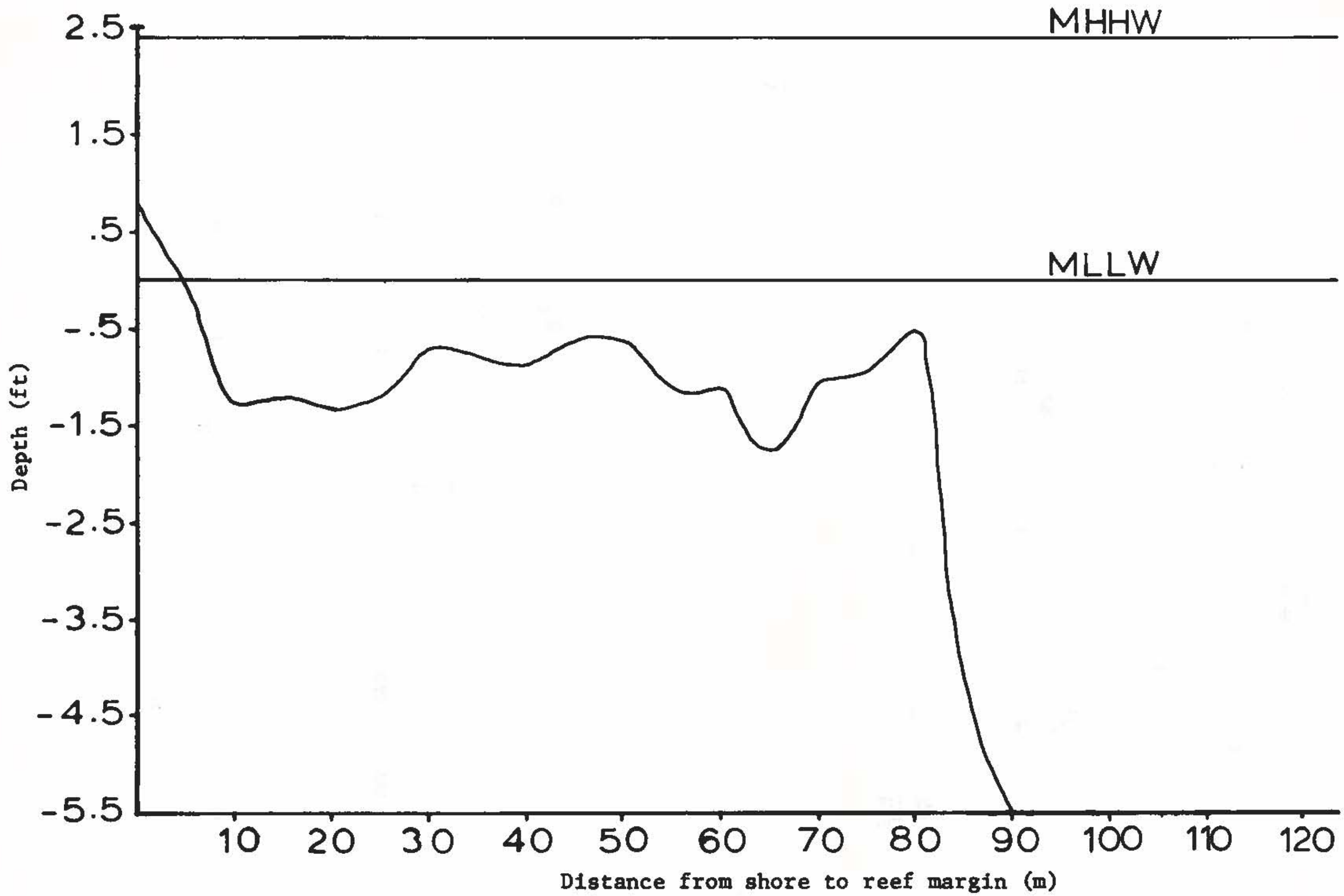

Fig. 23. Shows a vertical profile transect taken at Station 8. Profile is shown in relation to the MLLW and MHHW.

Fig. 24. Searching the inner reef flat for organisms at Station 8.

Fig. 25. Underwater view south of the causeway showing concrete blocks along the reef flat at Station 8.

Fig. 26. View showing the outer reef flat along Station 9.

Fig. 27. Seaward view of gridded quadrat being randomly tossed for quantifying the substratum.

Fig. 28. Recording invertebrates noted at Station 9.

Fig. 29. Bathymetry map showing depths in contours from the causeway (Station 7) to seaward (Station 10).

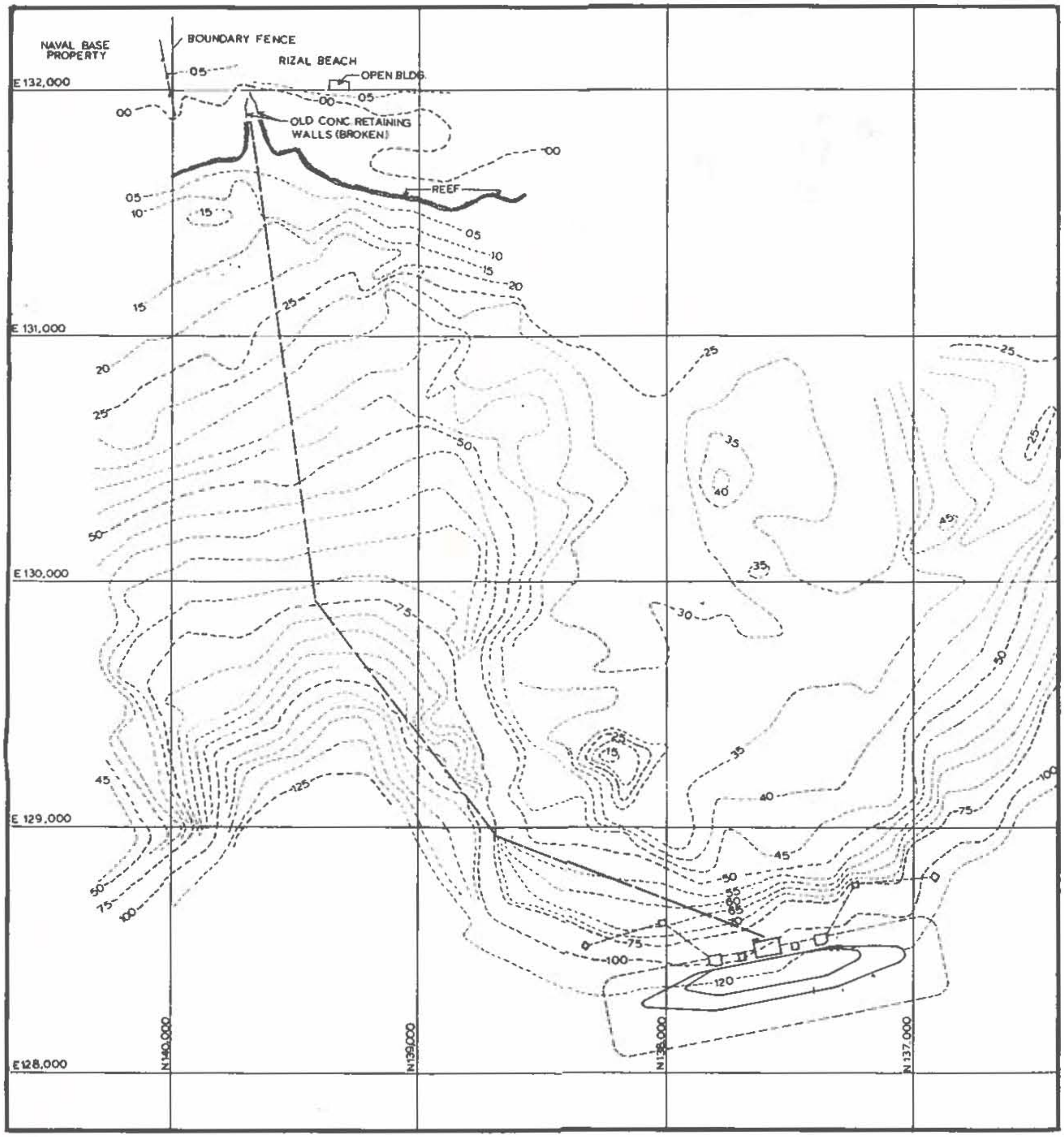

Fig. 30. Searching and recording invertebrates from well-developed nip at north end of Station 11.

Fig. 31. Underwater view showing muddy substratum devoid of algae and coral; typical of Station 11.

Fig. 32. Sampling the substratum using a sift box at Station 18.

Fig. 33. Underwater view showing silty substratum with the alga Halimeda macroloba at Station 18.

Fig. 34. Underwater view showing bed of Enhalus acoroides on the inner reef flat at Station 21.

Fig. 35. View looking north from Station 22 showing the mud-sand beach at low tide.

Fig. 36. View taken from Station 23 looking south along the shore from near the Agat Community Center. Note the rocky out cropping.

Fig. 37. Large deposits of rubble along the peninsula at Gaan Point.

Fig. 38. North side of the peninsula at Gaan Point. Note, the old sewer line running along the top.

Fig. 39. Looking south along Station 27. Note--Yona Island in the distance.

INVERTEBRATES
L. G. Eldredge

The invertebrates of Agat Bay show great diversity and, as might be expected, relatively low abundance. Because of the state of knowledge of these groups, some are more well known than others. Therefore, the invertebrates are divided into separate sections of this report, the corals, gastropods and bivalves, and opisthobranchs appearing separately below. This section includes primarily the crustaceans and echinoderms, along with comments on other groups. Two tables provide the checklist of the crustaceans (Table 1) and echinoderms (Table 2).

In general the Agat reef flat is typical of the leeward coast of Guam and is divisible into separate habitats (or biotopes) so described by the physical conditions of each area.

At the sandy beaches along the bay, ghost crabs (Ocypode spp.) are the most common macrocrustacean. In the turtle grass (Enhalus acoroides, Biotope I) zone, sponges are common, primarily Spirastrella vagabunda. Cinachyra australiensis is quite common on the reef flat. Numerous polychaete annelids are found in the sand, and the boxcrab Calappa hepatica is the most common, although rare, macrocrustacean. A number of small crustaceans are found among the boulders at the outer reef flat and reef margin. The echinoderms were sampled in somewhat more detail. Three transects were established--(1) mooring site (Sta. 13), (2) parallel to reef front at Rizal Beach Channel (Sta. 8), and (3) perpendicular to the shore at Rizal Beach (Sta. 7). Many, but not all, of the species listed in Table 2 were found in these three areas.

In the 200 m^2 searched at the mooring site three species (four individuals)--Echinostrephus aciculatus, Holothuria edulis, and Macrophiothrix longipeda--were observed. In the shallow depths (2-3 m) along the reef front, ten different species were observed, echinoids being the most common comprising 156 individuals of the 189 counted. Relative frequency values are 38 and 24.3 for Echinometra mathaei and Echinothrix calamaris, respectively. The third transect was taken from between the old causeway (Sta. 7), running perpendicular to the shore for a distance of 100 m. Five species were counted -- three echinoids, one holothurian, and one ophiuroid. Echinometra mathaei was the most common.

Interestingly enough, no crinoids were observed or collected at Agat Bay during the survey.

A number of coral colonies were broken open to collect the associated organisms. Pocillopora eydouxi provided a number of crustacean species -- Alpheus sp., Saron neglectus, Munida sp., Thalamitoides quadridens, Domecia hispida, Trapezia cymodoce, T. intermedia, and Menaethuis monoceras. Ophiuroids, asteroids, gastropods, and fish were also noted. The growth form of one colony contained an unusually high number of the galatheids, Munida. Whether or not there is a relationship between these is unknown.

Two species of crabs--Percnon guinotae and Plagusia immaculata --and one barnacle--Lepas sp.--were collected from the mooring float on several occasions. All of these are regular inhabitants of floating objects.

Night-light plankton samples were collected on 20 September and 22 November. Mysid crustaceans were the major organism present. A few fish and stomatopod larvae, as well as crab zoea were present.

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Table 1. Crustaceans collected at Agat Bay.

	High Inter Tidal	Inner Reef Flat	Outer Reef Flat	Reef Front	Reef Terrace
Cirripedia					
Lepadidae					
Lepas sp.					X
Stomatopoda					
Gonodactylidae					
Gonodoctylus (?) *platysoma* Wood-Mason			X		
Ondontodactylus cultrifer (White)					X
Decapoda					
Alpheidae					
Alpheus sp.					X
Hippolytidae					
Saron neglectus de Man					X
S. marmoratus (Olivier)		X			
Stenopodidae					
Stenopus hispidus (Olivier)			X	X	X
Palinuridae					
Panulirus versicolor (Latreille)				X	
Galatheidae					
Munida sp.					X
Porcellanidae					
Petrolisthes lamarcki (Leach)		X			
Callianassidae					
Callianassa sp.		X			
Diogenidae					
Calcinus gaimardi (H. Milne Edwards)		X	X		
C. laevimanus (Randall)		X		X	X
C. latens (Randall)		X	X		
C. minutus Buitendijk					X
Clibanarius striolatus Dana	X				
Dardanus deformis (H. Milne Edwards)			X		
D. guttatus (Olivier)			X	X	X

	High Inter Tidal	Inner Reef Flat	Outer Reef Flat	Reef Front	Reef Ter- race
D. lagopodes (Forskal)		X	X	X	X
D. megistos (Herbst)		X	X	X	
D. scutellatus (Dana)		X			
Trizopagurus strigatus (Herbst)				X	X
Coenobitidae					
Coenobita cavipes	X				
C. brevimanus	X				
Hapalocarcinidae					
Hapalocarcinus marsupialis Stimpson				X	X
Calappidae					
Calappa gallus (Herbst)					X
C. hepatica (Linnaeus)		X	X	X	
Portunidae					
Portunus granulatus (Milne Edwards)		X			
Thalamitoides quadridens Milne Edwards					X
Xanthidae					
Domecia hispida Eydoux and Souleyet					X
Eriphia sebana Rathbun			X	X	
Tetralia glaberrima (Herbst)					X
Trapezia cymodoce (Herbst)					X
T. intermedia Miers					X
Grapsidae					
Grapsus tenuicrustatus (Herbst)	X				
Metapograpsus messor (Forskal)	X				
Percnon guinotae Crosnier					X
Plagusia immaculata Lamarck					X
Ocypodidae					
Ocypode ceratophthalmus (Pallas)	X				
O. laevis Dana	X				
Majidae					
Menaethuis monoceros Latreille					X
Parthenopidae					
Daldorfia horrida (Linnaeus)			X		

Table 2. Echinoderms collected at Agat Bay.

	Inner Reef Flat	Outer Reef Flat	Reef Front	Reef Terrace
Asteroidea				
<u>Acanthaster</u> <u>planci</u> (Linnaeus)			X	X
<u>Asterina</u> sp.		X		
<u>Cistina</u> <u>columbiae</u> Gray		X		X
<u>Culcita</u> <u>novaguineae</u> Müller and Troschel		X	X	X
<u>Dactylosaster</u> <u>cylindricus</u> (Lamarck)		X		
<u>Fromia</u> <u>hemiopla</u> Fisher		X		
<u>Gomophia</u> <u>egyptiaca</u> Gray		X		
<u>Leiaster</u> <u>leachi</u> (Gray)			X	X
<u>Linckia</u> <u>guildingi</u> Gray		X		
<u>Linckia</u> <u>laevigata</u> (Linnaeus)	X	X		
<u>Linckia</u> <u>multifora</u> (Lamarck)	X	X	X	X
<u>Linckia</u> sp.				X
<u>Mithrodia</u> <u>clavigera</u> (Lamarck)		X		X
<u>Ophidiaster</u> <u>granifer</u> Lutken		X		X
<u>O.</u> <u>squameus</u> Fisher		X		
Echinoidea				
<u>Diadema</u> <u>savignyi</u> Michelin	X			
<u>D.</u> <u>setosum</u> (Leske)			X	
<u>Echinometra</u> <u>mathaei</u> (de Blainville)	X	X	X	
<u>Echinostrephus</u> <u>aciculatus</u> A. Aggasiz	X	X	X	X
<u>Echinothrix</u> <u>calamaris</u> (Pallas)		X	X	
<u>E.</u> <u>diadema</u> (Linnaeus)			X	
<u>Eucidaris</u> <u>metularia</u> (Lamarck)			X	
<u>Heterocentrotus</u> <u>mammillatus</u> (Linnaeus)		X	X	
<u>Tripneustes</u> <u>gratilla</u> (Linnaeus)		X		
Holothuroidea				
<u>Actinopyga</u> <u>echinites</u> (Jaeger)	X	X		
<u>A.</u> <u>mauritiana</u> (Quoy and Gaimard)		X	X	
<u>Afrocucumis</u> <u>africana</u> (Semper)	X	X		
<u>Bohadschia</u> <u>argus</u> (Jaeger)	X	X		
<u>B.</u> <u>bivittata</u> (Mitsukuri)	X			
<u>Euapta</u> <u>godeffroyi</u> (Semper)	X	X		
<u>Holothuria</u> <u>atra</u> Jaeger	X	X	X	X
<u>H.</u> <u>difficilis</u> Semper		X	X	
<u>H.</u> <u>edulis</u> Lesson	X	X		
<u>H.</u> <u>hilla</u> Lesson	X	X		
<u>H.</u> <u>impatiens</u> (Forskal)	X	X		
<u>H.</u> <u>leucospilota</u> Brandt	X	X		
<u>H.</u> <u>nobilis</u> (Selenka)	X	X	X	
<u>H.</u> <u>pervicax</u> Selenka	X	X		
<u>Stichopus</u> <u>chloronotus</u> Brandt		X	X	X

	Inner Reef Flat	Outer Reef Flat	Reef Front	Reef Terrace
S. horrens Selenka	X	X		
Synapta maculata (Chamisso & Eysenhardt)	X	X		
Thelaneta ananas (Jaeger)				X
Ophiuroidaea				
Macrophiothrix longipeda (Lamarck)	X	X	X	X
Ophiarthrum elegans Peters	X	X	X	
O. erinaceus Müller and Troschel		X	X	
O. pica Müller and Troschel	X	X		

CORALS
Richard H. Randall

The fringing reef and coral descriptions follow the order given in the outline of biotopes presented above (p. 6). For the most part the descriptions are of a qualitative nature, augmented with some quantitative data concerning the percentage of substrate coverage for corals at representative biotopes.

Qualitative aspects were made by making a 20-minute observation along both sides of a 100 m transect line to reveal coral species' diversity and their relative abundance within the various biotopes. A nearly complete list of corals from Agat Bay was originally compiled from the general reconnaissance surveys of the entire bay area. This list was placed on an underwater slate, and then while swimming along the transect length (10 minutes on each side) the species observed were recorded. From the number of occurrences each coral species was observed in a given biotope. A relative abundance value was assigned (see Table 3) to it as follows: dominant (D), the species occurring most frequently throughout the biotope range; abundant (A), the species frequently observed and widely distributed throughout the entire biotope range; common (C), a species which can usually be found throughout the biotope range but with less frequency than (A) above; occasional (O), a species not observed throughout the entire biotope range and is commonly restricted to certain geographic regions of the bay or occurs in certain facies of the biotope; uncommon (U), a species observed at infrequent intervals and restricted to certain geographic regions of bay and to specific biotope facies; and rare (R), a species whose occurrence is based upon one to five observations and is nearly always restricted to a specific geographic region of the bay and biotope facies. Table 3 shows the coral species diversity for the entire area of Agat Bay and their relative abundance within the various biotopes.

The coral community was quantitatively analyzed by using a modified point-centered quarter technique as described by Cox (1972). In this technique a series of 10 points, 10 meters apart were selected along a 100-meter transect line on the substratum within a given biotope. The area around each transect point was divided into four equal quadrants. The coral nearest the transect point in each quadrant was located and its diameter and distance from the center of the corallum to the transect point were recorded. From these values the percentage of substrate covered by each coral was determined. Table 4 tabulates the results of these transect data. A discussion of the coral distribution follows biotope designations.

BIOTOPE I

The reef flat platform along Agat Bay is for the most part an unfavorable environment for coral settlement and growth. Exposure of much of the outer reef flat during average low tides and the inner reef flat during low spring tides inhibits the development of corals on much of the platform surface. Table 3 lists only 11 species and 8 genera known to occur in this biotope. Coral density was so low that quantitative measurements were not conducted. The few scattered coral colonies observed were mostly restricted to holes, cracks, and depressions which retain water during low spring tides. Many of the shallower of these reef flat depressions and holes also lack corals because the water temperature increases to lethal or sublethal levels when low spring tides are correlated with midday insolation. Coral settlement and growth are further inhibited where unstable substrates are present, and the reef flat is subject to fresh water runoff and associated silt and mud near river and stream mouths.

A few Pocillopora damicornis, Porites lutea, Porites lobata, and Favites abdita colonies were observed in some of the deeper reef flat holes and depressions and along the marginal walls of the reentry channels south of the Pelagi Islets and opposite Gaan Point. Most of the colonies are small and stunted with few being found larger than 5-8 cm in diameter. The Porites colonies were mostly lumpy irregular growths, which in cross-section show a developmental history of periodic growth followed by partial death and rejuvenation.

On the extreme outer reef-flat platform some of the Porites lutea colonies were found growing in surprisingly small holes just a few centimeters in depth and width. An occasional Favites abdita with pale tan walls and bright green peristomes a few centimeters in diameter were also found in these small outer reef flat holes.

Small bushy clumps of yellow-brown Pocillopora damicornis colonies were occasionally found in the inner reef flat but were generally irregular in shape from partial death of some parts from emersion at low tide and mechanical damage from mobile substrates moved about by storm waves. A few ramose tufts of Psammocora contigua were observed on the outer reef flat along the southern part of the bay. Other living corals observed on the reef-flat platform consisted of living fragments of Pocillopora and Acropora colonies which normally live on the reef margin and reef front biotopes. These fragments are derived from these two biotopes by storm waves and only live for a short period of time on the reef-flat platform.

BIOTOPE II

Facies A - Upper Reef Margin Slopes

The nodular irregular surface relief of this facies supports only a scattered community of corals for the most part, but at certain zones local aggregations of corals constitute the dominant organisms. Pink-colored encrusting patches and nodular clusters of calcareous red algae cover much of the surface and appear to be the major reef-builder here, but examination of pieces of reef rock show that corals have actually contributed more of the bulk. In fact most of the nodular irregularities which give the surface most of its relief consists of coral growths with thin encrusting layers of algae covering them. The inner part of the reef margin slope is subject to more exposure to air and hence supports fewer corals than the outer seaward part.

Common corals growing in this facies consist of small irregular lumpy *Porites lutea* forms; a scattering of pinkish-brown *Pocillopora danae* and *Pocillopora brevicornis* colonies which form small clusters with closely set branches; occasionally larger heavier and thicker branched yellow-brown to pinkish-brown *Pocillopora meandrina* clusters are found along with colonies of closely set meandering fronds of *Pocillopora setchelli* on the floors and sides of shallow grooves and troughs. Irregular encrusting to massive patches of brown colored *Goniastrea retiformis* occurs in small depressed hollows, nodular growths and vertical plate-like growths of yellow *Millepora platyphylla* are conspicuous here and there on the upper surface of knobs and ridges of buttresses, and small greenish brown encrusting patches of *Porites* sp. 1 encrusts the subcavernous cavities and holes. Corals less commonly observed were small ramose tufts of reddish purple tipped *Acropora nasuta*, irregular branches of pale yellow-tan *Acropora murrayensis*, green encrusting patches of *Psammocora* (*P.*) *haimeana*, angular nodules of *Favites abdita* with bright green peristomes, purplish brown nodules of *Porites* lobata, and delicate reddish purple clumps of *Acropora nana*.

On the outer parts of the upper buttress surface where wave agitation is greater *Acropora monticulosa* with large scattered cone-like projections arising from a thick encrustation and greenish brown to purplish brown thinner encrusting patches of *Acropora palmerae* are occasionally found. *Acropora ocellata* also forms small clusters of thick stumpy branched colonies on the upper buttress surface where it dips downward at the beginning of the reef front biotopes.

Conspicuous also in the inner part of the reef margin are encrusting patches of zoanthids which sometimes encrust 2 to 15 or more square meters of reef surface. *Palythoa tuberculosa*, a light tan species is common in the more exposed part of the facies. A dark gray species of *Zoanthus* with bright green peristomes occupies a zone further seaward which is less exposed.

Facies B - Open Surge Channels

This facies can be divided into two zones in respect to coral distribution. These zones consist of the upper surge channel walls and margin where coral growth is more prominent and the lower surge channel walls and floors where coral growth is abenst or patchy and subject to periodic abrasion from a mobile substrate of loose sediments moved back and forth by storm waves.

In terms of percentage of substrate covered, the upper surge channel margin is higher than the upper walls, but species diversity is lower. Mostly Pocillopora species; particularly P. setchelli, P. meandrina, and P. brevicornis occupy this zone. These bright reddish pink to brown globular-shaped colonies are particularly conspicuous during low tide when they are temporarily exposed as wave troughs approach the reef margin. At places these colonies, along with various crustose species of calcareous red algae, form a projecting shelf over the open surge channel. These shelves, projecting from opposite walls, may meet and fuse, forming caverous regions below. Other corals found on the upper surge channel margins or on the upper surface of projecting shelves are corymbose colonies of Acropora nasuta, A. surculosa, and encrusting Porites sp. 1 colonies.

The upper surge channel walls are a region of less light intensity and more commonly support thick encrusting to low convex massive forms of Favia pallida, F. stelligera, F. matthai, Goniastrea retiformis, Acanthastrea echinata, Porites lutea, and P. lobata; encrusting patches of Montipora verrili, M. patula, Psammocora (P.) haimeana, P. nierstraszi, Leptastrea purpurea, Pavona varians, and Porites sp. 1; and a few projecting bracket-like growths of corymbose Acropora nasuta, A. convexa, and A. surculosa.

The lower surge channel walls and floors are absent of corals or they consist of small colonies of both encrusting and ramose forms, common on the upper walls and margin, which have developed between periods of storms or typhoons when currents are not strong enough to cause much erosion in these regions. Exceptions to this pattern are found in the shallow shoreward end of the surge channels, the floor of which is sometimes separated from the outer part by a steep drop-off or slope of a meter or more. These inner surge channel floors and lower walls commonly contain no mobile substrates and are occupied by coral assemblages similar to those described for the upper surge channel margin and walls.

Facies C - Cavernous Surge Channels

These regions of low light intensity are mostly encrusted by calcareous red algae, but occasional corals are found, particularly where the cavernous channels grade into open parts and reef margin pools. Here a few corals such as Pavona (P.) pollicata, Pavona (P.) obtussata, and Porites sp. 1 form encrusting or explanate shelf-like growths. In regions with less light, encrusting Leptoseris species are occasionally found and finally in the darkest places hermatypic corals are absent. A few ahermatypic colonies of Paracyathus may occasionally be found, particularly in the small holes which communicate with the upper reef margin platform.

Facies D - Reef Margin Holes

These holes are found principally at the inner shoreward part of the reef margin where surge channels have been enlarged by erosion or where cavernous parts have collapsed. Large boulders and smaller mobile substrates occur on the floor of the pools and have coral communities similar to those described for the lower surge channel walls and floors. The upper walls and margins of the pools commonly contain, in addition to many species already mentioned from Facies A, B, and C, a few corals which are more common on the upper reef front biotope such as: Pocillopora elegans P. verrucosa, greenish humpy Porites australiensis, reddish-brown Porites lichen, yellow-brown Goniastrea pectinata and G. parvistella, and Acropora humilis.

Table 3 lists 29 coral genera representing 86 species for the reef margin which is considerably higher than for the adjacent reef flat, but much lower than the reef front and seaward slope biotopes further seaward (Table 3). Coral substrate coverage (Table 4) is very irregular with parts of the reef margin having less than 5 per cent while other regions have up to 20 per cent. Overall the percentage of substrate covered by living corals is much lower than for the reef front and seaward slope biotopes.

In general, the reef margin along Agat Bay is quite variable in respect to structural physiographic and developmental aspects and coral distribution. The reef margin shows evidence of more active reef development, greater physiographic relief, and higher coral diversity and percentage of substrate coverage at the northern end of the bay between Neye Island and the middle part of Dadi Beach. The middle part of the bay, from the southern part of Dadi Beach to the Pelagi Islets, shows less reef development, physiographic relief, and coral diversity and substrate coverage than either the northern or southern parts of the bay (Table 4). Coral diversity and percentage of substrate coverage are particularly low along this middle stretch. The remaining reef margin south of the Pelagi Islets is very irregular in physiographic structure and coral development, diversity, and substrate coverage, and appears to be somewhat in between the northern and middle parts of the bay in these respects.

Less evidence of active reef margin development and lower coral diversity south of the Pelagi Islets compared to the northern end of the bay is probably a reflection of the rivers and streams which reach the fringing reef platform at the former and are absent at the latter. The poor reef margin development along the middle part of the bay, although no streams or rivers empty on the platform there, seems to be related to the shallow sandy submarine terrace which borders the reef platform.

BIOTOPE III

Considerable variation exists in coral distribution, both vertically and horizontally along the reef front biotope. The upper part of the reef front is in a well-lighted region of strong oscillating currents, located immediately seaward of the breaking surf, whereas the lower parts receive less water movement and light, particularly along the southern part of the bay where river and stream discharge causes considerable turbidity of the water at times.

One hundred forty-seven species and 42 genera of corals were observed in the reef front biotope which is higher than for any other (Table 3), although with a more thorough search of the deeper parts of the seaward slope biotope, it would probably be as high or possibly higher in species diversity. This high diversity arises in part from the great variety of habitats found in the biotope. Coral substrate coverage was also higher here than for any other biotope, although it was also quite low at places where reef front development was poor. Overall the substrate coverage ranged from about 11 to 60 per cent (Table 4).

Facies A - Upper Buttress Slopes

This facies is comprised of the upper surface of the lobate submarine buttresses or general reef front slope where such features are lacking or poorly developed. The major reef building corals in this facies are *Goniastrea retiformis* and *Favia stelligera*, both which form massive colonies with irregular lumpy surfaces. Sometimes these colonies cover several square meters of surface area and are commonly patchy in distribution with other corals interspersed over their surface. Other conspicuous corals are *Acropora smithi* which forms pyramid-shaped colonies of thick tapering, blunt tipped, anastomosing masses of arborescent branches, sometimes nearly a meter high and wide, *Acropora palmerae* and *A. monticulosa*, and massive lumpy to subhemispherical colonies of *Porites lutea* and *P. lobata* (Fig. 40). *Pocillopora* colonies are common along the entire length of the buttress surface and in addition to the same species found in the reef margin biotope; *Pocillopora woodjonesi*, *P. elegans* *P. eydouxi*, and *P. verrucosa* are also found (Figs. 41, 42, and 43). A conspicuous number of colonies are dead. Knobs and buttress crests are commonly crowned with flabellate plates of *Millepora platyphylla* and *Pocillopora meandrina*. Some corymbose colonies of *Acropora nasuta*, *A. surculosa*, and *A. humilis* occur at scattered places along the upper buttress surface. At locations where reef front development is prominent *Acropora nana*, *A. hystrix*, and *A. syringodes* form brightly colored cespitose clumps composed of thin fragile branches. An occasional large *Acropora abrotanoides* colony was also encountered at the northern and southern ends of the bay.

Of particular interest is the rich coral development along the northern part of the bay between Neye Island and the middle part of Dadi Beach. Most noticeable here is the development of many large flabellate growths of Heliopora coerulea along the sides and seaward end of the buttress surfaces (Figs. 44 and 45). Some of these colonies are a meter across and high. Psammocora (S.) togianensis develop large columnar colonies with their branches arranged somewhat in flabellate series oriented at right angles to the surge or current direction (Fig. 46) and cuneate-shaped colonies of Pavona clavus are conspicuous on the outer parts of the buttresses.

Facies B - Submarine Channels

This facies consists of the steep vertical-faced channel walls and channel floors. Where channel floors contain mobile substrates coral development consists of a few small encrusting colonies or is absent. Leptastrea purpurea, Pavona varians, and various species of Montipora form small encrusting patches in this unfavorable coral environment. Leptastrea purpurea in particular can tolorate the presence of considerable amounts of sandy sediments. Low convex massive colonies of Porites, Favia, Favites, Platygyra, and Goniastrea; encrusting patches of Porites, Montipora, Leptastrea, Acanthastrea, and Pavona; and a few shelving growths of Acropora are found on mid-part of the channel walls. The upper margin of the channels are more diverse with brightly colored Pocillopora species and Millepora platyphylla being the most conspicuous corals present.

Where the channels and buttresses grade into the adjacent submarine terraces the walls are commonly V-shaped and subject to more light intensity. It is on these sloping buttress or channel walls where some of the most luxuriant coral growth occurs (Fig. 47). Cushion-shaped clusters of crustose red algae form growths of closely divided branches up to a half-meter across on the sides of some of these more gentle sloping channel walls along the reef front at the northern end of the bay (Fig. 48).

Facies C - Cavernous Parts of the Reef Front

This facies is not as extensively developed as in the reef margin and is found primarily along various parts of the channel walls. Most commonly, these habitats are found where the lower channel walls are undercut, forming a poorly lighted ceiling where a few corals such as Porites (S.) hawaiiensis, Pavona (P.) obtussata, Leptoseris incrustans, Paracyathus, Polycyathus, Desmophyllum, and Distichopora are found. Other reduced light environments are found on the undersides of projecting shelves at the upper channel margins and small cavities, holes, and tunnels along the mid-part of the wall. Diversity in these upper channel cavernous regions is slightly greater than that found along the lower walls, mainly because of greater light intensity there.

Facies D - Large Open Holes

At many places along the reef front at Agat Bay, submarine channels widen into large open holes. These generally have rather flat floors consisting of either sand or boulder rubble which supports only a few corals, but the steep to vertical walls usually support a varied coral community. The coral community of the larger deeper holes usually includes some species normally found in deeper water biotopes such as Porites (S.) iwayamaensis, P. (S.) convexa, Acropora palifera, A. delicatula, and Pavona maldivensis.

Facies E - Knobs, Knolls, Patch Reefs, and Mounds

These topographic relief structures extend up above the general level of the reef front where increased light and water movement enhance coral growth. Commonly a small mound, knob, or pinnacle will consist initially of a single large coral colony such as Porites lutea, Diploastrea heliopora, or Porites (S.) sp., upon which other corals settle and develop (Fig. 40). Millepora platyphylla, M. dichotoma and Pocillopora species typically grow on the summits of these relief features, particularly when the upper part extends to near the surface. Figure 49 shows the coral growth and development at the base of a large reef patch on the outer part of the reef front near Dadi Beach.

BIOTOPE IV

In general the rocky submarine terraces have less coral diversity and percentage of substrate coverage than the reef front (Biotope III) or seaward slopes of this biotope. Sandy-floored terraces are devoid of corals except for a few scattered colonies, which usually had been broken off from colonies growing on adjacent rocky areas, and rocky pinnacles, knobs, and mounds which rise above the sandy floor. Table 3 lists 115 species represented by 41 genera for the biotope as a whole and Table 4 shows that percentage of substrate coverage by corals ranges from 1 to 50 per cent. Coral growth and coverage are very irregular on the rocky substrate surfaces, but locally some areas may support a rather diverse coral community while adjacent nearby areas possesses only a few scattered corals.

Much of the irregularity of coral distribution in this biotope may be related to previous Acanthaster planci predation on the corals of Agat Bay during 1969-1971 (Tsuda, 1971). Although A. planci predation was less intense along the southwest coast than along the northwest coast, local areas could have sustained considerable damage and much of the dead coral framework noticeable along the submarine terraces of Agat Bay could have been the result of such predation. Small coral colonies growing on the surfaces of these dead intact corals are indicative that recolonization is occurring, but studies of similar A. planci-devastated reef regions at Tanguisson Point by Randall (1973a, 1973b, 1973c) show that recolonization progresses rather slowly. The higher percentage of substrate coverage by corals on the seaward slope facies indicates that A. planci predation was probably less intense there or never reached that stage of infestation. The pattern of A. planci infestation along other parts of Guam's coastline shows that shallow submarine terraces bordering the reef front suffered the greatest predation pressure first, followed later by migrations to the deeper seaward slope zones (Randall, 1973b).

Facies A - Submarine Terraces with Rocky Substrates

Although coral coverage is very irregular in this facies, local areas support diverse coral communities and fairly high percentage of substrate coverage, particularly where the facies grade into the reef front biotope or seaward slope facies. Poorest coral development is found in regions lying opposite of reentry channels and along parts of Salinas Beach.

The most conspicuous corals here are large Pocillopora eydouxi colonies which at times reach a meter in diameter and height (Fig. 50). Some of these were of an unusual lavender-pink color that has not been observed elsewhere on Guam. Large colonies of Millepora platyphylla with wide yellow flabellate fronds form conspicuous colonies where the terrace grades into the reef front biotope (Fig. 51). Other common to abundant corals are branching Pocillopora verrucosa, P. elegans, and P. meandrina; encrusting Leptastrea purpurea, Pavona varians, Montipora verrucosa, and M. verrilli; corymbose colonies of Acropora humilis and A. delicatula; and massive and columnar colonies of Goniastrea pectinata, G. parvistella, Porites lutea, P. australiensis, P. (S.) iwayamaensis, P. (S.) convexa, Platygyra rustica, P. sinensis, Leptoria phrygia, Cyphastrea serailia, and various Lobophyllia species. Porites species are the dominant corals, particularly P. lutea, which is found throughout the facies. Some of the largest coralla are the columnar species of P. (S.) convexa and P. (S.) iwayamaensis, similar to the colony shown in Figure 26. Large thick-branched colonies of Acropora palifera are common along the deeper parts of the terrace (Fig. 52).

Facies B - Submarine Terraces with Unconsolidated Substrates

Corals are absent for the most part in this facies because mobile substrates are unfavorable for settlement of coral planula and subsequent growth and development. A few corals become established here by being broken off from other colonies growing on nearby rocky substrates by storm waves. These larger fragments have a greater chance of survival from burial in the shifting sandy substrates than small newly settled corals by virtue of their greater size. Most of the living fragments are eventually killed by burial in this environment. A few encrusting Leptastrea purpurea were found where the sediments were just a few centimeters thick. Other than the few scattered corals mentioned above, coral development in this facies is more or less restricted to regions where rocky substrates protrude through the sediments and provide a relatively stable substrate.

Facies C - Upper Seaward Slope

Coral growth is more diverse and average substrate coverage higher here on these steep slopes than on the shallower submarine terrace (Facies A and B). The seaward slope bordering the broad rocky terrace between Rizal Beach and the reentry channel south of the Pelagi Islets was investigated more thoroughly than any other along Agat Bay. The entire slope to 50 or more meters supports a rich and diverse coral community. Most conspicuous are the tabuloid species of Acropora rambleri, A. rayneri, A. kenti, and A. delicatula (Figs. 53 and 54). Large arborescent Pocillopora eydouxi colonies similar to those observed on the reef front and submarine terraces are found widely scattered on the slope (Fig. 55). Light tan-colored Pavona maldivensis forms large subcolumnar colonies on the slope (Fig. 56), and cuneate-shaped Pavona clavus colonies were occasionally observed at the upper slope where it grades into the adjacent terrace (Fig. 15). Some of the largest corals on the slope, but widely scattered, are the massive dark brown Diploastrea heliopora colonies (Fig. 57), which sometimes reach a diameter of three or more meters. Corals more or less restricted to this deep water facies are foliaceous whorls of Leptoseris, Pachyseris speciosa, Pavona minuta, and Montipora foliosa; encrusting colonies of Montipora danae; nodular submassive patches of Stylocoeniella guentheri; and columnar and explanate forms of Porites (S.) horizontalata. Other common corals are Heliopora coerulea, Porites (S.) convexa, P. (S.) iwayamaensis, P. lichen, Acropora syringodes, A. hystrix, Psammocora (S.) togianensis, Favia speciosa, F. pallida, Goniastrea pectinata, Pocillopora elgans, Cyphastrea serailia, and Seriatopora hystrix.

Facies D - Knobs, Knolls, Mounds, and Pinnacles

Coral growth is generally enhanced on the upper surface of these topographic relief features because of the increased light, water movement, and relative freedom from sedimentation. Commonly these relief features become "mushroom"-shaped because of the greater coral development on the upper parts. Millepora, Platygyra, Porites, and Goniastrea species are commonly found on the cap of these features and in some instances the entire upper surface was found encrusted with alcyonacean soft coral species. These topographic structures apparently are initiated by the growth of large individual coralla, like Porites lutea, which later are expanded by the settling and growth of other species on their upper surface as shown in Figure 54.

OTHER CORAL ENVIRONMENTS AT AGAT BAY

Neye Island

The seaward exposed west and south side of Neye Island lacks a fringing reef platform (Figs. 4 and 5). Here a low sea cliff forms the shoreline (Fig. 58) which has a well-developed nip cut into its limestone face at sea level (Fig. 59). The base or floor of the nip coincides more or less with the mean low tide level. Limpets, nerites, and chitons are abundant in this wave-washed zone and its overall pink color is caused by a layer of encrusting calcareous algae which thinly encrusts most of its surface (Fig. 60). As wave troughs approach, the subtidal surface below the nip is temporarily exposed, showing a number of holes enlarged primarily by solution and the rich algal pavement which continues on down the slope. Snorkel observations around this part of the island revealed steep slopes to 20 or more meters deep on the west side and 6 to 10 meters deep on the south side. These slopes support a community type of coral growth consisting mostly of widely scattered clumps of *Pocillopora* and encrusting patches of *Montipora*. Cracks and fissures along the upper part of the slope contained a few ramose reddish violet-colored *Distichopora* colonies a few centimeters high. At the base of the slope a few large blocks had a number of crinoids with yellow and black pinnules clinging to them. A few large discoid foraminiferans, a centimeter or more in diameter were attached to the low algal turf, but in general the pink colored calcareous algae dominated the slope surface, particularly the upper parts where wave wash was more pronounced. Echinoids have intricately dissected parts of the upper slope into a meandering system of grooves.

Submarine Cables

A series of five or six submarine cables cross the reef front, submarine terrace, and seaward slope at the north end of Dadi Beach (Fig. 4). At places these cables are heavily encrusted with corals, mainly *Pocillopora* and *Porites* species.

Seaward Face of Alutom Island

A very similar submarine environment, as described for Neye Island, is found along the seaward side of this island (Fig. 7). The principal differences are the presence of an erosional spur-and groove system with a narrow submarine terrace and a more diverse coral community along the seaward side of Alutom Island.

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Table 3. Checklist of corals and their relative frequency of occurrence at Agat Bay. Symbols for relative frequency are: D= dominant, A= abundant, C= common, O= occasional, U= uncommon, and R= rare.

BIOTOPES	I	II	III	IV
Stylocoeniella armata (Ehrenberg)		C	C	C
Stylocoeniella guentheri (Bassett-Smith)			O	C
Psammocora contigua (Esper)	U			
Psammocora nierstraszi van der Horst		U	O	C
Psammocora profundacella Gardiner		U	O	O
Psammocora verrilli Vaughan		R	O	
Psammocora (S.) togianensis Umbgrove			C	C
Psammocora (P.) haimeana Milne Edwards & Haime		R	O	O
Stylophora mordax (Dana)		C	C	C
Seriatopora hystrix (Dana)		O	O	A
Pocillopora brevicornis Lamarck		O		
Pocillopora damicornis (Linnaeus)	U	O	O	O
Pocillopora danae Verrill		O		
Pocillopora elegans Dana		O	C	C
Pocillopora eydouxi Milne Edwards & Haime		O	O	O
Pocillopora ligulata Dana			O	
Pocillopora meandrina Dana		C	C	O
Pocillopora setchelli Hoffmeister		C	U	
Pocillopora verrucosa (Ellis & Solander)		U	C	C
Pocillopora woodjonesi Vaughan		O	O	U
Acropora abrotanoides (Lamarck)		R	R	
Acropora brueggemanni (Brook)			U	O
Acropora convexa (Dana)		O	O	
Acropora delicatula (Brook)			O	C
Acropora echinata (Dana)				R
Acropora formosa (Dana)				R

Table 3. (continued)

BIOTOPES	I	II	III	IV
Acropora humilis (Dana)		O	O	O
Acropora hystrix (Dana)		U	C	O
Acropora kenti (Brook)			C	C
Acropora monticulosa (Bruggemann)		O	U	
Acropora murrayensis Vaughan		O		
Acropora nana (Studer)		O	U	
Acropora nasuta (Dana)		O	O	U
Acropora ocellata Klunzinger		O		
Acropora palifera (Lamarck)			U	C
Acropora palmerae Wells		O		
Acropora rambleri (Bassett Smith)			O	D
Acropora rayneri (Brook)			O	A
Acropora smithi (Brook)		R		
Acropora squarrosa (Ehrenberg)	R	O	R	
Acropora surculosa (Dana)		U	O	O
Acropora syringodes (Brook)		O	O	O
Acropora studeri (Brook)		O	O	
Acropora tubicinaria (Dana)				R
Acropora valida (Dana)			O	
Acropora sp. 1			R	
Acropora wardii Verrill		O	O	
Astreopora gracilis Bernard		O	C	C
Astreopora listeri Bernard			O	
Astreopora myriophthalma (Lamarck)		C	C	A
Astreopora profunda Verrill			C	C
Montipora composita Crossland			R	O
Montipora conicula Wells			U	U
Montipora danae Milne-Edwards & Haime			O	C
Montipora ehrenbergii Verrill			U	O
Montipora elschneri Vaughan		O	C	U

Table 3. (continued)

BIOTOPES	I	II	III	IV
Montipora floweri Wells			U	
Montipora foliosa (Pallas)				O
Montipora foveolata (Dana)		O	C	U
Montipora granulosa Bernard			O	O
Montipora hoffmeisteri Wells			C	C
Montipora lobulata Bernard		R	U	
Montipora monasteriata (Forskaal)		U	O	O
Montipora patula Verrill		O	C	O
Montipora socialis Bernard			C	C
Montipora subtilis Bernard			O	O
Montipora tuberculosa (Lamarck)			O	U
Montipora verrilli Vaughan		C	A	C
Montipora verrucosa (Lamarck)		O	C	A
Pavona clavus (Dana)		U	U	U
Pavona maldivensis (Gardiner)			O	O
Pavona minuta Wells			O	C
Pavona varians Verrill		C	A	A
Pavona gardineri van der Horst			R	R
Pavona (*P.*) *pollicata* Wells		R	U	
Pavona (*P.*) *planulata* (Dana)			O	O
Pavona (*P.*) *obtusata* (Quelch)		R	C	O
Pavona (*P.*) sp. 1			O	
Leptoseris hawaiiensis Vaughan		R	U	C
Leptoseris incrustans (Quelch)		R	O	C
Leptoseris mycetoseroides Wells			O	C
Pachyseris speciosa (Dana)			U	C
Anomastraea sp. 1		O	C	C
Coscinaraea columna (Dana)			U	U
Cycloseris sp. 1				O

Table 3. (continued)

BIOTOPES	I	II	III	IV
Fungia concinna Verrill			U	O
Fungia fungites (Linnaeus)			U	
Fungia paumotuensis Stutchbory			U	O
Fungia scutaria Lamarck			C	C
Herpolitha limax (Esper)				O
Goniopora columna Dana			O	U
Goniopora arbuscula Umbgrove			O	C
Goniopora sp. 1			U	
Goniopora sp. 2			U	
Porites andrewsi Vaughan			O	
Porites australiensis Vaughan		O	C	C
Porites cocosensis Wells			R	
Porites compressa Vaughan			R	
Porites duerdeni Vaughan			U	
Porites lichen Dana		U	O	C
Porites lobata Dana	U	C	C	C
Porites lutea Milne Edwards & Haime	D	A	D	A
Porites murrayensis Vaughan		O	C	O
Porites matthaii Wells			O	
Porites sp. 1	O			
Porites sp. 2			U	
Porites (*S.*) *convexa* Verrill		O	C	C
Porites (*S.*) *hawaiiensis* Vaughan		R	C	A
Porites (*S.*) *horizontalata* Hoffmeister				O
Porites (*S.*) *iwayamaensis* Eguchi			C	C
Porites (*S.*) sp. 1		O		
Alveopora verrilliana Dana			R	
Alveopora sp. 1			O	O
Favia favus (Forskaal)			O	R

Table 3. (continued)

BIOTOPES	I	II	III	IV
Favia matthai Vaughan		U	O	
Favia pallida (Dana)		O	A	A
Favia speciosa (Dana)		O	O	C
Favia stelligera (Dana)		A	A	
Favia rotumana (Gardiner)			U	U
Favites abdita (Ellis & Solander)	U	O	U	
Favites complanata (Ehrenberg)		O	O	O
Favites favosa (Ellis & Solander)			U	
Favites flexuosa (Dana)			U	U
Favites virens (Dana)			U	
Oulophyllia crispa (Lamarck)			O	O
Plesiastrea versipora (Lamarck)		U	C	O
Plesiastrea sp. 1			O	O
Goniastrea parvistella (Dana)		U	C	O
Goniastrea pectinata (Ehrenberg)		U	C	C
Goniastrea retiformis (Lamarck)		D	C	R
Platygyra rustica (Dana)		U	C	O
Platygyra lamellina (Ehrenberg)		U	O	O
Platygyra sinensis (Milne Edwards & Haime)		U	C	O
Leptoria phrygia (Ellis & Solander)		O	C	O
Hydnophora microconos (Lamarck)			O	
Leptastrea bottae (Milne Edwards & Haime)	R			
Leptastrea purpurea (Dana)	U	C	A	A
Leptastrea transversa (Klunzinger)		O	C	O
Cyphastrea chalcidicum (Forskaal)	R	O	O	C
Syphastrea serailia (Forskaal)		U	C	O
Cyphastrea sp. 1			R	
Echinopora lamellosa (Esper)		U	O	O
Diploastrea heliopora (Lamarck)			U	O

Table 3. (continued)

BIOTOPES	I	II	III	IV
Galaxea fascicularis (Linnaeus)		O	C	O
Galaxea sp. 1			U	O
Acrhelia horrescens (Dana)			R	
Merulina ampliata (Ellis & Solander)			O	O
Lobophyllia corymbosa (Forskaal)			O	O
Lobophyllia costata (Dana)		U	O	O
Lobophyllia hemprichii (Ehrenberg)			U	U
Acanthastrea echniata (Dana)	U	O	O	
Acanthastrea sp. 1			R	
Echinophyllia asper Ellis & Solander		O	O	C
Mycedium sp. 1			U	O
Desmophyllum sp. 1			O	C
Paracyathus sp. 1		O	O	
Polycyathus verrilli Duncan		O	R	
Plerogyra sinuosa (Dana)			U	O
Euphyllia glabrescens (Chamisso & Eysenhardt)			O	O
Heliopora coerulea (Pallas)		U	C	C
Millepora dichotoma Forskaal		O	C	O
Millepora exaesa Forskaal		O	A	C
Millepora platyphylla Hemprich & Ehrenberg		A	C	O
Distochopora sp. 1		O	O	U
Total Species per Biotope	11	86	147	115
Total Genera per Biotope	8	29	42	41
Total Species for Agat Bay 164				
Total Genera for Agat Bay 46				

Table 4. Percentage of reef substrate coverage by reef corals at Agat Bay.

