APPENDIX A

A GEOLOGICAL AND BIOLOGICAL SURVEY OF THE RITIDIAN POINT COASTAL REGION OF GUAM

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INTRODUCTION

Because of anticipated construction and development at the U.S. Naval Facility, located on a low coastal terrace at Ritidian Point, a U.S. Navy Sub-Contractor, JT Davis/Herrera and Cash Architects, Inc., requested assistance from the University of Guam, Micronesian Area Research Center (MARC) to provide them with specific archaeological and environmental services. MARC, in turn, requested the University of Guam, Marine Laboratory to assist in providing a part of these services.

A proposal to provide specific archaeological and environmental services at the Ritidian Point U.S. Naval Facility and adjacent coastal region was submitted by MARC on September 7, 1987, to the U.S.Navy Sub-Contractor, and on September 24, 1987, an agreement between the two parties was signed (Amendment No. 0011 of Contract N62766-86-D-0008).

Project Description and Scope of Work Objectives

This study and report constitute a part of the services provided by the University of Guam, Marine Laboratory. More specifically the study included the following scope of work objectives and work responsibilities:

1. Provide background environmental data (Randall).
   a) General geographic setting (physical).
   b) General geological setting.

2. Conduct a survey of beaches and coastal terraces adjacent to the study area, with emphasis on unconsolidated coastal terraces and emergent Holocene reef deposits (Randall).

3. Conduct a survey of fringing reef platforms within the study area (Baker and Randall).

   a. Quantitative assessment (community structure) of the reef-building corals (Baker).

   b. Qualitative assessment of the reef-building corals and other reef building organisms (Randall).

4. Determine the sequence of natural historical events and processes that were important in site formation of the immediate study area around the U.S. Naval Facility, particularly the unconsolidated terrace deposits upon which the facility is built (Randall).

Fieldwork Schedule

Field reconnaissance of the overall study area, collection of geological and biological samples, and transect studies were conducted on coastal terraces and beaches during the months of February 1988 and June 1989. Quantitative and qualitative assessments of adjacent fringing reef flat platforms were conducted during the first seven months of 1982 (January - July). Although the quantitative assessment of reef-building corals was primarily conducted over six years ago, we feel that the data from that period is valid for use in interpreting site formation processes and historical development of the unconsolidated storm terrace deposits in the immediate vicinity of the U.S. Naval Facility. No other such data base for this region exists, and during the month of February 1988, high surf and strong currents prevented safe acquisition of transect data from the fringing reef flat platforms. A period of relatively calm weather during the month of June 1989, allowed safe acquisition of geological samples from the west Ritidian reef platform, and additional qualitative data from fringing reef platforms.

METHODS

Background Environmental Data and Survey of Beaches and Coastal Terraces

Background environmental data, consisting primarily of a general geographic and geologic setting of the study area (see Fig. 1), was acquired by reviewing existing literature and from field reconnaissance observations. Although a reconnaissance of the entire coastal region between Achae Point and Pajon Point was made, the primary focus of field observations was on the geomorphic interpretation of emergent Holocene limestone outcrops and coastal processes related to the formation of the unconsolidated terrace deposits upon which the U.S. Naval Facility is presently situated. In addition to overall general observations the beaches and coastal terraces were studied in more detail by making observations along eight transects (H-W1 through H-W4 and H-E1 through H-E4) at locations shown in Figure 2. These transects were primarily located where emergent Holocene outcrops extended to, or near the shoreline. The transects were established by laying out a plastic surveyor's tape perpendicular from the shoreline to a point inland where the Holocene outcrops either became buried beneath beach and storm deposits or lapped onto older Pleistocene deposits. A checklist of fossil reef-building corals encountered along the transects is compiled in Table 1 and representative vertical profiles of each are shown in Figures 3 and 4.

At Transect H-E4, just northwest of Pajon Point, a quantitative analysis of an emergent Holocene limestone outcrop was completed by utilizing the line intercept method used by Randall et al. (1984) on an emergent Holocene outcrop at Ylig Point, Guam. At this location a massive algal ridge facies at the shoreline and an adjacent backreef platform facies, which extended inland about 25 meters, were exposed. At most locations along the northern coast of Guam the backreef platform facies of the Holocene limestone outcrops are buried beneath a veneer of unconsolidated storm deposits which support a dense surface cover of halophytic and xerophytic strand vegetation. In January 1988, "Typhoon Roy" struck Guam and at Transect H-E4 the storm deposits and strand vegetation were removed from the backreef platform by storm waves, providing access for observation and assessment of reef-building corals. The reef surface beneath the entire length of the transect line was identified and recorded as reef corals, calcareous red algae, detrital matrix, or Pleistocene limestone outcrop. Because of their excellent state of preservation all reef corals could be identified to genus, and for most to specific taxons. Calcareous red algae refers to crustose types that could be identified as in situ encrusting and nonarticulated ramose forms. Matrix is any consolidated detrital material, and Pleistocene limestone outcrop is inliers of such material that was encountered. Quantitative measures used to determine the community structure at Transect H-E4 were total substrate coverage and frequency of occurrence by individual species of corals, calcareous red algae, detrital matrix, and Pleistocene outcrop. Total coverage for each of these groups and individual coral species was calculated as the total length of each group or species intercepted by the transect line divided by the length of the transect line within each of the various physiographic facies discriminated (two algal ridge subfacies and a backreef platform facies). Frequency of occurrence was calculated as the total number of times individual coral species, calcareous red algae, detrital matrix, and Pleistocene limestone outcrop were encountered within each physiographic facies or subfacies. Quantitative data from Transect H-E4 are presented in Table 2.

Fringing Reef Flat Platform Survey

Coral communities were analyzed along eight reef flat platform transects by using the plotless point-centered or point-quarter technique of Cottam et al. (1953). Transects were established by placing a line divided into meters along the reef flat platform surface at the locations shown in Figure 5. In general the transects were run perpendicular from the shoreline to the reef margin zone, which was about as far seaward on the platform as measurements could be safely made. Three transects, W-1 through W-3, were placed more or less equidistant apart on the West Ritidian reef platform and five transects, E-1 through E-5 were similarly placed on the East Ritidian reef platform. Stations were established at 5-meter intervals along the length of each transect. At each of these stations a chisel hammer was randomly tossed over the surveyor's shoulder, starting first when facing left of the transect and then facing right for the next random toss. Tossed hammers landed within a 5-meter corridor on each side of the transect line, making the transect sample width area about 10 meters wide. Where the tossed hammer came to rest, a sample point was established at the intersection of the hammer handle and head. Four quadrants were then formed around the point by establishing one axis along the hammer handle and another at right angles to it along the hammer-chisel head. The coral nearest the sample point in each quadrant was located and its specific name, size (diameter if round, or maximum length and width if irregular), and the distance from the center of the corallum to the sample point were recorded. If there was no coral observed within a distance of 1.0 meter from the sample point, the quadrant was recorded as no coral encountered with a sample point to colony distance of 1.0 meter. From these point-quarter data the following calculations were used to estimate the following community structure parameters:

1. $$\text{Total density of all species} = \frac{\text{unit area}}{(\text{mean point-to-colony distance})^2}$$

2. $$\text{Relative density} = \frac{\text{individuals of a species}}{\text{total individuals of all species}} \times 100$$

3. $$\text{Density} = \frac{\text{relative density of a species}}{100} \times \text{total density of all species}$$

4. $$\text{Total percent coverage} = \text{total density of all species} \times \text{average coverage value for all species}$$

5. $$\text{Percent coverage} = \text{density of a species} \times \text{average coverage value for the species}$$

6. $$\text{Relative percent coverage} = \frac{\text{percent coverage for a species}}{\text{total coverage for all species}} \times 100$$

7. $$\text{Frequency} = \frac{\text{number of points at which a species occurs}}{\text{total number of points}}$$

8. $$\text{Relative frequency} = \frac{\text{frequency value for a species}}{\text{total of frequency values for all species}} \times 100$$

9. $$\text{Importance value} = \text{relative density} + \text{relative percent coverage} + \text{relative frequency}$$

Colony size distribution data (Y = arithmetic mean, s = standard deviation, and w = size range) were also calculated from the point-quarter data.

Coral species recorded during the point-quarter analysis indicate the predominant and common species encountered along the transects. The presence of uncommon or rare species, generally not encountered during the point-quarter analyses, were determined for each transect by making ten-minute snorkel observations along each side of the transect line for each 100 meters of transect length, and within the reef platform areas between transects. Species encountered within the inter-transect areas were recorded to whatever transect they were observed closest to. An overall checklist of species recorded from the study area is compiled for each transect by combining those encountered during the point-quarter analysis with those from snorkel observations in Table 3. Quantitative data of coral species encountered from the point-quarter analysis are presented in Table 4.

Vertical profile sections representative of Transects E-1 through E-3 and W-1 through W-3 are shown in Figure 6. Physiographic zones are discriminated along the transect profile sections. Water depths indicated on the profile sections were obtained by recording depths at 5-meter intervals and then corrected to lower low tide level (datum).

ENVIRONMENTAL SETTING OF THE STUDY AREA

Geographic Setting of the Coastal Terraces and Peripheral Plateau

The study area is located along the northernmost part of Guam at Ritidian Point (Fig. 1). More specifically it encompasses the low coastal terraces, beaches, and adjacent fringing reef platforms in the immediate vicinity of the U.S. Naval Facility that lie between the base of the northern limestone plateau scarp and the Pacific Ocean (Fig. 7). In order to more adequately determine site process formation at this study location the entire coastal area between Achae Point and Pajon Point was investigated.

The coastal region along this northernmost tip of Guam consist of a series of limestone terraces, unconsolidated terraces composed of bioclastic material of reef origin, white-to-buff-colored beaches, and broad fringing reef platforms. Collectively these features make up a relatively low coastal fringe, generally less than 25 meters in elevation and up to 0.4 km wide, that borders cliffs and associated steep slopes along the peripheral scarp margin of a much higher limestone plateau (Figs. 2, 5, and 7). This limestone plateau of northern Guam is developed upon what was probably a barrier reef complex enclosing a relatively shallow lagoon, both of which were formed and deposited during Pliocene and Pleistocene time. This area has since been subjected to regional uplifting and recurrent Pleistocene sea level changes, resulting in the emergence of the entire barrier reef and associated lagoon limestone deposits.

The upper plateau cliff margin between Achae Point and Pajon Point has a general elevation of slightly more than 150 meters and at Mount Machanao is in excess of 183 meters. Cliff faces along this section are cut by long vertical fractures, joints, and solution fissures. Dense recrystallized limestone sheaths the cliff faces at many locations, giving them a white-washed appearance. Drip stone formations are particularly abundant in notches and caves located on the cliff faces around Ritidian Point. The lower lying coastal region bordering the limestone plateau in the vicinity of Ritidian Point represents what was formerly the seaward dipping reef slopes of a peripheral barrier reef. The seaward slopes themselves have been modified by intermittent faulting, local slumping, and various sea level fluctuations. Sea stands of sufficient lengths of time must have occurred during the various sea level fluctuations to produce the many terrace levels and notches presently observed along the coast. Some of these terraces may have formed by sea level erosion (truncation), whereas others may have formed by fringing reef development, and at lower elevations by storm deposit accumulation. Coastal terraces between Achae Point and Pajon Point range from low emergent limestone outcrops along the shoreline less than a meter above mean low tide to prominent forested limestone levels up to 25 meters in elevation. Widest coastal terraces occur at elevations ranging from 12 to 25 meters between Pajon Point and Ritidian Point and from 6 to 25 meters between Achae Point and Ritidian Point. Terraces between the shoreline and 6 meters elevation tend to be relatively narrow. Terraces above 30 meters elevation are for the most part restricted to the steep plateau scarp slopes located between Achae Point and Ritidian Point. A particularly good series of these higher terraces can be seen along Route 3 highway as you decend from the higher plateau level to the lower Naval Facility level (Fig. 5). At 25 to 30 meters elevation most coastal terraces abruptly abut against the steep basal slopes and cliffs along the peripheral margin of the limestone plateau. Between Pajon Point and Ritidian Point plateau scarps are buttressed with house-sized blocks and much smaller-sized talus rubble that have slumped from near vertical cliffs which occur along much of this sector.

Except for a prominent unconsolidated terrace generally less than 6 meters in elevation, that extends from Achae Point to Ritidian Point, the coastal terraces are developed upon emergent detrital or reef facies limestones. Most of the limestone terraces slope downward toward the coast and at their outer margins terminate rather abruptly in the form of scarps or steep slopes. Major relief features found on the lower coastal limestone terraces consist of such step-like scarps and slopes. Overall relief on the coastal limestone terraces themselves is somewhat subdued, generally less than 2 meters, except where local sinks, marginal scarps, and large slump blocks occur. Evenso, walking across these limestone terraces is difficult at most places because of rainwater dissolution and biogenic erosion which have sculptured their surfaces into a jagged, pinnacled, karrenfeld topography. In addition, where the limestone terraces are densely forested there are numerous, loose, angular-shaped boulders strewn about which results in unstable footing as well. The distribution of, at least, many of these loose angular boulders appears to be related to the presence of large trees. Reconnaissance observations on coastal terraces near Pajon Point several weeks after "Typhoon Roy", which struck Guam in January 1988, showed that may large trees intact with root systems had been toppled over. Because of the general absence of much soil on these terraces the roots of trees penetrate downward into cracks and fissures within the limestone. When these trees topple over many firmly entangled sections of limestone within the root system are broken loose and carried upward above the terrace surface. Subsequent decomposition of the roots then releases the limestone pieces. Falling tree trunks also break off pieces of limestone pinnacles, adding to the surface accumulation of loose boulders as well. These sources of loose boulders may seem minor, but when considering typhoon frequency in the Mariana Islands this process of loose boulder production has most likely occurred repeatedly over entire forested terrace surfaces since their emergence. Interestingly, there are fewer loose pieces of limestone on unforested terraces, even though a well-developed solution-pinnacled karrenfeld topography exists.

As previously mentioned an unconsolidated terrace occupies the immediate coastal region between Achae Point and Ritidian

Point (Fig. 5). The terrace extends inland from the beach along this coastal stretch to the base of the lowermost of a series of step-like terrace scarps that form the steep-sloped plateau escarpment along this sector. A prominent notch occurs along the base of this lowermost terrace scarp where unconsolidated terrace deposits have not obscured it. Drip stone formations are abundant in the notches and caves which are formed at places along the base of the scarp as well. The terrace is about 1.6 km long with a maximum elevation of about 6 meters. Terrace deposits in the immediate vicinity of the Naval Facility have been extensively disturbed and much of the remaining terrace southwestward to Achae Point also appears to have been disturbed to some degree as well.

Although a detailed compositional analysis of the unconsolidated terrace deposits was not made, general observations of materal excavated from archaelogical test pits on the inner part of the terrace and from construction activities on the outer part of the terrace revealed a composition that is very similar to that of the adjacent beach deposits described below. Except for minor amounts of organic material, incorporated primarily from decaying vegetation, the terrace deposits appear to be composed entirely of bioclastic grains of reef origin. It is possible, though, that some clasts derived from erosion of older and higher levels could be intermixed with more recent bioclastics along the inner part of the terrace.

Beaches

White to buff-colored beach deposits, here called Ritidian Beach, occupies most of the shoreline between Achae Point and Pajon Point (Figs. 2, 5, 7 and 8). This uninterrupted stretch of beach deposits is 3550 meters long and at places near Ritidian Point and Achae Point are up to 46 meters wide (Randall and Eldredge, 1976). Width at other locations is generally between 15 and 20 meters. Field examination of the beach deposits show them to be composed almost entirely of bioclastic grains of reef origin. Conspicuous contributors include whole and broken foraminiferan tests, coral fragments, whole and broken mollusc shells, and fragments of both green and red calcareous algae. Solitary stellate and discoid foraminiferan tests are particularly abundant, giving the deposits much of their tan coloration. Red colored fragments of colonial foraminifers are also conspicuous, but are much less abundant than solitary forms. Green algal segments of the genus Halimeda are the most abundant contributors of the calcareous algae. Analysis of two beach samples collected from Ritidian Point (Sta. 12, Sample No. 41 taken at high tide level and Sample No. 42 taken at low tide level) by Emery (1962) showed that no insoluble residues (after digestion in dilute HCl) were present in either sample. The lack of any insoluble residue is not unusual since there are no streams developed on the adjacent coastal terraces and limestone plateau which could carry insoluble silt or clay deposits to the shoreline. Other characteristics of Emery's two beach samples include a mean grain size (texture) of 0.38 mm and a Trask Sorting Coefficient of 1.26 for the high tide level sample and a mean grain size of 1.04 mm and a Trask Sorting Coefficient of 3.80 for the low tide level sample. Beach slopes at Sta. 12 were 10.7 degrees for the high tide level and 0.0 degrees for the low tide level, which was sampled at the toe of the beach on the reef platform that was relatively level. Field examination of the remaining deposits along Ritidian Beach show little to only minor departures from the beach characteristics analyzed by Emery (1962) at his Ritidian Point Sta. 12 site. Texturally the deposits are mostly sand-sized with only minor amounts of gravel- and rubble-sized fractions. In regard to composition, conspicuous fan-shaped thalli from the green calcareous alga Udotea were observed on the upper beach slopes between Ritidian Point and Pajon Point.

Between Ritidian Point and Pajon Point seaward dipping, imbricate beachrock intermittently occurs at the immediate shoreline (Fig. 10b). Here the beachrock forms a linear band less than a meter in elevation above the adjacent reef flat platform and is generally less than 6 or 7 meters wide. The beachrock is well indurated and texturally and compositionally quite similar to adjacent unconsolidated beach deposits located immediately behind the outcrops. A minor exception, though, is the presence of more rubble-sized pieces of subrounded corals embedded in the beachrock than in the present beach deposits.

Except for the above mentioned beachrock exposures, rocky shorelines are only present at Achae Point and at Pajon Point where a coastal limestone (Merizo Formation) terrace, generally less than 4.0 meters in elevation, forms a rugged solution-pinnacled shoreline (Figs. 2, 7, and 8). On the Ritidian Beach side of the limestone terrace at Pajon Point the outcrops are intermittent and have seven entrant zones where beach deposits occur (Figs. 2 and 10a-10d). These Holocene terrace outcrops at Pajon Point and Achae Point are discussed in more detail in the "Emergent Holocene Terrace Deposits" and "Geologic History" sections of the report.

GEOLOGIC SETTING

Rock Units

Principal rock units mapped within the study area include a Reef Facies (QTmr) and a Detrital Facies (QTmd) of the Mariana Limestone Formation of Pliocene-Pleistocene age, and beach and unconsolidated terrace deposits (Qrb) of Recent age (Tracey et al., 1964). In addition to the two Mariana Limestone facies, minor outcrops of Merizo Limestone (Qrm) of Recent (Holocene) age were recognized during this study just north of Achae Point and at a more extensive outcrop along the shoreline at Pajon Point that were previously mapped by Tracy et al. (1964) as a reef facies of the Mariana Limestone. These Merizo outcrops are described in detail in a later section of the report. The distribution of the various rock units are mapped in Figure 8.

Reef facies outcrops of Mariana Limestone are found on the high plateauland and upper parts of the peripheral plateau cliffs and scarps, and as elongate outcrops and patches on successive terrace levels of the lower coastal region. Detrital facies outcrops of Mariana Limestone are exposed at lower elevations along the peripheral plateau cliffs and scarps and on the lower coastal region, principally on slopes and scarps between reef facies deposits on elongate terrace surfaces.

Although no detailed descriptions of the Mariana Limestone facies were made, a number of reconnaissance traverses were run across the low coastal region from the shoreline to about 30 meters elevation between Achae Point and Pajon Point. Observations along these traverses indicate that the bulk of the deposits are a detrital facies with some of the more flattened terrace surfaces veneered over by an undetermined thickness of reef-facies deposits. Although Tracey et al. (1964) did not map the detrital deposits lying outside the peripheral plateau reef facies at Ritidian Point as a forereef facies, because of the lack of seaward-dipping bedding planes, the deposits are quite analogous to present-day forereef detrital material accumulating on shallow to moderately deep terraces immediately seaward of the present fringing reef platforms within the study area. Towed snorkel and face mask observations over these present-day submarine terraces revealed rapid lateral changes in terrace deposit texture and composition and at may places, particularly on shallower terraces, local mounds and pinnacles of framework reef accretion occurred here and there. A similar number of detrital subfacies could be recognized on the now emergent coastal terraces, often changing quite abruptly from one to another. Local regions of framework reef deposits, dominated by _in situ_ coral colonies, also occurred sporadically within the detrital outcrops. Subfacies recognized within the detrital outcrops included: 1) a compact detrital coral subfacies containing abundant coral fragments and whole colonies, some worn and rounded, but others showing little to no worn surfaces, in a well-lithified sand- to gravel-sized matrix, 2) an undifferentiated subfacies composed predominantly of sand-sized sediments containing abundant small fossils, but with no recognizable group predominating (similar to the present sand-sized submarine terrace deposits accumulating immediately offshore of Ritidian Channel, (see Fig. 9), and 3) a detrital _Halimeda_ subfacies dominated by whole segments or molds of segments of _Halimeda_. Reef facies encountered along the coastal terrace traverses were more homogenous in composition than the detrital facies, but some differences were noted, primarily in the algal-coral ratio from one part of the larger outcrops to another. An _in situ_ framework assemblage of mostly large coral heads cemented with abundant laminated crusts of crustose red algae, located in a low Mariana Limestone scarp near Transect H-E3, typifies a reef facies with a high algal-coral ratio. Here a cluster of flabellately-branched _Pavona duerdeni_ colonies, up to 153x140 cm in outcrop dimensions, intermixed with other corals has intercoral areas of the framework mostly occupied by laminated crustose red algae crusts and minor amounts of detrital material. At other localities framework assemblages of *in situ* corals are less abundantly cemented by crustose red algae, typifying reef facies with a low algal-coral ratio. Where the algal-coral ratio is low more of the intercoral framework matrix areas are infilled with fine to coarse sand-sized sediments. Several reef facies outcrops located about midway between Ritidian Point and Pajon Point (Fig. 8) on coastal terraces ranging in elevation from 10 to 15 meters have *in situ* corals and other reef-building fossils that are in a remarkably well-preserved state. A collection of corals revealed that alteration of original skeletal material to calcite had occurred, but with considerable less loss of skeletal fabrics than similar fossils in adjacent detrital facies outcrops. These reef facies patches resemble some of the Tanapag Limestone outcrops at similar elevations on Saipan, which Cloud *et al*. (1958) assigns to younger Pleistocene deposits.

The distribution and composition of unconsolidated terrace and beach deposits (Qrb), as well as the general physiographic features of the overall coastal terrace region, are discussed in a previous part of this section (pp. 5 to 8).

Structural Geology

Although Tracey *et al*. (1964) did not map any major faults or fault zones within the study area, they did indicate a number of prominent joints within the peripheral plateau escarpment and coastal terrace deposits (Fig. 8). One set of these joints at Ritidian Point has a strike of 7° west of north and are in the general plane of alignment of what we think is a small fault at Ritidian Channel (Fig. 8). The second area of jointing planes occurs near Mt. Machanao and constitute two sets which strike about 65° west of south and 80° west of south in a general plane of alignment toward Achae Point. A third area of complex jointing planes is mapped in the peripheral plateau and coastal terrace deposits at Pajon Point. At Pajon Point a number of these prominent joints extends to the shoreline. A prominent offset with as much as 50 cm of relief cuts diagonally across the reef platform just southwest of Transect W-2 (Fig. 9). The strike of the offset is about 6° west of north, which is about the same direction as the Ritidian Channel jointing planes.

The fault at Ritidian Channel appears to be a hinge fault with downward displacement occurring on the east Ritidian reef platform. Movement along the fault most likely occurred before the deposition of Holocene limestone since elevation of nearby shoreline deposits at Transect H-E2 is about the same as those at Pajon Point and along the Tarague embayment farther to the southeast. For further evidence of fault displacement see the section on "Geologic History".

EMERGENT HOLOCENE TERRACE DEPOSITS

Distribution and General Setting

Emergent Holocene limestone deposits outcrop at the shoreline from Pajon Point in a northwestward direction for 1.1

km and intermittently from Achae Point in a northeasterly direction for 600 meters as shown in Figure 2. Representative outcrops of these deposits are shown in vertical profiles in Figures 3 and 4, with H-W1 through H-W4 showing sections northeast from Achae Point and H-E1 through H-E4 showing sections northwest from Pajon Point. The remaining shoreline of the study area is occupied by modern beach deposits and beachrock outcrops (Fig. 2). If emergent Holocene deposits are present elsewhere they must be buried beneath these beach deposits or adjacent unconsolidated storm terrace deposits. No soil or test boring records of excavations made for a cable run between the U.S. Naval Facility buildings and the shoreline could be found to see if buried Holocene reef deposits were present or not. Also no Holocene reef deposits were encountered in the archaeological test pit holes, or where present construction activities had removed some unconsolidated storm terrace deposits around the north side of the Facility. Such diggings and construction activities could have missed buried outcrops or might not have been dug deep enough to encounter them, since the storm terrace elevation above MLLW rises from +4.6 to +5.5 meters where it abuts against Mariana Limestone outcrop to +6.1 to +6.7 meters at the crest adjacent to the present day beach deposits. Another possible explanation for the absence of emergent Holocene outcrops southeastward from Ritidian Point is that suggested hinge faulting at Ritidian Channel has dropped the deposits downward and they do not become emergent again until about 1.3 km further to the southeast at Transect H-E2. The general absence of supratidal Holocene pinnacles and ridges, so common on the reef platforms of the Tarague embayment (Randall and Siegrist, 1988), also supports the possibility that hinge faulting has occurred between Ritidian Channel and Pajon Point. Absence of emergent Holocene reef deposits on the reef platform immediately southwest from Ritidian Point is more puzzling because the general elevation of the West Ritidian reef flat platform is higher than that of the East Ritidian reef flat platform and one might expect to find some supratidal remnants. Also the emergent Holocene reef deposits that are present near Achae Point are for the most part a detrital facies. Massive algal ridge deposits so pervasive along the shoreline at Pajon Point were not observed. Possibly the Holocene reef deposits prior to general island-wide emergence about 3000 years B.P. were patchy in distribution and at some places were absent, or if present had not yet grown upward to sea level equilibrium.

The emergent Holocene reef deposits described in this study are assigned to the Merizo Limestone formation on the basis of similar paleontologic and lithologic characteristics, state of alteration from aragonite to calcite, radiometric dates for what is though to be a correlative facies described and dated by Randall and Siegrist (1988) within the nearby Tarague embayment area along the northern coast of Guam, and elevation of the deposits in respect to present sea level. Merizo Limestone was named from extensive outcrops along the southwest coast by Tayama

(1952), redescribed and dated at 3400 years B.P. primarily from the same outcrops by Tracey et al. (1964), and redated at 2975 to 5115 years B.P. and further traced around much of the island by Easton et al. (1978). Curray et al. (1970) also dated a Merizo Limestone outcrop at Toguan Bay at 2800 years B.P. during the CARMARSEL expedition. More recently at a Merizo Limestone outcrop at Ylig Point the community structure of reef-building corals was described by Randall et al. (1984), the functional morphological group variation within the coral community was described by Siegrist et al. (1984), and the petrography of the outcrop analyzed by Siegrist et al. (1984). Similar studies describing the community structure of reef-building corals and petrography of extensive Merizo Limestone outcrops at Aga Bay were conducted by Siegrist and Randall (1985), and the outcrop as well as the adjacent modern reef platform were dated at elevations ranging from +1.8 meters to -4.64 meters with ages ranging from 260 to 4130 years B.P. by the Japanese HIPAC teams (Sugimura, 1986; and Yonekura, 1988). The Japanese HIPAC team also dated other Merizo Limestone outcrops on Guam with dates ranging from 2350 to 4050 years B.P. (Sugimura, 1984 and 1986, and Yonekura, 1988). Randall and Siegrist (1988) interpreted the geomorphic history of the emergent Merizo Limestone deposits within the Tarague embayment along the northern coast of Guam and reported dates ranging from 3900 to 4880 years B.P. from elevations ranging from 0.0 to more than +4.0 meters. In the same study a date of 810 years B.P. was recorded from an algal sample collected on the backcrest slope of an adjacent modern algal ridge facies.

