COASTAL SURVEY OF GUAM

Richard H. Randall and Jeanne Holloman

UNIVERSITY OF GUAM, MARINE LABORATORY

Technical Report No. 14

August, 1974

COASTAL SURVEY OF GUAM

By

Richard H. Randall

and

Jeanne Holloman

FINAL REPORT

Submitted to
U. S. Army Corps of Engineers
Contract No. DACW84-72-C-0015

University of Guam, Marine Laboratory

TECHNICAL REPORT NO. 14

August, 1974

CONTENTS

Contents (continued)

LIST OF FIGURES

Page

Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

Guam is a small oceanic island situated in the tropical western Pacific Ocean. The ratio of coastline to land area is high in a small island setting such as Guam. For this reason, the importance of the coastal environment is magnified. Guam is presently experiencing economic and population booms that are placing increased demands on its shoreline regions. Geometric increases in tourism, expanding industry and its associated services, military growth, and housing development have progressed at a rate which was not remotely anticipated a few years ago.

A visiting tourist envisions a tropical island as a place with placid blue lagoon-like water bordered with white sandy beaches which, in turn, are clothed in an emerald backdrop of lush tropical vegetation. The businessman sees the island with its expanding economy, population, and tourism as a place for investment and increased production of goods and services. A large segment of the island economy has always been related closely to military activities, which have expanded considerably in the last few years. Land is being utilized at a frantic rate for housing to meet the increased population demands. All these activities have, in turn, necessitated increases in governmental services, educational needs, recreational facilities, power production, water demands, transportation, communications, and waste-disposal facilities.

All of these activities also require increases in areal space, a fixed and finite commodity. Some rightfully require utilization of the shoreline environment. As the demand for land use grows, more coastal land will be taken to fulfill island needs for activities, some of which could be developed elsewhere. Conflicting demands for shoreline use have naturally arisen from the many interest groups wanting to develop this valuable resource.

If the shoreline environment is to best serve the needs of the entire community not only for the present but for future generations as well, a comprehensive plan must be quickly established to carefully develop this resource. A comprehensive plan must start with an evaluation of what the shoreline is at the present, what it has been in the past, and what it could become in the future. Good management of this resource should logically start with an assessment of exactly what there is to work with and should identify physical and biological features, problem areas, present development, and areas about which knowledge is weak or lacking.

Under Public Law 91-611 (River and Harbor Act of 1970) the Chief of Engineers, under the direction of the Secretary of the Army, was given the responsibility to conduct a survey of "Rivers and Harbors in the Territory of Guam in the interest of navigation, flood control, and related water resources purposes." As part of this study the University of Guam Marine Laboratory was contracted by the Army Corps of Engineers to conduct a coastal assessment of the Territory of Guam. A contract (No. DACW84-72-C-0015) for this work was agreed upon, and the notice to proceed was received on June 29, 1972.

SCOPE OF WORK

Location of the study area includes all the coastal regions of the Territory of Guam with major emphasis on those areas where there is special need for the purposes of navigation, flood control, and related water resource programs. "Coastal region" is here defined as "the sea and land area bordering the shoreline." It is more or less limited in a seaward direction to the 60-foot-depth contour. In landward direction it includes the beach zone to the top of the first major change encountered in topographical structure

The study objectives include a general assessment of the major structural elements comprising the environment of the coastal regions of Guam. In assessing these elements, the following specific items are included:

1) Major vegetation zones
2) Rivers
3) Estuaries
4) Bays
5) Beaches and other coastal areas of unconsolidated materials
6) Rocky coastlines
7) Reef zones
8) Water masses and circulation patterns
9) Climatic zones
10) Geology and soil types
11) Development areas and use patterns
12) Areas of rare or unique animals or plants

These items are discussed in a systematic way around the island and are augmented by illustrations, maps, charts, tables, and photographs. In the assessment of the major structural elements, areas where knowledge is weak or lacking are pointed out. Special attention is given to the following:

1) The presence of rare or endangered species
2) Unique botanical elements
3) Wetland habitats
4) Fisheries
5) Culturally important areas - sanctuaries, park lands, cemeteries, and so forth

Utilization of knowledge gained from the assessment will be used in defining Guam's water-resource needs, in developing plans to meet these needs, and analyzing the environmental impact of specific plans.

GEOGRAPHY[1/]

LOCATION

Guam, the largest and southernmost of the Mariana Islands, is at 13°28' 29"N, 144°44'55"E (Agana monument). It is about 49 kilometers (30 miles) long and tapers in width from 14 kilometers (8-1/2 miles) in the north to 6-1/2 kilometers (4 miles) at the central waist, widening again at the south to a maximum width of 18-1/2 kilometers (11-1/2 miles) from Orote Point to Ylig Bay (Fig. 1). The land area, exclusive of the reefs, is 550 square kilometers (212 square miles). North of the narrow waistline, which extends from Agana to Pago Bay, the axis of the island trends northeast-southeast; south of the waist the trend is north-south. There are twelve small limestone islands along the reef, the largest being Cocos Island off the south-west coast, a "low island" similar to the atoll islands of the Pacific.

RELIEF

The northern half of Guam is a broad, gently undulating limestone plateau, bordered by steep cliffs. The plateau slopes generally southwestward from an elevation of approximately 183 meters (600 feet) in the north to

---

[1/]The following discussion on geography has been taken, in part, from "The Military Geology of Guam, Mariana Islands" (Tracey et al., 1959, pp. 3–6).

less than 30 meters (100 feet) at the narrow mid-section of the island. Three prominent peaks rising above the level of the north plateau are Mt. Santa Rosa (262 meters or 860 feet) and Mataguac hill (180 meters or 592 feet), both made up of volcanic rock, and the limestone peak of Barrigada Hill (200 meters or 660 feet).

The limestone is so permeable that no permanent streams exist on the plateau, but well developed sinkholes are numerous. Along the shore the plateau is bordered in places by a coastal plain, irregular in width and fringed by a coral reef. The steep seaward cliffs which encircle the plateau are marked by wave-cut escarpments and terraces irregularly spaced above one another.

The southern half of Guam is a broad, ruggedly dissected upland developed chiefly on volcanic rocks. The surface is weathered into peaks, knobs, ridges, and basin-like areas and is deeply incised by streams. A nearly continuous mountain ridge, the crest of which lies from 1–2 miles inland, parallels the west coast from the highland west of Piti to the southern tip of the island. The principal peaks (Fig. 1) from north to south on this backbone ridge are Mount Alutom (328 meters or 1,076 feet), Mount Tenjo (309 meters - 1,014 feet), Mount Alifan (266 meters - 872 feet), Mount Lamlam (405 meters - 1,328 feet), Mount Jumullong Manglo (365 meters - 1,197 feet), Mount Bolanos (372 meters - 1,210 feet), Mount Schroeder (321 meters - 1,053 feet), and Mount Sasalaguan (338 meters - 1,109 feet). The west coast is bordered by a plain which rises from sea level to approximately 90 meters (300 feet). Two prominent limestone masses, Cabras Island and Orote Peninsula, project westward from the plain at Apra Harbor.

The dissected upland slopes gently eastward from the mountain ridge and merges into a narrow limestone plateau from 30 to 107 meters (100–350 feet) above sea level which fringes the east side of the island from Pago Bay to Inarajan.

ROADS

A network of paved and secondary roads cover the northern and central parts of the island (Fig. 1). A well-paved road crosses the waist from Agana to Pago Bay and follows the coast around the southern half of the island.

POPULATION

The constantly changing military population of perhaps 19,037 (Kim, 1972) is concentrated principally at Andersen Air Force Base in the northeast part of the island, at the Naval Communication Station in the northwest part of the island, at the Naval Air Station near Agana, and at the Naval Station at Apra Harbor. The Naval Air Station is used by military and commercial airlines; Apra Harbor, by commercial and military shipping.

The non-military population, some 67,892 people (Kim, 1972) is concentrated in villages in the central section, along the coastal road around the southern half, and in two villages in the north part of the island.

OCEANOGRAPHY AND REEFS

The ocean environment dominates the island of Guam and is largely responsible for its climate. The ocean surface temperature is about 81°F. the year around.

Currents and Tides

The North Equatorial Current caused by the northeast trades generally sets in a westerly direction near the island of Guam with a velocity of 1/2–1 knot. Currents in the western Pacific are not as well known as are those in the Atlantic.

Tides at Guam are semidiurnal with a mean range of 1.6 feet and a diurnal range of 2.3 feet. Datum for the island is mean lower low water, and other applicable data are tabulated below with relation to this datum:[2/]

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

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

[2/] Additional data on winds, typhoons, frequency, & oceanographic data are contained in "Agana Small Boat Harbor" report, U. S. Army Engineer Division, Pacific Ocean, 1972.

Waves and Swells

Wind waves are dominantly from northeast to southeast, driven by the trade winds. Normal trade-wind waves are low, less than 2 feet, to medium, less than 9 feet high; most are less than 5 feet. Occasional calms are common from April to September, but periods of more than 2 or 3 days of calm are rare. Wind waves higher than 6 feet are usually associated with storms.

Considerable damage may be done by waves generated periodically by storm centers as distant as 1,000 miles. Most commonly, such waves are caused by typhoons moving westward after they have passed by the island. Severe waves are sometimes associated with large typhoons which strike Guam.

Reefs

Guam is completely encircled by fringing reefs except along parts of the limestone cliffs. In two places barrier reefs have developed which fully or partially enclose small lagoons: at Apra Harbor on the west coast and at Cocos Island to the southwest.

The fringing reefs range from narrow cut benches around limestone headlands, thinly veneered by encrusting algae below sea level, to broad reef flats more than 3,000 feet wide containing a variety of corals and algae. Although the reefs vary greatly in character from place to place, the development of specific features seems to depend to some extent on particular locations.

BACKGROUND AND REVIEW

No broad study has been made of Guam with the specific aim of assessing all the coastal regions for the objectives outlined above, although several studies have been made in which certain aspects of the coastal region were included as part of an investigation of the island. Many limited regions of the coastal environment have been studies in considerable detail in relation to special plans and development projects (Johnston and Williams, 1973).

Recent studies in which the overall investigations included coastal descriptions of geology, soils, vegetation, and water resources of Guam were made as part of a program of geologic mapping of some islands of the western Pacific. These investigations were conducted jointly by the Corps of Engineers, U. S. Army, and the U. S. Geological Survey, and are published by Tracey et al. (1959) in a report entitled the "Military

Geology of Guam, Mariana Islands: Part I, Description of Terrain and Environment; Part II, Engineering Aspects of Geology and Soils." A later water resources supplement to the "Military Geology of Guam" was published by Ward and Brookhart (1902).

A series of "Geological Survey Professional Paper" publications resulted from the field work and studies conducted during these investigations and from other related special investigations. They include:

Chapter A, Tracey et al., 1964, "General Geology of Guam" — a general summary of the stratigraphy, structure, physical geography, and geologic history of the island.

Chapter B, Emery, 1962, "Marine Geology of Guam" — studies on the general aspects of submarine geology which include offshore island slopes, lagoon floors, channels through the fringing reefs, surfaces of barrier and fringing reefs, beaches, and rocky shores.

Chapter C, Stark, 1963, "Petrology of the Volcanic Rocks of Guam" — with a section on "Trace Elements in the Volcanic Rocks of Guam" by Tracey and Stark.

Chapter D, Schlanger, 1964, "Petrology of the Limestones of Guam" — with a section on "Petrography of Insoluble Residues" by Hathaway and Carroll.

Chapter E, Cole, 1963, "Tertiary Larger Foraminifera from Guam."

Chapter F, Carroll and Hathaway, 1963, "Mineralogy of Selected Soils from Guam" — with a section on "Description of Soil Profiles" by Stensland.

Chapter G, Johnson, 1964, "Fossil and Recent Calcareous Algae from Guam."

Chapter H, Ward, Hoffard, and Davis, 1965, "Hydrology of Guam."

Chapter I, Todd, 1966, "Smaller Foraminifera from Guam."

Most of the background information and parts of the coastal sector descriptions presented in Chapter IV of this report were drawn from the above publications. A much more detailed review of the geologic literature of Guam is given by Tracey et al. (1964) and by Cloud, Schmidt, and Burke (1956). The latter also includes a review of exploration and early scientific investigation for the Mariana Islands with brief descriptions of coastal features and reefs.

An extensive review of the botanical literature of Guam is given by Stone (1970) in "The Flora of Guam," a comprehensive taxonomic analysis of the vascular plants of Guam. Fosberg (*In* Tracey et al., 1959) describes the vegetation of Guam and includes a vegetation map of the island.

Fosberg (1960) gives a detailed description of the forest types and plant communities of "Micronesia. This work has a special section describing the plant communities of Guam.

Overall descriptions of the reefs of Guam were made by Tracey et al. (1959, 1964). Tracey (1964) divides the coastal region into nine sectors, giving the general characteristics for each and making descriptive transects of the fringing reef platforms at Tumon Bay, Agana Bay, the northwest barrier reef at Cocos Lagoon, and the fringing reef platform near the Ylig River. The four reef transect descriptions and parts of his other sector descriptions are included herein.

Descriptive reef transects and quantitative assessment of the coral diversity, percentage of substrate coverage, corallum size, and corallum growth forms have been made at Tumon Bay and Tanguisson Point (Randall 1973a, 1973b). The study at Tumon Bay was conducted prior to the killing of many corals there by the starfish *Acanthaster planci*. One hundred and forty-six species of corals were recorded from the fringing reef along Tumon Bay. The study at Tanguisson Point was conducted after *A. planci* had killed many of the corals there. A total of 96 species were recorded from the Tanguisson Point fringing reefs. An account of coral recovery in an area where corals were extensively killed by *A. planci* at Tanguisson Point is given by Randall (1973c).

Descriptions of the fringing reefs from Achang Bay to Ajayan Bay, Pago Bay, and Cocos Lagoon Barrier reefs and lagoon floors were made by Emery (1962) who reported on characteristics of the channels cutting through fringing reefs of Guam as well as detailed studies of three of the channels—Pago Bay Channel, Mamaon Channel, and Manell Channel. These studies consider general topography and sediment composition characteristics as well as the water characteristics at Pago Bay Channel.

Offshore slope topography and sediment studies were conducted by Emery (1962), who made 40 depth profiles at various locations around the island. At the same time, he also investigated beach and reef-flat sediments, the effects of typhoons on beaches, beach profiles, the effects of holothurians (sea cucumbers) on reef-flat sediments, and special features of rocky shorelines—such as nips cut at sea level, solution basins, rimmed terraced pools on beach platforms, and interstitial beach

water. Tracey et al. (1959, 1964) and Stearns (1941, 1945) discuss the various low-lying limestone coastal terraces around the island.
The hydrology of Guam is given by Ward and Brookhart (1962) and by Ward, Hoffard, and Davis (1965). These works describe ground-water areas, the Ghyben-Herzberg lens system, streamflow, and runoff characteristics.

Inshore coastal current patterns are poorly known except at specific locations where projects required detailed analysis (Pacific Island Engineers, 1951; Anon,, 1971; and Jones and Randall, 1971, 1973).

According to Emery (1962), the north equatorial current splits at Pati Point (Fig. 1). One part sweeps down the east coast around the southern part of the island to the western end of Cocos Barrier Reef. From Cocos it then flows northward to Orote Point, where it rejoins the other stream moving from Pati Point around Ritidian Point and down the northwest coast.

Annual-cycle current studies have been conducted by Jones and Randall (1971, 1973) at the Agana Outfall and at Tanguisson Point. These studies revealed a complicated bidirectional current in the inshore water mass dependent upon the conditions of tide, wind direction, sea and swell height and direction, and submarine topography. Both of these studies were made on the leeward northwest coasts. Little is known about the current patterns on the windward eastern and southern coasts.

Current patterns on the reef-flat platforms are dependent upon reef-flat topography and upon the mass transport of water over the reef margin and outer flat zones. Where mass transport of water over the outer reef-flat-platform edge occurs and a well developed inner reef-flat moat exists, usually longshore currents are generated which flow toward depressed regions at the reef margin, through which the reef-flat water then returns to the sea. Reef-flat currents are also generated during a falling tide, and the currents follow much the same pattern as when mass transport over the reef margin occurs.

The soils of Guam have been described by Stensland (In Tracey et al., 1959), and the mineralogy of selected soils of Guam has been reported by Carroll and Hathaway (1963). Additional information on soils and geology is found in "The Military Geology of Guam, Mariana Islands: Part II, Engineering Aspects of Geology and Soils" by May and Schlanger (In Tracey et al., 1959).

The climate and microclimates of Guam have been summarized by Blumenstock (*In* Tracey et al., 1959).

CHAPTER II

METHODS AND PROCEDURES

The work for this study was divided into two phases. The first involved a review of the literature pertinent to the objectives outlined in the scope of work (Chapter I). From this literature, it was determined in which of the objective areas information was weak or lacking. The second phase consisted of an overall reconnaissance of the coastal regions, with supplementary field work, to fill in the areas where information was scanty or missing.

The coastal region of Guam was divided into twelve sectors or macro-divisions, each consisting of a stretch of coast having fairly similar biological and physical characteristics. Each of the scope-of-work objective items is then discussed within the framework of the smaller division rather than for the whole island. To keep the size of each description small and to avoid repetition in the descriptions of various features present in several sectors, a summary of background information is provided (Chapter III) which contains more in-depth information than that given in the sector descriptions themselves.

A review of the literature is presented in Chapter I. Whenever possible, data used in this report were taken from previous works, being selected so as to fit into the specific objective areas and then used directly, or consolidated, summarized, or tabulated into a form appropriate for this coastal survey.

Information in objective areas weak or lacking in the literature was filled in with field data whenever possible or practical within the time frame and budget of this study. Specific items of weakness were found regarding estuaries, rocky coastlines, reef zones, water circulation patterns, and areas of rare or unique animals or plants. Field work in the estuarine environment included salinity determinations and depth measurements at the Inarajan, Talofofo, Ylig, and Pago Rivers. Rocky coastlines were mapped in the field or from aerial photographs. Reef zones were determined mostly from field work. The zones were identified by direct observation or from aerial photography. The subtidal reef front and shallow submarine terrace zones were investigated by using two-man tow survey and SCUBA equipment. This technique involves pulling two snorkelers attached to several lines 20–50 feet behind a small, shallow-draft boat.

Water circulation patterns are poorly known around Guam and are beyond the scope of this project.

CHAPTER III

SUMMARY OF BACKGROUND INFORMATION

INTRODUCTION

In Chapter IV the twelve specific around-the-island work items outlined in the scope of work (Chapter I) are discussed in a systematic way. The coastal region is divided into 12 sectors or macrodivisions (See Fig. 35) and each item is then discussed within the framework of these units. It became obvious that a summary of previous work would be needed to form a background of information to discuss such topics as: vegetation zonation, reef zonation, climate, beaches, archaeology, and various other topics under the broad heading of geology, including physiography, geologic rock descriptions, structural geology, hydrology, soils, and engineering aspects of geology and soils. This chapter is a summary of background information for each of the above work items. Other work items—rivers, estuaries, bays, rocky coastlines, water masses and circulation patterns, developmental areas and use patterns, and areas of rare or unique animals and plants–are discussed only as encountered within the coastal macrodivisions.

Maps are used to present as much of the above information as possible. Maps showing soil units, reef zones, rocky shores, beaches, and general locations were originally prepared for each of the 12 coastal macrodivisions at 1:25000 or 1:2000 scales and then reduced in scale to fit the page format of the report. Geologic formations, vegetation zones, and engineering aspects of geology and soils were originally prepared on three series of maps of five sheets each at 1:50000 scale and then reduced to fit the page format as above. Maps showing physiographic units, hydrological ground-water areas, and archaeological sites were prepared on individual sheets. General-location maps are used to indicate positions of bays, rivers, estuaries, mountains, and developmental areas. Reef-zonation maps are used to indicate locations of beaches and other unconsolidated materials and rocky coastlines.