Biotope	Transect No.	Per cent of Coverage
I	(no transects because of low coral density)	
II	1	20.1*
II	2	4.9
II	3	11.0
II	4	15.7*
III	5	59.8*
III	6	11.2
III	7	28.6
III	8	41.1*
IV	9	22.3*
IV	10	1.0
IV	11	50.2
IV	12	33.7*

*Data from straight line transect method (unpublished field notes, Randall, 1971-72).

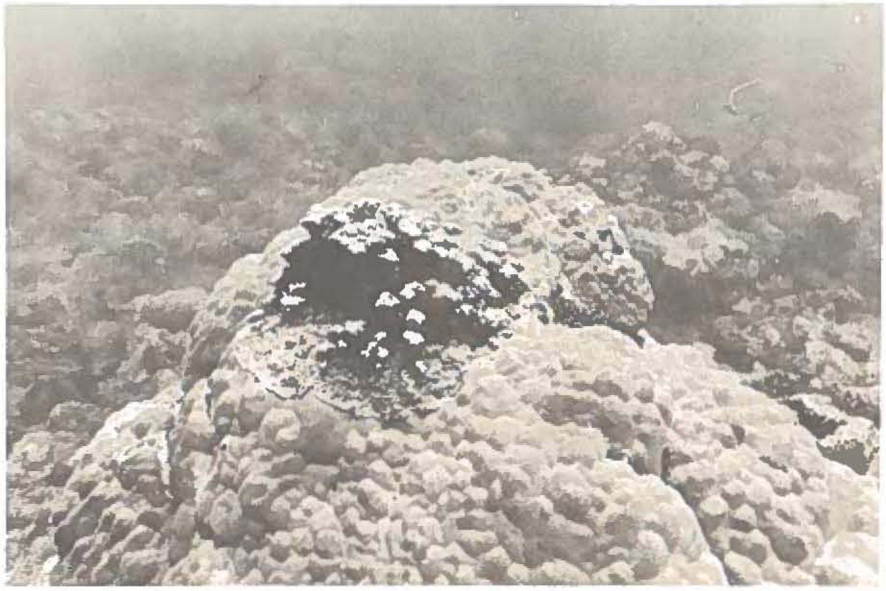

Fig. 40. Porites lutea colony growing on the outer reef front (Biotope III) about a meter across and high with a smaller Porites (S.) convexa colony growing from its upper surface. Depth about 8 meters.

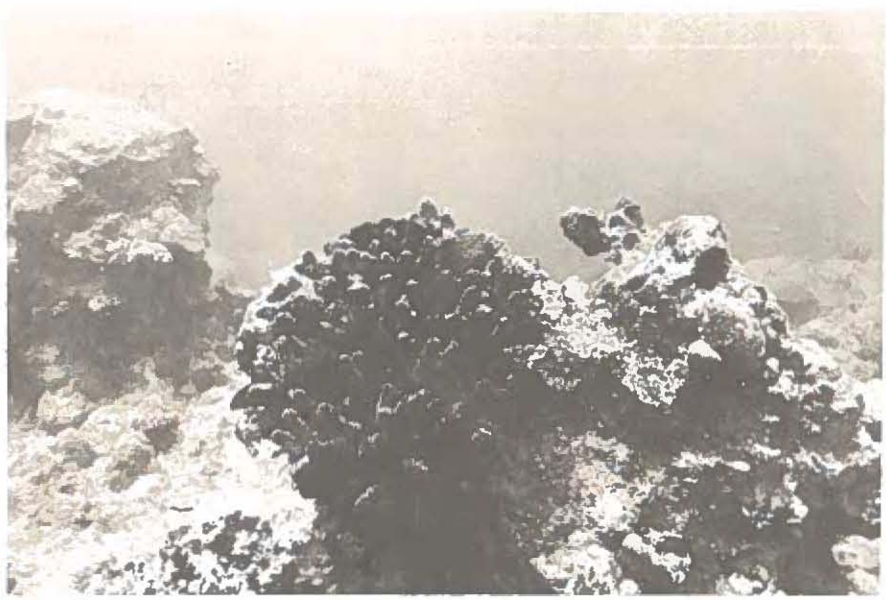

Fig. 41. Irregular upper surface of a reef front buttress (Biotope III, Facies A) with a large dead Pocillopora verrucosa colony about 35 cm diameter in the foreground. Depth about 4 to 5 meters. Large Porites lutea colony forms a knob at the left.

Fig. 42. Upper surface of a seaward dipping reef front buttress (Biotope III, Facies A) with a Pocillopora meandrina colony about 40 cm diameter. Depth about one meter in background and 2 meters in the foreground. A mixed coral community gives the upper buttress a very irregular surface.

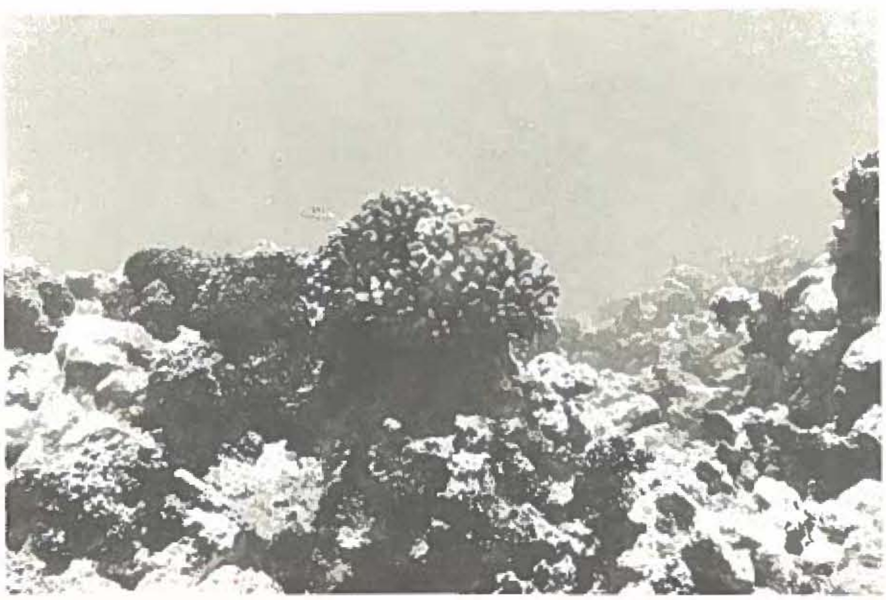

Fig. 43. Large Pocillopora elegans (center) growing on the side of a lobate-shaped reef front buttress (Biotope III, Facies A). Porites and Goniastrea colonies form much of the framework development here. Depth about 4 meters.

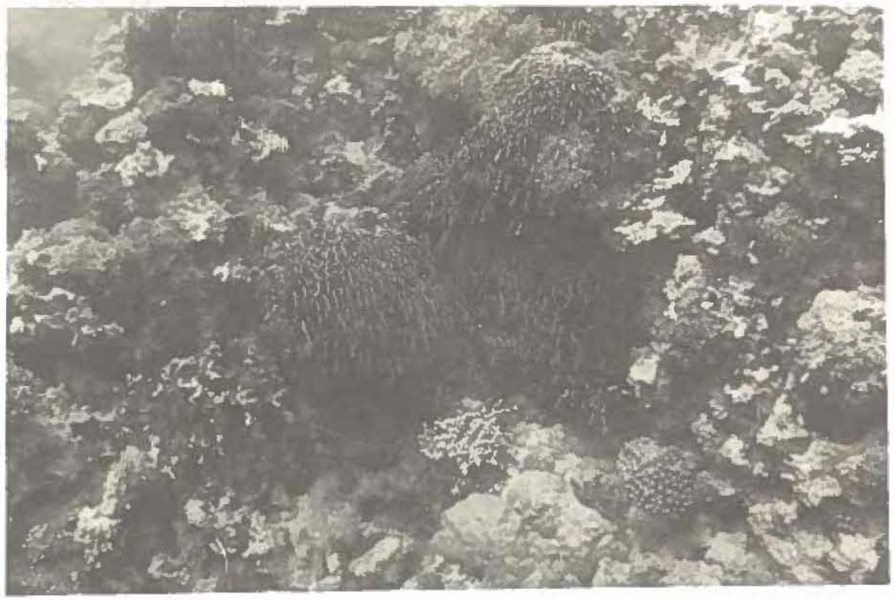

Fig. 44. Rich coral development on the side of a reef front buttress (Biotope III, Facies A). Conspicuous are the large Heliopora coerulea colonies with wide meandering flabellate fronds. Depth at base of photo about 10 meters.

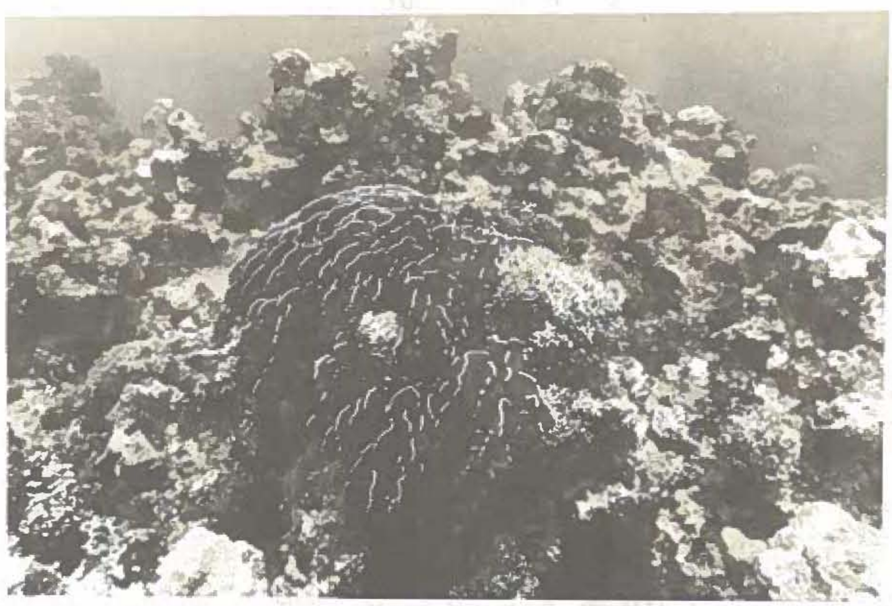

Fig. 45. Large Heliopora colony growing on side of a reef front buttress (Biotope III, Facies A). The upper ridge-line of the buttress (background) is very irregular due to coral growth. Depth at crest of buttress about 3 meters.

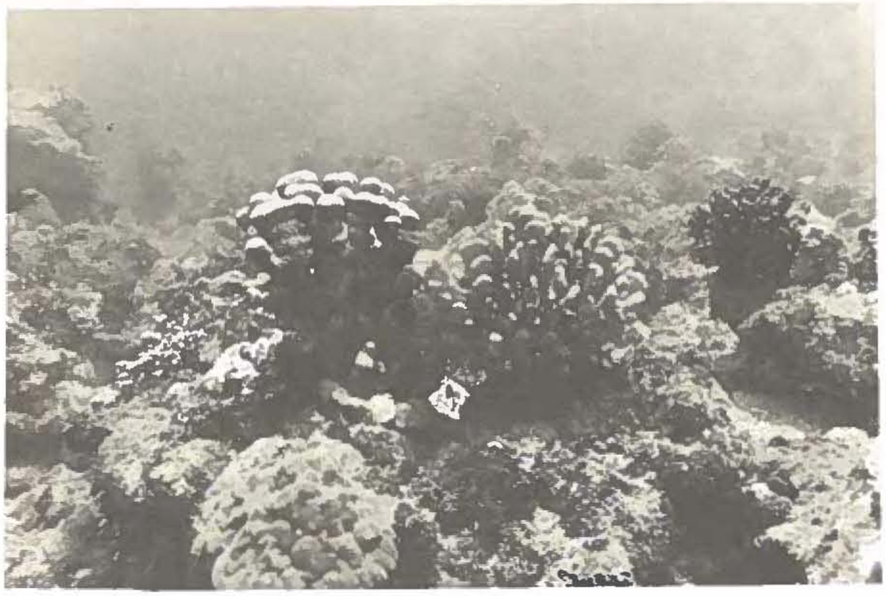

Fig. 46. Psammocora (S.) togianensis (columnar form) and Pocillopora elegans (arborescent form) grow upon the dead upper surface of a Porites lutea colony on the outer reef front (Biotope III). Depth about 10 meters.

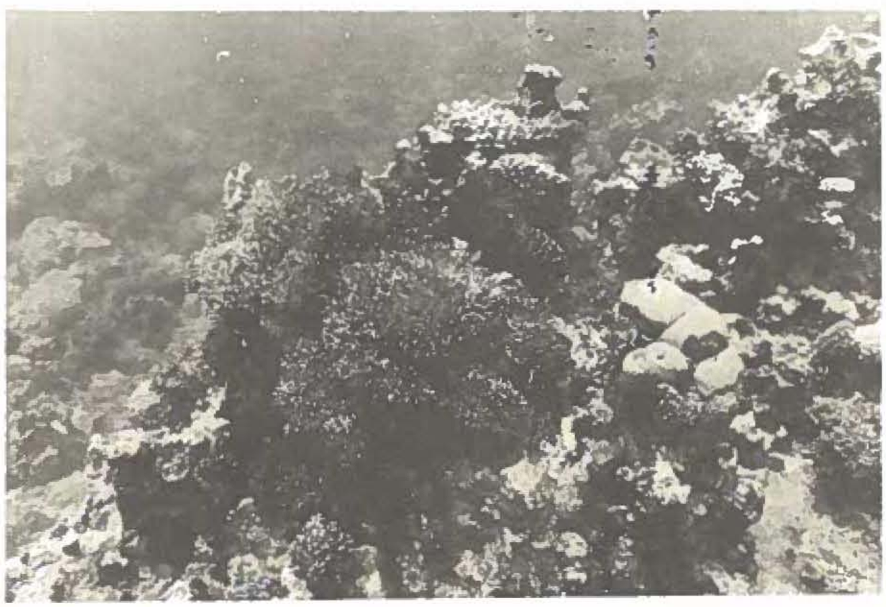

Fig. 47. Mixed coral growth along the upper ridge of a reef front submarine buttress (Biotope III, Facies A) and side of an open "V" shaped submarine channel (Facies B). Depth about 6 meters.

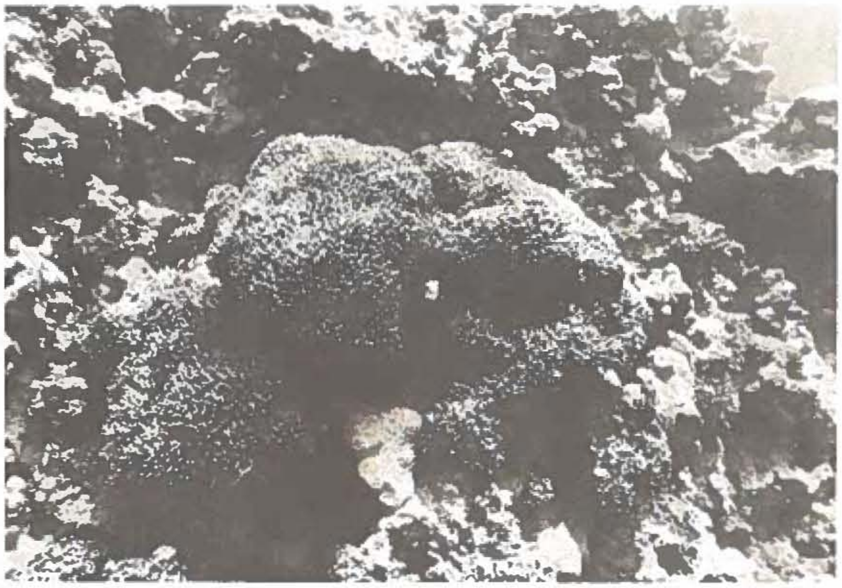

Fig. 48. Large growth of finely branched crustose calcareous algae, about 40 cm across, growing on the side of an open channel wall (Biotope III, Facies B).

Fig. 49. Mixed coral growth at the base of a large patch reef near Dadi Beach (Biotope III, Facies E). Depth about 10 meters.

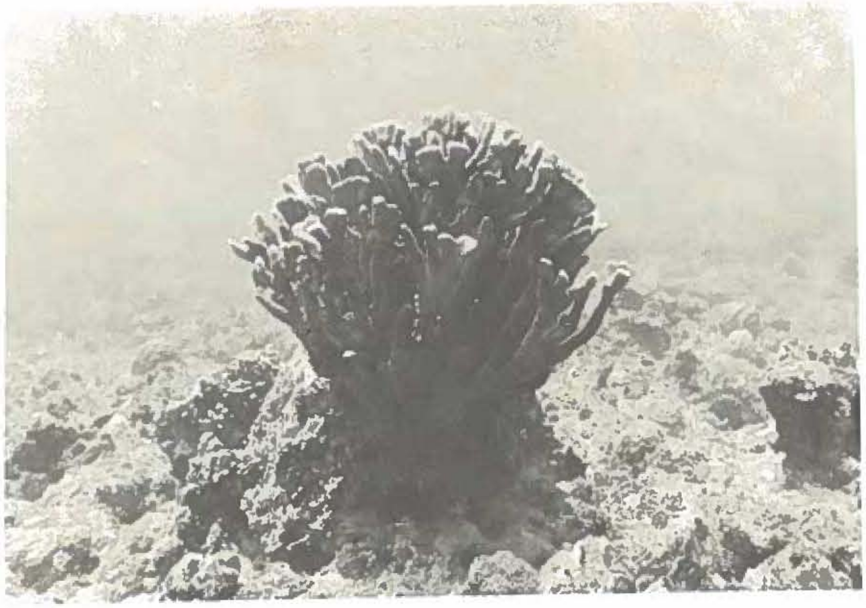

Fig. 50. A large Pocillopora eydouxi colony, about a meter high and wide, growing on the submarine terrace (Biotope IV, Facies A) at the northern end of Agat Bay. Depth about 10 meters.

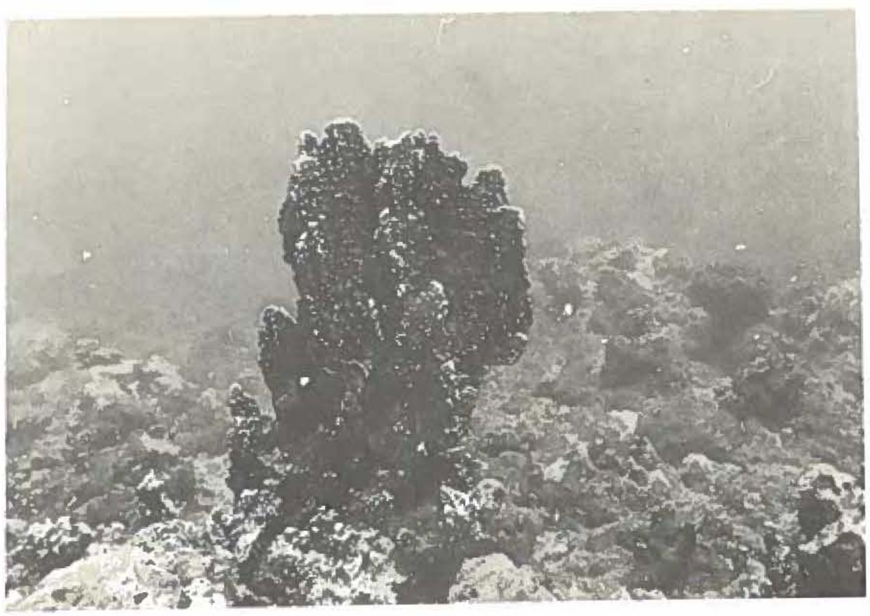

Fig. 51. Large Millepora platyphylla colony with wide flabellate fronds growing on the submarine terrace near mooring Site A (Biotope IV, Facies A), at about 10 meter depth.

Fig. 52. Stoutly branched colony of Acropora palifera growing on the outer terrace at the base of a large sand floored hole (Biotope IV, Facies A). Depth about 20 meters. (Photo by T. L. Tansy).

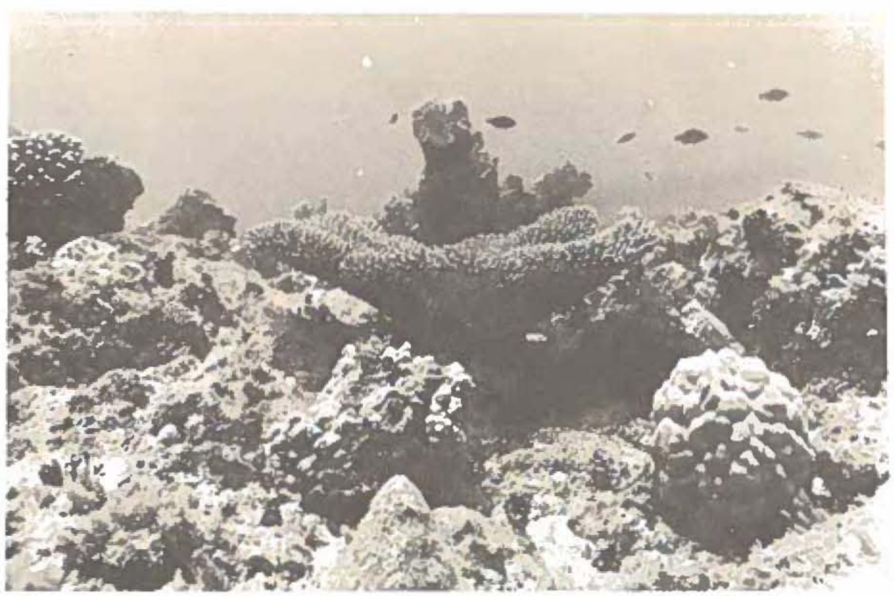

Fig. 53. Large vasiform Acropora delicatula (center), Pocillopora elegans (upper left), modular Porites lutea (lower right) and other corals growing on the upper part of the seaward slope (Biotope IV, Facies C). Depth about 20 meters.

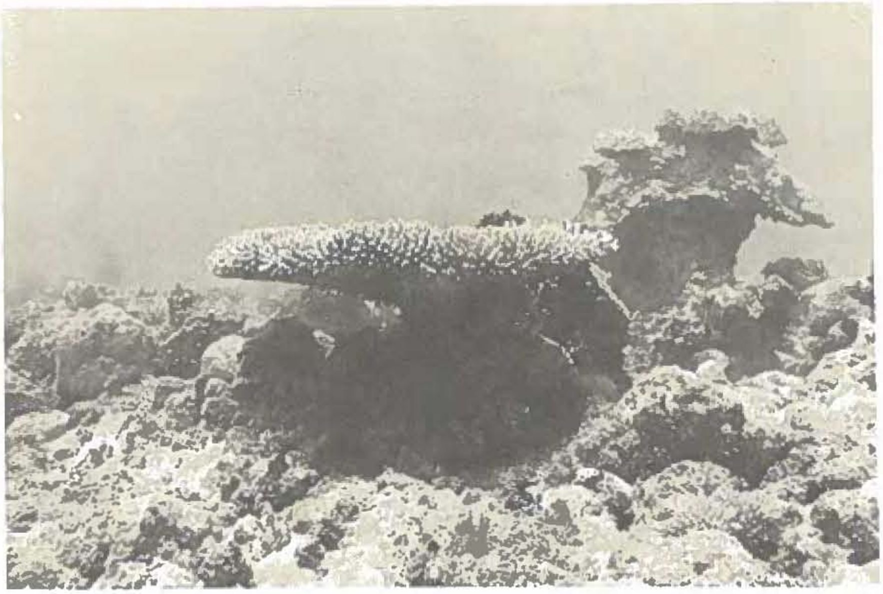

Fig. 54. Large tabuloid Acropora rambleri growing on the seaward slope (Biotope II, Facies C) near mooring Site A. Large mushroom-shaped Porites colony has a number of corals growing on its upper surface in the background. Depth between 20-25 meters.

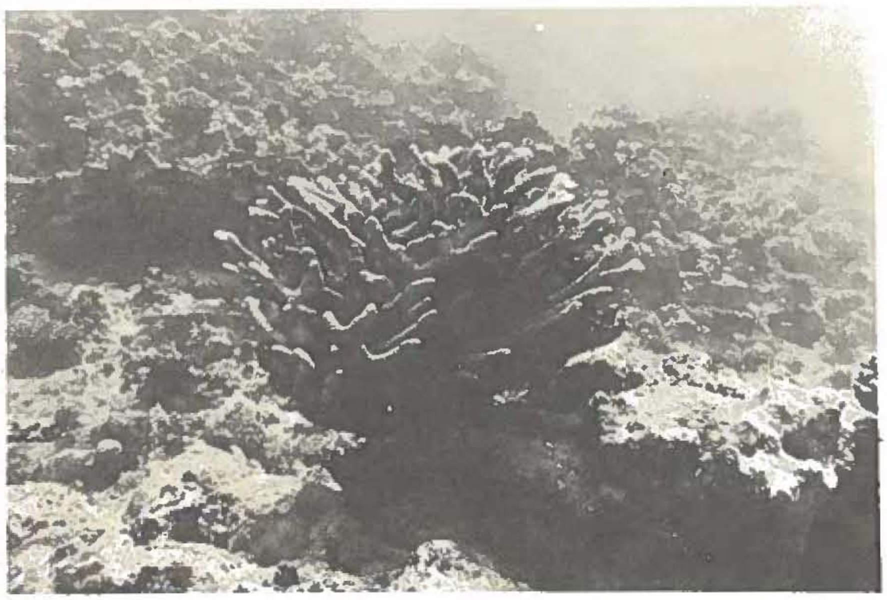

Fig. 55. Pocillopora eydouxi colony growing at 30 meters depth on the seaward slope (Biotope IV, Facies C). Note the more open branching compared to that of the same species in Figure 50 at a shallower habitat with greater light intensity.

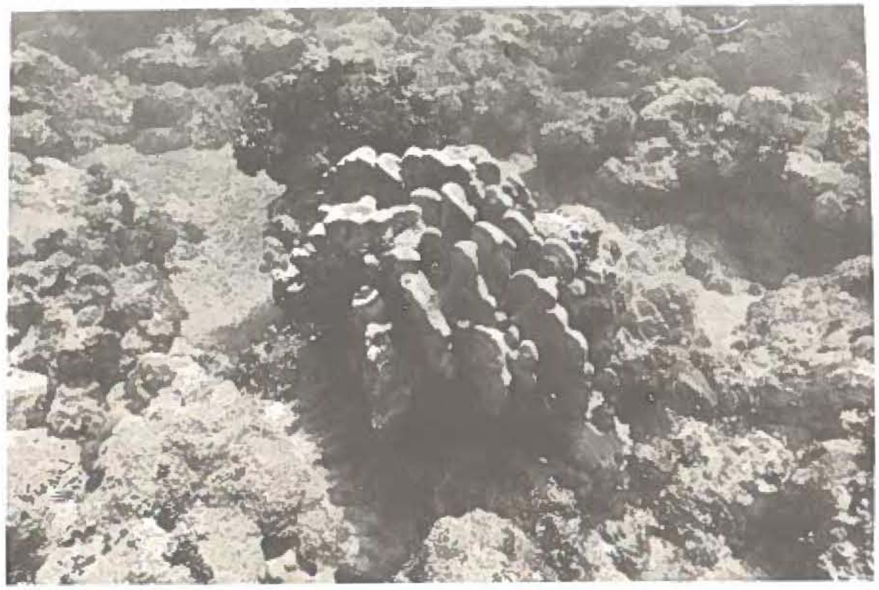

Fig. 56. Subcolumnar colony of Pavona maldivensis growing on the upper seaward slope (Biotope IV, Facies C) at about 22-25 meters depth.

Fig. 57. Large massive colony of Diploastrea heliopora growing on the seaward slope (Biotope IV, Facies C). These colonies commonly attain diameters of three meters or more and form the structural base for knolls and mounds on the seaward slope (Facies D). Depth about 25 meters.

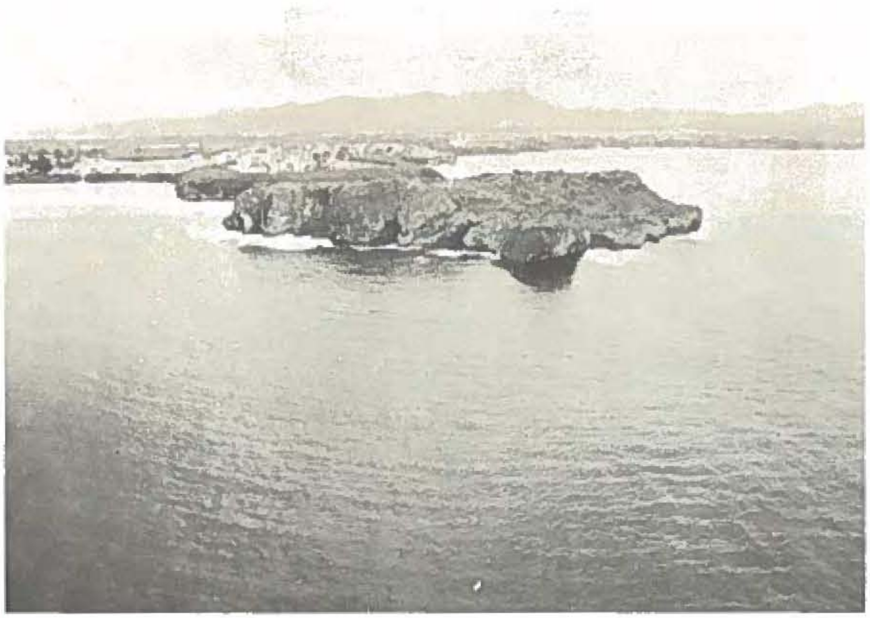

Fig. 58. Aerial view of Neye Island (foreground). A rocky seacliff forms the shoreline here and fringing reef development is absent. Northern Agat Bay is visible on the right and Tipalao Bay on the left. The mountainous land of central Guam is visible in the background.

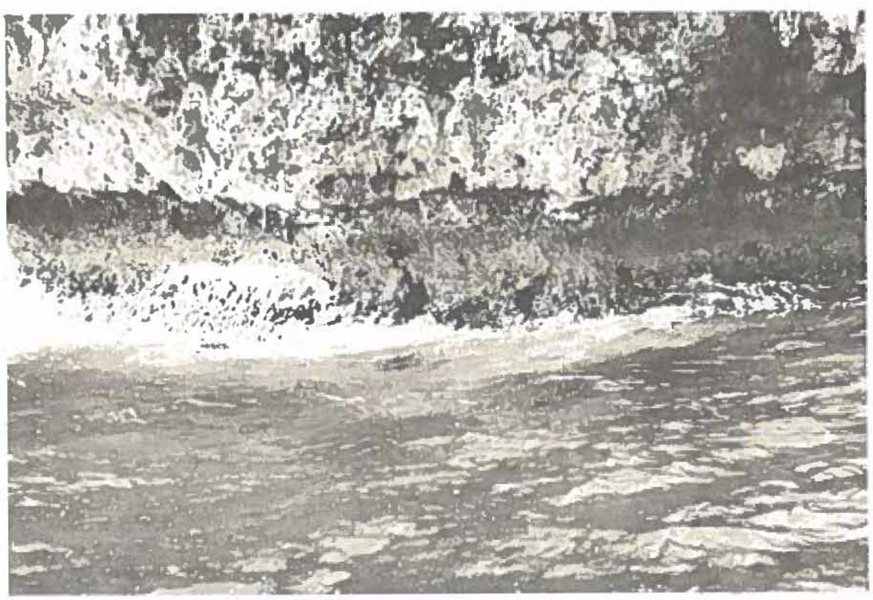

Fig. 59. Sea-level "nip" cut into the base of the limestone cliff at Neye Island. The large holes at the basal part of the nip appear to be formed by solution.

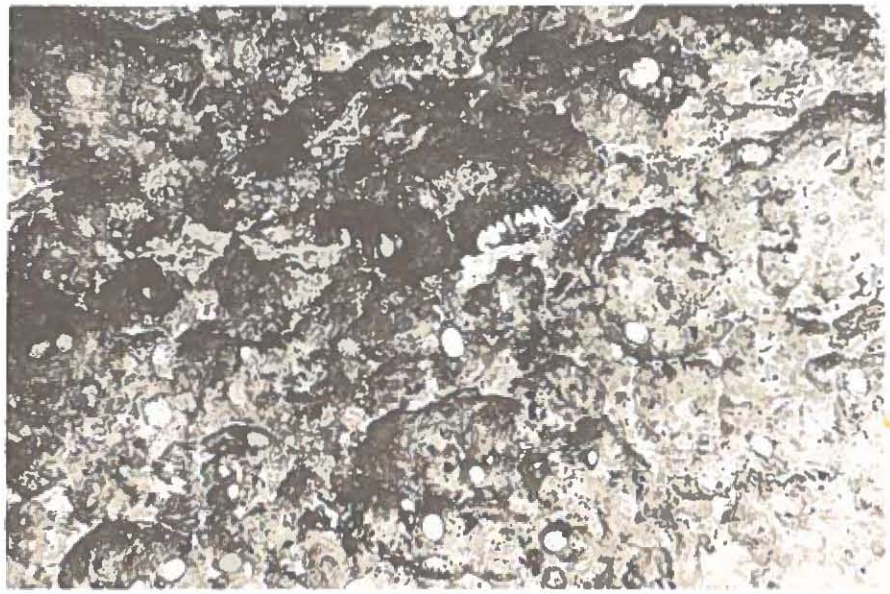

Fig. 60. Limpet and chiton community located in the basal part of the sea-level "nip" illustrated in Figure 59. Pink-colored encrusting algae covers most of the surface not occupied by these molluscs.

GASTROPODS AND BIVALVES

Richard Dickinson and Steve Moras

Marine gastropods and bivalves were collected or identified from all of the 29 stations at Agat Bay (Fig. 17). Reef flat stations were studied during low tides by reef walking and at high tides by snorkeling. Sampling during both tidal periods was necessary because some gastropods are active only during high tides and others only at low tides. Reef front and terrace stations were sampled using SCUBA. Dives were made from the chartered vessels during the 24-hour current stations or from the smaller chase boats. A Zodiac inflatable boat was also used extensively as a dive boat.

Various methods were employed in attempts to quantify the numbers of individuals, but we were not satisfied with the results except for larger aggregations of high intertidal species (Fig. 61).

One method attempted for quantifying involved the use of a 10 sq. meter quadrat on the reef flat. All gastropods or bivalves within the quadrat were identified and counted to give an estimated density. One of these quadrats was sampled at Station 9 and two at Station 17.

A density of two individuals of Vasum turbinellus per 10 sq. meters was found at Station 9 along with many single individuals of other species. The Station 17 quadrats also yielded single individuals but no more than two individuals of any one species per 10 sq. meters.

A 100 m transect tape was used in another sampling method. The transect tape was stretched from the reef flat out over the margin into the deeper water at the reef front. Points were established at 10 m intervals and all gastropods and bivalves within one meter of the point were identified and counted. Thus an area of 31.4 m^2 was searched and a density could be established. Two transects using this technique were run at Station 19 and at both stations only a few species were noted. Some of the more common ones were: Nerita albicilla, Drupa ricinus, Nassarius margaritiferus, Trochus niloticus, Cantharus fumosus, and Gafrarium pectinatum.

At Station 24 (Fig. 37) large numbers of high intertidal gastropods were observed and three transects were run to estimate their density. The transects were sampled during a low tide of 0.0 feet, July 13, 1975.

Transect A began at a point approximately one-third of the distance to the end of Gaan Point penninsula and extended north from the shoreline into the ocean. Transect B began two-thirds of the way along the penninsula and ran parallel to Transect A, and as Transect C began at the end of Gaan Point penninsula and ran parallel to Transects A and B. Gastropods were collected within a 400 cm^2 quadrat at 0.5 m intervals (Fig. 61) along a 10 m tape.

Cerithium morus was the dominant gastropod with a mean density of 160 and 169 individuals per square meter at Transects A and B, respectively. Transect C had no Cerithium morus. Neritina bensoni was also noted with densities per square meter of 12.5, 2.5, and 2.5 at Transects A, B, and C respectively.

The greater numbers of Cerithium morus at Transects A and B is attributed to their more protected location. Transect C was located at the end of Gaan Point penninsula, near the reef margin and would be exposed to more direct wave action.

Another aggregation of Cerithium morus was found along the shore of Station 2 but was not quantified (Fig. 62).

The two reef flat methods for quantifying gave low densities which is significant. However, in order to provide the complete species list of gastropods and bivalves requested by GORCO, we needed to search more and different habitats. We, therefore, discontinued quantifying the gastropods and bivalves, except for the high intertidal aggregation at Gaan Point, and devoted our time to covering a greater area.

Table 5 is a species list of the 93 gastropods and Table 6 is a species list of the 17 bivalves which were noted or collected by Marine Laboratory personnel during the project. This list includes all of the common gastropods and bivalves in Agat Bay. However, some more rare specimens are reported to have been collected from here but only those seen or collected by our field workers are listed.

Table 5 . Gastropods collected at Agat Bay.

	High Inter Tidal	Inner Reef Flat	Outer Reef Flat	Reef Front	Reef Ter-race
Acmaeidae					
Acmaea sp.	X				
Architectonicidae					
Heliacus sp. [cf. *H. variegatus* (Gmelin)]					X
Buccinidae					
Cantharus fumosus (Dillwyn)		X	X		
Cantharus sp.			X		
Bursidae					
Bursa cruentata (Sowerby)			X		
B. verrucosa (Sowerby)			X		
Cerithiidae					
Cerithium aluco (Linnaeus)		X			
C. morus Bruguiere		X			
C. nodulosum Bruguiere		X			
C. pfefferi Dunker		X			
C. ravidum Philippi		X			
Cerithium sp.		X	X		
Conidae					
Conus chaldaeus (Röding)			X		
C. ebraeus Linnaeus			X		
C. flavidus Lamarck			X	X	
C. lividus Bruguiere		X	X	X	
C. miliaris Bruguiere			X	X	
C. miles Linnaeus			X	X	
C. rattus Bruguiere			X	X	
C. sponsalis Bruguiere			X	X	
C. striatus Linnaeus		X			
C. virgo Linnaeus			X		
C. vitulinus Bruguiere			X		
Conus sp.				X	
Cymatiidae					
Cymatium hepaticum (Röding)					X
C. muricinum (Röding)			X		
C. nicobaricum (Röding)		X	X		

Table 5 (continued).

	High Inter Tidal	Inner Reef Flat	Outer Reef Flat	Reef Front	Reef Ter- race
Cypraeidae					
Cypraea annulus Linnaeus			X		
C. arabica Linnaeus			X	X	
C. caputserpentis Linnaeus			X	X	
C. cassiaui Burgess				X	
C. erosa Linnaeus				X	
C. moneta Linnaeus		X	X		
C. tigris Linnaeus			X		
Fasciolariidae					
Peristernia nassatula (Lamarck)			X	X	
Latirus sp. 1			X		
Latirus sp. 2				X	
Littorinidae					
Littorina coccinea (Gmelin)	X				
L. scabra (Linnaeus)	X				
L. undulata Gray	X				
Magilidae					
Coralliophilia violacea (Kiener)			X	X	
Quoyula madreporarum (Sowerby)				X	
Mitridae					
Imbricaria olivaeformis (Swainson)					X
Mitra cucumerina Lamarck		X	X		
Mitra sp.			X		
Strigatella paupercula (Linnaeus)				X	
Strigatella sp. (cf. *S. litterata* Lamarck)		X			
Muricidae					
Chicoreus penchinati (Crosse)		X	X		
Drupa grossularia (Röding)			X	X	
D. morum (Röding)			X	X	
D. ricinus (Linnaeus)			X	X	
D. rubusidaeus (Röding)		X		X	
Drupella cornus (Röding)			X	X	
Morula granulata (Duclos)		X	X	X	
M. penistrada Blainville				X	
M. triangulata Pease			X		
M. uva (Röding)			X	X	
Morula sp. [cf. *M. fiscella* (Gmelin)]		X			
Morula sp. (Röding)		X	X		
Nassa serta (Burguiere)			X		
Thais armigera (Link)			X	X	

Table 5 (continued).

	High Inter Tidal	Inner Reef Flat	Outer Reef Flat	Reef Front	Reef Terrace
Nassariidae					
Nassarius margaritiferus (Dunker)		X	X		
Naticidae					
Mamilla opaca (Recluz)			X		
Natica gualtieriana Recluz					X
Natica sp.			X		
Polinices melanostomus (Gmelin)		X	X		
Polinices sp.					X
Neritidae					
Nerita albicilla Linnaeus	X	X	X		
N. plicata Linnaeus	X				
N. polita Linnaeus	X				
Neritina bensoni (Recluz)	X				
Olividae					
Oliva sp.					X
Olivella sp.					X
Patellidae					
Patella sp.	X				
Patella sp.	X				
Planaxidae					
Planaxis decollatus Quoy & Gaimard	X	X			
P. sulcatus (Born)	X	X			
Siphonariidae					
Siphonaria guamensis Quoy & Gaimard	X				
Strombidae					
Lambis lambis (Linnaeus)		X	X		
L. truncata (Humphrey)					X
Strombus luhuanus Linnaeus		X	X		
S. mutabilis Swainson		X	X		
S. urceus Wood					X
Terebridae					
Terebra sp. 1					X
Terebra sp. 2					X
Trochidae					
Gibbula sp.				X	
Tectus pyramis (Born)				X	
Trochus niloticus Linnaeus		X	X	X	
T. maculatus Linnaeus			X	X	
Trochus sp.				X	

Table 5 (continued).

	High Inter Tidal	Inner Reef Flat	Outer Reef Flat	Reef Front	Reef Ter-race
Turbinidae					
Australium petrosum (Martyn)			X	X	
Turridae sp.					X
Vasidae					
Vasum ceramicum (Linnaeus)				X	
V. turbinellus (Linnaeus)		X	X	X	

Table 6. Bivalves collected at Agat Bay.

	Inner Reef Flat	Outer Reef Flat	Reef Front	Reef Terrace
Carditidae				
Cardita variegata Bruguiere	X	X		
Chamidae				
Chama sp.	X	X		
Donacidae				
Donax sp.	X			
Limidae				
Lima sp.	X			
Mytilidae				
Isognomon sp. 1				X
Isognomon sp. 2	X	X		
Modiolus auriculatus Krauss	X			
Septifer bilocularis (Linnaeus)		X		
Pectinidae				
Chlamys sp.				X
Pectin sp.				X
Pinnidae				
Pinna muricata Linnaeus	X			
Pteriidae				
Pinctata margaritifera Linnaeus	X			
Tellinidae				
Arcopagia scobinata (Linnaeus)		X		
Quidnipagus palatam Iredale	X			
Tridacnidae				
Tridacna maxima (Röding)	X	X	X	
Veneridae				
Gafrarium pectinatum Linnaeus	X			
periglypta reticulata (Linnaeus)	X	X		

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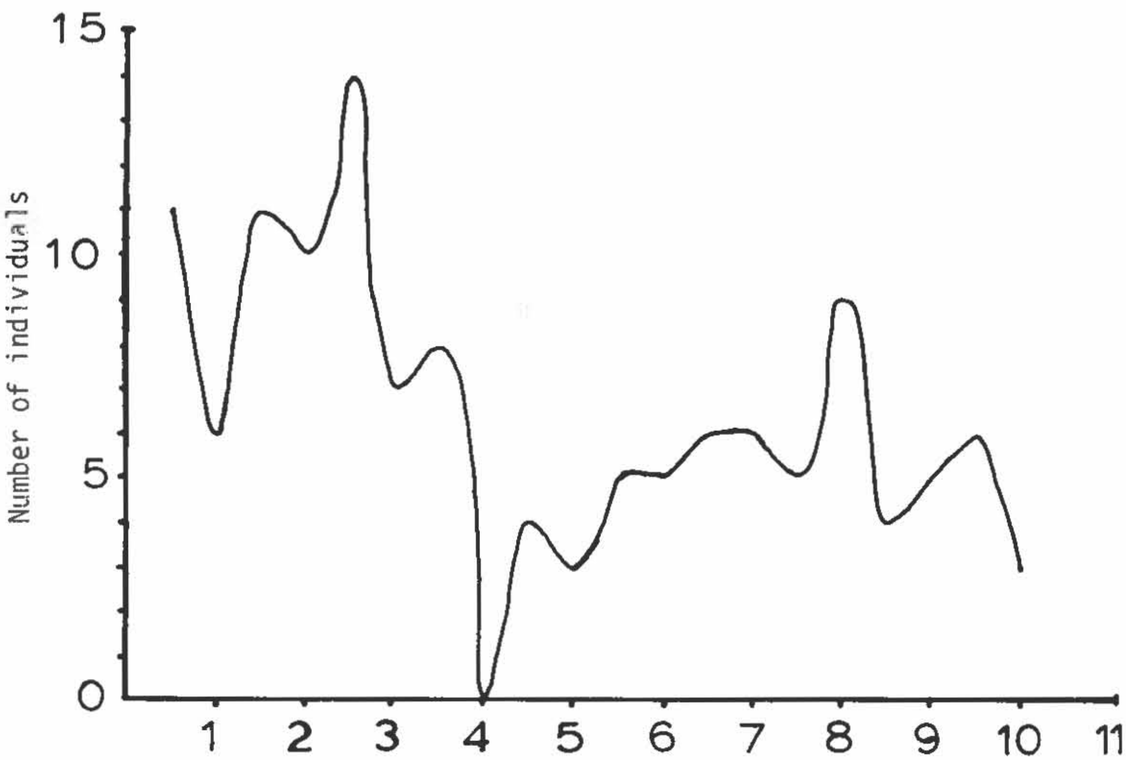


Sample points at 50 cm intervals along Transect A.

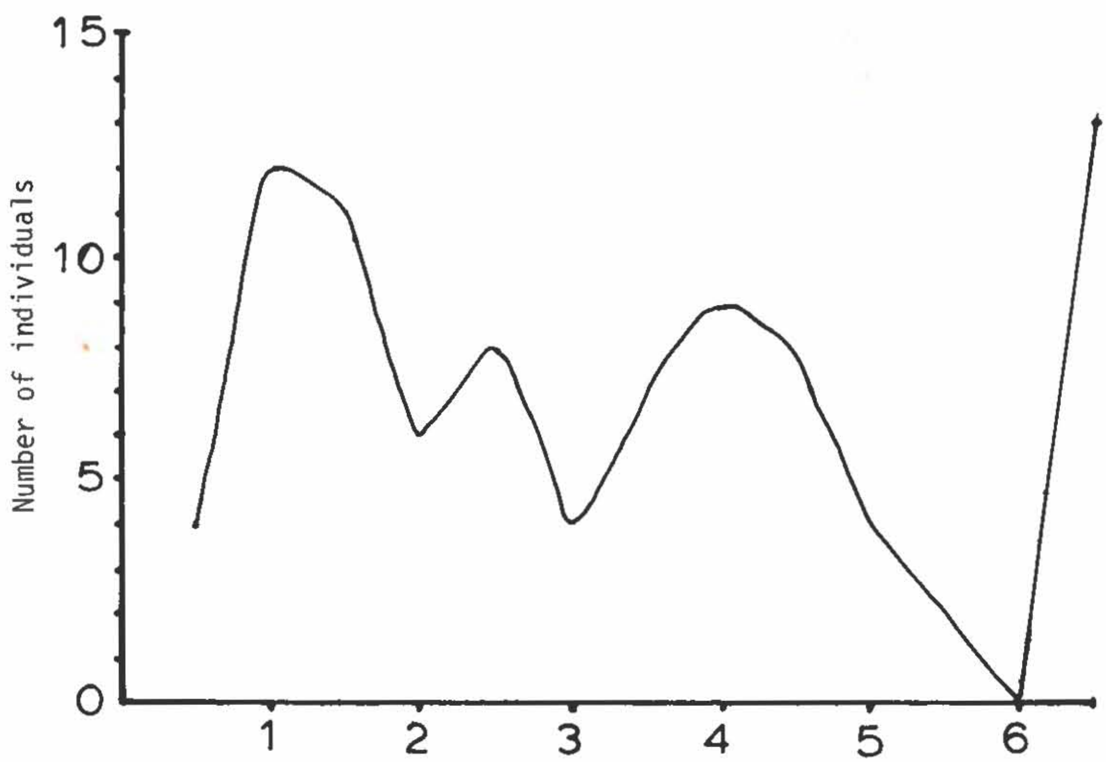


Fig. 61. Shows the number of individuals of <u>Cerithium</u> <u>morus</u> Bruguiere collected along Transects A and B at Station 21.