Decription and Community Structure of Corals Along Selected Outcrops

Outcrops Along the West Ritidian Platform

Transect H-W1 is located at Achae Point where a prominent headland of limestone forms a cliff at the shoreline (Figs. 2 and 3). At the north side of the headland a double concave notch is cut into a vertical cliff face. The base or floor of the lowermost notch is approximately +2.0 meters in elevation with the deepest cut portion located at about +2.5 to +2.7 meters elevation. The notch floor is somewhat flattened and at the seaward edge slopes abruptly downward to a seaward sloping lower terrace that is veneered along the inner part by a layer of coarse bioclastic beach deposits. The seaward edge of this lower terrace consists of a zone of supratidal, worn and rounded pinnacles and knobs of limestone. Sampling of the cliff face, uppermost notch, and lower terrace revealed a composition of dense, hard, recrystallized reef limestone of the Mariana Limestone Formation, but the floor and concave part of the lower notch were veneered over in places with unaltered coral colonies. An encrusting colony of Heliopora coerulea, 154 cm in longest outcrop dimension and 15 or more centimeters thick, still with a blue-grey coloration, occupies most of the notch floor and an encrusting colony of Porites sp., with an outcrop dimension of 42 x 32 cm, occupies the concave part of the lowermost notch. No other unaltered corals were observed. These veneering corals indicate that the Holocene sea once stood at least +2.0 meters above the present MLLW level at Achae Point. Obviously the lowermost notch had been cut before the corals grew there, possibly during a higher than present Pleistocene stand, but the notch could also have been cut during the early part of the Holocene high stand and then later veneered with corals just before emergence.

Transect H-W2 is located about 100 meters northeast of Achae Point in the middle of long, lenticular, mostly intertidal Holocene outcrop that is 83 meters long and about 2 meters across at the widest section (Figs. 2 and 3). Beach deposits occur on the landward side of outcrop and at the seaward margin it grades into the inner reef flat moat zone. The outcrop consists mostly of coral rubble in a grainstone matrix which is partly overlain at places along the seaward margin by a rubbly beachrock layer. Many cobbles are abraided and not in position growth. In situ corals, especially Acropora spp., cemented with laminated calcareous red algae form scattered patches here and there along the upper outcrop margin and some cobbles of the main lenticular body are thinly encrusted with laminated red calcareous algae as well, otherwise the outcrop resembles an exposed section of beachrock. Five species of corals distributed among four genera were identified from cobbles and in situ patches (Table 1). One in situ flabellately branched colony of Heliopora coerulea had an outcrop dimension of 70 x 64 cm. All the corals appeared to be relatively unaltered aragonite and the *Heliopora* specimen still retained a blue-grey color on fractured faces. This composite outcrop, composed mainly of a cobbly detrital facies with scattered patches of *in situ* reef framework deposits, is quite similar to a larger shoreline outcrop at Transect H-W4. The deposit at Transect H-W4 is longer, wider, and thicker and has a much greater proportion of *in situ* framework deposits. The outcrop at Transect H-W2 is most likely a discontinuous lower section of the outcrop located at Transect H-W4. The reef framework facies at Transect H-W2, along with the contained coral species, and the presence of a mud-free grainstone matrix indicates an environment with good water circulation and currents, possibly on a subtidal reef flat platform.

Emergent Holocene deposits at Transect H-W3 consist of an elongate series of three discontinuous sections of a detrital limestone that begins at the northeast end of the outcrop at Transect H-W2 and continues in the same direction for 127 meters more (Figs. 2 and 3). Unlike the outcrops at Transects H-W2 and H-W4, these deposits are separated from the low tide shoreline by 13.5 meters of bioclastic beach deposits. Similar beach deposits occur on the landward side of the outcrop as well. Transect H-W3 is located on the middle section of the series where the outcrop has a maximum width of 4.6 meters. Relief of the outcrop section above the enclosing beach deposits at the transect location is 105 cm and the maximum elevation of the section is about +2.5 meters above MLLW level. The transect location is fairly representative of the entire outcrop series and for the most part contains abundant worn, rounded to subrounded pieces of gravel- to boulder-sized pieces and whole colonies of corals, and a few clasts of large molluscs (Tridacna and Turbo spp.) in a coarse grainstone matrix. The matrix is well lithified and is dominated by abundant flattened Halimeda segments intermixed with solitary foraminifers, red colored colonial foraminifers, fragments of crustose and articulated calcareous red algae, and whole and fragmented pieces of molluscs. Both coral cobbles and matrix are relatively unaltered aragonite with Helipora clasts retaining a blue-grey coloration. Nine species of corals representing eight genera were identified from the outcrop (Table 1). Without dates this detrital outcrop is difficult to place in the chronology of Holocene events. Lack of in situ reef framework deposits indicate a backreef environment, but where water circulation was strong enough for the relatively mud-free matrix to accumulate. Similar cobble and boulder fields which trap abundant mud-free sediments are accumulating at a number of locations on reef platforms around the island today. The detrital deposits could have accumulated on a shallow platform during the Holocene high stillstand and then were subsequently buried by storm deposits and lithified after the sea level dropped to the present level.

About 50 meters beyond the northeastern end of the detrital series of outcrops at Transect H-W3, another emergent Holocene deposit outcrops at the shoreline. This outcrop is 237 meters long (265 meters if small intermittent patches at both ends are included) and has a maximum width of about 5.5 meters near the middle part where representative Transect H-W4 is located (Figs. 2 and 3). Bioclastic beach deposits border the outcrop on the landward margin and at the seaward margin it grades onto the adjacent reef flat platform. The seaward third of the elongate outcrop is intertidal and at the landward margin has a maximum elevation of about +0.5 to +0.6 meters above MLLW level. In regard to lithologic and compositional characteristics the outcrop is very similar to that described at Transect H-W2. A principal difference, other than larger dimensions, is found in a much greater abundance of reef framework deposits, composed of numerous _in situ_ corals and laminated calcareous red algae, that forms an almost unbroken veneer along the higher outcrop elevations at Transect H-W4. Twenty-three species of corals, representing 15 genera, were identified along the outcrop (Table 1). One _in situ_ flabellate colony of _Heliopora coerulea_ had an outcrop dimension of 252 x 204 cm. Other coral colonies in excess of 100 cm outcrop dimensions includes: low convex masses of _Acropora monticulosa_, arborescent clusters of _Acropora irregularis_, and irregular lumpy masses of _Favia stelligera_, _Leptoria phrygia_, and _Goniastrea retiformis_. The outcrop most likely represents a discontinuous section of the outcrop located at Transect H-W2 and probably formed under the same environmental conditions.

Outcrops Along the East Ritidian Platform

Transect H-E1 is located about 400 meters southeast of Ritidian Channel and represents a typical section of a narrow band of seaward dipping imbricate beachrock about 1 km long that is exposed along the shoreline between Ritidian Point and the emergent Holocene reef deposits near Pajon Point (Figs. 2 and 4). At the transect location the beachrock is about 5.5 meters wide, and in profile section forms two irregular low ridges, one intertidal and one supratidal in elevation. These two ridges consist of separate imbricate layers with the contact where the lowermost layer is overlaped by the uppermost layer forming a valley-like depression. Maximum elevation of the exposure is at most places less than one meter above MLLW level. On the seaward side the beachrock is bordered by the troughlike sandy moat zone of the inner reef flat platform where longshore currents are strong. Bioclastic beach deposits occupies an extensive region between the beachrock deposit and strand vegetation at most locations. The surface of the beachrock is solution-sculptured into numerous pinnacles and rimmed basins, particularly on the supratidal portion. At scattered locations layers of rock have been quarried out by the hydraulic plucking action of large storm waves. Several freshly quarried areas were observed that were most likely plucked out by large waves from "Typhoon Roy" in January 1988. The beachrock is composed mostly of bioclastic sand-sized grains of solitary foraminifers and other undifferentiated material intermixed with gravel- and cobble-sized clasts of corals, Halimeda segments, red colored colonial foraminifers, fragments of whole mollusc shells (including vermetid tubes), fragments of crustose red calcareous algae, stems of articulated red calcareous algae, and echinoid spines. Composition of the beachrock is very similar to that of the present surface beach deposits found immediately behind the outcrop, except that the present beach deposits appears, at least on the surface, to contain less cobble-sized clasts. Six species of corals representing six genera were identified from coral clasts embedded within the beachrock matrix at the transect location (Table 1). Although this exposure of beachrock was formed in a subsurface intertidal beach environment, it must have been exposed to subaerial weathering for some time to have acquired the solution sculptured topography now present on the surface.

Transect H-E2 is located where the first occurrence of emergent Holocene reef outcrop occurs southeast of Ritidian Point (Figs. 2 and 4). Here the outcrop forms a low lobate-shaped ridge that is flanked on both sides by bioclastic beach deposits. On the eastern side of the ridge (transect location) a reentry zone provided a good cross section of the outcrop. Sampling along the transect revealed two distinct facies consisting of an outer massive concave type algal ridge facies dominated by crustose red calcareous algae that extends from the shoreline to the crest of the outcrop (0-15 meters), and a backreef platform facies (15-20 meters) that at most places was veneered over by bioclastic storm deposits and tangled strand vegetation. A small outcrop protruding through the storm deposits revealed some clasts of Goniastrea retiforms in a detrital matrix. This was the only coral species observed in backreef moat zone along the immediate transect line (Table 1). A sand-scoured section at the seaward end of the transect revealed some in situ corals (Acropora spp.). Transect samples collected at 2 meter intervals across the algal ridge facies, and three additional samples collected at 5 meter intervals along the axis of the crest (normal to the transect line) were all boundstones dominated by laminated, massive, or tabulate masses of crustose calcareous red algae. Vesicular, red-colored, colonial foraminferal masses were nonuniformily interspersed throughout the crustose algal masses, being particularly abundant between the thin laminate and thicker massive crusts and less abundant between tabular masses. Permeating throughout this algal-foram framework is a network of vermetid mollusc tubes about a millimeter in diameter. Some tubes are empty, while others are filled with what appears to be a lithified, very fine-grained mud (micrite). Some tubes possess two septa-like laminations that extend outward from opposite sides of the tube wall, sometimes meeting and dividing it into two parts. Bioclastic detrital grains, consisting of worn and fragmented solitary foraminifers, worn red colored colonial foraminiferal clasts, coral fragments, small whole and fragmented mollusc shells, fragments of articulated calcareous red algae, and much undifferentiated fine- to coarse-sized sand material, fills what was presumably voids in the constructional algal-foram-mollusc-tube framework. The massive, concave type algal ridge deposits at this transect indicates a high energy environment. The nearly complete absence of corals in the algal ridge facies indicates deposition at an intertidal-supratidal level along the seaward margin of a narrow reef flat platform, or shallow bench, where wave run-up was considerable. A modern analogue of such an algal ridge buildup is found along the seaward reef platform margin between Ritidian Channel and Pajon Point (see section on "Assessment of the Fringing Reefs" for a description). Although maximum elevation of the algal ridge facies at Transect H-E2 is about +3.0 to +3.5 meters above present MLLW level, sea level at that time was most likely about three-fourths of a meter lower. Maximum elevation of the modern massive, convex type algal ridge just southeast of Ritidian Channel is nearly +1.0 meter above MLLW level, which means that about three-fourths of a meter of the buildup is intertidal and one-fourth meter of it is supratidal. Although not much of the backreef platform facies was exposed, the presence of a few corals and general elevation indicate a shallow region with some water retained during MLLW level.

Transect H-E3 is located at the fifth rocky outcrop southeast of Ritidian Point where emergent Holocene reef deposits are in exposed basal contact with Mariana Limestone deposits (Figs. 2 and 4). The outcrop is flanked on both sides by bioclastic beach deposits that have accumulated in small coastal reentry areas. On the north side of the outcrop erosion along the reentry zone has exposed a vertical section showing the Holocene-Pleistocene, Mariana Limestone contact. Sampling along the transect revealed two distinct facies, an outer massive concave type algal ridge facies and an inner backreef platform facies, similar to those described at Transect H-E2. Principal differences between the two transects include the following:

1) the presence of some honeycombed coral-algal framework deposits between MLLW and +1.0 meter elevations at the seaward end of Transect H-E3 (between 0 and 2 meters), which indicates deposition within a shallow subtidal to low intertidal environment at a more seaward position of the algal ridge than that exposed at H-E2,

2) the presence of more scattered _in situ_ corals on the algal ridge crest, especially _Goniastrea retiformis_ and _Montastrea curta_, indicating an environment where a few corals could flourish, possibly in a small rimmed terraced pools on the backcrest slope (similar habitats are found on the modern algal ridge zone on the adjacent reef platform margin between Ritidian Point and Pajon Point), and

3) the presence of a wider backreef platform facies at Transect H-E3 (between 19.6 and 40.2 meters) that abuts against a prominent notch, 1.7 meter high and 47 cm deep, cut into a low scarp of Mariana Limestone.

Although the backreef platform was partially swept free of overlying storm deposits and strand vegetation by "Typhoon Roy", we were not able to quantitatively analyze the community structure of corals along the transect. Evenso, sediment free areas scattered about revealed the presence of eight species of corals representing seven genera (Table 1) that were attached as single colonies, or as small clusters of colonies, directly upon a surface of truncated Mariana Limestone. Apparently the backreef platform coral community consisted of a few scattered patches growing in a shallow moat behind an elevated algal ridge that had developed on the seaward edge of narrow limestone bench (Fig. 4). Near a scarp behind the algal ridge crest several exposures of detrital limestone resembling beachrock were also exposed. In a section exposed along the reentry area the algal ridge facies is developed directly upon the margin and outer slope of the Mariana Limestone bench (Fig. 4). Here an entire crest to contact vertical section of the algal ridge facies is exposed. The vertical section is composed entirely of the algal-mollusc-foram framework described at Transect H-E2, except where a rubbly layer fills a few pocket-like depressions along the contact. Overall nine species of corals representing seven genera were identified along the transect. Predominant corals included Pocillopora setchelli in the lowermost section of the algal ridge forecrest slope, Goniastrea retiformis and Montastrea curta on the algal ridge crest, and eight species (including colonies of G. retiformis and M. curta) in the backreef platform facies (Table 1).

Transect H-E4 is located near the northern end of a 650 meter-long coastal terrace of emergent Holocene reef deposits at Pajon Point (Figs. 2 and 4). Along this stretch of coast the terrace is mostly less than 50 meters wide, and at the shoreline forms a vertical scarp and isolated pinnacles 2.0 to 3.5 meters above MLLW level. The seaward margin is irregularly cut with reentry channels and at places prominent notches are cut between

MLLW and the +1.0 meter level. Where salt spray is considerable the surface is barren of vegetation, but at most places a prostrate growth of Pemphis acidula forms a zone up to 10 meters wide along the shoreline. Further inland the outcrop supports a more mixed type of strand vegetation which is quite tangled and difficult to walk through. At places the inner half of the terrace is veneered with bioclastic storm deposits. Storm waves from "Typhoon Roy" fortuitously stripped most the strand vegetation and storm deposits from the terrace surface at the transect location, which made it possible to conduct a quantitative analysis of the outcrop surface deposits (Table 2). Sampling along the transect revealed two distinct facies as was similarly found at Transects H-E2 and H-E3. At some locations, though, the backreef platform facies is absent and the algal ridge facies abuts directly against Mariana Limestone outcrops. The seaward algal ridge facies is divided into a forecrest slope subfacies (between 0-14.8 meters) that dips downward toward the ocean and a backcrest slope (between 14.8-22.0) meters that dips downward toward the island. Maximum elevation at the algal ridge crest is between +4.0 and +4.5 meters above MLLW level. The relatively flat backreef platform facies (between 22.0-46.4 meters) is about 1.0 to 1.5 meters lower in elevation than the algal ridge crest, and is physiographically delimited from the backcrest slope by a small scarp about one meter high. On the landward side the backreef platform is in onlap contact with a steep slope of Mariana Limestone. In regard to surface composition (Table 2) the algal ridge facies is dominated by laminate crusts of calcareous red algae. In the forecrest slope subfacies 90.9% of the surface substrate was occupied by algal crusts and the remaining 9.1% of the surface was occupied by reef-building corals. In the backcrest slope subfacies coverage by algal crusts was slightly lower at 87.0% and coverage by reef-building corals was slightly higher at 13.0%. On the backreef platform facies the percentage of outcrop surface occupied by various groups was 37.1% for reef-building corals, 4.1% for calcareous red algal crusts, 17.7% for detrital matrix, and 41.1% for Pleistocene limestone inliers (Table 2). Detrital matrix material was mostly confined to pockets or depressions on the platform and to a lesser degree as infilling between coral colonies or branches of colonies. The detrital matrix material was mostly composed of Halimeda segments and undifferentiated, bioclastic, sand-sized grains. A dense, recrystallized, Halimeda-rich, detrital limestone also made up about a third of the Pleistocene limestone outcrops as well. Thirty-one species of reef-building corals representing 16 genera were encountered along the transect line and within the general area of the transect (Table 1).

ASSESSMENT OF THE FRINGING REEF PLATFORMS

General Setting

Fringing reefs border the entire coastal region between Achae Point and Pajon Point. These fringing reefs are directly exposed to the prevailing Northeast Trades and throughout the year receive greater wave assault than at any other location around the island (Fig. 9). The reefs also lack surface drainage from the land since porous limestone terraces and plateauland border the entire coastal region. Although lacking surface drainage, some nutrient enrichment in the form of nitrates and phosphates are introduced into the system by ground water discharge at the shoreline from the Guyben-Herzberg lens system. Morphologically these fringing reefs consist of a relatively flat, shallow, platform-like surface which extends outward from the shoreline and an outer forereef slope that dips downward to the dwindle point of vigorous reef framework development at about 100 meters depth. Direct observation of shallower parts and fathometer profiles of deeper parts (fathometer profiles nos. 14 and 15 of Emery, 1962) show that the general downward dip of the forereef slope to 100 meters depth is interrupted by flattened regions (submarine terraces) at a number of levels. Some of these submarine terraces have significant amounts of bioclastic sediment accumulation on their surfaces, while others are mostly free of sediments or patchily veneered here and there by a thin layer. Most conspicuous of the shallower sediment-veneered terraces is found immediately offshore in the vicinity of Ritidian Channel (Fig. 9). Dredge hauls in the vicinity of Ritidian Point indicate that below 100 meters depth the forereef slope is a zone where sediments, consisting mostly of bioclastic reef detritus that has been transported downslope from shallower zones of more active reef growth, accumulates. Although some steeper regions of the deep forereef slope may be free of such sediment accumulation, it is mostly a zone of forereef detrital accumulation that extends downward for hundreds of fathoms.

Reef Flat Platform Current Patterns

Although no quantitative current assessment was made on the reef flat platforms, some obvious current patterns were noted during the study (Fig. 9). Reef flat currents are primarily generated by wave transport of water onto the shallow platforms and to a minor degree by water flowing onto and off the platforms during flooding and ebbing tides respectively. These most northerly situated fringing reefs receive almost constant wave and swell assault generated by the Northwest Trades. Calms are relatively rare, occurring most commonly during the wet season months when tradewind speeds are somewhat reduced and wind direction more variable. East Ritidian reef flat platform receives the most direct and greatest wave and swell assault, but evenso, waves and swells are refracted around Ritidian Point which produces considerable wave assault on the West Ritidian reef flat platform as well (Fig. 9). During high sets of waves and swells water is transported across the reef margin and algal ridge onto the inner reef flat platform which is somewhat lower in elevation than the reef margin. Such wave transport causes a hydrostatic head of water to build up in the somewhat channelized reef platform region between the shoreline and elevated reef margin zone. Longshore currents are then generated when this hydrostatic head of water flows from regions of higher reef flat elevations to regions of lower elevation. During a particularly windy day on February 23, 1988, at Transect HE-4, a set of high waves temporarily raised the inner reef flat platform water level 79 cm at the shoreline.

On the East Ritidian platform the wave-driven longshore current flows in a northwestern direction from a high reef flat elevation at Pajon Point toward a lower reef flat elevation at Ritidian Channel where the water exits the platform to the open ocean. On the West Ritidian platform the wave-driven longshore current flows in a northeast direction from the high side of a reef flat offset (small fault) near Transect W-2 toward a lower reef flat elevation at Ritidian Channel where the water exits the platform to the open ocean. Some water also leaves the West Ritidian platform as a seaward-flowing rip current through a prominent reentry channel that penetrates into the reef flat zone at the fault offset near Transect W-2. South of the reef flat offset near Transect W-2 the wind-driven longshore current flows in a southwest direction toward Achae Point where it exits the platform to the open ocean through a depressed region along the reef margin zone. Figure 9 shows the generalized wave-driven longshore current patterns observed on the reef platforms during our field study period.

Longshore currents were strongest near the shoreline and attenuate toward the outer reef platform. At the reef margin water motion tends to be strongly oscillatory in a pattern normal to the reef axis -- surging in a landward direction through surge channels and over the reef margin and algal ridge as each wave crest advances, then reversing itself and surging in a seaward direction, mainly through surge channels, as each wave trough advances. Net water movement, though, is toward the reef flat platform depression where the current direction becomes parallel to the shoreline. During flood tides, when wave assault was high, it was difficult to maintain one's footing when walking in the main axis of the longshore current near the shore. When a particularly high set of waves raises the hydraulic head of water on the reef platform to a level 50 or more centimeters higher than the open ocean, it is dangerous to be near large open or cavernous surge channels at the reef margin because of strong seaward-flowing currents that are temporarily generated as the water rapidly flows off the platform when wave assault abates somewhat. During periods of high wave assault it was also common to see translatory waves (waves with highly elliptical movement), with a trough to crest height of 50 or more centimeters, travel from the reef margin to the shoreline and break on sandy beaches. Where rocky scarps form the shoreline such waves are reflected back toward the reef margin, producing a local region with complex water motion and currents. During periods of calm or low wave assault the longshore currents diminish considerably or are absent. When periods of calm or low wave assault are coupled with low spring tides the reef platform region between the shoreline and elevated reef margin zone becomes a moat of impounded water with little to no water movement. Significant parts of the West Ritidian reef flat platform become exposed during low spring tides.

Reef Flat Platform Sediments

Sediment distribution on the reef flat platforms within the study area is for the most part a patchy veneer, or absent, particularly on the outer part where high wave assault and strong surging currents are prevalent. Sediment accumulation appears to be in somewhat of a state of equilibrium on the platform as a whole. Significant amounts of sediment are being produced and much fluxes across the platform surface, but at any one time the total amount present remains about the same. The only significant amount of sediment accumulation observed was at places in the moat-like trough along the shoreline (Fig. 7) where water depth is greater and longshore currents strongest. Arborsecent Acropora thickets on the East Ritidian platform act as a baffle and trap some sediment, and rhizoids and roots of the angiosperm, Halodule uninervis, also binds and stabilizes some sediment on the inner reef flat and moat zones. Luxuriant algal growth of genera such as: Microdictyon, Avrainvillea, Udotea, and Halimeda, particularly on the East Ritidian platform, trap and hold a veneer of sediment at localized areas. Shorter algal turf (< 2.0 cm high) also traps fine sediment, and along with the more extant types are habitats of abundant solitary formainifers. A 100 cm^2 sample of short algal turf from the West Ritidian platform yielded an estimated 7000 specimens of Baculogypsina madgurensis that had a dry weight of 92 grams. If the turnover rate of these foraminifers is about one year, a square meter of such turf would produce 9.2 kg of sand-sized sediment annually. Minor amounts of sediment also veneers the floors of some platform holes, troughs, surge channels, and depressions.

Sediments on the fringing reef platforms arise from diverse origins, some directly from free living and attached benthic organisms which liberate whole and fragmented skeletal material upon death, some from biogenic and physical degradation of reef framework and detrital deposits, and some is transported onto the platform from other reef zones by currents and storm waves. Identifiable free-living and attached sediment-producing organisms identified in the bioclastic fractions of reef platform and intertidal beach sediment samples include: 1) broken and whole tests of free-living foraminifers, 2) abraided gravel-sized nodules of red colored colonial foraminifers, 3) whole and broken Halimeda segments, 4) flakes of Udotea thalli, 5) submillimeter diameter stems of articulated calcareous red algae, mainly of the genera Amphiroa and Jania, 6) various sized masses of fused stems and plates of nonarticulated calcareous red algae, mainly of the genera Porolithon and Neogoniolithon, 7) whole and broken shells of many species of molluscs, 8) finger-sized sticks and a wide range of worn gravel- to boulder-sized pieces of reef-building corals, 9) sclerites and spicules from soft corals, holothurians, and sponges, and 10) assorted skeletal parts from echinoderms and arthropods.

Most important of the physical factors that produce sediment on the reef platform is the action of currents and waves, particularly those generated by storms and typhoons, which break off pieces of reef framework and fragments as well as entire skeletons of various reef-building organisms. Loose material is further comminuted into smaller-sized sediments by impact and abrasion when currents and waves actively transport sediments across the reef platform surface. Various-sized pieces of reef rock are broken loose by hydraulic plucking action when large storm waves forces water into cracks and cavities within the reef framework. After "Typhoon Roy" the presence of hydraulically plucked sections of reef rock were especially evident on crustose algal-veneered surfaces of the reef margin and on rocky intertidal shorelines.

Biogenic erosion is also an active agent of sediment production by the boring, scraping, rasping, biting, and carbonate dissolving activities of numerous organisms. Freshly fractured surfaces of nearly any piece of loose gravel- to boulder-sized detrital material, reef rock, crustose algae, and dead or living coral colonies revealed the presence of extensive galleries of boring sponges as well as the more symmetrical cavities of boring sipunculans, molluscs, arthropods, and other reef rock in fauna. Fish, molluscs, and arthropods actively bite, scrape, and rasp the surface of corals and crustose red algae. Much of the reef rock surface, particularly in the intertidal and supratidal zones, is bored and penetrated by endiolithic algae giving it a grey color where supratidal and a darker grey to greenish black color on intertidal surfaces. Numerous intertidal organisms, mainly mollusc and arthropods, graze and rasp this submillimeter algal-penetrated layer. Scrape marks from these grazers, which penetrate through the algal layer into fresh reef rock, are abundant on both the intertidal and supratidal limestone surfaces, as well as their lime-rich fecal pellets which collect in depressions and flat-floored solution pools. Bioerosion also weakens skeletons of attached reef-building organisms and the integrity of reef rock surfaces, making them more vulnerable to physical breakage and erosion by currents and wave action. Comminution of loose sediments into finer material is also enhanced when the clasts are bioeroded.

Texturally the reef platform sediment ranges from large block- and boulder-sized material torn loose from the platform itself and adjacent reef front slope by storm waves to fine lime mud produced by the disintegration of reef deposits by boring sponges. Textural size at any location depends to a large extent upon the abundance and preference of sediment-producing organisms for certain habitats and by transporting and sorting of available material by currents and wave action.

Although considerable sediment is produced on the reef platform, prevailing strong currents and reoccurring storm waves keep much of the surface swept free and prevent large amounts from accumulating. Most of the coastal beach and storm terrace deposits were derived from the adjacent reef platforms or were transported across them. The presence of a large sand-floored terrace immediately seaward of Ritidian Channel (Fig. 9) indicates that large amounts of sediment are being transported from the reef platforms. Strong longshore currents generated along the shoreward margins of both the East and pat of the West Ritidian platforms funnel large amounts of sediment into Ritidian Channel. Swimming observations in these longshore current tracts showed sediment being transported by suspension, saltation, and traction. Observations farther seaward on the reef platforms also showed similar sediment transport toward the shoreline, primarily by translatory wave action. During periods of heavy surf suspended sediment and organic algal detritus reduced visibility in the water column at times to less that two meters on the East Ritidian platform. Submarine terraces below six meters in depth bordering the West Ritidian fringing reef platform are also veneered at places with abundant sand-sized sediments. The presence of abundant reef-flat-dwelling foraminifers in these terrace sediments indicate that a considerable fraction is being derived from the adjacent shallower platforms.

Physiographic Setting

Principal physiographic zonation patterns encountered on the fringing reef platforms between Achae Point and Pajon Point include a relatively wide reefflat platform along the inner part and a relatively narrow wave-washed reef margin along the seaward edge. This stretch of fringing reef platform is conspicuously interrupted by several deep channels at Ritidian Point. These channels, collectively called Ritidian Channel, extend inward nearly to the shoreline, thus bisecting the fringing reef platform into an eastern and western part (Figs. 2 and 10a). Superficially these two reef platforms appear to be quite similar, but upon closer inspection are very different in physiographic structure, geomorphic development, and in the community structure of associated reef organisms. Seaward reef slopes associated with the two reef platforms are also quite distinct from each other in most aspects as well.