CLIMATE

The following discussion of climatic characteristics, earthquakes, and tsunamis has been taken in part and summarized from Blumenstock (In Tracey et al., 1959, pp. 14–54) .

Although regional differences in climatic characteristics exist on Guam, they are not discussed in a systematic manner within each coastal division but are treated in relation to the island as a whole. Localities from which climatic data were collected are shown in Fig. 2.

Broad Climatic Characteristics

Regardless of the time of year, the weather on Guam is warm. Even at the higher elevations on the island, nights bring but a slight lowering of temperature. Both night and day the humidity also is high, often uncomfortably so. Yet despite the uniformity of temperature and humidity, an observer in time comes to recognize that there are pronounced weather seasons on Guam, that there are marked weather events such as tropical storms, and that there are significant variations in weather and climate from one place to another on the island. These seasonal variations, weather episodes, and areal differences in weather and climate are for practical purposes of even more importance than the relative temporal and areal uniformity of temperature and humidity conditions. Indeed, it is these variable aspects of the weather and climate which give Guam its distinctive climatic regime. There are two distinct seasons on Guam: a dry season of five months, January through May, and a wet season of five months, July through November. The two intermediate months of June and December are transitional.

Temperature Conditions

The major features of the temperature regime on Guam are illustrated by the data of Table 1, which present mean and extreme temperatures by months and for the year at Sumay, at the Agana Navy Yard, and at the Agricultural Experiment Station. Throughout the island, the coolest period is January–February; the warmest, May–June. The temperature range between these periods is, however, less than 3°F in terms of average monthly temperature. This is far less than the mean diurnal temperature range, which averages at least 8°F in all months at all stations for which data are available.

In areas on the coast or at elevations below about 80 feet near the coast, daytime temperatures are commonly between 83° and 88° during the warmest part of the afternoon and in the middle seventies during the coolest part of the night, just before dawn. In extreme instances, however, maximum daily temperatures are in the middle to high nineties, and nighttime temperatures fall to 65°–70°. For localities on or near the coast, the greatest extremes of record are 100° at the old Agricultural Experiment Station and 64° at Sumay, both in February.

On the northern plateau, maximum and minimum temperatures are about 2° lower than at low elevations near the coast. During a 4-1/2 year period, 93° was the extreme high temperature observed at Harmon Field, whereas at Andersen AFB there were only two readings of 90° or higher during a 5-year period. At the other extreme, a minimum temperature of 62°–63° has been observed at Harmon Field; at Andersen AFB there have been eight instances of minima of 69° or below.

During the dry season, with moderate to strong trade winds blowing, eastcoast localities tend to be 2° or 3° cooler than west-coast areas, especially during the afternoon. At all times of the year there are minor temperature variations from place to place associated with local variations in cloudiness. Similarly, the precise variations in temperature throughout the day at any one locality are certain to reflect diurnal variations in cloud cover.

Humidity

The very high humidity of the air passing across Guam is well illustrated by the relative humidity values for the Naval Air Station (Table 2). As is evident from that table, relative humidity commonly exceeds 84 per cent at night all year long. Even during the warmest part of the day, average humidity is at least 66 per cent every month. Further, with humidity, as with temperature, the variation from one season to another is slight, the dry season being only a little less humid than the wet.

Even in extreme instances, relative humidity at the Naval Air Station has rarely dropped below 60 per cent. Of the 5+,000 hourly observations taken over a period of 5-3/4 years, only 1.4 per cent were below 60 per cent; only 11 observations showed a relative humidity of less than 50 per cent. No observations showed less than 40 per cent. At the other extreme, 14.4 per cent of the observations showed a relative humidity of 90–100 per cent.

Wind Conditions

The outstanding characteristic of the wind regime on Guam is dominance of the trade winds. Trade-wind flow is dominant even during the period of July through October, when winds from every direction are not uncommon. Trade-wind flow is especially pronounced and persistent during the dry season, from January through May, when the winds blow from between the NE and ESE more than 90 per cent of the time. The dominance of the trades is evident from Table 3, which shows wind-direction frequencies by months at Naval Air Station and Harmon Field. The table also shows the greater variability in wind directions during the period of July through October.

Except for very occasional tropical storms and typhoons which bring exceedingly high-speed winds, the greatest wind speeds usually occur under trade-wind conditions. At the Naval Air Station, during a 5-year period, the wind speed was 21 knots (23.7 mph) or higher 1.8 per cent of the time during February, and of the 74 occurrences observed, all were from between NE and SE. In August, when the winds are most variable, winds of 21 knots or greater were observed 1 per cent of the time; of the 47 occurrences making up this per cent, 27 were from between NE and SE, and 9 more were from the SSE.

Rainfall

General Rainfall Regime

The distribution of mean annual rainfall on Guam is shown in Fig. 3. As is evident from that figure, the average rainfall varies from less than 90 inches in the vicinity of Apra Harbor to more than 110 inches in the most mountainous section of the island. The only stations (see Fig. 2) for which there are more than ten years of reliable rainfall records are Sumay (41 years; 1906–39, 197–53), the Agana Navy Yard (19 years; 1915–1933), and the old agricultural Experiment Station (14 years; 1918–1931). The average annual rainfall values for these stations in those years are 86.5" at Sumay, 89.3" at the Agana Navy Yard, and 93.8" at the old Agricultural Experiment Station. The mean annual rainfall map of Fig. 3 is approximate only, for it is based on data from 19 stations with only four to eight years of concurrent records. It was necessary, therefore, to use interpolated values for one to four years at all but three of the stations and then to adjust all values to the long-term Sumay mean to compensate for the shortness of the eight-year period.

The map of Fig. 4 shows the monthly distribution of rainfall in terms of the median, which is the middle rainfall value during the eight years of record used. The maps represent the best estimates that could be made, and the values shown by the isohyets (or obtained by interpolation between the isohyets) are certainly not in error by more than 20 per cent and probably are not in error by more than 10–15 per cent.

The important features of the maps are the geographic variations that they bring out and the marked quantitative contrast between the maps of the rainy season and those of the dry season. Also, as is clear from a comparison of the maps for February and August, in percentage terms there is usually far more variation in rainfall from one locality to another during the dry season than during the wet season. During the wet season there is almost always ample rainfall everywhere on Guam. During the dry season, rainfall is frequently barely ample in favored mountainous localities, while at the same time it is decidedly inadequate in other areas. This statement assumes a definition of "ample" that calls for 46 inches of monthly rainfall or more for such local requirements as sufficient catchments in open reservoirs to meet minimum household needs for potable water.

Seasonal variations in rainfall on Guam involve variations not only in monthly totals but also in the character of the rainfall and in its diurnal distribution. During the dry season, on virtually all days with rain, rainfall occurs in the form of showers which usually are very light. During the wet season, on about one-third of the days with rain, rainfall lasts longer and is properly described as "steady rain." Throughout the year, drizzle, the third kind of rainfall, is so rare as to be recorded on less than 1 per cent of all rainfall days. These values are based on data from the Naval Air Station but apply in a general sense to all locations on Guam.

Judging from 5-2/3 years of hourly rainfall records at Andersen AFB, there is relatively little diurnal variation in the frequency of rain. During the dry season, diurnal variations are not statistically significant. However, during the wet season, especially in August, there is somewhat more chance that rain will occur between 1500 and 1900 local standard time (150°E.) than at other times of the day. For August, the mean rainfall frequency at hourly observation times between 1500 and 1900 averaged 16 per cent, whereas for the remaining hours of the day the average was 12 per cent; for no other period of five consecutive hours was it more than 13 per cent. In this particular respect, Guam differs markedly from most other islands in the tropical Pacific, where there are pronounced diurnal variations in rainfall frequency at all seasons of the year.

Drought

Drought is a normal feature of the climate of Guam. Severe drought is not unusual. The period of greatest drought hazard is February through April. Intense dry periods of several weeks' duration have been recorded from the first week of December until the end of May.

Storms

Two principal kinds of storms contribute markedly to the climatic character of Guam: small-scale storms, notably squalls and thunderstorms, and large systems, i.e. tropical storms and typhoons. The small-scale storms are evanescent and at any one moment dominate the weather over areas of perhaps 10–20 square riles. The large storm systems persist for many days or even two or three weeks and at any moment dominate the weather over areas as extensive as 100,000 square miles. The large systems are usually well-defined and moving, dictating the weather on Guam for a period of a few days at most, after which they move to other regions.

Small-scale Storms — Squalls may occur in the Guam area at any time of year. Their frequency and character vary, however, from the dry to the wet season.

During the dry season it is usual on any day to have a few scattered squalls in the immediate 8–10 mile vicinity of Guam. These are small storms, perhaps 1–3 miles in diameter, and embedded in the trade winds, moving east to west. Over the water they produce showers which may be quite intensive for a few minutes, and often yield gusty winds with momentary speeds in excess of 25 mph. When they move onto the land, their gustiness usually decreases, especially inland from the immediate shore area.

During the wet season, especially on those frequent days when winds are light and variable, there are often many squalls over the waters immediately surrounding Guam. Sometimes these are distinguishable as individual squalls. Usually, however, the squalls are so numerous and closely spaced that they simply produce "squally weather" with frequent showers over wide areas of the sea. Winds are typically intermittent, suddenly springing up, achieving a high gust velocity of 15–20 mph or so, and then dying out again. This process is repeated again and again, often with marked variations in wind direction over distances of a few hundred yards. At the same time, beneath the different squall clouds, rainfall will vary greatly. In one small area there may be extremely intense rain for 5–10 minutes, while at the same time only a light shower half a mile away in one direction, and no rain at all half a mile away in another. Wet-season squalls of this kind often drift onto Guam. When they do, the arrangement of clouds and rainfall becomes a little more-regular because of the tendency of the squally clouds to mass along the mountain crests where the most intense and prolonged rainfall is apt to occur.

During conditions of squally weather in the wet season, there are occasional well-developed thunderstorms. In the vicinity of the Naval Air Station, thunderstorms have been reported on 1.4 per cent of the days in July and on approximately 0.5 per cent of the days in the other months of the wet season. For May and June, they have been reported only 0.1 per cent of the time; all the remaining months of the year, from December through April, thunderstorms have been reported only four times in six years. These percentages are approximately duplicated by data for Harmon Field on the northern plateau.

Tropical Storms and Typhoons — Major tropical weather disturbances are commonly classified on the basis of intensity in terms of wind speeds produced and associated surface air pressure. In these terms, the mildest disturbance is a pressure wave not sufficiently pronounced to produce a closed storm system or to yield winds more than a few miles an hour greater than average. Sometimes, however, pressure waves produce moderate to heavy rainfall over wide areas—areas much larger than Guam. More pronounced than the pressure wave is the tropical depression, which can be recognized (on the weather map) as a closed pressure system, but which still does not yield notably high winds even though excessive rain may fall. Tropical storms are closed pressure systems about which the air moves counter-clockwise in the northern hemisphere with wind speeds of 33–65 knots (38–74.9 mph). Typhoons are similar to tropical storms but are accompanied by winds of 65 knots or greater. Both the tropical storm and typhoon commonly yield very large amounts of rainfall. Major tropical weather disturbances of these kinds occur at Guam. Far more frequent during the rainy season than the dry, they have occurred in all months of the year.

Table 4 shows the frequency of typhoons, tropical storms, and "possible typhoons" passing within 120 nautical miles of Guam during the period 1924–53. During this 30-year period, 43 typhoons passed within this distance of Guam, If tropical storms and storms which were "possibly" typhoons are included, the total becomes 82. Taking the lower figure, of 43 typhoons in 30 years, the average figure for number of typhoons per year within 120 miles of the island is 1.4. By actual count, however, during the 30 years in question, there was one typhoon or more in only 18 of the 30 years, so the chances of there being one or more typhoons within 120 miles of Guam in any particular year are roughly 18 in 30 or 3 in 5. This rough probability, compared with the actual frequency, reflects the fact that during some years of the 30-year period there were 2 or more typhoons; indeed, in three of these years (1940, 1943, 1945) there were as many as 5. Such an extreme clustering of typhoon passages within a relatively small area (within 120 miles of Guam) in the same year is only moderately unusual, since sometimes one typhoon forms and moves virtually in the wake of another, and in general, the kind of weather situation favorable to typhoon formation in a certain wide region of the ocean and conducive to the movement of that typhoon through a particular broad zone across the ocean may persist for a period of several weeks.

The seven typhoons whose centers moved directly across Guam (Table 4) occurred in six different years. (There were two square hits on Guam during 1941—in July and September.) The chances are therefore roughly 6 in 30 or 1 in 5 that Guam will suffer a direct hit by a typhoon in any particular year. A typhoon however, can be just as damaging to the island if its center passes within a few miles as when the center actually passes across the island. The center of the extremely destructive typhoon of November 3, 1940, came only "very close" to the island, as did that of the more recent, destructive typhoon of October, 1953. Each was far more damaging than the typhoon of August, 1953, whose center crossed Guam.

The likelihood of typhoons is greatest during July through September, least during January through April, and intermediate in May-June and November-December. Although Table 4 shows no typhoons passing within 120 miles of Guam in April during the years 1924–53, there is at least a slight chance of experiencing a typhoon in April as well as in every other month of the year. There are seasonal variations in the character of typhoons in the Guam area as well as in frequency. The typhoons of January through :day are usually small and intense with winds in excess of 75 mph, extending outward only 25–50 miles from their centers. Those of December, May, June, and July are somewhat larger, often with highspeed winds at distances of 5075 miles from their centers. Typhoons of August, September, October, and November are usually the largest and most intense of all. Their high-speed winds may reach outward 100 miles, and wind speeds near their centers tend to be higher than those of typhoons in other months. Typhoons of this period not uncommonly carry sustained wind speeds of 150 mph in the inner core, that is, within 25 miles of the center of the storm. For all typhoons in the northern hemisphere, wind speeds are greatest on the right-hand side of the storm, the right-hand side being defined with reference to an observer facing the direction the typhoon is moving.

One of the major hazards of a typhoon is that it may sweep water onshore and thus produce a "tidal wave." In any particular instance, the pattern of inundation on Guam is closely related to the direction in which the storm moves and its direction from Guam at point of nearest approach, or if its center crosses Guam, its exact track across the island. As shown in Fig. 5, nearly all typhoons in the Guam area move either from east to west or from southeast to northeast. For storms with such movements, inundation will occur almost exclusively on the east and south coasts for storms passing to the south or southwest, and on the north and west coasts for storms passing to the north or northeast. When the center of a typhoon crosses Guam, inundations will occur on the right-hand side of the storm center along the coast of arrival and on the lefthand side of the storm center along the coast of departure. Thus a typhoon passing squarely across Guam from east to west will inundate the northeast and southwest coasts. Figure 5 presents a tabulation of the direction of movement of typhoons in the vicinity of Guam during the period 1924–53 and the direction of the typhoons from Guam at the point of closest approach.

Even if there is no appreciable inundation of the coast in the sense that there is an actual rise in sea level, damage in beach areas is apt to be especially great because of unusually high surf. In general, the most vulnerable locations are exposed beaches and small bays, localities lying in saddles approximately parallel to the direction of very strong winds, hill tops, and relatively flat open areas unprotected by dense vegetation, such as are found two or three miles NNW of Inarajan and in many parts of the northern plateau.

Often the only extensive damage from a typhoon is that resulting from heavy rains. This is especially true of typhoons whose centers do not approach within thirty or forty miles of Guam. Tropical storms with maximum winds between 33 and 65 knots may also produce very heavy rains. Certainly, rains of 3–5 inches in a day might readily result from the passage of a tropical storm, and rains of this intensity are sufficiently great to produce heavy local flooding. The impression given by Table 4, that tropical storms are far more unusual than typhoons is certainly not correct. Quite likely all, or almost all, of the storms tallied under "possible typhoons" were tropical storms. This would make tropical storms about as frequent as typhoons, which is probably the case.

Moderately extreme rains of 2–4 inches in a day are often produced by a passing pressure wave or by a tropical depression. However, neither of these kinds of storms produces anything like the torrential rains sometimes produced by typhoons or by well-developed tropical storms; neither carries with it the danger of extremely high winds or waves.

Surface Air Pressure

The mean seasonal variation in air pressure at Sumay (elevation 61.4') see Fig. 2 for station locations) ranges from a minimum of 1009.3 nib (29.805") in August to a maximum of 1012.1 mb (29.887") in February (after Clayton). For general purposes, mean surface air pressure on Guam may be reduced to sea level or to other elevations by applying a correction factor of 3.5 mb (0.103") per 100' of elevation. When these factors are applied to the Sumay values, the approximate seasonal pressure variations at sea level and at the Naval Air Station (elevation 245 feet) are as follows:

Sea Level — 1011.4 to 1014.2 mb (29.868 to 29.950 inches)

Naval Air Station — 1002.8 to 1005.6 mb (29.616 to 29.698 inches)

Diurnal variations in air pressure at Guam are of the same order of magnitude as seasonal variations. During the dry season, the mean diurnal range is about 4 mb (0.12"); during the wet season, about 2.5 mb (0.07"). The highest daily air pressure occurs about 10 a.m.; the lowest, about 4 p.m. There is a secondary daily maximum about 10 p.m. and a secondary minimum about 4 a.m.

Sea level pressures of below 1,000 mb occur only with a tropical storm or typhoon somewhere in the vicinity of Guam.

Illumination Regime and Insolation

The period between sunrise and sunset on Guam ranges from 12 hours and 56 minutes at summer solstice June 21, to 11 hours and 19 minutes at winter solstice, December 22–23. Throughout the year, the duration of civil twilight is almost constant, varying from 22 to 24 minutes. This increases the length of the daylight period by 44 to 48 minutes, which provides a period of more than 12 hours in late December and more than 13 ½ hours in late June with sufficient illumination to pursue nearly all outdoor work without the need for artificial illumination.

The mean figures just given do not take into account the shadowing effect of the mountains on Guam. Therefore, the period of "broad daylight" may be shortened by an hour or so in localities where the rising or setting sun is totally obscured by mountains or hills.

Because of the great cloudiness, it is very unusual on Guam to experience bright sunlight with the sun unobscured for more than 30 or 40 minutes consecutively. On many days, especially during the wet season, the sun is not visible at all, and cloudless skies are exceedingly rare at all times of the year.

At the latitude of Guam, the solar radiation at the outer limits of the atmosphere varies from a maximum of about 900 gram-calories/day around the first of May to a minimum of about 700 at winter solstice. Not quite 900 gram-calories are also received around August first. This secondary maximum results from the fact that both length of day and solar declination influence the amount of incoming solar radiation, and declination is 13-1/2 N. (The latitude of Guam) both in late April and in mid-August.

The great cloudiness at Guam and the high amounts of water vapor present in the atmosphere, even on relatively cloudless days, result in considerably more reflection and absorption of the incoming solar radiation than is usual at most places in the world. It is doubtful that more than 675 gram-calories/sq cm/day ever reach the ground surface on Guam, and certainly on many days the total is less than 450 around the time of winter solstice and less than 550 during April–August.

Cloudiness, Ceiling, and Visibility

The average cloud cover in terms of tenths of the total sky-dome varies from a minimum of 6.8 tenths during the period of January–March to a maximum of 8.0 during July–September.

In contrast, January is the month of most favorable ceiling conditions; ceilings below 1,050 feet occur less than 2 per cent of the time, and ceilings above 9,750 feet, more than 75 per cent of the time. These somewhat more favorable ceiling conditions are generally characteristic of the period December through May.

Just as ceiling conditions are generally excellent on Guam, so also are visibility conditions. Even during August, when conditions are least favorable, the visibility at both Harmon Field and Naval Air Station exceeds six miles 92 per cent of the time. In January, which is the most favorable month, it exceeds six miles 96 per cent of the time. In all months either the ceiling is higher than 2,000 feet or the visibility is more than three miles at least 98 per cent of the time. It is, therefore, almost certain that at all times of the year aircraft can land aided by ground control devices.