Fig. 62. Large aggregation of the gastropod, *Cerithium morus*, at Station 2.

OPISTHOBRANCHS

Clayton Carlson and Patty Jo Hoff

Between June, 1974, and May, 1975, thirteen collections of opisthobranchs were made in the Agat Bay area. A total of 52 species were found. All except one species had previously been collected in the area of Bile Bay, Merizo.

SYSTEMATICS

The Opisthobranchia are a subclass of marine moluscs of the class Gastropoda. The animals collected at Agat represent 5 orders and one unclassifiable specimen. The codes in brackets, [C.43], [E1.9], etc., are the reference numbers of particular species in the author's collection.

SUBCLASS: Opisthobranchia

Order: Cephalaspidea

Family: Acteonidae

Pupa sulcata (Gmelin 1791)

Family: Scaphandridae

Acteocina voluta (Quoy & Gaimard 1824)

Acteocina sp. [C.43]

Family: Aglajidae

Odontoglaja sp. [C.11]

Chelidonura hirundinina (Quoy & Gaimard 1832)

Philinopsis gardineri (Eliot 1903)

Family: Gastropteridae

Gastropteron brunneomarginatum Carlson & Hoff 1974

Gastropteron flavum Baba 1964

Sagaminopteron nigropunctatum Carlson & Hoff 1973

Sagaminopteron psychedelicum Carlson & Hoff 1974

Family: Runcinidae

Ilbia sp. [C.16]

Metaruncina setoensis (Baba 1954)

Runcinidae sp. [C.54]

Family: Atyidae

Atys cylindrica (Helbling 1779)

Atys sp. [C.42]

Family: Smaragdinellidae

Phanerophthalmus sp. [C.48]

Order: Anaspidea

Family: Aplysiidae

Dolabrifera dolabrifera (Rang 1828)

Phyllaplysia taylori (Dall 1900)

Stylocheilus longicauda (Quoy & Gaimard 1824)

Order: Nataspidea

Family: Pleurobranchidae

Berthella sp. [#44]

Order: Sacoglossa

Family: Elysiidae

Elysia sp. [El.6]

Elysia sp. [El.12]

Elysia sp. [El.27]

Elysia sp. [El.9]

Elysia halimedae Macnae 1954

Elysia ratna Marcus 1965

Elysia trisinuata Baba 1949

Placobranchus ocellatus vanHasselt 1824

Order: Doridoidea

Family: Phyllidiidae

Phyllidia cf. *variabilis* (Collingwood 1881)

Phyllidia sp. [P.9]

Family: Dorididae

Chromodoris sp. [D.16]

Chromodoris sp. [D.I.1.a]

Chromodoris fidelis (Kelaart 1858)

Chromodoris quadricolor (Ruppell & Leukart 1831)

Doriopsis pecten (Collingwood 1881)

Family: Hexabranchidae

Hexabranchus sp. [D.80]

Family: Polyceridae

Gymnodoris citrina (Bergh 1877)

Family: Vayssiereidae

Okadaia elegans Baba 1931

Family: Dendrodorididae

Dendrodoris elongata Baba 1936

Dendrodoris nigra (Stimpson 1856)

Order: Dendronotoidea

Family: Marianiidae

Marianina rosea (Pruvot-fol 1930)

Order: Eolidoidea

Family: Flabellinidae

<u>Coryphella ornata</u> Risbec 1928

<u>Coryphella</u> sp. [Eo.4]

Family: Glaucidae

<u>Favorinus japonicus</u> Baba 1949

<u>Pteraeolidia ianthina</u> (Angas 1964)

Family:

<u>Phestilla sibogae</u> Bergh 1905

<u>Eolid</u> sp. [Eo.1]

<u>Eolid</u> sp. [Eo.16]

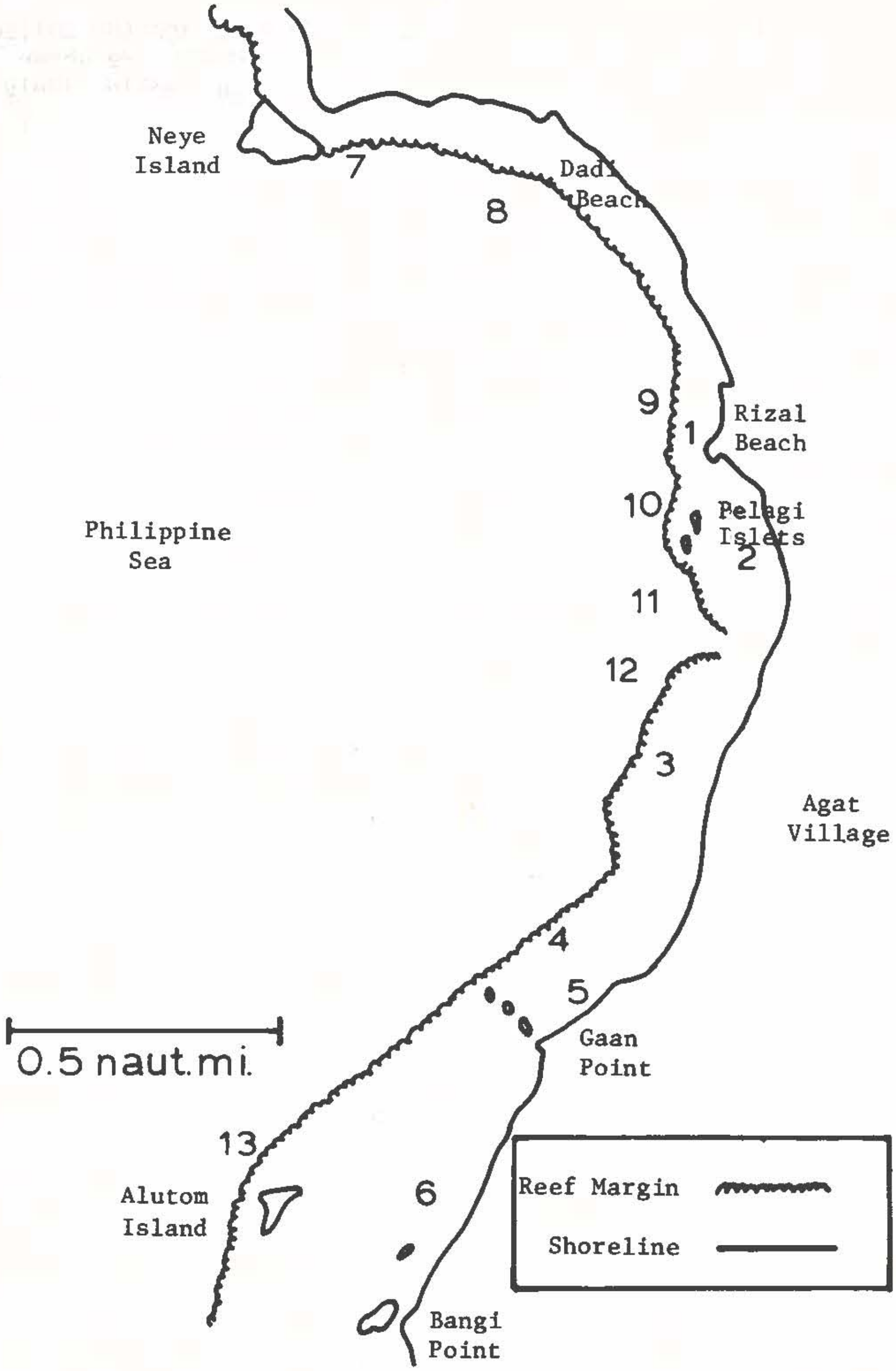
<u>Eolid</u> sp. [Eo.17]

"Opisthobranch sp." [El.42]

COLLECTING STATIONS

The approximate location of the collecting stations is shown on the following map.

Station number	Date	Comments
1	3/23/75	reef flat
2	6/15/74	reef flat
3	5/26/75	reef flat
4	2/ 2/75	outer reef flat
5	10/ 4/74	reef flat
6	7/20/74	inner reef flat
7	6/16/74	reef margin to meters
8	2/16/75	reef front, 3 - 9 meters
9	11/11/74	reef margin
10	7/26/74	reef front, 3 - 6 meters
11	3/15/75	reef front, 3 - 7.5 meters
12	5/ 1/74	reef margin
13	6/22/74	reef front, 2 - 7.5 meters



Opisthobranch collecting stations

The following table lists the opisthobranchs and the collecting areas where they were found. Reef flat stations are shown first and then reef margin and reef front stations collectively made up the second group. The number represents the number of specimens found and A stand for 'Abundant' (more than 15 or 20).

SPECIES	STATION NUMBER Reef flat 1	2	3	4	5	6	Reef margin/front 7	8	9	10	11	12	13
Pupa sulcata											1		
Acteocina voluta	4		3			A					5		
Acteocina sp. [C.43]				1									
Odontoglaja sp. [C.11]							1		1				
Chelidonura hirundinina			3										
Philinopsis gradineri											1		
Gastropteron brunneomarginatum												1	
G. flavum									1				
Sagaminopteron nigropunctatum							1						
S. psycheledlicum													2
Ilbia sp. [C.16]									1				
Metaruncina setoensis			A						2	1		1	
Runcinidae sp. [C.54]												1	
Atys cylindrica			1										
Atys sp. [C.42]		3		1		A					7		
Phanerophthalum sp. [C.48]									1				
	1	2	3	4	5	6	7	8	9	10	11	12	13

	1	2	3	4	5	6	7	8	9	10	11	12	13
Dolabrifera dolabrifera	2		2		3								
Phyllaphysia taylori			6	A	A								
Stylocheilus longicauda								1			1		
Berthella sp. [#44]			2	1									
Costasiella sp. [El.58]		A	A	A	A	A							
Elysia sp. [El.6]											1		
Elysia sp. [El.12]	1												
Elysia sp. [El.27]									1				
Elysia sp. [El.9]							1						
Elysia halimedae	1	3	1										
Elysia ratna			2				2				1		
Elysia trisinuata							1						
Placobranchus ocellatus	5		6	3	2				1				
Phyllidia cf. variabilis								1				1	
Phyllidia sp. [P.9]							1						
Chromodoris sp. [D.16]												1	
Chromodoris sp. [D.I.1]							1						

1 2 3 4 5 6 7 8 9 10 11 12 13

	1	2	3	4	5	6	7	8	9	10	11	12	13
Chromodoris fidelis	1												
Chromodoris quadricolor								2			1		2
Doriopsis pecten			1										
Hexabranchus sp. [D.80]													1
Gymnodoris citrina								1					
Okadaia elegans	1												
Dendrodoris elongata			2										
Dendrodoris nigra					1		1						
Marianina rosea			9	1	1		1						
Coryphella ornata									2				1
Coryphella sp. [Eo.4]									2				
Favorinus japonicus											3	1	
Pteraeolidia ianthina							1						
Phestilla sibogae											1		
Eolid sp. [Eo.1]									2				
Eolid sp. [Eo.16]	1												
Eolid sp. [Eo.17]			1	1								1	
"Opisthobranch sp." [El.42]							1						
	1	2	3	4	5	6	7	8	9	10	11	12	13

In addition to the above, one additional eolid was found that would represent a new species for Guam. However, since the animal was disintegrating, it was not recorded.

REMARKS

The opisthobranch fauna and the numbers found in the Agat area are similar to those found in other areas on the lee side of Guam. All species found, with the exception of the uncataloged eolid, have also been collected in the area of Merizo.

Heavy populations of Costasiella sp. [El.58] were found on Avrainvilla obscura. This would be expected whereever this alga is found. The cephalaspid, Atys sp. [C.42], is common on sandy areas that are overlayed with fine sediment. The Agat population found in the inner reef flat area of heavy mud sediment (Station 6) was somewhat unique in that it represented a breeding population--the first found of this species by the authors on Guam.

Lack of population was noticeable in two areas. At Station 10, although Halimeda macroloba was profuse, the associated sacoglossan, Elysia halimedae, was not found. This area was also the least populous of the study area. The aplysoid form, Phyllaphysia taylori is very common on the sea grass Enhalus acoroides. In the Agat study area P. taylori was observed where expected (stations 4,5) except for Station 2 where none were found.

FISH

M. Gawel

Introduction

A survey of the marine fishes of Agat Bay, Guam was conducted from October through December 1974 in coordination with studies of currents, reef physiography, corals, mollusks, other invertebrates, and algae of that area.

Review of Literature

The only previous references to fishes of the Agat Bay area are found in the checklists of Guam fishes by Kami et al., 1968, and Kami, 1971. Twenty-five marine species from the Agat area were listed, with no ecological data.

Methods

To provide better data, eleven 100 m transects covering different reef zones and habitats were made. Each transect followed a tape marked in centimeters and lying on the substrate. All species of fish seen during a 20 minute reconnaisance of the area near the tape were recorded. Then a 20-minute count was made of all fish observed within one horizontal meter of the transect line, i.e. in an area of 100 x 2 m. The length and species of each fish was recorded in pencil on mylar sheets. The number of 10 m segments along the transect in which each species was found provided a frequency of the species in the transect.

The results of these transects may be used as a comparison with those of future duplicate transects to measure environmental changes due to effects of coastal developments or other factors impacting on the ecology of the area. The author has retained records of lengths of every one of the 1,182 individual fishes counted. When conversion factors have been derived for calculating the biomasses of the more important species based on their lengths, an estimate of the biomass of fish per area along each transect can be calculated. But such results must await a study to measure live weights of large numbers of the important fish species of Guam.

Biotopes

The biotopes and facies described in Randall's study of the corals of Agat Bay apply to the survey of fishes as well. The following list of biotopes and facies are followed by the numbers of the fish transects that were made in each:

Biotope I - Fringing Reef-Flat Platform		1, 2
Facies A	Inner Reef Flat	1, 2
Facies B	Outer Reef Flat	1, 2
Facies C	Reef Flat Holes or Tide Pools	1, 2
Facies D	Reef Flat Reentry Channels	1
Biotope II - Reef Margin		3, 4
Facies A	Upper Reef Margin Slope	3, 4
Facies B	Open Surge Channels	3, 4
Facies C	Cavernous Surge Channels	3, 4
Facies D	Reef Margin Holes	4
Biotope III - Reef Front		5, 6
Facies A	Upper Reef Front Slopes	5, 6
Facies B	Submarine Channels	5, 6
Facies C	Cavernous Regions	0
Facies D	Reef Front Holes	5, 6
Facies E	Knolls, Knobs, Pinnacles & Patch Reefs	5, 6
Biotope IV - Upper Seaward Slopes, Shallow Submarine Terraces		7, 8, 9, 10, 11
Facies A	Rocky Submarine Terraces	9
Facies B	Unconsolidated Submarine Terraces	10, 11
Facies C	Upper Seaward Slopes	7, 8
Facies D	Knobs, Knolls & Pinnacles	7, 8

Results

The location of each fish transect is shown on the map following. Table 7 contains the complete checklist of fishes observed during this study and/or recorded in the literature as occurring in Agat Bay. Scientific names are listed alphabetically in the categories of families, genera, and species. The total number of individuals observed and the number of 10 m segments having the species are recorded for each species on each of the transects. Transects 10 and 11 on the submarine terrace facies of unconsolidated substrate (sand, silt, and clay) produced no fish observations and are omitted from the table. The last column "L" indicates reference in previous literature to the species being in the Agat area. If a fish were observed on reconnaisance dives but not counted on a transect, it is indicated by "O."

Transects 1 and 2 were made diagonally across the inner and outer reef flat facies opposite Rizal Beach. Both crossed small holes in the reef flat (Facies C) and the first also crossed some reentry channels (Facies D). The most important families of fishes seen were Pomacentridae (damselfishes) and Labridae (wrasses), which remain in the transect area during all tide phases, and Acanthuridae (surgeonfishes), which are most common at high tide but normally are not seen at low tide. Thirty of the 130 fishes counted were the small wrasse Halichoeres margaritaceus while the damselfishes Abudefduf amabilis and A. leucopomus (which may be color variations of the same species) numbered 22 and 51, respectively. Seventy-nine per cent of the individuals counted were of these three species. Fourteen other species made up the rest of the count while 32 different species were observed altogether.

Transects 3 and 4 were made along the reef margin between the Pelagi Islands and the deep hole south of them which forms a channel over 10 m deep interrupting the normal line of the reef margin. All four facies of the reef margin biotope were sampled by these transects. One hundred sixteen species were observed here, more than in any other biotope. Also the reef margin had more families and genera than other biotopes. The most numerous species was Pomacentrus melanopterus, which also showed the greatest frequency of occurrence. Twenty-one per cent of the fishes counted were of this species, while the second most common species Acanthurus nigrofuscus, made up only 7.5% of the count. Families with greatest representation were Pomacentridae, Labridae, Acanthuridae and Blenniidae. Eight species of Apogonidae (cardinal fish), six of Muraenidae (moray eels), and a few of other families were cryptic species found at the poison station but otherwise not observed along the reef margin transects. The area of poisoning was a four meter stretch of reef margin comparable to the transect areas but located approximately 100 m north of Pelagi Islands.

Transects 5 and 6 covered the reef front, Biotope III, although they missed the facies of the cavernous regions. They were made in an area with rich coral growth and relatively great relief due to holes, pinnacles, knobs, knolls, and large coral colonies. Depth along these transects varied from three to six meters. Three hundred thirty-two individuals of 44 species were counted, while 79 species were observed in this biotope. Again damselfish are the most important of the families, followed by wrasses, surgeonfish and blennies in descending order. The most abundant species, Pomacentrus vaiuli, made up 14% of the total count, while 66% of all the fish counted were in the family Pomacentridae. The density of fishes counted, averaged over both transects, was 0.83 fish per square meter, a higher density than that of any of the other three biotopes.

The two transects covering the upper seaward slopes, Facies C of Biotope IV, were at different depths and separate locations, but were in such similar habitats that the fish communities were very much alike. These transects 7 and 8 are therefore combined to provide data for comparison with other facies. Two hundred thirty-one individuals of 38 species were counted among the numerous coral colonies there and 51 species were observed in toto. Pomacentrus amboinensis was the most numerous fish, making up 19% of the fish counted. The damselfish family was again the most important in numbers of individuals. Thirteen different species of Labridae were observed and eight different Pomacentridae.

The submarine terrace facies of Biotope IV was sampled by a single transect near the anchorage of the ship Havaiki, which was the Marine Lab's base for field work in Agat Bay. The hard rock substrate did not have as great a cover of coral as the seaward slopes of this biotope but the fish density, 0.91 per m^2, was higher. The community composition at this depth of 20-25 m was markedly different from that at shallower transects. Damselfish were represented by five species while ten species of wrasses, nine butterflyfish (Chaetodontidae), seven triggerfish (Balistidae) five surgeonfish and no blennies were seen. The most numerous species, Pomacentrus vaiuli, also had the greatest frequency. It composed 36% of all the fish counted on Transect 9. The second and third most numerous species were also damselfish.

As mentioned earlier, two hundred meters of transect on the facies of unconsolidated submarine terrace at 14-15 m depth failed to produce any fish. The lack of fish on this facies balances the abundance of fishes on the other three facies of this biotope to give an overall lesser density than Biotopes II and III. However, in the case of fishes it is more meaningful to consider the unconsolidated submarine terrace as a special facies not to be compared with those having coral cover or solid substrate.

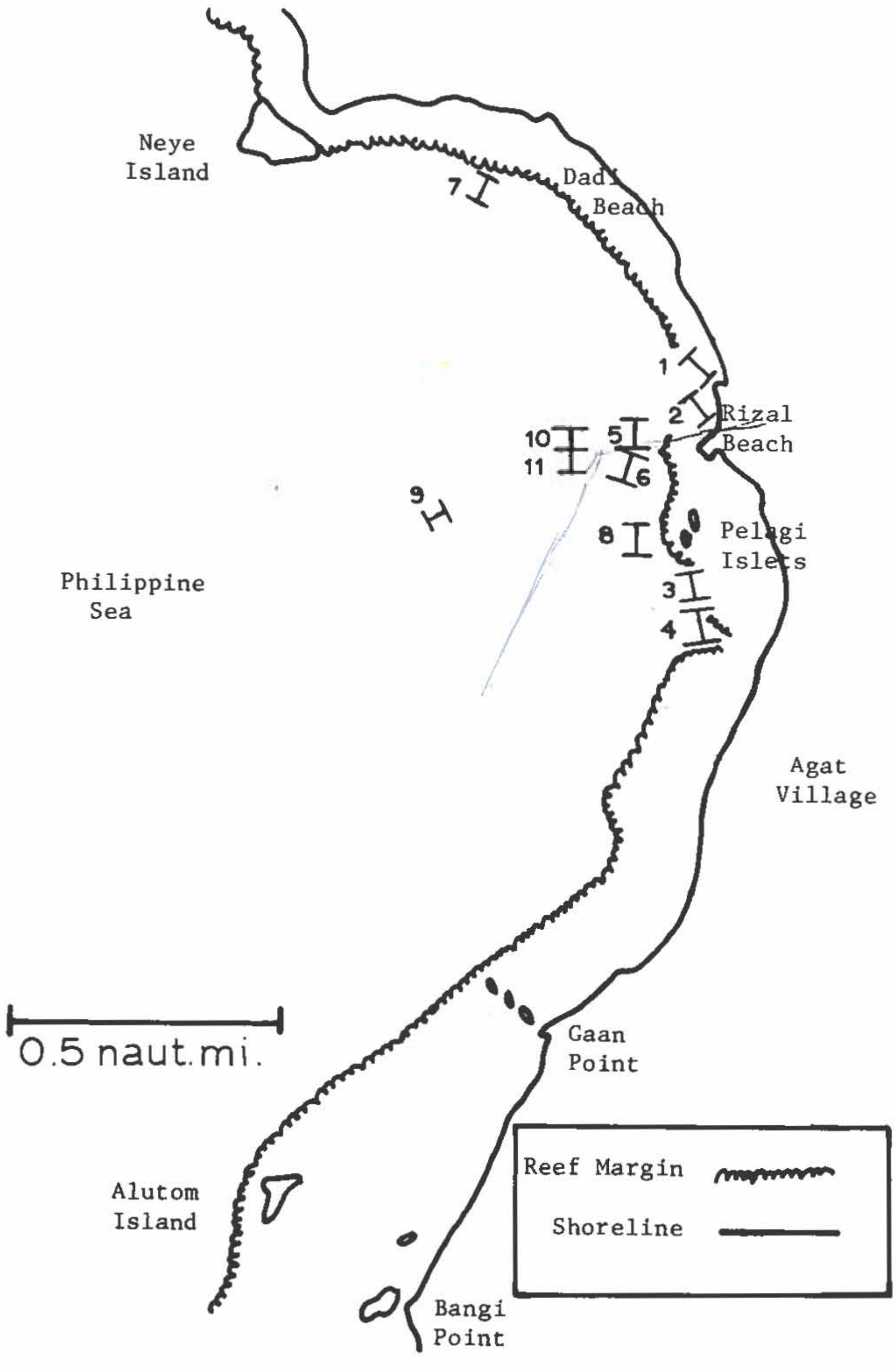
Discussion

The methods used in this fish survey and the data produced are valid in that they provide a good basis for future comparisons run in the same manner in the same biotopes. They represent the small territorial fishes or ones with small home ranges quite well. Larger free-swimming and wide ranging species, nocturnal species and cryptic species were not emphasized in this survey. However, it can be assumed that the areas found to have a paucity of visible fish along their transects also had a relatively low population of the less-visible species.

The transects on the reef flat and reef margin were made at high tide, a time when more fish are present and more are observable in those biotopes. Any future surveys in those two biotopes should also be made at high tide for better comparison with this survey. Transects in the other two biotopes would not noticeably be affected by tidal fluctuations.

Conclusions

The fish fauna of Agat Bay is diverse and numerous. This survey listed 202 species in 99 genera and 44 families. A general estimate of the overall density of highly visible fishes in the four biotopes studied gives one fish per 1.86 m^2 or 0.54 fish per m^2. However, the richness of fish communities differed very much depending on the environmental facies considered. The facies of the submarine terrace of unconsolidated sediments showed no fishes, so that any change occurring in fish numbers there would be an increase probably due to an improvement in fish habitats. The dense and diverse fish communities of the reef margin and reef front biotopes could be expected to be harmed by any change in their habitats. Although the transect methods used provide good data for comparing changes in the fish communities, they do not show total numbers of fish or of species present. Cryptic species only observed after poisoning with rotenone seem to be important at least in the reef margin biotope, where 22 of the 116 species listed could not be found without poisoning.



Fish collecting stations

Table 7 . Fish Transect at Agat Bay.

Transect	Nearest Station No.	Zone	Depth	Date	Species	Individuals
1	8	Reef Flat	0-1 m	30 Nov. 1974	25	75
2	9	Reef Flat	1-2 m	28 Nov. 1974	15	55
3	17	Reef Margin	1-2 m	5 Dec. 1974	99	148
4	17	Reef Margin	1-2 m	5 Dec. 1974	54	159
5	10	Reef Front	4-5 m	7 Dec. 1974	54	182
6	10	Reef Front	3-6 m	7 Dec. 1974	49	150
7	4	Reef Slope	7-9 m	29 Nov. 1974	43	131
8	16	Reef Slope	14-15 m	29 Nov. 1974	30	100
9	14	Submarine Terrace	20-25 m	12 Dec. 1974	56	182
10	12	Sand Flat	14-15 m	21 Nov. 1974	0	0
11	12	Sand Flat	14-15 m	21 Nov. 1974	0	0

Total Number/Frequency*

FAMILY/SPECIES	TRANSECT 1	2	3	4	5	6	7	8	9	L**
Acanthuridae										
Acanthurus glaucopareis Cuvier	-	-	-	0	-	-	-	-	-	-
A. lineatus (Linnaeus)	-	-	3/2	0	1/1	-	-	-	-	-
A. nigrofuscus (Forskal)	-	-	4/2	19/8	3/3	5/4	4/3	1/1	2/1	-
A. nigrorus Cuvier & Valenciennes	0	0	0	-	-	-	-	-	0	-
A. olivaceus Bloch & Schneider	0	-	-	-	0	-	-	-	-	-
A. triostegus (Linnaeus)	0	1/1	0	5/1	-	0	-	-	-	-
A. xanthopterus Cuvier & Valenciennes	-	-	-	-	0	-	-	-	0	-
Ctenochaetus striatus (Quoy & Gaimard)	0	-	1/1	1/1	-	0	-	-	-	-
Naso hexacanthus (Bleeker)	-	-	-	-	-	-	-	-	0	-
N. lituratus Bloch & Schneider	-	-	0	1/1	4/1	0	2/2	4/2	4/2	0
N. unicornis (Forskal)	-	-	-	1/1	1/1	-	-	1/1	-	-
Apogonidae										
Apogon coccineus Ruppell	-	-	0	-	-	-	-	-	-	-
A. exostigma (Jordan & Starks)	-	-	0	-	-	-	-	-	-	0
A. isostigma (Jordan & Seale)	-	-	0	-	-	-	-	-	-	-
A. lateralis Valenciennes	-	-	0	-	-	-	-	-	-	-
A. nigrofasciatus Schultz	-	0	1/1	-	1/1	-	0	-	-	-
A. novemfasciatus Cuvier & Valenciennes	0	-	0	-	-	-	-	-	-	0

*Total number in 100 m/number of 10 m sections of transect having this species. 0=observed but not counted on transect.

**L = Recorded from Agat Bay area in previous literature.

Table 7 (continued).

FAMILY/SPECIES	TRANSECT 1	2	3	4	5	6	7	8	9	L
Apogon novae-guineae Valenciennes	-	-	0	-	-	-	-	-	-	-
A. savayensis Gunther	-	-	0	-	-	-	-	-	-	-
Apogon sp.	-	-	0	-	-	-	-	-	-	-
Archamia biguttata Lachner	-	-	-	-	-	-	-	-	-	0
Cheilodipterus macrodon (Lacepede)	-	-	-	-	-	-	-	-	-	0
Atherinidae										
Pranesus insularum (Jordan & Evermann)	-	-	-	-	0	-	-	-	-	0
Aulostomidae										
Aulostomus chinensis (Linnaeus)	-	-	-	-	-	0	-	-	-	0
Balistidae										
Balistapus undulatus (Mungo Park)	-	-	-	-	0	-	0	-	1/1	0
Balistoides niger (Bloch)	-	-	-	-	-	-	-	-	0	-
Melichthys vidua Solander	-	-	-	-	-	-	-	-	0	-
Odonus niger (Ruppell)	-	-	-	-	-	-	0	0	7/4	-
Pseudobalistes flavomarginatus (Ruppell)	-	-	-	-	-	-	-	-	0	-
Rhinecanthus aculeatus Linnaeus	1/1	-	-	-	-	-	-	-	-	-
Sufflamen bursa (Bloch & Schneider)	-	-	-	-	-	0	-	1/1	1/1	-
S. chrysoptera (Bloch & Schneider)	-	-	-	-	0	0	1/1	-	0	-
Blenniidae										
Aspidontus taeniatus Quoy & Gaimard	-	-	-	-	0	-	-	-	-	-
Cirripectes fuscoguttatus Strasburg & Schultz	-	-	0	-	1/1	-	-	-	-	-
C. jenningsi Schultz	-	-	1/1	1/1	-	-	-	-	-	-

Table 7 (continued).

FAMILY/SPECIES	TRANSECT 1	2	3	4	5	6	7	8	9	L
Cirripectes sebae (Cuvier & Valenciennes)	-	-	0	1/1	-	-	-	-	-	-
C. variolosus (Cuvier & Valenciennes)	-	-	7/5	4/4	2/2	-	-	-	-	-
Cirripectes sp. 1 [cf. C. quagga (Fowler & Bean)]	-	-	3/1	2/2	-		-	-	-	-
Cirripectes sp. 2	-	-	4/1	3/3	2/2	2/2	-	-	-	-
Cirripectes sp. 3	-	-	3/3	0	0	1/1	-	-	-	-
Istiblennius sp.	0	-	2/1	1/1	-	1/1	-	-	-	-
Meiacanthus atrodorsalis (Gunther)	-	-	1/1	-	-	1/1	1/1	1/1	-	-
Runula tapeinosoma (Bleeker)	-	-	-	-	1/1	6/3	-	-	-	-
Brotulidae										
Dinematichthys iluocoeteoides Bleeker	-	-	0	-	-	-	-	-	-	-
Dinematichthys sp.	-	-	0	-	-	-	-	-	-	-
Canthigasteridae										
Canthigaster amboinensis (Bleeker)	-	-	1/1	-	-	-	-	-	-	-
C. bennetti (Bleeker)	-	-	-	-	-	-	-	-	-	0
C. solandri (Richardson)	1/1	-	2/1	1/1	2/1	2/1	2/1	1/1	0	0
C. cinctus (Richardson)	-	-	-	-	-	-	1/1	-	-	-
Caracanthidae										
Caracanthus unipinnus (Gray)	-	-	0	1/1	-	1/1	-	-	2/1	-
Carangidae										
Caranx melampygus Cuvier	-	-	-	-	-	-	-	-	0	-
C. sexfasciatus Quoy & Gaimard	-	-	-	-	-	-	-	-	0	-
Selar crumenophthalmus (Jordan & Evermann)	-	-	-	-	-	-	-	-	0	-

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Table 7 (continued).

FAMILY/SPECIES	TRANSECT 1	2	3	4	5	6	7	8	9	L
Chaetodontidae										
Centropyge bispinosus (Gunther)	-	-	-	-	-	-	-	0	1/1	-
C. flavissimus (Cuvier)	-	-	0	-	-	-	-	1/1	-	-
Chaetodon auriga Forskal	-	-	0	-	-	-	-	-	-	-
C. citrinellus Cuvier	0	-	3/3	7/4	3/2	-	3/2	0	-	-
C. ephippium Cuvier	-	-	-	-	-	-	-	-	2/1	-
C. ulietensis Cuvier & Valenciennes	-	-	-	-	0	-	-	-	-	-
C. lunula (Lacepede)	0	-	-	-	0	0	-	-	0	-
C. mertensii Cuvier	-	-	-	-	-	-	-	1/1	1/1	-
C. ornatissimus Cuvier & Valenciennes	-	-	0	2/1	-	-	-	-	-	-
C. punctato-fasciatus Cuvier	-	-	-	-	-	-	-	2/2	1/1	-
C. reticulatus Cuvier	-	-	0	-	-	-	-	-	0	-
C. trifasciatus Mungo Park	-	-	0	3/2	0	0	-	-	-	-
Forcipiger longirostris (Broussonet)	-	-	-	-	-	-	-	-	0	-
Heniochus permutatus Cuvier	-	-	0	-	-	-	-	-	0	-
Holacanthus trimaculatus Cuvier	-	-	-	-	-	-	-	-	0	-
Megaprotodon strigangulus (Gmelin)	-	-	2/2	-	0	-	-	-	-	-
Cirrhitidae										
Cirrhitichthys serratus Randall	-	-	-	-	-	-	2/2	-	3/3	-
Neocirrhites armatus Castelnau	-	-	-	-	-	-	0	-	-	-
Paracirrhites arcatus Cuvier & Valenciennes	-	-	-	-	-	0	3/3	1/1	5/5	-
P. forsteri (Bloch & Schneider)	-	-	-	-	1/1	-	-	-	1/1	-
Dactylopteridae										
Dactyloptera orientalis (Cuvier & Valenciennes)	-	-	-	-	-	-	-	-	-	0
Echelidae										
Kaupichthys sp.	-	-	0	-	-	-	-	-	-	-

Table 7 (continued).

FAMILY/SPECIES	TRANSECT 1	2	3	4	5	6	7	8	9	L
Eleotridae										
Valenciennea strigatus Broussonet	-	-	0	-	5/3	-	3/2	-	-	-
Eleotrid sp.	-	-	-	-	-	-	0	-	-	-
Ptereleotris microlepis (Bleeker)	-	-	-	-	-	-	-	-	-	-
P. tricolor Smith	-	-	-	-	0	-	0	-	3/2	-
Fistulariidae										
Fistularia petimba Lacepede	-	-	-	-	-	-	-	-	-	0
Gobiidae										
Gobiodon citrinus (Ruppell)	-	-	0	-	-	-	-	-	-	-
Goby sp.	-	-	-	-	0	-	-	-	-	-
Hemiramphidae										
Hemiramphus marginatus Forskal	-	-	-	-	-	-	-	-	-	0
Halfbeak unidentified sp.	-	-	-	2/1	-	-	-	-	-	-
Holocentridae										
Adioryx lacteoguttatus (Cuvier)	-	-	-	1/1	-	0	-	-	-	-
A. rubra Forskal	-	-	0	-	-	-	-	-	-	-
A. spinifer Forskal	-	-	-	-	-	-	-	-	-	-
Flammeo sammara Forskal	-	-	0	-	-	-	-	-	-	-
Myripristis kuntee (Russell)	-	-	-	-	-	1/1	-	-	-	0
M. murdjan Forskal	-	-	-	-	-	2/1	-	-	-	-
M. chryseres Jordan & Evermann	-	-	0	-	-	-	-	-	-	-
Kyphosidae										
Kyphosus cinerascens (Forskal)	-	-	-	1/1	-	-	-	-	-	-

Table 7 (continued).

FAMILY/SPECIES	TRANSECT 1	2	3	4	5	6	7	8	9	L
Labridae										
Cheilinus chlorourus (Bloch)	-	0	-	1/1	-	-	0	-	-	-
C. fasciatus (Bloch)	-	-	-	-	-	-	-	-	0	-
C. rhodochrous Gunther	-	-	0	-	-	0	0	1/1	2/2	-
C. trilobatus Lacepede	0	-	0	1/1	0	0	1/1	-	-	-
Cheilio inermis (Forskal)	-	-	0	-	-	-	-	-	-	-
Coris gaimardi (Quoy & Gaimard)	-	-	-	-	-	-	-	-	0	-
Epibulus insidiator (Pallas)	-	-	-	-	-	-	1/1	-	0	-
Gomphosus varius Lacepede	-	-	-	1/1	0	-	-	-	-	-
Halichoeres biocellatus Schultz	-	-	2/1	1/1	-	-	0	8/6	9/5	-
H. hoeveni (Bleeker)	0	-	1/1	-	-	-	-	-	-	-
H. hortulanus (Lacepede)	-	-	1/1	-	5/4	3/3	-	0	-	-
H. margaritaceus (Cuvier & Valenciennes)	29/7	1/1	-	1/1	-	-	-	-	-	-
H. marginatus Ruppell	-	-	1/1	1/1	0	0	2/2	-	4/4	-
H. nebulosus (Cuvier & Valenciennes)	-	-	-	2/2	5/3	-	1/1	-	-	-
H. trimaculatus (Quoy & Gaimard)	1/1	1/1	-	-	0	-	10/7	-	-	-
Halichoeres sp.	4/4	-	4/3	6/3	2/1	-	-	-	0	-
Hemigymnus fasciatus (Bloch)	-	-	-	-	-	0	-	-	-	-
H. melapterus (Bloch)	-	-	-	-	-	-	-	-	-	-
Labrichthys sp.	-	-	1/1	-	-	-	-	-	-	-
Labroides bicolor Fowler & Bean	-	-	-	-	-	-	-	-	0	-
L. dimidiatus (Cuvier & Valenciennes)	-	-	1/1	1/1	1/1	2/1	1/1	0	-	-
Macropharyngodon pardalis (Kner)	-	-	-	-	3/2	-	4/2	2/2	-	-
Stethojulis bandanensis (Bleeker)	-	-	0	-	1/1	-	-	-	-	-
S. linearis Schultz	-	-	6/6	2/2	2/2	-	3/3	0	-	-
Thalassoma hardwickei (Bennett)	-	-	1/1	3/3	0	-	-	-	-	-
T. lunare (Linnaeus)	-	-	-	-	-	-	2/2	-	1/1	-
T. amblycephalus (Bleeker)	-	-	1/1	-	-	-	-	-	-	-

Table 7 (continued).

FAMILY/SPECIES	TRANSECT 1	2	3	4	5	6	7	8	9	L
Thalassoma lutescens (Lay & Bennett)	-	-	-	-	-	-	-	-	-	-
T. purpureum (Forskal)	-	-	1/1	-	-	-	-	-	-	-
T. quinquevittata (Lay & Bennett)	1/1	-	6/4	1/1	18/8	13/4	5/3	1/1	11/4	-
Thalassoma sp.	-	-	3/2	-	-	-	-	-	-	-
Xyrichthys taeniourus (Lacepede)	-	0	-	-	-	-	-	-	-	-
Leiognathidae										
Gerres oblongus Cuvier & Valenciennes	-	-	-	-	-	-	-	-	-	0
Lethrinidae										
Lethrinella miniata (Bloch & Schneider)	-	-	-	-	-	-	-	-	-	0
Monotaxis grandoculis (Forskal)	-	-	-	-	-	-	-	-	0	-
Lutjanidae										
Aphareus furcatus (Lacepede)	-	-	-	-	-	-	-	-	-	0
Lutjanus bohar (Forskal)	-	-	-	-	-	-	-	-	0	-
L. janthinuropterus (Bleeker)	0	-	0	2/2	-	-	-	-	-	-
L. kasmira (Forskal)	-	-	0	-	-	-	-	-	-	0
L. monostigmus (Cuvier & Valenciennes)	0	-	-	-	-	-	-	-	-	-
L. vaigiensis (Quoy & Gaimard)	-	-	-	-	-	-	-	-	-	0
Monacanthidae										
Amanses carolae (Jordan & McGregor)	-	-	0	-	-	-	0	-	-	-
Oxymonacanthus longirostris (Bloch & Schneider)	-	-	1/1	-	-	-	-	-	-	-
Paraluteres prionurus (Bleeker)	-	-	-	0	-	-	-	-	-	-

Table 7 (continued).

FAMILY/SPECIES	TRANSECT 1	2	3	4	5	6	7	8	9	L
Monodactylidae										
<u>Monodactylus argenteus</u> (Linnaeus)	-	-	-	-	-	-	-	-	-	0
Mugiloididae										
<u>Parapercis cephalopunctatus</u> (Seale)	-	-	-	-	-	-	-	-	0	-
Mullidae										
<u>Parupeneus barberinus</u> (Lacepede)	-	-	-	-	-	0	-	-	-	-
<u>P. bifasciatus</u> (Lacepede)	0	-	0	-	0	-	-	-	-	-
<u>P. cyclostomus</u> (Lacepede)	-	-	0	-	-	3/2	-	-	0	-
<u>P. luteus</u> (Cuvier & Valenciennes)	-	-	-	-	-	-	-	-	-	0
<u>P. pleurotaenia</u> (Playfair)	-	-	-	0	-	-	-	-	-	-
<u>P. trifasciatus</u> (Lacepede)	-	0	0	2/2	1/1	1/1	1/1	2/1	0	-
Muraenidae										
<u>Gymnothorax buroensis</u> (Bleeker)	-	-	0	-	-	-	-	-	-	-
<u>G. flavimarginatus</u> (Ruppell)	-	-	0	-	-	-	-	-	-	-
<u>G. meleagris</u> (Shaw & Nodder)	-	-	-	-	-	-	-	-	0	-
<u>G. thyrsoideus</u> (Richardson)	-	-	0	-	-	-	-	-	-	-
<u>Gymnothorax sp.</u>	-	-	0	-	-	-	-	-	-	-
<u>Rabula fuscomaculata</u> Schultz	-	-	0	-	-	-	-	-	-	-
<u>Uropterygius</u> sp. [cf. <u>U. supraforatus</u> (Regan)]	-	-	0	-	-	-	-	-	-	-
Ostraciontidae										
<u>Ostracion meleagris</u> (Shaw)	-	-	-	-	-	1/1	-	-	-	-

Table 7 (continued).

FAMILY/SPECIES	TRANSECT 1	2	3	4	5	6	7	8	9	L
Pempheridae										
Pempheris oualensis Cuvier & Valenciennes	-	-	0	-	-	-	-	-	-	0
Pomacentridae										
Abudefduf amabilis (DeVis)	22/4	-	9/4	10/3	23/6	-	-	-	-	-
A. bankieri (Richardson)	-	-	-	1/1	11/5	21/7	13/9	21/9	32/9	-
A. coelestinus (Cuvier)	-	-	-	0	-	3/2	-	-	-	-
A. curacao (Bloch)	-	-	-	1/1	-	-	-	-	-	-
A. dicki (Lienard)	-	-	12/7	9/4	12/9	8/5	3/2	1/1	-	-
A. imparipennis (Vaillant & Sauvage)	-	1/1	0	-	-	5/4	-	-	-	-
A. johnstonianus (Fowler & Ball)	-	-	-	-	1/1	3/3	-	-	-	-
A. lacrymatus (Quoy & Gaimard)	-	-	2/2	2/1	2/2	25/8	0	5/3	3/2	-
A. leucopomus (Lesson)	13/6	38/9	10/6	4/3	17/7	3/2	-	-	-	-
A. leucozona (Bleeker)	1/1	3/2	0	17/6	1/1	-	-	-	-	-
A. septemfasciatus Cuvier & Valenciennes	-	-	-	1/1	-	-	-	-	-	-
A. sordidus (Forskal)	0	1/1	0	-	-	-	-	-	-	-
Amphiprion perideraion Bleeker	-	-	-	-	-	1/1	-	-	2/1	-
Chromis caeruleus (Cuvier & Valennciennes	-	-	0	-	-	-	-	-	-	-
C. dimidatus (Klunzinger)	-	-	-	-	-	0	-	-	-	-
C. leucurus Gilbert	-	-	0	-	-	-	-	-	-	-
C. vanderbilti (Fowler)	-	-	-	-	-	-	2/1	-	-	-
Dascyllus aruanus (Linnaeus)	-	-	-	-	-	-	-	2/1	-	-
D. reticulatus (Richardson)	-	-	-	-	-	0	13/4	9/4	16/3	-
D. trimaculatus (Ruppell)	-	-	-	-	-	-	-	-	-	-
Pomacentrus albofasciatus (Schlegel & Muller)	1/1	10/5	2/2	1/1	-	-	-	-	-	-
P. amboinensis Bleeker	-	-	-	-	6/4	3/2	23/8	22/9	-	-

Table 7 (continued).

FAMILY/SPECIES	TRANSECT 1	2	3	4	5	6	7	8	9	L
Scorpaenidae										
Scorpaenodes guamensis (Quoy & Gaimard)	-	-	0	-	-	-	-	-	-	-
Serranidae										
Cephalopholis urodelus (Bloch & Schneider)	-	-	-	-	-	-	1/1	-	1/1	-
Epinephelus merra Bloch	-	-	0	-	-	-	-	-	-	-
Siganidae										
Siganus argenteus (Quoy & Gaimard)	-	-	-	-	-	0	-	-	-	-
S. spinus (Linnaeus)	1/1	-	0	-	-	0	-	-	-	-
Sphyrnidae										
Sphyrna lewini (Cuvier, Griffith & Smith)	-	-	-	-	-	-	-	-	-	0
Syngnathidae										
Corythoichthys intestinalis (Jordan & Seale)	-	-	-	0	-	-	-	-	-	-
Synodontidae										
Synodus variegatus (Lacepede)	-	-	0	-	-	-	0	-	-	-
Tetraodontidae										
Arothron hispidus (Linnaeus)	-	0	-	-	-	-	-	-	-	-
A. nigropunctatus (Schneider)	-	-	0	-	-	-	-	-	-	-
Zanclidae										
Zanclus cornutus Linnaeus	-	-	1/1	-	0	-	0	1/1	0	-

MARINE FLORA

Roy T. Tsuda

Introduction

A survey of the marine flora was carried out between February and July 1975 in relationship with the proposed construction of a new tanker berth in Agat Bay. The algal study was undertaken to obtain baseline information in localized sites which would be directly affected through dredging during the laying of the pipes from the shore to the tanker berth and the anticipated damage that would occur on the reef flats by an oil spill.

I acknowledge both Richard Dickinson and Steven Moras who served as my diving companions and who provided me with certain algal specimens which they collected during their year long study in the bay.

Methodology

Nine of the 15 algal stations (Fig. 63 and Table 8) were localized adjacent to the site of the proposed pipeline and the remaining six stations were located on the reef flat and reef front near Gaan Point where two of the three drift drogues were grounded. The algal community at 12 of the stations were quantified by the "point-quadrat" method to obtain values relating to relative abundance (in this respect similar to percent cover) and the frequency of occurrence.

A quadrat frame divided into a grid of 25 squares, each 5 cm x 5 cm, and providing 16 interior "points" where the grid line intersected were placed at 5 or 10 m intervals along a 100 m long transect or thrown randomly in a given area. Each algal species was recorded at every "point." If no alga was found under any of the "points," then whatever was present, e.g., sand, dead coral, live coral, was recorded. From these numbers, values for relative abundance (RA) and frequency of occurrence (F) were calculated for each algal species at each station. The percent of algal cover in relationship to the amount of dead coral, live coral, and sand at each station was calculated by considering every item recorded under all "points" (Fig. 64).

Results

The results of the quantitative sampling program at 12 of the 15 stations are presented in Table 9 and is the source of information presented below. In addition, a checklist of those species observed in the various zones is provided in Table 10.

Discussion

Proposed Pipeline Site

The inner reef flat (Sta. 7a) can be described as a relatively dead limestone substratum where Padina tenuis and Sargassum polycystum are by far the dominant organisms covering 74 percent of the surface area. A greater diversity of algae is found on the outer reef flat where eight species cover 99 percent of the substratum. Udotea argentea, Geldium pusillum, and Halimeda opuntia are the predominant algae here.

The shallow channel (Sta. 6) possesses a lush algal flora with Padina jonesii, Lobophora variegata, and Tolypiocladia glomerulata covering 68 percent of the substratum.

The submarine terrace (Sta. 1 and 2) in 15 m of water had two types of substrata - sand and dead coral. Microcoleus lyngbyaceus, a filamentous blue-green alga, was the predominant alga covering vast expanse of the sandy area. Also present in this area were those algae with massive holdfasts, e.g., Halimeda macroloba, Halimeda incrassata, and Udotea argentea. Low lying turfs, e.g., Amphiroa fragilissima, Jania capillacea, and Gelidiopsis intricata, dominated the dead coral substratum. Brown and red macroalgae also were found scattered on the terrace. Padina jonesii, Dictyota bartayresii, Turbinaria ornata, Desmia hornemanni, Galaxaura oblongata, and Galaxaura fascicularis were present on the submarine terrace.

The edge of the submarine terrace (Sta. 5a) was about 20 to 25 m deep and possessed about 15 percent live coral. Padina jonesii and Desmia hornemanni covered about 50 percent of the substratum. The most conspicuous alga on the slope, which descended to a depth of 45 m, was Halimeda incrassata.

Vulnerable Sites

The shallow reef flats are the areas most vulnerable to damage if an oil spill did occur. The water circulation studies conducted in this bay indicate that the currents on few occasions can shift towards the reef flat as indicated by the three grounded drift drogues (see "X" on Fig. 63). One drift drogue ran aground just north of Rizal Beach. The other two ran aground near Gaan Point in the general vicinity of algal stations 8-12. The algae on the reef flat and reef front here were the calcareous types such as Jania capillacea, Jania tenella, Porolithon onkodes, and Neogoniolithon sp. The stations near Alutom Island were found to be extremely rich in live corals, especially in the reef front. This site appeared to be an actively growing area.

The algae present in this area is not unique, nor especially abundent or depauperate. It is comparable to other sites, thus far, studied around Guam--Agana Bay (Jones and Randall, 1971), Tanguisson (Jones and Randall, 1973), Talofofo Bay (Randall, 1974), and Cocos Lagoon (Randall *et al.*, 1975). There are no endangered species nor are there any endemic species of algae here.