East Ritidian Fringing Reef Platform

The East Ritidian fringing reef platform between Pajon Point and Ritidian Channel is about 2.5 km long and ranges in width from 130 meters at Transect E-1 to 210 meters at Transect E-4 (Figs. 5, 7, and 10a-d). The reef platform can be divided into two distinct physiographic zones consisting of a wide reef flat that roughly occupies the inner two-thirds to three-fourths of the platform and a reef margin with a well developed elevated algal ridge that roughly occupies one-third to one-fourth of the platform. In respect to the algal ridge the reef flat is somewhat of a depressed zone with water depth ranging from 1.0 to 1.5 meters during high tides and from 0.3 to 0.8 meters during low tides. In local holes, troughs, and depressions, though, water depth may be 1 to 2 meters deeper than on the general reef flat surface. In contrast, the reef margin algal ridge is up to a meter higher than the general reef flat surface. During low tides much of the algal ridge crest is exposed, but when normal NE Tradewind-generated seas and swells are present it remains wave-washed and a good flow of water is maintained on the reef flat (see previous section on "Reef Flat Platform Currents"). During low spring tides water depths on the reef platform are considerably shallower and the algal ridge crest is even more exposed. When low seas and swells, or periods of calm, accompany low spring tides, water may fail to wash over the algal ridge crest and an impounded moat of water with reduced circulation is formed on the reef flat. During such low tide conditions many corals become partially exposed, particularly the upper branch tips of arborescent Acropora species. The upward limit of coral growth is more or less limited by mean low tide water depth, giving these arborsecent Acropora thickets a clipped or truncated appearance and promoting the formation of flat-topped and microatoll shapes in other colonies.

Based upon physiographic features, such as sediment accumulation, water depth, currents and wave action, and topographic relief the East Ritidian reef flat can be divided into three subzones at most localities. Distinct distribution patterns of corals and other reef organisms can also be associated with the various physiographic subzones as well. In a seaward direction from the shore these subzones consist of: 1) a narrow troughlike depression with few corals and some accumulation of sediments along the shoreline called the sand-floored moat, 2) a relatively wide inner reef flat platform characterized by irregular topographic relief and patchy sediment distribution which at many places is dominated by arborescent Acropora species, and 3) an outer reef flat platform of intermediate width occupied by a more mixed coral community growing on an irregular reef rock pavement that is mostly swept free of sediments. Although these three subzones can be recognized on the East Ritidian reef flat platform at most locations, there are local regions where the divisions are less distinct, particularly near Ritidian Channel. Vertical profiles representative of Transects E-1 through E-3 in Figure 6 show water depth, generalized topographic relief, and physiographic zonation patterns. General distribution patterns of major reef-building corals and regions of principal topographic relief (regions of prominent reef rock outcrops and major holes, troughs, and depressions) are mapped for the East Ritidian reef platform between Ritidian Channel and Transect E-4 in Figures 10a through 10d.

In cross section the sand-floored moat is a trough-shaped depression along the shoreline which is slightly deeper than the adjacent inner reef flat platform. It appears to be partly an erosional feature formed by the scouring action of sediments transported by strong longshore currents, and partly to some extent by solution of reef rock by water escaping along the shoreline from the freshwater lens system. During normal NE Tradewinds considerable sand-sized sediments accumulate in the trough, and at places become stabilized by rhizoids and root of

Haladule uninervis. During storms currents are considerably stronger in the moat and much of the accumulated sand is transported toward Ritidian Channel. During typhoons some regions of the moat may be swept free of sediments, even areas stabilized by marine grasses. It is mostly likely during these storm events that bedrock scouring of the moat floor takes place.

Topographic relief on the inner reef flat platform is quite irregular, consisting mostly of both living and dead coral colonies and scattered holes, depressions, and outcrops of reef rock that form small offsets and scarps. Arborescent Acropora aspera forms flat-topped thickets of closely packed branches, 20 to 40 cm high, and up to 10 or more meters across. The tops of these thickets, killed by repeated low tide exposure, sometimes become fused together by crustose algal growth which at places forms a framework strong enough to walk upon, but at other places collapses, making walking on the platform difficult. Small clusters and isolated colonies of stoutly-branched Acropora palifera impart up to 50 cm of positive relief where they occur. Massive coral colonies, as well as some compact branching forms, are limited in upward growth to about mean low tide level. Further growth in these colonies progresses in a horizontal (centrifugal) direction which produces flat-topped or mesitalike forms. Continued low tide exposure generally kills the upper flattened colony surfaces, leaving only a peripheral margin alive. Microatoll-shaped colonies are formed when erosion excavates the central dead region of the upper colony surface, leaving a higher peripheral margin which impounds water during low-spring tides. Extensive regions of reef rock pavement may be formed by the coalescent growth of adjacent flat-topped and microatoll-shaped colonies. The flattened tops of coral colonies on reef platforms are good indicators of the low tide water level. Scattered flat-floored holes, bowl- and trough-shaped depressions, and channels provide up to a meter or more of negative relief on the inner reef flat at places. Many of these shallower depressions are formed where pockets of coral growth are absent, particularly within or between, arborescent Acropora thickets, and where coalescent growth of adjacent massive colonies is incomplete. Channelways, holes, and troughs between adjacent coral thickets are generally veneered with sand- to cobble-sized sediments. Sometimes storm waves will pluck out areas of arborescent Acropora thickets, leaving conspicuous depressions. Deep holes and channels are less common on the inner reef flat platform, but where they are found they are generally aligned normal to the reef margin and most likely represent remnant surge channels with open pools along their length that have been incompletely infilled by sediments or coral-algal growth as the reef margin prograded in a seaward direction. Outcrops of reef rock forming small offsets and scarps are also conspicuous forms of topographic relief on the inner reef flat platform, particularly where it grades into the sand-floored moat (see Figs. 10a-10d). Along the moat the offsets may represent erosional remnants as the trough was eroded and deepened by sediment transport or solution. At other places the offset and scarp patterns resemble erosional remnants of dead, massive flat-topped or microatoll-shaped colonies. Some of the more irregular-shaped outcrops may represent erosional remnants of reef rock deposited during a higher than present Holocene sea level stand, particularly toward Pajon Point where such supratidal remnants are common along the shoreline.

In respect to the inner reef flat the outer reef flat is generally a narrower, shallower subzone which has more reef rock pavement exposure with less sediment accumulation. Open and cavernous surge channels commonly extend well into the outer part of the subzone from the adjacent reef margin. Surging currents are stronger on the outer part of the platform, and during the dry season NE Tradewind-generated surf commonly extends well into the subzone. The boundary between the inner and outer reef flat subzones is quite distinct where Acropora thickets occur on the former, but where such thickets are absent differences between the subzones are less distinct. In addition to physiographic differences noted between the inner and outer reef flat subzones above, a significant distinction is the present of a more diverse coral community on the outer reef flat that includes a considerable number of reef front slope species. An elevated algal ridge dominated by crustose red algae rather sharply delimits the seaward boundary of the outer reef flat platform.

Between Ritidian Point and Pajon Point a relatively wide, well-developed, elevated algal ridge forms a prominent, asymmetrical, convex crest along the seaward margin of the fringing reef platform (Figs. 2, 6 and 7). The overall reef margin, defined as a high wave-energy or wave-washed zone at the outer edge of a shallow reef platform (a platform at sea level equilibrium in regard to further upward growth) includes not only the algal ridge, if developed, but other shallow subtidal-intertidal regions and deeper surge channels and open pools that may penetrate into the platform as well. In simplest terms an algal ridge facies or subzone is a localized intertidal to possibly slightly supratidal constructional carbonate buildup, composed mostly of crustose forms of calcareous red algae, that is generally located on the seaward margin of a shallow platform where intense wave energy dissipation occurs throughout the year. Because of relatively low tolerance to emersion coral growth is more or less limited to about mean low tide level, and hence can not build up such an elevated edifice at the seaward edge of a shallow platform. Crustose forms of calcareous red algae active in algal ridge development, though, are relatively more tolerant to emersion, and thus can develop upward and construct such an edifice at shallow platform margins to an elevation that will be rather constantly washed over by wave action during low spring tides throughout the year. Algal ridge crest height can thus be quite variable, depending upon the magnitude of wave assault, but the factor that determine whether or not an algal ridge will develop at all at a particular location depends upon the rather year-long constancy of the wave assault. Eventhough wave assault may be quite high during most of the year, just a few days of calm when run up may be reduced or absent will limit upward ridge growth or prevent one from developing at all.

In vertical section, normal to the algal ridge crest axis, the overall reef margin forms a cuestal-shaped profile which can be divided into a relatively short seaward-dipping forecrest slope subzone and a wider shoreward-dipping backcrest slope subzone, similar to the zonation patterns discriminated along the Holocene outcrops at Transect H-E2 through H-E4 (Fig. 4). From a physiographic perspective the reef margin consists of a fairly regular system of parallel buttress ridges and surge channels aligned normal to the reef margin axis. At the seaward margin the system of ridges and channels becomes subtidal and is for the most part contiguous with the upper reef front slope channel and buttress system. At about 6 to 10 meters depth the reef front channel and buttress system grades into a submarine terrace zone and becomes less discernable on an irregular hummocky terrain, and at some places disappears altogether on a pavement-like surface.

Buttress ridges on the outer part of the forecrest slope are relatively narrow, lobate in outline with a low convex or rounded upper surface, and separated by relatively wide open surge channels. In cross section these surge channels a roughly U- or V-shaped, but more often are modified to some degree by erosion and undercutting along the lower walls and floor, and by growth along their upper wall margins in the form of projecting shelves.

Surge channel floor erosion and lower wall undercutting are achieved primarily by abrasion as sand- to boulder-sized sediments are moved along the channel floor by strong surging currents and storm waves. During normal wave assault the smaller grain-sized sediment fraction is moved along the surge channel floor by traction, saltation, and temporary suspension. Larger gravel- to boulder-sized pieces are generally stable until storm events occur. Larger stable-sized boulders and blocks will commonly become encrusted by calcareous algae, corals, and other reef organisms between storms. Observations in high-energy reef zones after such storms reveals freshly scoured surfaces on cobbles, boulders, and blocks as well as the lower surge channel walls and floors. Surge channels can be thus be eroded to the depth that waves, particularly those generated by storms, can actively transport and move sediment about along their floors. It is fairly common to find extensions of reef margin surge channels out onto adjacent shallow submarine terraces that are cut several meters deeper than the general terrace floor level. Such channels commonly terminate at pot holes containing large rounded boulders. Initial algal ridge development begins, and is most active, on the outer part of the forecrest slope where reef margin elevation is only slightly intertidal. Vigorous wave run-up there promotes rapid growth of a coral-algal framework on the upper surfaces of buttress ridges and along the upper margins of surge channel walls forming projecting shelves or ledges. As upward growth of forecrest slope surfaces proceeds, algal growth is favored over coral growth because of more intertidal exposure. Upward growth of predominantly red calcareous algae continues to crest height where low tide exposure inhibits further development. Growth of cushion-shaped masses and laminate crusts of crustose red algae as well as scattered branching and encrusting corals gives the forecrest slope a very irregular topographic surface. Interconnecting cavities, as a result of irregular surface growth, permeate the framework giving it a porous honeycombed structure through which water can freely flow with each wave surge. This labyrinthiform network of cavites provides numerous microhabitats of reduced light, but with good water exchange where secondary framework builders, such as, encrusting colonial foraminifers, bryozoans, tube-forming worms, vermetid molluscs, and barnacles tend to infill framework cavities. Bioerosion of the framework also concurrently takes place by boring sponges, arthropods, molluscs, and echinoderms which tend to increase cavity space and voids within the framework. Many other organisms live within the framework galleries as well. In the crest region projecting shelves or ledges from opposite sides of upper surge channel walls commonly grow toward each other and fuse, forming cavernous channels below. Only some of the wider forecrest surge channels penetrate into the backcrest slope region. Where active reef front buttress development is occurring, as is the case along the East Ritidian fringing reef system, the coral-algal framework region at the leading edge of the forecrest slope is shifted seaward.

The older crest region as well as the backcrest slope receive less wave run-up, resulting in a buildup of the crest at a more seaward position where wave action is more constant. Height along the crest axis is quite variable, being highest where buttress ridges occur and lowest or absent where cavernous and open surge channels extend into the backcrest slope.

In respect to forecrest slope physiography the backcrest slope is generally wider and forms a more gentle-dipping convex surface that has been modified by erosion and some growth. Most of the time breaking waves and swells keep backcrest slope surfaces well inundated or wave washed, providing an environment favorable for some further framework accretion, but during low spring tides when wave and swell height are reduced the backcrest slope is wave-washed less frequently than the forecrest slope. When occasional clams occur, especially during periods of midday insolation, the backcrest slope may remain exposed for periods long enough to kill previously accreted crustose algae. Because of these periodic exposures it is doubtful that there is any net framework accretion on backcrest slopes that could significantly build the surface upward. As on the forecrest slope, the framework of the backcrest slope is permeated by a system of interconnected cavities and galleries where some framework accretion as well as bioerosion is occurring, a continuing process which started in the forecrest region by a similar assemblage of organisms. Such intraframework accretion tends to infill cavities and galleries producing a more solidly constructed framework. Infilling of cavities and galleries appears to be more advanced along buttress ridges in a gradient from the algal ridge crest axis toward the reef flat platform, and least advanced along surge channel axes. At many locations the inner one-third of the backcrest slope appears to be solid reef pavement. Some of the more prominent (higher and wider) buttress ridges also appear to be solid reef rock nearly to the crest axis. Additional infilling of cavities and galleries occurs by accumulation of detrital material as well. Similar detrital infilling was also observed in the Holocene algal ridge deposits exposed at Transect H-E2 through H-E4. Other backcrest regions of framework accretion include the walls of surge channels, primarily by laminated crusts of calcareous red algae and a few corals that tolerate habitats of reduced light intensity. A coral-algal assemblage also builds up the margins of open surge channels and pools where roof-collapse of cavernous surge channels has occurred. Surge channels that are incompletely fused or roofed over along their length and the margins of blowholes commonly have vertical lip-shaped buildups of calcareous red algae along their fusion zones and around their margins respectively. At those locations wave surge maintains an outpouring of water at higher elevations than the general backcrest slope surface, demonstrating how vertical buildups are related to how high a surface can be consistently washed over. Much of the backcrest slope is modified by differential erosion from one part to another. Backcrest buttress ridge slopes, particularly those in which the framework deposits are relatively solid instead of honeycombed, commonly have a descending series of small rimmed terraced pools developed from near the crest to where the slope grades into the adjacent reef flat platform. Similar pools are commonly developed on the seaward margin of supratidal bench platforms along the eastern coast of Guam. Apparently biogenic erosion, solution, or a combination of both excavate the rimmed terrace pool floors. During low tides the pools are filled by wave surge which causes water to flow over the pool rims like miniature spillways. These spillways areas promote the growth of abundant fleshy algae, articulated red calcareous algae such as Jania and Amphiroa, thin warty-looking crusts of crustose calcareous red algae, abundant vermetid molluscs, and various other boring organisms. Some of the rim flora and fauna tend to build up the deposit by skeletal accumulation while others tend to destroy and remove the carbonate deposits. Sampling of numerous pool rims show that in situ coral colonies and crustose algal deposits are being eroded away. Commonly the upper 1 to 5 cm of the terraced rims will also be bored to such an extent that the deposits are reduced to a porous reticulum that can be crumbled with finger pressure. Rimmed terraced pools seldom exceed several meters in longest dimension and range in depth from just a few centimeters in smaller pools to 50 or more centimeters in larger ones. Some of the larger and deeper pools that retain water during low spring tides sometimes contain a surprising number of corals.

Where the backcrest slope merges with the reef flat platform there is commonly a zone of solution-pitted pinnacles, resembling a low karrenfeld topography, where the algal ridge deposits are undergoing pronounced erosion. Width of the zone is very irregular and patchy in distribution, some places absent, and yet at other locations may extend into the reef flat platform up to 10 or more meters. Most often the pinnacles are associated with regions of higher elevation along the backcrest slope. At first these pinnacles were thought to be remnant patches of emergent Holocene limestone which occurs as ridges and isolated patches on reef platforms along the nearby Tarague embayment. A radiometric age of 810 years B.P. obtained by Randall and Siegrist (1988) from a similar pinnacle sampled from the backcrest slope of an algal ridge system on the Jinapsin fringing reef platform near Pajon Point, indicates a more modern age. Six samples from emergent limestone ridges and patches on the reef platform along the Tarague embayment had ages ranging from 3900 to 4880 years B.P. (Randall and Siegrist, 1988). These dates indicate a Holocene age within the range of many other dated samples from low emergent limestone deposits formed along the shorelines and on reef platforms around the island (see section on "Emergent Holocene Terrace Deposits" for references). The pinnacled zone receives less wave wash than any other part of the algal ridge system, and during low tides is proportionally exposed to the effects of subaerial solution for a greater length of time. Samples collected from pinnacles ere dominated by crustose red algae permeated more or less throughout the framework by minor amounts of vermetid mollusc tubes and colonial foraminifers, occasional corals, and some pockets of detrital infill, identical to the composition of samples collected on more seaward parts of the backcrest slope. The solution-pitted pinnacles more distant location from the wave washed algal ridge margin, similarity in composition and other lithologic characteristics to adjacent backcrest slope deposits, and modern age all indicate a region that represents a foundered trailing edge of an active seaward-prograding algal ridge system. This foundered trailing edge, no longer in a forward position to remain wave washed during low spring tides, is slowly undergoing subaerial erosion and being truncated to mean low tide level. If the dated pinnacle sample, collected 50 meters behind the present algal ridge margin on the Jinapsin reef platform, was originally accreted in the forecrest slope 810 years B.P., the rate of algal ridge progradation must be in the range of about 6 cm/year. Examination of the outer reef flat platform reveals a pavement of reef rock which has been eroded to about mean low tide level, except for remnant solution-pitted pinnacles here and there which gives it a very irregular topography. The pavement surface has scattered in situ corals in a matrix of crustose red algae that have been truncated to reef flat level. These observation indicate that the outer reef flat platform is a subzone where former algal ridge deposits have been truncated down to about mean low tide level. If we use the above algal ridge seaward progradation rate of about 6 cm/yr, and the average width of the outer reef flat pavement at about 120 meters, then it must have taken about 2000 years for the pavement to form. If we add the 810 years for an average algal ridge width of 50 meters to the time it took the outer reef flat pavement to form, then it must have taken about 2810 years for the algal ridge to prograde to its present location. If the outer reef flat pavement and algal ridge zones represent a modern fringe of reef platform accreted since a relative drop in sea level about 3000 years B.P. then an estimate of about 2800 years for the two zones to accreted based upon progradation rates is in fairly good agreement.

In summary the algal ridge development along the East Ritidian reef platform is a dynamic intertidal zone of active framework accretion and biogenic and physical erosion located at the seaward margin of shallow platform where wave assault is maintained more or less continuously over time. Nearly constant wave wash at the seaward margin provides an environment where framework accretion exceeds erosion and a seaward-dipping slope (forecrest slope) is constructed both in a seaward direction over reef front deposits and upward to a crest height where accretion and erosion are in dynamic equilibrium. Behind the crest a shoreward-dipping slope (backcrest slope), located in an environment where wave-wash is less constant, undergoes differential erosion in a gradient from near equilibrium conditions of accretion and erosion near the crest to a zone of rapid erosion at the trailing edge where deposits are disappearing. The height, width, and physiographic form of the algal ridge depends upon the rate at which it progrades in a seaward direction, and the magnitude and integration of wave wash across its surface. In a geological sense, any one part of an actively prograding algal ridge system is somewhat evanescent, it rapidly forms and them just as rapidly vanishes. If seaward progradation of an algal ridge is slow, because of a relative steep reef front slope, or stationary, if the reef front is a vertical wall, the overall system will more or less be maintained in a state of static equilibrium. Such algal ridge systems are generally narrower with steeper forecrest and backcrest slopes because equilibrium conditions of growth and erosion are being maintained over the entire surface, and they are generally more solidly constructed with a more smooth surface topography because infilling processes can have time to close up voids and cavities. Emery _et_ _al_. (1954) called these more solidly constructed algal ridge systems a concave type, and those similar to what is presently developed along with East Ritidian reef platform a convex type. An algal ridge, defined as an intertidal carbonate buildup of mainly crustose red algae, is seldom preserved in the geologic record. What is most often referred to as an algal ridge facies is the upper reef front slope deposits where a coral-algal framework is developed. Algal ridge facies survive in the geologic record most often when there is a rapid rise in sea level and the zone becomes buried by subtidal reef, and or, detrital deposits. Algal ridge facies survive for relatively short periods of time when area sea level rapidly drops and the system is subaerially exposed, such as the Holocene algal ridge deposits described at Transect H-E2 through H-E4 at Pajon Point, but unless buried by deposits rather quickly the facies will disappear without a trace, mainly by subaerial solution and biogenic erosion.

West Ritidian Fringing Reef Platform

The West Ritidian reef platform is about 1.6 km long and ranges in width from 230 meters near Ritidian Channel at the north end to 120 meters at Achae Point at the south end (Figs. 5 and 6). The reef platform can be divided into two distinct physiographic zones consisting of a wide reef flat that occupies the inner three-fourths to four-fifths of the platform and a reef margin dominated by a intertidal-supratidal, pseudoalgal ridge that occupies the outer one-fourth to one-fifth of the platform. The pseudoalgal ridge superficially has the appearance of a massive concave type of algal ridge system, but was actually found to be a Pleistocene solution rampart thinly veneered by crustose red algae. Water depth on the reef ranges from 0.5 to 1.2 meters during high tides and from local areas that are emergent to 0.7 meters during low tides. In local holes, depressions, and along a local platform offset near Transect W-2 the water may be up to a meter deeper than the general reef flat surface level. On the outer platform margin the Pleistocene rampart stands from 1.0 to 1.8 meters above the adjacent reef flat surface, and as a result is significantly exposed during low tides. Under normal NE Tradewind conditions the Pleistocene rampart remains periodically wave washed during low tides. Water transported over the rampart generates a surge of water which translates shoreward and periodically inundates emergent parts of the reef flat platform during low tides as well. During low spring tides water depths are considerably shallower and the Pleistocene rampart and reef flat platform are even more exposed. When low spring tides coincide with reduced seas and swells, or periods of calm, water may fail to wash over the Pleistocene rampart and emergent reef flat platform areas. During such low tide conditions water that is retained in depressions and holes on the reef flat become cut off from open ocean circulation, and if the low tides coincide with midday insolation the trapped water may be elevated to sublethal or lethal temperatures for many reef organisms. Where corals occur the upper parts or branch tips are commonly exposed during low spring tides, promoting the formation of flat-topped colonies similar to those described on the East Ritidian platform.

Based upon physiographic features such as sediment accumulation, water depth, currents and wave action, nature of the substrate, and topographic relief the West Ritidian reef flat can be divided into three to four subzones. Distinctive corals and other reef organisms can also be associated with the various subzones as well. In a seaward direction from the shore the subzones discriminated include: 1) a narrow troughlike depression with few corals and some sediment accumulation along the shoreline called the sand-floored moat (absent at Transect W-2), 2) a relatively wide inner reef flat characterized by subtidal areas of irregular topographic relief with scattered sediment-floored pockets and depressions that contain a few widely scattered coral colonies as well as sizeable intertidal areas of reef rock pavement, 3) a middle reef flat (developed only at Transect w-2) characterized by mostly intertidal reef rock pavement with some scattered corals in pockets and holes that retain water during low spring tides, and 4) an outer reef flat characterized by subtidal areas of irregular reef rock pavement that contain few to many corals and intertidal reef rock pavement areas lacking corals. Vertical profiles representative of Transects W-1 through W-3 in Figure 6 show water depth, generalized topographic relief, and physiographic zonation patterns.

Physiographic aspects of the sand-floored moat is very similar to those described for the same subzone developed along the East Ritidian reef flat platform shoreline, except that here there is less sediment accumulation on the trough floor and the marine angiosperm, Halodule uninervis, is much less abundant. At places the sand-floored moat is not very distinctively developed and at Transect W-2 is not distinguishable from the adjacent subtidal inner reef flat platform zone.

The inner reef flat is a relatively wide subzone which ranges in width from 45 meters at Transect W-2 to 80 meters at Transect W-1 (Figs. 5 and 6). At places the topographic relief is somewhat irregular with scattered subtidal depressed areas partially infilled with dead and living coral colonies (Transects W-1 and W-2). At other locations the topography is rather flat, such as that at Transect W-3 where intertidal reef rock pavement dommates the zone. Corals are more or less restricted to larger depressed regions where water is retained during low spring tides. Intertidal pavement areas are generally covered with a short algal turf which traps some sand-sized sediment and has abundant solitary foraminiferans living among the algal filaments.

The middle reef flat subzone at Transect W-2 is a region of mostly intertidal reef rock pavement with a few shallow holes and depressions situated between a deeper platform area toward the shoreline and a coral-rich basin-like depression on the seaward side. The boundary between the intertidal pavement of the middle reef flat and the deeper basin-like outer reef flat is a low scarp 20 to 40 cm high (Fig. 9).

The outer reef flat platform is a moat like depression of variable width that lies immediately behind the reef margin rampart (Fig. 6). At most places the subzone retains water during low spring tides and is well flushed with water as long as wave transport is maintained across the reef margin rampart. Where abundant coral growth is present, such as at Transect W-2, the topography is very irregular, and where corals are less abundant a smoother reef rock pavement prevails.

The most distinctive physiographic zone of the West Ritidian reef platform is the presence of the Pleistocene solution rampart that occupies the seaward margin of the reef platform. This rampart, which rises from 1.0 to 1.8 meters above the adjacent reef platform, was at first thought to be a modern massive algal ridge constructed primarily by laminated crusts of crustose red algae, similar to the cuestal type of algal ridge buildup described by Emery et al. (1954) from Bikini Atoll in the Marshall Islands. Such cuestal algal ridge systems are characterized as being relatively narrow and constructed rather solidly, without a system of interconnected holes and cavities as is common in the structure of the lower convex systems found along the East Ritidian platform. The unusual height of the rampart ridge, which attenuates from a maximum elevation of 1.8 meters above the adjacent reef platform near Ritidian Channel to about 1.0 meter above reef platform near Achae Point, was through to be attributable to the rather constant wave assault from swells and sea waves that are refracted around Ritidian Point as shown in Figure 9. These refracted wave are highest immediately southwest of Ritidian Channel and diminish in height toward Achae Point, which would account for a similar ridge height attenuation in that direction as well. Reef physiography immediately seaward of the reef margin rampart consists of a very steep to vertical scarp that drops downward about 4 to 6 meters to a submarine terrace. Because of this reef front scarp, the supposed algal ridge could not prograde in a seaward direction and thus it was thought to represent a static cuestal type of algal buildup which was in equilibrium with refracted swell and wave heights that could be maintained rather constantly throughout the year. Such a static algal ridge would account for its rather narrow width, since it was not prograding forward and leaving a trailing backcrest slope zone behind to be slowly removed by erosion, and it would also account for the rather solid nature of the deposit because interconnected voids and cavities, if originally present, would have had ample time to become infilled by secondary accretion.

During June of 1989, a series of low spring tides, coupled with near calm sea conditions, allowed a team to collect samples on the rampart and make detailed observations along its entire length between Ritidian Channel and Uruno Point. Twenty-six rampart samples were collected from the crest as well as from various elevation on the backcrest and forecrest slopes between Ritidian Channel and Uruno Point for comparison with similar samples collected from both the emergent Holocene and modern algal ridge deposits along the East Ritidian platform. Somewhat to our surprise all 26 samples were found to be composed of a recrystallized limestone reef facies with abundant in situ corals and crustose red algae at some locations and a detrital facies with abundant coral fragments and cobbles at other locations. Apparently the West Ritidian reef platform is a Pleistocene terrace with a remnant solution rampart forming a prominent ridge along this seaward margin and a wide moat-like depression that extends inland to the shore. This moat-like region possibly underlies all or part of the adjacent coastal terrace composed of unconsolidated storm deposits as well. During the maximum Holocene transgression, about 5000 years B.P., the Pleistocene terrace was flooded, or at least partly flooded, and an unknown thickness of reef and detrital deposits were veneered over its surface. Evidence of these Holocene deposits are found along the present shoreline near Achae Point at Transects H-W1 through H-W4 (see section on "Emergent Holocene Terrace Deposits").