The excellent ceiling and visibility conditions at all locations on Guam except perhaps at the highest mountain peaks is in keeping with the high cloud cover only because of the frequent occurrence of middle- and high-level clouds at altitudes of 8,000 feet and more. At all times of year, the sky is often partially or wholly covered by high-level cirrus clouds and by middle-level stratus or cumulus with only scattered to broken cloud layers at lower altitudes.

EARTHQUAKES

Guam, which lies about 70 miles northwest of the deep Mariana Trench, is in an active seismic zone. Repetti (1939) published a "Catalogue of Earthquakes felt on Guam from 1825 to 1938," compiled from many sources, including records and observations of the Guam seismograph Station destroyed during World War II.

The Pacific Islands Engineers (1948, unpublished) made a complete review of the literature and records dealing with the seismology of Guam.

Destructive Earthquakes

The most destructive earthquakes listed in Repetti's catalogue are tabulated below with estimated intensities on the Rossi-Forel scale and on the modified Mercalli scale.

Date	Estimated Intensity Rossi-Forel scale	Equivalent Intensity Modified Mercalli scale
April, 1825	VIII	VII–VIII
May, 1834	VIII	VII–VIII
Jan. 25, 1849	IX	VIII–IX
July 1, 1862	VII	VI
Dec. 7, 1863	VI	V–VI
June 24, 1866	VI	V–VI
May 13, 1870	VI	V–VI
Inlay 16 , 1892	VIII	VII–VIII
Sept. 22, 1902	IX	VIII–IX
Dec. 24, 1902	VI	V–VI
Feb. 10, 1903	VII	VI
Dec. 10, 1909	VIII	VII–VIII
Oct. 26, 1912	VI	V–VI
May 10, 1917	VI	V–VI
Nov. 24, 1917	VI	V–VI
June 12, 1932	VI	V–VI
Oct. 30, 1936	VIII	VII–VIII
Nov. 12, 1936	VI	V–VI
Dec. 14, 1936	VII	VI

Since 1825, there have been 19 recorded shocks of estimated Rossi-Forel intensity of VI or more and two of an estimated intensity of IX.

Great damage by the severe earthquake of September, 1902, was described in some detail by Cox (1904), who mentioned, among other observations, that many landslides in the mountains were caused by the shocks.

From WW II, no consistent seismic records were kept until 1956, when the U. S. Navy set up a seismograph station. In 1960, the U. S. Coast and Geodetic Survey established the Guam Magnetic Observatory for both seismic and magnetic observations. The U. S. Navy Microseismic Laboratory on Nimitz Hill kept records of seismic shocks for a time in 1951 and 1952 using an adapted microseismograph. Records from the station during this period show an average of about two shocks a day strong enough to be recorded. Of these, about two/month were strong enough to be felt.

Seismic Sea Slaves (Tsunamis)

Except for a sea wave associated with the earthquake of January 1849, no damaging tsunami has been recorded from Guam. The wave caused by the 1349 earthquake is reported by Repetti to have rolled into Talofofo Bay and carried out to sea a woman who was walking on the coastal road.

A tsunami was recorded on November 5, 1952. It originated from an earthquake, the epicenter of which was at 51°N 153°E according to the warning sent out by the Magnetic Observatory at Honolulu. This tsunami was recorded at Guam as a seiche of 40–50 minute period in Apra Harbor with an initial amplitude of foot or less.

In Ylig Bay a series of waves with periods of about 8 minutes were observed, the largest having an amplitude of more than 5 feet. According to John Knauss, an oceanographer from the Office of Naval Research who made the observations, the computed period of the seiche for Ylig Bay is about 8 minutes. Approximate seiche periods for other bays are as follows:

Talofofo	7-3/4 minutes
Umatac	5-3/4 minutes
Inarajan	7-3/4 minutes

The seiche period of all these bays is between five and ten minutes. Tsunamis are reported to have periods of ten minutes to one hour. It is therefore possible that large and destructive oscillations might be set up in any of the open bays of Guam by tsunamis larger than that of November 5, 1952. The probability of a large tsunami's causing considerable damage appears remote, however, as most of the low land on the island is protected by a band of coral reefs which acts as a filter or baffle for long-period waves. Open bays unprotected by reefs—such as Pago, Talofofo, and Inarajan—are most likely to be flooded if a tsunami should strike Guam.

PHYSIOGRAPHIC DESCRIPTION OF GUAM

The following general physiographic description of Guam is taken from the "Military Geology of Guam, Mariana Islands; Part I, Description of Terrain and Environment" (Tracey et al., 1959, pp. 56–58). References to plates, tables, and figures in that work have been omitted or substituted for others in this report. The descriptions of the seven physiographic units have been taken in part and summarized from the detailed descriptions occurring in the "Military Geology of Guam, Mariana Islands, Part I, Description of Terrain and Environment" (Tracey et al., 1959, pp. 58–75). The descriptions of the plateau land, coastal lowland, and valley floors were taken from that source entirely because much of the coastal region is represented by those descriptions.

<u>General Description</u>

The present physiography of Guam results primarily from the stratigraphic and structural relations of the formations present. The island is broadly divisible into three physiographic provinces: the northern plateau, the central mountains, and the southern mountains. The northern plateau is the product of uplift, tilting and normal faulting and weathering of reef and bank limestones. The scarps that separate the northern plateau from the central mountains are due to a fault, down-thrown to the north, which crosses the island from Adelup Point to Pago Bay (Figs. 1, 6).

The dissected terrain developed on the central mountains is largely fault-controlled. Mounts Tenjo, Chachao, and Alutom are all bounded by high-angle normal faults. Lithologic differences in beds in the Alutom formation are responsible for many ridges and knobs in this central region.

The southern third of the island is dominated by a high cuesta which approximately parallels the west coast, and by a gentle dip slope which reaches from the cuesta ridge to the capping limestones along the east coast. It is thought that some tilting to the east accompanied by normal faulting along the west coast and in the interior of the southern part of the island is responsible for the over-all configuration of this end of Guam.

Guam is made up of Eocene limestones and volcanic rocks, shales of the Oligocene age, Miocene volcanic rocks, and Miocene to recent limestones (Figs. 7a–7f, Fig. 8). The mountainous central core of the island is a succession higher than 600 meters (2,000 feet) of folded and faulted marine tuffs, limestones, conglomerates, and lava flows of the Eocene and Oligocene age (the Mahlac member). The northern plateau is a limestone cap resting unconformably on the Alutom formation and made up of the relatively flat-lying Bonya limestone, the Janum formation, and the Barrigada limestone, all Miocene, and the Mariana limestone of Plio-Pleistocene age. The southern third of the island is made up of a succession of Miocene volcanic rocks and limestone approximately 670 meters (2,200 feet) thick, dipping gently to the east and includes the Umatac formation which is composed of 4 members: the Facpi volcanic, the Bolanos pyroclastic, the Maemong limestone, and the Dandan flow. This southern succession is thought to be in fault and overlap contact with the central Eocene and Oligocene mass. Fig. 8 shows the stratigraphic relationships of the various formations.

Several distinct periods of structural deformation affected these formations. The Eocene Alutom formation is, in general, intensely folded and faulted. Numerous high-angle faults with closely associated joints characterize many outcrops here. At Mount Santa Rosa there is evidence of overthrust faults and tight folding. The Alutom formation is structurally the most complex formation on the island. The Miocene volcanic and limestone rocks have been normally faulted throughout and display minor folding. The Miocene to Pliocene and Pleistocene limestone cap which forms the northern plateau is cut only by high-angle normal faults associated with wide breccia zones. Prominent normal faults cut across the island in both northwest-southeast and northeast-southwest directions (Fig. 6).

Physiography

General Statement

Guam, with a total area of about 580 square kilometers (225 square miles), is one of the larger and more complex islands of the Pacific Ocean. It is composed of volcanic flows and tuffs partly covered by coralline limestones. Different Darts of the island have been eroded to different degrees, the result being a complex pattern of topography and physiography.

The total surface is divided into seven physiographic units (see Fig. 9): rough summit land, mountainous land, dissected sloping and rolling land, hilly land, plateau land, interior basin and broken land, and coastal lowland and valley floors. The units have been divided and discussed according to the simplest grouping of the primary physiographic characteristics of relief, slope, surface, and drainage. These characteristics in turn depend upon elevation, the lithology of underlying rock, geologic structure, soils, and vegetation.

Rough Summit Land — The rough summit land unit occurs entirely in southwest Guam and includes the summits of mounts Alifan, Almagosa, and Lamlam plus the area included between these peaks (see Fig. 1). The unit is elongate in a north-south direction, comprising roughly 5–8 square kilometers (2–3 square miles) with a maximum north-south dimension of 7 kilometers (4 miles). Rough summit land includes high knobs, sharp elongate hills, irregular depressions with vertical walls, scarps, and cone-shaped peaks. Land intervening between these features is rough and forms a small proportion of the total area of the unit. The unit has a median elevation of about 290 meters (950 feet). The south part of the unit is highest with a maximum elevation of 405 meters (1,328 feet), the highest on the island. The principal or over-all slope of the entire unit is very gentle downward to the north.

The rough summit land is developed entirely upon the Alifan limestone and accompanying alluvium. Soils are a few inches thick to absent over much of the unit but thicken to two or three feet in low depressions where alluvium may occur. Vegetation is very heavy and consists of large and small trees, bushy undergrowth, and tangled vines. The microrelief or surface detail is rough to jagged, boulder-strewn, and generally rocky with many rock slopes. Talus deposits at the bases of some slopes may be several feet thick. No surface streams occur in the unit; all drainage is downward into the porous underlying limestone (Fig. 10). During excessive rains sheetwash probably helps deposit alluvium in depressions. The rough summit land has been formed by solution and recrystallization of a greatly jointed and faulted limestone formation originally 200 to 300 feet thick.

Mountainous Land — The mountainous land unit occurs mainly as the western half of southern Guam, and includes (see Fig. 1) Mounts Alutom, Tenjo, Chachao, and Macjna in the north part of that unit and Mounts Jumullong Manglo, Bolanos, Schroeder, Finasantos, and Sasalaguan in the south. Mount Santa Rosa, in northern Guam, forms a relatively small additional patch. Mountainous land forms all of the rugged southwest coast of tine island except where that coast is bordered by relatively small ramps of coastal lowland and valley floor units. North of Facpi Point, the coastal unit broadens significantly and forms a wide apron of lowland between the mountainous land unit and the shoreline. The Pago Bay - Adelup Point fault system forms the abrupt northern boundary of the mountainous land (see Fig. 6). The eastern boundary is sinuous where the mountainous land merges gradually with dissected rolling and sloping terrain, except where the interior basin and broken land make a pronounced westward indentation into the unit. This indentation continues as a south-trending arm of rough summit land. The greatest north-south dimension of the mountainous land is about 25 kilometers (16 miles), and the east-west width varies between 6 and 13 kilometers (4 and 8 miles). The northern patch is not more than 2 kilometers (1 mile) in any direction. The total area of the entire unit is about 116 square kilometers (45 square miles).

The mountainous land ranges in elevation from sea level to about 380 meters (1,250 feet) at Mount Jumullong Manglo. Most slopes in the mountainous land unit are steep to precipitous. There is no principal or over-all slope for the entire unit. Summits in the northern part form a very slight northward slope, which is denoted by the general upper surface of the Tenjo block (see Fig. 6). Summits of the southern mountains decrease in elevation in a southerly direction but display a very uneven profile.

The mountainous land is developed upon the Alutom and Umatac formations. Soils are absent to fifty feet or more thick, and many bare rock faces are exposed in steep slopes. Vegetation is largely bushy and grassy on humps and open slopes, but in ravines or along other water courses there are forests with tangled undergrowth. The surface or microrelief is smoother in the northern part of the unit where a clayey surface is more common. Even here, there are many abrupt, steep-sided gullies and ravines which cannot be crossed easily on foot. Although rough rocky surface occurs in many places in the northern part of this unit, it is most common to the south, where fractured and boulder-strewn rock faces form long, steep, sloping sides of mountains. Some smoother, clayey surface also occurs in the southern part. The mountainous land is drained by many streams (see Fig. 10), the steeper western slopes of the unit being drained by a system including about 35 larger streams at the shoreline where they empty into the ocean. Most of these streams have several large tributaries and many small ones. In general, they constitute a parallel drainage system. The eastern, less steep slopes are drained by approximately the same number of streams, but they form a roughly dendritic drainage pattern where they flow eastward across the unit boundary into the dissected sloping and rolling land. The mountainous land was formed as the result of the stream dissection of stratified lava flows and tuffs raised relatively high above sea level.

Dissected Sloping and Rolling Land — The dissected sloping and rolling land unit occurs entirely in the eastern part of southern Guam. It occupies two areas east of and adjacent to the mountainous land unit; it is separated into north and south divisions by the NW-SE-trending interior basin and broken land unit. Generally, it is bounded on the north and east by the hilly land unit except for bordering patches of the coastal lowland and valley floor unit. The two dissected sloping and rolling land areas trend north-south and comprise a total area of about 78 square kilometers (30 square miles). The longest dimensions of the two units are roughly in line in a north-south direction and are about 8 and 12 kilometers (5 and 7-1/2 miles) for the northern and southern areas respectively. The unit includes the relatively long, gradual eastern slopes of the mountains forming the mountainous land unit in the western part of southern Guam. The dissected sloping and rolling land ranges in elevation from yea level to about 200 meters (660 feet) at the eastern foot slope of Mount Bolanos and the east slope of the Mount Tenjo-Mount Alutom block.

The dissected sloping and rolling land is developed upon exposures of the Alutom Formation, Mahlac shale, Bolanos pyroclastic member, and the Dandan flow member. Soils are thin to absent in some bare rock faces but may be 50 or more feet thick in relatively flat areas. Vegetation is bushy and grassy in much of the flat to gently sloping topography. In stream valleys, vegetation is mostly thick forest with tangled undergrowth. Some forest occurs also in the flat to gently sloping topography. The surface or microrelief is generally smooth and clayey with scattered patches of large boulders. Stream beds contain boulders in many places. Some boulder talus formation may be found at the bases of valley sides, where they may make very loose stream banks. Drainage of the dissected sloping and rolling land is accomplished by a network of streams emptying along the east coast of southern Guam (see Fig. 10). The dissected sloping and rolling land was formed by stream erosion of broad, sloping land beveled by successive advances and retreats of the sea.

Hilly Land — The hilly land unit occurs in central and southeastern Guam. It separates the dissected sloping and rolling land from the plateau forming the coast. This strip of hilly land is divided by the interior basin and broken land unit as well as by the coastal lowland and valley floors unit. The central Guam area of hilly land is bordered on the north and east by plateau land, on the west by coastal lowland and valley floor land, and on the south by mountainous land. The maximum dimension of the hilly land in any direction is about 12 kilometers (71/2 miles) east and west in central Guam. The entire unit comprises some 52 square kilometers (20 square miles). The hilly land includes much hilly, rolling, and undulating topography showing a relatively fine dendritic pattern of dissection of what was originally a flat surface. The median elevation of most of the unit is about 50 meters (165 feet). Most of the hilly land has a relief of 30–60 meters (100 to 200 feet) throughout the labyrinthine network of little valleys and rounded hill crests. The principal slope of the hilly land is very slightly downward toward the south. An exception to this is the area between Yona and Talofofo, where the slope is slightly downward to the north.

Hilly land is developed upon exposures of the Agana argillaceous member of the Mariana limestone as well as on some pure Mariana limestone and some Alifan limestone. Soils are extremely variable in thickness, ranging from a foot or less on some ridge crests to more than twenty feet on some valley sides. Vegetation in the unit is mostly forest with tangled undergrowth, but in some places it is grass, particularly swordgrass. The surface or microrelief is gently rolling to rocky and rough for most areas of the unit. Talus is not common. Limestone pinnacles three or four feet high occur sporadically. The hilly land shows only a minor development of surface drainage, particularly in central Guam, where the intermittent Fonte and Agana (or Chaot) Rivers drain that area. Most drainage is downward into the rock mass. The hilly land evidently formed as the result of erosion of clayish limestone by small streams having small tributaries. At present, only torrential rains flood the valley bottoms and cause active erosion; otherwise, the relatively small volume of runoff either percolates gradually down into the rock or seeps laterally through alluvium or soil in the valley floors.

Plateau Land — The plateau land includes all but a small part of northern Guam, a belt along the southeast coast of the island, much of Orote Peninsula, and Cabras Island. In northern Guam the plateau is bordered by patches of coastal lowland and valley floor land except along the southwest border near Barrigada village, where it adjoins the hilly land of central Guam. The mountainous land and valley floor units of Mount Santa Rosa are completely enclosed by the plateau land unit. Along the southeast coast, hilly land borders the plateau land on the west. Discontinuous patches of coastal lowland and valley floor divide the plateau land into separate areas and border it on the east side between Ylig Bay and Asanite Bay. Both Orote Peninsula and Cabras Island are outlying areas of plateau land separated from the main body of Guam by coastal lowland and valley floor. The longest dimension of any separate part of the plateau land is roughly 26 kilometers (16 miles) in a north-south direction in the large area of the north Guam plateau. The remaining areas of this unit are relatively small. The total area of the unit is about 233 square kilometers (90 square miles). The plateau land unit in north Guam consists essentially of a single broad plateau surface bordered by steep coastal cliffs. The surface of the plateau includes scarps, mounds, sinkholes, cliff summit ramparts, elongated swales, and coastal terraces. Mount Barrigada, a broad-domed hill, protrudes above the general plateau surface. The most prominent scarp upon the plateau extends from Tamuning village northeastward to Finegayan and then eastward toward Sabanon Pagat. The southeast coast area of plateau land has many relatively small scarps, most of them transecting the upper surface at an angle to the coastal cliffs. Orote Peninsula has one very prominent scarp parallel to the trend of the peninsula. The Orote Peninsula sea cliffs are vertical and sheer and have no coastal lowland on the south side. In some places step-like terraces are prominent in the plateau cliffs. The best display is between Achae Point and Ritidian Point, on northern-most Guam, where six terraces occur between the upper plateau surface and sea level. Elevations in the plateau land unit range from sea level to about 210 meters (690 feet) in northern Guam near Mount Santa Rosa. Mount Machanao, near the north tip of the island, is 192 meters (630 feet) above sea level, Pati Point is 170 meters (560 feet), Fadian Point is 100 meters (330 feet), Uruno Point is 170 meters (560 feet), Haputo Point is 125 meters (410 feet), Amantes Point is 125 meters (410 feet), and Ypao Point is about 60 meters (200 feet). These elevations are indicative of the general elevation of the included plateau surface. Mount Barrigada, rising above the plateau, reaches about 200 meters (655 feet). The median elevation for the north plateau is about 107 meters (350 feet). In the southeast coast area, the maximum is about 126 meters (415 feet) along the northern cliffline overlooking Talofofo Bay. The area east of Assupian reaches 110 meters (360 feet) and the Camp Witek area reaches 116 meters (380 feet) above sea level. The median elevation in this area is about 64 meters (210 feet). Orote Peninsula ranges up to about 60 meters (200 feet) above sea level, and Cabras Island, to about 20 meters (65 feet), which is approximately the median elevation for Orote Peninsula.

Most of the relief in the surface of the plateau land is subtle compared with the broad expanse of the plateaus. The near-vertical cliffs, some 183 meters (600 feet) high in northern Guam, bordering the plateau land constitute the major relief of the unit. Mount Barrigada is the major eminence above the north Guam plateau and has a total relief of about 85 meters (280 feet). The Tamuning-Finegayan-Sabanon Pagat scarp has a maximum relief of about 80 meters (260 feet) immediately north of Mount Barrigada. Most other scarps have a relief of less than 28 meters (90 feet). Some of the sinkholes near Maputo are 30 meters (100 feet) deep. Generally the plateau land in northern Guam as flat to slightly undulatory and has a relief of only 4-1/2 to 6 meters (15 to 20 feet). Relief diminishes with total elevation in the long slope southward to sea level near Tamuning. Orote Peninsula, with a total relief of 61 meters (200 feet), has in its upper surface a scarp with a relief of about 11 meters (35 feet). Most of the plateau land unit in southeast Guam has less relief in its plateau surface than does Orote. Sea cliffs along the southeast coast, however, have a total relief of as much as 126 meters (415 feet).