Algae have very little esthetic value to the laymen when compared to the beautiful reef fishes and corals. However, these primary producers are crucial to the very existence of all other life on the reef. The algae serve as shelter for many invertebrates and small fishes, and also serve as a food source for the multitude of herbivorous animals inhabiting the reef. The coralline algae near Alutom Island are critical as building blocks and cementing agent in reef growth.

Thus, it is especially important that siltation be kept at a minimal during dredging operations since light penetration will definitely be a limiting factor for the survival of the benthic flora.

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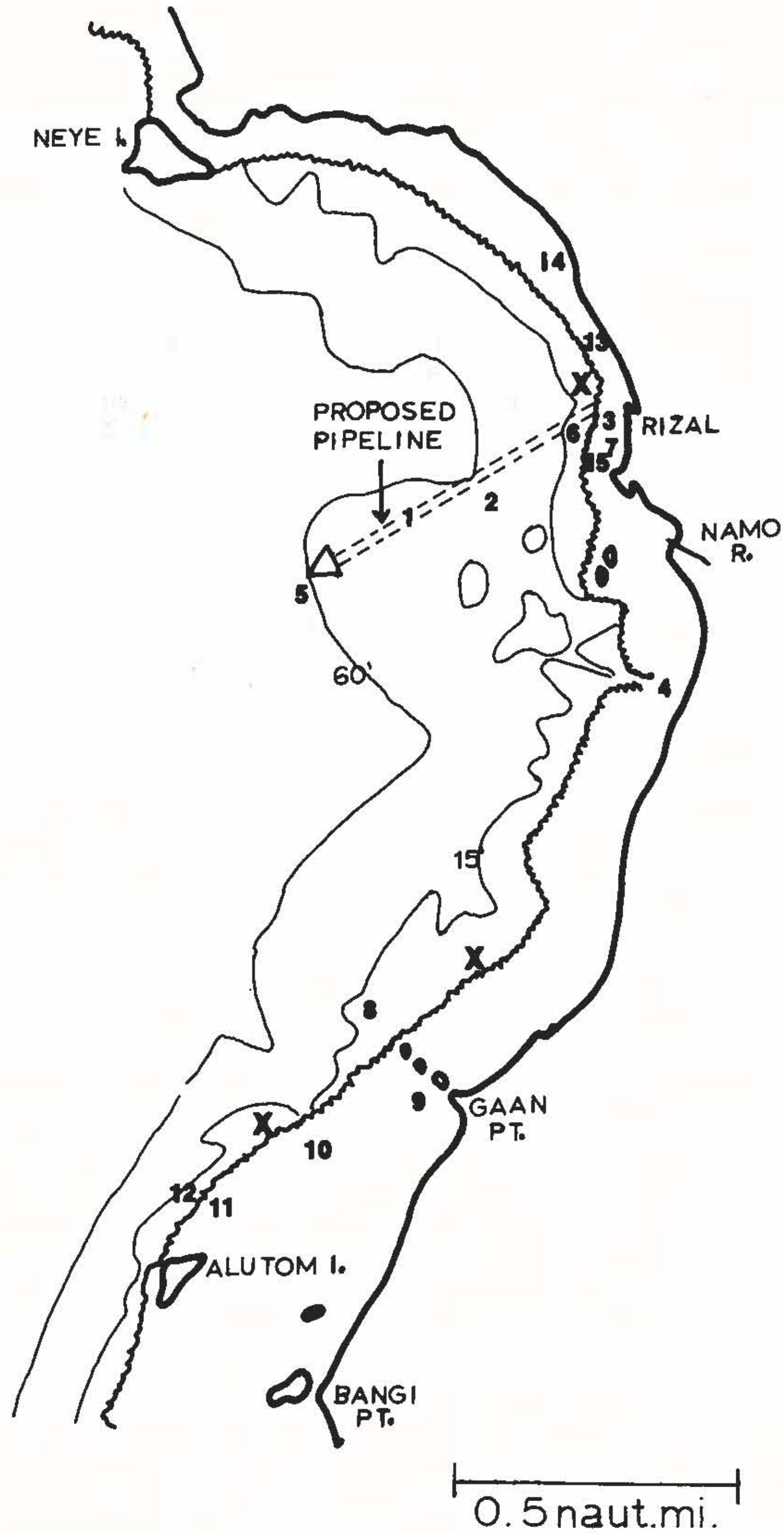

Fig. 63. Location of each algal sampling station. X = sites where drift drogue were grounded.

Fig. 64. Quadrat frame used for quantifying algae.

Table 8. Description of the 15 stations studied.

Station No.	Description
1	Submarine terrace, 40' deep, .5 miles off Rizal Beach, Feb. 6, 1975.
2	Submarine terrace, 40' deep, .25 miles off Rizal Beach, Feb. 6, 1975.
3	Reef front, 8-10' deep, off Rizal Beach, Feb. 28, 1975.
4	Inner reef flat, sandy substratum, .25 miles south of Namo River, May 22, 1975.
5a	Submarine terrace, 60-70' deep, mooring site, May 22, 1975.
5b	Submarine slope, 100-130' deep, mooring site, May 22, 1975.
6	Shallow channel (can be considered reef front), 8-10' deep, off Rizal Beach, May 22, 1975.
7a	Inner reef flat, 1-2' deep, off Rizal Beach, May 22, 1975.
7b	Outer reef flat, 2' deep, off Rizal Beach, May 22, 1975.
8	Submarine terrace, 19' deep, site of sewer outfall, Gaan Point, May 22 and July 22, 1975.
9	Inner reef flat, 4' deep, south of Gaan Point, July 25, 1975.
10	Outer reef flat, 3-4' deep, between Gaan Point and Alutom Island, May 22, 1975.
11	Outer reef flat, 3' deep, inside of reef front, 600 feet north of Alutom Island, May 22, 1975.
12	Reef front, 6-10' deep, 200 m north of Alutom Island, May 22, 1975.
13	Inner reef flat, 2-3' deep, just north of channel, Rizal Beach, July 28, 1975.
14	Inner reef flat, 2-3' deep, 600 feet north of Rizal Beach, July 28, 1975. (foliose algae absent.)
15	Inner reef flat, 2-3' deep, southern end of Rizal Beach, July 28, 1975.

Table 9. Relative abundance (RA) and frequency of occurrence (F) of benthic algae quantified at 12 sites in Agat Bay. The sites are listed under each of the four major zones recognized in the Bay. Only those species covering 5% or more are considered and listed here. (N=number of tosses).

Species	RA	F
INNER REEF FLAT		
Station 7a (N = 14) - dead coral = 20%, live coral = 0, sand = 1%.		
Padina tenuis	61	71
Sargassum polycystum	13	21
Station 9 (N = 10) - dead coral = 74%, live coral = 0, sand = 0.		
Jania capillacea	11	60
unidentified crustose coralline	8	40
Station 13 (N = 20) - dead coral = 77%, live coral = 0, sand = 0.		
Padina tenuis	13	55
Dictyota bartayresii	8	35
Station 14 (N = 20) - dead coral = 100%.		
[no algae]		
Station 15 (N = 20) - dead coral 65%, live coral = 0, sand = 0.		
Sargassum polycystum	24	60
Padina tenuis	10	40
OUTER REEF FLAT		
Station 7b (N = 6) - dead coral = 1, live coral = 0, sand = 0.		
Udotea argentea	23	33
Gelidium pusillum	21	33
Halimeda opuntia	12	33
Porolithon onkodes	9	33
Jania capillacea	8	67
Caulerpa racemosa	9	33
Actinotrichia fragilis	7	50
Padina tenuis	5	17

Table 9. (continued).

Species	RA	F
Station 10 (N = 10) - dead coral = 49%, live coral = 0, sand = 0.		
unidentified coralline	32	90
Amphiroa fragilissima	13	6
Station 11 (N = 20) - dead coral = 0, live coral = 1%, sand = 2%.		
Jania tenella	38	55
Porolithon onkodes	35	55
Neogoniolithon sp.	12	45
Halimeda opuntia	5	35
REEF FRONT		
Station 6 (N = 20) - dead coral = 1%, live coral = 0, sand = 3%.		
Padina jonesii	35	90
Lobophora variegata	21	75
Tolypiocladia glomerulata	12	35
Dictyota bartayresii	9	50
Jania capillacea	5	35
Station 12 (N = 10) - dead coral = 4%, live coral = 62%, sand = 0.		
Jania tenella	10	20
Gelidium pusillum	10	40
Neogoniolithon sp.	6	40
Jania capillacea	5	20
SUBMARINE TERRACE AND SLOPE		
Station 5a(N = 20) - dead coral = 17%, live coral = 15%, sand = 0.		
Padina jonesii	36	45
Desmia hornemanni	13	60
Dictyota divaricata	5	25
Halimeda incrassata	4	30

Table 9. (continued).

Species	RA	F
Station 8 (N = 20) - dead coral = 15%, live coral = 3%, sand = 2%.		
Galaxaura oblongata	35	95
Polysiphonia sp.	16	35
Lobophora variegata	9	45
Schizothrix calcicola	4	15

Table 10. Checklist of marine benthic algae and seagrasses collected or observed in Agat Bay.

Species	Inner Reef	Outer Reef	Reef Front	Submarine Terrace & Slope
Division CYANOPHYTA (blue-greens)				
Hormothamnion enteromorphoides B. & F.	X			X
Microcoleus lyngbyaceus (Kutz.) Crouan	X	X	X	X
Schizothrix calcicola (Ag.) Gomont		X	X	X
Schizothrix mexicana Gomont		X	X	X
Division CHLOROPHYTA (greens)				
Avrainvillea obscura J. Ag.	X			
Boodlea composita (Harv.) Brand		X	X	
Caulerpa racemosa (Forskal) J. Ag.	X	X		X
Chlorodesmis fastigiata (C. Ag.) DucKer		X	X	
Codium edule Silva		X		X
Dictyosphaeria cavernosa (Forskal) Boerg.			X	
Dictyosphaeria versluysii W. V. Bosse		X		
Enteromorpha clathrata (Roth) Ag.	X			
Halimeda discoidea Decaisne		X	X	X
Halimeda incrassata (Ellis) Lamx.				X
Halimeda macroloba Decaisne	X		X	X
Halimeda micronesica Yamada		X		X
Halimeda opuntia (L.) Lamx.	X	X	X	X
Neomeris annulata Dickie	X		X	X
Neomeris vanbosseae Howe			X	
Udotea argentea Zanardini		X	X	X
Udotea geppi Yamada	X			X
Valonia fastigiata Harvey	X			
Valonia ventricosa J. Ag.			X	X
Division PHAEOPHYTA (browns)				
Dictyota bartayresii Lamx.	X	X	X	X
Dictyota divaricata Lamx.				X
Lobophora variegata (Lamx.) Womersley	X	X	X	X
Padina jonesii Tsuda			X	X
Padina tenuis Bory	X	X	X	
Ralfsia pangoensis Setchell	X			
Sargassum polycystum C. Ag.	X	X		
Sphacelaria tribuloides Meneghini			X	
Turbinaria ornata (Turner) J. Ag.		X		
Zonaria hawaiiensis Doty & Newhouse				X

Table 10. (continued).

Species	Inner Reef	Outer Reef	Reef Front	Submarine Terrace & Slope
Division RHODOPHYTA (reds)				
Actinotrichia fragilis (Forskal) Boerg.		X	X	X
Amphiroa foliacea Lamx.	X			X
Amphiroa fragilissima (L.) Lamx.	X			X
Botryocladia skottsbergii (Boerg.) Levring				X
Ceramium sp.				X
Chondria repens Boerg.		X		X
Desmia hornemanni Lyngbye			X	X
Galaxaura fasciculata Kjellman		X	X	X
Galaxaura filamentosa Chou	X	X		X
Galaxaura marginata Lamx.				X
Galaxaura oblongata (E. & S.) Lamx.	X	X	X	X
Gelidiella acerosa (Forskal) Feldm. & Hamel		X		X
Gelidiopsis intricata (Ag.) Vickers		X		X
Gelidium divaricatum Martens				X
Gelidium pusillum (Stackh.) Le Jolis		X	X	
Gracilaria lichenoides (L.) J. Ag.				X
Halymenia durvillaei Bory			X	X
Hypnea pannosa J. Ag.				X
Jania capillacea Harvey	X	X	X	X
Jania tenella Kutz.		X	X	X
Liagora sp.				X
Neogoniolithon sp.		X	X	
Peyssonelia sp.	X			X
Polysiphonia sp.			X	X
Porolithon onkodes Foslie	X	X	X	X
Tolypiocladia glomerulata (Ag.) Schmitz & Hauptfleisch			X	
Division ANTHOPHYTA (seagrass)				
Enhalus acoroides (L.f.) Royle	X			

CURRENT STUDIES
Richard Dickinson and Steve Moras

Methods of Study

The evaluation of nearshore circulation in Agat Bay was accomplished by monthly, 24-hour current studies. Monthly studies were chosen to include seasonal variations caused by the shifting tradewinds and a 24-hour period in order to include a full diurnal tidal cycle, as well, for each station. All months from May 1974 to May 1975 inclusive were sampled with the exceptions of June and January. Two attempts in June were made but because of strong winds and high seas both were cancelled and a trip in early July was made instead. Another trip was held later in July for that month. Marine Laboratory personnel were off-island in January and a station was not held.

The yacht "Havaiki", a 50-foot sailing catamaran, was chartered for ten of the 24-hour current studies and the yacht "New World", a 69-foot extreme schooner was chartered for the remaining two. The vessels functioned as oceanographic platforms and provided a release point for the drift drogues. Additionally they served as a floating laboratory, staging area for field work, and berthing and messing facility for the research teams on each of the monthly current studies. The vessels were moored to a permanent buoy at a point along the 60 foot isobath, due east of Pelagi Islets in Agat Bay (Fig. 6). This anchorage corresponds with the docking site marked as "Alternate Location A" in a report given to the Marine Laboratory by GORCO (Van Houton & Associates, Inc., 1973) and, in discussion with GORCO personnel it was decided to use this site as the most feasible.

The drogues used for the current studies consisted of sheet metal crosses, or vanes, suspended from poured, polyurethane foam buoys (Fig. 65). They were released in pairs (one with a 1 m line between float and vane and the other with a 5 m line) usually every two hours.

Marine Laboratory outboard chase boats were tied alongside the larger vessels (Fig. 66) and were used to follow the drogues as well as providing transportation for work elsewhere in the bay.

Every hour, personnel in the chase boats maneuvered alongside the drogues and bearings to shore points were taken using a hand bearing compass. The shore points were fixed by previously surveyed day markers for the daylight hours and with colored navigation lights at night. The foam night drogues were similar to the day drogues except they were equipped with xenon flashing lights for night location.

The exact location of each drogue was then immediately plotted on a large working map (Fig. 67) aboard the research vessel. Drogues moving west or southwesterly were usually retrieved after passing out of a 0.5 nautical mile radius from the mooring site. If the drogues drifted shoreward they were not recovered after moving out of the radius and their movements and locations continued to be taken hourly. When drogues were found not to move out of the 0.5 nautical mile radius within 2-3 hours they were usually recovered and reset. However, times of drift varied according to the discretion of the watch standers.

At each hourly interval the wind speed and direction was taken with a hand held anemometer (Fig. 68) and the sea and swell were recorded. Also, a tide staff was cemented in place on the reef margin next to the Pelagi Islets and the relative tidal heighth was noted for comparison with the predicted Apra Harbor tides. The tide staff was used for the two trips and it was found that the local, Agat Bay, tide followed the predicted tide closely. This substantiated the findings of a one-year Marine Laboratory project at Toguan (Jones, Randall, and Strong, 1974), where a similar tide staff also followed the predicted tide. Subsequent storms and large waves destroyed the Pelagi Islet tide staff and its use was discontinued.

The drogue trackings and data sheets (Figs. 70-117) made during the 24 hour current studies, show a complex series of factors are involved in the nearshore water movement in Agat Bay. The wind is believed to be the most important factor and will be discussed first.

Guam lies in the belt of the northeast tradewinds (Fig. 69 Wyrtki) and is under their influence especially during the winter months (Guam's dry season) from November to May when they are the strongest. Strong trade westerlies may occur during January and February (Wyrtki et al., 1975) but easterly trades dominate with a strong northerly component from November through March and a strong southerly component from April to June. Wind speeds during this period commonly exceed 13 knots (15 mph) and calms are rare (Tracey, 1964).

During the summer months of June to October, Guam's rainy season, the effect of the northeast tradewinds is diminished considerably and winds from every direction are not uncommon. These highly variable winds seldom exceed 13 knots, and calms are frequent. Strong winds of 22 knots (25 mph) are nearly always associated with cyclonic disturbances.

The hourly wind readings (Appendix III) taken during the current studies coincide well with that found in the literature for wind speeds and directions on Guam (above). The wind readings from stations held in June to October showed no winds exceeding 12 knots

(14 mph) and they were variable but with a predominant (42% of the time) northeast trade. Winds came from the northwest 17% of the time and from the southeast and southwest, 21% and 20% of the time, respectively.

For the dry season months (November - May) winds exceeding 13 knots (15 mph) were recorded during two of our stations. The predominant direction was from the northeast (58% of the time) with wind from the southeast and northwest, 39% and 3% of the time, respectively. No wind was recorded from the southwest during these stations.

The slowest wind speeds were usually recorded during the early morning hours (0300-0800) and the greatest speeds later in the day (Appendix III).

Besides the typical winds described, Guam often experiences tropical storms and typhoons. Regions north of 5°N are in an area of great typhoon frequency and a large percentage of all typhoons of the western north Pacific are first observed here (U. S. Naval Oceanographic Office, 1964). Even those which form further eastward nearly always begin their movement on a west or northwest course and pass through this region. Typhoons are particularly common in the area of the Palau Islands and the Mariana Islands.

The formation of a tropical cyclone or typhoon is most likely when the tradewinds are at their greatest strength and the intertropical convergence zone is most active. These conditions are more likely in the late summer with August being the so-called "heighth" of the typhoon season for Guam.

Typhoons are moderately common on Guam and may occur in any month, but they are five times more likely to occur during the rainy season (June to October). The chances are two in three that one or more typhoons will pass within 120 nautical miles of Guam in any particular year and a chance of one in three that in any year one or more typhoons will cause considerable damage.

In addition to typhoons which have wind velocities greater than 64 knots (75 mph), tropical storms with wind velocities between 33 and 64 knots (38 to 75 mph) are also moderately common on Guam. Besides strong winds, these storms bring unusually high seas. One such storm, Tropical Storm Mary, struck Guam on August 12, 1974. This storm came up from the south and generated a tremendous swell, with waves reaching 6.1 m (20 feet) and higher on Guam's western shores. The impact to Agat Bay's shoreline was dramatic.

Field observations and subsequent diving after the storm were made. The entire reef flat along Rizal Beach was littered with large blocks of coral and much rubble. These blocks were broken off from reef front by the large storm waves and washed up onto the reef flat where they were rolled back and forth completely crushing and flattening the raised reef.

Rizal Beach itself was altered considerably. The storm deposited over 2 feet of sand inside the beach pavilion and covered the entire area with a layer of coral rubble extending approximately 20-30 m inland. The sand from the beach was washed inland, forming a broad burm covered with coral debris.

The reef front (deeper water seaward of the reef flat) had been devastated. Large coral colonies, especially massive Acropora sp. with a diameter of 1-1.5 m were broken off and were found lying in the surge channels or had been driven into small reef flat cuts. Virtually all live coral had been damaged in some degree. This may be evidence for the large amounts of nonliving coral rubble found at the reef terrace stations in deeper water; storm waves break up coral development along the reef front and smaller pieces are gradually washed down the gently sloping terrace.

There are other fairly recent typhoons which have affected the Agat Bay area. Typhoon Hester, on December 31, 1952 brought winds from the south and southeast at speeds of 35-40 knots (40-46 mph) with gusts up to 67 knots (77 mph). Several beach profiles had been made prior to the typhoon (Emery, 1962) and were rerun for comparison. One of the largest cuts of all, to about 12 m inland, was near Dadi Beach, though it may have been because the beach was backed by soft dredged material and was not in equilibrium. Sand samples rechecked showed that the typhoon produced a coarsening of the sediment and an increase in the sorting coefficient (indicates less well sorted).

Another typhoon, Nina, came from the southwest on 10 August 1953. The winds ranged from 35-50 knots (40-58 mph) and waves from 4.5-6 m (15-20 feet) were breaking along the south side of Orote Peninsula. The greatest modification by the typhoon occurred on the southwest beaches that were exposed. Dadi Beach was cut to a depth of several feet though the beach mark was lost.

In both typhoons, cuts in the beaches were restricted to parts of beaches above high tide and the sand removed was carried seaward to be deposited below the high tide level or washed ashore.

Tyhpoon Karen (November 11-12, 1962) passed directly over Guam causing inestimable damage. The 150 knot winds (172.7 mph) with gusts to 180 knots (207.2 mph) destroyed 95% of all civilian homes and shoreline damage was considerable on all coasts. Vessels anchored or moored in Apra Harbor had been given ample warning but were unable to safely secure their ships and many were lost.

Storm winds such as these not only cause damage directly to existing structures but can be a major current producing force. Winds impinging on the ocean's surface act as a driving force and may generate strong currents in the same way the North Equatorial current is produced by the northeast trade winds. These currents may originate many miles from Guam and mask the currents otherwise present.

The study area is on the lee side of Guam, relatively close to shore, and it is virtually impossible for any major offshore currents to be generated by easterly winds. Our study, however, showed a close correlation between wind direction and drogue movement but we believe this to be caused by the wind acting directly against the drogues. The drogues used in the studies were made in a low profile to minimize this effect but not eliminate it entirely. This is especially true for the one meter drogues where the metal vane is suspended one meter beneath the float. This creates less of a drag than the 5 meter drogues which have a greater line friction.

A two depth study is necessary because the five meter crosses are more responsive to tidal or other current shifting phenomena, while the one meter is controlled more by the wind. Both parameters need to be studied to provide a complete picture of the circulation of Agat Bay.

A TSK direct reading current meter was used at the mooring during two of the trips but its readings were ambiguous and not sensitive enough for our work. Later, it proved to be defective and its use was discontinued. Aside from these problems, a stationery current meter provides water movement data for one specific point, and only a complex array of current meters could duplicate the many directions recorded by our tracking as water drifts our of Agat Bay.

The correlation between the wind direction and the drogues is readily apparent from Figs. 70-117. Based on 266 hourly readings taken during the 12 current stations, winds were recorded from the northeast 136 times of 51% of the time and from data based on the 119 drogue tosses, the one meter drogue drifted to the southwest 63 times or 53% of the time. We also had winds from the southeast 31% of the time and had one meter drifts to the northwest 39% of the time. Winds from the northwest and southwest occurred 12% of the time for each with one meter drogue drifts moving northeast and southeast 4% of the time for each. The correlation of wind with the five meter drogue drifts is evident though not as consistent. This analysis is based on data from the entire year and the correlation between drifts and wind direction is closer for some individual trips (See Tables 11 and 12).

Tides are also a major factor in analyzing current patterns and current direction and velocity are correlated somewhat with the tidal phase (Jones and Randall, 1973). Guam has semi-diurnal tides with considerable diurnal inequality (Table 13). The mean range is 0.51 m and the diurnal range (difference in heighth between the mean higher high water and mean lower low water) is 0.73 m (Randall and Holloman, 1974). Tides can be a major current-producing force and are especially important in shallow water or in enclosed channels or straits. On Guam current shifts may occur within 20 minutes because of tidal changes. Furthermore, because of the large diurnal inequality the difference in heights between the high and low tides must be taken into consideration when evaluating water movement around Guam.

Our drogues were affected by tidal fluctuations, though to a lesser degree than by the wind. Drogues tended to move southerly during ebb tides and southwesterly during flood tides.

The sea and swell also influence drogue movement. The term sea refers to ocean surface waves caused directly by incident wind and is therefore a localized phenomenon. Swell refers to waves that have progressed beyond the influence of the generating winds. The sea direction is therefore the same as that of the local wind, whereas the swell direction depends on the location of the generating area. Sea and swell are generally present at the same time, although one may obscure the other according to the local conditions.

In the vicinity of Guam the sea direction is mostly from the northeast to southeast and is driven by the northeast trades. The normal tradewind waves are between two and nine feet (0.6-2.7 m) and range mostly between three and five feet (0.9-1.5 m) in heighth. Wind waves higher than nine feet are usually associated with storms.

The swell directions and heights were taken in Agat Bay during each of the 12 current stations. The swell was predominantly from the northwest (88% of the time) with a mode height of 2-3 feet (0.6-1.0 m) and a mean heighth of 1.8 feet (0.5 m). This northwest swell, probably originates in the northeast but as it strikes Guam it is refracted and enters Agat Bay as a northwest swell. During one of the stations a swell from the southwest was noted with a heighth of 3-4 feet (0.9-1.2 m). The remaining three stations had virtually no swell and any detectable heighth or direction was masked by the sea.

Although we had a northwest swell 88% of the time we had drogues moving toward the southeast only 8% of the time and it appears to be of only minor importance in surface water movement.

Still another factor to consider in understanding water movement around Guam is the effect of major ocean currents besides those generated by storms. The major oceanic effecting Guam is the North Equatorial Current. The NEC, caused by the northeast trades, sets westward across the central Pacific between 8° and

15°N and has a surface speed ranging from 0.3 to 0 through speeds of 2 knots (2.3 mph) can be reached during strong winds. The surface current directions of the NEC varies from the northwest quadrant during winter to the southwest quadrant during summer. This major ocean current sweeping past Guam is undoubtedly an important factor controlling nearshore currents, especially Guam's east coast and along the northern and southern ends. The NEC is described by Emery (1962) as approaching the northeast corner of Guam where it splits into two branches which flow around the island to region somewhere off to the east of Apra Harbor. This picture is not entirely complete, especially for water movement close to the fringing reefs of Guam. Current studies by the Navy (Huddell et al., 1974) and the University of Guam Marine Laboratory (Jones and Randall, 1971 and Dickinson and Tsuda, 1975) have shown water currents moving toward the northeast against the prevailing northeast tradewinds.

The U. S. Navy has used four current meters in Agat Bay (Huddell et al., 1974) and their findings are pertinent to this project. One of their stationery current meters was placed (February, 1971) 274 m offshore of the Agat Outfall (Station 26) in 10.7 m of water. The readings showed slight currents running parallel to shore with a net movement west, but with a high frequency of currents setting normal to the shoreline and probably due to the effect of wave action. The currents tended to move generally southwest on the ebbing tide which confirms our findings which also showed a predominant southerly drift during ebbing tides.

Another current meter used by the Navy was installed (August, 1971) several hundred meters further offshore than the one near the sewer outfall. It showed a dominance of northeast currents which were also faster than the winter (February) data.

Dye injections were made in winter and summer at the outfall and the general pattern of water movement from the outfall is that of sluggish eddying currents. On two of these injections, dye from the mouth of the outfall moved shoreward then over the reef and spread out along the shoreline.

The other two Navy current meters were placed just north of Neye Island in 19.8 m of water. The first used in the winter (February, 1971), showed a net westerly movement with currents strongly influenced by the tides. The highest current speeds occur occurred one to two hours after each low tide. Currents were westerly during the peak flows changing to southeasterly after each high tide when speeds were least. The second current meter, installed in the summer, showed peak speeds during rising tide and lower speeds during the ebb. This meter also showed speeds generally higher during the summer with a maximum of 0.55 knots and a northwest movement during flood and variable southeast and northwest during ebb.

Dye patches were also made by the Navy off of Dadi Beach. Three of the patches showed sluggish eddying currents while one patch, during a flood tide, was subject to a strong current setting to the south. This southerly flow during flood was exactly opposite to the general pattern found at Tantapalo Point (north of Neye Island) and illustrates the eddying nature of currents in Agat Bay.

The maximum speed observed during our study was 0.5 knots (one meter drogue; Trip 5) with a minimum speed of 0.05 knots (one and five meter drogues; Trip 10). The speeds of all drogues increased as a function of their distance from shore; as drogues approached a distance of 0.5 nautical miles from the release point, they were more influenced by major oceanic currents, probably the north equatorial current sweeping past Orote Point, and moved west or southwesterly at faster speeds.

Groundings (drogues drifting onto the reef flat) occurred during Trips 1, 4, 5, and 6. Two of the groundings (Trips 4 and 5) were at Rizal Beach reef flat (Stations 6-9) and two occurred near Gaan Point, one north near Station 21 (Trip 6) and one just south near Station 29 (Trip 1). The groundings at Rizal were during flood tides and those near Gaan Point were during ebb tides. All of the groundings were one meter drogues.

During Trip 1, 21% of all hourly wind readings from the northwest for the year were recorded. Trips 4, 5, and 6 had 25%, 61%, and 14% of all the southwest winds recorded, respectively. Compiling the wind data for these four trips, it was found that 100% of the southwest wind readings were recorded during those trips and 88% of all northwest wind readings were recorded.

The remaining trips had generally west or southwest drifts except Trip 3 which had some northerly movement.

There is a general tendency for winds to abate during late evening and early morning hours (Appendix III) and subsequently drift tracks for those hours show decreased speeds and a more meandering drift direction, indicating less surface water movement.

The analysis of the circulation of Agat Bay is complex. All of the parameters discussed affect the drift direction to some extent during the year. These forces may occur at the same time in varying degrees of magnitude and duration, and may either mask or enhance one another.

The general water movement from the mooring site on the 60 foot isobath is westerly and predominantly southwest. On occasions of southwest or northwest winds there is a great probability of onshore water movement and any surface contamination would tend to move shoreward. These winds are usually associated with storms and are not common. The water movement closer to shore is much less predictable as seen by the meandering and sluggish tracking of drogues, especially on days of light winds.

Out study confirms the Navy's conclusions that bays and other semienclosed waters exhibit slow eddying of surface waters and is in marked contrast to the stronger, more consistent flows they observed off Facpi Point, Orote Peninsula, and Tantapalo Point.

CAUSEWAY CURRENTS

Observations were made during a heavy rainfall at the old causeway on the north end of Rizal Beach (Fig. 22). It had also been raining heavily the night before and the small stream which flows into the causeway was unusually large. It was felt that some information about input from the stream onto the reef flat might be useful.

Fluorescein dye patches were used to measure current velocity in the stream and causeway. Water samples were taken at three points, shown in the figure, and were analyzed for turbidity using a Hach laboratory nephelometer. The three samples were then filtered using Munkten's filter paper for finely grained precipitates. An estimate was then made of the sediment load in the water at the three respective points.

The velocities at A and B are shown in Fig. 118. This study was done during an ebb tide and heavy rainfall (July 26, 1975; 1215 hrs) for comparison with dye studies made during nonrainy days (Figs. 119, 120). The water movement through the causeway is more than nine times greater during heavy rainfall.

Turbidity readings for samples A and B were 280 NTU and 160 NTU (Nephelometric Turbidity Unit; A high NTU reading indicates greater turbidity) respectively. Sample C contained fluorescein dye from the earlier dye study and the turbidity reading was invalid. However, the water in sample C was virtually clear.

All three samples were filtered to give some idea of the sediment load, with the following results: Sample A had 0.36 grams per liter, B had 0.21 grams per liter, and Sample C had 0.036 grams per liter. From this data, it can be estimated that sediment is carried through the causeway at a rate of 64.8 g/sec (513.2 lbs/hr).

A large dye patch was released from Point B and observed for one hour. The patch moved swiftly out of the causeway and turned towards the northeast. As it approached the reef margin its speed became less and it dispersed gradually in all directions, spreading over the outer reef flat and reef front moving both north and south.

At point C the turbid water was restricted to the surface, and the water immediately beneath the murky top layer was clear. Apparently sediment carried by the stream is held in suspension in the fresh water lens overlaying the denser sea water and is carried out to the reef flat. The dye patch was evident after one hour but it had diffused seaward in all directions and was disappearing.

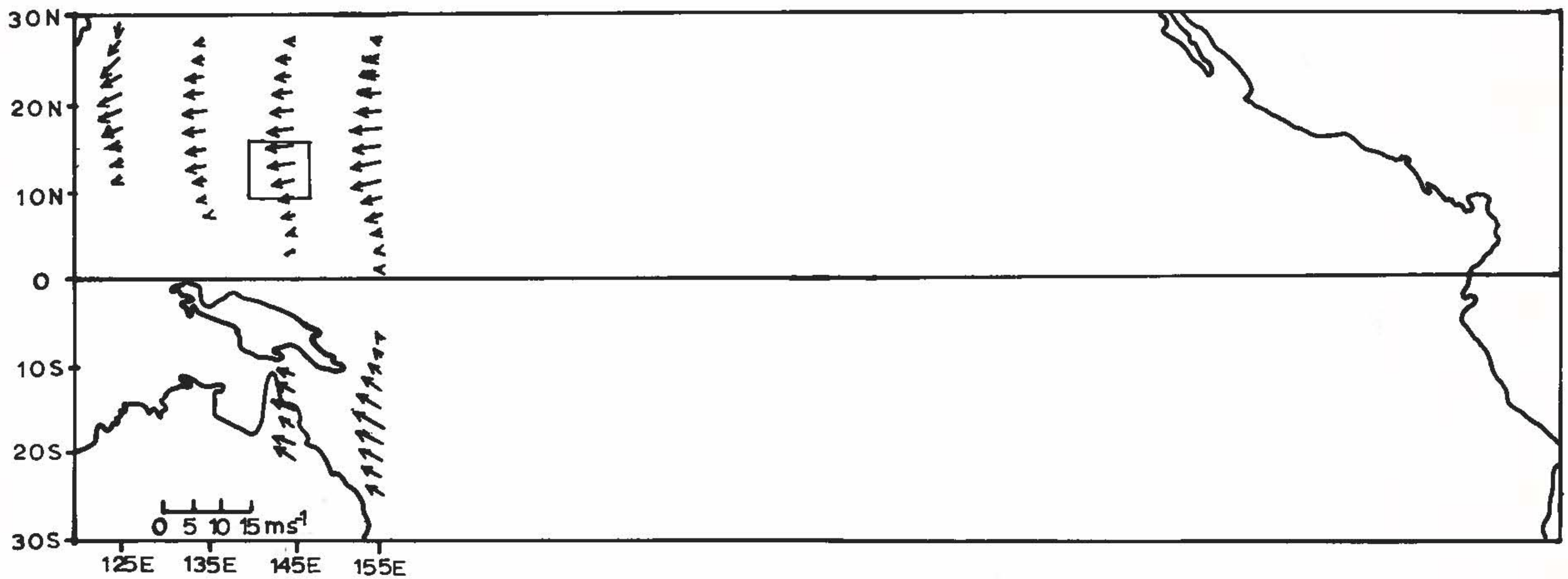

Fig. 69. Annual mean surface wind velocity. The enclosed area indicates location of Guam (modified from Wyrtki and Meyers, 1975).

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Table 11.

Number of 1 meter drogues in respective quadrants after drifting (mean drift time: 3.4 hours)

TR. NO.	NE	SE	SW	NW
1 (May)	0	0	7	2
2 (July)	0	0	5	4
3 (July)	0	0	5	5
4 (Aug.)	2	1	3	4
5 (Sept.)	3	0	3	4
6 (Oct.)	0	1	7	1
7 (Nov.)	0	0	0	11
8 (Dec.)	0	0	9	2
9 (Feb.)	0	0	9	3
10 (Mar.)	0	0	7	3
11 (Apr.)	0	3	6	1
12 (May)	0	0	2	6
All trips	5	5	63	46 = 119
Total Percentage	4%	4%	53%	39%

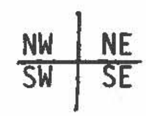


Table 12.

Number of 5 meter drogues in respective quadrants after drifting (mean drift time: 3.4 hours)

TRIP NO.	NE	SE	SW	NW
1 (May)	0	0	7	2
2 (July)	0	0	5	4
3 (July)	1	0	5	4
4 (Aug.)	1	1	3	5
5 (Sept.)	3	2	1	4
6 (Oct.)	0	2	6	1
7 (Nov.)	0	0	1	10
8 (Dec.)	0	0	10	1
9 (Feb.)	0	0	9	3
10 (Mar.)	0	0	7	3
11 (Apr.)	0	3	7	0
12 (May)	0	0	2	6
All trips	5	8	63	43 = 119
Total Percentage	4%	7%	53%	36%

NW	NE
SW	SE

Table 13. Datum for Guam is mean lower low water, and other data are shown with relation to this datum (Randall and Holloman, 1974).

	Feet
Highest tide (observed)	3.31
Mean higher high water	2.40
Mean high water	2.30
Mean tide level	1.45
Mean low water	0.60
Mean lower low water	0.00
Lowest tide (observed)	1.89

Extreme predicted tide range at Guam is about 3.5 feet (from 2.6 to minus 0.9 feet) and occurs during the months of June and December.

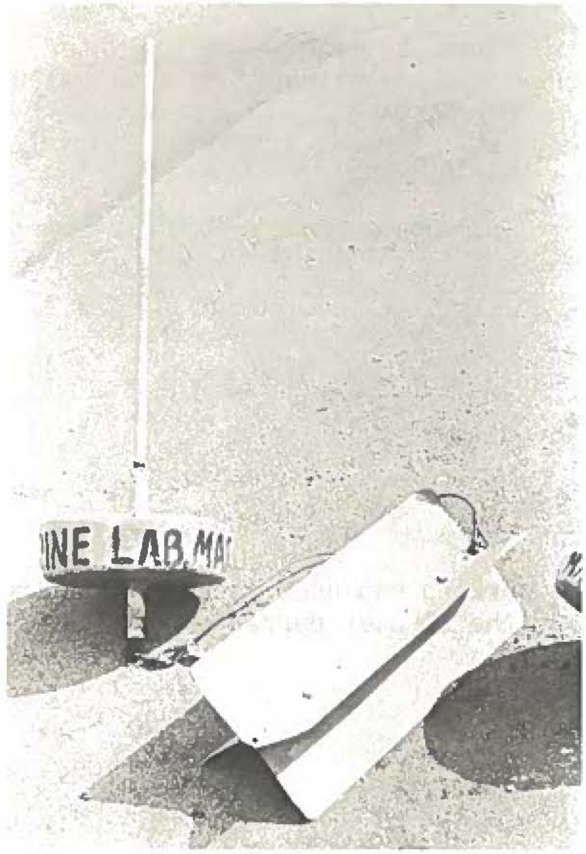


Fig. 65. Drift drogue for current studies. Note, the polyurethane buoy with metal vane attached by 1 m line.

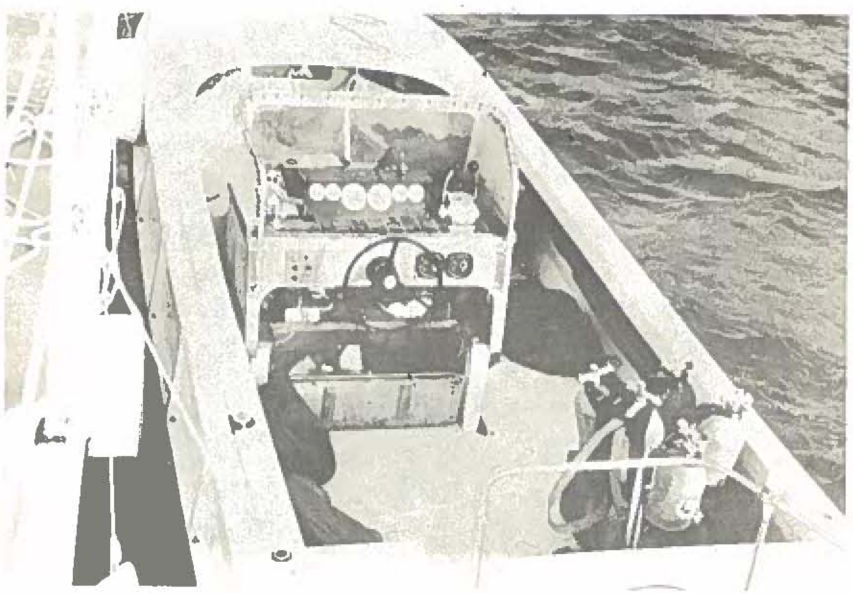


Fig. 66. Ma.ine Laboratory chase boat tied alongside the Havaiki.

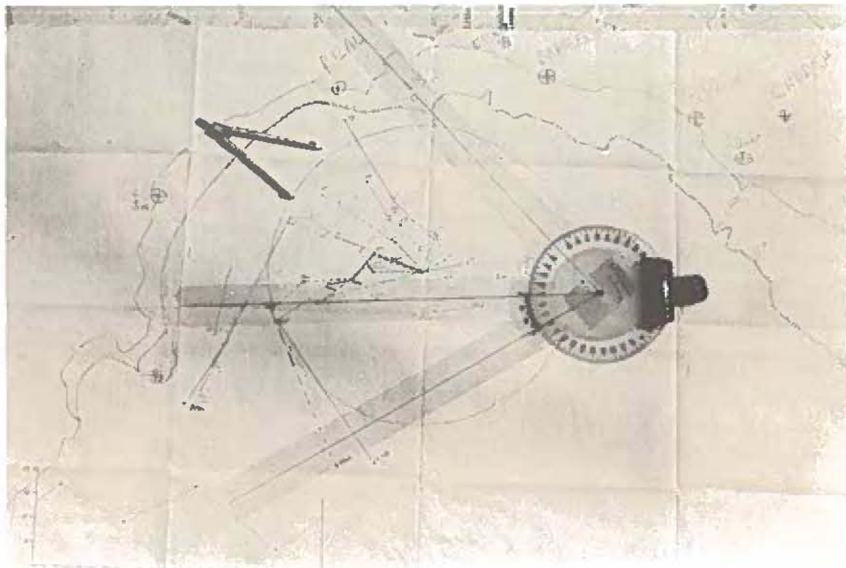


Fig. 67. Large working map used to plot drogue movements during the 24 hour current studies.

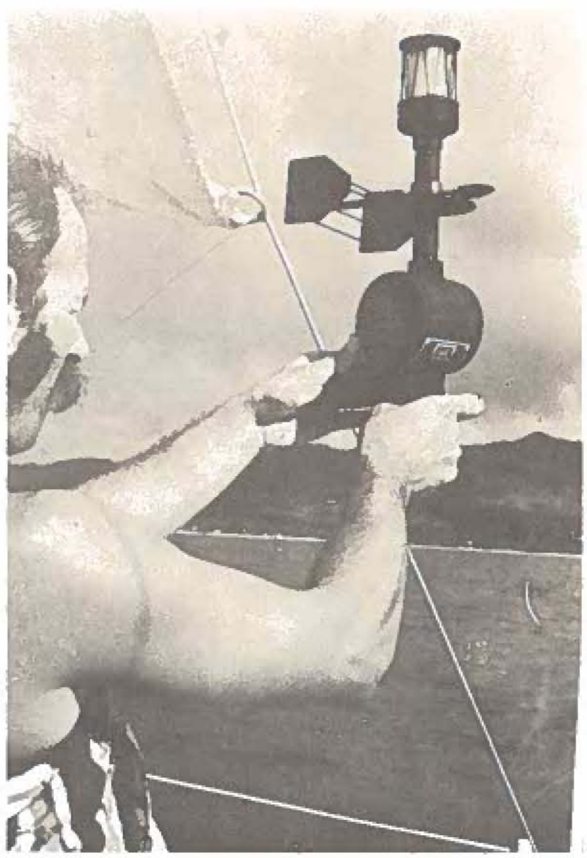


Fig. 68. A hand held anemometer used to record wind speed and direction at hourly intervals during the 24 hour current stations.

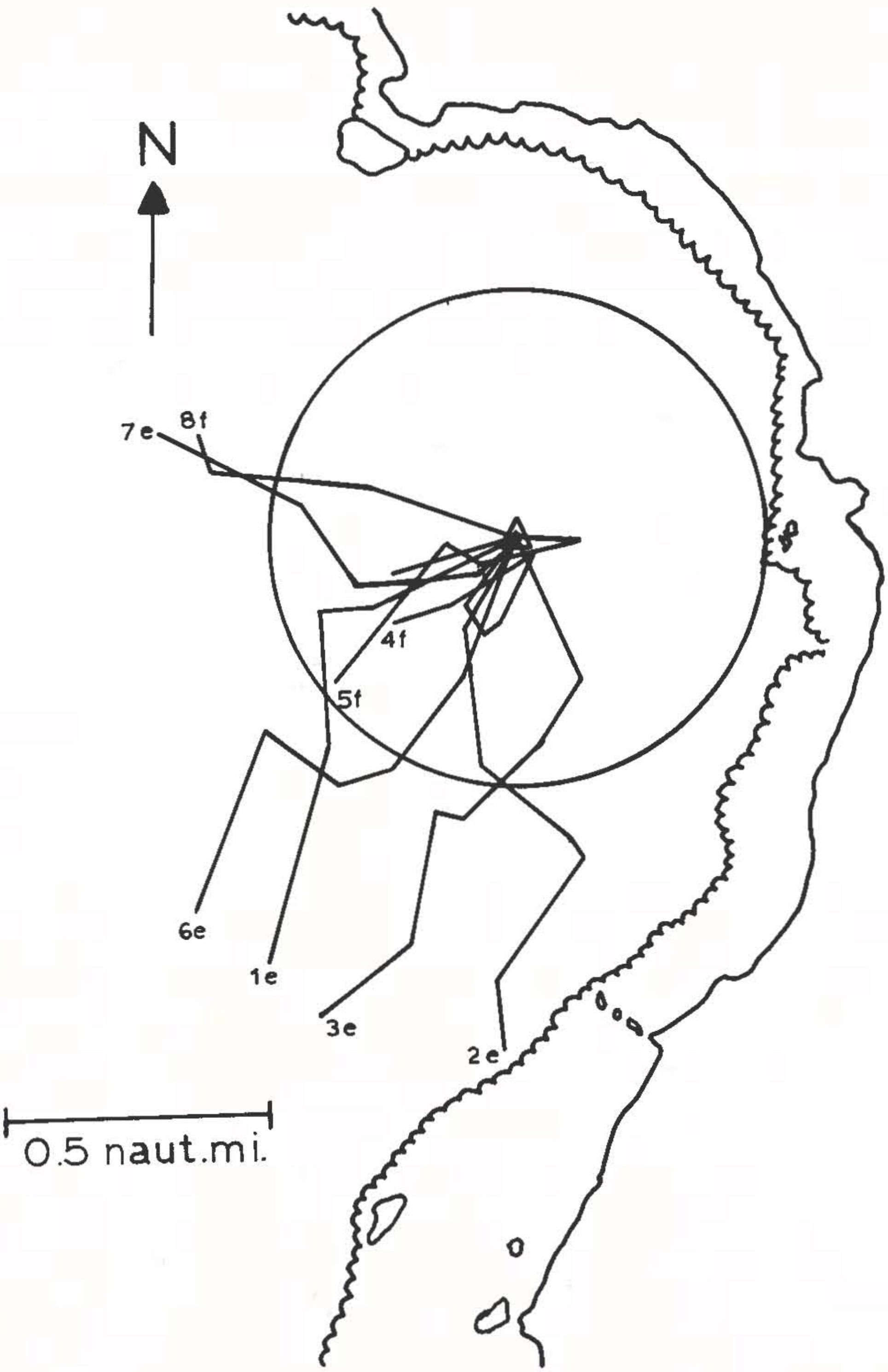
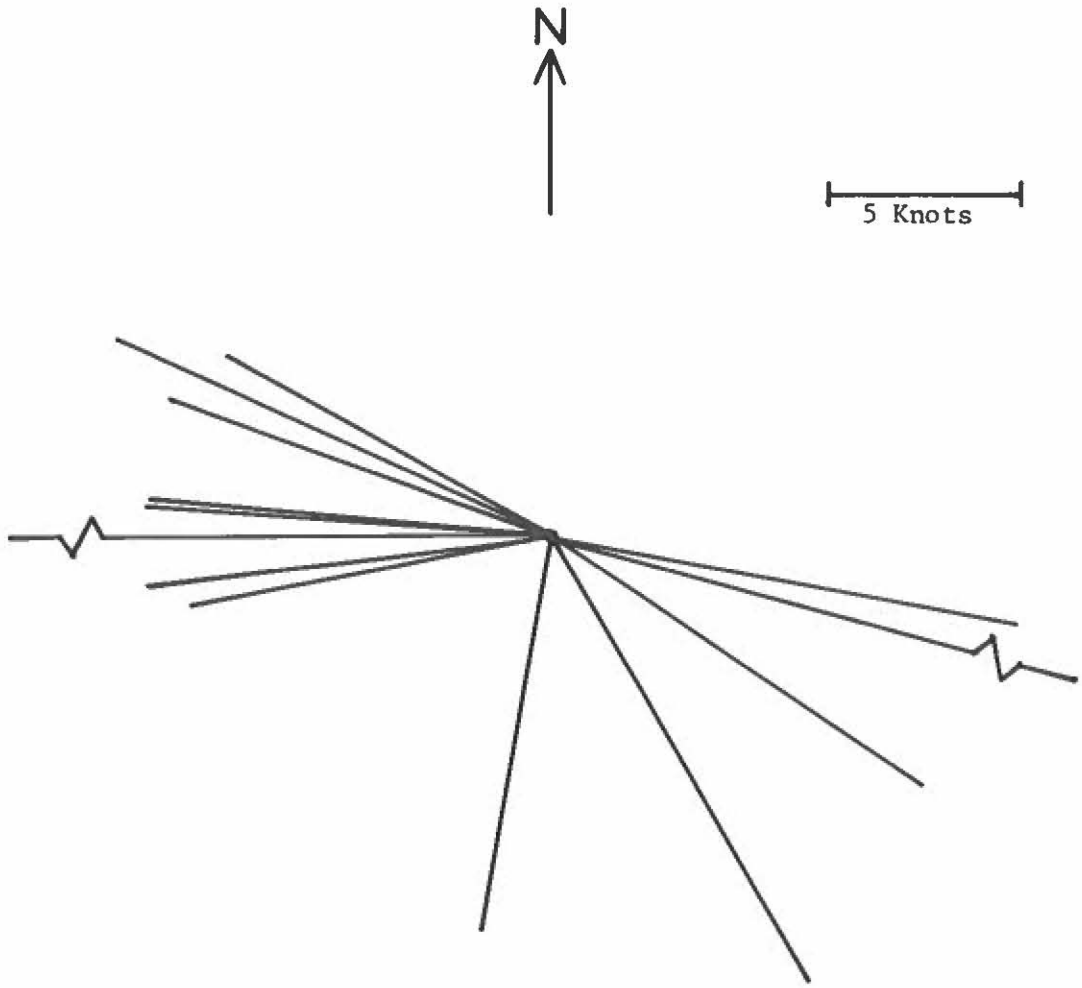


Fig. 70. Trip 1, 1 m drogue movement (May 23-24, 1974).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (Knots)
1	0800	4	1.08	0.27
2	1030	6.5	1.11	0.17
3	1300	7	1.12	0.16
4	1700	7	0.77	0.11
5	2000	4	0.76	0.19
6	0000	5	1.10	0.22
7	0130	4.5	0.86	0.19
8	0500	3	0.72	0.24
9	0700	1	0.23	0.23

Fig. 71. Wind histogram and 1 m drift data--Trip 1, May 23-24, 1974.