The solution rampart forms a prominent asymmetrical ridge that ranges from 20 meters in width and up to 1.8 meters in height near Ritidian Channel to 5 meters in width and up to 1.0 meter in height at Achae Point (Figs. 6 and 7). In vertical section, normal to the ridge crest axis, the solution rampart can be divided into a relatively short, steep, seaward-dipping forecrest slope and a somewhat wider, less steep, shoreward-dipping backcrest slope, similar to physiographic zonation patterns discriminated at Holocene outcrops along Transects H-E2 through H-E4 and across the modern algal ridge buildup along the East Ritidian reef platform (Figs. 4, 6, and 7). At somewhat irregular intervals of about 10 to 20 meters the rampart crest is interrupted by relatively wide saddle-shaped openings which reduces the ridge to a series of elongate asymmetrical hummocks. Such saddle-shaped openings differ from surge channel development, where active framework accretion is taking place, in that they are up to 10 or more meters wide, do not extend downward below the general reef flat platform level, and are not generally contiguous with channel development on the adjacent submarine terrace platform. Occasionally a short , narrow, somewhat deeper channel will be cut in the low point of a rampart saddle, but even here the openings appear to be formed mostly by erosion along solution joints and fissures inherited from the Pleistocene terrace when it was flooded. In the vicinity of Transect W-2, where a small scarp forms an offset on the reef platform (Figs. 5 and 9), a large reentry channel about 10 meters wide and 4 to 7 meters deep cuts entirely through the solution rampart and into the reef flat platform. Whenever water is being actively transported over the rampart a strong seaward-flowing rip current is generated in this reentry zone appears to be related structurally to a small fault scarp that was present before the Holocene transgression and has since been enlarge by erosion. The reentry channel floor is scored into prominent elongate ridges and trough and has abundant large rounded boulders and blocks scattered along its length. This wide reentry channel and a few of the smaller fissure-like chutes are the only channels we observed that cut completely through the reef margin and continued outward onto the adjacent submarine terrace. About 200 meters south of Ritidian Channel the solution rampart hummocks are conspicuously absent where a broad crescent-shaped reentry zone (convex side facing toward the shore) about 100 meters wide interrupts the reef margin. The shape and absence of hummocks along this reentry zone suggests that a large slump occurred along the terrace scarp which removed a section of the solution rampart before the onset of the Holocene transgression.

The forecrest slope of the solution rampart is relatively short, usually occupying about a third or less of the overall ridge width, and generally steeper than a corresponding section of the backcrest slope. Commonly the forecrest slope is concave, forming bowl- or cirque-shaped depressions, particularly where the zone is steep and narrow. Although the slope has a pavement-like appearance and is relatively smooth, it actually has many small irregularities which provides up to 3 centimeters or more of relief and numerous small holes scattered over the surface. Porolithon onkodes, an encrusting crustose red algae, dominates the forecrest slope surface and imparts an overall pinkish-red color to the surface. This surface layer of red algae is deceiving in that it gives the impression that the rampart must be composed of numerous calcareous layers which have built the ridge upward to its present intertidal-supratidal position in response to the height that consistent wave runup could be maintained by refracted sea waves and swells around Ritidian Point (Fig. 9). In sampled rock sections, though, this red algal surface was revealed to be only a few millimeters thick at most places, and was directly encrusted upon an intensely bio-eroded zone of recrystallized Pleistocene limestone up to 3 cm thick. Organisms responsible for removing much of the limestone in the bioeroded layer include: 1) alpheid shrimp which live in, and presumably excavate irregular-shaped galleries as well as symmetrical cavities up to 10 centimeters wide and 2 centimeters high, 2) sipunculid worms which rasp a network of round tunnels up to 5 millimeters in diameter, some of which extend deeper into the limestone than the bioeroded layers, 3) clionid sponges which etch out an extensive network of galleries, 4) boring barnacles and other arthropods which excavate a variety of shapes of cavities, and 5) limpets and other molluscs which excavate or dissolve holes and depressions into the limestone surface. The most conspicuous of the biocroders are the alpheid snapping shrimps which excavate the largest cavities, but most likely boring sponges and sipunculids actually remove a greater volume of limestone. The location of underlying alpheid galleries are easily recognized because each communicates with the surface through a cluster of rather uniformly spaced funnel-shaped roof perforations. The perforations range in diameter from 3 to 5 mm at the surface and narrow to about 2 to 3 mm in the gallery roof. Similar galleries excavated by the apheid shrimp, <u>Alpheus idiocheles</u>, on wave-washed erosional bench platforms from Guam were described by Kropp, 1987. Density of perforations within a cluster was found to be about 5.1 cm^2, and at places on the wave-washed forecrest rampart slopes such clusters of holes occupied about 30% of the substrate. Funnel-shaped upper parts of the perforations as well as the surface area between them are occupied by encrusting red algae. Areas between roof perforations within the galleries are generally occupied by encrusting colonial foraminiforans, mostly red colored forms of Minacina. Very small calcareous worm tubes (< 0.1 mm dia.) and a few scattered Minacina colonies occupy other surface areas within galleries as well. Elongate scrape marks were present on crustose algal areas around the perforation apertures, particularly in the funnel-shaped regions, indicating that the openings were actively being maintained. Galleries that were examined generally contained a pair of shrimp. Each shrimp has a thin elongate leg with a modified claw-like chela which is presumably used in maintaining the gallery roof perforation. Examination of gallery roofs revealed a laminated structure which was thickened mostly by encrusting foraminiferal growth from below and also by a zone of encrusting algal growth upon the surface. Roof perforations in galleries that did not contain shrimp were generally in some stage of being infilled by foram-algal growth. Possibly when the gallery roof reaches a certain thickness the holes can not be maintained by the shrimp and become overgrown. Some of these abandoned galleries were also partially to completely infilled with fine-grained sediment. Occasionally galleries were also found in which the roof of some galleries appeared to have been physically removed, possibly by hydraulic plucking or impact during storms. Shrimp galleries were also observed in reduced densities on the backcrest rampart slope and on algal encrusted pavement surfaces on the algal ridge along the East Ritidian reef platform. On actively growing algal ridge facies the galleries tend to become buried by successive algal laminations, whereas on erosional or static habitats the cavities remain a surface feature which is formed at about the same rate they are removed by erosion. Samples of crustose algae collected from the massive Holocene algal ridge facies of Transects H-E2 through H-E4 also revealed the presence of abundant laminations of crustose algae and red colored foraminiferans, as well as cavities infilled with detrital materials, suggesting that shrimp galleries were present then as well.

The backcrest slope generally occupies about two-thirds of the overall solution rampart width at any given location, and as a result dips downward less steeply than the forecrest slope. At some places slopes are slightly convex while at other locations they are concave. Where the slope grades into the adjacent reef flat platform it is commonly eroded into a narrow zone of low solution sculptured knobs and pinnacles. One of the larger knobs that was sampled near Transect W-2 was 38 cm high and 33 cm wide at the base. A large in situ colony of Acropora humilis occupied the basal part of the knob. Where large hummocks occur the slope commonly has a descending series of low concentric ridges developed upon the surface, forming miniature rimmed terraced pools. These ridges are generally less than 10 cm high and vary greatly in composition and origin. Some have formed as a result of differential erosion of the rampart itself and are very solid except for a bioeroded surface rind. Differential erosion apparently results from abundant vermetid mollusc tubes and crusts of crustose red algae that veneers the ridge tops. Other ridges form as a result of local regions of carbonate buildups composed of a combination of vermetid mollusc tubes ranging from 1 to 10 mm in diameter and crustose red algae. At some locations these mollusc-algal ridge buildups are relatively solid, whereas at other places they are so bioeroded that they can be crushed with finger pressure. Integrity of these badly bioeroded ridges is principally maintained by sponge infilling in cavities and a dense surface mat of fleshy and articulated calcareous algae species. Between wave sets during low spring tides these ridges temporarily impound small pools of water which cascades from one ridge level to another. The algal mats and rock cavities host a large number of invertebrate species. Fifteen years ago the first author sampled material from ramparts along the West Ritidian reef platform, but because of rather hazardous surf conditions small limestone pieces were chiseled off with a geology hammer at several localities between wave sets. To sample pavement sections of the dense recrystallized limestone regions of the rampart one needs to use heavy chisels and a sledge hammer. Unfortunately both of the earlier collected samples were composed of the mollusc-algal ridge material which resembled the composition of an active algal ridge facies at other locations around the island. Based upon these inadequate samples, the rampart was incorrectly classified as a classic example of a massive static type of algal ridge buildup.

Occasionally potholes up to a meter in diameter and depth, sometimes containing large rounded boulders, were found on backcrest slopes. Potholes with boulders had rather smooth scoured surfaces and lacked coral growth on their walls, whereas those holes lacking boulders commonly had a few corals growing on transport boulders into the holes from the adjacent submarine terrace, and at the same time empties some holes of boulders when they become reduced in diameter by abrasion. Boulder transport from the adjacent submarine terrace apparently is relatively uncommon because after "Typhoon Roy" only two fresh boulder-sized pieces were found along a stretch of beach deposits between Ritidian Point and Achae Point. One of these pieces was a microatoll of living Porite lutea that was apparently plucked off the reef flat platform, and the other was a rounded boulder located opposite from the large reentry channel near Transect W-2, from where it presumably originated. Beach deposits along this entire coastal section are mostly sand-sized and are relatively free of boulders and cobbles, eventhough many large trees along the strand were uprooted from the recent typhoon. At one of the higher hummocks a hole about two meters long and a meter wide was eroded into the mid-rampart slope. In this particular hole five species of corals, which included three species of Acropora, were actively infilling parts of the depression. The presence of corals vigorously growing in such a small intertidal-supratidal pool attests to the fact that water in the pool is more or less constantly replenished by wave run-up, even during low spring tides.

One of the most conspicuous differences between the forecrest and backcrest slopes is the presence of abundant fleshy and articulated calcareous red algae species and less encrusting crustose red algae on the latter. Large areas of the lower parts of backcrest slopes were covered with 10 to 25 cm long thalli of Thurbinaria ornata. Sargassum cristaefolium, thickets of several species of Caluerpa, Mastophora clumps, and tough short mats of Gelidiella accerosa also were locally abundant. Articulated calcareous red algae consisting mainly of Jania spp. growing epiphitically on larger fleshy algal thalli and Amphiroa spp. growing as thick mats on reef rock surfaces or intermingled among other fleshy algae were also abundant.

In addition to organisms which primarily remove limestone material there are others associated with the solution rampart which accrete carbonate material to the surface. Such accreting organisms include: 1) crustose calcareous red algae consisting primarily of Porolithon onkodes, which form thin crust a few millimeters thick, 2) colonial foraminifera which form encrusting holes, and small overhangs, 3) vermetid mollusc tubes ranging from 1 to 10 millimeters in diameter which occur in dense clusters, especially on backcrest ridges, or as isolated individuals on both forecrest and backcrest slopes, and 4) calcareous worm tubes and encrusting bryozoans which contribute minor amounts of carbonate in cavities and holes. Although surface coverage of encrusting calcareous algae is relatively high, especially on the forecrest slope, and some accretion is occurring as well from other organisms, the dominant resultant process on the solution rampart is erosion. The only location where carbonate accretion appeared to building up over a few millimeters thick was on the backcrest slope where concentric rimmed pool ridges were developed, but even here significant areas of the ridges were extremely bioeroded and the overall resultant process is again that of erosion. Based upon rock samples and direct observations the pseudoalgal ridge is a solution rampart that developed subaerially along the scarp margin of a Pleistocene terrace and was then flooded during the last transgression. At present time the solution rampart is undergoing differential erosion, mainly by differences in biogenic erosion rates between the forecrest and backcrest facies as well as along its length. Although all the accreting organisms as well as the bioeroders can tolerate some intertidal-supratidal exposure, the latter group can withstand such effects for longer periods of time. Many of the biocroders (boring sponges and molluscs, arthropods, and sipunculans) reside within the rock itself and thus are not directly exposed to direct sunlight and desication. Bioeroders such as limpets and chitons are also well adapted to intertidal-supratidal spray habitats. Encrusting crustose red algae and vermetid molluscs are the principal accreting organisms on the rampart ridge. Red algae accretes directly upon the exposed surfaces and is partially killed during summer months when low spring tides coincide with times of calms and exposure to direct sunlight. During June 1989, a series of low spring tides exposed the rampart ridge for significant periods of time. Many of the rock samples that were collected from the rampart after this period of exposure hand significant areas of encrusting red algae on their surface that had been recently killed (white chalky appearance), particularly on samples from more elevated ridge areas and backcrest slopes which receive the least amount of wave run-up. Accreting organisms such as colonial foraminifers, calcareous tube-forming worms, and bryozoans require cryptic habitats which are mainly provided by cavities and holes excavated by bioeroders. Some vermetid molluscs were also killed by low tide exposure, particularly at higher ridge elevations on backcrest slopes. Survival of vermetid molluscs seemed to be enhanced where they were associated with dense mats of fleshy and articulated calcareous red algae. Such habitats tend to retain water somewhat like a sponge during periods of exposure which keeps associated organisms moist. Largest vermetid molluscs were generally found associated with dense fleshy algal mats located on concentric backcrest rimmed terrace ridges and on the floors of their associated terraced pools of water. It is most likely this mollusc-algal mat association that is partly responsible for the development of rimmed terrace pool ridges by differential surface erosion.

Although evidence indicates that erosion is predominating over accretion on the solution rampart as a whole, the rate of erosion is differentiated by an increasing ratio of erosion to accretion in a seaward to landward direction across its surface. Because of its seaward facing position the forecrest slope consistently receives more wave run-up over average sea conditions which lowers the erosion-accretion ratio. Conversely the backcrest slope receives less wave wash resulting in a higher erosion-accretion ratio. The rampart thus looses less limestone to erosion along its leading seaward edge resulting in higher elevations and short steep slopes. On backcrest slopes limestones erosion increases in a shoreward direction from the crest resulting in longer, less steep slopes. Where the backcrest slope grades into the reef flat platform longer periods of exposure and reduced wave wash commonly promotes the development of a low, narrow, pinnacled zone by rainwater solution in addition to bioerosion. Along the East Ritidian reef platform a similar pinnacled zone is formed where an actively seaward prograding algal ridge leaves the trailing edge exposed to rainwater solution. The general decrease in rampart crest height between Ritidian Point and Achae Point can also be explained by differential erosion in response to an attenuation of refracted waves and swell height in a southwest direction from Ritidian Channel. Such wave height attenuation produces a decreasing gradient of wave run-up on the rampart toward the southwest, which in turn, increases erosion-accretion ratio rates in the same direction. Over time this erosion gradient has decreased both the height and width of the rampart as observed southwestward from Ritidian Channel. Farther southward from Achae Point the rampart height and width both continue to decrease, and at places has disappeared altogether, but at Uruno Point it becomes emergent again to a about a meter in height in response to a change in coastline orientation which causes higher wave run-up to occur.

Although the upper forereef slope along the West Ritidian fringing reef was not a zone of primary investigation it was observed at numerous locations to more adequately interpret geomorphic structure of the adjacent solution rampart. At many places the seaward edge of the solution rampart forecrest slope terminates abruptly about a meter below MLLW level at the upper margin of a steep to vertical scarp that extends downward to a submarine terrace 3 to 5 meters in depth. The terrace is at most places less than 75 meters wide, which along its seaward margin terminates at another steep to vertical scarp that extends downward to a second level submarine terrace 10 to 15 meters in depth. This deeper terrace level is extensively veneered with mostly sand- and some cobble-sized bioclastic sediments, particularly below the scarp margin. Although this deeper terrace was not extensively investigated during this study, aerial photographs indicate that the bioclastic deposits form a fairly wide and contiguous band along the West Ritidian coastal region. Samples of the sand-sized fraction from the terrace deposits revealed an abundance of shallow-water foraminiferan tests, composed mainly of species of the genera Baculogypsina and Marginopora. Many of these tests were probably derived from the adjacent reef flat platform where similar living foraminiferans species abundantly occur in mats of short algal turf that grows on intertidal and subtidal reef rock pavement areas. The shallower submarine terrace is cut at irregular intervals by channels 2 to 4 meters deeper than the general terrace surface level. Although these channels seldom extend into the rampart ridge or reef flat platform, they may undercut the vertical scarp face and solution rampart forecrest slope up to several meters at places. Where such undercutting occurs a conspicuous projecting shelf is formed along the upper scarp wall. The terrace channels have relatively flat floors with vertical to overhanging walls and at places are extensively undercut at floor level. Large rounded and subrounded boulders are scattered along the length of the channel floors and at places coarse sand, gravel, and cobbles forms a patchy veneer on a scoured reef rock surface. A few of these channels extend completely across the terrace forming chutes that funnel sediments down onto the lower terrace floor. Other channels extend only part way across the terrace, commonly terminating in potholes containing large well-rounded boulders. Between channels the terrace surface is occupied by abundant corals and pavement-forming crustose red algae and is kept relatively free of sediment accumulation by strong surging currents. Local patches of abundant coral growth and individual large colonies imparts a somewhat hummoncky topography of up to several meters of local relief on interchannel terrace surface areas.

COMMUNITY STRUCTURE OF THE REEF-BUILDING CORALS

Reef-building scleractinian, octocorallian, and hydrozoan corals are sessile invertebrates with potentially long life spans and distribution patterns that depend upon the particular environmental setting found from one habitat to another. Their strong calcium carbonate skeletons are important contributors to both _in situ_ framework and detrital reef deposits in both the reef platform and forereef slope environments at Ritidian Point. They are also important contributors to beach and coastal storm terrace deposits as well. Characteristic coral communities have developed in response to variable environmental conditions found from one place to another within the study area. Environmental conditions within the study area range from those completely unfavorable for corals to optimum conditions where corals are the dominant organisms. Corals are sensitive to many environmental variables, particularly from emersion during low spring tides, temperature elevation, storm waves, currents and water circulation patterns, presence of suspended materials in the water column, stability of the substrate upon which they are attached, sediment accumulation, sea water dilution from surface drainage and groundwater discharge, various forms of pollution from toxic substances and thermal, storm drain, and sewage discharges. In addition to the various physical factors listed above, complex biological interactions also have an important influence on the community structure of corals.

Coral Distribution and Biozonation Patterns

Preliminary reconnaissance observations of the study area, as well as analysis of the transect data, revealed that distinctive coral communities were associated with the various physiographic zones that were discriminated and described in an earlier part of this report. Within these distinctive coral communities considerable variation also occurred in species richness, colony size, frequency of occurrence, density, and percentage of substrate coverage between zones within an individual transect, between transects, and between the East and West Ritidian reef platform (Tables 3 and 4).

Much of the zonal and regional variation found in the commonly structure of corals is attributable to the fact that parts of the reef platform are exposed during low tides. Corals are unable to survive long periods of emergence, particularly when low spring tides conincide with calms and the drying effects of mid-day insolation, and are thus restricted to parts of reef platforms that retain water during such times. Low tide exposure accounts for the general low coral density and percentage of substrate coverage recorded on inner reef flat platform zones at Transects E-5, W-2 (including middle reef flat zone), and W-3, and on the outer reef flat platform zone at Transect W-3. Coral density and percentage of substrate coverage both increases considerably on inner and outer reef flat platform zones that retain sizeable moats of water during low sprig tides.

Substrate composition is another factor that influences community structure of corals across the reef platforms. Most corals require a hard surface or relatively stable unconsolidated substrate to settle upon and successfully grow, although large fragments of branching corals can be transported onto unstable substrates at some localities and survive because of a refuge in size.

Although considerable suspended sediment was observed in the water column during periods of normal NE Tradewind seas, it did not appear to have a detrimental effect on the coral community because strong currents and water motion prevents particles from setting out onto living coral tissues or accumulating to a great extent upon the substrate.

Considerable freshwater lens discharge was noticed at places along the shoreline. During low spring tides when wave transport of water onto the platform and longshore currents are minimal there may be some effect on corals from such discharge in the sand moat zone. When normal NE Tradewinds are present, though, the effect from freshwater dilution on the inner reef platform appears to be negligible because of rapid turnover of reef flat water from wave transport and strong longshore currents. A more important aspect of freshwater lens discharge results from nutrient enrichment of reef flat platform waters. It has been established that lens discharge water is considerably higher in nitrates and phosphates than nearshore marine waters and that such enrichment enhances algal growth, particularly where shoreline discharge borders shallow reef flat platforms (FitzGerald, 1978). Some of the most luxuriant standing crops of fleshy algae observed on Guam are maintained on reef platforms adjacent to the study area, particularly on the East Ritidian reef platform. Community structure of these fleshy algal stands are also somewhat unique in that large thalli of Udotea geppi, Avrainvillea sp. (up to 50 cm high), and Microdictyon okamurai dominate the substrate at many places. These stands of large algal thalli are certainly in competition for space with corals by preventing coral larval settlement and by rapid overgrowth of small corals that do fortuitously become established (Birkeland, 1977). Where these dense algal communities are present the coral community consists of widely scattered large colonies that have gained a refuge in size from fast growing algal species.

Water temperature elevation is generally not a limiting factor for coral settlement and growth in reef zones where a good exchange of nearshore marine waters occur, such as along upper reef front slope and the adjacent reef margin. Water temperature may be elevated to sublethal or lethal levels for corals, though, on shallow fringing reef platforms where moats and pools of water in depressed regions become isolated from open ocean exchange and circulation during low spring tides. Because of a relative sea level drop of 2 to 3 meters about 3000 years B.P. many older parts of reef platform are out of equilibrium with present day sea level, particularly on the West Ritidian reef platform.

Species Richness

A combined total of 93 species of reef-building corals representing 26 genera and 11 families were recorded from the eight transects combined and the regions between the transects on the shallow reef flat platforms (excluding the reef margin zone) between Achae Point and Pajon Point (Table 3). Species richness was highest on East Ritidian reef flat platform (Transects E-1 through E-5) where 92 species distributed among 25 genera were recorded and lowest or West Ritidian reef flat platform transects W-1 through W-3 where only 34 species distributed among 16 genera were recorded. Along the East Ritidian reef platform species richness attenuates from a high of 72 species representing 23 genera at Transect E-1 toward Pajon Point where 25 to 27 species representing 12 to 11 genera were recorded at Transects E-4 and E-5 respectively (Fig. 5 and Table 3). Along the West Ritidian reef platform species richness ranged from 22 species representing 13 genera at Transect W-2 to 17 species representing 9 genera at Transect W-1. Of the 93 species recorded from the overall study area 6 species were common to all 8 transect areas, and of the remaining 87 species 3 were common to 7 transect areas, 8 were common to 6 and 5 transects areas each, 6 were common to 4 transect areas, 13 were common to 3 transects areas, 21 were common to 2 transect areas, and 28 were found only at a single transect area.

Coral Communities Assoicated With The Reef Platforms

Sand Moat Zone

Although the narrow trough-shaped sand moat commonly retains water during low tides, strong longshore currents and the general presence of unconsolidated sediment generally renders the substrate unstable for coral recruitment and development. Where the sand moat zones are developed (absent or poorly developed at Transects E-4, E-5, and W-1) only four species of corals were encountered along three transects. Corals were moat abundant at Transect E-1 where scattered colonies of Pocillopora damicornis and a few small heads of Porites lutea were attached to bare areas of the moat floor or to small remnant knobs of reef rock. At Transect E-3 a single colony each of P. damicornis and Porites australiensis was encountered, and at Transect W-1 a single clump a single clump of P. damicornis was recorded within the transect zone. Where corals occurred in the sand moat zone substrate coverage ranged from 1.4% at Transect E-1 to 0.02% at Transect W-1, coral density (colonies per square meter) ranged from 1.27 at Transect E-1 to 0.01 at Transect W-1, and mean colony diameter ranged from 22.0 cm at Transect W-1 to 0.15 cm at Transect E-1 (Table 4).

Inner Reef Flat Zone

Considerable variation was found in the community structure of corals within the inner reef flat zones on both East and West Ritidian reef platforms. Much of this variation results from differences in substrate composition and degree of platform exposure and water temperature elevation in isolated moats or pools of water during low spring tides. Although a considerable part of the inner reef flat zone along the East Ritidian platform is veneered with a layer of sediment, the high percentage of substrate coverage by corals at Transect E-1 though E-3 result primarily from the presence of large thickets of Acropora aspera (Figs. 10a-10d). These arborescently-branched corals commonly fragment during storms and pieces are transported onto relatively unstable sediment-veneered substrates. Because of their relatively large fragment size (up to 30 cm or more long) and shape (tree-like branches), these broken pieces are rather inherently stable, even on shifting sandy substrates. Smaller branch pieces (several centimeters long), or coral planulae settling upon small-sized grains, would most likely soon be buried by such unstable substrates. Relative percentage of substrate coverage by thickets of Acropora aspera on Transects E-1 through E-3 was 55.9, 98.4 and 30.5 respectively. At Transect E-4 the inner reef flat zone is dominated by thick-branched colonies of Acropora palifera (relative percentage of substrate coverage is 97.5) which occur in irregular holes and depressions. At Transect E-5 the inner reef flat zone is much shallower and during low tides becomes partly emergent with many isolated holes and depressions that retain water. Because of water temperature elevation in these isolated pools only five coral colonies were encountered on the transect and substrate coverage was only 0.30%. Along the East Ritidian inner reef flat zone coral substrate coverage values ranged from 28.0% at Transect E-2 where dense Acropora aspera thickets occur to 0.3% at Transect E-5 where low tide isolated pools contained only a few scattered colonies, coral density (colonies per square meter) ranged from 0.35 at Transect E-3 to 0.04 at Transect E-5, and mean colony diameter ranged from 94.1 cm at Transect E-2 to 32.3 cm at Transect E-5 (Table 4).

Much of the inner reef flat zone along the West Ritidian reef platform exposes or is quite shallow during low spring tides, resulting in considerable lower values of coral density and percentage of substrate coverage than on corresponding regions of the East Ritidian platform. Coral density (colonies per square meter) was 0.13 at all three transect (W-1 through W-3) and substrate coverage ranged from 9.93% at Transect W-1 to 0.64% at Transect W-2 (Table 4). The considerable higher substrate coverage at Transect W-1 is primarily a result of a somewhat deeper reef platform than at the other two transect locations.

Outer Reef Flat Zone

Considerable variation was found in the community structure of corals within the outer reef flat zones on both East and West Ritidian reef platforms. In contrast to the inner reef flat zones this outer part of the reef flat is mostly swept free of loose sediment, but is shallower except at Transect E-1 which remains subtidal even during low spring tides. Principal differences in community structure of corals between the inner and outer reef flat zones include a greater number of species, higher density (except at Transect W-3), and a smaller coral size (except at Transect W-2) in the outer reef flat. The most conspicuous difference in species composition is found in the near absence of thickets of Acropora aspera on the outer reef flat zones of the East Ritidian reef platform. During normal NE Tradewind seas the outer reef flat is a zone of strong surging currents and highly adjitated water, and thus has many species in common with similar zones of rough water in the reef margin and upper reef front slope. Occasional colonies of Stylophora mordax were found in the outer reef flat which is quite unusual for this species on Guam. Stylophora mordax is generally restricted to subtidal reef margin and forereef habitats where there is good water circulation and little departure from normal nearshore seawater temperatures (Jones et al. 1974). Temperature elevation on shallow water habitats is most likely the factor that restricts this coral from most reef flat zones on Guam, but along the northern coasts the platforms are directly exposed to the prevailing tradewinds resulting in good water circulation and little water temperature elevation during low tides.

On the outer reef flat zones coral density (colonies per square meter) ranged from 1.12 at Transect E-1 to 0.03 at Transect W-3, percent of substrate coverage ranged from 64.82% at Transect E-1 (highest coverage value for any transect zone) to 0.03% at Transect W-3, and colony size (dia. in centimeters) ranged from 71.0 at Transect E-1 to 11.0 at Transect W-3 (Table

4). Most of the variation in community structure is related to variation in water depth and subsequent degree of exposure during low spring tides. Except for a small fault offset, which increased water depth considerably on the outer reef flat at Transect W-2, the West Ritidian reef platform is much shallower and as a result has much lower values of coral density and percent of substrate coverage than similar zones along the East Ritidian platform.

Coral Communities Associated With The Reef Margin

Breaking surf and wave surge prevented safe acquisition of quantitative transect data from the reef margin zone during this study. Evenso, a considerable number of observations and coral collections have been made along the reef margin between Achae Point and Pajon Point during infrequent periods of calm over the last decade. During these calms an extensive representative collection of corals was made, and on several occasions scuba dives were made to investigate cavernous pools and surge channels that extended through and beneath the algal ridge system.

Along the East Ritidian platform corals primarily occur along the walls and upper margins of open pools and surge channels of both the forecrest and backcrest algal ridge slopes. A surprising number of corals also occur in intertidal rimmed terraced pools that are developed on the backcrest slope of some buttress ridges, and a few occur even in cavernous parts of surge channels as well as around surface openings of tunnels and galleries that permeate throughout much of the algal ridge deposits.