The principal slope of the main area of plateau land is very slightly downward to the south-southwest, from 210 meters (690 feet) near Mount Santa Rosa down to sea level near Tamuning, 17.5 kilometers (11 miles) distant. Orote Peninsula slopes gradually downward to the east. In general, the sea cliffs are either precipitous from base to summit or else steeply sloping in the lower, and precipitous in the upper parts. Scarps and sinkholes have moderate to steep slopes. Other slopes in the plateau land, particularly the mounds and swales, are gentle. The plateau land is developed mainly upon exposures of the Mariana limestone, Barrigada limestone, and Alifan limestone. Soils are very thin, generally not more than a few inches thick. Vegetation is largely forest with tangled undergrowth in most of the plateau land, although much clearing has been accomplished for purposes of farming and construction. Secondary growth in some of these areas is low and bushy. The surface or microrelief is variable between extremes of smooth ground and rough, rocky, boulder-strewn, or jagged, limestone -pinnacled ground. The latter occurs particularly near cliff-summit ramparts in northern Guam.

There are no streams in the plateau land (see Fig. 10); drainage is by downward percolation into the porous limestone. During torrential rains, sheetwash flows in many areas, particularly into swales. Standing water bodies may accumulate and require two or three days to drain. The plateau land was formed during a time when this part of the island mass was beneath the sea. Coralline limestone accumulated in shallower areas both as growing reefs and as fragmental deposits. Probable regional uplift resulted in the emergence of the great expanse of land that is now plateau land. Intermittent faulting and wave erosion produced the bordering sea cliffs. Fault scarps and ground-water solution features such as sinkholes and swales probably developed after emergence.

Interior Basin and Broken Land — The interior basin and broken land unit occurs entirely in south central Guam. It is bordered chiefly by the mountainous and the dissected sloping and rolling land units as well as by some areas of rough summit land, hilly land, and coastal lowland and valley floor. The shape of the unit is elongate northwest-southeast, the longest dimension being about 10 kilometers (6 miles). The total area is about 31 square kilometers (12 square miles).

The interior basin and broken land is heterogeneous in topographic expression. It includes karst topography, many small conical hills, an artificially constructed freshwater body, some dissected sloping land, some deeply eroded stream valleys, many scarps, some gently undulating land in the bottom of the basin, and many small valley floors. The median elevation for the entire unit is roughly 64 meters (210 feet). The greatest relief in the interior valley and broken land unit is in the eastern part along the north bank of the Talofofo River, where individual scarps are as high as 80 meters (260 feet). The principal slope of the interior basin and broken land, as reflected by the slope of the floor of the basin, is slightly southeastward, but secondary slopes, generally gentle to steep, are inward toward the center of the basin.

The unit is developed upon exposures of the Alutom formation, Umatac formation, Bonya limestone, Talisay formation, Alifan limestone, Mariana limestone, and much present alluvium. Soils are absent to many feet thick. Vegetation on the flanks or perimeter slopes of the basin is largely grassy with some patches of forest growth. Within the lower part of the basin, this changes to thick forest with heavily tangled undergrowth. Many marshes and swamps occur throughout the unit. The surface or microrelief includes everything noted under the other physiographic unit descriptions plus much clayey ooze and wet muck in the lowlands. The surface may be smooth, rough, rocky, boulder-strewn, limestone-pinnacled and jagged, Bullied, or combinations of these characteristics. Talus deposits are common, some of soft clay and others of hard limestone boulders.

The interior basin and broken land is drained ultimately by surface streams but the unit includes some limestone exposures upon which runoff does not occur. Instead, water percolates downward into the rock and reappears as springs at the basal contact of the permeable limestone masses where they overlie relatively impermeable volcanics. Originally a structural depression, the interior basin and broken land has been flooded by the ocean several times during the geologic history of southern Guam. Estuaries reaching far inland have permitted the deposition of many limestone formations. All of these, upon emergence, have been eroded to yield the hilly, bumpy, or karst topography now characteristic of the area.

Coastal Lowland and Valley Floor — The coastal lowland and valley floor unit occurs discontinuously along the coast of the island except for the long stretch around the northeast side between Pago Bay and Tarague. In addition, it penetrates inland as valley floor at Agana, Pago, Ylig, Talofofo, Inarajan, Merizo, Umatac, and near Apra Heights. Penetrations of 3-1/2 to 5 kilometers (2–3 miles) occur at Agana and Talofofo. The longest straight line dimension of the unit is about 13 kilometers (8 miles) from Piti to south of Agat. The total area of the unit is about 39 square kilometers (15 square miles). Coastal terrace or flat land, beaches, and the floors of wide valleys make up this unit, most of the land being flat and having little relief. Low coastal scarps, beach berets, and natural levees formed by streams are the main landforms of the unit.

Elevations in the coastal lowland and valley floor unit range from sea level up to about 12 meters (40 feet) for the valley floor and slightly higher, perhaps 15 meters (50 feet), for some of the inner margins of coastal lowland. The median elevation is about 6 to 7-1/2 meters (20–25 feet). The sharpest relief displayed by this unit is between 3 and 4-1/2 meters (10 and 15 feet), at the storm berets along some beaches. In the Agana River marsh, however, several limestone hummocks protrude as much as 9 meters (30 feet) above the surface. West of Apra Heights, near Camp Roxas, more limestone hummocks occur. One or two broad hills about 15 meters (50 feet) high are situated where the Orote Peninsula joins the island.

The principal slope of this unit is gently seaward, except for the eastern part of Orote Peninsula, where the slope is very slightly eastward toward the main island mass. Some typical valley floors, such as those of the Ylig and Talofofo Rivers, have slopes of 1 in 525 and 1 in 240, respectively. The marsh area along the Agana River has an average slope of about 1 in 390, although it is somewhat rougher than the afore-mentioned two valley floors.

Beaches in the unit have average foreshore slopes ranging from 1 in 4 near Inarajan to 1 in 30 near Agat. The majority of slopes in this class, however, approximate 1 in 7.

The coastal lowland and valley floor unit is developed upon exposures of present alluvium, beach sands, and Mariana limestone. Soils are thin over the beach sands, generally thin over limestone lowland terrain, and generally thick, mucky, or marshy in valley floors. Vegetation is cleared in much of the lowland but may be present as coconut palms on beaches, as at Tumon, Haputo, and Tarague. Swamps in valley floors may include thick forest, as in the valleys of the Talofofo and Ylig Rivers. Swamps such as the one along the Agana River are very grassy and have thinner forest cover. Surface or microrelief is smooth and sandy at beaches, sandy to muddy in lowlands such as the Agat area, and rough, rocky, boulder-strewn, and pinnacled near some beaches where limestone has been actively eroded. Valley floors are generally smooth and clayey but may have tangled roots of large trees two feet above the ground surface. Drainage at beaches and on adjacent limestones is by percolation downward into the rock. Some coastal lowland—for example, that in the Inarajan, Agat, and Asan-Piti Districts—is not well drained. Wide bodies of standing water accumulate to depths of several inches in very rainy weather.

The valley floors are partially drained by their major streams but may also have accumulations of standing water three feet or more deep in the rainy season. In some places, minor accessory streams drain the back-swamp pools lying outside the natural levees built by the main streams. Valley floors have developed as the result of filling of older, deep valleys with alluvium transported by streams. Coastal lowlands have been formed of stream alluvium in places; in many places it has been mixed with sand from the shoreline zones. Beaches are largely sand thrown upon the shore. In places such as Tumon, Hilaan, Acahe Point, and Tarague, great quantities of sand have accumulated. Some lowland has been planed or beveled by waves associated with previous higher stands of sea level.

GEOLOGIC SUCCESSION

The following descriptions of the rock units exposed on Guam are taken in part and summarized from the detailed descriptions in Tracey, et al. (1959, pp. 75–96) except for references to plates, tables, and figures which have been omitted or substituted for others in this report. The names of the Bolanos conglomerate member, the Facpi basalt member, and the Dandan basalt member of the Umatac formation and the Lafac sand member of the Mariana limestone formation have been changed to the Bolanos pyroclastic member (Tub), the Facpi volcanic member (Tub), and the Dandan flow member of the Umatac formation (Tub) and the fore-reef facies (QTmf) of the Mariana limestone, respectively, following Tracey, et al., (1960 .

Rock Units

Alutom Formation (Ta)

The Alutom formation of Eocene and Oligocene ages., named for Mount Alutom, is the oldest rock sequence exposed on Guam, cropping out over a large area in central Guam. Mount Santa Rosa,, Mataguac Hill, and nearby Pali Hill are inliers of the formation, which underlies much of the north plateau. Regions exposed within the coastal region are located near Adelup Point, Asan, Piti, and Agat (Figs. 7a–7f, 8).

The Alutom formation is characterized by well-bedded, fine-grained, water-laid tuffs with lensing gradations into fine sandstone. The tuffs range in color from gray to chalky white and form steep cliffs, projecting ledges, and rounded peaks. The formation consists of about 10 per cent basic lava flows and about 20 per cent conglomerate beds composed of blocks of basaltic rock ranging from coarse conglomerate with blocks up to eight feet in diameter to a lapilli pyroclastic breccia. There are many gradations into tuffaceous sandstone and gravelly beds, but the dominant rock is the white to grayish-green, fine-grained tuffaceous shale. Limestone fragments ranging from small chips and grains to blocks two feet in diameter are prominent in some of the lapilli conglomerate beds.

The structure of the Alutom formation is markedly more complex than that of younger formations. It has a regional strike to the northeast and displays many small anticlines and synclines and local areas of extremely complex folding. The base of the formation is not exposed, but the thickness exposed above sea level is estimated to be 2,000–3,000 feet. Intense weathering, ranging in depth from a few inches to at least forty feet, characterizes surface outcrops.

The Alutom formation contains larger Foraminifera of Tertiary b (Eocene) and Tertiary c (Oligocene) age. Eocene planktonic Foraminifera and Radiolaria have also been identified. All volcanic explosions and extrusions responsible for the building up of Guam from the ocean floor are believed to have been submarine.

Mahlac Member (Tam) — The Mahlac member of the Alutom formation is named for the Mahl9c River in southern Guam. Outcrops are confined to the interior basin except for a small patch on the west slope of Mount Alifan (Figs. 7d and 7e). The Mahlac member is a buff to tan or yellowish-tan, partly weathered, friable, fossiliferous shale composed of volcanic detritus deposited in water. In some exposures the matrix is calcareous.

The Mahlac member is thin-bedded to laminated. In the Fena basin north of the reservoir, it is fractured and crushed. The known thickness in the Mahlac River exposure is 200 feet. The Mahlac shale is tentatively assigned to the Tertiary c (Oligocene), on the basis of smaller Foraminifera.

Umatac Formation

The Umatac formation, of early Miocene age and named for the village of Umatac, is made up of four members: the Facpi volcanic (Tuf), the Maemong limestone (Tum), the Bolanos pyroclastic (Tub), and the Dandan flow (Tud). The bulk of the formation is made up of the Facpi volcanic and the Bolanos pyroclastic members (Fig. 8).

Facpi volcanic member (Tuf) — The basal member of the Umatac formation, the Facpi volcanic, is named for Facpi Point, where a thick section of pillow basalts cut by dikes is exposed. This member consists of approximately 1,400 feet of basic lava flows and pillow basalts which include, in the vicinities of Merizo and Umatac, beds of tuffaceous limestone and pure limestone 15–260 feet thick. The basal flows crop out along the west coast of Guam (Fig. 7d) from a point at the extreme southern tip of the island, approximately two miles east of Merizo, and continue northward through Facpi Point to Taleyfac. The flows form large outliers at Agat and Santa Rita (Fig. 7d). The lava flows extend eastward from the west coast and form the major part of the deeply weathered foothills between Mount Lamlam and the sea.

Many dikes one inch to six feet wide cut the flows in the vicinity of Facpi Point and southward along the coast to Umatac. Flat marine benches exposed at low tide border the cliffs of pillow lavas between Umatac and Cetti Bay. Glassy selvages around the ellipsoidal pillows are more resistant to erosion and form rims an inch or less thick around the pillows. At low tide the bench becomes a surface of shallow basins with glassy rims surrounding more deeply eroded centers of the ellipsoids. The pillow lavas are fresher in cliff surfaces than on the deeply eroded uplands, but in no outcrops are they entirely unaltered. Most outcrops are weathered to red, brown, and yellow clay rock easily dug into with a pick. Even in those most deeply weathered, the outlines of ellipsoidal structures are preserved by differences in color because of weathering between the peripheries and centers of the pillows. In other deeply weathered exposures, a stockwork of zeolite veins gives the rock an appearance of being a clastic breccia or conglomerate. Such outcrops can commonly be traced through gradational stages into unmistakable lava flows.

Maemong limestone member (Tum) — The Maemong limestone member of the Umatac formation, named for the Maemong River, is exposed in two principal areas. The first is in the Fena-Mapao area of central Guam, where a shallow-water facies of the member occurs as outliers upon volcanic rocks. This facies is typically a white or pink-white, hard, compact, fine-to coarse-grained, partly recrystallized, fossiliferous, detrital limestone. The second area of outcrop of the Maemong limestone member is along the western slopes of southern Guam, where limestone and tuff are exposed in stream valleys (Figs. 7d and 7e) as a deep water facies ranging in lithology from gray, fine-grained, laminated, tuffaceous limestone to thick-bedded, conglomeratic limestone. The beds of this facies contain large foraminifers identified as middle or late Tertiary e in age, corresponding generally to the early Miocene, and thus also establish the age of the Facpi member as Tertiary a (Miocene). The Maemong limestone member is approximately 260 feet thick where measured along the Geus River.

Bolanos Pyroclastic Member (Tub) — The Bolanos pyroclastic member is made up of water-laid conglomerate, breccia, and sandstone and shale beds. It is named for the thick section forming the upper 750 feet of Mount Bolanos. Deposits of this member cover the interior mountain range and flanking uplands of southern Guam (Figs. 7d and 7e), many surface exposures being so deeply and so intensely weathered that the original character is obscured.

The Bolanos pyroclastic member is above the Facpi volcanic member and the Maemong limestone member (Fig. 8) and also includes limestone fragments containing large foraminifers of Tertiary a age, particularly at the top, where well-preserved fossils are present in the matrix. These foraminifers do not appear to be abraded or derived from pre-existing rocks, and are identified as late Tertiary e.

Dandan Flow Member (Tud) — Basaltic lava flows cap small areas of Bolanos pyroclastics on top of Mount Jumullong Manglo and on high points of the dissected upland east of the south-central mountain range. These flows are especially prominent in Dandan, for which the unit is named, and extend over a considerable area between Dandan and Mount Bolanos, as indicated by residual boulders scattered over the dissected area east of the mountain range (Figs. 7d and 7e). Many boulders of the Dandan flow are fresh basaltic rock composed essentially of plagioclase, pyroxene, magnetite, and olivine. Commonly the olivine is completely altered to secondary serpentine. The fresh rock ranges in texture from fine to medium grained. Phenocrysts are always present.

The Dandan flow member is separated from beds of the underlying Bolanos pyroclastic member (Fig. 8) by a bed of basal flow breccia as thick as ten feet. No volcanic units younger than the Dandan flow have been recognized. In the Fena basin near Mount Almagosa, lavas mapped as Facpi flows but possibly equivalent to the Dandan flow member are overlain by Bonya limestone of Tertiary f age. The Dandan flow member is assigned to the later Tertiary a age on this basis.

Bonya Limestone (Tb)

Bonya limestone is named for the Bonya River, which flows through the outcrop area of this limestone in the Fena basin in central south Guam. The principal Bonya exposures are concentrated in a relatively small area in the Fena-Talofofo Rivers valley (Figs. 7d and 7e).

Bonya limestone is a buff-white, pink, brown, gray or gray-black, porous to dense, friable to indurated, generally medium- to coarse-grained, clayey or volcanically contaminated, fossiliferous, detrital limestone. It contains remains of corals, calcareous algae, and molluscs. This limestone is medium-to thick-bedded, pointed, and fractured throughout, and is horizontal or dips as much as 20°, generally eastward. The thickness of the Bonya limestone generally does not exceed 120 feet, resting upon rocks of Tertiary a (early Miocene) age in southern Guam.

Bonya limestone also crops out along the east coast of northern Guam (Fig. 7a), where it unconformably overlies the Alutom formation and sharply underlies the Janum formation (Fig. 8).

From the foraminifera which occur in the Bonya limestone, it is tentatively assigned a Tertiary f (Miocene) age.

Barrigada Limestone (Tbl)

Barrigada limestone is named for Mount Barrigada, along the lower slope of which is exposed the type section. The rock is white, even-grained, and has a chalky fracture. The base of the formation is not exposed in northern Guam; the top is overlain by Mariana limestone (Fig. 8). Barrigada limestone crops out from Harmon Field and Mount Barrigada north to Haputo and east to Mount Santa Rosa. It forms a ring-shaped area 6 miles in diameter, and the width of outcrop averages about a mile (Fig. 7a). A small inlier is mapped at the base of the Tarague cliffs (Fig. 7b).

Barrigada limestone is moderately homogeneous over most of its area of outcrop. It is thick-bedded to massive, intensely white, pure detrital limestone. It is compact in appearance but finely porous and permeable. Much of the limestone is tough and difficult to break with a hammer; a fresh fracture has a dusty or chalky appearance. Its maximum thickness is unknown. It is no more than 100 feet thick in any outcrop or well in southern Guam. Rock from the bottom of a well near Haputo, drilled in limestone to a depth of 543 feet, is similar in lithology and foraminiferal content to Barrigada limestone exposed at the surface. The maximum thickness is therefore presumed to be greater than 543 feet.

The age of Barrigada limestone is also not definitely known. In northern Guam it is believed to be Tertiary g (late Miocene), as one species of *Operculina* resembles a species obtained from the Tertiary g of a Bikini core at a depth of 900 feet.

Janum Formation (Tj)

This formation is named from Janum Point on the northeast coast of Guam. The type section is at Catalina Point where approximately 70 Feet of the formation is exposed in a coastal reentrant (Fig. 7a).

The Janum formation crops out in seven places along the northeast coast between Lujuna Point and Anao Point. Lenses exposed north and south of Catalina Point thin away from the type locality. At Anao Point six feet of the formation is exposed; at Lujuna Point, four feet.

The rock is compact to friable, red, pink, brown, yellow, or white, slightly to highly tuffaceous or argillaceous, fine- to medium-grained, well-bedded, foraminiferal limestone. The beds are closely faulted and jointed.

Contacts with the overlying Mariana limestone are sharp and well-defined unconformities except at Anao Point where a conglomerate of mixed cobbles is present, bearing pink fragments of the Janum formation and white cobbles of the Mariana limestone. At Lujuna Point the lower contact is sharp and well defined with the Janum formation resting conformably on compact, white, jointed Bonya limestone. At Catalina Point the Janum formation grades downward into a few feet of Barrigada limestone which, in turn, grades down into Bonya limestone (Fig. 8).

A profuse variety of pelagic and some benthonic foraminifera is abundant in the Janum formation. These fossils are thought to indicate deposition at depths of from 100 to 1,500 fathoms, more likely closer to 100 fathoms. The Foraminifera are Miocene in age. The Janum formation possibly represents an offshore equivalent of Barrigada or Alifan limestones and therefore may be Tertiary g in age.