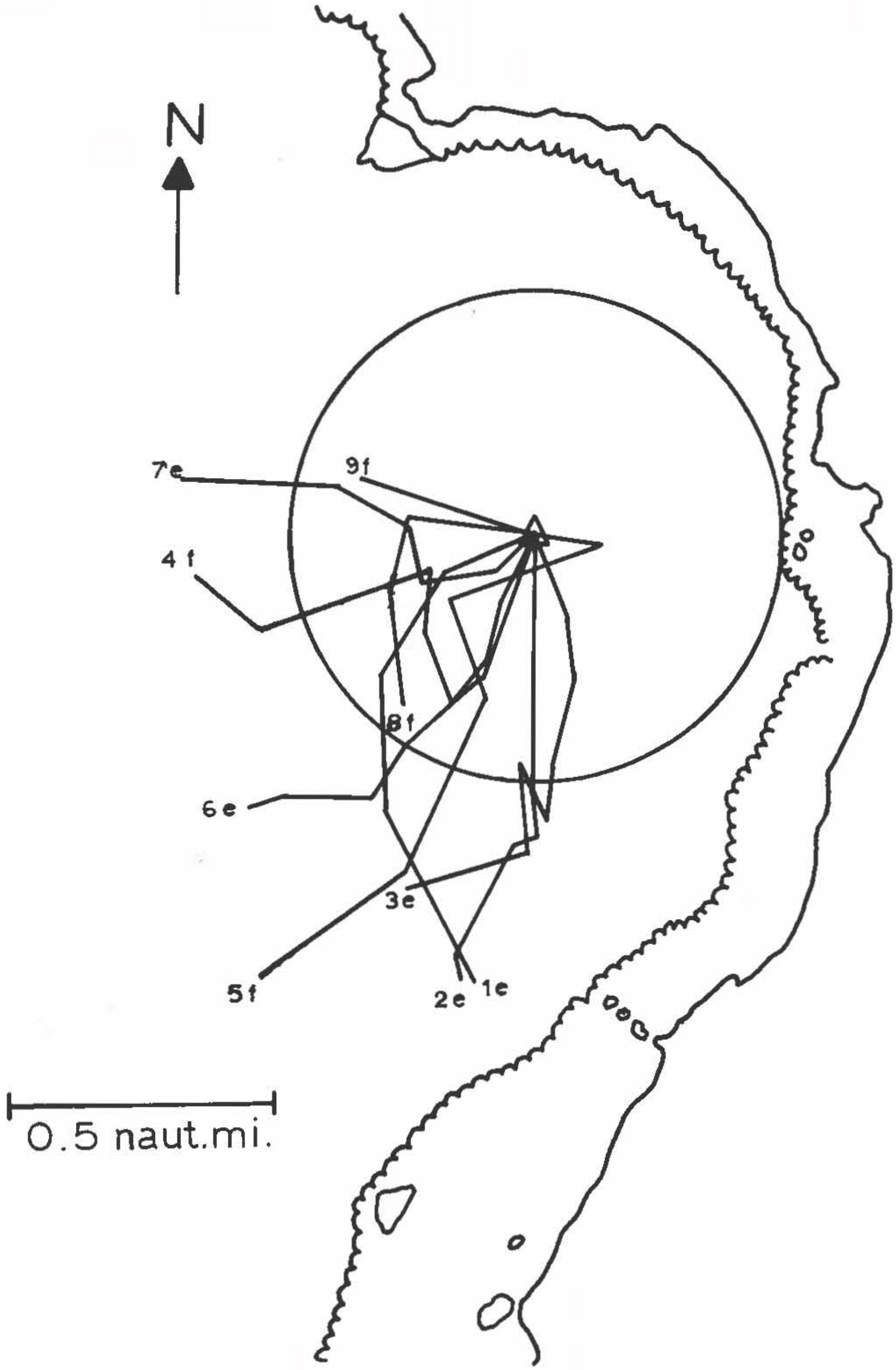
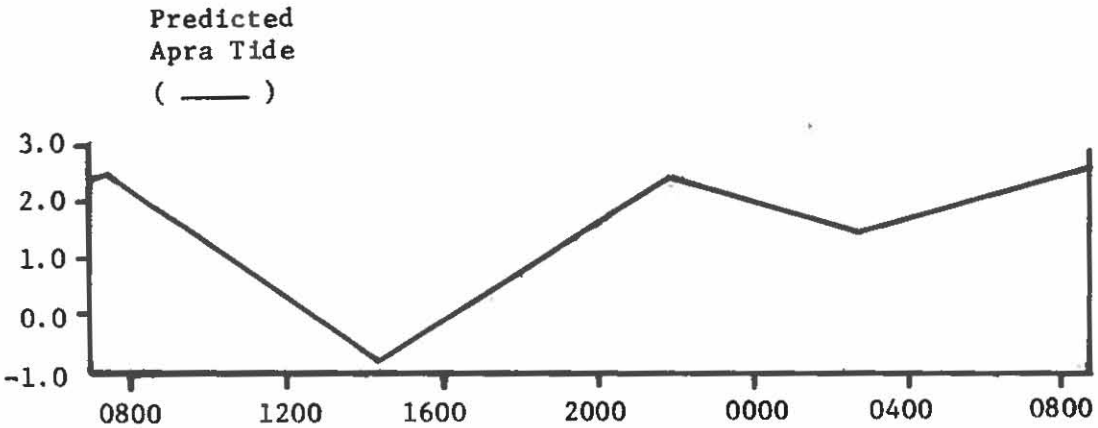


Fig. 72. Trip 1, 5 m drogue movement (May 23-24, 1974).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	4	0.96	0.24
2	1030	6.5	0.91	0.14
3	1300	7	1.12	0.16
4	1700	7	1.19	0.17
5	2000	4	1.40	0.35
6	0000	5	0.80	0.16
7	0130	4.5	0.77	0.17
8	0500	3	0.57	0.19
9	0700	1	0.33	0.33

Fig. 73. Predicted Apra Harbor Tide and 5 m drift data--Trip 1, May 23-24, 1974.

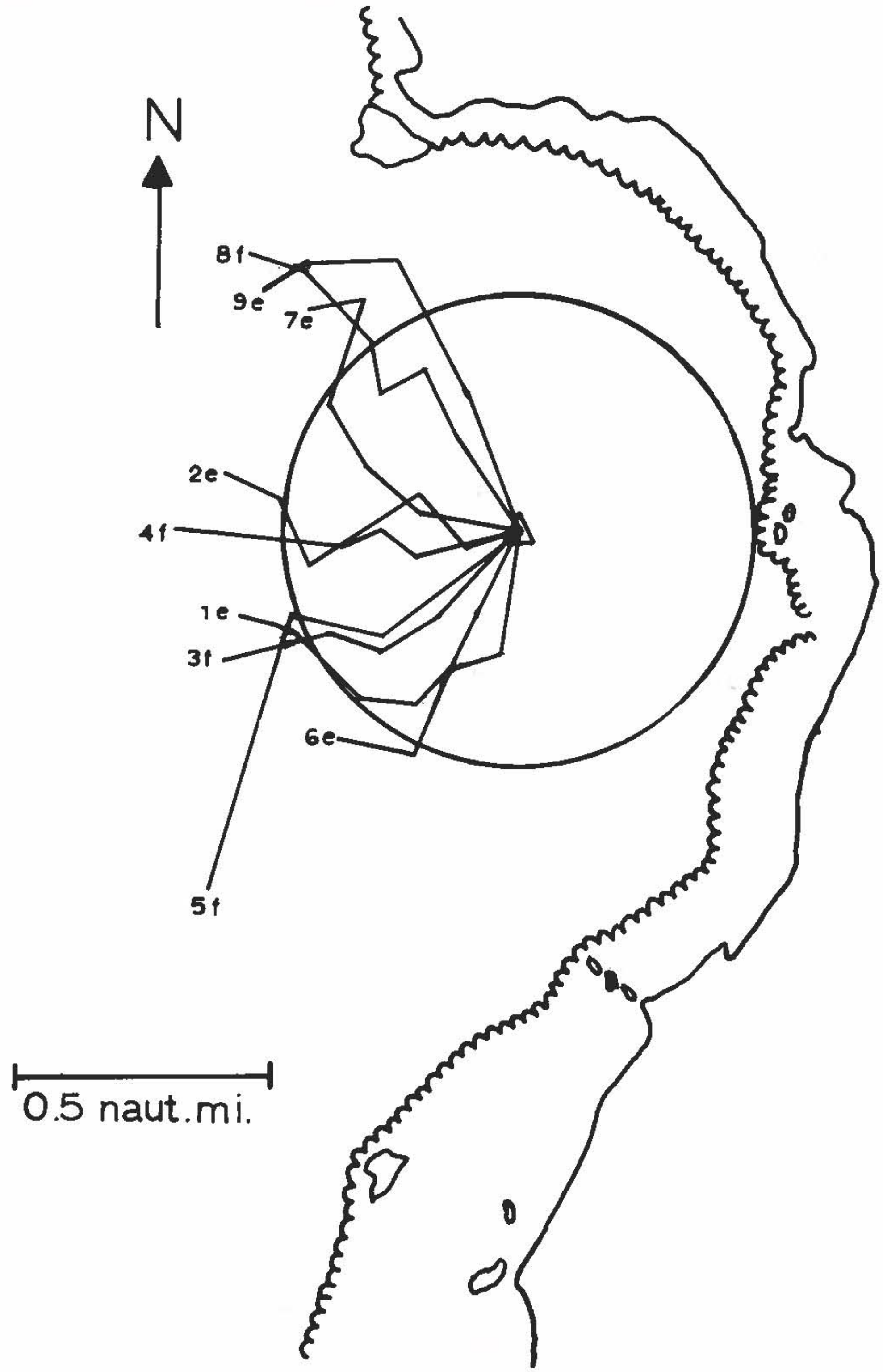
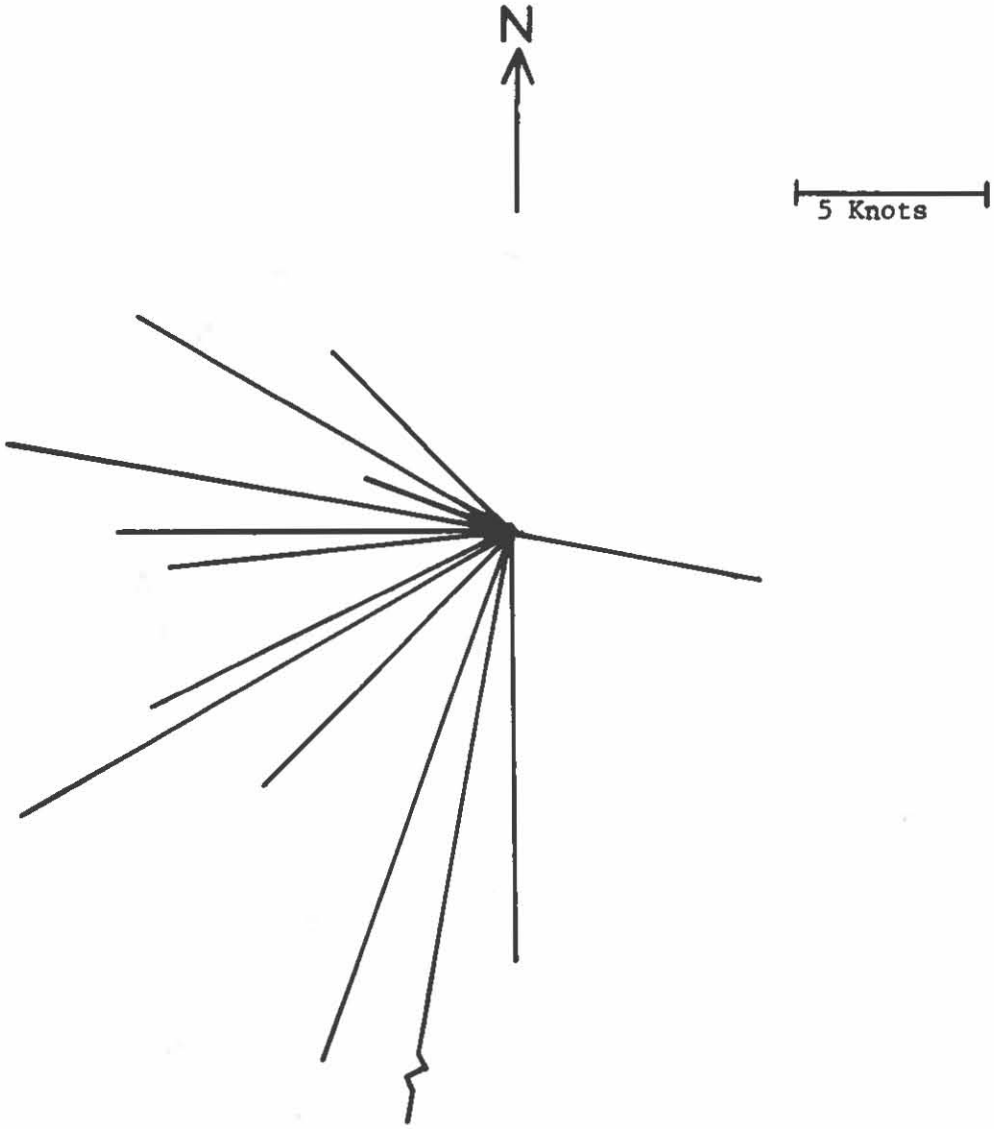


Fig. 74. Trip 2, 1 m drogue movement (July 2-3, 1974).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0900	7	0.84	0.12
2	1100	5	0.70	0.14
3	1500	4	0.64	0.16
4	1700	4	0.68	0.17
5	2000	3	1.05	0.35
6	2200	3	0.63	0.21
7	0000	5	0.75	0.15
8	0200	6	0.90	0.15
9	0600	3	0.81	0.27

Fig. 75. Wind histogram and 1 m drift data--Trip 2, July 2-3, 1974.

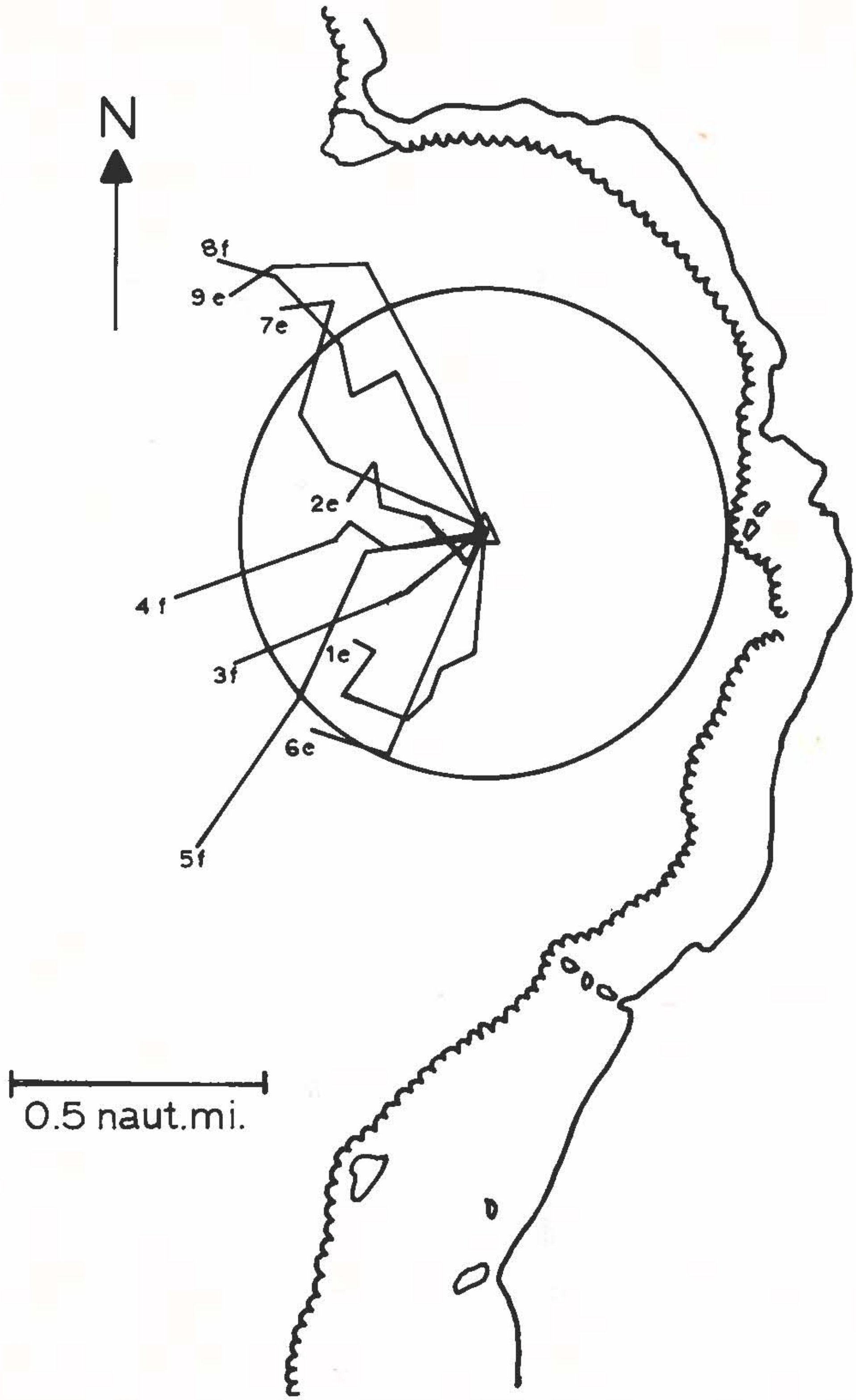
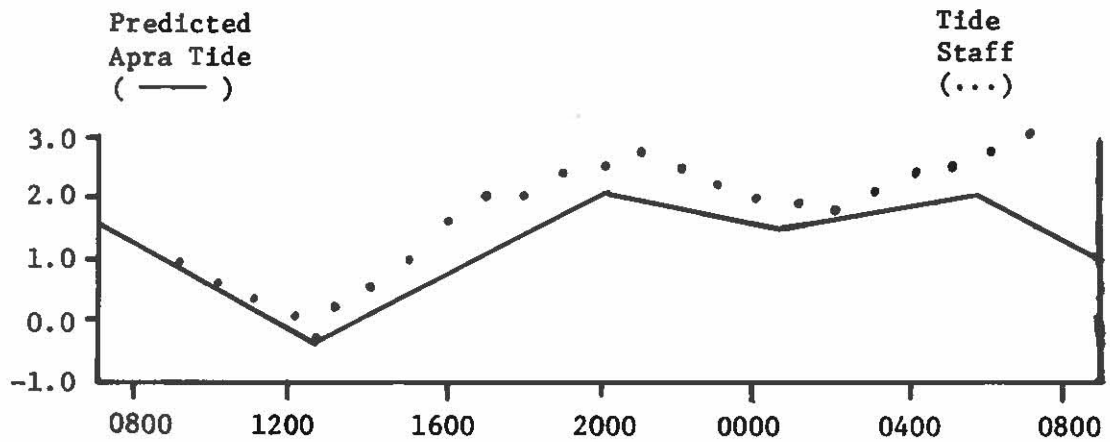


Fig. 76. Trip 2, 5 m drift movement (July 2-3, 1974).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0900	7	0.63	0.09
2	1100	5	0.45	0.09
3	1500	4	0.56	0.14
4	1700	4	0.60	0.15
5	2000	3	0.90	0.30
6	2200	3	0.63	0.21
7	0000	5	0.75	0.15
8	0200	6	0.90	0.15
9	0600	3	0.81	0.27

Fig. 77. Predicted Apra Harbor Tide compared with Agat Bay Tide staff and 5 m drift data--Trip 2, July 2-3, 1974.

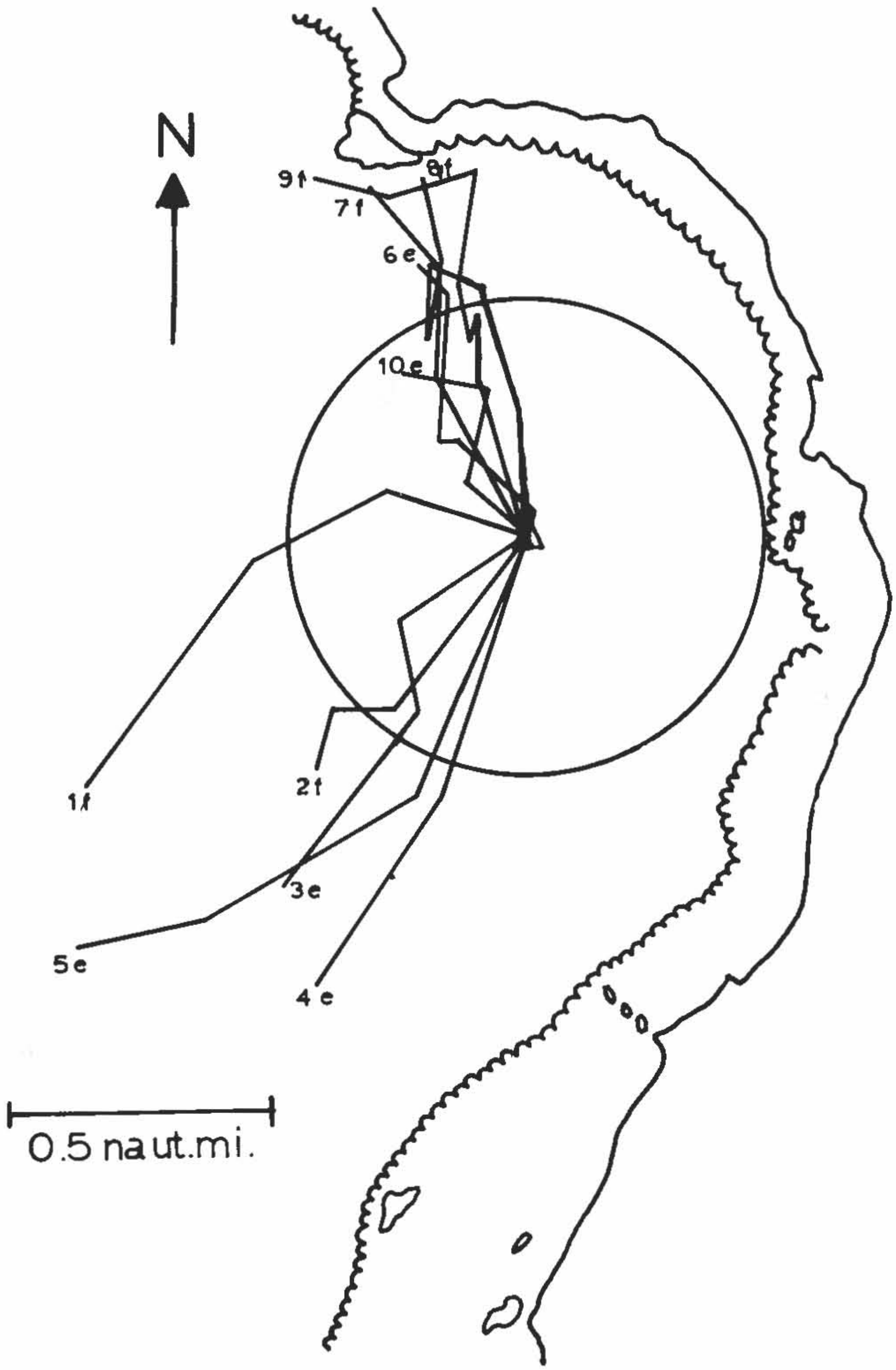
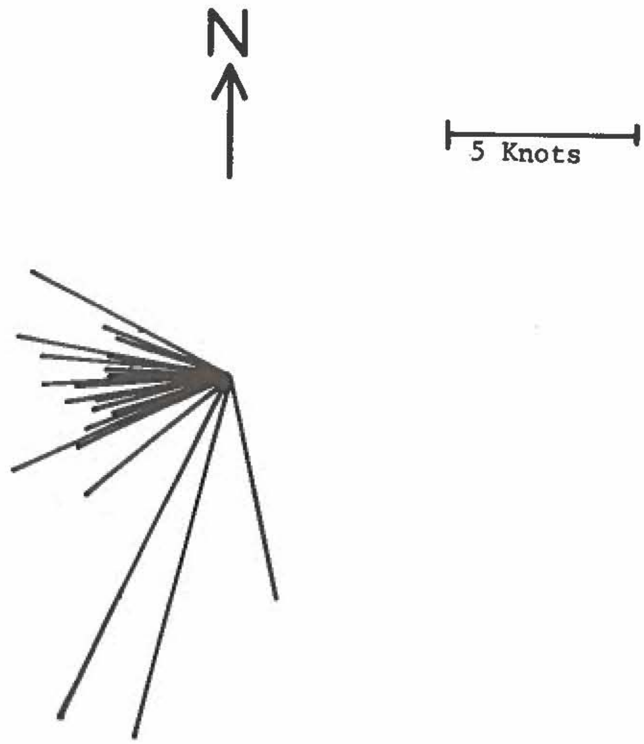


Fig. 78. Trip 3, 1 m drift movement (July 25-26, 1974).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	3	1.05	0.35
2	1000	3	0.66	0.22
3	1100	3	0.90	0.30
4	1300	4	0.96	0.24
5	1400	4	1.20	0.30
6	1700	5	0.55	0.11
7	2000	3	0.69	0.23
8	2200	7	0.70	0.10
9	0000	7	1.19	0.17
10	0500	3	0.51	0.17

Fig. 79. Wind histogram and 1 m drift data--Trip 3, July 25-26, 1974.

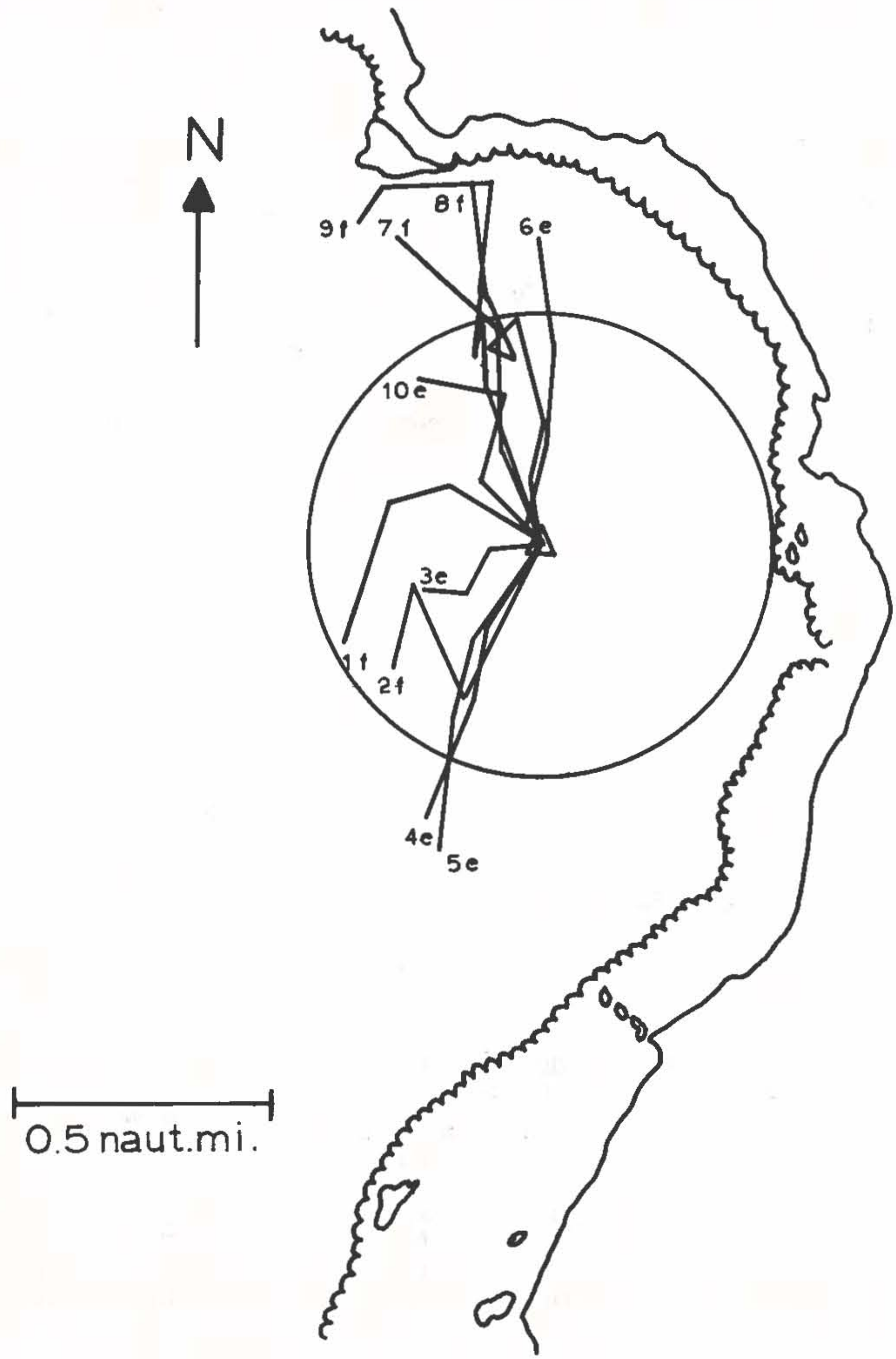
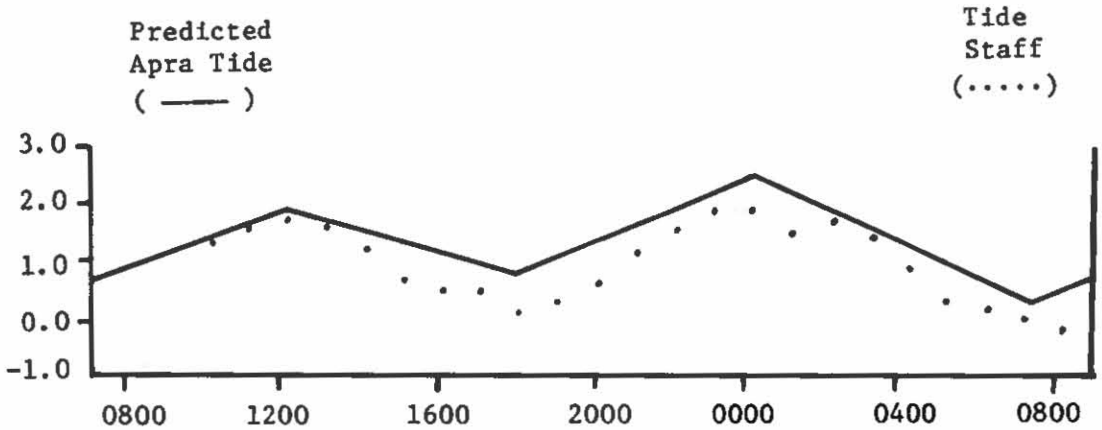


Fig. 80. Trip 3, 5 m drift movement (July 25-26, 1974).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	3	0.60	0.20
2	1000	3	0.69	0.23
3	1100	3	0.30	0.10
4	1300	4	0.80	0.20
5	1400	4	0.64	0.16
6	1700	5	0.55	0.11
7	2000	3	0.63	0.21
8	2200	7	0.84	0.12
9	0000	7	1.12	0.16
10	0500	3	0.51	0.17

Fig. 81. Predicted Apra Harbor Tide compared with Agat Bay Tide staff and 5 m drift data--Trip 3, July 25-26, 1974.

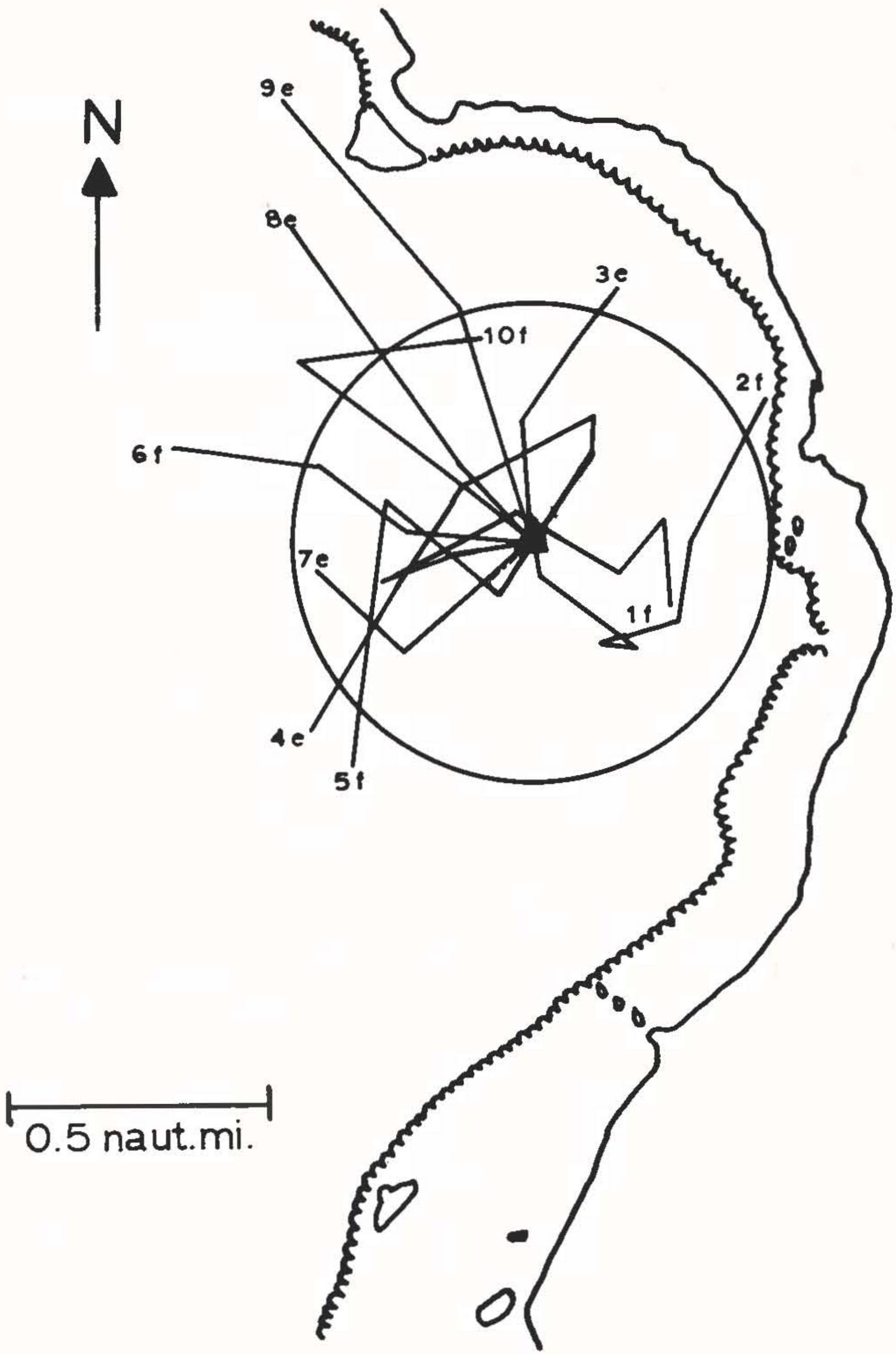
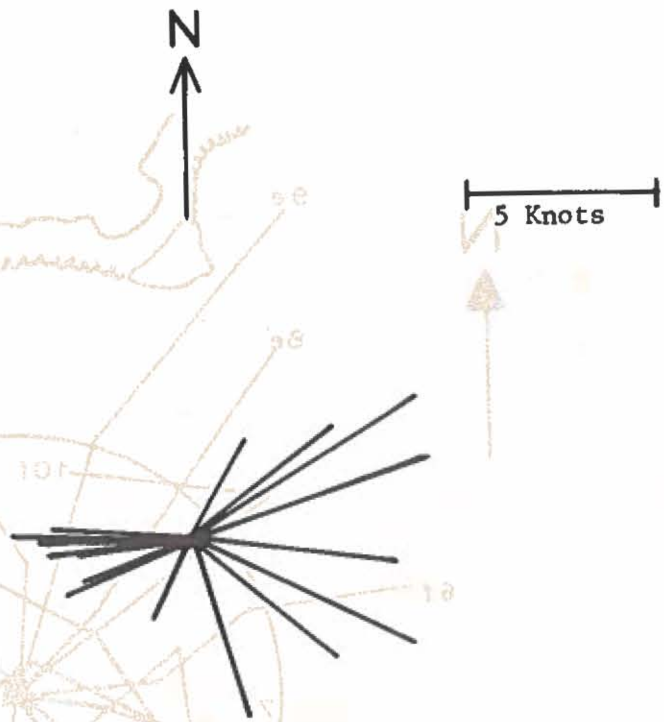


Fig. 82. Trip 4, 1 m drift movement (August 22-23, 1974).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	6	1.08	0.18
2	1000	7	0.91	0.13
3	1400	3	0.51	0.17
4	1700	5	1.10	0.22
5	1900	3	0.90	0.30
6	2220	2.66	0.72	0.27
7	2400	2	0.54	0.27
8	0200	2	0.72	0.36
9	0400	2	0.98	0.49
10	0600	2	0.86	0.43

Fig. 83. Wind histogram and 1 m drift data--Trip 4, August 22-23, 1974.

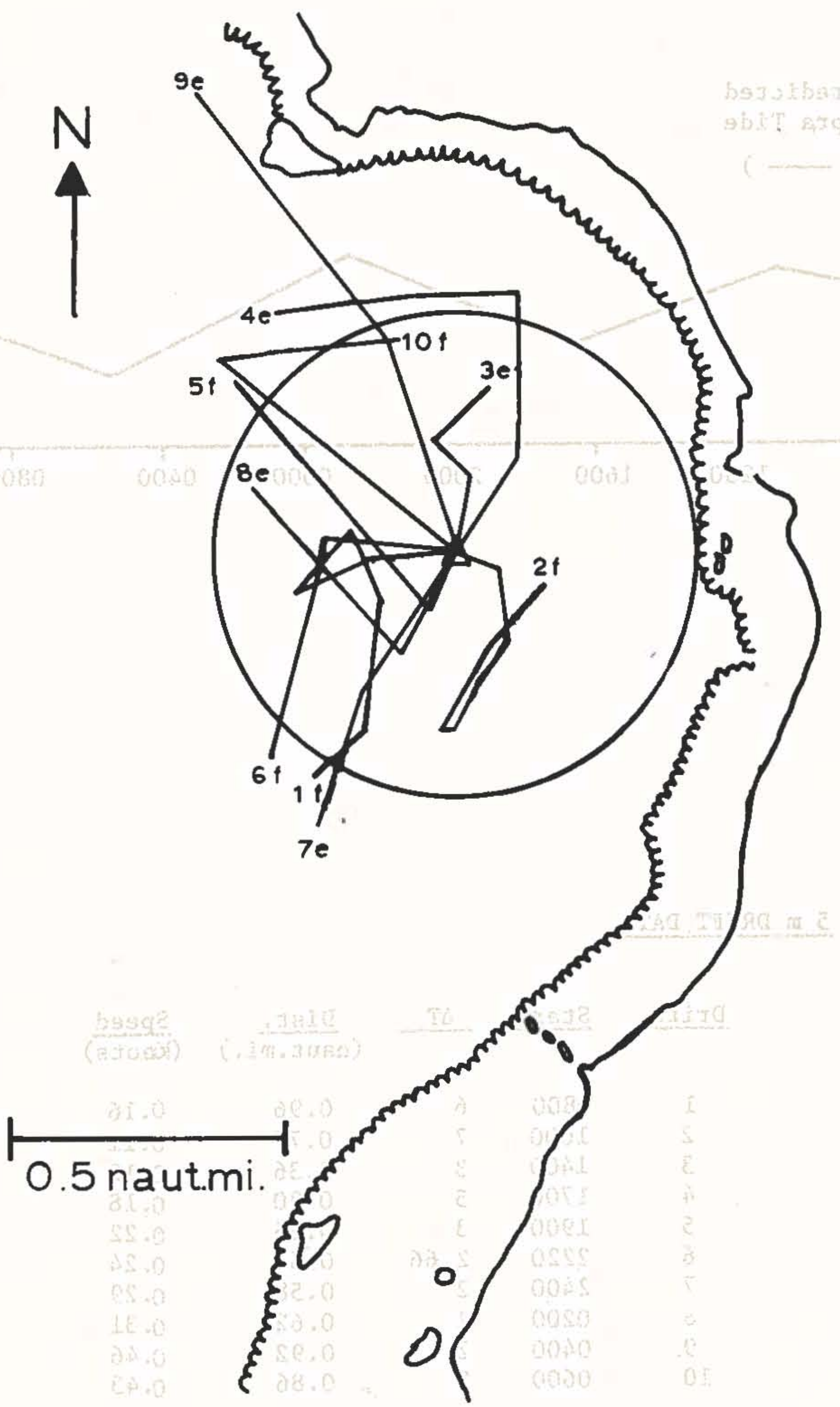
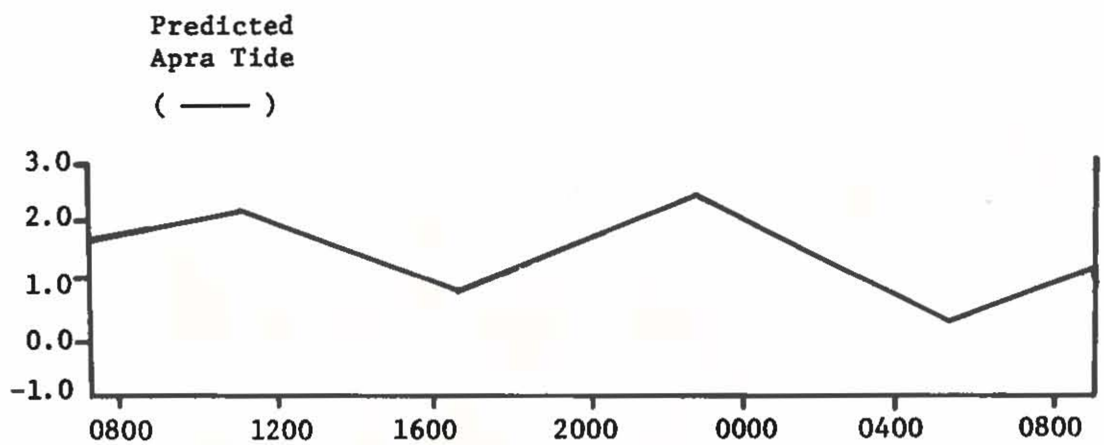


Fig. 84. Trip 4, 5 m drift movement (August 22-23, 1974).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (Knots)
1	0800	6	0.96	0.16
2	1000	7	0.77	0.11
3	1400	3	0.36	0.12
4	1700	5	0.90	0.18
5	1900	3	0.66	0.22
6	2220	2.66	0.64	0.24
7	2400	2	0.58	0.29
8	0200	2	0.62	0.31
9	0400	2	0.92	0.46
10	0600	2	0.86	0.43

Fig. 85. Predicted Apra Harbor Tide and 5 m drift data-- Trip 4, August 22-23, 1974.

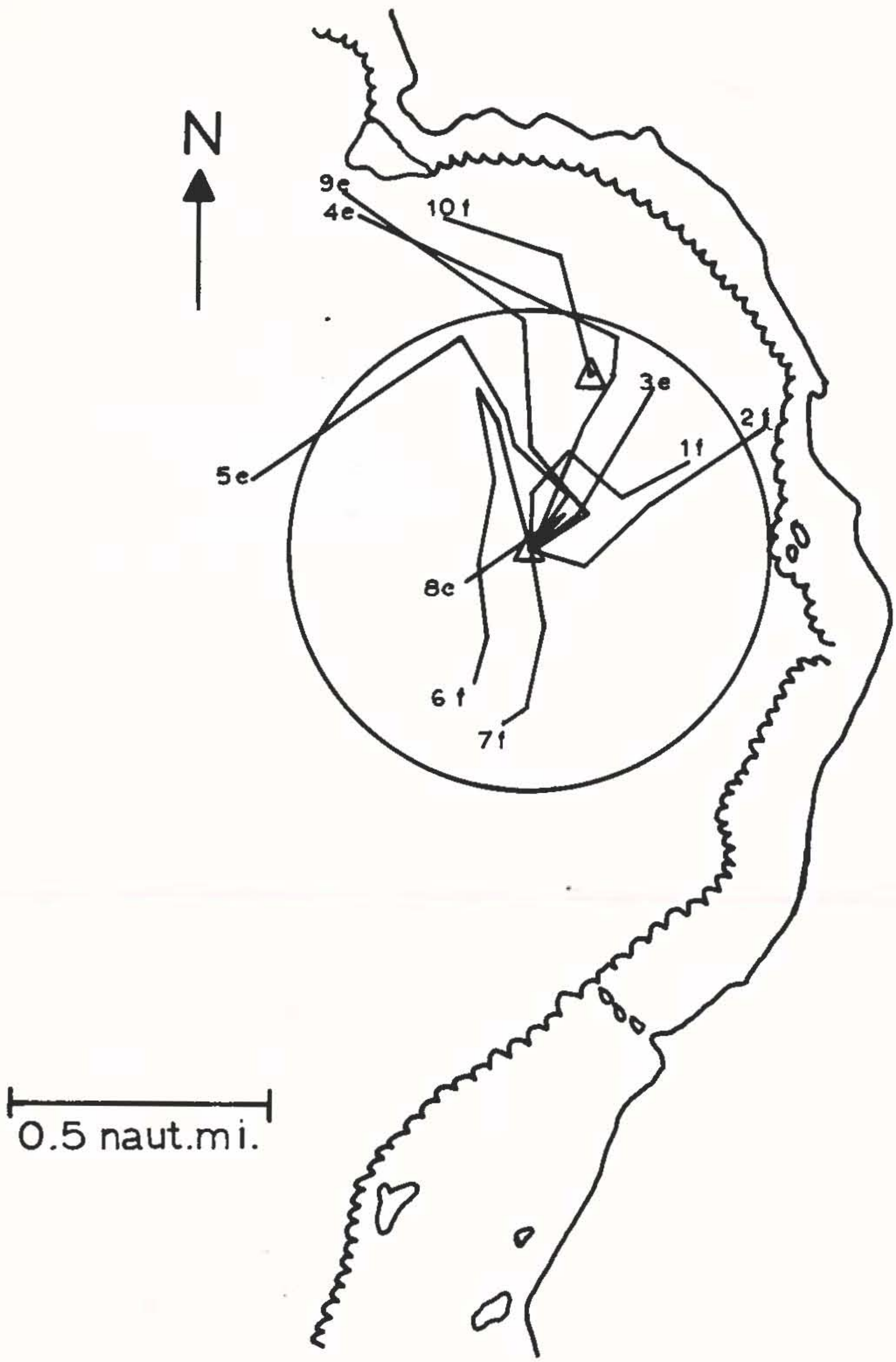
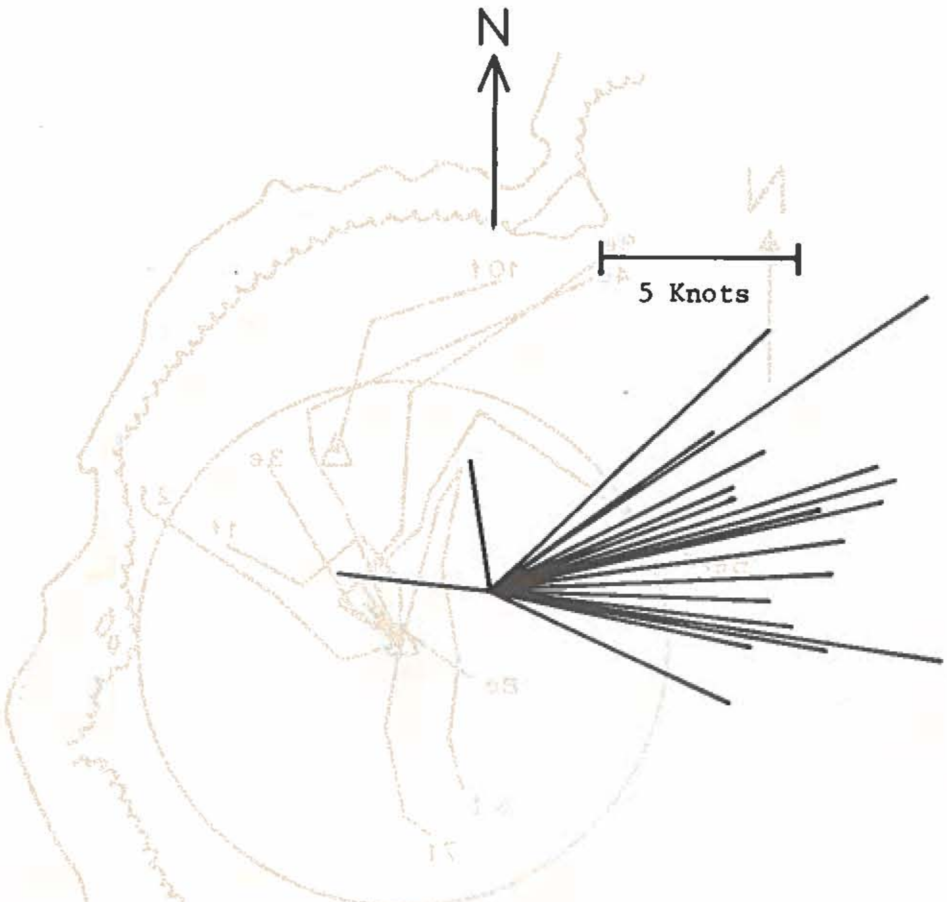


Fig. 86. Trip 5, 1 m drift movement (September 19-20, 1974).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	4	0.48	0.12
2	1000	3	0.54	0.18
3	1200	2	0.36	0.18
4	1400	4	2.00	0.50
5	1500	5	1.90	0.38
6	1900	6	1.56	0.26
7	2100	3	0.72	0.24
8	0100	3	0.63	0.21
9	0300	5	1.85	0.37
10	0500	2	0.92	0.46

Fig. 87. Wind histogram and 1 m drift data--Trip 5, September 19-20, 1974.