Conspicuous corals occupying the well-lighted upper margins of open surge channels and pools of both the forecrest and backcrest slope subzones include: 1) abundant brown and red color forms of Pocillopora setchelli which at places occur in closely set clusters of colonies and dominate upper margins of both surge channels and pools, 2) lumpy masses of Goniastrea retiformis and Favia stelligera, particularly along pool margins of backcrest slopes, 3) occasional yellow-colored colonies of Millepora platyphylla which form vertical plates arising from an encrusting base, 4) scattered cespitose and corymbose colonies of Acropora digitifera , A. cerealis, A. surculosa, A. azurea, A. valida, and A. humilis, 5) large, lumpy, encrusting masses of Acropora monticulosa and projecting shelves of A. irregularis, 6) scattered bluish-brown, flabellately-branched colonies of Heliopora coerulea, and 7) inconspicuous, but abundant, small lichen-like encrusting spats of Porites superfusa.

Corals communities observed on deeper walls and floors of open surge channels and pools are more diverse in terms of species richness, but overall substrate coverage at most places is less than that along the upper well-lighted channel and pool margins. Lower substrate coverage is to a large extend a result of shading where extensive overhanging shelves project outward from surge channel and pool wall margins. Although many corals are restricted from these shaded habitats, encrusting crustose algae and colonial foraminifers abundantly veneers and builds up such surfaces. Sections of projecting shelves that were broken off revealed a buildup of encrusting calcareous algae up to 10 cm or more in thickness. Upper surge channel pool walls revealed even thicker algal buildups, but part or much of this accumulation may have accreted before such wide projecting shelves had formed. Near Ritidian Channel some of these overhanging shelves projected outward up to two or more meters from walls of channels and pools. Corals are also mostly absent on surge channel and pool floors that are veneered with unconsolidated smaller-sized sediments, particularly on the outer seaward reef margin where wave surge and currents are strong enough to keep such clasts in motion and cause abrasion of reef rock surfaces. Large stable boulders and blocks, though, are relatively stable and many have a considerable part of their surfaces covered with attached coral colonies. Conspicuous corals growing in deeper parts of open surge channels and pools that are not overly shaded include: 1) large bracket-like shelves of Acropora irregularis, 2) large encrustations of Montipora verrilli, M. ehrenbergii, M. hoffmeisteri, M. elsehneri, Montipora sp.3, and Leptastrea transversa, 3) small encrusting patches of Porites superfusa, Porites (N.) vaughani, and Pavona sp.3, 4) rounded to irregular massive colonies of Goniastrea retiformis, Favia stelligera, F. matthaii, Montastrea curta, F. favus, Favites abdita, Leptoria phrygia, Porites lutea and P. lichen, 5) compact branching colonies of Pocillopora setchelli, and more open branching colonies of Pocillopora verrucosa, P. ligulata, and P. eydouxi, 6) cespitose and corymbose forms of Acropora humilis, A. digitifera, A. valida, A. ocellata, A. surculosa, A. cerealis, and A. azurea, 7) thick lobately-branched colonies of Acropora palifera, and 8) occasional large phaceloid colonies of Lobophyllia corymbosa and L. hemprichii. Corals associated with dimly-lighted parts of honeycombed galleries and tunnels and poorly-lighted overhanging shelves, walls, and cavernous sections of surge channel include: 1) small encrusting spats of Porites superfusa and Porites (N.) vaughani, 2) small adherent patches or free plates of Leptoseris incrustans and Pavona varians, 3) subramose colonies of Pavona maldivensis, 4) compact branching chumps of Alveopora virdis, and 5) several ahermatypic solitary species and small hydrozoan colonies of Distichopora gracilis in dark honeycombed galleries and tunnels.

Some of the larger intertidal rimmed terraced pools developed on the backcrest slopes of larger buttress ridges contained an assemblage of scattered coral species similar to those listed above for the upper margins of open surge channels and pools. Although these pools are somewhat isolated from consistent wave wash during periods of calm when low spring tide occur, apparently occasional sets of waves provide an exchange of water frequent enough to prevent significant temperature elevation, at least in some of the larger pools where corals are more abundant.

A combined total of 40 species of reef-building corals and 3 ahermatypic species representing 18 genera were observed in the reef margin zone along the East Ritidian reef platform. These observations were made for the most part made in the immediate vicinities of Transects E-1 through E-5. An overall search between transect localities would most likely reveal another 10 or so species.

Corals on solution rampart habitats along the West Ritidian reef platform are less abundant and their distribution more restricted than those on the East Ritidian algal ridge zone. Some scattered corals were observed on the floors of some shallow saddle-shaped channels that occur between ridge crest hummocks and in some pot-holes that have been eroded into backcrest slopes at several locations. Conspicuous corals in channel floors between hummocks include: 1) small brown and red color forms of Pocillopora setchelli, 2) corymbose colonies of Acropora digitifera, 3) cespitose clumps of Acropora azurea and A. cerealis, and 4) some lumpy encrustations of Acropora monticulosa, Montastrea curta, and Goniastrea retiformis. In a large pot hole on the backcrest rampart slope located about midway between Transects W-1 and W-2 a large shelving colony of Acropora irregularis, several colonies of A. digitifera and A. cerelais, and small massive colonies of Goniastrea retiformis and Favia matthaii were observed. Corals were absent on other surfaces of both the backcrest and forecrest slopes because of periodic low tide exposure.

GEOLOGIC HISTORY

In developing a chronological reconstruction of geologic events in the study area the most difficult period of history to account for is that following the major deposition of the Mariana Limestone sometime during the Pleistocene, when the general emergence of Guam was occurring concurrently with sea level changes associated with reoccurring glacial and interglacial stages. Primarily because of the lack of good unaltered dating material the sequence of Pleistocene terrace formation is not well established for Guam. Recurrent episodes of faulting associated with some or all ustatic and tectonic events makes even the correlation of terrace levels from one part of the island to another difficult to establish. Although the sequence of events leading to the deposition of the unconsolidated terrace deposits between Ritidian Point and Achae Point was at first thought to be a Holocene reconstruction, the presence of faulting at Ritidian Channel and the occurrence of a 1-2 meter Pleistocene rampart along the seaward edge of the West Ritidian reef (bench?) platform leads to uncertainties about the age of the terrace deposits without some further dating. Beginning with the Holocene transgression about 17,000 years B.P. the following sequence of developmental events are suggested for the Ritidian Point study area.

About 17,000 years B.P. the Holocene transgression began causing a relatively rapid sea level rise of about 7-9 mm per year to about 7000 to 6000 years B.P., bringing the sea level to within -4 to -8 meters of the present stand. On Guam maximum sea level regression during the last glacial stage is thought to be represented by a -96 meter terrace which Emery (1962) found in 16 fathometer profiles around the island (Fig. 11). Along the East Ritidian coastal area this transgression most likely covered Pleistocene terrace platforms or slopes seaward of the present shoreline that were lower than -4 to -8 meters, especially at the north end near the present Ritidian Channel where a downfaulted terrace was possibly lower in elevation. Along the West Ritidian coastal area the Pleistocene terrace was probably at or near its present elevation and thus was not flooded, at least not the solution rampart along the outer margin. If the inner moat region was significantly lower than the solution rampart, by at least 4 meters, then some shallow flooding could have occurred these as well.

Following the rapid transgressive phase a slower sea level rise of 4-5 mm per year bought the sea level to about 3.0 to 3.5 meters above the present stand about 5000 years B.P. along the East Ritidian coastal area. Water on terraces previously flooded during an earlier rapid transgressive phase increased in depth, and a narrow intermittent terrace about 1.0 to 3.0 meters above the present shoreline was covered by water, possibly being intertidal at higher elevations. Data from transects H-E2 through H-E4 (Fig. 4) indicate the following sequence of events for these shallow flooded terraces: 1) vigorous upward reef growth on terrace surfaces formed narrow reef flat platforms that were in sea level equilibrium, 2) at Transect H-E3 a prominent notch suggests that the mean tide level was about 0.5 to 0.7 meters higher than the reef flat platform, but the notch could also have been cut previously during the time of Pleistocene terrace formation as well (see discussion of Transect H-W1 below), 3) a massive algal ridge system developed along the seaward margin of the narrow reef flat platform in response to vigorous wave assault along this part of the coast (at Transect H-E3 the algal ridge developed directly upon the outer margin of the Pleistocene terrace), 4) the elevation of this algal ridge facies was up to a meter higher than the elevation of the backreef platform, similar to the present algal ridge zone developed along the East Ritidian reef platform, and 5) reef growth on terraces seaward of the algal ridge had not yet grown upward to sea level equilibrium. Figure 12 shows a generalized reconstruction of the Holocene reefs at Pajon Point about 5000 years B.P. Along the West Ritidian coastal area the Pleistocene terrace (moat area behind the rampart) was flooded by about 3.0 meters of water. The seaward solution rampart was most likely a shallow submerged ridge at this time. If an algal buildup developed upon the rampart surface during this time, no remnants of such a deposit have been found along its length at the present time.

Between 5000 and 3000 years B.P. the sea level regressed about 1.5 meters from a MLLW high of about +3.5 meters to +2.0 meters. Randall and Siegrist (1988) suggested a date of about

3900 years B.P. for this regression along northern Guam since this is the youngest surface date found for emergent Holocene deposits along the Tarague embayment. Randall and Siegrist (1988) also suggest that this regression was possibly caused by local uplift of northern Guam since equivalent aged emergent Holocene deposits of southern Guam are 1.0 to 2.0 meters lower in elevation. Corresponding Holocene sea level notches in the north are also 1.0 to 2.0 meters higher in elevation than those in the south. Along the East Ritidian coastal area this 1.5 meter regression caused emergence of the fringing reef flat platform and algal ridge deposits. Some beach and storm deposits many have started to accumulate on the emergent backreef platforms at this time as well. Associated forereef terrace deposits lying seaward of the newly emerged reef platform and algal ridge crest apparently were not exposed by the 1.5 meter regression, or if some emergence did occur there the deposits have since been removed by erosion. Forereef deposits continued to accumulate, possibly growing upward to or near sea level at places. Along the West Ritidian coastal area the 1.5 meter regression most likely caused a shoaling on the Pleistocene terrace moat area and parts of the submerged solution rampart became intertidal. Some emergence as well as beach and storm deposit accumulation many have occurred on the inner terrace at this time (presently covered by unconsolidated deposits) if it was significantly shallower than the outer part (present reef platform). Figure 13 shows a generalized reconstruction of the Holocene reefs at Pajon

Point after a sea level regression of about 1.5 meters 3900 years B.P.

Further evidence of the 5000 year B.P. Holocene high sea level stand and the regression about 3900 years B.P. to about +2.0 meters above the present stand is found at Achae Point. At the north end of Achae Point a large double concave notch (two notches at slightly different elevations superimposed into a single larger notch) is cut into the face of a vertical scarp of Mariana Limestone, as shown in Figure 3. The deepest part of the uppermost concave notch (floor is missing) is approximately +3.5 to +3.7 meters above present MLLW level, and was possibly cut during the Holocene high stand about 5000 years B.P. The deepest part of the lowermost concave notch is about +2.5 to +2.7 meters above the present MLLW level and was possibly cut when the sea level regressed 1.0 to 1.5 meters about 3900 years B.P. Complicating the process of notch formation at Achae Point is the presence of unaltered corals veneering the notch floor (see p. 23 for discussion). These corals suggest that the notch may have been cut by a higher than present Pleistocene sea stand and then veneered later by corals during a later Holocene high sea stand. If a Pleistocene age for notch formation is accepted the latest time of cutting would have been during the last interglacial stage, over 100,000 years B.P. The +2.0 meter notch (floor level) at Achae Point, as well as other +2.0 meter notches around Guam, appear to be much more recently cut, or by coincidence the

Pleistocene stand that cut the original notch was about the same elevation as the Holocene stands 5000 to 3000 years B.P.

About 3000 to 2800 years B.P. the sea level regressed another 2.0 meters to its present stand. This sea level drop appears to have affected the entire island, and must have been fairly rapid because sufficient time would be required to cut the present sea level notches that abound around the coast of Guam. Along the East Ritidian coastal area forereef terrace deposits, lying seaward of the backreef platform and massive algal ridge facies that became emergent during the 1.5 meter regression, possibly were not exposed by the 2.0 meter regression. Emergence of the forereef deposits can not be completely ruled out, though, because of the absence of Holocene remnants on the present reef platform. At places the inner part of the present reef flat platform is composed of a truncated reef rock pavement whose surface cuts across many large in situ coral colonies. This truncated reef flat platform, as well as the presence of conspicuous offsets that form small irregular scarps, indicate an erosional surface of possibly a Holocene deposit that was exposed during the 2.0 meter regression. In contrast to the absence of emergent Holocene deposits on the present reef platform between Ritidian Channel and Pajon Point, Randall and Siegrist (1988) report abundant supratidal Holocene remnant pinnacles and ridges on the reef platforms along the Tarague embayment. Along the West Ritidian coast the 2.0 meter regression lowered the sea level on the Pleistocene moat and rampart ridge to its present level. During low spring tides parts of the moat platform are exposed while other areas retain a few decimeters of water. The solution rampart became an intertidal-supratidal ridge at the seaward edge of the platform, much like it is at present. Inland from the present shoreline an unknown thickness of unconsolidated beach and storm deposits began to accumulate on the terrace surface. Such an accumulation may have begun much earlier, depending upon the platform elevation. This regression exposed several low outcrops of Holocene limestone along the present shoreline at Transects H-W2 through H-W4, and at Transect H-W1 a few Holocene corals veneer the floor of a large double notch at Achae Point (Fig. 3). No trace of the emergent algal ridge and backreef facies deposits that are present along the shoreline at Pajon Point are found along the West Ritidian coastal area. If other emergent Holocene outcrops were exposed by the regression they are either covered by beach and storm deposits that lie inland from the present shoreline or they have been truncated to the general level of the reef platform seaward of the present shoreline. At places the reef platform reef rock pavement surfaces cut across large _in situ_ coral colonies. These truncated coral colonies were not sampled on the inner reef platform areas, but a large colony of _Acropora humilis_ collected where the outer reef platform grades into the backridge slope of the solution rampart was recrystallized, suggesting an older than Holocene age for the outer platform deposits. Inland from the rampart the original flooded Pleistocene terrace may have been lower (a solution moat) where corals could have flourished, as they do presently on low depressed parts of the platform. Figure 14 shows a generalized reconstruction of the Holocene reefs at Pajon Point after a sea level regression of about 2.0 meters 3000 years B.P.

Since the 2 meter regression about 3000 year B.P. to the present time the sea level has apparently been fairly stable. Evidence for such stability is found in the presence of abundant sea level notches cut in rocky shorelines and truncation of emergent limestone outcrops to mean low tide level. The deepest cut parts of these notches within the study area are at about mean tide level. Elsewhere, at rocky headlands or where adjacent rocky shorelines are not bordered by sea level reef platforms, deepest parts of notches may be found at somewhat higher elevations than mean tide level, especially where wave assault is high. Within the span of this 3000 year period of relative sea level stability the present reef platforms of the study area have developed most of their principal geomorphic features observed today. Detailed history of the present reef platforms would be difficult without resorting to extensive core sampling and dating of the deposits, but based upon observable differences in physiographic and lithologic patterns across the reef platforms as well the facies relationships of emergent Holocene and Pleistocene deposits the following sequence of development is suggested.

As discussed above there is some evidence of previous emergent Holocene deposits along the inner part of the present reef platform between Ritidian Channel and Pajon Point, but during the last 3000 years such outcrops were truncated to the present platform level. If such an emergent platform was present, it was probably best developed (wider and higher in elevation) near Pajon Point, between Transects E-2 and E-4, least developed in the vicinity of Transect E-1, and probably not developed at all on the downfaulted platform near the present Ritidian Channel (Figs. 5 and 10a-10d). If we assume no emergence at all from the 3000 year B.P. regression the reef platform would require a seaward progradation rate of 6 to 7 cm per year to achieve its present width, which is about that calculated for the reef margin progradation rate at Jinapsin reef (see page 59). If the 3000 year B.P. regression left reef growth on the forereef terrace very close to sea level (less than a meter) it is possible that such rapid reef platform formation could take place. Based upon the presence of abundant large corals, such as Platygyra daedalea, Goniastrea retiformis, and Favia stelligera, that have been truncated to present platform level, it is possible that much of the presently designated inner reef flat zone between Transect E-2 and Pajon Point (Figs. 5, 6 and 10a-10d) became emergent during the 3000 years B.P. regression. An algal ridge facies then developed along the seaward edge of this newly emerged platform, very similar to the present platform described along the northern coast of Rota by Bell and Siegrist (1988), although at Ritidian Point the emerged platform was most likely much lower in elevation and has since been removed by erosion. If emergent Holocene deposits were at a higher elevation, remnants of such should still be present as they are on the northern Rota coast and along the Tarague embayment area to the southeast (Randall and Siegrist, 1988). The algal ridge has since prograded seaward upon shallow forereef terrace deposits to its present position by processes described earlier (pp. 60-62), forming the presently designated outer reef flat platform as a result (Fig. 6). Between Transect E-2 and Ritidian Channel the forereef terrace deposits were much deeper, remaining submerged after the regression, and are just now reaching sea level equilibrium. Another possible explanation for the absence of emergent Holocene deposits on the present inner reef flat platform along the East Ritidian coastal region is that hinge movement on the fault at Ritidian Channel has dropped reef platform deposits downward sometime after the 3000 year B.P. regression. Such fault displacement would be restricted to the platform region between Transect E-2 and Ritidian Channel because the raised Holocene deposits in the vicinity of Pajon Point are at the some elevation as those along the Tarague embayment.

Unconsolidated storm terrace and beach deposits, that may have initially stared to accumulate on Holocene terraces exposed by the regression 3900 years B.P., continue to accumulate along the present shoreline. Between Ritidian Channel and Transect H-E2 beach and storm deposits extend inland to higher Pleistocene terrace outercrops, and may cover a portion of the present reef platform. Between Transect H-E2 and Pajon Point similar deposits have accumulated along a number of reentry areas, along emergent Holocene outcrops (Figs. 2,4, and 10a-10d). Typhoon waves alternately buildup and remove storm deposits from emergent Holocene terraces in the vicinity of Pajon Point. Several years ago a quantitative assessment of the backreef platform facies of these Holocene terrace outcrops would not have been possible because of accumulated storm deposits, but during Jan. 1988, "Typhoon Roy" stripped these surface deposits away revealing the platform surface at Transect H-E4 (Fig. 4). A one-kilometer stretch of beach rock outcrop along the shoreline between Transect H-E1 and Ritidian Channel (Figs. 2,4 and 10a-10d) indicates that beach deposits once more extensively covered of the reef platform than now. A short distance south of Tarague Beach a ridge of imbricate beach rock, stranded tens of meters from the present shoreline, also indicate a more seaward position of the past beach shoreline there as well. Possibly there has been some slight submergence of the reef platform in the rather Recent past to change the equilibrium of these beach shorelines and shift to a more inland position.

Sediment transport by longshore currents, as well as possible solution of limestone from freshwater escaping at the shoreline from the lens system, has eroded a shallow channel like depression along the shoreline, which in this report is called the sand-floored moat (Fig. 6). If the beach shoreline between

Transect H-E2 and Ritidian Channel has regressed somewhat, as the exposed beach rock suggests, the shoreline moat subzone may have been repositioned as well. Possibly some of the erosional scarps, located just seaward of the present moat subzone, were formed by earlier moat erosion.

Along the West Ritidian coastal area the following sequence of reef platform and coastal terrace development is suggested since the sea level dropped to its present level about 3000 years B.P. The most conspicuous coastal developments during this time-frame were the intertidal-supratidal emergence of the solution rampart on the outer margin of the reef platform, which resembles a convex type of algal ridge buildup, and the formation of the extensive unconsolidated terrace deposits between Achae Point and Ritidian Point. As previously mentioned, accumulation of the unconsolidated terrace deposits may have begun as early as 5000 years B.P. when at least part, or all, of the Pleistocene platform was flooded. If the inner part of the platform, now covered by storm deposits, was flooded by the 5000 years B.P. transgression some of the lower accumulation on the terrace may be consolidated or unconsolidated backreef deposits rather than storm deposits. If the same part of the platform was at an elevation high enough not to be flooded, then the lower terrace deposits may be composed mostly of storm transported bioclastic material of reef origin. In either case some unconsolidated terrace deposits most likely began to accumulated as early as 5000 years B.P. along the shoreline as beach deposits and on flooded parts of the platform as backreef deposits. As increased shoaling on the reef platform continued, as a result of the 3900 years B.P. and 3000 years B.P. sea level regressions, storm deposits continued to accumulate and build the terrace seaward to its present position. Storm terrace deposits are most likely still accumulating along parts of the West Ritidian coastal area, particularly along an 800 meter section between Ritidian Channel and Transect H-W4 (Fig. 2). No beachrock is exposed along this section of shoreline that would indicate beach regression. A conspicuous storm berm up to 6 meters in elevation has built up along the seaward margin of the terrace between Ritidian Channel and Transect H-W4.

ACKNOWLEDGEMENTS

The authors are grateful for financial support received from the Micronesian Area Research Center to conduct the study around the Ritidian Point area. Results from this study has greatly augmented our knowledge of the geology and fringing reefs of this little-known most northern part of Guam.

We appreciate the support from Commander Ruth Cooper, Commanding Officer of the U.S. Naval Facility for giving us permission and access to the military reservation areas around Ritidian Point during our work until June of 1989, and to Lt. Commander Roberta Bolyard for permission and access for some final fieldwork after June of 1989.

A special thanks goes to our Marine Laboratory administrative staff Ms. Angela F. Duenas and Ms. Marie B. Peredo who typed and finalized our draft and final report through the many changes and revisions it has undergone over the last two years of the study.

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Figure 1. Map of Guam showing the location of the Ritidian Point study site (inset area). Fringing, barrier, and intertidal bench platforms are shown in black.

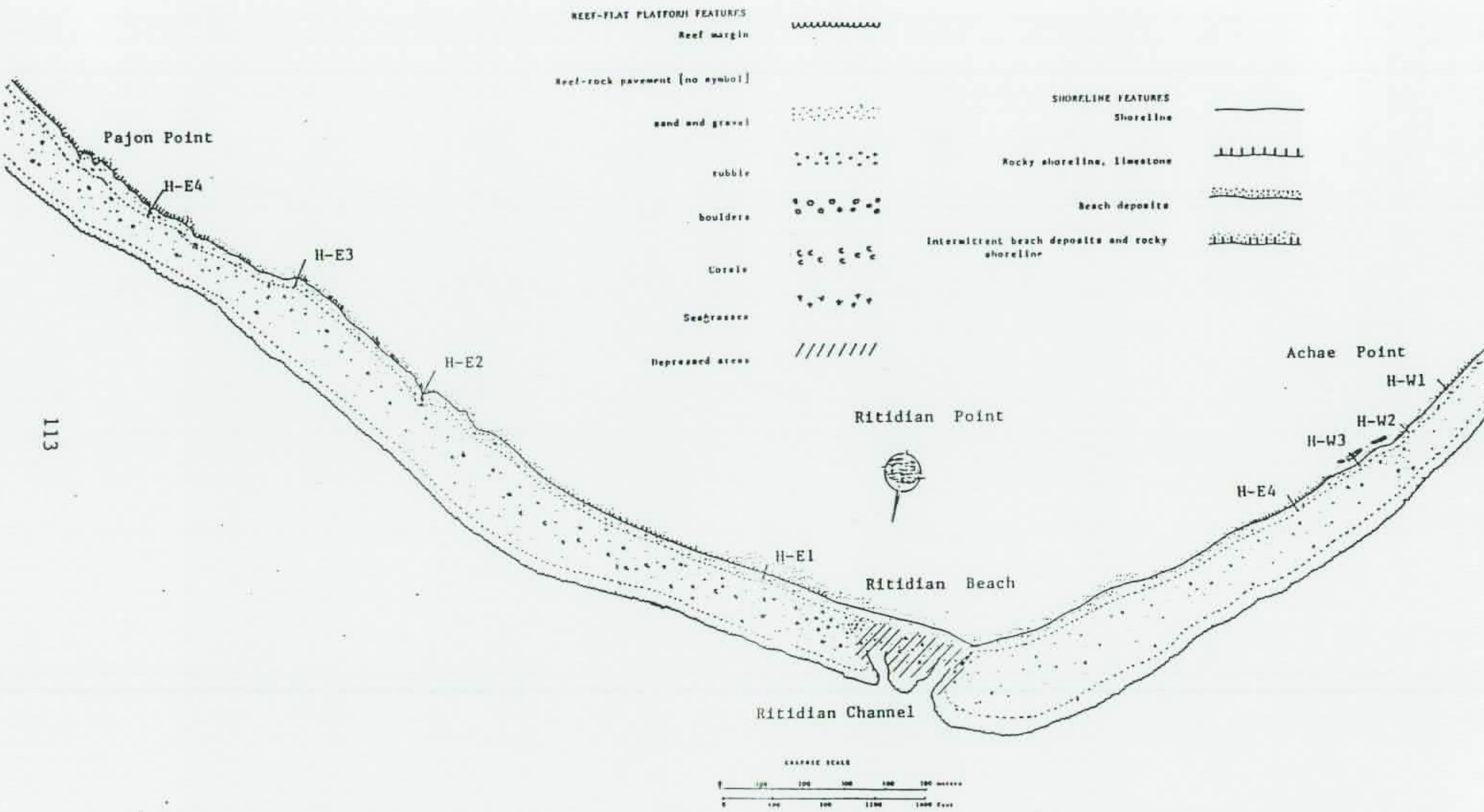

Figure 2. Map of the study area showing the location of Transects H-E1 through H-E4 and Transects H-W1 through H-W4 that were established along the coast to conduct assessments of emergent Holocene limestone outcrops. The dashed lines on the reef platform delineate a narrow sand-floored moat zone along the shoreline, a wide reef flat zone on the middle part, and a narrow reef margin zone along the seaward edge.

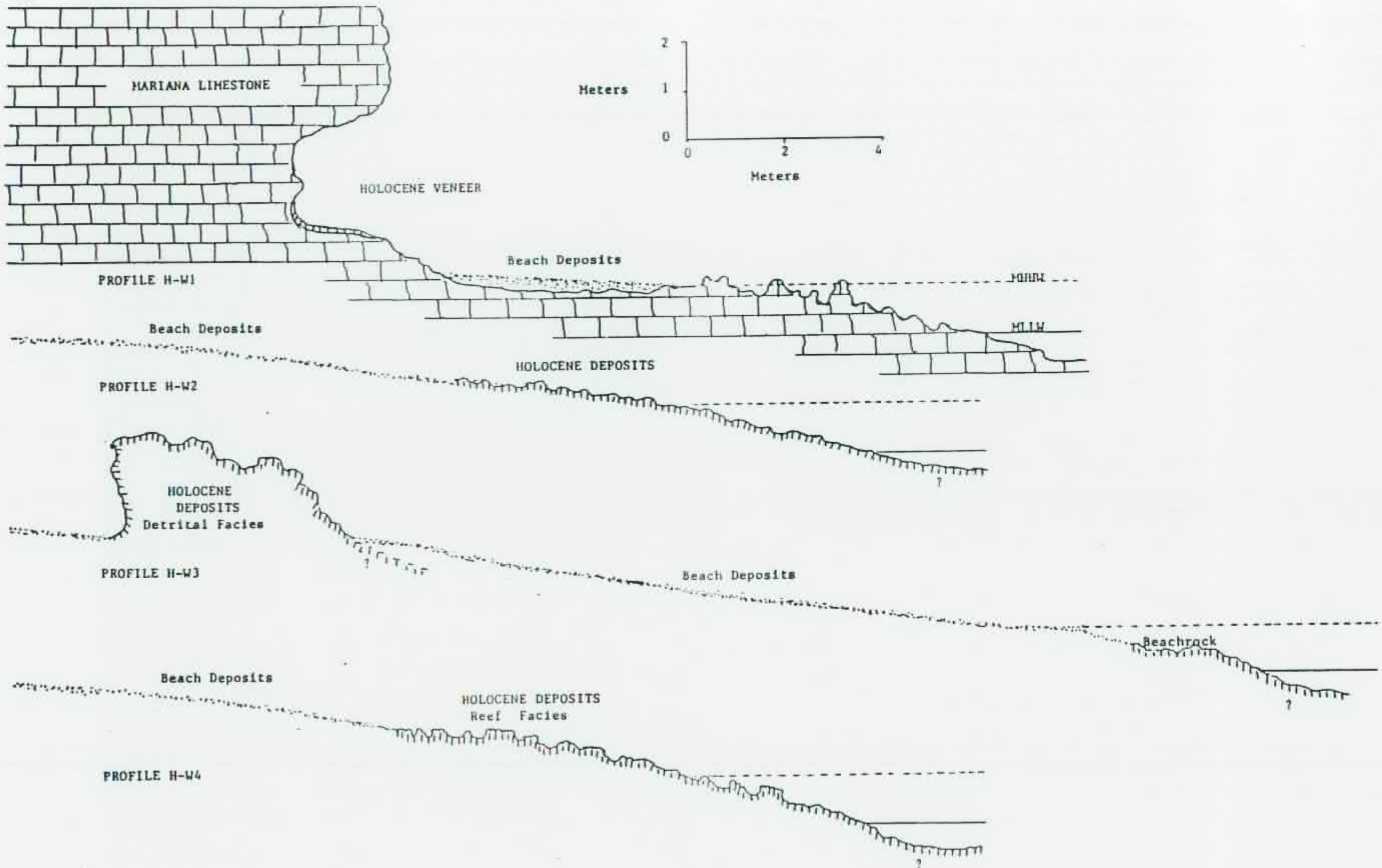

Figure 3. Representative vertical profiles of Transects H-W1 through H-W4.