Alifan Limestone (Tal)

Alifan limestone is named for Mount Alifan, where the best section of the formation is exposed in the Mount Alifan (Naval Ammunition Depot) Quarry. Other exposures include the remainder of the limestone cap on the Mount Lamlam-Alifan ridge, patchy occurrences in the interior basin and Togcha River valley, along the coastal region from Agat to Agana, Mount Santa Rosa, the Orote Peninsula at Gabgab Beach, Sinajana, Yoga, Nimitz Hill, and near Dandan on the southeast side of Guam. (Figs. 7a-7e).

The limestone exposed in the Mount Alifan Quarry is a crudely-bedded, white to buff, detrital limestone containing molds of molluscs and branching corals and some recrystallized massive corals. The bottom of the quarry is pink to red, compact, fine limestone with abundant large tubes, probably those of boring molluscs about an inch in diameter, 1–3 feet long, crooked, and nearly vertical. The maximum thickness of Alifan limestone probably is more than 200 feet on Mount Almagosa. Inferring a maximum thickness is difficult on the Mount Alifan-Mount Lamlam ridge because of the irregularity of the surface of the underlying volcanic rocks.

At Agana, limestone interpreted to be Alifan is unconformably overlain by the Agana argillaceous member of Mariana limestone (Fig. 8) which probably is of Pliocene age. The Alifan formation, therefore, probably is Tertiary g (late Miocene) or Tertiary h (early Pliocene) in age.

Talisay Member (Tt) — This member is named for the Talisay River, which flows through the area of outcrop in the western part of the Fena River basin and the east slopes of Mount Alifan (Figs. 7d and 7e). The Talisay member is made up of volcanic conglomerate, beaded marine clay, marl, and clayey limestone. The member appears to be mostly a nearshore deposit of clay, conglomerate, and marl derived in part from extensive subaerial weathering and erosion of volcanic rocks. The formation blankets and obscures pre-existing topography. The member is thickest in the west side of the Fena River basin. A 30-foot Talisay section below an outlier of Alifan limestone consists of marl overlying volcanic conglomerate; the lower contact is concealed. The conglomerate is more than seven and probably less than fifteen feet thick. In another outcrop half a mile southeast, the Talisay consists only of volcanic conglomerate about thirty feet thick.

The Talisay conformably overlies Bonya limestone, whose top contains the foraminifer *Cycloclypeus* (*Katacycloclypeus*), probably of Tertiary f age. The top of the Bonya also marks the disappearance of *Lepidocyclina* and *Miogypsina*, the original definition of the Tertiary f–Tertiary g contact. For these reasons, the Talisay formation is tentatively assigned to the Tertiary g, or late Miocene. The Talisay is probably equivalent in age to at least a part of the Barrigada limestone.

Mariana Limestone

Mariana limestone forms about 80 per cent of the exposed limestone of Guam. It is correlated with the Mariana limestone of probably older Pleistocene and possibly Pliocene age (Cloud et al., 1956) previously described on Saipan and Tinian. Mariana limestone is a complex of reef and lagoonal limestone mapped as five units (Fig. 11). The reef facies (QTmr) forms a discontinuous peripheral belt of rock at or near tile present cliffline; this facies encloses the detrital facies (QTmd) and the molluscan facies (QTmm), both of lagoonal origin. The Agana argillaceous member (QTma) is restricted to a fringe around the older volcanic rocks which were the source of the clay in this member. The fore-reef facies (QTmf) is a foraminiferal sand and gravel of fore-reef type on low coastal terraces and scarps.

As can be seen from the geologic maps (Figs. 7a–7e), Mariana limestone is the most widely exposed formation on Guam. It covers most of the north plateau, including almost all the cliffs and terraces, thinly fringes the west coast from Adelup Point to Facpi Point, forms the massive cliffs of the Orote Peninsula, and makes the broad marginal limestone apron from Pago Bay nearly to Merizo.

Mariana limestone formed as interlensing lagoonal sediments and peripheral reef deposits on a floor of irregular volcanic rock and older limestone. The thickness of the formation is therefore highly variable. As the base of the formation is rarely exposed, the thickness is difficult to judge, but it ranges from a thin edge, where the formation lenses out on older deposits, to more than 500 feet on some coastal cliffs.

Mariana limestone unconformably overlies Alifan limestone and Barrigada limestone and in places the older volcanic rocks near the coasts (Fig. 8). It is not overlain by any deposits except on its margins, where late terraces were cut into it and recent coral and sandy veneers were deposited.

Reef Facies (QTmr) — This facies is best exposed near Mount Machanao on northwest Guam where extensive areal deposits of coral and algal reef rock overlie and grade laterally into the detrital facies. Three rock types were mapped separately and later combined into this facies: a reef rock containing abundant corals, a large proportion of which are in position of growth; a coral-algal reef rock containing abundant corals, many in place and cemented by algal crusts; and an algal reef rock made up mainly of calcareous algae similar to the *Porolithon* on present-day reef margins.

The lithology of the reef facies is distinctive. The coral and algal remains form a well-consolidated rock which is generally porous but near cliffs is completely recrystallized with pores filled by calcite to form a sheath of compact limestone. Joints and faults are zones 's of recrystallization near cliffs.

Inshore from the cliffs, the abundant corals become more scattered, and the proportion of detrital material between corals increases until the reef facies merges with the detrital facies described (Fig. 11). The detrital facies is interpreted as lagoonal in origin. Patches of highly coralliferous reef rock, many of them large enough to be mapped, are common among the lagoonal sediments and are interpreted as reef knolls formed in the lagoon, within the encircling reef. Reef corals of types such as *Favia*, blunt *Acropora*, *Pocillopora* and meandrine or "brain" corals are common. Reef molluscs such as *Trochus*, *Turbo*, and elongate coral borers are abundant in places. The distribution of the reef facies is shown on the geologic maps (Figs. 7a–7e). This facies is neither continuous nor uniform but generally forms the peripheral cliffs of the island. Some discontinuities and breaks, for instance near Campanaya Point, can be interpreted as more deeply submerged intervals or channels in the original reef, where detrital material was dominant. Other gaps between mapped areas of the reef facies, such as between Tanguisson and Amantes Points, are probably caused by subsequent removal of parts of the cliffline by erosion or faulting.

Detrital Facies (QTmd) and Molluscan Facies (QTmm) — The detrital facies is well exposed in the north-facing cliff behind Tarague beach and in quarries on Andersen Air Force Base. The molluscan facies is well shown at Salisbury Junction. The detrital and molluscan facies include several lithologic and biologic varieties: 1) A detrital coral rock in which corals are the dominant fossil. A significant proportion of the corals are broken or worn, but in places some may be found in position of growth; in other places the worn corals form a conglomerate. Corals in general make up less than 10 per cent of the rock. 2) Detrital-molluscan limestone containing pelecypod and gastropod molds in a fine- to medium-grained detrital matrix. 3) A coral-molluscan limestone containing abundant corals and molluscs. 4) Pock in which scattered fossils are abundant but in which no single .fossil group is predominant. 5) Fine-grained, almost sublithographic limestone containing molds of mud-burrowing clams and gastropods. 6) A *Halimeda*-rich limestone.

Agana Argillaceous Member (QTma) — The pale-yellow to yellowish-brown clayey limestone which fringes most of the volcanic mass of southern Guam has been mapped as a member of Mariana limestone and is named the Agana argillaceous member, after the city of Agana. The type locality of the member is the cliff behind Agana where argillaceous limestone overlies with marked unconformity a massive, fractured, pure limestone mapped as Alifan limestone.

The Agana argillaceous member generally overlies volcanic rocks and is distributed around the southern part of the island, from Agat north to Adelup Point, and from Pago Bay south nearly to Merizo. North of the Adelup Point-Pago Bay fault (Fig. 6), on the north plateau of Guam, the Agana member forms a triangular area of exposure which ends near Mount Barrigada, about 5 miles from the volcanic hills (Figs. 7a–7e).

The Agana argillaceous member contains lenses of rock equivalent to members mapped in pure Mariana limestone. These lenses have not been differentiated as members within the bounds of the Agana argillaceous member. The lithology is mostly similar to that of the detrital and detrital-molluscan facies of Mariana limestone except for a contaminating clay, which is mostly disseminated sparsely through the limestone but which here and there is concentrated in pores and cavities within the limestone by percolation of water. The Agana argillaceous member contains roughly 26 per cent of clay disseminated through the rock. Many cuts, for example the roadcuts and quarries between Talofofo Bay and Inarajan and roadcuts from Asan to Orote, show much clay in cavities, fissures, and small pockets. The total clay content in many cuts exceeds 20 per cent and in a few exceeds 50 per cent of the rock mass, but throughout most of the mapped area the limestone in a fresh fracture does not appear to contain much clay.

Fore-reef Facies (QTmf) — The fore-reef facies is exposed in two areas on the east coast of Guam (Figs. 7a and 7e). At Lafac Point, the type locality, this facies forms apron-like, wedge-shaped deposits which thicken seaward and directly overlie the rest of the Mariana limestone. At the type locality, at least 150 feet of the facies is exposed, and the beds extend below sea level (see Fig. 7a). The deposit here is a thin-bedded, white, well-sorted, friable, medium- to coarse-grained limestone made up almost entirely of tests of foraminifers weakly cemented by calcite. The beds dip gently to the southeast and cover massive Mariana limestone. The second exposure of this facies, flanking the mouth of the Togcha River, is made up of conglomeratic limestone containing pebbles and boulders of Bonya limestone in a matrix of weaklycemented tests of foraminifers (Fig. 7e). This matrix greatly resembles the lithology of the type locality.

The fore-reef facies of Mariana limestone contains *Calcarina spengleri, Amphistegina, Marginopora,* and *Gypsina*—a foraminiferal assemblage of the Pleistocene epoch. The facies occurs generally as a mantling deposit on older parts of Mariana limestone; it is believed to have been laid down as a fore-reef sand and, possibly, talus conglomerate during late Mariana limestone time.

Some detrital limestone on terraces seaward and below the reef facies must have formed as off-reef slope deposits seaward of the reef. Few if any of the supposed off-reef deposits can be differentiated lithologically from the lagoonal detrital deposits. Notable exceptions are the bedded, gently-dipping, foraminiferal fore-reef facies dust described, and the well-bedded, steeply-dipping, conglomerate beds along the northeast coast from Janum Point to Catalina Point. These conglomerate beds dip about 25–30 degrees to the southeast and, like the fore-reef facies, are interpreted as off-reef deposits.

STRUCTURAL GEOLOGY

The following description of the structural provinces, faults, and other structural features of Guam have been summarized from Tracey et al., 1964, pp. A53–A57 and Tracey et al., 1959, pp. 98–100.

Structural Provinces

The limestone plateau of northern Guam, the folded Eocene volcanic rocks of central Guam, and the east-dipping Miocene rocks of central Guam form the three major structural provinces of the island. Each of these structural provinces consists of several blocks separated by fault zones (Fig. 6).

Northern Guam is comprised of the Machanao and Barrigada blocks, separated by the Tamuning-Yigo fault zone, and the Santa Rosa horst, which is bounded by normal faults.

Central Guam between the Adelup fault and the Talofofo fault zone consists of the mountainous Tenjo block and the limestone plateau of the Orote block, separated by the Cabras fault.

Southern Guam contains the large Bolanos block and the small Cocos block, which are separated by the Cocos fault.

Faults and Other Structural Features

The island of Guam displays structures such as folds, normal faults, and thrust faults in Eocene volcanic rocks; normal faults and minor folds in Miocene volcanic rocks; and normal faults in limestones of Miocene and post-Miocene age. Prominent joint zones and structural breaks are well developed in both limestones and volcanic rocks. The joint zones in limestones are characterized by parallel, narrow, deep fissures, between which have developed elongated spines and ridges. The rock itself is generally not brecciated. The volcanic rocks are cut by structural breaks, easily traced on aerial photographs, which show either as a series of knobs and ridges cutting across topographic trends or as long, straight alignments in otherwise normal terrain. Drainage patterns are determined in places, by these lines, as are valley-wall alignments. Minor movement along these joint zones and breaks may have occurred, but significant stratigraphic displacement has not been found. These zones and breaks are shown on the geologic map (Figs. 7a–7e) by aligned joint symbols. Joints are present in all formations on the island.

Major Faults and Fault Zones

Several large faults of considerable displacement cut the island. Some of these listed below form boundaries between physiographic, lithologic, and structural units. Figure 6 shows the major structural subdivisions and fault zones of Guam.

Adelup Fault — This fault extends across the narrow waist of the island and forms the structural boundary between the northern and southern parts of Guam (Fig. 6). Total vertical displacement is estimated to be about 300 feet. Major movement along this fault took place after the deposition of Alifan limestone but before the deposition of the Agana argillaceous member of Mariana limestone. Post-Mariana movement along this fault is shown by the tilt of the north plateau towards the southwest and by smaller associated faults which offset the Mariana limestone (Fig 7c).

Tamuning-Yigo Fault Zone — This high-angle, normal fault zone on the north plateau extends from the west coast of Guam at Tamuning to the alluvial flat at the southwest corner of the Santa Rosa block (Figs. 6, 7a, and 7c). The south side of the fault is uplifted to a maximum of 200 feet. Northeast of Mount Barrigada the trace of the fault is faint and continues into the vertical normal fault which extends southwest from the Santa Rosa block. The displacement on this hart of the fault is opposite to that on the Tamuning segment. Major movement along this zone probably took place contemporaneously with the major post-Alifan, pre-Mariana movement on the Adelup fault.

Faults Bounding the Santa Rosa Horst — Mount Santa Rosa has been uplifted as a horst section bounded by three high-angle normal faults (Fig. 7a). The most conspicuous fault forms hart of the southwest boundary of the volcanic rock exposures and extends southeast to the scarps at the cliffline. The second fault forms the northeast boundary and cuts both Alifan and Mariana limestones. The third fault forms the southeastern boundary of the block. The last significant movement along these faults took place after the deposition of the uppermost reef facies of Mariana limestone. The intense shearing in Alifan limestone does not extend into the overlying Mariana limestone. This relationship indicates that an earlier major period of faulting took place in the interval between Alifan and Mariana times. These two periods of faulting probably correlate with the two periods of movement on the Adelup fault.

Pugua Fault — This high-angle, normal fault strikes west of north, and extends from Uruno Point, where its trace lies offshore, through the cliff at Pugua (Fig. 7a). It dies out in the Barrigada limestone near Taguac. Major movement along the fault took place before the deposition of Mariana limestone; minor movement took place possibly as late as post-Mariana limestone time.

Talofofo Fault Zone — The major Talofofo fault zone, separating the central and southern Guam structural provinces, extends from Talofofo Bay to the west end of Orote Point and runs parallel to the Adelup fault (Fig. 6). The zone is occupied by numerous faults, lineaments, and joint zones (Figs. 7d and 7e). Faults do not continue into the overlying Mariana limestone, although prominent lineaments in the volcanic rocks pass directly into long joint zones in that limestone. Late movements probably correlative with the post-Mariana movement described for northern Guam, offset the Mariana limestone in the high cliffs around Talofofo Bay.

Cabras Fault — The tilt of Orote Peninsula indicates movement of this block after deposition of the reef facies of Mariana limestone. On the basis of this tilt and because of the remarkably straight coastline from Facpi Point to Cabras Island, a fault called the Cabras fault is inferred to separate the Orote block from the Tenjo block (Figs. 6 and 7c).

Cocos Fault — Cocos reef and lagoon are thought to have grown on a basement of the Umatac formation. The shape of the reef supports the idea that a block of the Umatac formation dropped along a fault which strikes almost parallel to the Talofofo fault zone and the Adelup fault. The Cocos fault separates the Bolanos and Cocos blocks (Fig. 6).

SOILS

General Description of Guam Soils

The following general description of Guam soils is taken from Stensland (*In* Tracey et al., 1959, pp. 118–119).

Guam is well within the belt of tropical soils, and although the soil-forming processes are predominantly lateritic, the island has no significant areas of true laterite soil (ground-water laterite). Regosols, Lithosols, Latosols, and Lithosolic Latosols are the great soil groups most extensively represented on Guam.

In the northern half of Guam, which is chiefly an undulating limestone plateau, is an extensive Lithosolic Latosol (Kellogg, 1949). This soil, although generally slightly alkaline, is rich in hydrated oxides of iron and aluminum. It is red, soft, friable, and porous throughout. Although generally shallow, it ranges in thickness from a few inches on gently rounded ridgetops to a few feet in small depressions or solution cavities. In southern Guam, Regosols and Latosols are predominant on the volcanic rocks. They generally are acid, reddish, yellowish, and brownish clays over deeply weathered volcanic material on hilly to mountainous upland. Minor areas of reddish-brown and yellowish-brown Lithosols and Latosols are on the hills and scarps of fringing limestone terrace remnants along the coast and on limestone outliers in the volcanic rocks.

In central Guam, separating the mayor soil provinces of the north and south, is a large, fan-shaped axis of moderately deep, yellowish-brown and red plastic clays (with dark brown surface horizons) on argillaceous limestone. These soils may be considered (McCracken, 1957) to be intergrades between Latosols and some group such as the Red-Yellow Podzolic soils.

Other soils on Guam include: a Regosol formed on discontinuous, narrow coastal terraces of calcareous sand slightly higher than the present beach and with soil similar to the Shioya soil mapped in the Palaus, Okinawa, and Saipan; and Alluvial soils consisting of sediments from limestone and volcanic uplands, accumulated in sink basins, re-entrants, valley flats, alluvial fans, and low coastal terraces, most of which are periodically flooded in the rainy season and some of which are marshy.

Miscellaneous land types which cannot be classed as soils are limestone rock land and made land, the latter consisting chiefly of artificial fill. Stream drainage patterns are developed in the southern province of volcanic soils and in the central area of limestone karst, but no continuous surface drainageways are developed in the more porous limestones of the northern plateau (Fig. 10).

The vegetation on the volcanic upland soils of the southern province is markedly different from that in central and northern Guam, consisting largely of coarse swordgrass, *Miscanthus floridulus*, and a *Dimeria* species. Many of the ravines in the central and southern areas contain thickets of mixed secondary forest, and secondary forest is common on uncleared parts of the northern plateau.

Stensland (1959) describes twelve soil types, of which five are from upland soils on volcanic rocks, three are from upland soils on limestone rocks, and four are from soils of coastal and valley floors. Three additional miscellaneous land types are also described, making a total of 15 described soil and land types. In this report all of these soil and land types were originally mapped on sections of 1:25000 scale mans corresponding to the boundaries of the macrodivisions of the coast and then reduced to fit the page format. The boundaries of these soils and land types are the same as those mapped by Stensland and Paseur (In Tracey et al., 1959, pl. 14) except that in this report only the coastal regions are differentiated. A brief description of the soil and land types which occur on each coastal macrodivision map is given in the legend explanations, also taken from the above source.

Additional characteristics of these soil and land types are given in Tables 5 and 6. The data on these two tables are to be used in conjunction with the various coastal macrodivision soil maps.

ENGINEERING GEOLOGY

The engineering aspects of geology and soils provide information for engineers on the suitability of rocks and soils of Guam for foundations and underground installations and on the characteristics, modes of occurrence, availability, and uses of construction material. These geological aspects have been described and mapped in nine different units by May and Schlanger (In Tracey et al., 1959). For this report, the above map with accompanying legend has been modified into five separate and smaller maps (Figs. 12a–12e), which show the distribution of the nine units for coastal regions only. The maps also indicate the locations of structural features and quarry sites. Soil characteristics given in Tables 5 and 6 are also keyed to the above nine units and can be used in conjunction with the engineering geology maps.

Engineering data on soils have been taken from two legend tables compiled by Stensland and Paseur (In Tracey et al., 1959, Pl. 49). The first, Table 5, gives a description of the soils, and the second, Table 6, gives soil drainage and erosion characteristics. These two tables are keyed to the basic soil units and are to be used in conjunction with coastal macrodivision soil maps (Figs. 12a–12e) to show areal distribution of various soil engineering aspects.

HYDROLOGY

The following account of the hydrology of Guam, the ground-water area and subarea descriptions, and the chemical characteristics of water were summarized from Ward et al. (1965) and Ward and Brookhart (1962). Refer to Figs. 1 and 7a–7e for locating place names used in discussing hydrology.