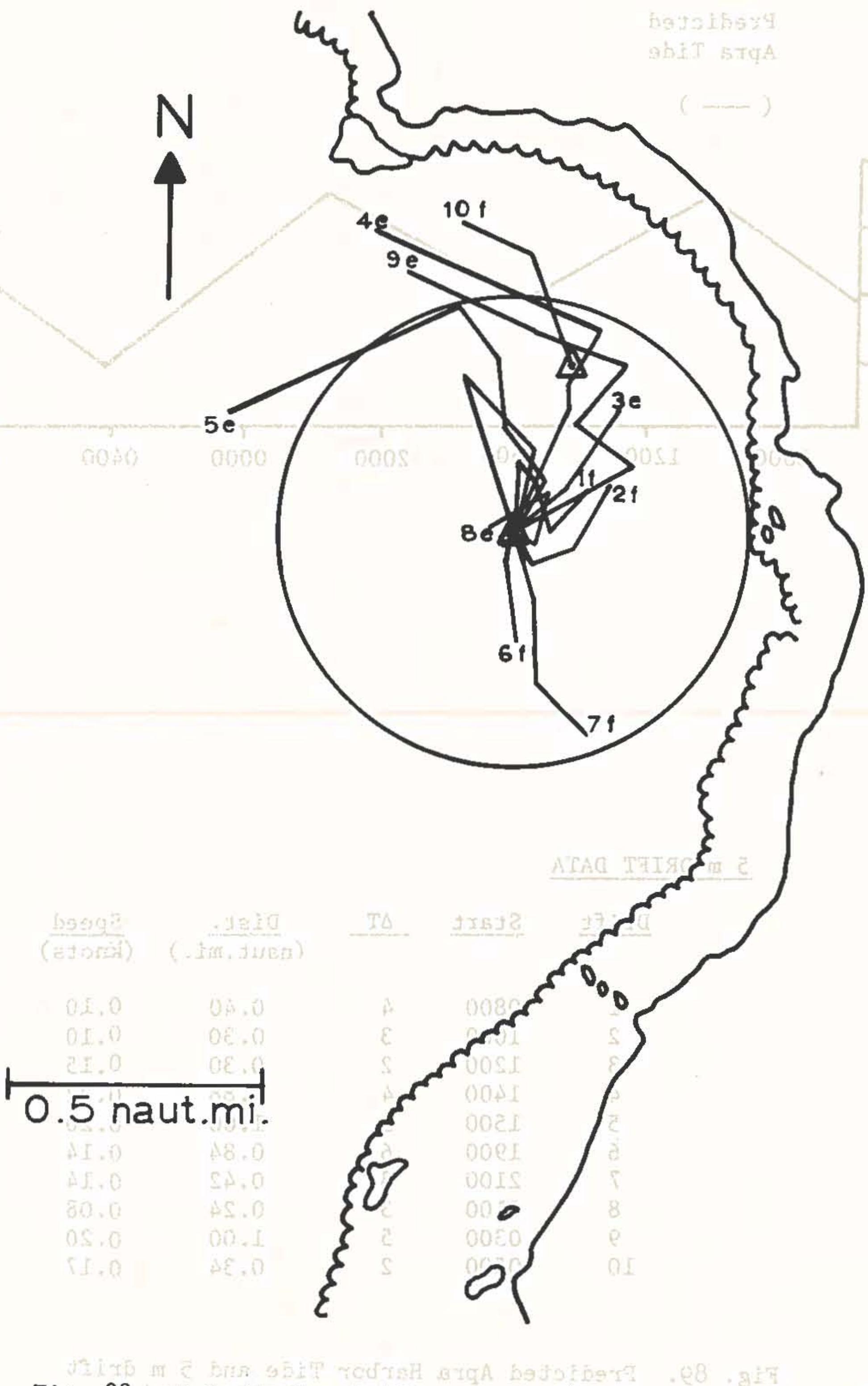
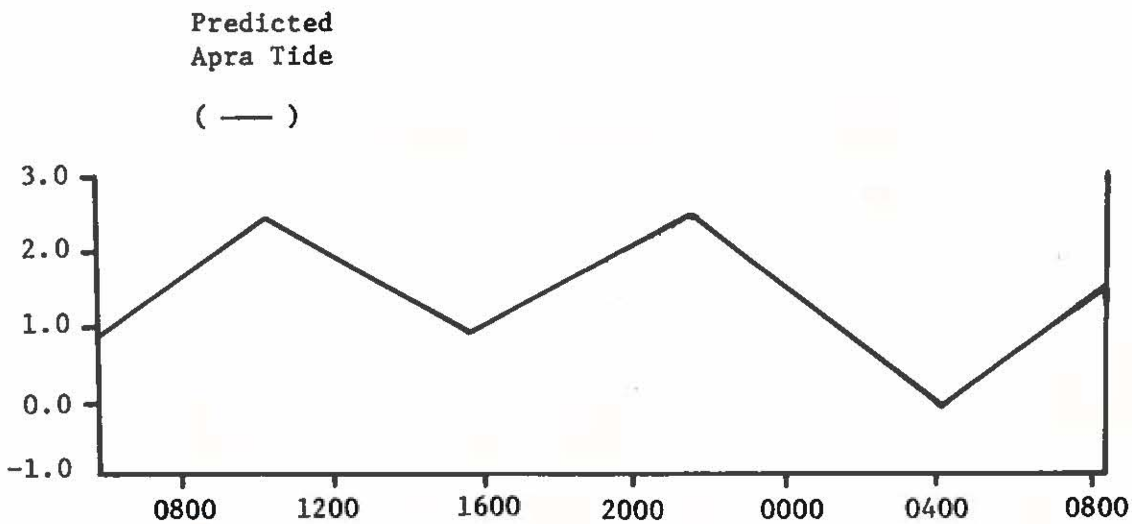


Fig. 88. Trip 5, 5 m drift movement (September 19-20, 1974).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	4	0.40	0.10
2	1000	3	0.30	0.10
3	1200	2	0.30	0.15
4	1400	4	0.88	0.22
5	1500	5	1.00	0.20
6	1900	6	0.84	0.14
7	2100	3	0.42	0.14
8	0100	3	0.24	0.08
9	0300	5	1.00	0.20
10	0500	2	0.34	0.17

Fig. 89. Predicted Apra Harbor Tide and 5 m drift data--Trip 5, September 19-20, 1974.

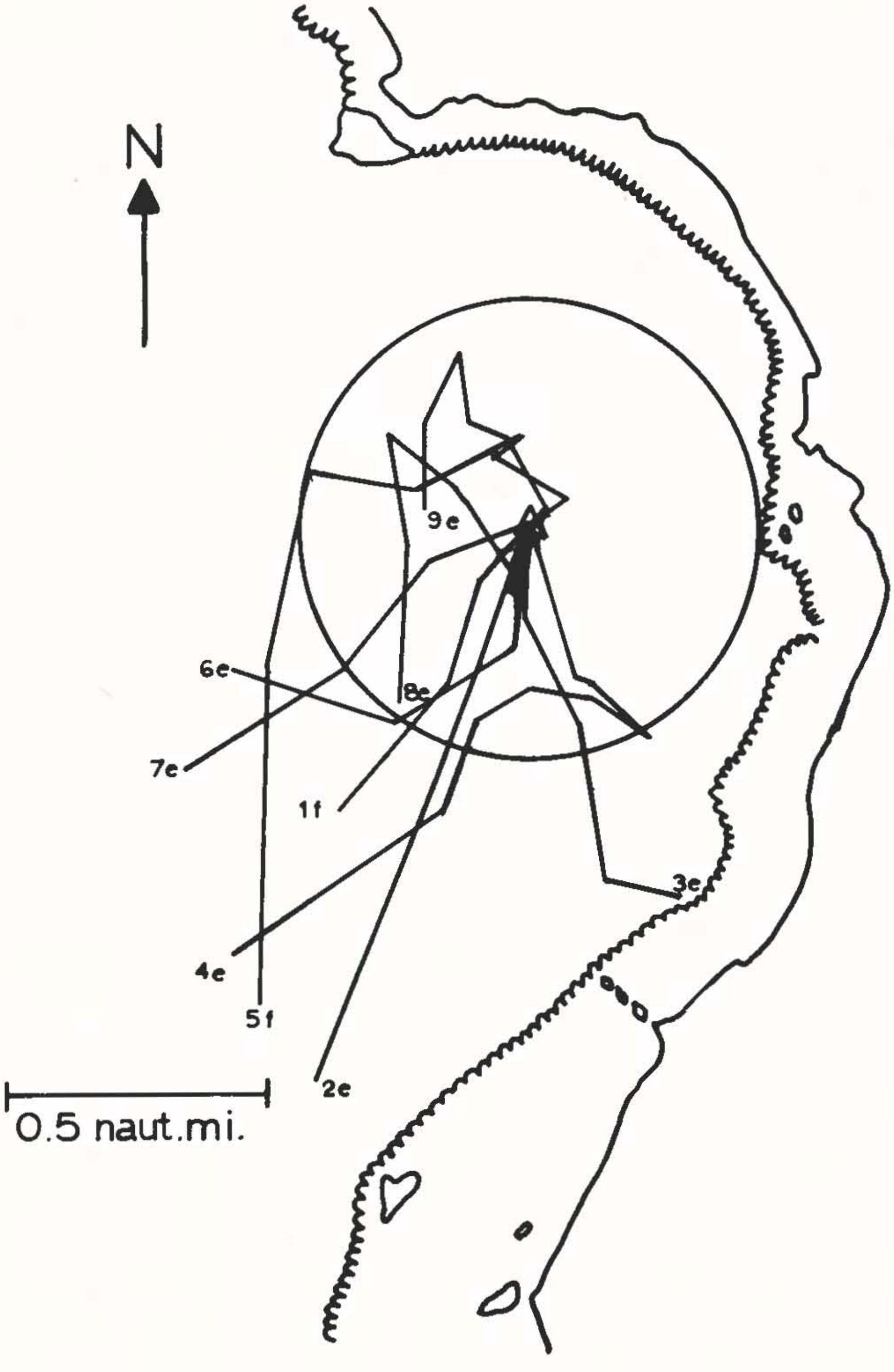
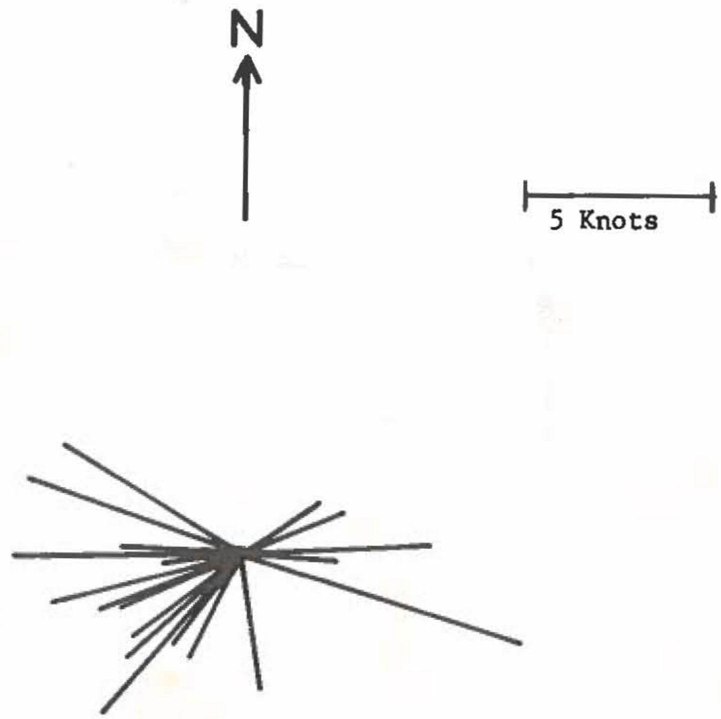


Fig. 90. Trip 6, 1 m drift movement (October 17-18, 1974).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	3	0.66	0.22
2	1000	3	1.08	0.36
3	1100	4	0.80	0.20
4	1300	9	1.53	0.17
5	1500	7	1.68	0.24
6	2200	3	0.84	0.28
7	2300	3	0.75	0.25
8	0100	7	0.98	0.14
9	0200	6	0.66	0.11

Fig. 91. Wind histogram and 1 m drift data--Trip 6, October 17-18, 1974.

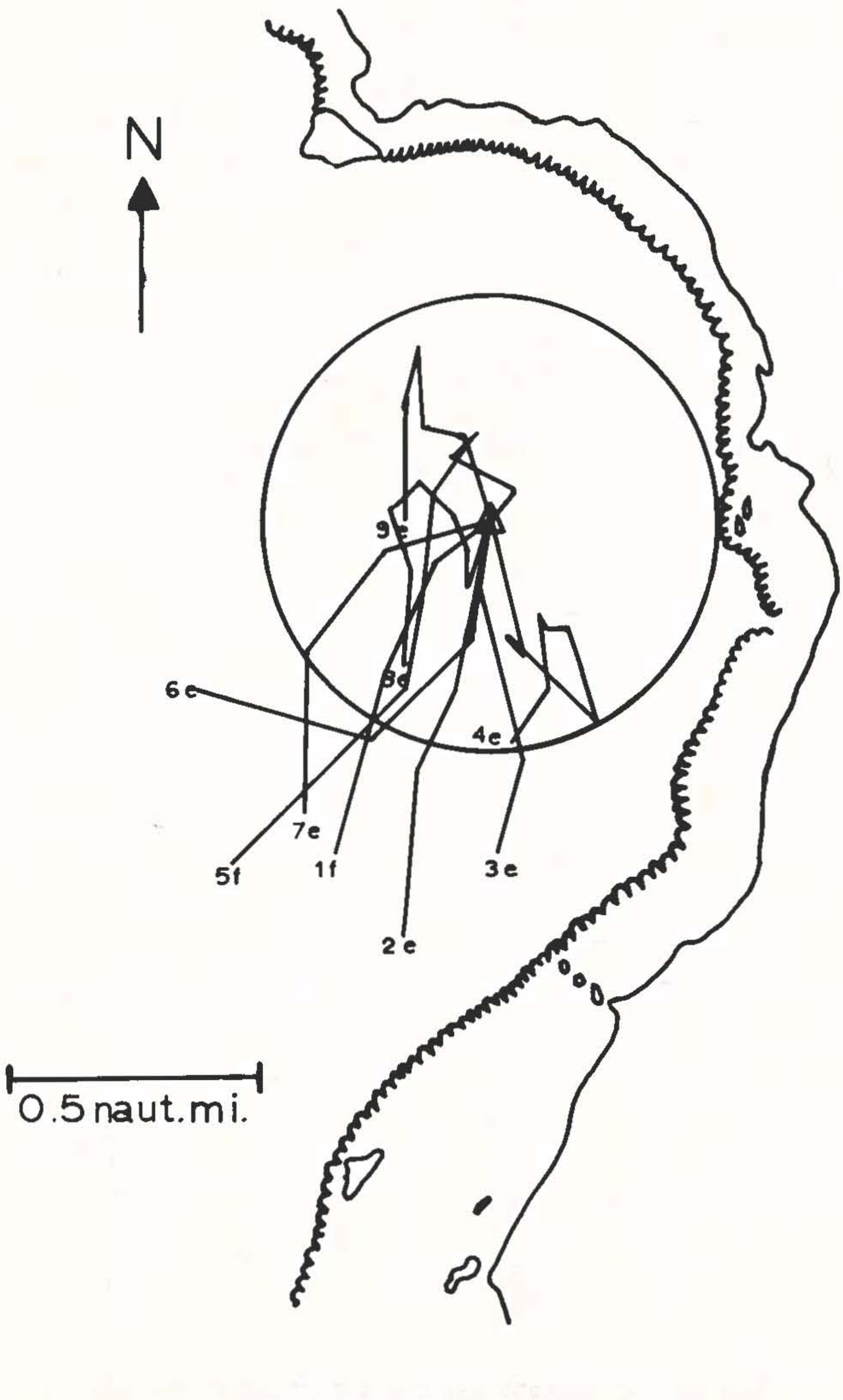
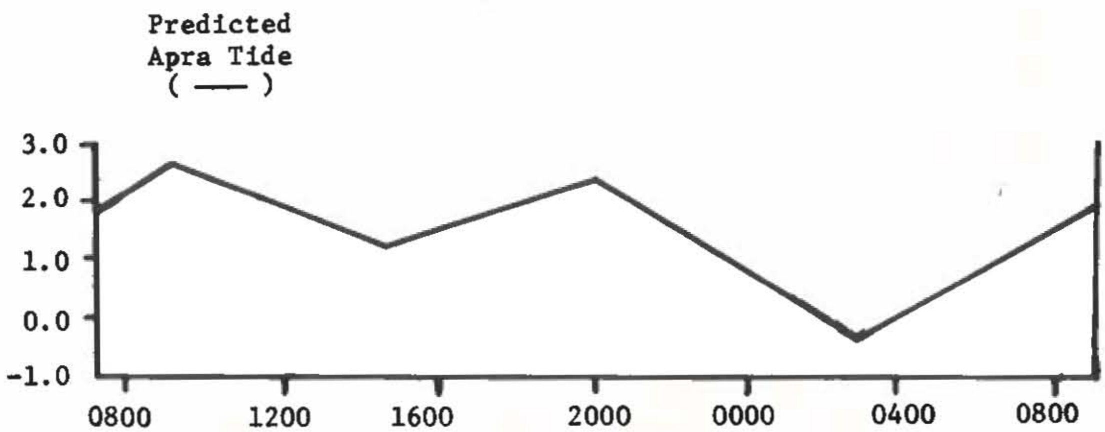


Fig. 92. Trip 6, 5 m drift movement (October 17-18, 1974).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (Knots)
1	0800	3	0.63	0.21
2	1000	3	0.84	0.28
3	1100	4	0.72	0.18
4	1300	9	1.08	0.12
5	1500	7	1.33	0.19
6	2200	3	0.90	0.30
7	2300	3	0.75	0.25
8	0100	7	0.70	0.10
9	0200	6	0.72	0.12

Fig. 93. Predicted Apra Harbor Tide and 5 m drift data--Trip 6, October 17-18, 1974.

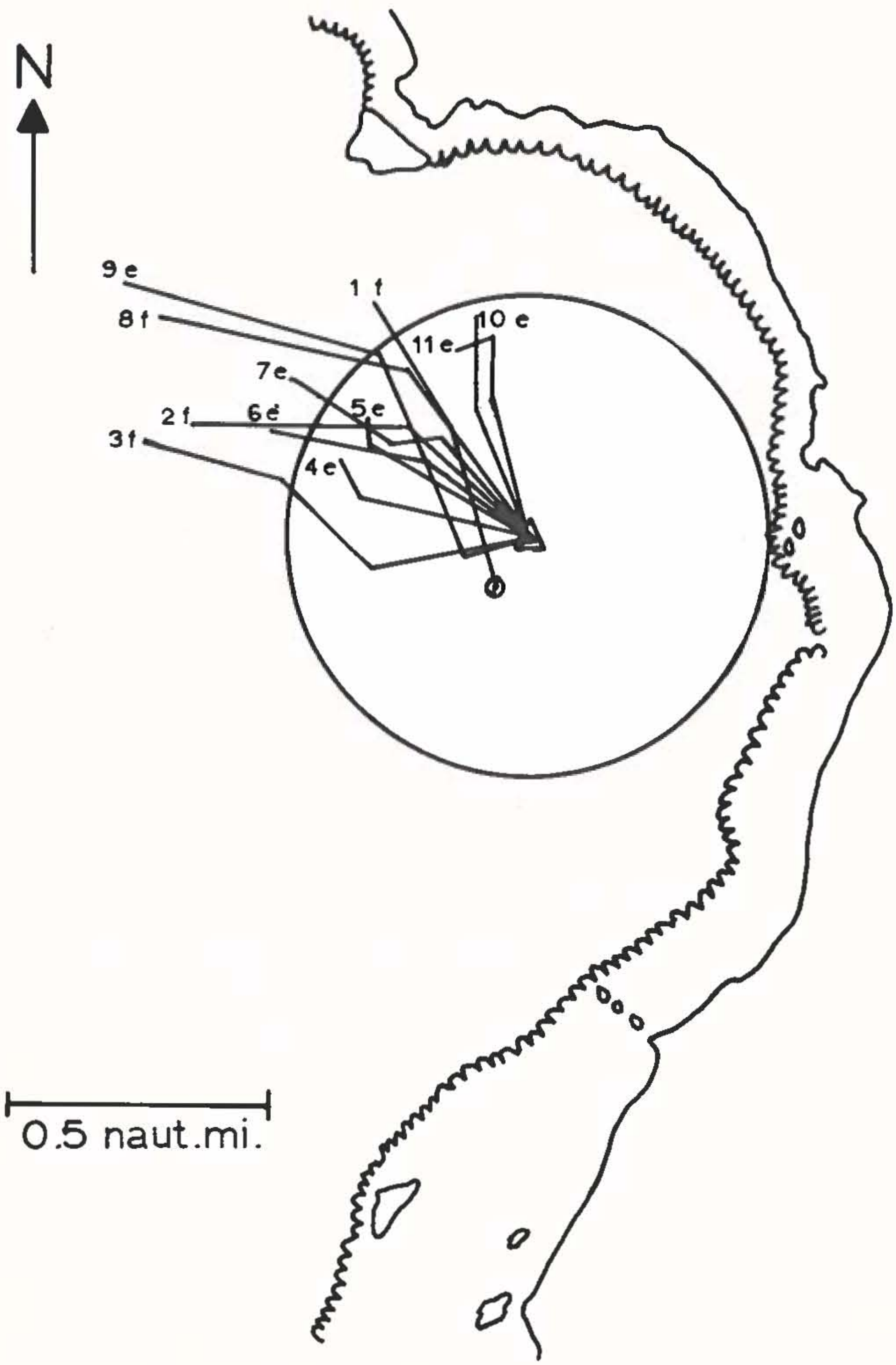
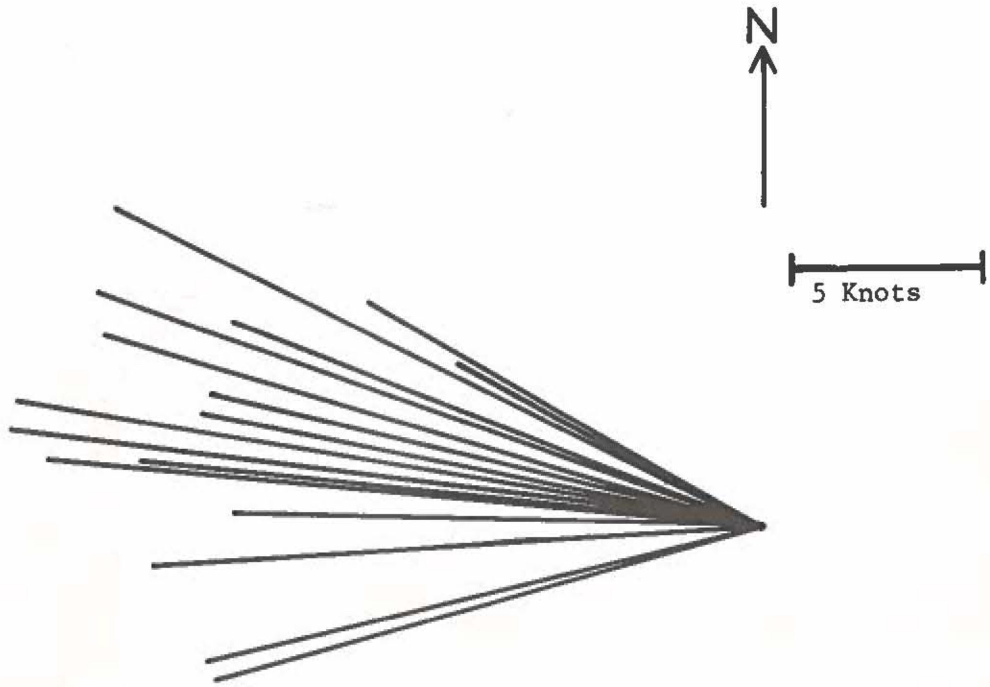


Fig. 94. Trip 7, 1 m drift movement (November 21-22, 1974).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0815	2.75	0.55	0.20
2	1000	3	0.69	0.23
3	1100	3	0.78	0.26
4	1300	2	0.40	0.20
5	1500	2	0.40	0.20
6	1700	2	0.52	0.26
7	1900	3	0.57	0.19
8	2200	2	0.88	0.44
9	0000	3	0.99	0.33
10	0300	2	0.44	0.22
11	0500	3	0.45	0.15

Fig. 95. Wind histogram and 1 m drift data--Trip 7, November 21-22, 1974.

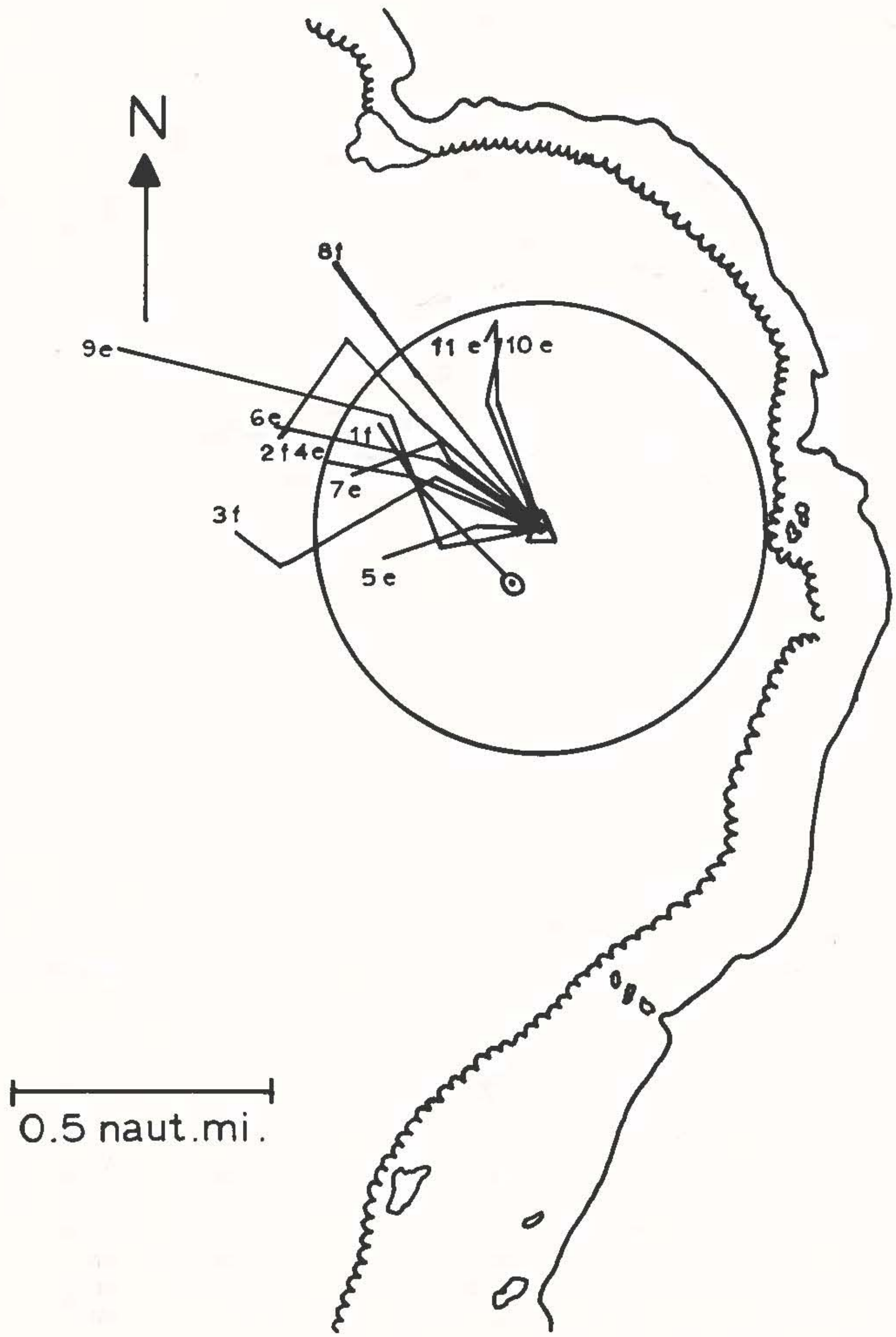
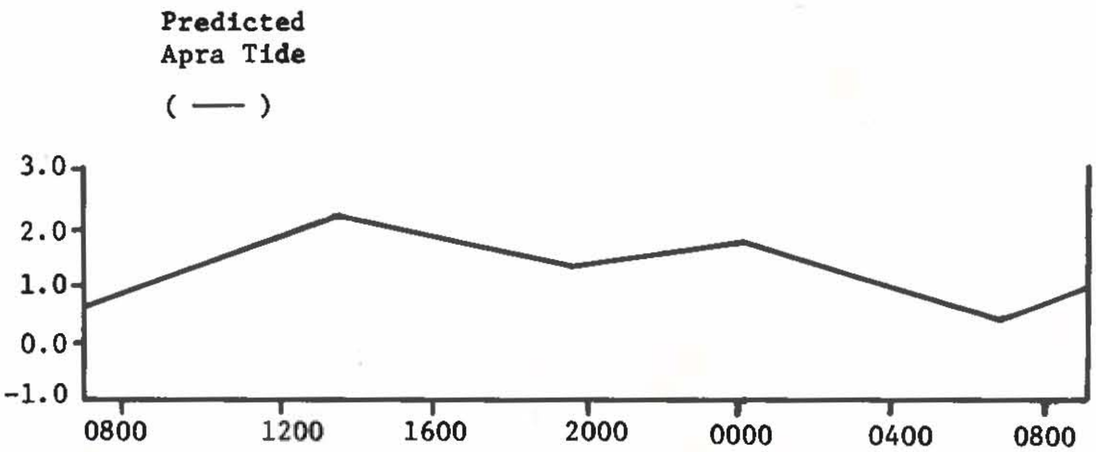


Fig. 96. Trip 7, 5 m drift movement (November 21-22, 1974).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0815	2.75	0.39	0.14
2	1000	3	0.63	0.21
3	1100	3	0.66	0.22
4	1300	2	0.40	0.20
5	1500	2	0.28	0.14
6	1700	2	0.52	0.26
7	1900	3	0.42	0.14
8	2200	2	0.64	0.32
9	0000	3	0.93	0.31
10	0300	2	0.40	0.20
11	0500	3	0.45	0.15

Fig. 97. Predicted Apra Harbor Tide and 5 m drift data--Trip 7, November 21-22, 1974.

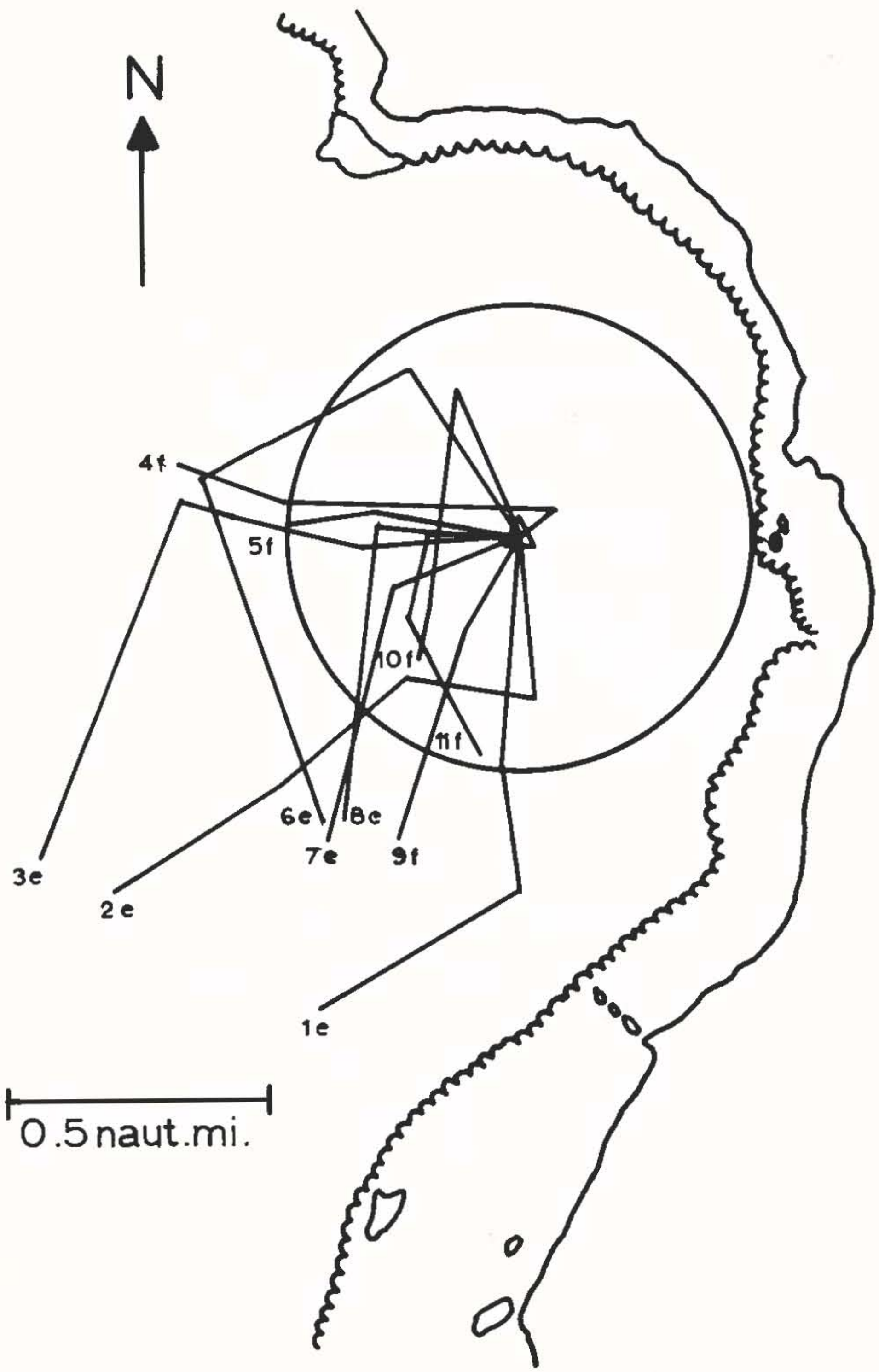
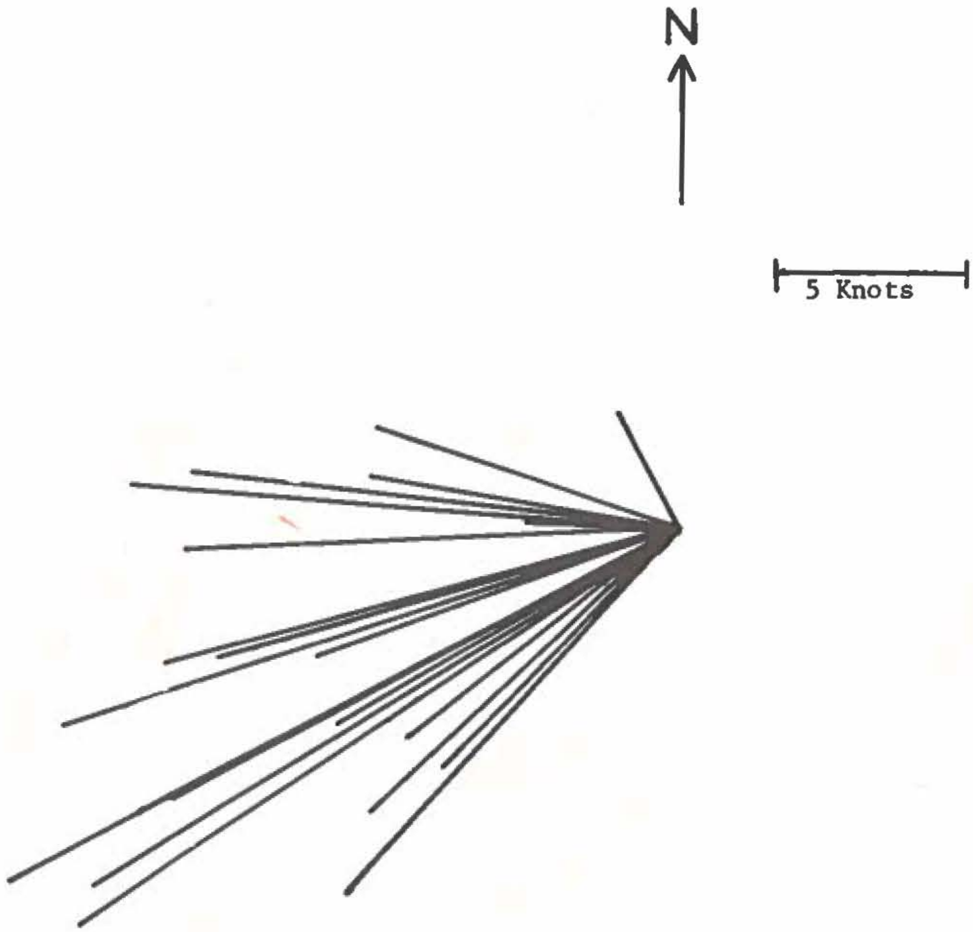


Fig. 98. Trip 8, 1 m drift movement (December 12-13, 1974).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0830	3.83	1.07	0.28
2	1000	4	1.24	0.31
3	1200	3	1.35	0.45
4	1400	3	0.78	0.26
5	1600	2	0.46	0.23
6	1800	3	1.50	0.50
7	2100	2	0.72	0.36
8	2300	2	0.84	0.42
9	0100	2	0.62	0.31
10	0300	3	0.78	0.26
11	0500	3	0.63	0.21

Fig. 99. Wind histogram and 1 m drift data--Trip 8, December 12-13, 1974.

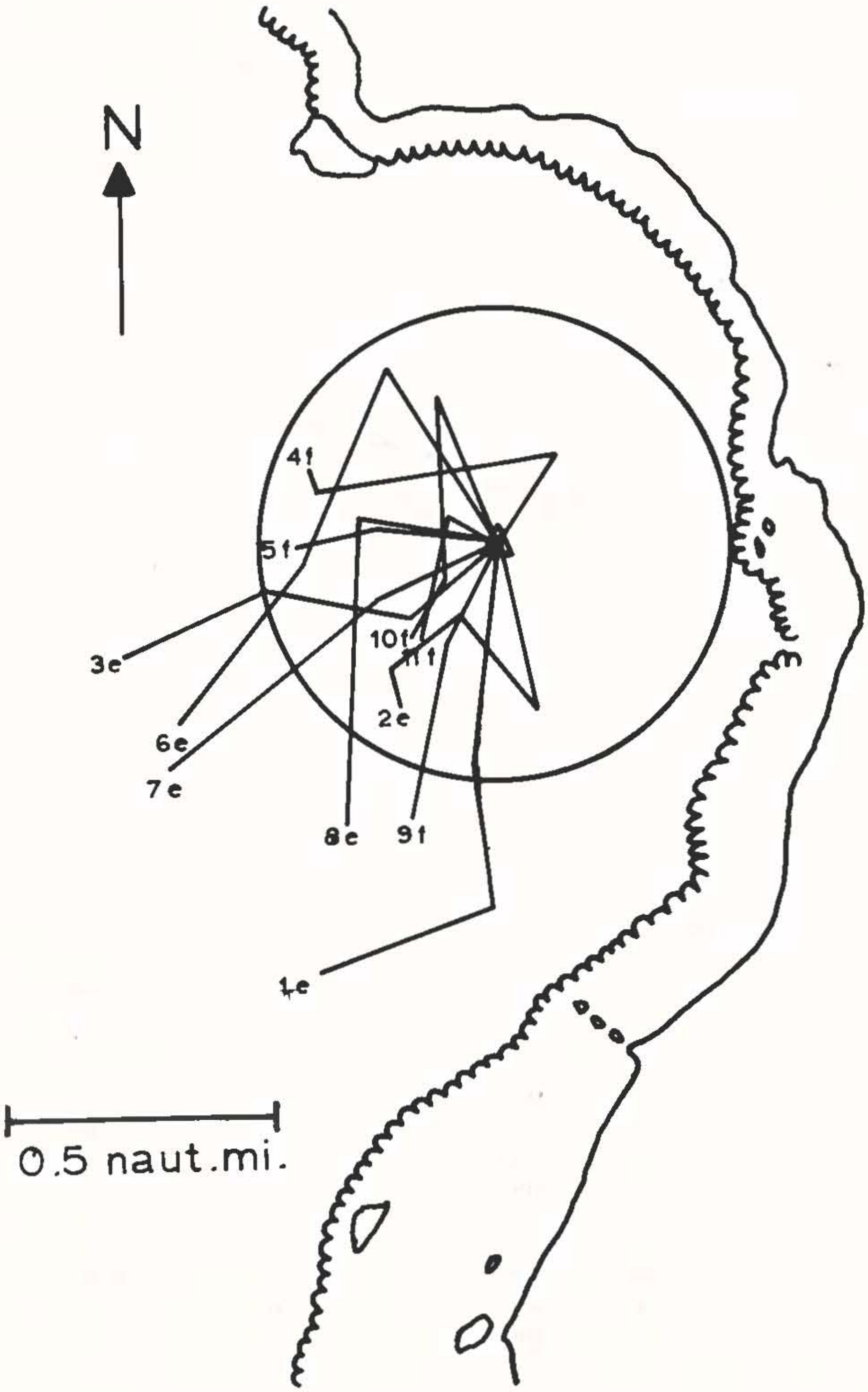
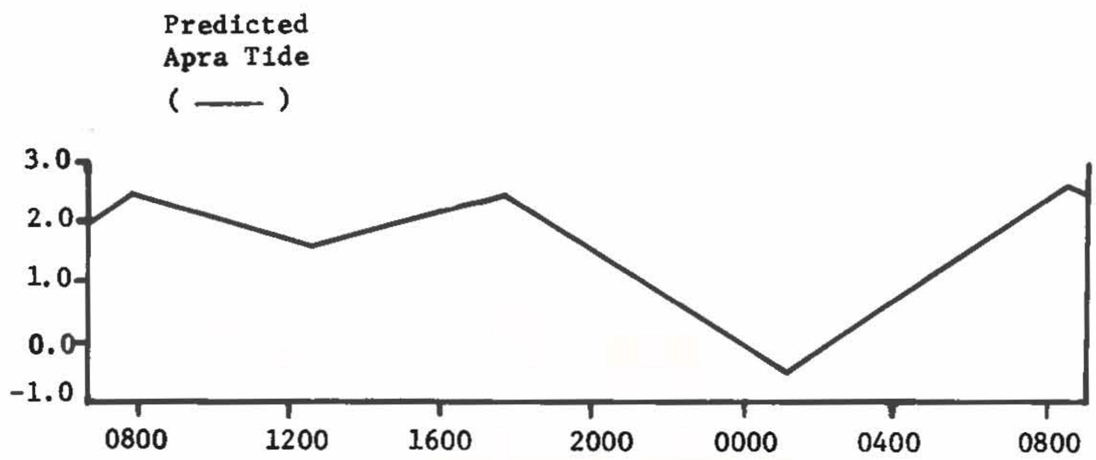


Fig. 100. Trip 8, 5 m drift movement (December 12-13, 1974).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0830	3.83	1.01	0.26
2	1000	4	0.72	0.18
3	1200	3	0.78	0.26
4	1400	3	0.63	0.21
5	1600	2	0.36	0.18
6	1800	3	1.14	0.38
7	2100	2	0.74	0.37
8	2300	2	0.84	0.42
9	0100	2	0.62	0.31
10	0300	3	0.75	0.25
11	0500	3	0.36	0.12

Fig. 101. Predicted Apra Harbor Tide and 5 m drift data--Trip 8, December 12-13, 1974.

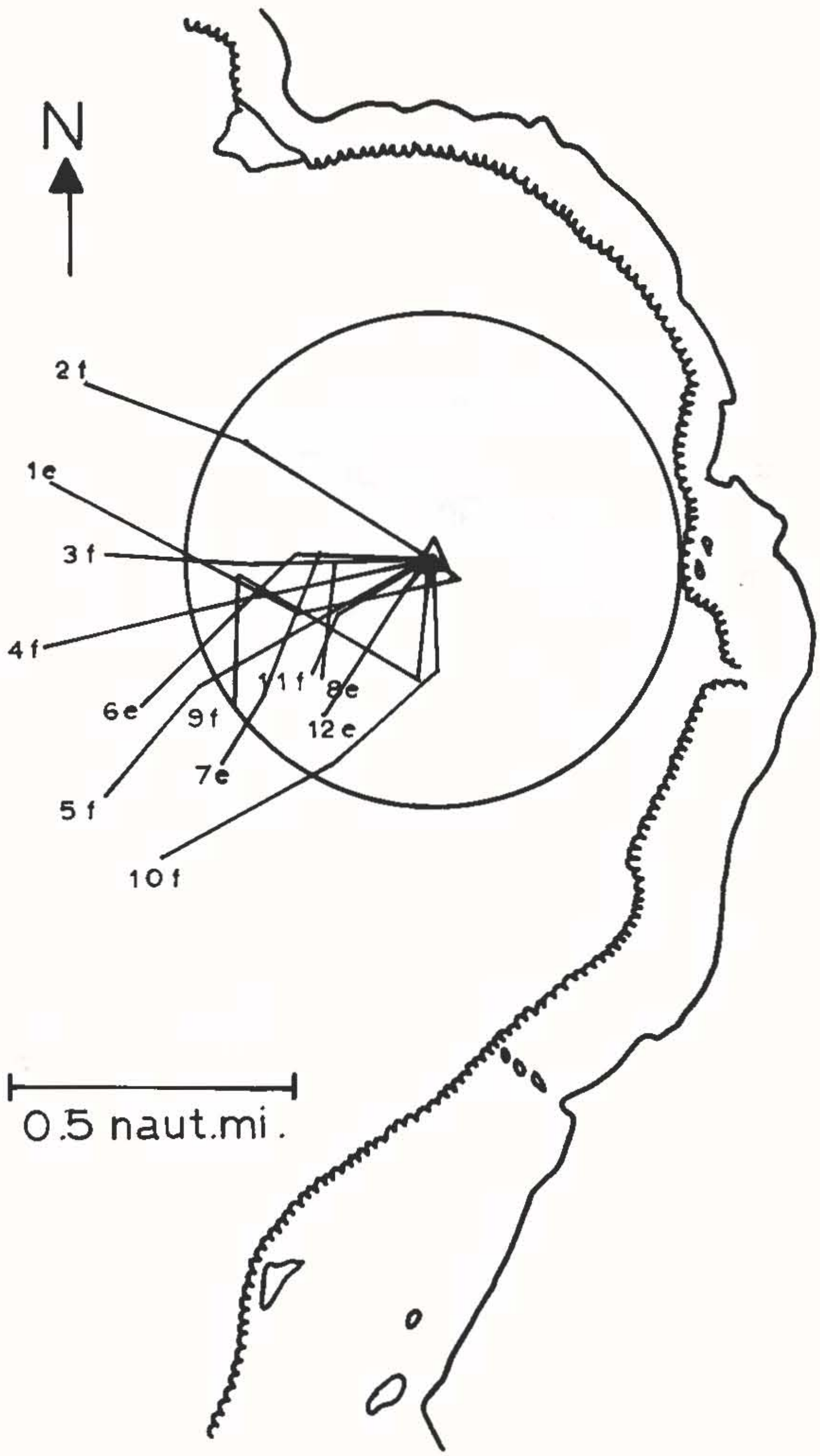
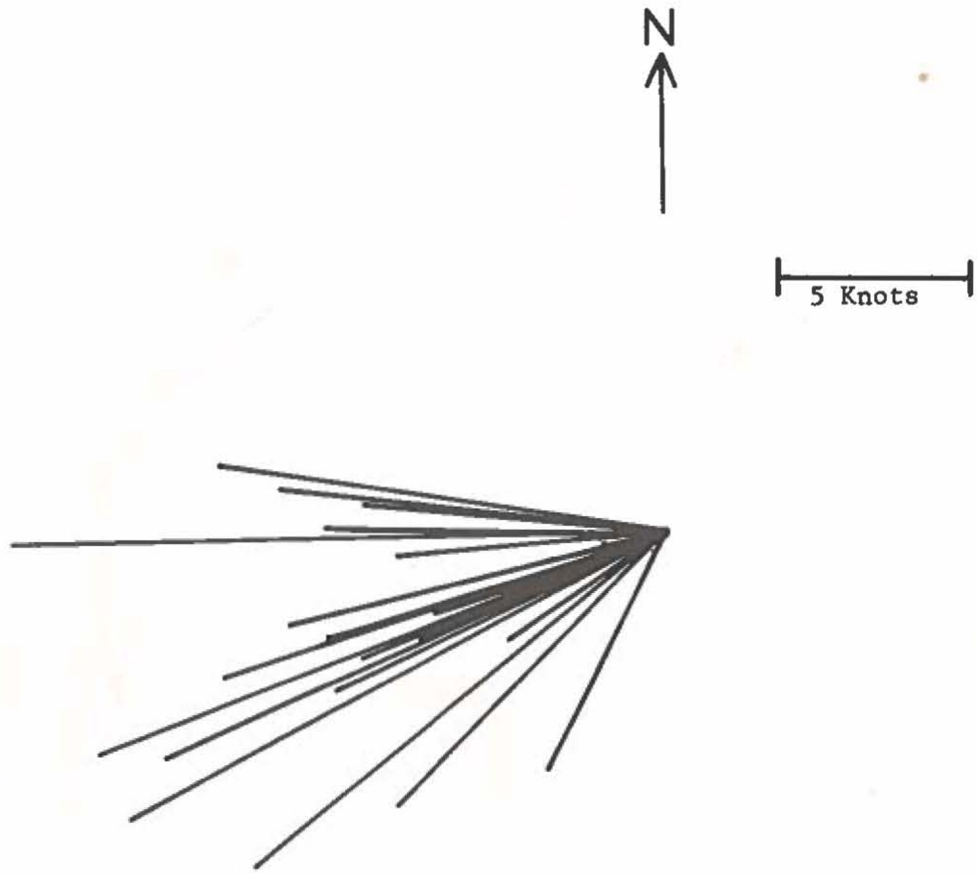


Fig. 102. Trip 9, 1 m drift movement (February 6-7, 1975).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	4	0.80	0.20
2	1100	2	0.66	0.33
3	1200	2	0.58	0.29
4	1300	2	0.68	0.34
5	1400	2	0.72	0.36
6	1600	2	0.62	0.31
7	1800	3	0.60	0.20
8	2100	3	0.36	0.12
9	2400	3	0.75	0.25
10	0300	3	0.72	0.24
11	0500	2	0.30	0.15
12	0700	1	0.33	0.33

Fig. 103. Wind histogram and 1 m drift data--Trip 9, February 6-7, 1975.