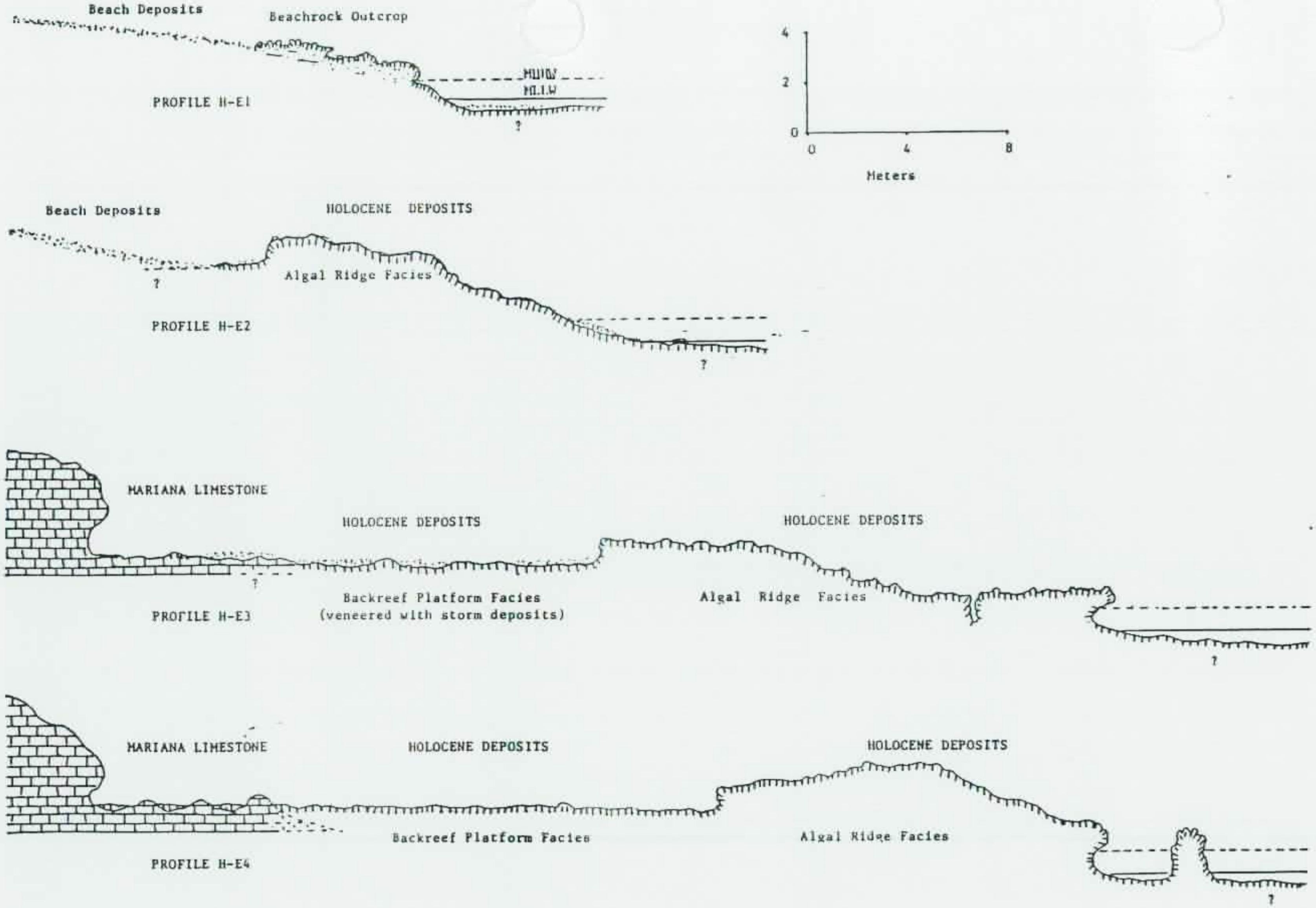

Figure 4. Representative vertical profiles of Transects H-E1 through H-E4

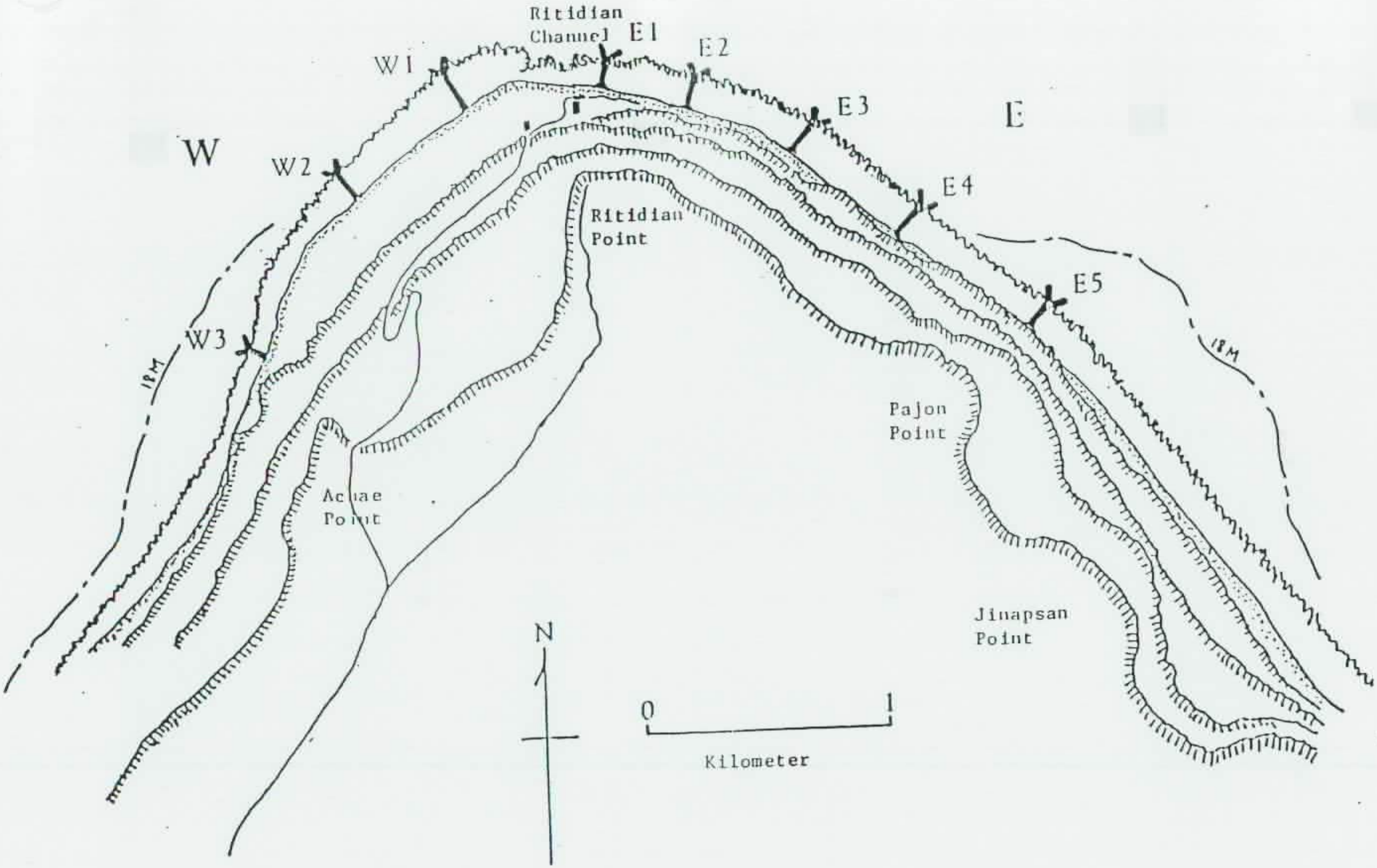

Figure 5. Map of the Ritidian Point study site showing the fringing reef flat platform transect locations.

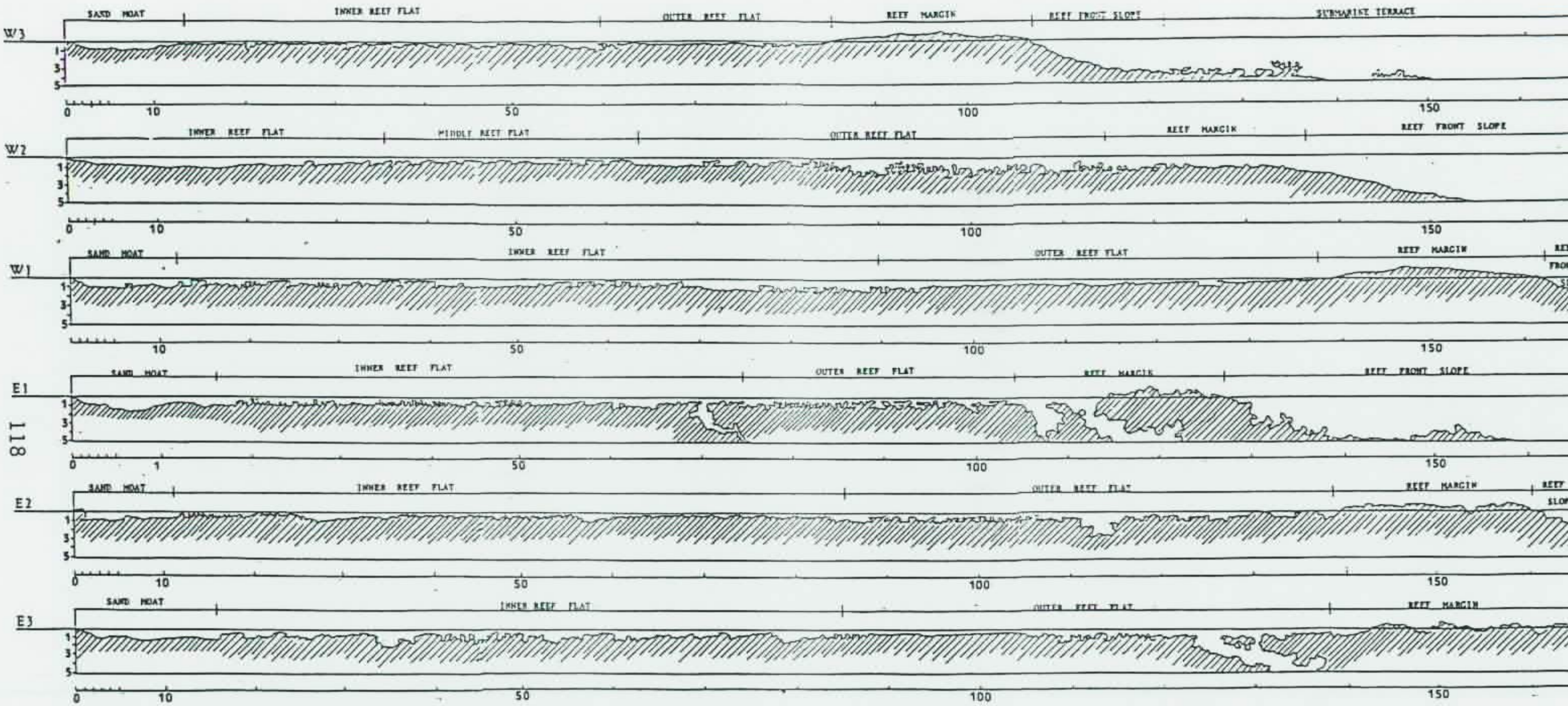

Figure 6. Representative vertical profiles of Transects W-1 through W-3 and E-1 through E-3 showing the physiographic zones that were discriminated and depth of water.

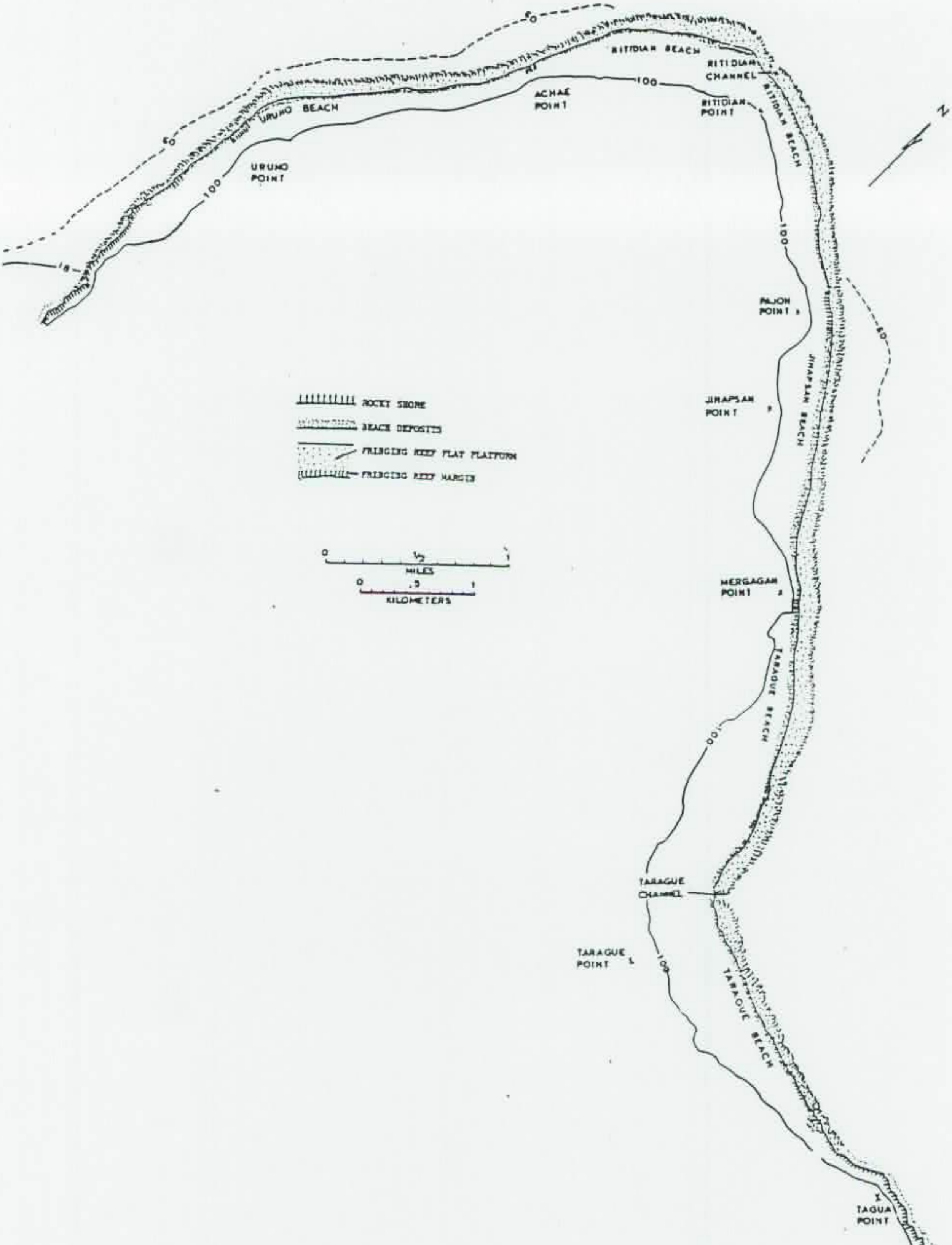

Figure 7. Map showing the 100 foot coastal contour (solid line), rocky shorelines, beach deposits, fringing reef-flat platforms (stippled region seaward of shoreline), reef margin, and the 18 foot (solid line) and 60 foot (dashed line) submarine contour lines where known.

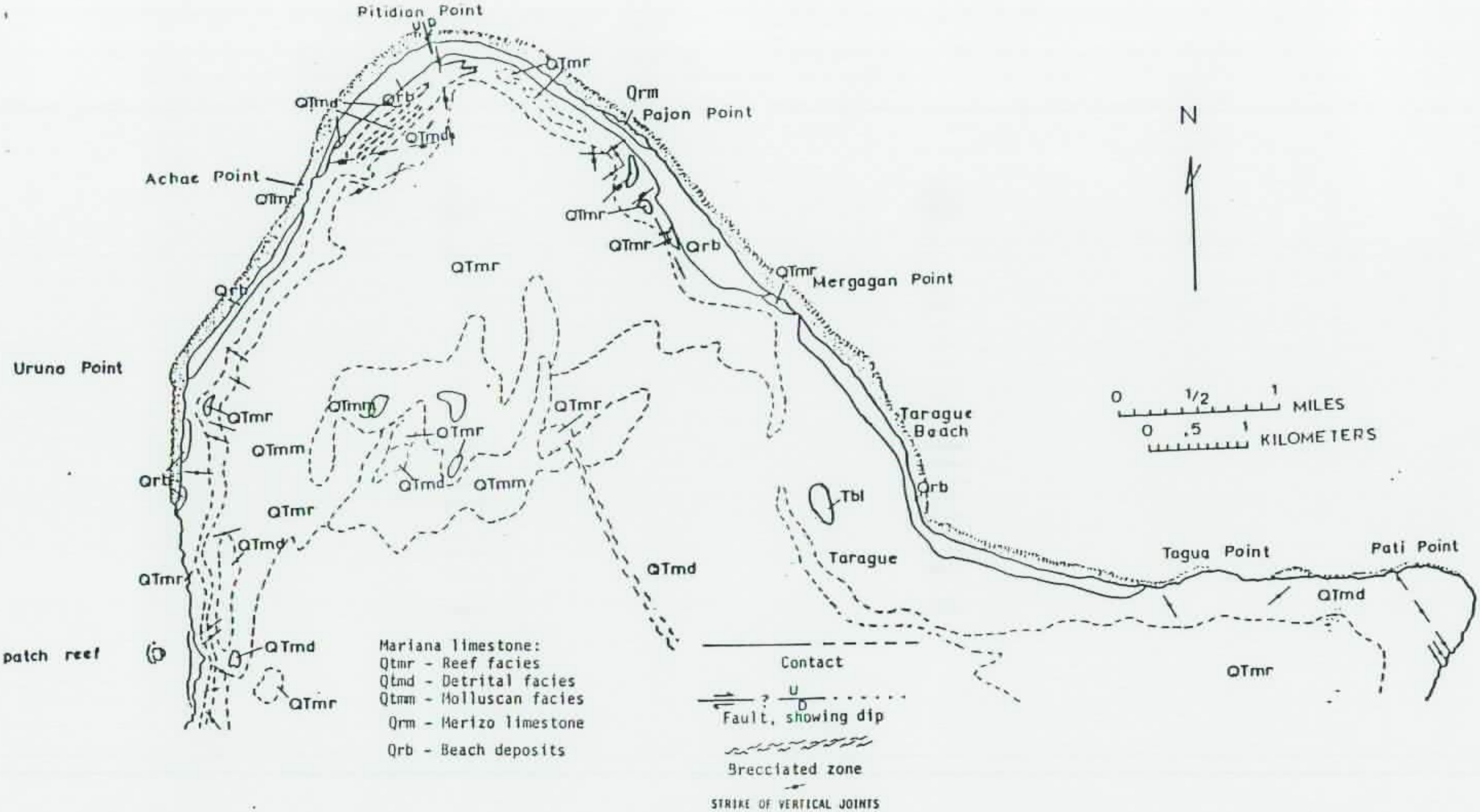

Figure 8. Geology map of the study area. Modified from Tracey et al., 1964.

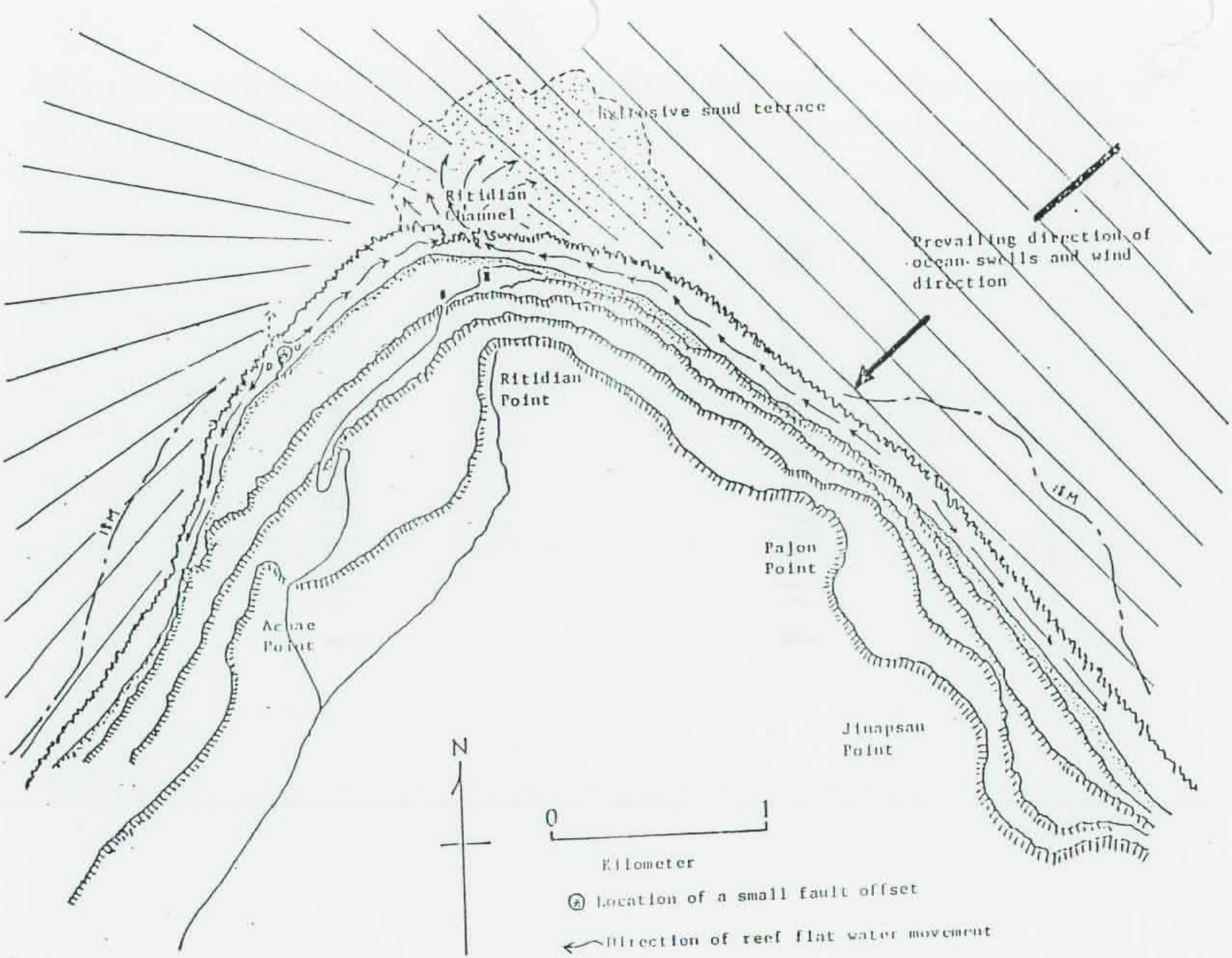

Figure 9. Map of the Ritidian Point study site showing the prevailing direction of reef flat water movement, direction of prevailing wind, and an offshore sand-floored terrace formed for the most part by sediments transported from the East and West Ritidian reef platforms through Ritidian Channel. Straight lines drawn offshore represent the refraction pattern of prevailing wind-generated waves and swell around Ritidian Point.

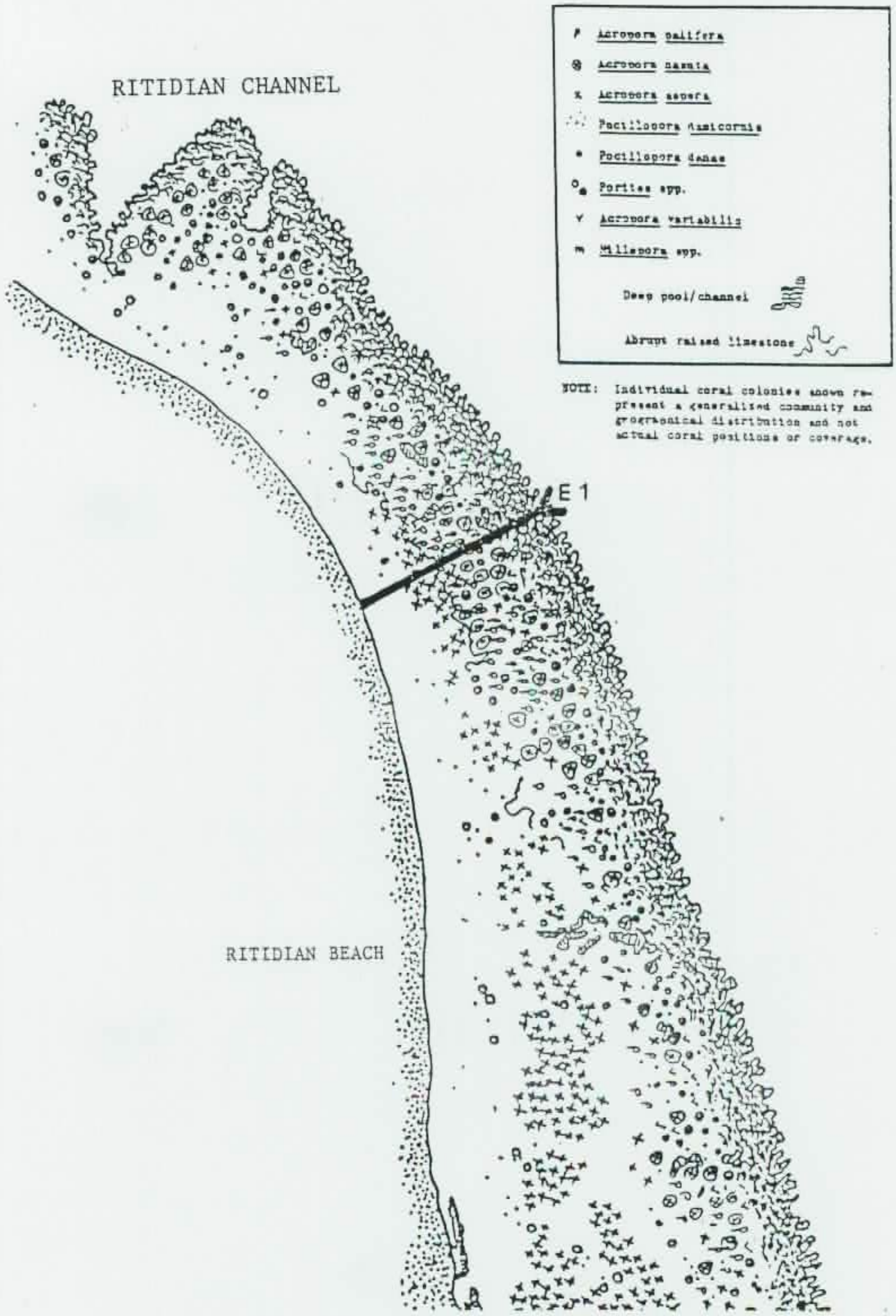

Figure 10a. Map of the fringing reef platform showing the relative abundance and distribution of major reef-building coral species in the vicinity of Transect E-1.