Broad Characteristics

The average rainfall on Guam amounts to nearly a billion gallons of water per day. Apart of the water escapes to the atmosphere by evaporation and transpiration, a part flows directly to the sea in streams, and a part moves downward through the soil and rock to ground-water reservoirs and thence to springs and seeps which discharge into the sea. The flow in streams and the recharge and discharge of ground-water differ greatly with locality according to character of the rock. No streams flow to the sea on the limestone plateau of northern Guam (Fig. 10). There, water moves rapidly downward through permeable rock to the zone of saturation, then laterally and more slowly through the aquifer to points of discharge at the shore. In southern Guam the volcanic terrain absorbs water at a low rate, and a large part of the rainfall flows quickly to the sea in closely spaced streams (Fig. 10). Ground-water discharge in the southern half is mostly at seeps and springs dispersed along these streams.

Streamflow

The average runoff to the sea from the streams of Guam is about 250 mgd (millions gallons per day). Virtually all the runoff is from the southern half of the island, where it amounts to about half the average daily rainfall on the drainage basins, and most of it is from streams flowing on the eastern slope of the island.

During various periods, beginning in 1951, measurements have been made of the total flow at gaging stations on major streams. The data, along with descriptions of the respective drainage basins of these streams, are given in Chapter IV, as they occur in the discussion of the macrodivisions of the coast.

Ground Water

Guam consists of two broad ground-water provinces of about equal size, each being subdivided into various areas and subareas shown in Fig. 13. In the northern half of the island, most of the ground water is contained near sea level in permeable limestone, from which it discharges at low altitudes near the shore, and only minor amounts are found in volcanic rock. In the southern half, the water is mostly in low-permeability volcanic rock, in which the water table rises to hundreds of feet above sea level and from which discharge occurs at all altitudes. The limestone in the southern half contains smaller amounts of water than that in the northern half.

Northern Guam (Water in Limestone) — The limestone forming northern Guam is a moderately to highly permeable aquifer which rests on an eroded surface of relatively impermeable volcanic rock (Fig, l4). The water table rises from sea level at the shore to heights of several feet above sea level in interior parts. It forms mounds near the northern end of the island and near the southern boundary of the limestone at the waist of the island (Fig. 15). In the northern mound, there is an area of about twelve square miles in which a hill of volcanic rock, buried beneath the limestone, stands above sea level and mostly above the water table (Fig. 14).

Recharge from rainfall moves rapidly downward through the cavernous limestone to the water table or to the top of the volcanic rock, where it is above the water table and moves laterally to the saturated zone. The recharge is intermittent and fluctuates sharply with rainfall. Discharge is at or near the shore, is continuous, and has smaller fluctuations because of the regulating effects of storage in the aquifer.

The Fresh Water Lens — The recharge from rainfall is fresh, and on reaching the zone of saturation, accumulates in a lens which floats on and displaces the slightly heavier sea water in the limestone below sea level (Fig. 16). The lens of fresh water is commonly called the Ghyben-Herzberg lens after W. Badon Ghyben (1889) and Alexander Herzberg (1901), who described the occurrence of fresh water floating on sea water in permeable rock in the coastal area of the Netherlands and in islands of the North Sea, respectively. The sea water is about one-fortieth heavier than fresh-water; consequently, the depth of a static fresh-water lens below sea level would be roughly 40 times the height of the water table above sea level. The lens is, however, a dynamic system through which water is in constant motion from areas of recharge to zones of discharge, and the energy involved in this movement affects the shape of the lens and the depth of the fresh water.

Water Perched On Volcanic Rock — In many areas, recharge from rainfall percolates down through the limestone and is stopped by the less permeable surface of volcanic rock before it reaches the water table (Fig. 14). This perched water may collect in small bodies if the slope and configuration of the volcanic surface are favorable, or it may travel down dip along the interface to a place of discharge.

Water In Volcanic Rock — The volcanic rock standing above sea level under the limestone probably is saturated to a considerable height above sea level, but the permeability generally is too low to yield appreciable amounts of water to wells.

Southern Guam (Water In Volcanic Rock) — The volcanic formations of southern Guam which contain water include lava flows, tuffaceous shale and sandstone, conglomerate and breccia, and small amounts of interbedded limestone—all of which form a widespread complex having overall low permeability. The rock in general is thoroughly weathered to depths as great as 50 feet. Several feet in the top part of the weathered zone over much of the area is a friable granular clay, which has a somewhat higher permeability than the underlying material. The limestone beds form local zones of higher permeability. Because of the wide-spread low permeability, the water table in the volcanic terrain has high relief, standing hundreds of feet above sea level under uplands and sloping steeply toward streams and lowlands along the shore.

Perched Water In Limestone — The limestone overlying volcanic rock in southern Guam has high permeability, and a large part of the rainfall on it moves quickly down to the less permeable rock. The discontinuous limestone platform on the east side of the island is underlain by an eastward-dipping volcanic surface which is mostly too steep for the accumulation of water. Except for meager perched bodies, the water here flows down the slope of the volcanics into the narrow band along the east coast where the limestone extends below sea level (Fig. 14). Limestone beds capping parts of the ridge on the west side of the island contain water perched on irregular but mostly gently sloping surfaces of volcanic rock. The water discharges along the edge of the limestone at nearly a dozen springs whose flows fluctuate through a wide range.

Water In Limestone At Sea Level — Coastal bands along the eastern and western shores of southern Guam are underlain by limestone extending below sea level (Fig. 14). Recharge to the limestone forms discontinuous lenses like those in the limestone of northern Guam, but they are small and mostly brackish or saline. Discharge occurs largely at the shore, although a few brackish springs flow at stream level in some valleys and cut through the limestone.

Ground Water Areas — On the basis of known or inferred geologic and ground-water conditions, Guam is divided into several ground-water areas, which are outlined in Fig. 13. The locations of the boundaries of most of the areas are approximate. A lack of information in some areas prevents precise definition, and in parts of the island the transition between areas is gradual. Descriptions of the areas are based generally on information that is available on wells and springs.

Area 1 — Area 1 forms a sharply curved band in north-central Guam, which almost encloses area 7 (Fig. 13). It is underlain by Barrigada limestone, which probably extends to or below sea level throughout the area. Beneath the limestone is relatively impermeable volcanic rock of the Alutom formation (Fig. 14). The contact between this limestone and the volcanic rock is an irregular surface which slopes generally outward from the roughly circular boundary between areas 1 and 7.

The limestone has high permeability, and it yields water readily to wells drilled below the water table, which stands five or more feet above sea level. The comparative remoteness of the area from the shores and the presence of relatively impermeable rock beneath the limestone apparently prevent the easy intrusion of sea water into the aquifer. The ground water is, therefore, relatively fresh, and contains less than 100 ppm of chloride. The freshness is maintained also by the considerable subsurface runoff of ground water from a mass of volcanic rock which lies above sea level in area 7.

Area 2 — Area 2 is a crescent-shaped strip lying west and north of area 1 (Fig. 13). The rocks at the surface are Mariana and Barrigada limestones. Volcanic rack of the Alutom formation underlies the limestone at unknown depths below sea level (Fig, l4). The height of the water table ranges from about 3–5 or more feet above sea level. Seawater intrusion apparently can occur throughout the area, but most of the water in the upper part of the fresh lens has low salinity. Most wells will yield as much as 200 gpm of water having a chloride content less than about 250 ppm.

Area 3 — The part of Guam lying north of a line across the island between Pago Bay and Adelup Point, except for the smaller parts included in Areas 1, 2, and 7, makes up Area 3. It is underlain by Mariana and Barrigada limestones, which extend below sea level in most of the area and contains ground water standing a few feet above sea level. It is divided into four subareas (Fig. 13).

A coastal band around the northern part of Guam and a broad segment of the island north of the waist forms subarea 3a. The base of the limestone is below sea level, except possibly along a part of the eastern coast between Lujuna and Mati Points, where the top of the underlying volcanic rock is at a shallow depth and may be above sea level in places. The chloride content of water tapped by wells in subarea 3a ranges from about 30 to 1,400 ppm.

Subarea 3b lies on the southeast side of the island's waist. It is underlain by Mariana limestone, which extends below sea level and contains ground water standing 1–4 feet above sea level. At wells where the water is undisturbed by pumping, the chloride content ranges from 30–400 ppm.

A strip across the waist of the island between Pago Bay and Agana forms subarea 3c. It is underlain largely by the Agana argillaceous member of Mariana limestone, which abuts against volcanic rock of the Alutom formation along much of the southwestern boundary. The height of the water table in the limestone ranges from about a foot above sea level near the shore to more than eight feet in the interior part of the subarea. The water table has a fairly steep slope (Fig. 15) as the result of a reduction in permeability caused by clayey material in the limestone. The chloride content of the water is generally less than 40 ppm except at the shore, where the salinity is high.

Subarea 3d, on the northwestern side of the waist of the island, is underlain by Mariana limestone in which the water table stands 1–4 feet above sea level. The chloride content of water undisturbed by pumping ranges from about 30 to a few hundred ppm.

Area 4 — Water-bearing limestone which caps hills of volcanic rock in southern Guam constitutes area 4 (Figs. 13 and 14). Water in the limestone is in mostly thin bodies perched on the less permeable volcanic rock. It discharges at seeps and springs at the edges of the limestone caps.

A limestone cap covering half a square mile in the Nimitz Hill area forms subarea 4a. Seeps along the south and southwest edges of the cap contribute to the flow of the Fonte and Asan Rivers.

The limestone cap covering about 2-1/2 square miles on the ridge between Mount Alifan and Mount Lamlam forms subarea 4b. Water discharges from the limestone at numerous seeps and several springs around the periphery of the cap and contributes to the flow of streams on the flanks of the ridge.

Area 5 — Area 5 includes narrow bands along the west and east coast of the southern half of the island, which are underlain by Mariana limestone, alluvium, beach deposits, and artificial fill (Figs. 13 and 14). The water table in the limestone is near sea level, and the water is mostly brackish. Locally, the alluvium, beach deposits, and fill contain meager amounts of fresh water.

The Orote Peninsula forms subarea 5a and is underlain by limestone, which on the low northeastern side is covered by a veneer of alluvium and artificial fill. Most of the water in the limestone is brackish or becomes brackish in wells at low or moderate rates of pumping.

A narrow strip underlain by limestone, alluvium, and beach deposits along the west coast of the island between Asan and Agat forms subarea 5b. Wells in the limestone and beach deposits have been reported to yield supplies ranging from 0.01–0.1 mgd, but the chloride content of the water was 500–1,000+ ppm. The alluvium in places contains water having a chloride content less than 100 ppm, but wells in the alluvium generally yield only meager amounts of water.

Subarea 5c is a narrow band along the eastern side of the island between Pago Bay and Inarajan, which is underlain by limestone and discontinuous beach deposits. The water table stands only slightly above sea level. Meager supplies of water having a chloride content less than 500 ppm may be available in wells dug near the inland edge of the beach deposits. Most of the water in this limestone has a chloride content greater than 500 ppm.

Area 6 — Area 6 includes most of southern Guam. It is underlain by volcanic rock and noncalcareous sedimentary rocks which were derived from volcanic rock having low permeability, and by permeable limestone containing only meager to small quantities of ground water. It is divided into two subareas (Figs. 13 and 14).

The rocks of subarea 6a are mostly lava flows, pyroclastic materials, and noncalcareous sedimentary deposits. The northern part of the subarea is underlain by tuffaceous shale and sandstone, conglomerate, and lava flows of the Alutom formation. The rocks in the southern part are lava flows, tuffaceous shale and sandstone, conglomerate, and scattered small lenticular limestone beds which constitute the Umatac formation. Small patches of Bonya limestone overlie the noncalcareous rock in the central part of the subarea. Thin deposits of unconsolidated alluvium underlie valley flats, and discontinuous beach deposits of calcareous sand and gravel lie along the shore. The water table commonly stands a few feet below the surface of the ground in alluvial fill under valley flats, but the alluvium has low permeability and yields water slowly to wells. Most of the beach deposits have moderate to high permeability, but most of the water in them is saline.

Subarea 6b forms a narrow band lying a short distance from the east shore of the island between Pago Bay and Inarajan. It is underlain by the permeable Mariana ,limestone, which rests on an eastward-dipping eroded surface of volcanic rock. Rainfall on the limestone moves quickly downward to the surface of the relatively impermeable volcanic rock and then down the slope of the surface into the groundwater body of subarea 5c. Water in the limestone is probably only in small quantities perched locally on volcanic rock.

Area 7 — Area 7 includes a crudely circular segment of about 12 square miles in northern Guam. The rocks at the surface are mainly Mariana and

Barrigada limestones, beneath which is volcanic rock of the Alutom formation which projects through the limestone at Mount Santa Rosa and Mataguac Hill (Figs. 13 and 14). The top of the Alutom wader the limestone is an irregularly eroded surface which has considerable relief and slopes generally away from the high points at Mataguac Hill and Mount Santa Rosa. Throughout the area, the surface of the volcanic rock probably is above sea level and above the water table of the surrounding areas.

Chemical Character Of The Water — The dissolved-solids content of rainfall on Guam is about that of greatly diluted sea water, being derived mostly from salt spray from the ocean which is intercepted in the atmosphere. When the rainfall strikes the surface, it picks up additional ocean salts deposited by spray blown inland from the generally continuous surf around the island shore.

The average dissolved-solids content of rain-water resulting from ocean salts picked up in the atmosphere and on the surface is estimated to be between 20 and 30 ppm, an average based on analyses of the chloride content of water from high-level springs and streams. Water having a dissolved-solids content of 25 ppm of ocean salts would have about 14 ppm of chloride, 8 ppm of sodium, 2 ppm of sulfate, less than 1 ppm each of calcium, magnesium, potassium, and bicarbonate, and a negligible content of silica. Analyses of water from several sources on Guam are shown in tables as they occur in the discussions of macrodivisions of the coast (Chapter IV).

In general, the dissolved-solids content of water flowing from volcanics is 200300 ppm, of which perhaps 20–30 ppm was contained in the water before it entered the rock. Most of the increase in dissolved solids probably takes place in the thick zone of weathering composed mostly of material produced by the decomposition of the silicate minerals in basaltic and andesitic rock and locally containing limestone beds and disseminated calcium carbonate. Water moving through the rock obtains substantial increases in the content of silica, calcium, and bicarbonate, and small increases in magnesium, sodium, and potassium.

Water in limestone unaffected or only slightly affected by mixing with sea water has a dissolved-solids content similar to that in volcanic rock. As in the volcanics, the movement of water through the limestone causes large increases in the calcium and bicarbonate content, but the increase in silica is small. The intrusion of sea water increases the dissolved solids and changes the relative amounts of the constituents.

BEACHES

The following general description of the beaches of Guam is summarized from a study made by Emery (1962, pp. B52–B61).

The beach sands of Guam are of two main types. White or buff sands which consist of calcareous organic remains comprise more than 75 per cent of the beaches. Other sands are light brown to black because of the presence of appreciable quantities of detrital volcanic minerals. Virtually all the beach sands from the northern half of the island are entirely of bioclastic origin. The general lack of stream development on the northern limestone plateau to carry nonbioclastic materials to the shoreline accounts for this (Fig. 10).

A more complex province exists in the southern half of Guam where surface rocks are dominantly of volcanic types. A network of large and small streams drains this area and transports nonbioclastic sediments to the heads of coastal embayments (Fig. 10), where the sands contain large percentages of insoluble or volcanic grains. The regions between these embayments have beaches composed of bioclastic sands generally containing less than 2 per cent insoluble grain to none at all. Apparently, the bioclastic sand of these intervening areas is washed ashore, and little of it enters the coastal embayments where streams empty. In turn, the volcanic sands carried by the streams are more or less contained in the general region of the embayment, there being little transport of stream-carried sands to the adjacent beaches with predominately bioclastic sands. Little detrital sand is contributed by sea cliffs because they consist of limestone; where of volcanic rock, the cliffs are protected from wave erosion by wide reef flats.

A third and intermediate type of beach environment exists on the west coast between Umatac and Agat, where volcanic rocks reach the coast and are subject to wave erosion. In this area, the beach is supplied with sediments from both land and the reef flat, resulting in a mixture of bioclastic and volcanic sediments.

The localities of 58 stations from which beach sands were collected are shown on Fig. 17. Samples were collected from all the stations at high-tide level and from 24 of the stations at low-tide level. Table 7 shows the characteristics of these beach sand samples. The insoluble residue is the per cent of the sample remaining after digestion in cold dilute hydrochloric acid. The weight loss of the sample is considered the bioclastic portion. Sand-grain sizes were determined by using a water column settling tube (Emery, 1938). Fine silt or clay sediments were analyzed by the standard pipette method. The degree of beach-sand sorting is expressed as the Trask sorting coefficient (Trask, 1932), the sorting coefficient being the square root of the ratio of the quartiles ($So = Q3/Q1$), where Q3 is the coarse quartile, and Q1 the fine quartile. Slopes of beaches were measured by using a simple survey method. Elevation of the beach was measured at six-foot intervals from an arbitrary bench mark established at the shore. The composition of selected beach sands are shown in Table 8, and the chemical analysis for two selected samples are shown in Tables 9 and 10.

REEFS

The shoreline of Guam is bordered by fringing reefs of various widths, narrow cut benches, seacliffs, and reef-like platforms. A triangular barrier reef encloses a shallow lagoon at the southwest corner of the island. A deep lagoon at Apra Harbor is enclosed by a submerged coral bank, a barrier reef, and a complex of fringing reefs bordering a raised limestone peninsula and island.

The island shoreline is bordered one-fourth by cut benches, one-half by limestone fringing reefs, and one-fourth by a combination of sea cliffs and truncated volcanic platforms partly veneered by organic reef accumulation. Regardless of the type of reef or platform present, most subtidal parts are covered with a variety of corals, benthic algae, and other reef-associated organisms. At some locations, reef development is exceeding erosion, and the platforms are growing seaward; at other places, reef development and erosion are in equilibrium, or a community of corals and calcareous algae thinly veneer an older substrate of limestone or volcanic rock.

Reef growth and development are quite variable from place to place. The type of reef present is controlled by orientation to prevailing winds, storm and typhoon damage, presence of fresh water and silt from streams and rivers, pre-existing topography, current patterns, shoreline use and development, and to some extent the kind of rock substrate present. The type of reef platform present is less predictable on high islands than on atolls, where controlling factors are fewer in number and more constant. There is no predominance of a certain reef type along any stretch of coast-line except for the 19-mile section from Pago Bay to Tagua Point, where cut benches are found.

Reef Zonation

For the purposes of coastal description, the reef platforms and slopes are divided into the several zones and sub zones suggested by Tracey et al. (1964), the divisions being based on such various physical parameters as degree of reef-surface exposure at high tides, degree of reef-surface submergence at low tides, amount of reef slope, and reef growth and erosional structures. Figures 18 and 19 each show a vertical profile through a fringing reef, the first with a wide reef flat and moat located at the north end of Tumon Bay and the second with a narrow reef flat and no moat at Tanguisson Point. Figures 20 and 21 show a vertical profile of the barrier reef located between Cocos Island and Merizo and a lagoon fringing reef near the head of Mamaon Channel, respectively. Figure 22 shows a truncated volcanic platform along the southern coast which has an outer fringe of reef development. Figure 23 shows a profile through a cut bench near Lafac Point. These profiles illustrate most of the major reef zones and their relationships to each other. All the fringing reef platforms and barrier reefs of Guam do not necessarily have all of these zones developed, but all are shown in the profiles. Some coastal regions lack reef development altogether, and others may lack certain features such as the first submarine terrace or inner and outer reef flat sub zones.