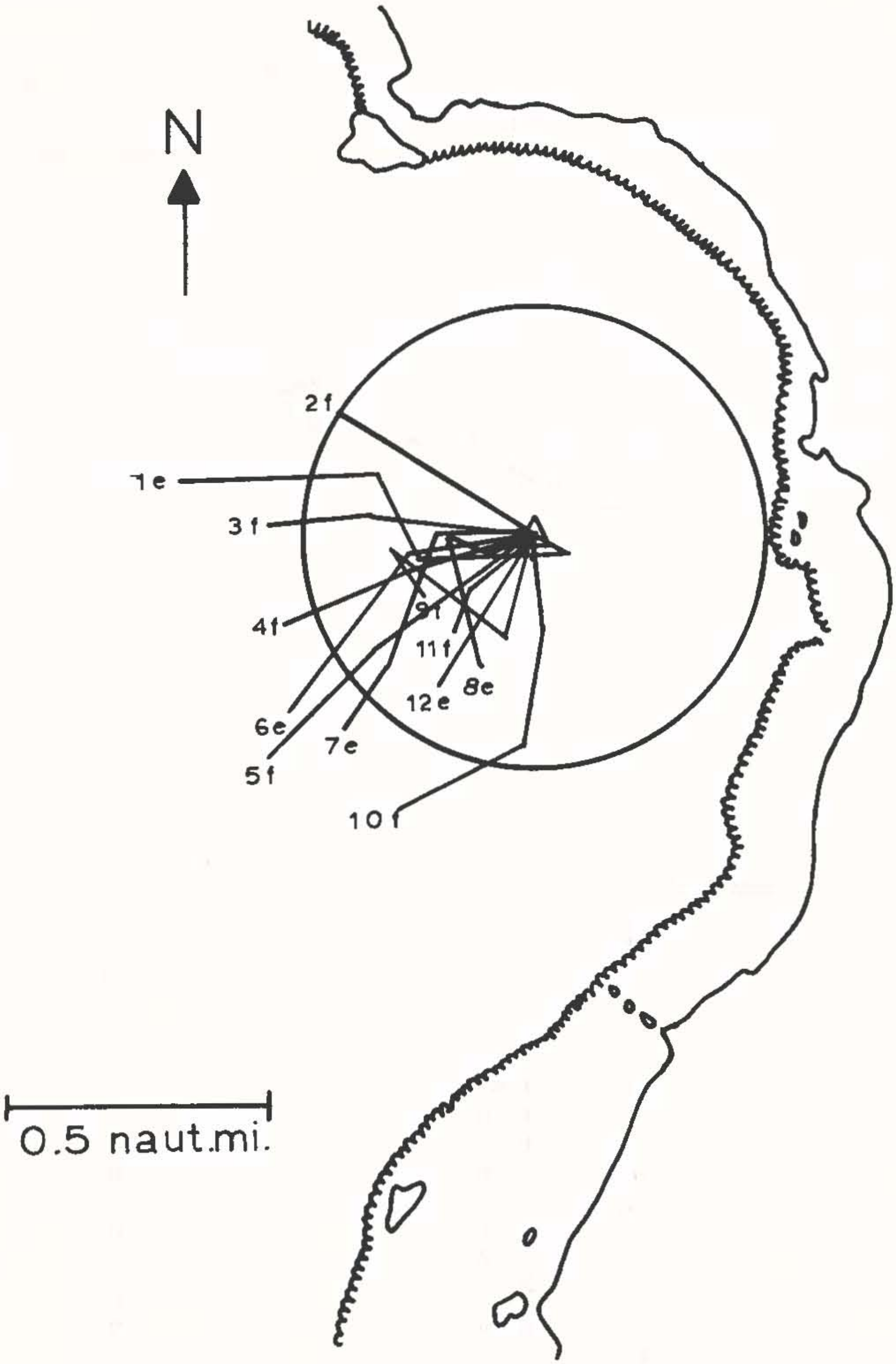
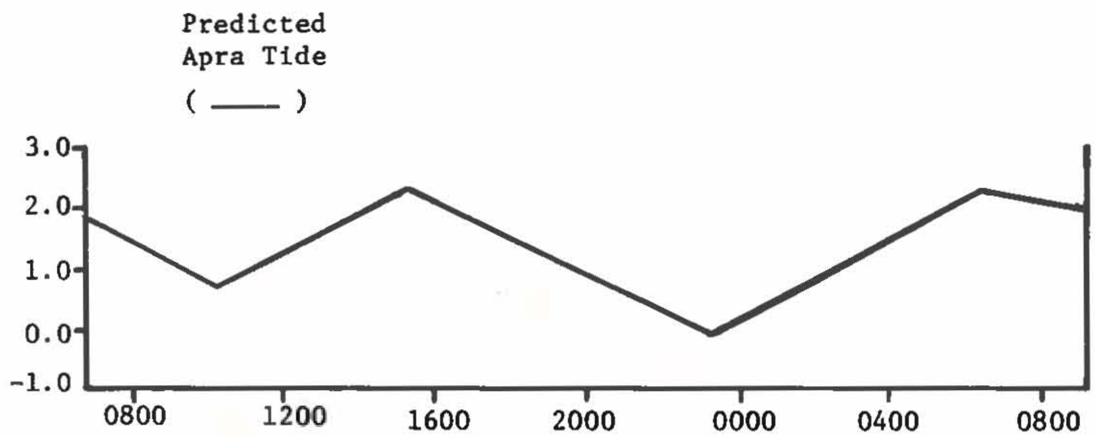


Fig. 104. Trip 9, 5 m drift movement (February 6-7, 1975).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	4	0.72	0.18
2	1100	2	0.50	0.25
3	1200	2	0.50	0.25
4	1300	2	0.50	0.25
5	1400	2	0.64	0.32
6	1600	2	0.60	0.30
7	1800	3	0.60	0.20
8	2100	3	0.42	0.14
9	0000	3	0.66	0.22
10	0300	3	0.69	0.23
11	0500	2	0.24	0.12
12	0700	1	0.33	0.33

Fig. 105. Predicted Apra Harbor Tide and 5 m drift data--Trip 9, February 6-7, 1975.

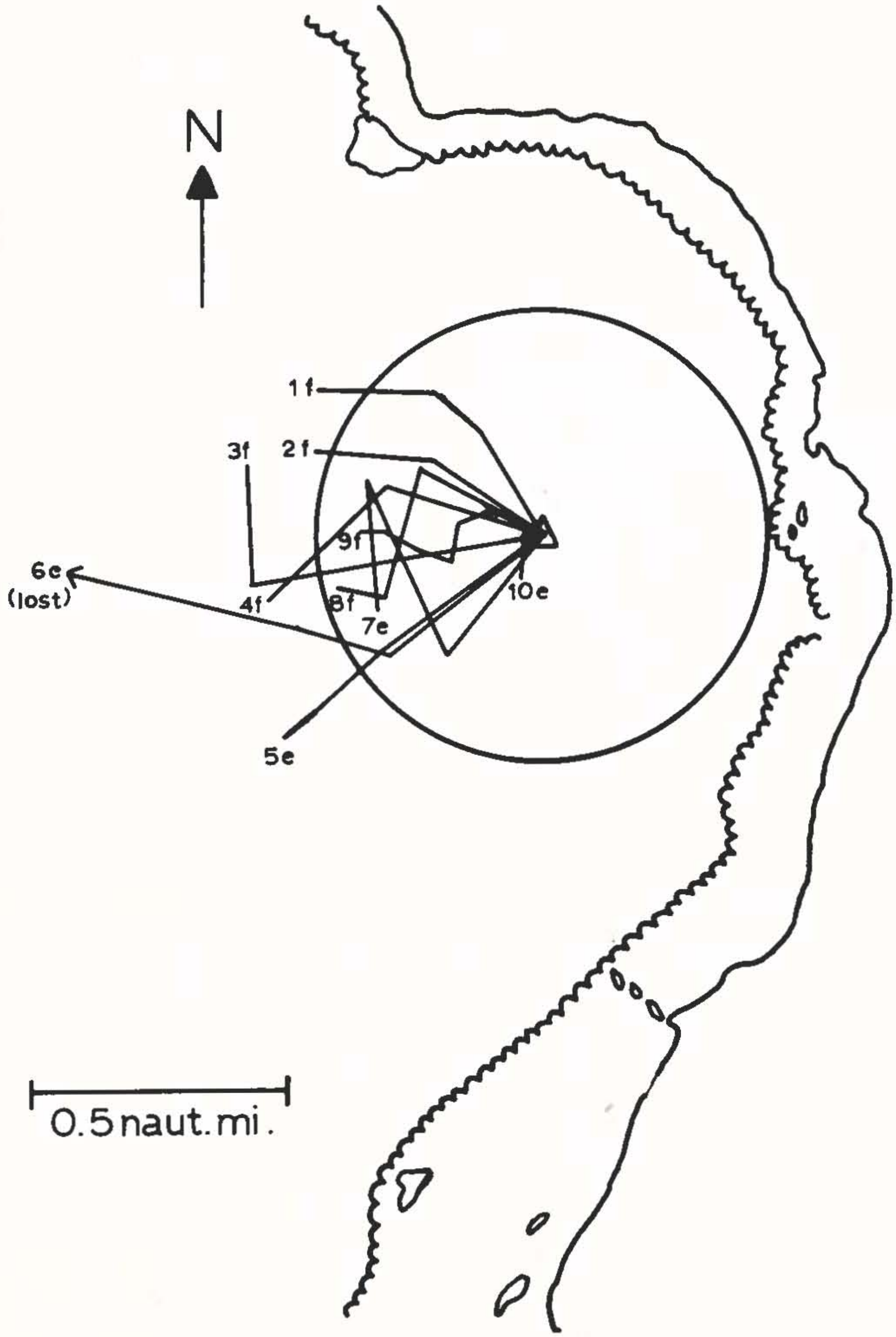
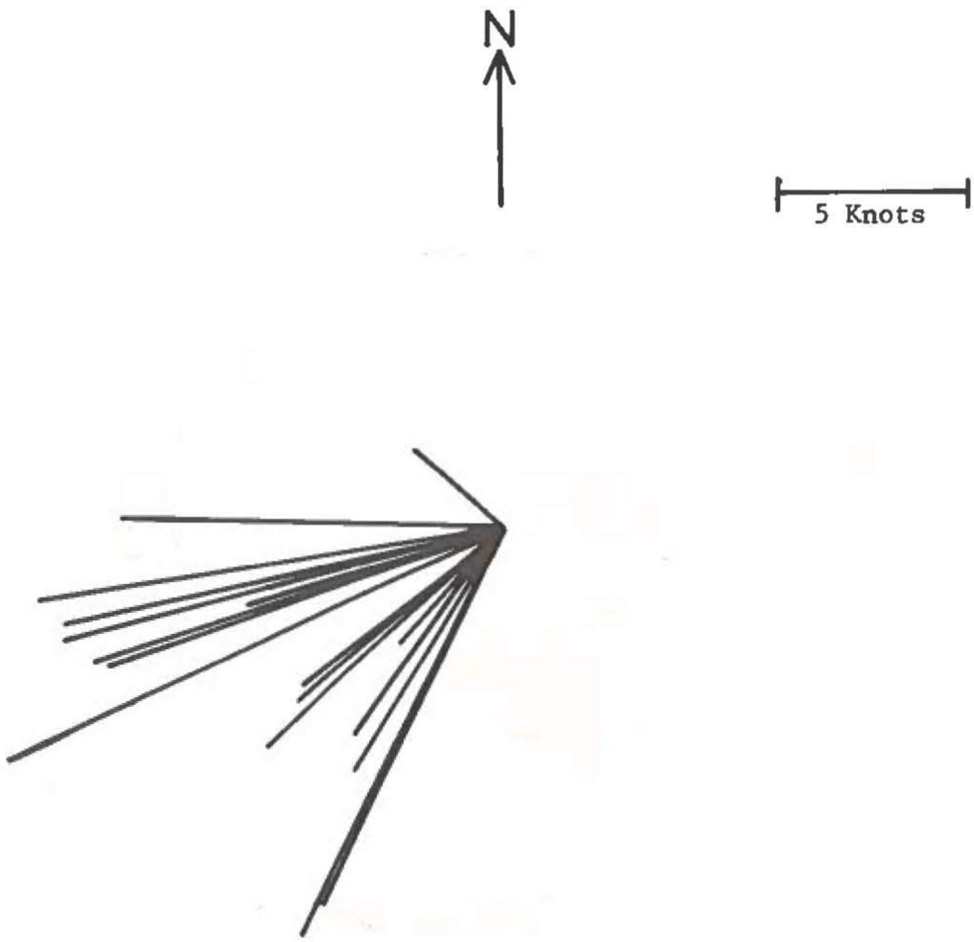


Fig. 106. Trip 10, 1 m drift movement (March 6-7, 1975).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	3	0.57	0.19
2	1000	2	0.48	0.24
3	1200	2	0.78	0.39
4	1300	2	0.40	0.20
5	1500	2	0.62	0.31
6	1600	3	> 0.75	>0.25
7	1800	3	0.90	0.30
8	2100	3	0.57	0.19
9	2400	6	0.42	0.07
10	0600	2	0.10	0.05

Fig. 107. Wind histogram and 1 m drift data--Trip 10, March 6-7, 1975.

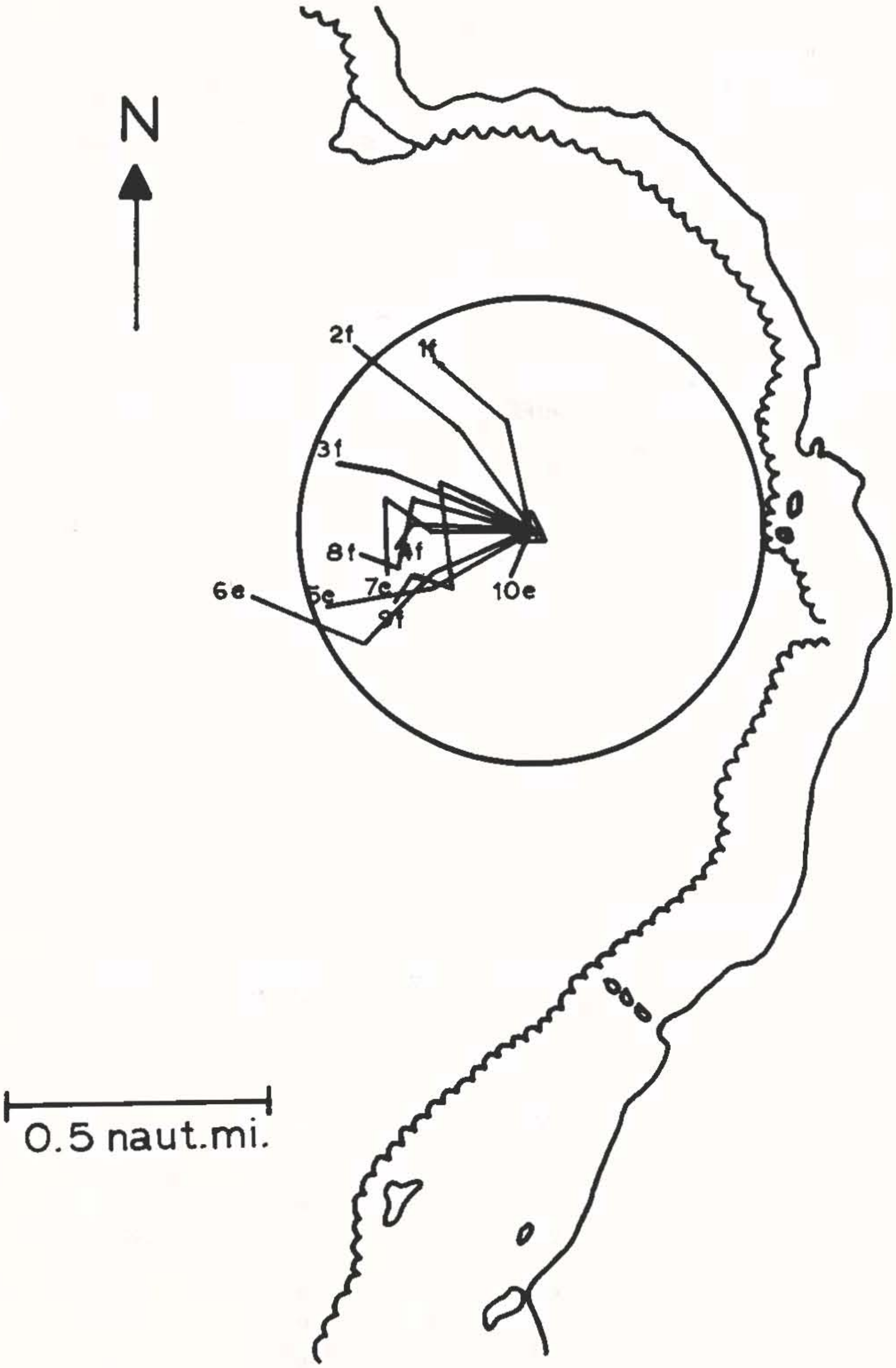
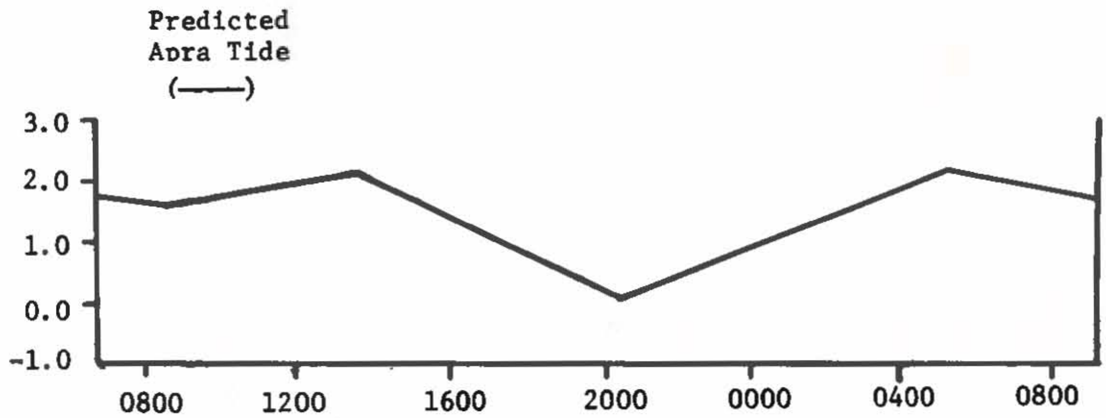


Fig. 108. Trip 10, 5 m drift movement (March 6-7, 1975).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	3	0.51	0.17
2	1000	2	0.46	0.23
3	1200	2	0.36	0.18
4	1300	2	0.30	0.15
5	1500	2	0.40	0.20
6	1600	3	0.60	0.20
7	1800	3	0.45	0.15
8	2100	3	0.48	0.16
9	2400	6	0.42	0.07
10	0600	2	0.10	0.05

Fig. 109. Predicted Apra Harbor Tide and 5 m drift data--Trip 10, March 6-7, 1975.

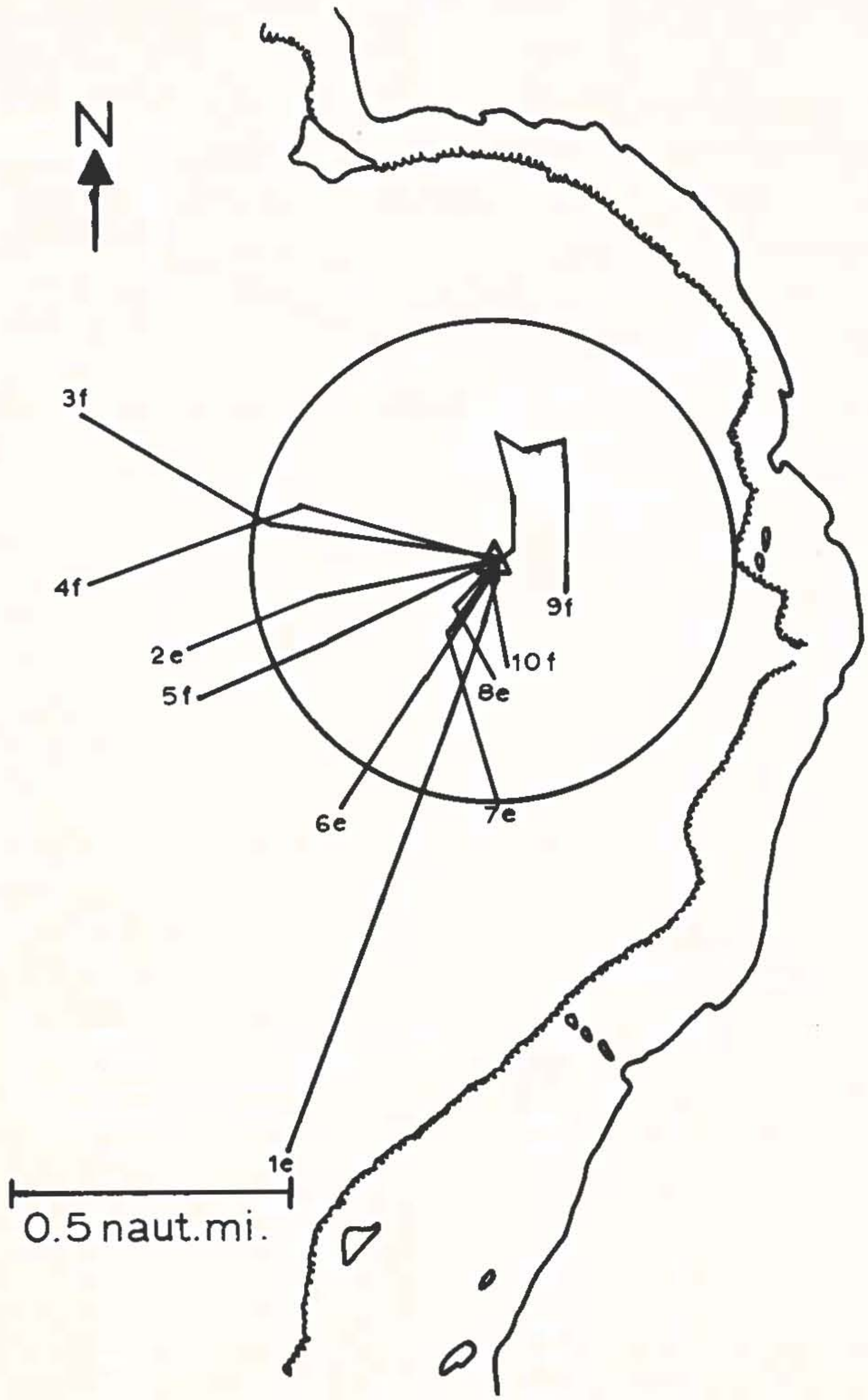
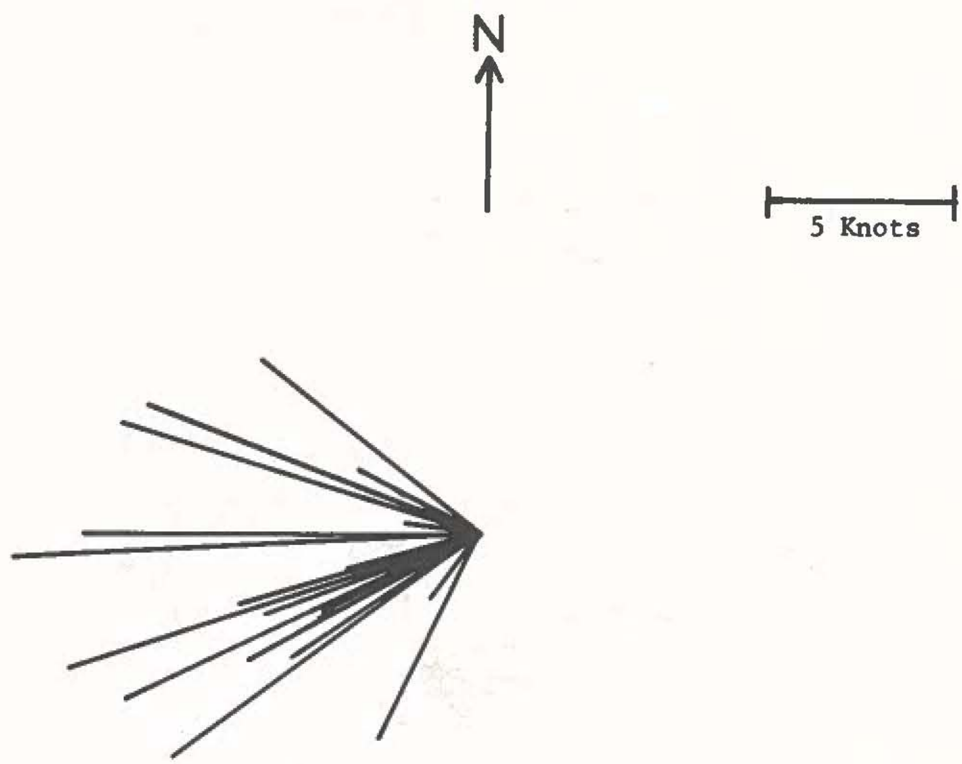


Fig. 110. Trip 11, 1 m drift movement (April 24-25, 1975).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	3	1.08	0.36
2	1100	2	0.60	0.30
3	1300	2	0.82	0.41
4	1500	2	0.80	0.40
5	1700	2	0.60	0.30
6	1900	2	0.52	0.26
7	2100	2	0.48	0.24
8	2300	2	0.24	0.12
9	0100	7	0.63	0.09
10	0615	1.75	0.21	0.12

Fig. 111. Wind histogram and 1 m drift data--Trip 11, April 24-25, 1975.

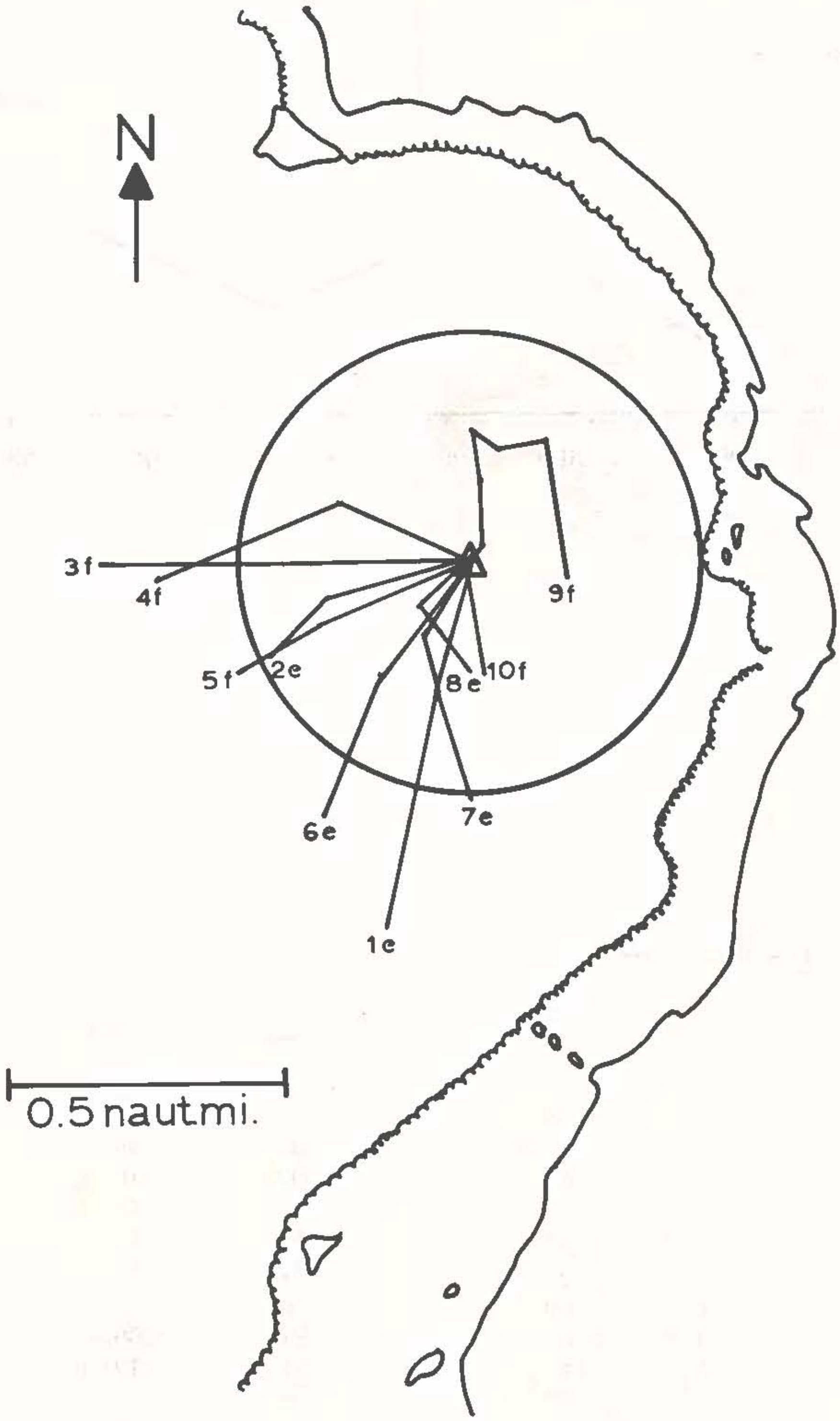
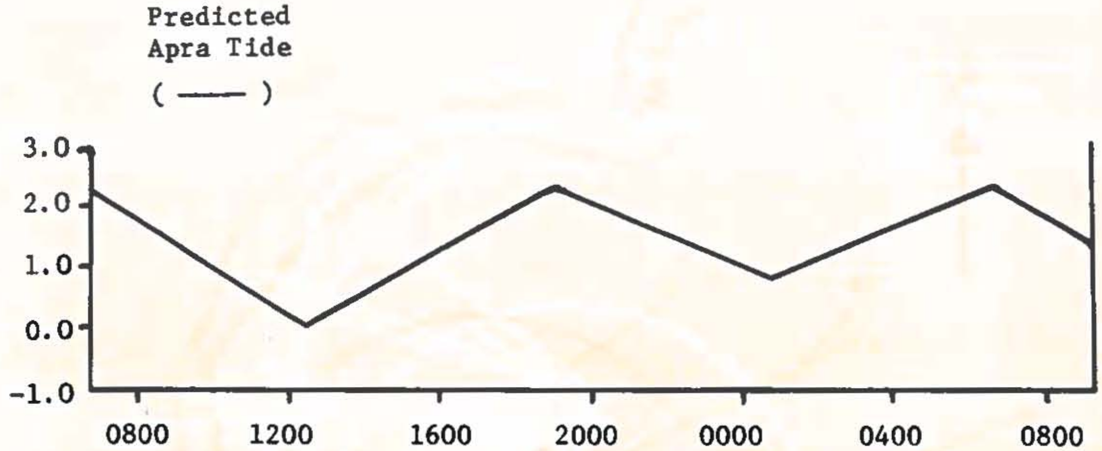


Fig. 112. Trip 11, 5 m drift movement (April 24-25, 1975).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0800	3	0.66	0.22
2	1100	2	0.42	0.21
3	1300	2	0.64	0.32
4	1500	2	0.60	0.30
5	1700	2	0.46	0.23
6	1900	2	0.46	0.23
7	2100	2	0.48	0.24
8	2300	2	0.24	0.12
9	0100	7	0.63	0.09
10	0615	1.75	0.21	0.12

Fig. 113. Predicted Apra Harbor Tide and 5 m drift data--Trip 11, April 24-25, 1975.

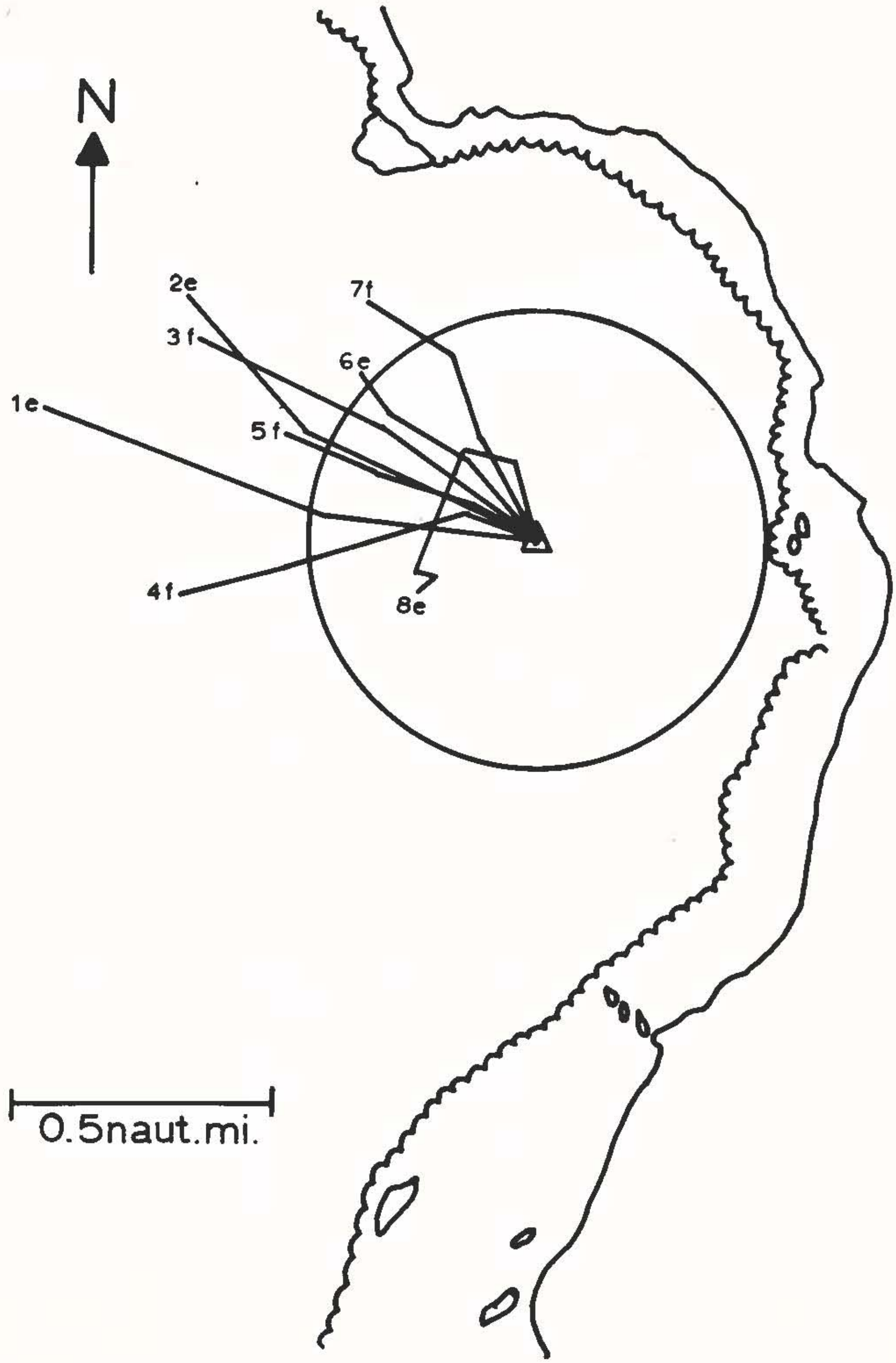
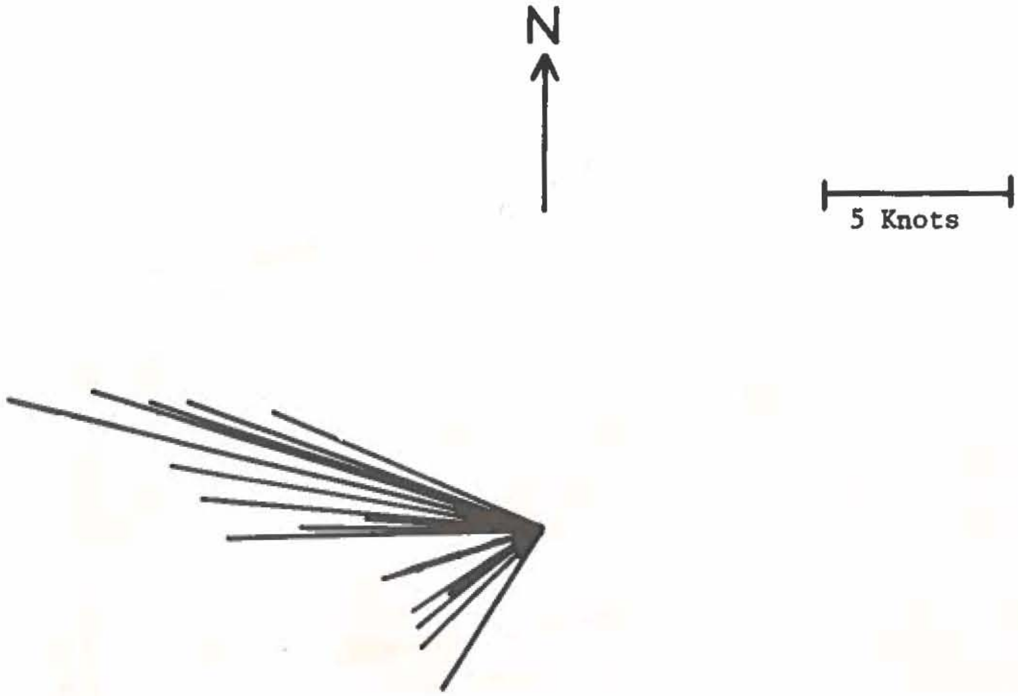


Fig. 114. Trip 12, 1 m drift movement (May 22-23, 1975).



1 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0900	2	0.96	0.48
2	1100	2	0.82	0.41
3	1300	2	0.76	0.38
4	1500	2.6	0.68	0.26
5	1800	3	0.51	0.17
6	2100	3	0.45	0.15
7	0000	3	0.57	0.19
8	0300	5	0.60	0.12

Fig. 115. Wind histogram and 1 m drift data--Trip 12, May 22-23, 1975.

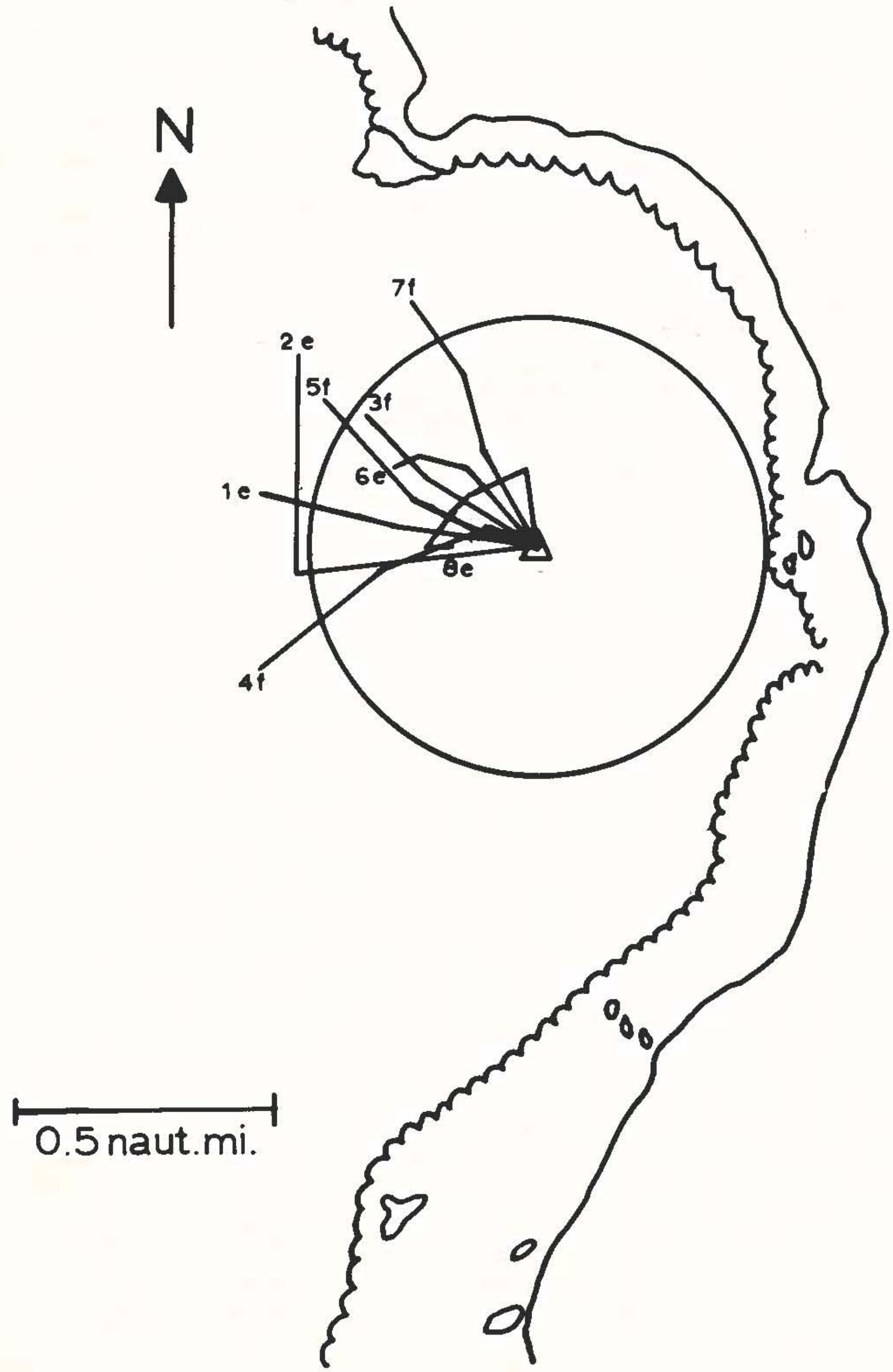
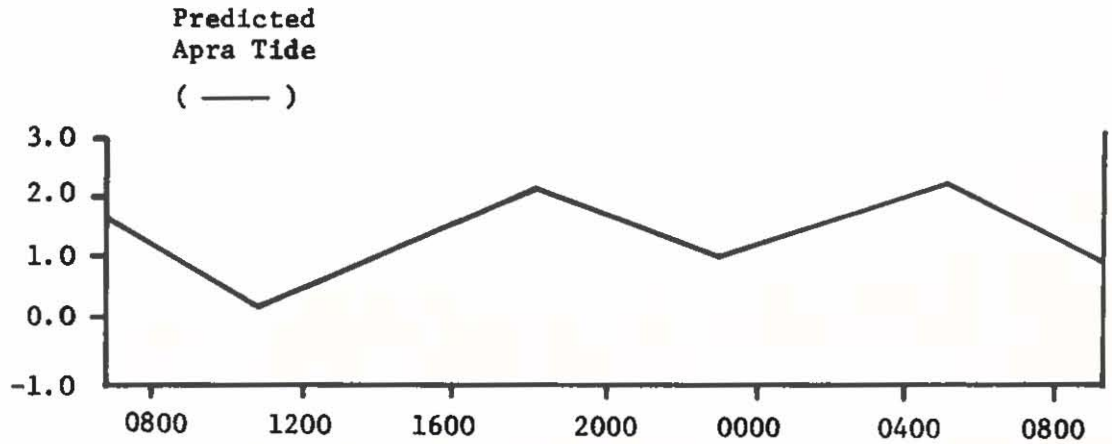


Fig. 116. Trip 12, 5 m drift movement (May 22-23, 1975).



5 m DRIFT DATA

Drift	Start	ΔT	Dist. (naut.mi.)	Speed (knots)
1	0900	2	0.54	0.27
2	1100	2	0.88	0.44
3	1300	2	0.42	0.21
4	1500	2.6	0.57	0.22
5	1800	3	0.51	0.17
6	2100	3	0.39	0.13
7	0000	3	0.54	0.18
8	0300	5	0.40	0.08

Fig. 117. Predicted Apra Harbor Tide and 5 m drift data--Trip 12, May 22-23, 1975.

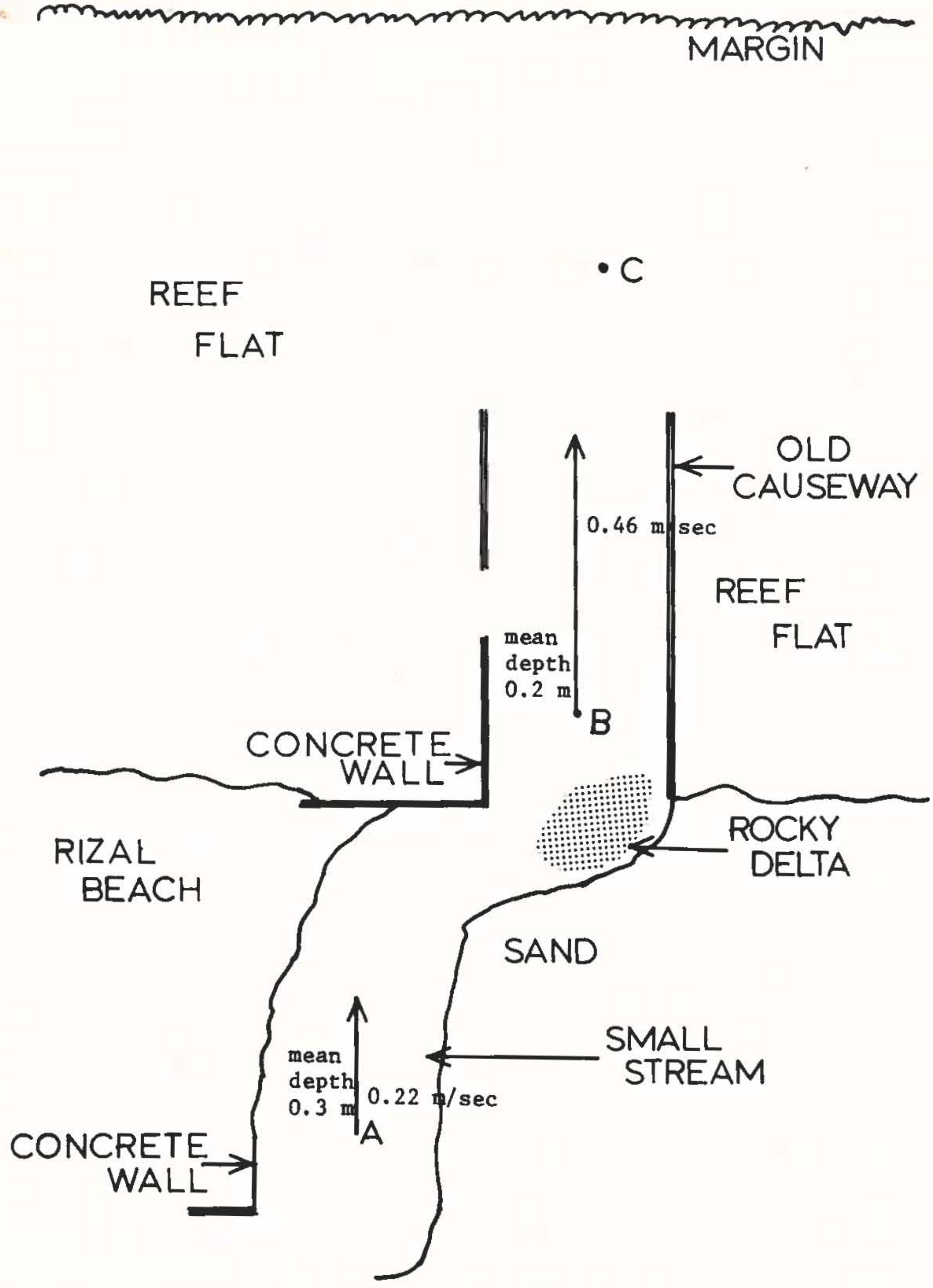


Fig. 118. Vector A indicates dye movement down the stream. Vector B indicates movement through the old causeway, Station 7. (Note: Drawing is not to scale) Points A, B, and C indicate where water samples were taken for turbidity analysis and sediment load.