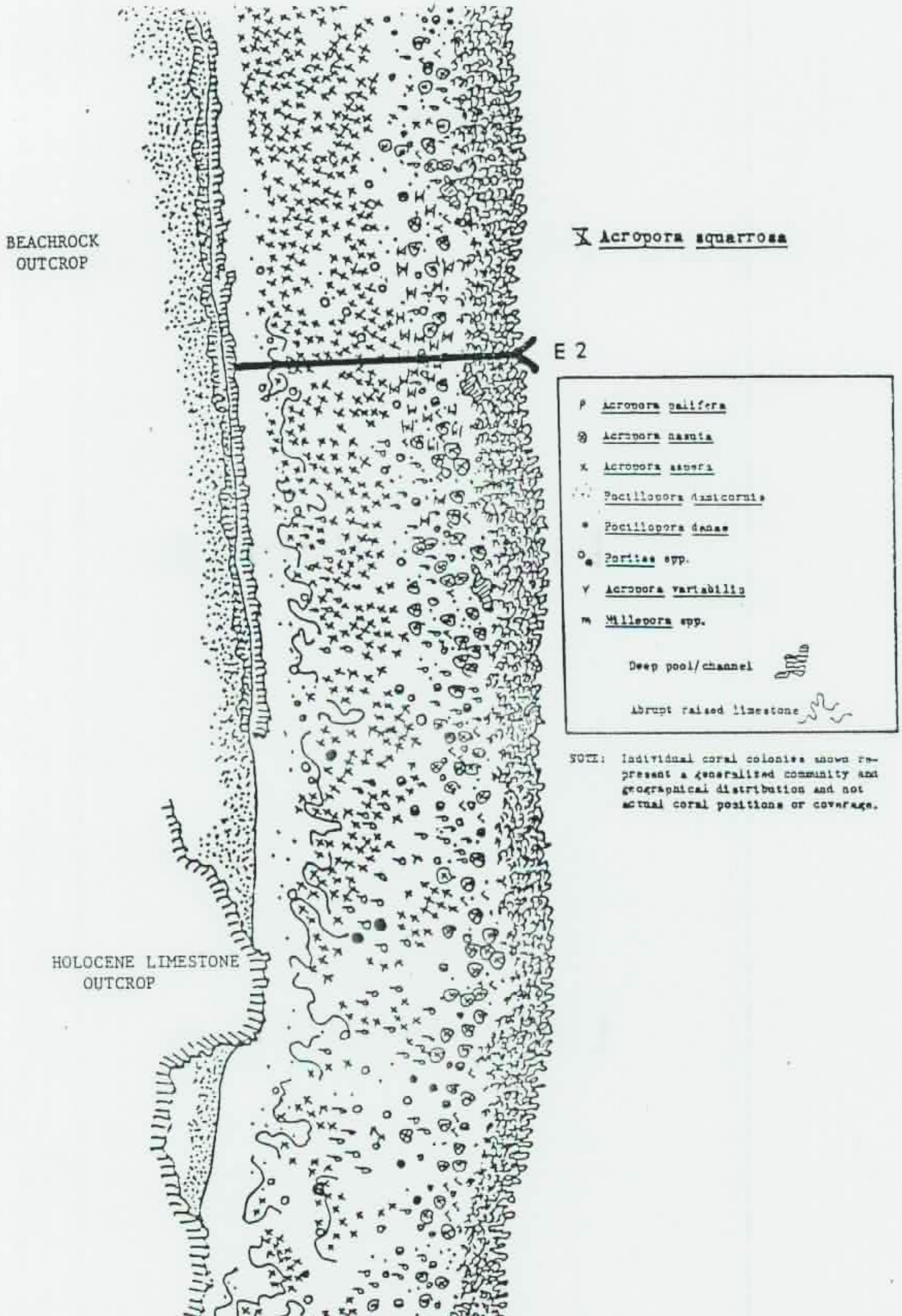

Figure 10b. Map of the fringing reef platform showing the relative abundance and distribution of major reef-building coral species in the vicinity of Transect E-2.

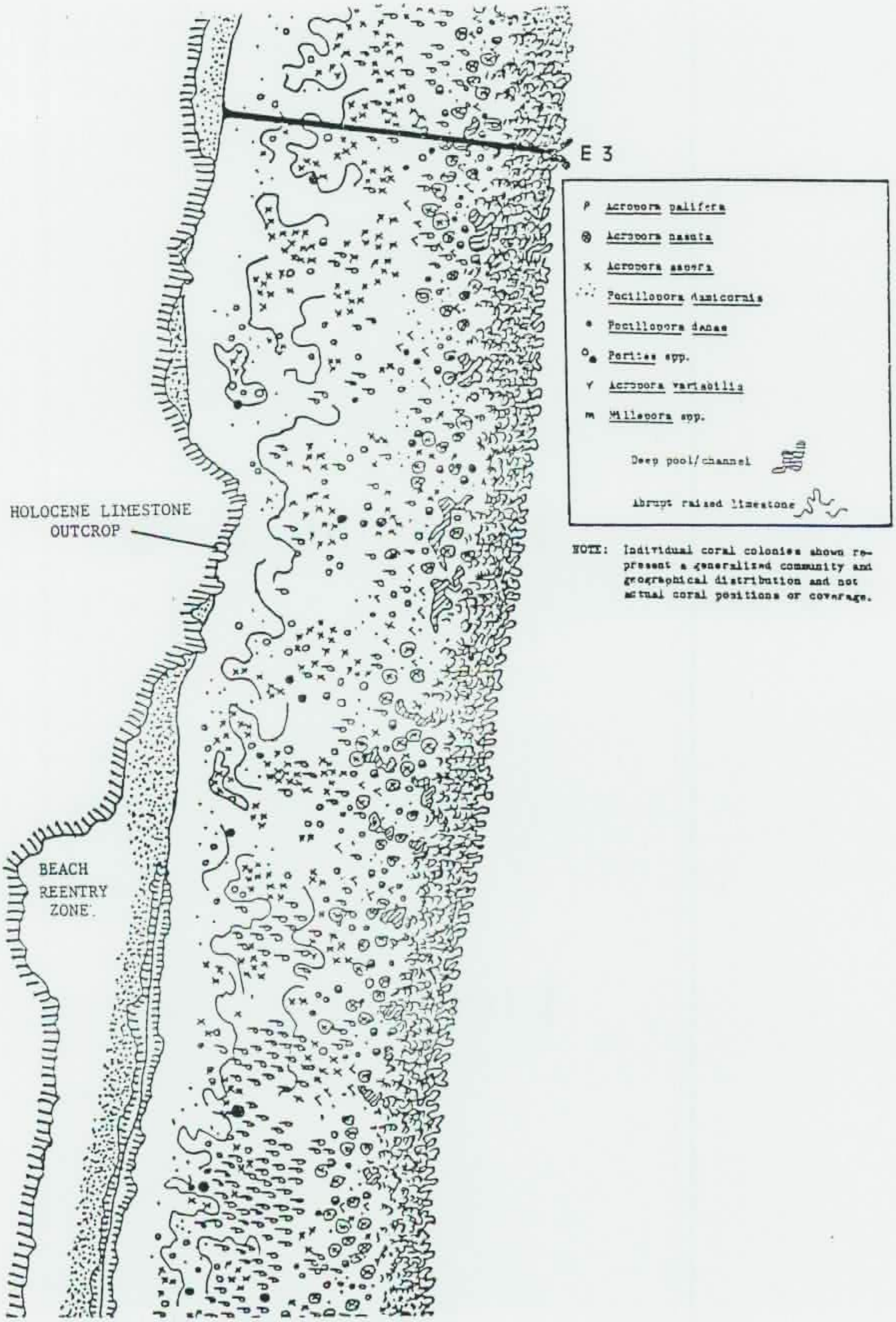

Figure 10c. Map of the fringing reef platform showing the relative abundance and distribution of major reef-builing coral species in the vicinity of and southeast of Transect E-3.

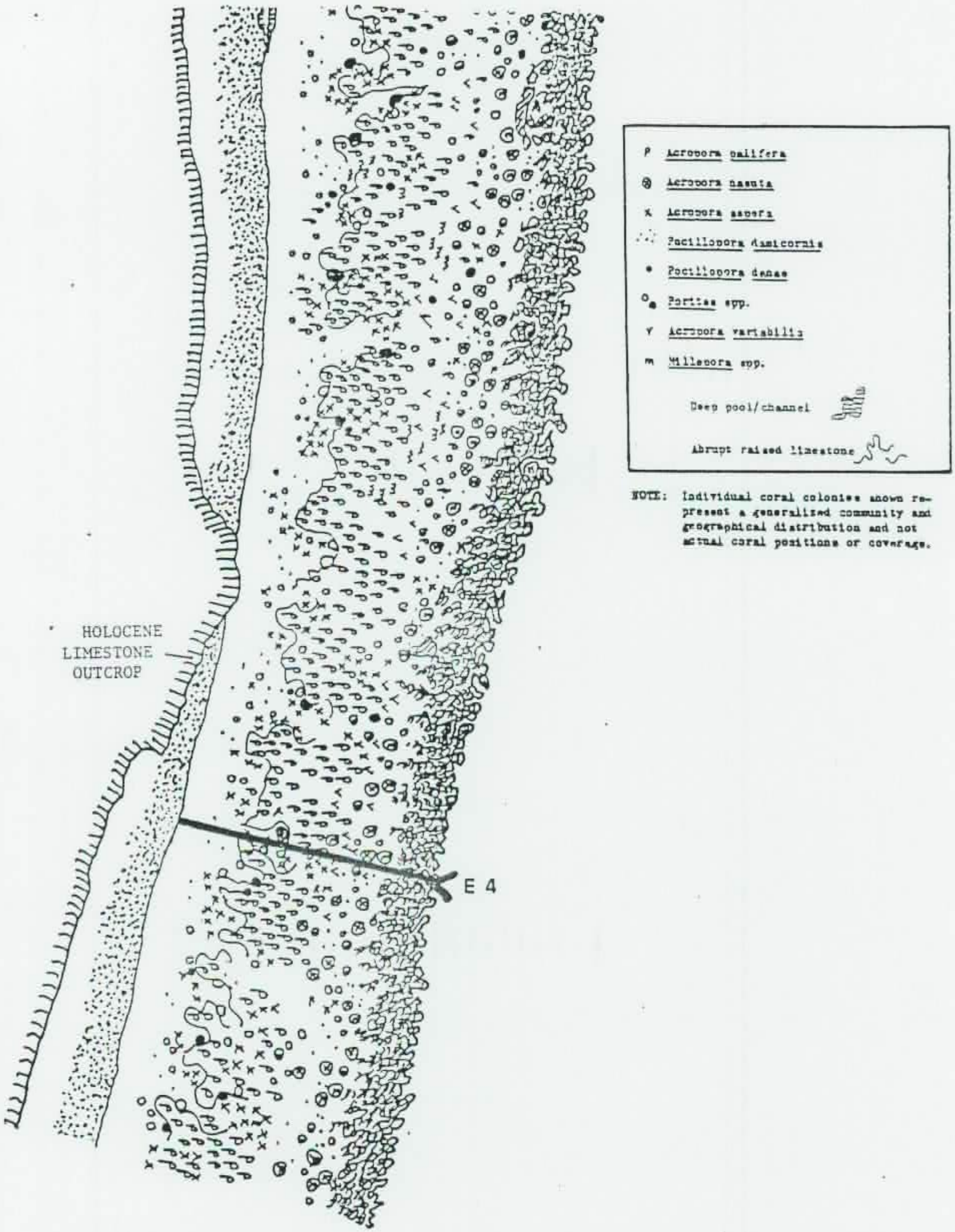

Figure 10d. Map of the fringing reef platform showing the relative abundance and distribution of major reef- building coral species in the vicinity of Transect E-4.

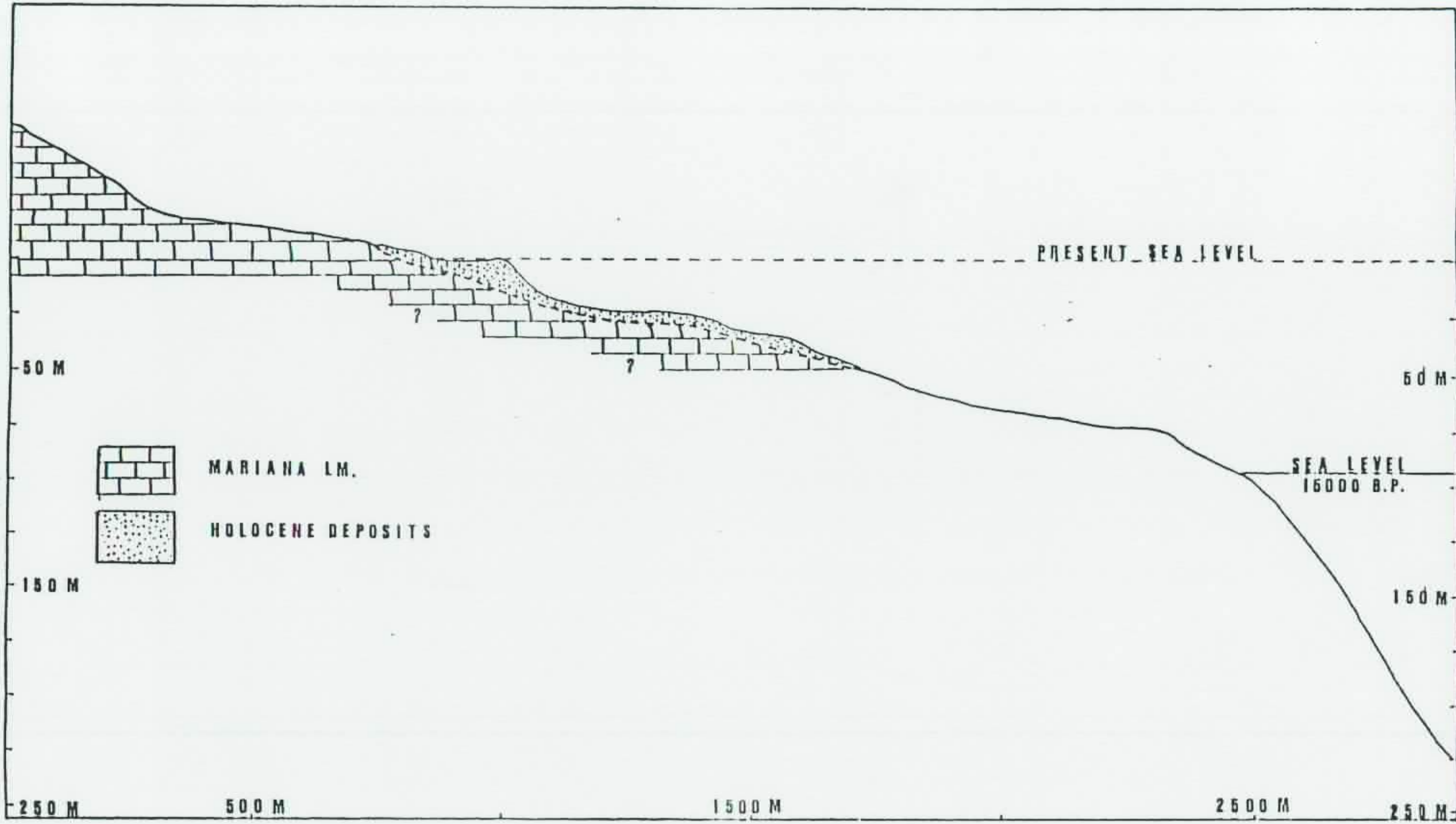

Figure 11. Generalized vertical profile of the northern coast of Guam showing the proposed sea level about 15,000 years B.P.

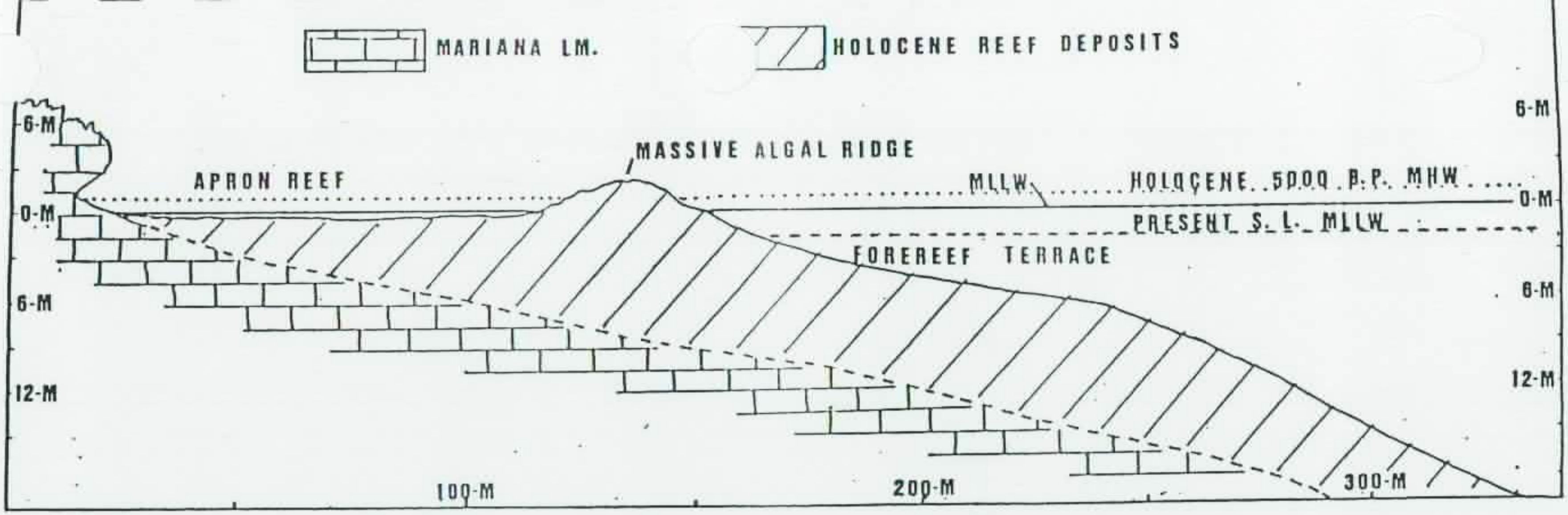

Figure 12. Vertical profile showing a generalized reconstruction of the Holocene fringing reefs about 5000 years B.P. along the northern coast of Guam.

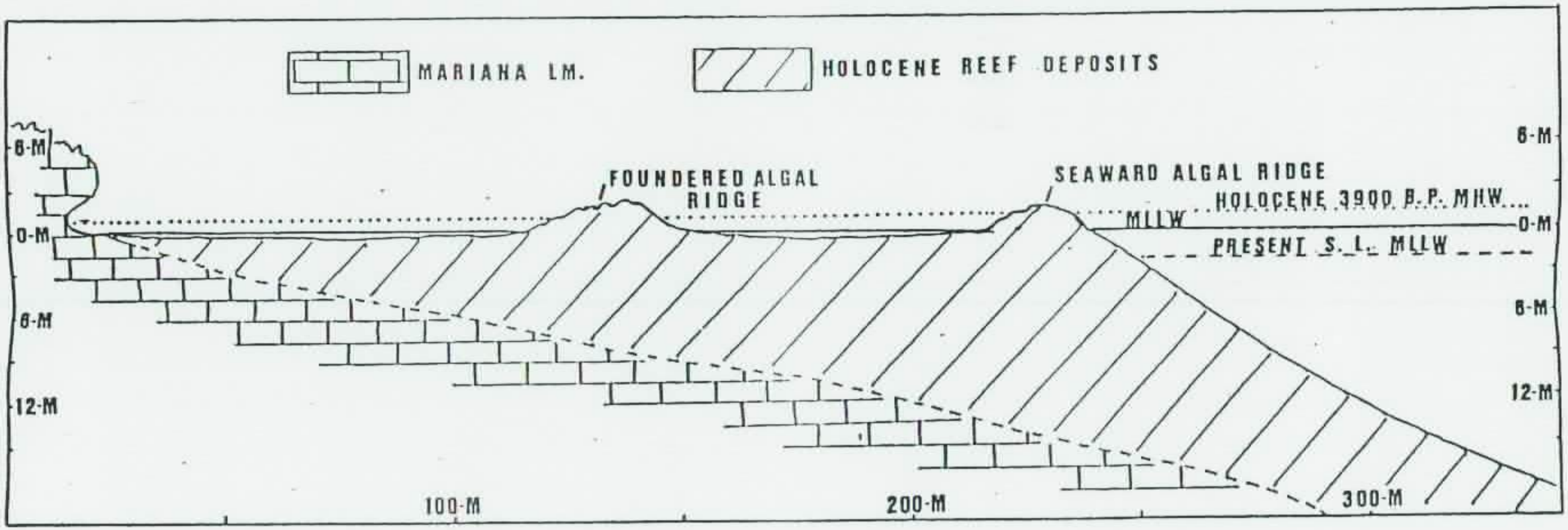

Figure 13. Vertical profile showing a generalized reconstruction of the Holocene fringing reefs about 3900 years B.P. aong the northern coast of Guam.

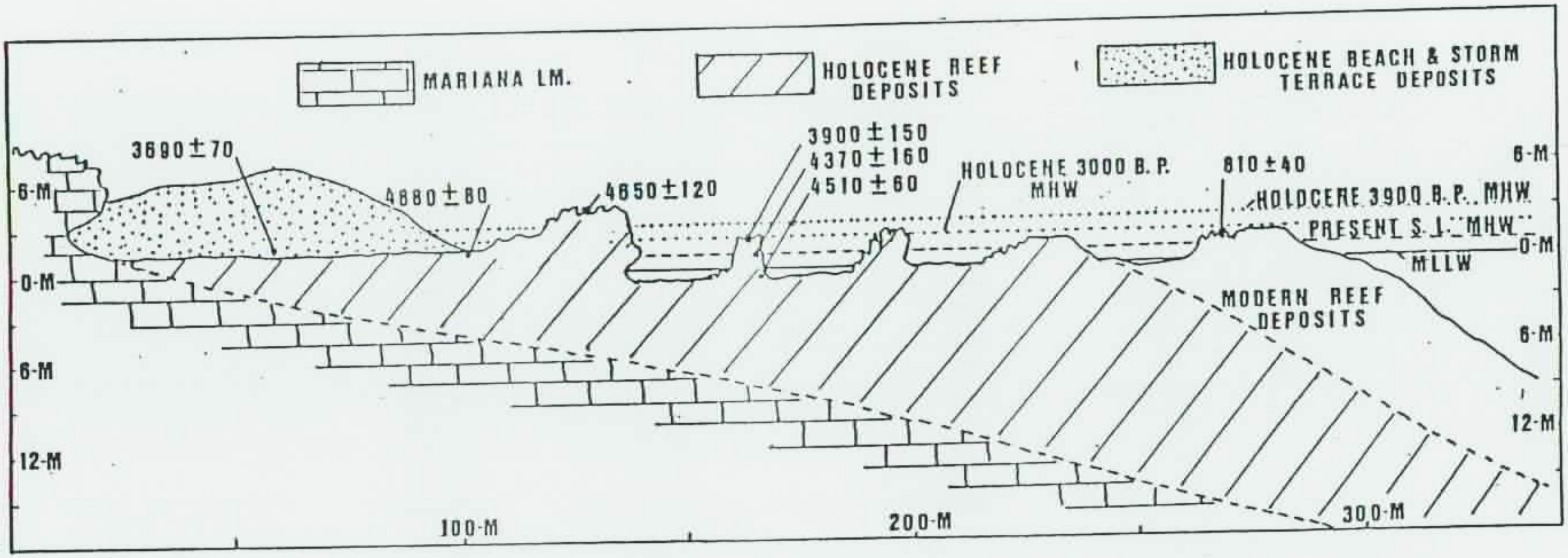

Figure 14. Vertical profile representation of a fringing reef system located 1km NW of Tarague Channel showing present elevations and facies relationships of Mariana Limestone, emergent Holocene and modern reef deposits, and storm and beach deposits. The locations and dates of radiometrically dated samples are also shown. The dashed contact between Mariana Limestone and Holocene reef deposits is inferred.

Table 1. Species list of fossil corals observed or collected from emergent Holocene reef and beachrock outcrop along Transects H-W1 through H-W4 and Transects H-E1 through H-E4. Transect locations are shown in Figure 4 and representation vertical for the transect are shown in Figure 5.

Table 1. Continued

Species	Transects	H-W1	H-W2	H-W3	H-W4	H-E1	H-E2	H-E3	H-E4
Class - Anthozoa									
Order - Scleractinia									
Family - Pocilloporidae									
Stylophora mordax (Dana, 1846)					x				
Pocillopora damicornis (Linnaeus, 1758)								x	
Pocillopora setchelli (Hoffmeister, 1929)								x	
Pocillopora sp. (Cespitos)									x
Family - Acroporidae									
Acropora digitifera (Dana, 1846)					x				x
Acropora humilis (Dana, 1846)					x			x	x
Acropora irregularis (Brook, 1892)					x				x
Acropora monticulosa (Bruggemann, 1879)			x	x	x				x
Acropora palifera (Lamarck, 1816)									x
Acropora surculosa (Dana, 1846)					x				x
Acropora sp. (Cespitose)			x			x	x	x	x
Astreopora sp. (massive)				x					x
Montipora sp. (encrusting)									x
Family - Agariciidae									
Pavona dverdeni (Vaughan, 1907)					x				
Family - Poritadae									
Porites lutea (Milne Edwards and Haime, 1860)					x			x	x
Porites sp.1 (Massive-nodular)		x		x					x
Porites sp.2 (subcolumnar)									x
Family - Faviidae									
Favia favus (Forskal, 1775)					x			x	x
Favia matthaii (Vaughan, 1918)				x		x			x
Favia pallida (Dana, 1846)					x				x
Favia stelligera (Dana, 1846)					x				x
Favites cf. abdita (Ellis and Solander, 1786)					x				x
Favites flexvosa (Dana, 1846)					x				x

Table 1. Continued

Species	Transects H-W1	H-W2	H-W3	H-W4	H-E1	H-E2	H-E3	H-E4
Goniastrea edwardsi (Chevalier, 1971)			x	x				x
Goniastrea retiformis (Lamarck, 1816)		x	x	x	x	x	x	x
Platygyra daedalea (Ellis and Solander, 1786)				x				x
Platygyra pini (Chevalier, 1975)								x
Leptoria phrygia (Ellis and Solander, 1786)		x		x	x		x	x
Hydnophora microconos (Lamarck, 1816)								x
Montastrea curta (Dana, 1846)				x			x	x
Leptastrea purpurea (Dana, 1846)								x
Leptastrea transversa (Klunzinger, 1879)								x
Cyphastera microphthalma (Lamarck, 1816)			x					x
Cyphastrea sp.				x				x
Echinopora cf. *lamellosa* (Esper, 1797)				x				
Family - Mussidae								
Acanthastrea echinata (Dana, 1846)								x
Lobophylla corymbosa (Forskal, 1775)				x				
Order - Coenothecalia								
Family - Helioporidae								
Heliopora coerulea (pallas, 1766)	x	x	x	x	x			
Class - Hydrozoa								
Order - Milleporina								
Family - Milleporida								
Mellepora platyphylla (Hemprich and Ehrenberg, 1884)			x	x	x			
Total Species	2	5	9	23	5	2	9	31
Total Genera	2	4	7	13	5	2	7	16

Table 2. Percent of substrate coverage by reef corals, calcareous algae, detrital matrix, and Pleistocene limestone outcrop calculated from a line intercept transect sampling area at Pajon Point (Transect H-E4). For a vertical profiles of the transect area see Figure 3.

Species or Group	Algal Ridge Facies				Backreef Platform Facies	
	Forecrest Slope Subfacies (0-14.8m)		Backcrest Slope Supfacies (14.8-22 m)		No subdivision (22-46.4 m)	
Reef-Building Corals	Occurrence	Percent Coverage	Occurrence	Percent Coverage	Occurrence	Percent Coverage
Acropora digitifera (Dana, 1846)					1	1.2
Astreopora sp.					1	0.2
Favia matthaii Vaughan, 1918			1	2.4	1	0.1
Favia stelligera (Dana, 1948)	1	6.4	2	3.9	1	0.4
Goniastrea edwardsi					1	1.0
Goniastrea retiformis (Lamarck, 1866)	1	1.0	1	3.8	6	20.2
Leptastrea purpurea (Dana, 1846)					1	0.4
Leptoria phrygia (Ellis and Solander, 1786)	1	1.7				
Montastrea curta (Dana, 1846)			1	1.6	1	0.4
Montipora sp.			1	1.3		
Platygyra daedalea (Ellis and Solander, 1786)					1	1.3
Pocillopora sp.					1	0.6
Porites sp.					4	11.3

Table 2. Continued.