Supratidal Bench Zone

This zone consists of narrow platforms which are cut into elevated rocky shorelines (Figs. 23 & 47). The average elevation of bench platforms is slightly higher than mean high tide level. In general, bench platforms located in areas receiving greater wave assault tend to be higher with respect to sea level than those found in areas of reduced wave assault. The benches on Guam are more or less restricted to coastal regions lacking a fringing reef platform, or to the seaward side of small islets located on the outer edge of fringing reef platforms. Most benches are located in regions where considerable wave or swell action occurs, although some of the better fringing reef development is presently taking place on shores which receive the greatest wave assault. The outer seaward margin of the wider benches is usually elevated with respect to the shoreward part and consists of a series of rimmed terraces (Fig. 23). The inner parts of these benches commonly contain a moat of impounded water with scattered patches of unconsolidated sediments.

A detailed description of this zone is given in Chapter IV, Sector I, which has a shoreline almost completely bordered by cut benches.

Intertidal Shoreline Zone

This zone comprises that portion of the beach or shore covered at high tide and exposed at low tide. It varies in width depending upon the tide range and the steepness of the shoreline slope. Here, the usage of the zone is restricted to the shoreline, even though various parts of the fringing reef platforms are commonly exposed during low tide (Fig. 145). Along the more seaward exposed regions, where the intertidal zone consists of limestone, well-developed swell indentations called "nips" usually develop (Fig. 92). Water seepage from the fresh water lens system is common along the intertidal zone.

Reef-Flat Zones

Much of the coastline of Guam is bordered by fringing-reef flats and offshore barrier-reef platforms of various widths and origins. The most common type of reef flats are those composed predominantly of reef limestone (Figs. 18 & 19), consisting of a relatively flat limestone platform which extends from the intertidal shoreline to the wave-washed reef margin. Generally, the outer seaward part of the platform is slightly elevated with respect to the inner shoreward section, and consequently is often exposed at low tide. Because of this, the reef flat can be divided into two subzones—an outer reef flat which is exposed at low tide, and an inner reef flat, covered at low tide. These subdivisions have not been mapped in this report, although they are sometimes referred to in the sector descriptions (Chapter IV). The inner reef-flat water mass retained at low tide is referred to as the "moat." Local patches of unconsolidated sediments veneer the platforms at some locations. When present, these sediments generally range from a few inches to a foot in thickness, although on some of the wider reef flat platforms, where well developed moats exist, the thickness may be much greater. The outer reef flats of the platforms are generally devoid of sediments because wave and surf action there tend to keep unconsolidated material swept away. Boulder tracts are a common feature where the outer reef flat grades into the inner reef flat.

A second type of reef flat is the fringing coastal platform composed predominantly of volcanic rocks which have been truncated to or near sea level by marine erosion. In some instances, the inner part of a platform may consist of truncated volcanic rock, whereas the outer part consists of recent reef limestone accretion (Fig. 22). This type of platform occurs in small isolated stretches along the southwest coast of Guam. The surfaces of these volcanic platforms, like those of limestone platforms, may contain thin local patches of unconsolidated sediments, usually less than a foot in thickness.

A third type of reef flat is the barrier reef-flat platform, as at Cocos Lagoon (Fig. 20) and Apra Harbor. Such a platform is divided into two parts, an outer seaward-facing sub zone and an inner lagoon-facing subzone. The outer reef-flat subzone consists of a flat pavement which is generally exposed during lower tides, being slightly elevated with respect to the inner lagoon reef flat. The inner lagoon reef-flat subzone slopes gradually into the lagoon forming a shelf. A well-defined reef margin is generally absent on the lagoon side of the barrier platform. The inner reef-flat subzone has an irregular relief because of the accumulation of boulder tracts and scattered reef blocks which are derived from the seaward reef margin zone. More vigorous wave action generally keeps the outer reef flat swept clean of unconsolidated sediments and boulders. At Apra Harbor, the barrier reef-flat zone has been greatly altered by the construction of a breakwater on its surface (Fig. 124) and by dredging and land filling.

Coral growth on the various reef-flat platforms is more or less restricted to the inner reef-flat-zone moat or to where pools and holes retain water at low tide.

Reef-Margin Zone

This zone consists of the shallow seaward edge of the reef-flat platform which is constantly awash during low tide. The reef margin varies in width from 10 to 50 meters. The seaward edge is very irregular and is cut at right angles by surge channels 1–3 m wide, 2–4 m deep, and as long as 50 m. Some surge channels coalesce and fuse at the upper margin forming cavernous channels beneath the reef-margin platform, most of which open at intervals along the fusion zone, forming pools and open cracks (Fig. 172). In cross section, most surge channels are wider at the bottom than at the upper margin, a shape perhaps partly due to growth at the upper regions and abrasion at the base or floor, which contain large rounded boulders. The boulders, however, do not show evidence of constant movement because most are encrusted with red algae and small coral growths; rather, they are moved about by waves generated by typhoons and storms. Sure channels are separated by lobate elevations (buttresses) (Fig. 24) which slope seaward toward the reef-front zone. The upper surface of the buttresses is very irregular, with low knobs and pinnacles, and in many places is honeycombed with numerous interconnecting holes (Fig. 24). The inner half of the reef margin is more gently sloping, and the surface is irregular because of the presence of small knobs, pinnacles, holes, and pools. Shallow extensions of the longer surge channels cut through the inner half of this zone and terminate in small pools 1–3 m in depth.

Where wave action is fairly vigorous, there may be a slight elevation called the algal ridge, present at the seaward edge of the reef margin (Fig. 25). This ridge is more common on windward exposed margins where reef development is taking place, although algal ridge development is sometimes encountered at other locations. The algal ridge is a region where extensive growth of crustose coralline algae and corals is favored at the breaking surf zone. Upward growth of the algal ridge to mean high tide level or above is possible because the reef margin is usually awash at low tide. Reef margins which are not exposed to this rather constant wash from sea waves or refracted swells do not develop algal ridges. As Emery et al. (1954) pointed out, the upper limit seems to be determined by the height to which waves can wash at low tides. The algal ridge usually develops into a gently sloping convex rim, 15–50 cm above the main reef flat or into a cuestal-shaped structure a meter or more above the main reef flat. Two distinct regions of the algal ridge are recognizable: a seaward-facing fore-slope, and a shoreward facing back-slope. The fore-slope, of the convex type, dips steeply from the axial ridge crest, whereas the back-slope curves more gently into longer attenuated dip. The cuesta type fore-slope is steep to concave, and the back-slope is convex but has a steeper slope compared to that of the convex type.

On Guam, the convex type is usually found where the reef margin is actively developing in a seaward direction. The room and pillar type of development described by Emery (1954) is a common feature. Surge channels 2–4 meters in depth and 1–2 meters wide cut through the entire ridge. In the fore-slope region the surge channels are mostly open, but at the upper margin a horizontal lip commonly develops outward, giving the surge channel a partially roofed-over appearance in cross section. In the axial crest and back-slope regions many surge channels fuse together, forming cavernous regions, or are nearly fused together, forming a fissure zone. Water wells upward through the fissure zone with each advancing wave crest and downward with the approaching wave troughs, communicating with the cavernous to semi-cavernous, surge channels below. Open pools are also common in the back-slope zone where the roofing-over has failed to develop or has been removed by wave erosion. In the fore-slope region, the reef margin surface is honeycombed with a network of numerous holes which connect to the cavernous portions below (Fig. 24). Where a well-developed convex algal ridge occurs, a zone of limestone remnants which are solution-sculptured and above the high tide level occupy the region behind the axial ridge crest. This zone appears to be undergoing erosion because of reduced wave wash at low tide. It probably represents the former location of the axial crest, which has since developed farther seaward in the optimum zone of wave wash as the reef margin grows outward into the sea.

On Guam, the cuestal type of algal ridge is less common than the convex type and appears to develop where there is little to no seaward development of the reef-flat platform. This type of algal ridge differs from the convex in the following manner: It is generally narrower but higher in elevation. Surge channels are shallow and seldom penetrate to the reef-flat platform. The margin structure lacks the room and pillar development and the surface is relatively smooth and compact, lacking the honeycombed network of intercommunicating holes. The back-slope is predominantly covered with soft benthic algae, and the fore-slope is predominantly covered with encrusting coralline algae of the pavement type. (The convex type is covered predominantly by pavement algae on the back-slope and by a combination of encrusting pavement and ramose globular clusters of coralline algae on the fore-slope.)

Reef-Front Zone

The reef-front zone is located at the extreme seaward edge of the reef flat platform, where the reef margin abruptly increases in depth (Figs. 18 & 19). This zone is constantly covered by water. The reef front is comprised of the seaward-sloping extensions of the reef-margin buttress-and-channel or spur-and-groove systems. The point where these features terminate marks the seaward boundary of the reef front. Generally, the 18–25 foot submarine contour coincides with the seaward limit of the reef front.

The reef-front slope may be contiguous with that of the seaward-slope zone, but at many locations these two zones are separated by a flattened region called the submarine terrace (Figs. 18 & 19). The width of the reef-front zone is variable. At locations where reef development or a shallow submarine terrace is found, the reef-front buttress-and-channel system may be several hundred feet in width. At places where active reef development is reduced, lacking, or where an erosional spur-and-groove system predominates, the reef-front zone will be narrower.

Submarine channels near the reef margin range in width from 2–10 feet and are 8–20 feet deep. They commonly dichotomize into secondary channels, or divide and then anastomose, leaving isolated ellipsoid pillars along the length. Both submarine channels and grooves are usually wider at the base than at the top. At places, the wall may locally overhang the floor by six feet or more. Submarine channels and grooves are relatively flat-floored, with large rounded boulders, coarse sand, and gravel scattered along the length (Fig. 26). Some channels and grooves widen into holes 15–50 feet in diameter. Occasional potholes containing large round boulders are also found in the reef-front zone, particularly at the ends of channels and grooves. At places along the fringing reef-front where longshore reef-flat currents return to the sea, the channels and grooves may be considerably wider.

Submarine buttresses slope seaward from 10° to 40°. The degree of slope is not uniform along the length and is less near the reef margin than at the seaward boundary, where they terminate. The upper surfaces along the lengths of the buttresses are irregular because of the presence of coral-algal knobs, bosses, and pinnacles (Fig. 27). At the seaward end of this zone, these various prominences may have a relief as great as 15 feet.

The features described above for reefs with a developmental submarine buttress-and-channel system differ from regions with an erosional submarine spur-and-groove system in the following ways. The development-al surface irregularity of the spurs is much reduced. The floor of grooves is commonly eroded well below the general reef surface where they terminate in a seaward direction. There is a stronger tendency for grooves to develop along structural fractures, points, and fissures which are present in the parent rock. Potholes are more prevalent, and there is usually a sharp drop downward from the general floor level of the reef margin surge-channel floor to that of the submarine-groove floor level.

The reef-front zone appears to be the zone of optimum coral development.

Submarine Terrace Zone

If the general slope of the reef-front and seaward-slope zones are broken by a noticeably flattened region, that area is referred to as a submarine terrace, and there may be more than one level at which terraces are developed. According to Emery (1962), there are four fairly well-developed submarine terraces on the offshore slopes around Guam. The mean outer-edge depth and occurrence of each of these terraces from a total of 40 depth profiles (Figs. 28 & 29) follows: 1) the shallowest was at 55 feet occurring in 20 profiles, 2) the least frequently encountered was at 105 feet occurring in 11 profiles, 3) the most frequently encountered was at 195 feet occurring in 25 profiles, and 4) the deepest was at 315 feet occurring in 16 profiles. A terrace between 10 and 25 feet in depth is common also on the southwest coast of Guam, the terrace level being fairly well developed between the reef front and a sharp drop to the 55-foot terrace.

Where active reef development is taking place, the upper-terrace level is a region of rich coral growth. The surface is usually irregular because of local clusters of coral growth which form mounds, pinnacles, and ridges. Where the terrace consists of an older rock surface, the coral growth and development are reduced, giving the surface a much smoother relief.

Seaward Slope Zone

The seaward slope zone is bordered at the upper margin by the reef front or seaward edge of the submarine terrace and continues down the offshore island slopes to the deep ocean floor. According to Emery (1962), the seaward slopes which lead down to the Mariana Trench are smooth and gentle with an average slope of 4° to the 6,000foot contour; the slopes of the west side are complex; and off the south half of Guam, they are steep, averaging about 14-1/2° to the 6,000-foot level. The upper parts of the seaward slopes are considerably steeper, as shown by 40 offshore profiles in Fig. 28. The steepness for the upper parts of these slopes ranges from 5° to 44°. At the point where the seaward slope breaks from the reef front or the first submarine terrace, the slope is even greater. Near-vertical slopes are not uncommon, and sea cliffs occur at some locations. At most places, this steep upper slope is interrupted by a second terrace ranging from 50 to 180 feet in depth at the shoreward edge. The upper parts of the steep slopes and terraces provide zones of rich coral growth. Fifty per cent of the substrate was covered with living corals at Tumon Bay in such a zone before extensive *Acanthaster planci* starfish predation (Randall, 1973a). Local regions of coral development have produced coral ridges, pinnacles, and mounds. These topographic irregularities are more widely scattered than on the first terrace, but in some instances the local relief is greater. Where the second submarine terrace is well developed, sediments accumulate and are intermixed with coral mounds, ridges, and pinnacles. Scuba observations show distinct sediment trails to the lower terraces from the upper reef front and first submarine terrace zones.

Reef Sediments

Emery made extensive studies of reef and lagoon sediments at Cocos Lagoon and channels, Achang reef flat, Agana reef flat, Pago Bay reef flat and channel, and at other selected sites (Fig. 17). Table 10 gives the chemical composition of some samples; Table 11 gives the textural characteristics for some samples; and Table 12 gives the composition of some reef-flat sediments.

SUMMARY OF CORAL-REEF DAMAGE BY *ACANTHASTER PLANCI* PREDATION

Background

The first increase in the number of *Acanthaster planci* on Guam was noted during the early part of 1967 at Tumon Gay (Randall, 1971). By the summer of 1968, this small population of a half-a-dozen starfish had increased to several hundred, observed on a single SCUBA dive. Nearly a year later (March, 1969) most of the corals in the submarine-terrace and seaward-slope zones of Tumon Bay were dead because of *A. planci* predation (Randall, 1973a).

During the summer of 1969, an island-wide survey of *A. planci* distribution and associated reef damage was made on Guam by Chesher (1969). Figure 30 shows the results of this survey. Figure 31 shows the status of *A. planci* one year later, from a resurvey conducted by a University of Guam team (Tsuda, 1970). Figure 32 shows the status of *A. planci* from a resurvey conducted in April, 1971, by another University of Guam team (Cheney, 1971).

Results of the 1971 Resurvey

The results of the 1971 resurvey are summarized from Tsuda (1971). This resurvey included most outer-reef-slope and terrace areas, the fringing reefs and lagoons of Tumon Bay, Anae Island, Cocos Island, and outer Apra Harbor. The Marine Laboratory and Fish and Wildlife teams completed 65 tows and 12 SCUBA and/or snorkel dives.

The distribution of *A. planci* on Guam remains generally similar to that observed by the Marine Laboratory team in 1970 (Tsuda, 1970). Some significant changes have occurred, however, and these may be noted by comparing the 1971 distribution chart (Fig. 32) with the Fig. 31 (Tsuda, 1970).

A. planci is still concentrated in large numbers from Catalina Point to Pati Point and from Anae Island to Tipalao Bay. Smaller groups were also observed in the lagoon and on the seaward slope of the west reef at Cocos. The density of starfish in these areas was one per square meter to one per 100 square meters. Less concentrated aggregations were seen from Pago Bay to Catalina Point, in Tumon Bay (on the reef flat) and in Piti lagoon.

Specific Observations

1. Catalina Point. Within the area between Catalina Point and Pati Point, *A. planci* has been able to maintain its numbers at a level nearly equal to the early "plagues" seen on the now-destroyed northwestern

reefs. At Catalina Point, a band of starfish, 15–30 m (45–90 ft.) wide was seen at less than 15 m.

A SCUBA dive in 20 m about 1 km north of Catalina Point revealed a coral cover of 70–80%, but only 200 of this coral was alive. Starfish were not all actively feeding, and feeding sites were not numerous. The density of *A. planci* was low, one per 10–100 square meters. These starfish probably were remnant individuals, consuming remaining available corals.

South of Catalina Point small groups of starfish and feeding sites were seen as far as Pago Bay where no starfish had been seen in earlier surveys. During January–February of 1971, a small population was recovered in 20–40 m of water off the UOG Marine Laboratory at Pago Bay. All were large, nearly two feet in diameter, sexually mature, and feeding mainly on *Acropora* sp.

2. Anae Island. The fringing coral reef from Anae Island north to Tipalao Bay has suffered heavy damage and still supports large numbers of *A. planci*. The 1971 results do not differ from the 1970 resurvey results. The beautiful reef around Anae Island, a potential conservation area, was fairly clear of starfish, but a grey sponge has displaced much of the coral.

3. Cocos. The reef flat of the leeward side of Locos lagoon was badly damaged by earlier starfish outbreaks. *A. planci* were widely dispersed, feeding on the few remaining coral heads. The reef slope of the same area had scattered, small groups of starfish in 10–30 m of water. Most of the starfish were located 1/4–1/2 km from the southern tip of Cocos Island on the outer reef flat.

4. Piti-Agat-Tumon. *A. planci* populations of these areas were moderate and were feeding on the remains of nearly dead coral reef. The starfish were small and often deformed, few were sexually mature, and little spawning activity was expected.

Feeding Site Observations

Apra Harbor was infested by a small population of starfish between 1969 and 1970 (Tsuda, 1970) but no starfish were seen during the 1971 resurvey. Many white spots or feeding scars were seen on coral adjacent to the Glass Breakwater in 3–10 m of water. The damage was restricted mainly to one type of coral, *Pocillopora damicornis* (Linnaeus, 1750. There were many areas classed as normal, such as Inarajan to Pago Bay, which had fewer than five feeding sites per tow but no visible starfish. These white spots probably resulted from feeding activity by Culcita or cushion stars.

Coral Cover

Live coral cover has not been greatly reduced since the 1970 Marine Laboratory survey. The Catalina Point area, however, has lost a large amount of live coral and will continue to do so until the existing *A. planci* population is brought under control.

Recolonization and regeneration are occurring on some reefs. In Tumon Bay, for example, there is regrowth of partially damaged heads and development of new colonies. However, there are still starfish in these areas which are feeding on the new growth. For further information on the regeneration of the coral cover in Tumon Bay and Tanguisson Point, see Randall (1973c).

Observations of *A. planci* made during this coastal survey are essentially the same as those given above. The principal difference was a decrease in the starfish population found in the general region around Anae Island.

VEGETATION

The general description of the vegetation of Guam and the general description of the nine vegetation map units are taken from Fosberg (*In* Tracey et al., 1959, pp. 168–172), the plate illustrations referred to by him having been omitted. The units are mapped on five reduced sections of a 1:50000 scale map (Figs. 33a through 33e). The boundaries of the individual vegetation units are the same as those mapped by Fosberg on Plate 28 (*In* Tracey et al., 1959).

General Description of Vegetation

The greater part of Guam is forested, but substantial areas, especially in the southern half of the island, are covered by coarse grass; small parts are in pasture or various kinds of cultivation. There are few large stretches of uniform vegetation, most of the island being covered by a mosaic of small patches of extremely varied appearance. Most forests are second growth, many of them thickets which are generally dense, tangled, and often with spiny undergrowth.

Limestone areas are usually wooded except for vertical cliffs and occasional clearings. The original forest of limestone was of large trees with a thick canopy. A long history of disturbance—by Guamanians, by frequent typhoons, and the destructive effects of World War II and subsequent military activities—has left little undisturbed primary forest on the island. Weed patches, partially revegetated clearings, thickets of fast-growing, soft-wooded, weedy trees, and scattered bare skeletons of dead forest giants are more characteristic than is undisturbed forest, scattered patches of which remain here and there on the northern plateau, especially on cliffs and relatively inaccessible terraces around the steep coasts of that half of the island.