July 26, 1975; 1215. During heavy rainfall.

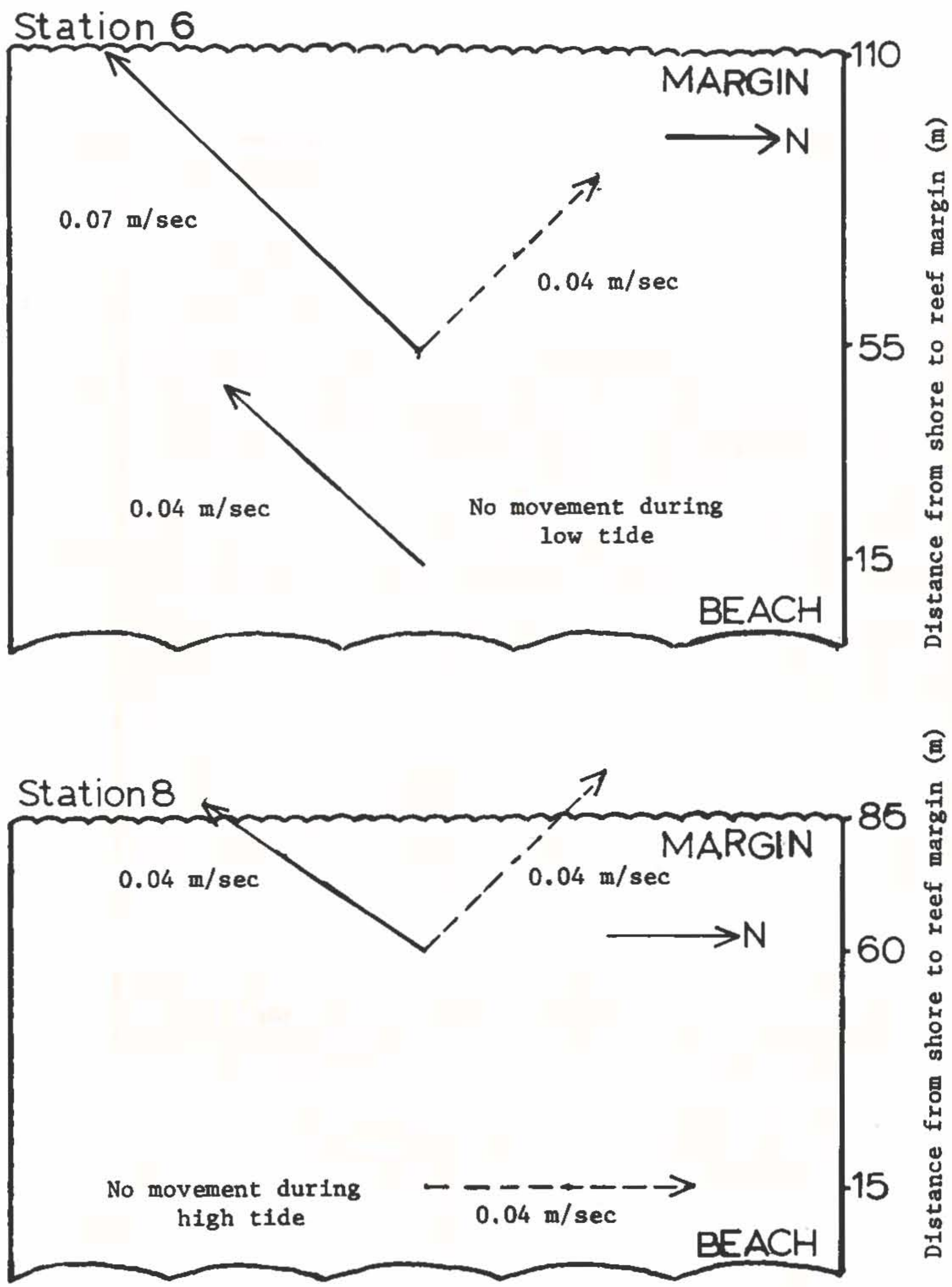


Fig. 119. Solid line vectors indicate dye movement over inner and outer reef flats at Station 6 and 8 during high tide. May 19, 1975; 1000. Wind 7 kts., direction 068°.

Dashed line vectors indicate dye movement during low tide. June 10, 1975; 1300. Wind 10 kts., direction 045°.

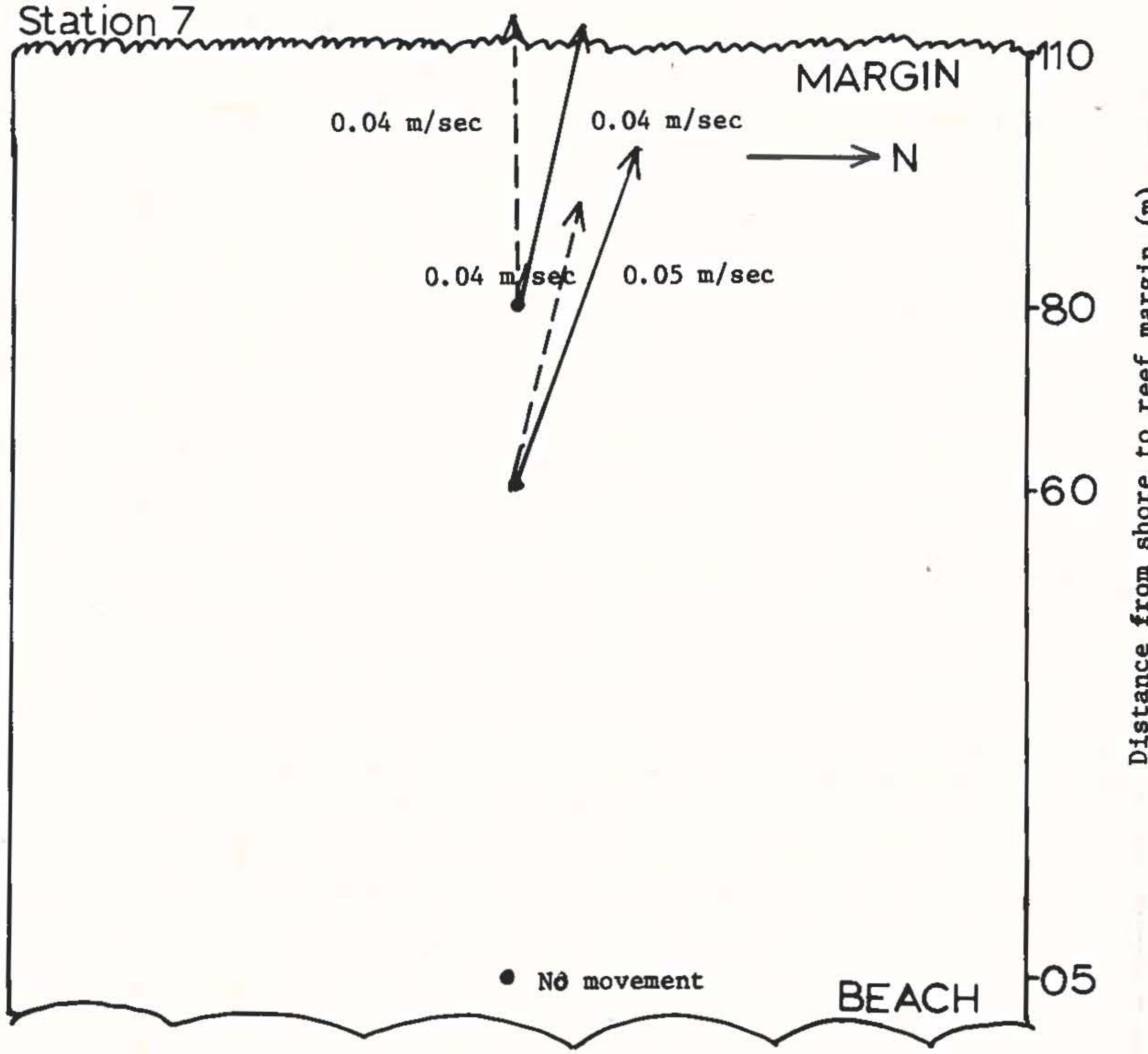


Fig. 120. Solid line vectors indicate dye movement over the reef flat at Station 7 (inside the old causeway) during high tide. May 19, 1975; 1000. Wind 7 kts, direction 068°.
Dashed line vectors indicate dye movement during low tide. June 10, 1975; 1300. Wind 10 kts., direction 045°.
A dye patch was also dropped at the shoreward edge during both high and low tides. No movement was recorded.

CONCLUSIONS

Operations should never be carried out under westerly or southwesterly wind conditions as evidenced by drogue groundings under these conditions, showing a shoreward surface current flow. The oil contingency plan should not rely completely on a westward current flow because this current is very slow and tends to form eddies and may spread shoreward under these conditions.

Although no information is available regarding effluent quality, the following general suggestions are made. If there is a warm-water cooling effluent, the pipeline should end at the 60-foot isobath where currents are more predictably seaward. If there is industrial waste, this should also be located at a depth of 60 feet and treated before discharge. If there is sewage disposal from the docking facility, all standards must meet all local and Federal standards, with the pipeline ending at a depth of at least 60 feet.

The tanker docking platform will probably act as an artificial reef. By doing so the pelagic fish population under it will increase because it is well known that the shadowing effect attracts such populations. The pilings themselves will be colonized by algae, corals, sponges, and other sessile organisms.

The shore-side staging facility at the shore end of the submerged pipeline should be built such that storms will not effect it. The results of Tropical Storm Mary and subsequent field observations emphasize the need for extremely sturdy protection for the pipeline, especially in the shallower water along the reef flat at Rizal Beach. Additionally, if a small boat marina is built to keep small boats for facility access, then this should be constructed to be a recreational asset to the entire area. Tug boats to handle off-loading tankers should be berthed in Apra Harbor. As estimated, these 3500 Hp tugs would have a draft at the site of nearly 20 feet and length of 150 to 170 feet. To build a harbor facility the amount of dredging necessary to handle these would greatly increase.

Dredging for this installation should allow for all future pipeline so that extreme dredging need not be repeated.

Judging from the frequency of storms in this area the reef flat itself has been disturbed numerous times. The effects of dredging have, in effect, been felt before at least at the surface of reef flat. This dredging is, however, more substantial.

Our survey indicates that the proposed site (Fig. 29) is the best for the pipeline for a number of reasons. The reef terrace along the dredging line has a low density of marine organisms and part of the pipeline would pass through the sand channel and extensive dredging would not be necessary. The reef flat adjacent to the causeway at Rizal Beach contains virtually no live corals, and is also the narrowest of the study area. Furthermore, the old causeway already provides a channel for the pipeline.

The shoreline to the south is densely inhabited and dredging would be more difficult, especially in those areas of higher recreational value.

It might be warranted to move the pipeline somewhat north as the reef flat is virtually the same. Such a move would alleviate a problem caused by the stream entrance and flow and would move a shoreside facility away from the popular recreational area at Rizal Beach.

Construction of the docking facility should allow for predominant northwest swell, although storm-generated southwest swells should be considered.

Any wharf facility constructed at the shore should have openings to allow water through culverts in order to prevent blocking the reef flat longshore flow.

Detonation of explosives should be made in sequence and in small charges to reduce the adverse biological effects of explosives under water. Excavated material should be removed from the water and stockpiled elsewhere until the pipeline can be covered. This will prevent doubling the damage to the reef flat and terrace, as well as the possible spreading of the material during storm conditions. The finished contours should be made as close to the original contours as possible.

The elevation of the concrete cast-in-place backfill at the reef margin should not exceed the natural profile of the reef flat and reef margin. The surplus backfill might be used in the wharf construction or removed from the beach.

It is suggested the marine biologists periodically assess the ongoing impact of construction.

Navigation lights should be provided on the loading platform.

Consistent with present trends and requirements an oil spill contingency plan should be developed which is compatible with projected operational procedures. The floating fence described in the plans by GORCO appears to be substantial, if the spill occurs at the docking site.

Drawings indicate a 17 ft. elevation above MLLW for the platform. It is suggested that associated structure on the platform be held to a minimum because of the frequency of high winds.

Although reef terrace modification will be extensive for the loading platform and dolfins, we believe that these changes will not greatly alter the adjacent environment because the coral density and related biota is depauperate, being in deeper water.

RECOMMENDATIONS

1. The proposed plans provided by GORCO should be used for location of the sea-island mooring facility, submarine pipeline, and shoreside facility.

2. Operations should be avoided during south and southwesterly wind conditions.

3. Construction should begin during the dry season when the northwest tradewinds are consistent.

4. Dredging on the reef flat should be carried out during low tides as much as possible.

5. Dredged material should be removed and stockpiled from the trenching site and returned as needed.

6. The shore-side wharf facility should be constructed so as not to interfere with the normal stream flow or with the reef flat longshore current flow.

7. Effluents should be confined to the 60-foot isobath; however, more specific information is needed concerning effluent quality.

8. An oil spill containment should be in place at all times while the ship is at the facility, and a contingency plan should be formulated for the pipeline, as well as the docking site to include all conditions such as earthquakes and tsunamis.

9. It is imperative that particularly sturdy protection be provided for the pipeline along the reef front, reef margin, and reef flat.

10. A small boat facility may be warranted, but the large maneuvering tug boats should be berthed within Apra Harbor.

11. The docking facility should be kept to as low as profile as practicable.

APPENDIX I

Landward Physiographic Setting

LANDWARD PHYSIOGRAPHIC SETTING

Richard H. Randall

GENERAL PHYSIOGRAPHIC SETTING

Somewhat inland of the shoreline at Agat Bay, the coastal region is bordered by steep-sloped volcanic mountain land (Fig. 9). The more immediate coastal land consists of a low coastal alluvial plain, generally less than 5 to 10 meters in elevation. This alluvial plain varies considerably in width and is about one kilometer wide at the northern end between the Namo River and Orote Peninsula. This low-lying coastal region consists mostly of marsh and swamp land. Toward the south it narrows and becomes somewhat less swampy and marshy partly because of landfilling and draining where the land is developed or occupied by residential and commercial dwellings. Limestone plateau land forms the coastal land along the northern end of the bay bordered by Orote Peninsula.

Inland from the low coastal plain the mountain slopes rise up to elevations of 265 meters at Mount Alifan and 309 meters at Mount Tanjo. These two mountains are separated by a low saddle about 115 meters high which separates the older Eocene volcanic mountain land to the north from the younger Miocene volcanic mountain land to the south. These mountain slopes are dissected into valley and ridge topography by many rivers and streams.

The limestone plateau land along the northern part of the bay slopes toward the southeast to a region of low swamp and marsh land which connects Orote Peninsula to the main part of the island. The general slope of the land along the remainder of the coastal embayment is toward the sea from the north-south trending mountain crest of central and southern Guam.

GENERAL GEOLOGIC SETTING[1/]

The coastal land along Agat Bay consists of low limestone plateau land along the northern border and alluvial low land interspersed with occurrences of higher limestone ridges and knobs along the central and southern parts. Further inland the limestone knobs and alluvial low land regions are bordered by the volcanic mountain slopes of central and southern Guam. Distribution of the various rock units are shown in Figure 3.

1/ The geologic description and distribution of the rock units around Agat Bay have been summarized in part from "The General Geology of Guam" by Tracey *et al*., 1964.

Reef facies of the Mariana limestone (QTmr) makes up the cliffed region along Orote Peninsula and Neye Island. This facies consists of massive, generally compact, porous, and cavernous limestone of reef origin, made up mostly of corals in position of growth in a matrix of encrusting calcareous algae. It is considered to be Pliocene and Pleistocene in age. The exposed seaward part of Neye Island is devoid of vegetation because of salt spray and is very irregularly sculptured into numerous pinnacles and ridges (phytokarst topography).

The Mariana reef facies grades into the Agana argillaceous member of the Mariana limestone (QTma) along the northern part of Dadi Beach. This member is a coarse-to-fine-grained pale-yellow, tan, or brown fossiliferous detrital limestone containing 2 to 5 per cent disseminated clay, sometimes more in cavities and pockets and includes unidifferentiated lines of the Mariana reef facies (QTmr). In age this limestone is generally thought to be contemporaneous with the Mariana reef facies. This limestone is probably in unconformable contact with either the Alifan limestone (Tal) or volcanic rocks of the Alutom formation (Ta), both of which border it to the east. This section of coastline is not cliffed as is the above Mariana reef facies, and is mostly bordered at the shoreline by a narrow band of beach deposits (Qrb) called Dadi Beach. The Pelagi Islets; Alutom, Bangi, and Yona Islands; and a small coastal patch at Agat Village are also composed of Agana argillaceous limestone. Phytokarst topography is developed on the subaerial parts of the above islands.

A low lying stretch of Alifan limestone (Tal) borders the coastal region and shoreline from Apaca Point southward to where Route 2 junctions with Route12 along the coast. This limestone is Pliocene in age and is massive coarse-to-fine-grained and recrystallized, generally pale pink, buff, or white but locally red, yellow, or brown and locally argillaceous above the base. South of the Namo River mouth this limestone is bordered by a narrow band of beach deposits (Qrb) known as Togcha Beach and north of the river mouth it is bordered by a very narrow and somewhat interrupted band of beach deposits called Rizal Beach.

Alluvial deposits (Qal) consisting mostly of muck and clay border much of the coastal area south of the above Alifan limestone region, except for a small patch of Agana argillaceous limestone which reaches the shoreline at Agat Village. Another stretch of alluvial deposits lies between the northern boundary of the Alifan limestone and the Agana argilaceous limestone at Orote Peninsula. Most of this alluvial low land is bordered at the shoreline by beach deposits (Qrb) except for a short stretch between Bangi Point and Agat Village where it reaches the shore.

The inland mountain slopes are composed of volcanic rocks of the Alutom formation (Ta) of Eocene age and the Umatac formation (Tuf) of Miocene age. Densely forested Alifan limestone (Tal) caps the upper part of the Mount Alifan crest and mostly savana vegetation grows on the steep weathered volcanic mountain slopes (Fig. 121).

SOILS[1/]

Two soil types (Units 1 and 4) and one steep rocky land type (Unit 13f) are developed on the limestone rock which borders the northern half of coastal region of Agat Bay. Three soil types (Units 9, 10, and 12) occur upon the alluvial low land and beach deposits along most of the coast from Dadi Beach south to Bangi Point. Three other soil types (Units 6, 7, and 8) are developed upon the inland volcanic rocks. Patches of marsh land (Unit 11) are found along the broad band of alluvial low land east of Dadi are Rizal Beaches. Distribution of the above soil and land units are shown in Figure 122.

Upland Soils Developed on Limestone

Guam clay (Unit 1) appears on the limestone plateau land at the northern end of the bay except for a narrow strip of steep limestone rock land (Unit 13f) which occurs along the steeply sloping and cliffed seaward margin of Orote Peninsula. Neye, Alutom, and Yona Islands; Bangi Point; and the Pelagi Islets also are classified as steep limestone rock land. Saipan-Yona-Chacha clays (Unit 4) are developed on the argillaceous Alifan and Mariana limestones at the eastern end of Orote Peninsula southward to the Namo River. Small patches also occur along the shore and somewhat inland between the Namo River and Bangi Point.

Guam clay (Unit 1) is a reddish, granular, permeable latosol; generally very shallow (less than 30 cm) but has some pockets or narrow troughs of deeper soil.

Steep limestone rock land occurs on the steeply sloping and cliffed land with scattered patches of thin (generally less than 5-9 cm) reddish or brownish clay among exposures of limestone bedrock, pinnacles, boulders, and rocky fragments. Little to no soil is found on the solution-sculptured rocky islands and islets along the bay.

Saipan-Yona-Chacha clays (Unit 4) consists of yellowish brown, firm clay (Chacha clay), and a red, firm clay (Saipan clay), with a neutral to acid reaction and latosolic intergrades. These soils

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1/ The soil unit descriptions around Agat Bay have been summarized from "Soils" by C. H. Stensland, 1959, _In_ Military Geology of Guam, Mariana Islands.

with a concave surface are 3 to 18 meters deep. Yona clay occurs as a shallow brownish lithosol on some of the narrow ridge-tops and steep slopes with a soil depth similar to that of Chacha and Saipan clays except that it generally grades into clayey limestone at about 30 to 60 cm below the surface.

Upland Soils Developed Upon Volcanic Rocks

Atate-Agat clays (Unit 6) are developed upon rolling volcanic land, whereas the Agat-Asan-Atate clays (Unit 7) and Agat-Asan clays and rock outcrop (Unit 8) are developed upon hilly and very hilly to steep volcanic land, respectively.

Atate-Agat clays (Unit 6) consists of remnant benches or small mesas of an old granular, porous, acid latosol (Atate clay) with deep reddish mottled, plastic to hard C horizon, pale yellow, olive or gray in the brown part; and its truncated counterpart (Agat clay) with similar C horizon of saprolitic clay, ranging in depth from less than a meter to about 30 meters.

Agat-Asan-Atate clays (Unit 7) consists of Atate-Agat clays and a dark grayish brown regosol (Asan clay) developed in more severely truncated saprolite, similar to the lower part of C horizon described in Unit 6. Soil depths of Unit 7 are similar to those of Unit 6, except for the Asan clay which ranges from less than a meter to generally less than 15 meters.

Agat-Asan clays and rock outcrops (Unit 8) consists chiefly of truncated latosol (Agat clay) and the regosol (Asan clay) with some unnamed dark grayish-brown lithosols and scattered small areas of volcanic rock outcrops. The soil depth to bedrock ranges from 0 to 15 or more meters.

Soils of the Coastal and Valley Land

Pago clay (Unit 9) is developed in the upper valley regions which are moderately well drained and Inarajan clay (Unit 10) is developed in the lower more poorly drained valleys and alluvial low land. Shioya soil (Unit 12) is developed upon the coastal limesand beaches. Marsh land (Unit 11) occurs in scattered patches within the coastal low land but is more extensive at the north end of the bay.

Pago clay (Unit 9) consists of brownish, granular to firm and plastic alluvial clay with gray mottling to within 0.5 to 1.0 meter of the surface. The clay is generally more than 3 but less than 50 meters in depth; moderately to well drained but subject to occasional flooding.

Inarajan clay (Unit 10) is similar to Pago clay but is lower, wetter, and shallower (thins out on coastal sands and bedrock), the water table is at or near the surface (within 0.7 meter) most of the time with mottlings (gray) within 15 to 30 cm of the surface. Depth of the clay to sand or bedrock ranges from 1 to 8 or more meters, and it is poorly drained and frequently flooded.

Shioya soil (Unit 12) consists of a pale brown to white, fine-, medium-, or coarse-grained limesand, commonly with a grayish-brown loamy sand or sandy loam surface horizon 15 to 45 cm thick. Depth to the water table ranges from 2 to 8 meters and to bedrock from 1 to 10 or more meters.

Marsh land (Unit 11) consists of black to brown, soft muck and peat, with some clay and silt. Depth to underlying material (chiefly limesand or shelly clay) ranges from 1 to 6 meters. The unit is poorly drained with the water table generally at or near the surface.

HYDROLOGY OF THE COASTAL LAND AREA OF AGAT BAY

From the rain which falls on the coastal area of Agat Bay, part escapes to the atmosphere by evaporation and transpiration, part flows directly to the sea via streams and rivers, part moves downward through the soil and rock to ground-water reservoirs and then to springs and seeps which discharge into streams or directly to the sea, and part moves downward through porous rocks to form a Ghyben-Herzberg fresh-water lens system which discharges at or near the shoreline.

The drainage area around Agat Bay can be divided into three ground-water areas according to Ward, Hoffard, and Davis (1965). Two of these, Area 5a and 5b, directly border the shoreline and a third, Area 6a, lies somewhat inland along the volcanic mountain slopes of central and southern Guam.

Area 5a occupies the limestone plateau land at the north end of the bay at Orote Peninsula. No surface streams are developed upon this porous limestone area. The fresh water percolates downward to the water table which is at or near sea level and forms a small lens system. The water, though, is mostly brackish at low or moderate rates of pumping.

A narrow band underlain by Alifan limestone, a few pockets of Agana argillaceous limestone, alluvium, and beach deposits along the remainder of the bay shoreline forms Area 5b. Wells in limestone and beach deposits have been reported to yield some fresh water, but the chloride content ranges from 500 to +10,000 ppm. The alluvium in places contains water having a chloride content less than 100 ppm, but wells in the area generally yield only meager amounts of water.

Area 6a is located on the volcanic mountain slopes which border the interior side of Area 5b. The rocks of this area absorb water at a low rate and a large part of the rainfall flows quickly to the sea via closely spaced rivers and streams. Ground-water discharge is mostly at springs and seeps dispersed along these streams.

Six streams reach the shore along Agat Bay (Fig. 2). These streams are relatively short and of steep gradient, especially where they originate in the steep mountain slopes. Volume discharge of these streams is very irregular. During periods of heavy rainfall stream discharge is high and the water muddy and turbid, resulting in a considerable load of suspended sediment and organic material carried to their mouths and adjacent fringing reef surface. As an example, maximum discharge of the short Finile River (drainage area 0.26 square miles), near Agat, was 314 cfs while the minimum was 0.11 cfs, during a five month period from April 1960, to September 1960 (U. S. Geologic Survey Water Supply Paper, No. 1937, 1971). The Namo River, which discharges onto the reef-flat platform near Apaca Point is the longest and has the largest drainage basin area of the six rivers along the bay.

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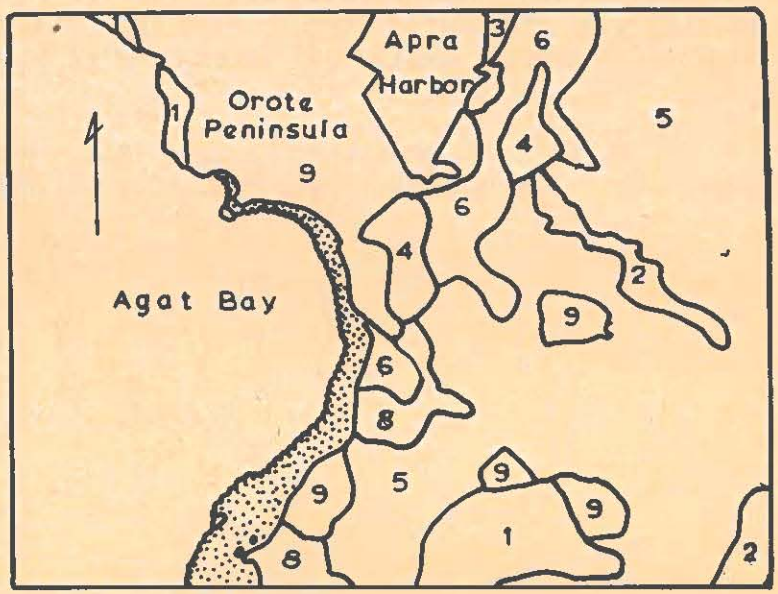

Fig. 121. Vegetation map for the Agat Bay study area. Unit 1 = mixed forest on limestone plateaus and cliffs, Unit 2 = mixed forest on volcanic soild in ravines and on limestone outcrops in valleys, Unit 3 = swamp forest, Unit 4 = reed marsh, Unit 5 = savana, Unit 6 = secondary thicket and cultivated ground, Unit 8 = predominantly open ground and pasture, and Unit 9 = bare ground and herbaceous to shrubby vegetation at military installations (map and unit descriptions from Fosberg, 1959).

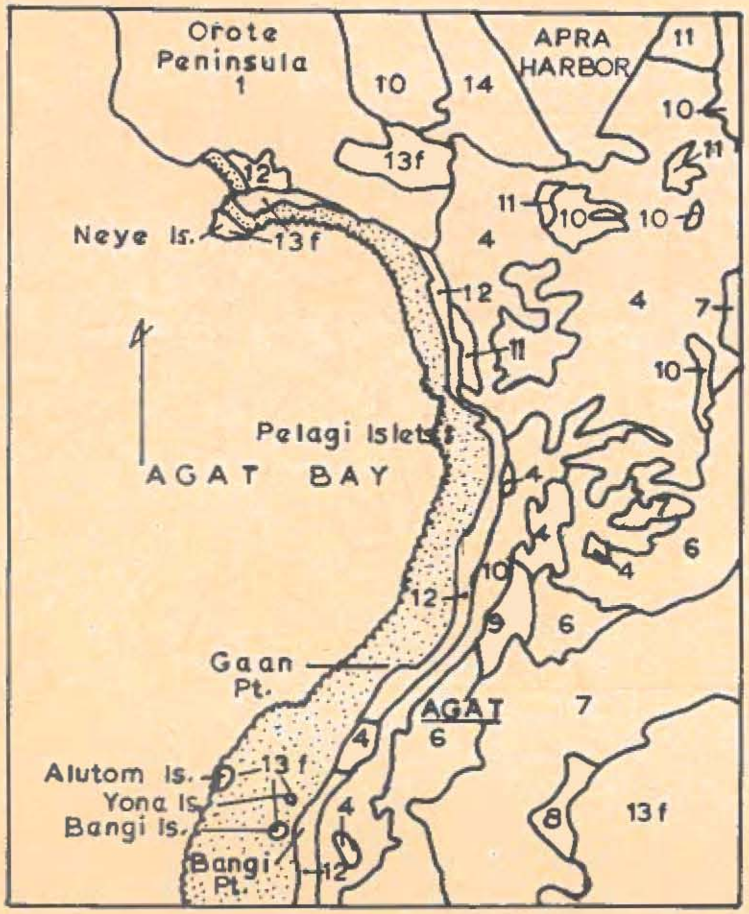

Fig. 122. Soil map of Agat Bay area showing the distribution of the various soil units described in the text. Reef-flat platform is stippled. Map modified from Stensland (1959).

APPENDIX II

Sediment Studies

SEDIMENT STUDIES

Russell Clayshulte

Sediment samples of an unconsolidated marine deposit were collected at three fathoms off of Rizal beach and analyzed for distribution of grain size, insoluble residue including major mineral constituents, pH, and organic content. A 54 cm core sample revealed no noticeable delineations in sediment deposition in Agat Bay. The reef front in sample area contains large and extensive deposits of unconsolidated sediments trapped between coral ridges. The sediment samples were collected in the trap deposit area near the reef margin.

Background Geology and Soils of Surrounding area

Orote Peninsula, the land mass to the north of collection site, is composed of Marianas Limestone of reef orgin. This is a porous white limestone, consisting of large coral head--*Favia*, *Acropora*, and *Pocillopora*--in growth positions. The spaces between the coral heads contain a fine grained dense limestone, predominantly calcareous algae, with lenses and pockets of *Halimeda* plates, algal detritus, and gastropod shells. Adjacent to this limestone outcrop is a deposit of Marianas limestone of the Agaņa argillaceous member. This limestone is a coarse to fine grained fossiliferous, detrital limestone containing two to five percent disseminated clay. The clay is present in two forms--a finely disseminated material in a limestone matrix, and a slightly calcareous material found in pockets and lenses, which can be as high as 50 percent clay by volume. This limestone is characterized by an abundance of molluscan-rich coquinoid deposits, containing a number of casts and molds of the gastropod *Turritella fibiola*, recrystallized to a medium-grained mosaic calcite. Bordering this limestone outcrop, directly behind sample area, is an extensive alluvial clay deposit of a limestone origin. Also bordering this area and just south of sample area is an outcrop of Alifan limestone. The limestone is a massive, coarse to a dense fine-grained mudstone recrystallized to a sedimentary marble. The formation is pierced by numerous tubes produced by boring molluscs and worms which are now calcite lined. The limestone is characterized by pencil-like *Porites* and *Acropora*, casts of bivalves, and fine molluscan debris in a matrix of sand and carbonate mud. This pale pink, buff or white limestone can be classified as a coral-molluscan coquinoid limestone (Schlanger, 1964).

Guam clay, Saipan-Yona-Chacha clays, and Shioya soils overlie the limestone and alluvial deposits of the land areas surrounding Agat Bay. Guam clay is a red, granular, permeable latosol that is generally less than 0.3 m (12 in.) deep. The Saipan-Yona-Chacha clays are a shallow brownish lithosal on convex slopes. The Chacha clay is a yellowish brown, firm clay, which is neutral to acid reaction, as is the red, firm Saipan clay. The Yona clay usually grades into clayey limestone and is alkaline or calcareous. The Shioya soils are pale brown to white, fine-, medium-, or coarse-grained limesands, commonly with loamy sand or sandy loam surface.

There is also the introduction of Inarajan clay, Pago clay, Atate-Agat clay, and Agat-Asan-Atate clays from the Namo River which drains these upland soils from regions to the east into Agat Bay. The Pago clay and Inarajan clay are brownish, granular to firm and plastic alluvial clays, with an alkaline to neutral reaction. The Atate-Agat clays are red granular-porous acid clays, associated with small bench-like mesitas, and a truncated latosol with solum almost all removed; there is red staining and reticulate mottling deep into C or saprolitic horizon. The Agat-Asan-Atate clays are a dark grayish brown regosol (Asan clay) developed in more severely truncated saprolite in conjunction with the Atate-Agat clays.

These upland soils overlie volcanic deposits, which include the Umatac formations and Alutom formations.

The Alutom formations are characterized by abundant white and light gray tuffaceous shales which are water-laid pyroclastic sediments. Interbedded in these sediments are lava flows and breccias of volcanic material. The Umatac formations contain more basalt and less tuffaceous material. The volcanic material in this formation ranges from basalt and olivine basalt to andesite, with more than 50 percent mafic andesite (Randall and Holloman, 1974; Carroll and Hathaway, 1963).

Analysis

The core sample, two surface samples, and three samples from an excavation at 10-30 cm, were dried to a constant weight and 100 grams run through mechanical separation (Table 14). The material retained on the first two sieves is predominately bivalve shells with some small gastropods found. The mollusc shells comprise from 9 percent to as high as 50 percent of the total volume of the sediment deposition. Approximately 50 percent of the sediment is a medium sand in the range of 0.25 - 0.5 mm. The surface samples contain very little silts and clays with an increase in percentage of silts and clays with depth.

The pH ranges from neutral to alkaline, with the alkaline material found predominately in the 10-30 cm range. This indicates the high concentration of limestone material in sediment sample. The organic content was tested in the surface and excavation samples and the results showed no measurable organic content. One burn out of bottom core sample showed a small amount of reduction in weight but was too small to be considered valid. The data on organic content in therefore inconclusive at present time.

Ten grams of dried sample were placed in 200 mls of 1:1 HCl and tested for completeness of reaction by con. HCl. The insoluble residue was collected, dried, and weighed (Table 15). This insoluble residue was examined under a compound microscope and the major minerals were identified on basis of color and intact crystals. The predominate minerals were illmenite, amphibole, and olivine, with noticeable quantities of opague grains, hypersthene, magnetite, and clay residues. Equipment is not available to do an in-depth analysis of minerals and clay residues, therefore only visual identification on minerals was used, possibly resulting in some minor errors. The high percents of insoluble residue found do indicate that large quantities of sediment are carried by the Namo River from upland sources to Agat Bay. The Namo River is located to the south of sample area, therefore the predominate current in Agat Bay sweeps toward Orote Peninsula, but with present data this is not conclusive. The presence of olivine in residue indicates that there is the introduction of volcanic material from the Umatac volcanic formations. This would indicate that large amounts of the Atate-Agat clays, Agat-Asan-Atate clays, and Saipan-Yona-Chacha clays are carried into the Agat Bay area, but the analysis showed low percentages of clay being deposited. The sediment samples were collected during the rainy season with heavy flows from nearby rivers, which possibly could explain the low clay content in the upper sediment layers and the 9 percent clay at 50 cm. Turbidity samples taken previously to sediment sampling showed relatively high percents of suspended material which would be silts and clays. The deposition of silts and clays should then be located further from reef front, this has not been confirmed in this sediment analysis.

There is an extensive deposition of sediments in Agat Bay which have the characteristics of upland soils and volcanic members mixed with Marianas limestone and Alifan limestone. Information is not available on the variation in deposition, nor the amount of deposition during long periods of time. The sediment material appears to be carried toward the north by offshore currents as a general trend.

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Table 14. Mechanical composition, in percent, and pH of unconsolidated sediments off Rizal Beach, 3 fathoms [tr., trace, < 1.0 percent].

Description	Depth	pH	Gravel < 2.0 mm	Very Coarse Sand 1-2 mm	Coarse Sand 0.5-1 mm	Med. Sand 0.25-0.5 mm	Fine Sand 0.15-0.25 mm	Very Fine Sand 0.01-0.15 mm	Silt 0.01-0.075 mm	Fine Silt and Clay > 0.075 mm
Surface Sample #II	0-5 cm	6.9	1.0 all bi-valves [molluscs]	13.3 broken molluscs	20.3 high % molluscs	49.2	13.1	2.2	tr.	tr. red silt and clay
Surface Sample #II	0-5 cm	7.0	2.0 all bi-valves	20.8	25.9 high % molluscs	44.1	5.7	tr.	tr.	tr. red silt and clay
Excavation Sample #I	10-30 cm	7.8	1.7 all bi-valves	14.8 broken molluscs	21.7 high % molluscs	46.0	10.6	2.1	tr.	3.02 red silt and clay
Excavation Sample #II	10-30 cm	7.8	1.9 all bi-valves	15.0 broken molluscs	17.7 high % molluscs	46.9	11.9	3.3	1.9	1.4 red silt and clay
Excavation Sample #III	10-30 cm	8.0	1.5 all bi-valves	10.9 broken molluscs	14.9 high % molluscs	50.7	15.4	4.0	1.9	tr. red silt and clay
Core Sample	0-2 cm	6.9	2.1 broken molluscs	18.4 broken molluscs	26.6 high % molluscs	43.1	8.3	tr.	tr.	tr. red silt and clay

Table 14. Continued.

Description	Depth	pH	Gravel < 2.0 mm	Very Coarse Sand 1-2 mm	Coarse Sand 0.5-1 mm	Med. Sand 0.25-0.5 mm	Fine Sand 0.15-0.25 mm	Very Fine Sand 0.01-0.15 mm	Silt 0.01-0.075 mm	Fine Silt and clay > 0.075 mm
	10-11 cm	7.6	2.3 all bi-valves	20.6 broken molluscs	24.3 high % molluscs	45.6	5.6	1.0	tr.	-
	19-21 cm	7.2	1.8 broken molluscs	14.3 broken molluscs	12.6	51.3	11.2	2.8	1.9	4.1 red silt and clay
	29-31 cm	7.6	1.9 broken molluscs	14.2 broken molluscs	20.3	47.2	9.4	3.2	1.5	2.3 red silt and clay
	40-42 cm	7.1	1.7 all bi-valves	9.8 broken molluscs	14.1	50.6	13.2	3.3	4.2	7.8 red and yellow silt and clay
	50-54 cm	6.9	1.5 all bi-valves	8.5 broken molluscs	13.3	50.5	12.7	2.6	1.6	9.3 red and yellow silt and clay

Table 15. Insoluble residues, in percent, or unconsolidated sediments [Minerals, Tr., trace; A, Major constituent; ++ Present].[1]

Sample	% Residue	Magnetite	Iron Oxides	Illme-nite	Augite	Hyper-sthene	Green Brown	Opaque Grains	Olivine	Clay	Zircon sphene Rutile	Others: Calcite Feldspars Quartz
Surface #I	7.60	Tr.	Tr.	++	Tr.	++	++	++	A ?	Tr.	Tr.	Tr.
Surface #II	12.42	Tr.	Tr.	++	++	++	A ?	++	++	Tr.	Tr.	Tr.
Excavation 10-30 cm #I	18.84	++	Tr.	A ?	++	++	++	++	Tr.	++	Tr.	Tr.
Excavation 10-30 cm #II	19.27	++	Tr.	A ?	++	Tr.	++	Tr.	++	++	Tr.	Tr.
Excavation 10-30 cm #III	17.66	++	Tr.	A ?	++	Tr.	++	Tr.	Tr.	++	Tr.	Tr.
Core 20 cm	9.35	Tr.	Tr.	++	++	++	A ?	Tr.	++	Tr.	Tr.	Tr.
Core 30 cm	14.34	++	Tr.	++	++	Tr.	A ?	++	++	Tr.	Tr.	Tr.
Core 30 cm	17.89	++	Tr.	++	Tr.	++	A ?	++	Tr.	++	Tr.	Tr.
Core 40 cm	17.68	++	Tr.	?	++	++	++	Tr.	++	++	--	Tr.
Core 50 cm	21.32	++	Tr.	++	++	++	A ?	Tr.	++	-+	Tr.	Tr.

[1] Identification was under compound scope using Dana's Manual of Mineralogy.

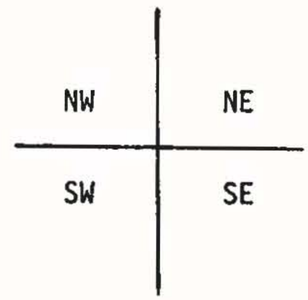
APPENDIX III

Current Studies Summaries

Summary: All Trips.

	1 m	5 m
Number of tosses	119	119
Total distance (naut. mi.)	92.11	74.84
Total hours	404.64	404.64
Average drogue speed (knots)	0.25	0.20

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	23	1.5
SE	24	3.8
SW	136	7.9
NW	83	7.4

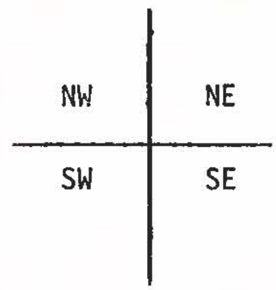
Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	8.6
1500-2000	9.1
2100-0200	6.5
0300-0800	6.4

Trip 1, May 23-24, 1974.

	1 m	5 m
Number of tosses	9	9
Total distance (naut. mi.)	8.05	7.75
Total hours	42	42
Average drogue speed (knots)	0.20	0.21

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	0	-
SE	5	13.3
SW	5	11.9
NW	8	9.4

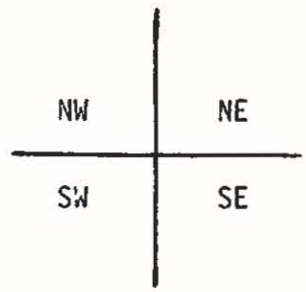
Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	7.2
1500-2000	6.3
2100-0200	9.9
0300-0800	10.0

Trip 2, July 2-3, 1974.

	1 m	5 m
Number of tosses	9	9
Total distance (naut. mi.)	7.0	6.23
Total hours	40	40
Average drogue speed (knots)	0.19	0.17

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	0	-
SE	2	9.0
SW	12	11.8
NW	5	8.5

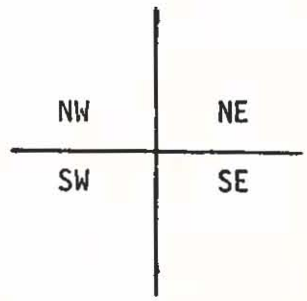
Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	5.5
1500-2000	14.7
2100-0200	8.7
0300-0800	5.1

Trip 3, July 25-26, 1974.

	1 m	5 m
Number of tosses	10	10
Total distance (naut. mi.)	8.4	6.7
Total hours	42	42
Average drogue speed (knots)	0.22	0.17

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	0	-
SE	1	5.9
SW	16	4.9
NW	7	4.2

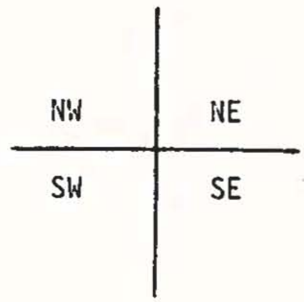
Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	6.8
1500-2000	6.0
2100-0200	3.5
0300-0800	3.4

Trip 4, August 22-23, 1974.

	1 m	5 m
Number of tosses	10	10
Total distance (naut. mi.)	8.32	7.27
Total hours	34.66	34.66
Average drogue speed (knots)	0.28	0.25

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	6	5.0
SE	6	4.9
SW	9	3.4
NW	2	4.0

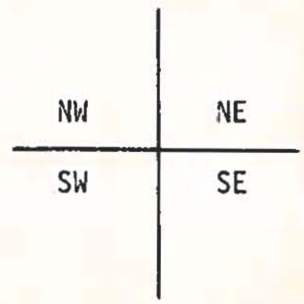
Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	4.8
1500-2000	5.6
2100-0200	3.5
0300-0800	3.3

Trip 5, September 19-20, 1974.

	1 m	5 m
Number of tosses	10	10
Total distance (naut. mi.)	10.96	5.72
Total hours	37.0	37.0
Average drogue speed (knots)	0.29	0.15

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	14	8.9
SE	7	8.2
SW	0	-
NW	2	3.8

Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	8.5
1500-2000	9.4
2100-0200	7.7
0300-0800	9.7

Trip 6, October 17-18, 1974.

	1 m	5 m
Number of tosses	9	9
Total distance (naut. mi.)	8.98	7.67
Total hours	45	45
Average drogue speed (knots)	0.22	0.19

Wind Histogram Analysis

NW	NE
SW	SE

Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	3	3.5
SE	3	4.6
SW	10	4.0
NW	8	3.7

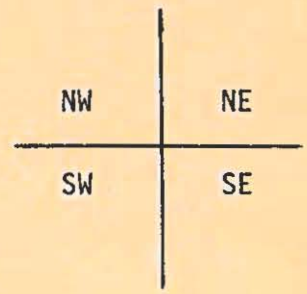
Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	3.8
1500-2000	5.0
2100-0200	3.5
0300-0800	3.2

Trip 7, November 21-22, 1974.

	1 m	5 m
Number of tosses	11	11
Total distance (naut. mi.)	6.67	5.72
Total hours	27.75	27.75
Average drogue speed (knots)	.24	0.21

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	0	-
SE	0	-
SW	4	15.2
NW	20	17.4

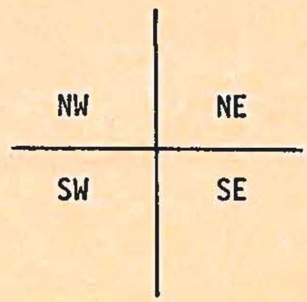
Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	14.3
1500-2000	16.3
2100-0200	12.7
0300-0800	14.6

Trip 8, December 12-13, 1974.

	1 m	5 m
Number of tosses	11	11
Total distance (naut. mi.)	9.99	7.95
Total hours	30.83	30.83
Average drogue speed (knots)	0.33	0.27

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	0	-
SE	0	-
SW	17	13.3
NW	5	7.8

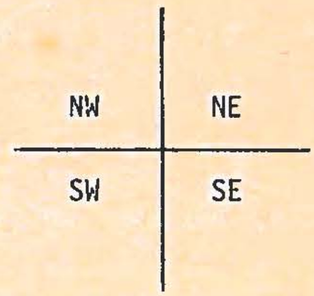
Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	7.4
1500-2000	11.1
2100-0200	16.3
0300-0800	11.4

Trip 9, February 6-7, 1975.

	1 m	5 m
Number of tosses	12	12
Total distance (naut. mi.)	7.12	6.4
Total hours	29	29
Average drogue speed (knots)	0.26	0.23

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	0	-
SE	0	-
SW	20	9.9
NW	4	9.8

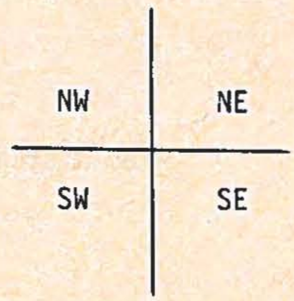
Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	12.7
1500-2000	8.6
2100-0200	8.6
0300-0800	8.4

Trip 10, March 6-7, 1975.

	1 m	5 m
Number of tosses	10	10
Total distance (naut. mi.)	5.59	4.08
Total hours	28	28
Average drogue speed (knots)	0.22	0.16

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	0	-
SE	0	-
SW	19	8.52
NW	3	5.33

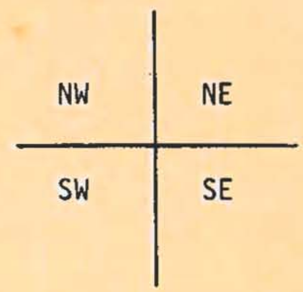
Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	12.0
1500-2000	8.9
2100-0200	5.3
0300-0800	4.1

Trip 11, April 24-25, 1975.

	1 m	5 m
Number of tosses	10	10
Total distance (naut. mi.)	5.98	4.8
Total hours	25.8	25.8
Average drogue speed (knots)	0.25	0.21

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	0	-
SE	0	-
SW	16	7.2
NW	8	4.6

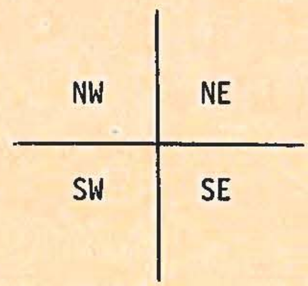
Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	9.3
1500-2000	9.2
2100-0200	4.7
0300-0800	1.5

Trip 12, May 22-23, 1975.

	1 m	5 m
Number of tosses	8	8
Total distance (naut. mi.)	5.35	4.25
Total hours	22.6	22.6
Average drogue speed (knots)	0.27	0.21

Wind Histogram Analysis



Quadrant	Number of Wind Vectors in Quadrant	Mean Speed (knots)
NE	0	-
SE	0	-
SW	8	4.3
NW	11	9.7

Mean Wind Speeds for Six Hourly Readings

Time	Mean Speed (knots)
0900-1400	11.0
1500-2000	8.2
2100-0200	2.2
0300-0300	2.2