Species or Group	Algal Ridge Facies: Forecrest Slope Subfacies (0-14.8 m)		Algal Ridge Facies: Backcrest Slope Subfacies (14.8-22m)		Backreef Platform Facies: No Subdivision (22-46.4 m)	
Calcareous Algae	Occurrence	Percent Coverage	Occurrence	Percent Coverage	Occurrence	Percent Coverage
Crustose red Algae (*Porolithon* sp.)	4	90.9	8	87.0	3	4.1
Detrital matrix					10	17.7
Pleistocene Limestone Outcrop					11	41.1
Totals		100.0		100.0		100.0

Table 3. Species list and relative abundance of living corals recorded on Transects E-1 through E-5 and W-1 through W-3. The list includes corals recorded on the transects and those observed within the general vicinity of the transects. Transects locations are shown in Figure 1 and vertical profiles for Transects E-1 through E-3 and W-1 through W-3 are shown on Figure 2. Relative abundance of species within each transect area is indicated with letters as follows: R = rare (1 occurrence), O = occasional (2 to 4 occurrence), C = common (5 to 8 occurrences), A = abundant (9 to 16 occurrences), and A = abundant (over 16 occurrences).

Species	Transects	E-1	E-2	E-3	E-4	E-5	W-1	W-2	W-3
Class - Anthozoa									
Order - Scleractinia									
Family - Astrocoeniidae									
Stylocoeniella armata	(Ehrenberg, 1834)	C	A						
Family - Thamnasteriidae									
Psammocora contigua	(Esper, 1797)	O	C	O			C	O	O
Psammocora digitata	(Milne, Edwards and Haime, 1851)	R							
Family - Pocilloporidae									
Stylophora mordax	(Dana, 1846)	C	R	C	R	O			
Pocillopora damicornis	(Linnaeus, 1758)	A	O	C	O	O	A	O	O
Pocillopora danae	(Verrill, 1864)	O	O	O	R	O	R	O	
Pocillopora elegans	(Dana, 1846)	R							
Pocillopora eydouxi	(Milne, Edwards and Haime, 1860)	R							
Pocillopora setchelli	(Hoffmeister, 1929)	C	C	C	C	C	O	O	O
Pocillopora verrucusa	(Ellis and Solander, 1786)	R	R						
Pocillopora sp. 1		O	R						
Family - Acroporidae									
Acropora aspera	(Dana, 1846)	A	D	R		O	O		
Acropora azurea	(Veron and Wallace, 1984)	O	O	O	O	R	R	C	O
Acropora cerealis	(Dana, 1846)	O	O	O	O			R	
Acropora digitifera	(Dana, 1846)	O	C	O	C	O			
Acropora humilis	(Dana, 1846)	R	R	R	R	R			
Acropora irregularis	(Brook, 1892)	R	R			R			
Acropora monticulosa	(Bruggemann, 1879)	R	R	R	R	R			X
Acropora nasuta	(Dana, 1846)		R						
Acropora ocellata	(Klunzinger, 1879)	R	O	O	R	O	O	R	O
Acropora palifera	(Lamarck, 1816)	D	O	C	D	O		O	
Acropora quelchi	(Brook, 1893)		R	R	R	R			
Acropora squarrosa	(Ehrenberg, 1834)	R	O	O	R	R			R
Acropora studeri	(Brook, 1893)		R						
Acropora surculosa	(Dana, 1846)	R	O						
Acropora tenuis	(Dana, 1846)	R		R					
Acropora sp. 1			R						

Table 1. Continued.

Species	Transects	E-1	E-2	E-3	E-4	E-5	W-1	W-2	W-3
Astreopora myriophthalma	(Lamarck, 1816)	R							R
Montipora berryi	(Hoffmeister, 1925)	R	R						
Montipora caliculata	(Dana, 1846)	R							
Montipora ehrenbergii	(Verrill, 1875)		R						
Montipora elschneri	(Vaughan, 1918)	R	R			R			
Montipora granulosa	(Bernard, 1897)	R							
Montipora hoffmeisteri	(Wells, 1954)	R	R						
Montipora lobulata	(Bernard, 1897)	R							
Montipora monasteriata	(Forskal, 1775)		R						
Montipora planiuascula	(Dana, 1846)	R	R						
Montipora tuberculosa	(Lamarck, 1816)	R	R						
Montipora venosa	(Ehrenberg, 1834)		R						
Montipora verrilli	(Vaughan, 1907)	R	R	R					
Montipora verrucosa	(Lamarck, 1816)		R						
Montipora sp.1		O	C	O	C	O			
Montipora sp.2				R					
Montipora sp.3		R	R						
Family - Agariciidae									
Pavona divaricata	(Lamarck, 1816)	R	R						
Pavona maldivensis	(Gardiner, 1905)		R						
Pavona varians	(Verrill, 1864)		R						
Pavona venosa	(Ehrenberg, 1834)	R	R					R	
Pavona sp.1		R						R	
Pavona sp.3		R	R	R					
Leptoseris incrustans	(Quelch, 1886)	R							
Family - Poritidae									
Porites annae	(Crossland, 1952)	R					R		
Porites australiensis	(Vaughan, 1918)	O	O	O		R	C	O	R
Porites cylindrica	(Dana, 1846)	R					R		
Porites densa	(Vaughan, 1918)	R	C						
Porites lichen	(Dana, 1846)	R	R	C	O	R	O		
Porites lobata	(Dana, 1846)		R						
Porites lutea	(Milne Edwards and Haime, 1860)	O	O	O	O	R	A	O	O
Porites murrayensis	(Vaughan, 1918)		R						
Porites superfusa	(Gardiner, 1898)	C	C	C	C	C			
Porites (N.) vaughan	(Crossland, 1952)	O	O						
Porites (S.) sp.1		R	R	R					
Porites (S.) sp.2		R							
Alveopora virdis	(Quoy and Gaimard, 1833)	R	R						

Table 1. Continued.

Species		Transects E-1	E-2	E-3	E-4	E-5	W-1	W-2	W-3
Family - Faviidae									
Favia favus	(Forskal, 1775)	R	R			R	R	R	R
Favia mattnaii	(Vaughan, 1918)	O		R	O			R	
Favia pallida	(Dana, 1846)	O	O	O	R	R			R
Favia stelligera	(Dana, 1846)	R	O						R
Favia abdita	(Ellis and Solander, 1786)	R	O		O			R	R
Favia flexuosa	(Dana, 1846)		R						
Favia russelli	(Wells, 1954)	R		R				R	
Goniastrea edwardsi	(Chevalier, 1971)	R							
Goniastrea pectinata	(Ehrenberg, 1834)	R							
Goniastrea retiformis	(Lamarck, 1816)	C	C	O				O	
Platygyra daedalea	(Ellis and Solander, 1786)		O		O			R	
Platygyra pini	(Chevalier, 1975)	O	R	O		R	R		
Leptoria phrygia	(Ellis and Solander, 1786)	O	R	R		R	R	R	R
Hydnophora microconos	(Lamarck, 1816)						R	C	R
Montastrea curta	(Dana, 1846)	O		O					
Leptastrea bottae	(Milne Edwards and Haime, 1849)	R			R				
Leptastrea purpurea	(Dana, 1846)	O	O	R		R		O	O
Cyphastrea microphthalma	(Lamarck, 1816)			R					
Cyphastrea serailia	(Forskal, 1775)		R			R			
Echinopora lamellosa	(Esper, 1797)		R						
Family - Oculinidae									
Galaxea fascicularis	(Linnaeus, 1758)	O	O	O	O				
Family - Mussidae									
Acanthastrea echinata	(Dana, 1846)	R	O	O					
Lobophyllia corymbosa	(Forskal, 1775)	R		R	O				
Lobophyllia hemprichii	(Ehrenberg, 1834)	R							
Order - Coenothecalia									
Family - Helioporidae									
Heliopora coerulea	(Pallas, 1766)	R	R	O					

Table 1. Continued.

Species	Transects	E-1	E-2	E-3	E-4	E-5	W-1	W-2	W-3
Class - Hydrozoa									
Order - Milleporina									
Family - Milleporidae									
Millepora dichotoma (Forskal, 1775)		R	0	R				C	
Millepora latifolia (Boschma, 1948)				R					
Millepora platyphylla (Hemprich and Ehrenberg, 1834)		0	0	0	0	0	0	R	0
Millepora tuberosa (Boschma, 1948)			0						
Total Species		72	69	41	25	27	17	22	21
Total Genera		23	21	20	12	11	9	13	13
Total Species for Transects E-1 - E-5		92							
Total Genera for Transects E-1 - E-5		25							
Total Species for Transect W-1 - W-3		34							
Total Genera for Transect W-1 - W-5		16							
Total Species for all Transects		93							
Total Genera for all Transects		26							

Table 4. Coral size distribution, frequency and relative, density and relative density, percent cover and relative cover, and importance value for coral species of Transects E-1 through E-5 and W-1 through W-3. Species are list in order of their importance values.

Transect No., Physiographic Zones, and Coral Species		Size Distribution (colony diameters in cm) n	y	s	W	Frequency	Relative Frequency	Density (per m²)	Relative Density	Percent Cover	Relative Percent Cover	Importance Value
Transect E-1												
Sand moat	(0-15 meters)											
<u>Pocillopora damicornis</u>		5	10.2	7.4	4.0- 23.0	1.00	59.88	0.79	62.50	0.92	65.25	187.63
<u>Porites lutea</u>		3	11.0	3.6	8.0- 15.0	0.67	40.12	0.48	37.50	0.49	34.75	112.37
	Totals	8	10.5	5.9	4.0- 23.0			1.27		1.41		
Transect E-1												
Inner Reef Platform	(14-75 meters)											
<u>Acropora aspera</u>		7	110.4	35.9	68.0-175.0	0.50	37.88	0.10	33.33	10.38	55.90	127.11
<u>Acropora palifera</u>		6	99.8	47.5	45.0-150.0	0.25	18.94	0.09	28.57	7.91	42.60	90.11
<u>Pocillipora damicornis</u>		5	14.9	5.1	10.0- 22.0	0.33	25.00	0.07	23.81	0.14	0.75	49.56
<u>Favia favus</u>		1	25.0	-	-	0.08	6.06	0.01	4.76	0.07	0.38	11.20
<u>Porites lutea</u>		1	18.0	-	-	0.08	6.06	0.01	4.76	0.04	0.22	11.04
<u>Porites lichen</u>		1	16.0	-	-	0.08	6.06	0.01	4.76	0.03	0.16	10.98
	Totals	21	71.7	54.2	10.0-175.0			0.29		18.57		
Transect E-1												
Outer Reef Platform	(75-105 meters)											
<u>Acropora palifera</u>		8	97.0	36.7	65.0-175.0	0.50	27.32	0.52	47.06	43.77	67.53	141.91
<u>Acropora digitifera</u>		3	35.0	7.5	27.0- 42.0	0.33	18.03	0.20	17.65	1.91	2.95	38.63
<u>Millepora dichetoma</u>		1	140.0	-	-	0.17	9.29	0.07	5.88	10.06	15.52	30.69
<u>Pocillopora setchelli</u>		2	13.4	7.4	8.0- 18.5	0.33	18.03	0.13	11.76	0.21	0.32	30.11
<u>Pocillopora danae</u>		2	13.8	1.8	12.5- 15.0	0.33	18.03	0.13	11.76	0.20	0.31	30.10
<u>Acropora irregularis</u>		1	130.0	-	-	0.17	9.29	0.07	5.88	8.67	13.38	28.55
	Totals	17	71.0	50.4	8.0-175.0			1.12		64.82		
Transect E-2												
Sand Moat (No corals encountered)		(0-10 meters)										

Table 4. Continued.

Transect No., Physiographic Zones, and Coral Species		Size Distribution (colony diameters in cm) n	y	s	w	Frequency	Relative Frequency	Density (per m²)	Relative Density	Percent Cover	Relative Percent Cover	Importance Value
Transect E-2												
Inner Reef Platform	(10-85 meters)											
Acropora aspera		17	123.9	51.2	36.0-200.0	0.67	58.26	0.20	70.83	27.58	98.43	227.52
Pocillopora damicornis		4	16.1	7.8	8.0-26.0	0.27	23.48	0.05	16.67	0.11	0.39	40.54
Acropora palifera		1	55.0	-	-	0.07	6.09	0.01	4.17	0.28	1.00	11.26
Porites lutea		1	18.5	-	-	0.07	6.09	0.01	4.17	0.23	0.11	10.37
Porites lichen		1	15.0	-	-	0.07	6.09	0.01	4.17	0.02	0.07	10.33
	Totals	24	94.1	64.3	8.0-200.0			0.28		28.02		
Transect E-2												
Outer Reef Platform	(85-140 meters)											
Acropora aspera		2	85.0	21.2	70.0-100.0	0.18	8.70	0.06	7.69	3.23	33.20	49.59
Acropora digitefera		5	25.3	8.9	17.0-38.0	0.36	17.38	0.14	19.23	0.76	7.81	44.42
Acropora squarrosa		4	26.3	3.9	21.0-30.0	0.27	13.04	0.11	15.38	0.61	6.27	34.49
Pocillopora danae		4	11.9	2.4	10.0-15.0	0.36	17.38	0.11	15.38	0.13	1.34	34.10
Porites australiensis		2	60.0	7.1	55.0-65.0	0.18	8.70	0.06	7.69	1.57	16.14	32.53
Heliopora coerulea		1	88.0	-	-	0.09	4.35	0.03	3.85	1.68	17.27	25.47
Acropora azurea		3	23.7	12.5	15.0-38.0	0.18	8.70	0.08	11.54	0.43	4.42	24.66
Acropora palifera		1	65.0	-	-	0.09	4.35	0.03	3.85	0.92	9.46	17.66
Porites lutea		1	25.0	-	-	0.09	4.35	0.03	3.85	0.14	1.44	9.64
Favia favus		1	22.0	-	-	0.09	4.35	0.03	3.85	0.11	1.13	9.33
Stylophora mordax		1	22.0	-	-	0.09	4.35	0.03	3.85	0.11	1.13	9.33
Pocillopora setchelli		1	14.0	-	-	0.09	4.35	0.03	3.85	0.04	0.41	8.61
	Totals	26	33.7	24.7	10.0-100.0			0.74		9.73		
Transect E-3												
Sand Moat		(0-15 meters)										
Pocillopora damicornis		1	16.0	-	-	0.33	50.00	0.015	50.00	0.03	60.00	160.00
Porites australiensis		1	12.5	-	-	0.33	50.00	0.015	50.00	0.02	40.00	140.00
	Totals	2	14.3	2.5	12.5-16.0			0.030		0.05		

Table 4. Continued.

Transect No., Physiographic Zones, and Coral Species		Size Distribution (colony diameters in cm) n	y	s	w	Frequency	Relative Frequency	Density (per m^2)	Relative Density	Percent Cover	Relative Percent Cover	Importance Value
Transect E-3												
Inner Reef Platform	(15-85 meters)											
Acropora aspera		6	74.5	24.2	48.0-110.0	0.29	16.96	0.08	22.22	3.77	30.50	69.68
Acropora palifera		4	97.3	22.0	84.0-130.0	0.29	16.96	0.05	14.81	4.09	33.09	64.86
Pocillopora damicornis		6	22.0	5.9	12.0-28.0	0.43	25.15	0.08	22.22	0.32	2.59	49.96
Millepora dichotoma		1	175.0	-	-	0.07	4.09	0.01	3.70	3.19	25.81	33.60
Favia pallida		2	22.5	10.6	15.0-30.0	0.14	8.19	0.03	7.41	0.12	0.97	16.57
Porites lutea		2	23.0	0.0	23.0-23.0	0.14	8.19	0.03	7.41	0.11	0.89	16.49
Pcropora squarrosa		2	34.0	8.5	28.0-40.0	0.07	4.09	0.03	7.41	0.25	0.02	13.52
Heliopora coerulea		1	65.0	-	-	0.07	4.09	0.01	3.70	0.44	3.56	11.35
Leptoria phrygia		1	21.0	-	-	0.07	4.09	0.01	3.70	0.05	0.40	8.19
Platygyra pini		1	8.0	-	-	0.07	4.09	0.01	3.70	0.01	0.08	7.78
Pocillopora danae		1	9.0	-	-	0.07	4.09	0.01	3.70	0.01	0.08	7.87
	Totals	27	52.0	41.8	8.0-175.0			0.35		12.36		
Transect E-3												
Outer Reef Platform	(85-140 meters)											
Acropora palifera		3	101.0	17.5	85.5-120.0	0.27	13.04	0.06	12.50	5.13	34.15	59.69
Porites australiensis		1	180.0	-	-	0.09	4.35	0.02	4.17	5.33	35.49	44.01
Acropora digitifera		4	26.6	2.9	23.0- 30.0	0.36	17.39	0.08	16.67	0.47	3.13	37.19
Porites lutea		2	63.0	26.9	44.0- 82.0	0.18	8.70	0.04	8.33	1.42	9.45	26.48
Pocillopora danae		3	12.3	0.3	12.0- 12.5	0.27	13.04	0.06	12.50	0.08	0.53	26.07
Acropora azurea		3	21.2	4.4	17.5- 26.0	0.18	8.70	0.06	12.50	0.23	1.53	22.73
Heliopora coerulea		1	80.0	-	-	0.09	4.35	0.02	4.17	1.05	6.99	15.51
Acropora aspera		1	56.0	-	-	0.09	4.35	0.02	4.17	0.52	3.46	11.98
Galaxea fascicularis		1	55.0	-	-	0.09	4.35	0.02	4.17	0.50	3.33	11.85
Montipora sp. 1		1	27.0	-	-	0.09	4.35	0.02	4.17	0.12	0.80	9.32
Stylophora mordax		1	23.0	-	-	0.09	4.35	0.02	4.17	0.09	0.60	9.12
Acropora humilis		1	16.0	-	-	0.09	4.35	0.02	4.17	0.04	0.27	8.79
Favia matthaii		1	14.0	-	-	0.09	4.35	0.02	4.17	0.03	0.20	8.72
Platygyra pini		1	6.0	-	-	0.09	4.35	0.02	4.17	0.01	0.07	8.59
	Totals	24	43.3	43.3	6.0-180.0			0.48		15.02		

Table 4. Continued.

Transect No., Physiographic Zones, and Coral Species		Size Distribution (colony diameters in cm) n	y	s	w	Frequency	Relative Frequency	Density (per m^2)	Relative Density	Percent Cover	Relative Percent Cover	Importance Value
Transect E-4												
Inner Reef Platform	(0-85 meters)											
Acropora palifera		21	70.5	60.4	8.0-200.0	0.47	49.47	0.25	72.41	15.54	97.49	219.37
Pocillopora damicornis		4	18.6	6.4	10.0-24.0	0.24	25.26	0.05	13.79	0.14	0.88	39.93
Acropora squarrosa		1	38.0	-	-	0.06	6.32	0.01	3.45	0.13	0.82	10.59
Porites lichen		1	34.0	-	-	0.06	6.32	0.01	3.45	0.11	0.69	10.46
Pocillopora danae		1	12.0	-	-	0.06	6.32	0.01	3.45	0.01	0.06	9.83
Pocillopora setchelli		1	6.5	-	-	0.06	6.32	0.01	3.45	0.01	0.06	9.83
	Totals	29	56.7	56.2	6.5-200.0			0.34		15.94		
Transect E-4												
Outer Reef Platform	(85-115 meters)											
Acropora digitifera		6	46.3	7.2	35.0-55.0	0.67	33.17	0.33	40.00	5.75	71.16	144.33
Porites lutea		2	30.5	20.5	16.0-45.0	0.33	16.34	0.11	13.33	1.00	12.38	42.05
Acropora azurea		2	20.0	2.8	18.0-22.0	0.17	8.42	0.11	13.33	0.35	4.33	26.08
Porites lichen		1	26.5	-	-	0.17	8.42	0.06	6.67	0.31	3.84	18.93
Pocillopora setchelli		1	22.0	-	-	0.17	8.42	0.06	6.67	0.21	2.60	17.69
Acropora humilis		1	20.0	-	-	0.17	8.42	0.06	6.67	0.17	2.10	17.19
Stylophora mordax		1	18.5	-	-	0.17	8.42	0.06	6.67	0.15	1.86	16.95
Favia pallida		1	18.0	-	-	0.17	8.42	0.06	6.67	0.14	1.73	16.82
	Totals	15	32.3	14.3	16.0-55.0			0.85		8.08		
Transect E-5												
Inner Reef Platform	(0-35 meters)											
Pocillopora damicornis		3	28.8	13.8	14.5-42.0	0.43	60.56	0.02	60.00	0.17	56.67	177.23
Porites lutea		1	38.0	-	-	0.14	19.72	0.01	20.00	0.08	26.67	66.39
Favia favus		1	28.0	-	-	0.14	19.72	0.01	20.00	0.05	16.67	56.39
	Totals	15	32.3	14.3	16.0-55.0			0.04		0.30		

Table 4. Continued.

Transect No., Physiographic Zones, and Coral Species		Size Distribution (colony diameters in cm) n	y	s	w	Frequency	Relative Frequency	Density (per m^2)	Relative Density	Percent Cover	Relative Percent Cover	Importance Value
Transect E-5												
Outer Reef Platform	(35-95 meters)											
Acropora palifera		4	108.3	29.8	86.0-150.0	0.25	20.00	0.06	20.00	5.46	54.27	94.27
Acropora aspera		2	105.0	21.2	90.0-120.0	0.08	6.40	0.03	10.00	2.47	24.55	40.95
Acropora azurea		5	19.7	6.8	10.0-28.0	0.17	13.60	0.07	25.00	0.23	2.27	40.87
Acropora digitifera		2	52.0	0.0	52.0-52.0	0.17	13.60	0.03	10.00	0.59	5.86	29.46
Pocillopora setchelli		2	10.8	3.9	8.0-13.5	0.17	13.60	0.03	10.00	0.03	0.30	23.90
Pocillopora danae		2	10.3	3.2	8.0-12.5	0.17	13.60	0.03	10.00	0.02	0.20	23.80
Acropora irregularis		1	100.0	-	-	0.08	6.40	0.01	5.00	1.10	10.93	23.33
Porites lichen		1	35.0	-	-	0.08	6.40	0.01	5.00	0.13	1.29	12.69
Leptoria phrygia		1	17.5	-	-	0.08	6.40	0.01	5.00	0.03	0.30	11.70
	Totals	20	52.0	44.5	8.0-150.0			0.28		10.06		
Transect W-1												
Sand Moat	(0-15 meters)											
Pocillopora damicornis		1	22.0	-	-	0.33	100.00	0.005	100.00	0.02	100.00	300.00
	Totals	1	22.0	-	-			0.005		0.02		
Transect W-1												
Inner Reef Platform	(15-90 meters)											
Porites australiensis		8	143.8	56.2	45.0-200.0	0.33	31.13	0.05	40.00	9.18	92.45	163.58
Pocillopora damicornis		6	15.0	2.8	12.0-20.0	0.33	31.13	0.04	30.00	0.07	0.70	61.83
Porites lutea		3	36.7	34.0	10.0-85.0	0.20	18.87	0.02	15.00	0.32	3.22	37.09
Porites lichen		2	45.0	14.1	35.0-55.0	0.13	12.26	0.01	10.00	0.21	2.11	24.37
Acropora aspera		1	55.0	-	-	0.07	6.60	0.01	5.00	0.15	1.51	13.11
	Totals	20	74.8	69.0	10.0-200.0			0.13		9.93		

Table 4. Continued.

Transect No., Physiographic Zones, and Coral Species		Size Distribution (colony diameters in cm) n	y	s	w	Frequency	Relative Frequency	Density (per m^2)	Relative Density	Percent Cover	Relative Percent Cover	Importance Value
Transect W-1												
Outer Reef Platform	(90-135 meters)											
Porites lutea		5	74.0	48.4	22.0-150.0	0.44	40.00	0.07	41.67	3.79	78.96	160.63
Pocillopora damicornis		4	12.1	1.8	10.0-14.5	0.33	30.00	0.05	33.33	0.06	1.25	64.58
Acropora aspera		1	95.0	-	-	0.11	10.00	0.01	8.33	0.93	19.38	37.71
Favia favus		1	8.0	-	-	0.11	10.00	0.01	8.33	0.01	0.21	18.54
Pocillopora danae		1	12.0	-	-	0.11	10.00	0.01	8.33	0.01	0.21	18.54
	Totals	12	44.5	45.6	8.0-150.0			0.15		4.80		
Transect W-2												
Inner Reef Platform	(0-35 meters)											
Pocillopora damicornis		3	19.2	7.5	12.0-27.0	0.43	60.56	0.02	60.00	0.07	10.94	131.59
Porites australiensis		1	95.5	-	-	0.14	19.72	0.01	20.00	0.52	81.25	120.97
Porites lutea		1	30.0	-	-	0.14	19.72	0.01	20.00	0.05	7.81	47.53
	Totals	5	36.6	33.7	12.0-95.5			0.04		0.64		
Transect W-2												
Middle Reef Platform	(35-65 meters)											
Hydnophora microconos		3	42.7	15.7	25.0-55.0	0.33	32.67	0.05	42.86	0.74	81.32	156.85
Porites lutea		1	24.0	-	-	0.17	16.83	0.02	14.29	0.07	7.69	38.81
Leptoria phrygia		1	18.0	-	-	0.17	16.83	0.02	14.29	0.04	4.40	35.52
Favia favus		1	15.0	-	-	0.17	16.83	0.02	14.29	0.03	3.30	34.42
Pocillopora damicornis		1	15.0	-	-	0.17	16.83	0.02	14.29	0.03	3.30	34.42
	Totals	7	26.3	16.3	15.0-55.0			0.13		0.91		
Transect W-2												
Outer Reef Platform	(65-115 meters)											
Millepora dichotoma		6	135.0	41.4	85.0-180.0	0.40	23.53	0.12	27.27	16.10	45.07	95.87
Millepora platyphylla		3	141.8	53.2	95.5-200.0	0.20	11.76	0.06	13.64	10.67	29.87	55.27
Acropora azurea		5	44.6	23.0	28.0-85.0	0.40	23.53	0.10	22.73	1.95	5.46	51.72
Porites australiensis		2	122.5	109.6	45.0-200.0	1.10	5.88	0.04	9.09	6.38	17.86	32.83

Table 4. Continued.

Transect No., Physiographic Zones, and Coral Species		Size Distribution (colony diameters in cm) n	y	s	w	Frequency	Relative Frequency	Density (per m^2)	Relative Density	Percent Cover	Relative Percent Cover	Importance Value
Pocillopora danae		3	12.0	3.8	6.0-15.5	0.30	17.65	0.06	13.64	0.07	0.20	31.49
Hydnophora microconos		2	40.0	7.1	35.0-45.0	0.20	11.76	0.04	9.09	0.52	1.46	22.31
Platygyra daedalea		1	14.0	-	-	0.10	5.88	0.02	4.55	0.03	0.08	10.51
	Totals	22	80.4	62.3	8.0-200.0			0.44		35.72		
Transect W-3												
Sand Moat	(0-10 meters)											
(no corals encountered)												
Transect W-3												
Inner Reef Platform	(10-60 meters)											
Porites australiensis		1	87.5	-	-	0.10	8.33	0.01	7.69	0.67	50.38	66.40
Pocillopora damicornis		4	13.0	1.9	12.0-15.5	0.30	25.00	0.04	30.76	0.06	4.51	60.27
Porites lutea		2	32.5	31.8	10.0-55.0	0.20	16.67	0.02	15.38	0.27	20.30	52.35
Acropora azurea		2	26.3	1.8	25.0-27.5	0.20	16.67	0.02	15.38	0.12	9.02	41.07
Hydnophora microconos		1	30.0	-	-	0.10	8.33	0.01	7.69	0.08	6.02	22.04
Galaxea fascicularis		1	28.0	-	-	0.10	8.33	0.01	7.69	0.07	5.26	21.28
Favia favus		1	20.0	-	-	0.10	8.33	0.01	7.69	0.03	2.26	16.28
Favia pallida		1	18.0	-	-	0.10	8.33	0.01	7.69	0.03	2.26	18.28
	Totals	13	28.4	22.2	10.0-87.5			0.13		1.33		
Transect W-3												
Outer Reef Platform	(60-85 meters)											
Pocillopora danae		2	11.5	0.7	11.0-12.0	0.40	66.67	0.02	66.67	0.02	66.67	200.01
Porites lutea		1	10.0	-	-	0.20	33.33	0.01	33.33	0.01	99.99	
	Totals	3	11.0	1.0	10.0-12.0			0.03		0.03		