Much of the plateau has been cleared for military establishments, either active or abandoned. Some clearings are relatively bare of vegetation; others are grown up to tall grasses, thickets, and larger areas of Leucaena (a tall, featheryleafed shrub or small tree which has multiplied enormously since WW II). Coconut groves are found in many parts of the island, both on the plateau and along the coast. The lower central part of the island has been subjected to disturbance much longer than have other parts. Much of it is under cultivation, mostly in small patches, or in larger areas of pasture with diverse thickets, *Leucaena*, bamboo clumps, and small coconut groves. A large reed marsh, Agana Swamp, is just east and north of Agana. Other marshes interspersed with small mangrove swamps lie along the west coast from Piti to south of Agat. The southern, volcanic half of the island is a complex mosaic of grassland and patches of forest. Lowlands in the valleys of the Talofofo and other river drainage systems are occupied by extensive swamp forests and occasional cultivated clearings. In these valleys, as well as on uplands along the east coast, are large coconut plantations. Patches of mangroves frequently occur at the river mouths.

If left unburned for a few years, the grasslands may be abundantly invaded by *Casuarina* trees, which may eventually form open forests. However, these trees are very susceptible to fire, and extensive stands of them in the savanna have grown up only since the Japanese invasion in 1941. They are again being destroyed by fire. Forest patches in the volcanic region occupy a substantial area, but are greatly broken up by grass-covered ridges and flats. The forest on volcanic soil in many respects resembles that on limestone but tends to be thicker, lower, more brushy, and characterized by betelnut palms. Volcanic-soil forests are more commonly found in ravines, valley bottoms, and on steep slopes; they were undoubtedly much more extensive before the Chamorro people arrived on Guam, and their destruction has been especially rapid since the coming of Europeans.

General Description of Map Units

Unit 1: (Mixed forest on limestone plateau and cliffs) — Unit 1 is basically a broad-leafed, evergreen, tropical, moist forest dominated in most relatively undisturbed areas by large trees of wild breadfruit (*Artocarpus*) and banyan (*Ficus*). In some parts of Guam, particularly in the center of the northern plateau, there are almost exclusive stands of screw-pine (*Pandanus*), only a partial component in most other areas. Locally, trees usually assume dominance in variable mixtures rather than in pure stands. On the edges and faces of cliffs and near the sea on rocky coasts, the forest varies to a dense scrub. On the rare sandy beaches which are not planted to coconuts, are groves of *Casuarina*. Areas formerly cleared and abandoned or which were badly damaged by war activities are now principally dense scrub forests of hibiscus and other secondary trees with scattered, large, dead or halfdead trunks towering above the general low level. The canopy in good examples of uncut forest is irregular, as high as 75 feet, and the larger trees (6 or more inches in diameter) may be fairly close to widely spaced. The undergrowth is sparse and often fairly tall where the forest is little disturbed but may be very dense where recent disturbande has been great; it is likely to contain a high proportion of palmlike cycads and spiny limon-de-china (*Triphasia*). Concealment in this unit is generally good, and cover, fair to poor. Visibility is not good, either from the ground or the air. Some temporary construction timber is available, but the logs are short and generally of poor quality. Coconut trees are common locally, providing some long slender logs for certain purposes but not for sawing.

Unit 2: (Mixed forest on volcanic soil in ravines and on limestone outcrops in valleys) — Unit 2 is also a broad-leafed evergreen tropical moist forest but is dominated locally by hibiscus or screw-pine (*Pandanus*), rarely by wild breadfruit (*Artocarpus*) or other trees, usually very mixed. It is commonly characterized by betelnut palm (*Areca*) and varies frequently to a dense prickly scrub of limon-de-china (*Triphasia*) or to patches of reed marsh, swamp, and hibiscus scrub. Coconut palms are occasional to locally common. This unit includes many small areas of savanna. The stature of this forest is generally low, seldom higher than 40 ft., and the canopy is dense to irregular. Larger trees are locally common, especially in ravines, and closely spaced. The undergrowth is generally good, visibility poor, and cover fair to usually poor. A little temporary construction timber of poor quality is available locally.

Unit 3: (Swamp forest) — Mangrove and Nypa swamps occur locally near the sea, especially in river valley mouths, changing upstream to a mosaic of types of freshwater swamp and reed marsh. The fresh-water-swamp types include stands of *Barringtonia racemosa*, hibiscus, hibiscus and screw-pine, and tangled mixtures of trees and reeds. The stature is variable but usually low. Where *Barringtonia* dominates, the canopy is about 50 feet high and continuous; elsewhere, it is usually much lower and irregular or may be absent. Undergrowth, except in the Barringtonia swamp, is very dense. The substratum may be mucky and unstable or firm enough to walk on but not to support vehicles. Concealment is good, visibility very poor, and cover fair to absent. There is little or no construction timber in this unit.

Unit 4: (Reed marsh) — In the marshes of Unit 4 are pure stands of reeds or cane (*Phragmites karka*) growing on wet ground or in standing water. The canes are up to one-half inch in diameter, hollow but tough. They grow 6–18 feet tall and are spaced very closely, often only several inches apart. Concealment in dense stands of reeds is fair; horizontal visibility very poor; and cover, lacking.

Unit 5: (Savanna) — The savannas are a mosaic of three very distinct kinds of grassland, other herbaceous vegetation, and erosion scars being revegetated by shrubs and tangled ferns. Swordgrass (*Miscanthus*) is dominant over large areas. Small ironwood trees (*Casuarina*) are scattered in many parts, locally forming a sparse woodland. The swordgrass is extremely dense, and well developed stands are hard to traverse on foot; the leaves are sharp and likely to lacerate the skin. Reed marsh is as described in map Unit 4. The other types are *Dimeria* grassland, weedy herbaceous vegetation, and erosion scars. Concealment is poor or lacking, except in tall swordgrass; horizontal visibility is good to poor; cover is lacking. Timber is generally lacking. This unit may include small areas of ravine forest, with the ravines tending to be filled by forest or thickets.

Unit 6: (Secondary thicket and cultivated ground) — Unit 6 includes an extremely varied vegetation resulting from long-continued disturbance by man and is usually found on argillaceous limestone. It is a fine mosaic of patches of forest usually dominated by breadfruit (*Artocarpus*), coconut groves, bamboo clumps, patches of scrub forest, home sites, small cultivated fields and patches, pastures, and large areas of tangantangan (*Leucaena*) thickets. The undergrowth is locally very dense and spiny, and marshy places are common. Trees more than six inches in diameter are very common and are closely spaced in patches of breadfruit forest and coconut groves; trees less than six inches are very abundant in other types of vegetation except in cultivated fields and pastures. Concealment is locally good, locally lacking; visibility varies similarly; cover is locally fair, locally lacking. Some poor quality construction timber is available.

Unit 7: (Coconut plantation) — Unit 7 areas are dominated by coconut trees, often planted in rows. The trees are 10–30 feet apart, closer where self-seeded. The canopy is 50–75 feet high, usually incomplete. Undergrowth is usually dense, often very dense, and sometimes spiny. Concealment is good, visibility poor, and cover fair. Coconut log timber is available, but of poor quality for most purposes.

Unit 8: (Predominantly open ground and pasture) — Unit 3 is mainly open ground, a mosaic of pasture land, cultivated fields, dwellings, and thickets. Concealment is usually lacking, visibility good, and cover usually lacking. There is no timber.

Unit 9: (Bare ground and herbaceous to shrubby vegetation at military installations and villages) — Unit 9 is complex of bare ground, tall grass, weed patches, and shrubby growth—all changing constantly. The vegetation is usually not a very significant feature and affords little or no obstruction, concealment, cover, or timber. However, within a very few years such weedy and bare areas on limestone soil may be expected to grow up to thick scrub, followed by scrub forest which resembles the vegetation of Unit 6.

THE ARCHAEOLOGY OF GUAM

A comprehensive survey of the coastal regions of Guam was conducted by Dr. Fred Reinman (Cal State, Los Angeles) from July, 1965, until June, 1966. He recorded a total of 138 sites, several of which have been previously noted by other persons. A total of 259 latte structures, the orientation of which could be determined, were recorded for these sites.

The only unsurveyed area was that between Tumon Bay and Facpi Point—a coastline of about 12 miles. The omission is presumably because of extensive disturbance of the area by highway and building construction.

The site designations for Fig. 34 are: Ma (Marianas Islands) and G (Guam) which is followed by a district symbol as shown on the Territorial Planning Commission Map of Guam, 1959. These symbols are followed by the site number which is in order of discovery or recording. The distribution of site remains—i.e., their discreteness of boundaries—and the general topography of the area of the site, were also taken into account when assigning numbers. If they were distinct units, separate numbers were assigned.

Caves were also noted and marked by x's on the map. In most cases, these were associated with surface sites and therefore not numbered.

Aside from pottery, common artifacts found in latte sites include many items of smell and bone, such as fish hooks and spear points of cone or shell, shell and stone adzes, and stone mortars, pestles and dishes. Also generally associated with these sites are remains (bone fragments) of fish and other animals and shell, material, all of which tend to be characteristic of the Latte Phase on Guam (Spoehr, 1957). Potteries associated with this phase are both plainware and some decorated shreds.

The pre-Latte period—which has worked bone and stone, shell beads, and shell and stone adzes—is characterized by Marianas redware and by lime-impressed sherds.

Knowledge of Guam's archaeology and prehistory can be gained from further studies of these coastal sites. Coastal regions played an important role in Guam's past life as well as present.

For more in-depth knowledge of the archaeology of Guam, consult Hornbostel and Birkedal (unpublished manuscript), Thompson (1932 & 1940), Osborne (1947 and unpublished manuscript), Reed (1952), Spoehr (1957), and Reinman (1968 and unpublished manuscript).

CHAPTER IV

THE COASTAL SECTORS

DIVISIONS OF THE COAST

The coast of Guam is divided into 12 "sectors" (Fig, 35), each being a contiguous stretch of coastline relatively similar in type and degree of reef development and coastal physiography. Both terrestrial and marine features of the coastal region have been taken into account to delimit the sectors. Within some, there may be several terrestrial characteristics associated with a single, rather well-defined stretch of .fringing reef, or subtidal features. Conversely, some sectors contain several marine features associated with a single stretch of coast with uniform terrestrial features.

Sector I

Physiography

The coastline along the sector trends northeasterly from Pago Bay to Pati Point, where it turns westerly to Tagua Point (Figs. 35 & 36). This stretch of coast is approximately nineteen miles long, and except for slight indentations between Pagat and Lujuna Points and between Anao and Lafac Points, has no major embayments. Limestone cliffs and associated steep slopes, elevated terraces, and cut sea-level benches make up the entire coast. The cliffs range in elevation from about 200 feet at the north end of Pago Bay to 600 feet near Pati Point. Fringing reef platforms are mostly absent along the entire sector (Figs. 35–37).

This sector forms the northeast edge of the northern Guam plateau land (Fig. 9), a more complete general description of which is given in Chapter III. The upper plateau along the cliffline has an average slope or tilt of 25 feet per mile toward the southwest. This tilting is the result of the down-faulting of the north structural block of Guam (see Fig. 6) along the Adelup fault and along other smaller faults within the northern plateau. The degree of tilting is more pronounced from Janum Point to Pago Bay, probably as a result of down-faulting along the northern end of the Tamuning-Yigo fault zone and along the southwest fault bounding the Santa Rosa horst block.

The coastal cliffs sometimes form headlands at the shoreline, but in most places the cliffs are set back from the shore by elevated terraces of varying widths. Prominent shoreline headlands are located at Iates Point (Fig. 38), Fadian Point, a short section of shoreline 4,000 feet south of Taguan Point (Fig. 39), a three-quarter-mile section north of Pagat Point, a half-mile section from Lujuna Point south, and a section from Anao Point northward to Pati Point. Well-developed elevated terraces separate the coastal cliffs at many places. Following are the locations of the more prominent terraces with maximum widths given in parentheses: Iates District (1,000 ft.), Fadian District (1,600 ft.), Huchunao District (900 ft.), Sasajyan District (Fig. 40, 4,000 ft.), Pagat District (1,300 ft.), between Lujuna Point and Mati Point (1,000 ft,), Anao District (700 ft.), and from Pati Point to Tagua Point (1,000 ft.).

The elevations of these terraces range from near sea level to about 60 feet at Huchunao District; from near sea level to 100 feet at Fadian District, between Lujuna and Mati Points, at Anao District, and from Pati Point to Tagua Point; from near sea level to 200 feet at Sasajyan; and from about 100 to 200 feet at Pagat and Iates Districts. At Huchunao District, a second fairly well-developed terrace lies between the 100- and 200-foot elevations; between Pati and Taguan points, a second narrow terrace lies between the 200- and 300-foot elevations. Other minor terraces form breaks in the steep slopes at the above-mentioned or other elevations in numerous places along the sector. Figures 38, 39, 40, and 42 are aerial photographs showing many of the above headlands and terraces.

The plateau land of northern Guam is developed upon what was probably an elongated 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, resulting in the emergence of the entire barrier reef and associated lagoon limestone deposits of northern Guam, the coastal region of this plateau land being represented by what was formerly the peripheral barrier reef and steep seaward slopes. The 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 nips (Fig. 38), presently observed along the coast. Some of these terraces were formed by sea-level erosion, whereas others may have formed by fringing-reef development. Many well-developed ramparts (Fig. 41) are on the upper rims of the limestone cliffs. One good example can be seen at Lafac Point, Andersen Air Force Base, where the rampart is exposed in cross section by a cut. A more accessible example is on the cliff rim above the District of Pagat. Here, the plateau vegetation has been cleared for an antenna field, and the rampart is plainly visible from

from Route 15, (back road to Andersen).

At many places cliff faces are cut by long vertical fractures, joints, and fissures (Fig. 42). The more prominent zones showing joints and fissures of this sector are shown in Fig. 7a. At sea level the scalloped, irregular pattern of cut benches is due, in part, to erosion along fractures, joints, and fissures (Fig. 43). Along vertical walls of cliffs, joints, and fissures, the limestone has recrystallized into a dense compact mass which sheathes the faces of these walls. Pores and cavities are partially to completely filled with calcite. Drip stone forms secondary deposits of calcite on the ceilings and floors of emergent sea caves, former sea-level nips, and overhanging cliff faces. The most conspicuous of these secondary deposits are stalactites and stalagmites, some of which are more than a foot in diameter at the base.

Geology

The entire coast along this sector is composed of limestone (see Fig. 7a). The cliffs, steep slopes, elevated terraces, and sea-level benches consist of the various facies of Mariana limestone formation except for localized small exposures of Bonya (Tb) and Janum (Tj) limestones and a small exposure of volcanic material (Ta), all of which are located between Pagat and Anao Points (Fig. 44). Much of the cliffline along this sector is capped with incrustate limestone (QTmr) belonging to the reef facies of the Mariana formation. Major exceptions to this general cliffline distribution pattern are found between Taguan and Campanaya Points, at Lujuna Point, and at Pati Point, where the cliffline, various elevated terraces, and sea-level benches are composed of detrital facies (QTmd) of Mariana limestone. At places the lower terraces are veneered with local deposits of limestone which appear to be of reef, rather than detrital, fad es origin. These local patches were not mapped and are difficult to trace in the field. Two sections of the fore-reef facies (QTmf) are exposed along the shore between Anao Point and Lafac Point, these exposures being composed of well-bedded white foraminiferal sand originally deposited as fore-reef sand in the deeper offshore water of the seaward-slope reef zone. A small exposure of volcanic rock of the Alutom formation is found along the southwest fault bounding the Santa Rosa horst block.

At the heads of several small coves between Fadian and Taguan Points slight deposits of unconsolidated beach materials (Qrb) have accumulated. Another small deposit of beach material is located at Janum Point.

Soils

A single soil type, Guam clay, and two miscellaneous land types consisting of gently sloping limestone rock land and steep limestone rock land are found along the coastal region of Sector I (Fig. 45). Guam clay (Unit 1) is found primarily on the flat plateau land somewhat inland from the coastal cliffs and on two raised terraces, one between the 25 and 50-foot elevations at Janum Point and the other on a small section of the large terrace at the Fadian district.

Gently sloping limestone rock land (Unit 13b) is found on wider coastal terraces and along the upper plateau margin bordering the coastal cliffs. Where present, the soil on these terraces is thin and patchy, Steep limestone rock land (Unit 13f) is the most extensive land unit along this coast. It includes all the steep slopes, cliffs, and most of the low-lying coastal terraces and benches. Soil is virtually absent on this type of land and, where found, is usually restricted to local depressions, solution holes, solution pipes, and fissures.

Additional soil-unit and land-type characteristics are given on the legend table accompanying the engineering geology map (Fig, 12a) and in Tables 5 and 6.

Engineering Aspects of Geology and Soils

The engineering aspects of geology have been previously described and summarized for the island into nine different units. The distribution of the five units occurring in Sector I are presented on the engineering geology map (Fig. 12a). Engineering aspects of soils are summarized in Tables 5 and 6. Table 5 is to be used in conjunction with the soil map (Fig. 45) and engineering geology map (Fig. 12a). Table 6 is keyed to the soil units and should be used with the soil map (Fig. 45).

Vegetation Zones

The vegetation along this sector is mapped on Fig. 33a. A general description of the units is given in Chapter III.

Hydrology

No streams have developed on the northern plateau (Fig. 10). The limestone along the coast of Sector I is permeable to rainwater which moves rapidly downward to a zone of saturation, thence more slowly in a lateral direction to points of discharge along the shore.

This sector of the coast is occupied by three ground-water areas and subareas (Fig. 13), the most extensive being subarea 3a which extends from Fadian Point northward to Pati Point and then westward to Tagua Point. The second most extensive is subarea 3b which extends from Iates

Point northward to Fadian Point. The least extensive is a area 7 which projects into the coastal region from Mount Santa Rosa. A more nearly complete description of these ground-water areas and subareas is given in Chapter III.

Two springs of notable size are located along the coast (Fig. 36), the largest being Janum Spring, where water flows from a cave in the limestone near sea level. Discharge data and the chemical analysis of this water during the years 1952 through 1956 are given in Tables 13 and 14, respectively.

The second major spring, Campanaya Spring, is situated at the base of a sinkhole which extends to the basal water table. It was used by the Japanese Military forces from about 1942 to 1944 and by the U. S. Army from 1947 to 1950. During the above time the chloride content was reported to be more than 1,000 ppm while pumping at 400 gpm and in January, 1957, the chloride content was reported at 600 ppm (Ward and Brookhart, 1962). Other minor springs are numerous along the coast, particularly in zones where large fractures, joints, and fissures cut the terraces and benches near sea level. Many of the numerous underwater springs noted during subsurface investigations along the coast were traced to structural joints and fissures.

Beaches and Rocky Shorelines

Rocky shorelines are indicated on the reef zonation map (Fig. 37), and zones of unconsolidated beach material are indicated on both this and the geologic map (Fig. 7a).

Rocky shorelines predominate along most of the coast of this sector. Although unconsolidated beach deposits are relatively rare, several small ones form veneers over the underlying limestone at the heads of some small coves located between Fadian and Taguan Points. Another small deposit is located on a downfaulted section of the shoreline below Janum Point (Fig. 46). Other unmapped, minor deposits of unconsolidated beach deposits are found in the moat and intertidal zones of some of the wider sea-level benches.

Beach samples were collected and analyzed by Emery (1962) at four locations along this sector (Stations 18–21). (See Fig. 17 and Table 7). Three of the sample localities—Fadian Point, Campanaya Point, and Catalina Point-show that beach materials contain little to no insoluble residue. This is not surprising, since the northern limestone plateau lacks a surface drainage system of rivers and streams to carry insoluble residues to the shore (Fig. 10). A clayey silt sample collected from the floor of Janum Spring (Station 19) consists of 80 per cent insoluble residue. This material was probably derived from ground water percolating

downward and along the volcanic rock interface which underlies the limestone belt between Mount Santa Rosa and the coast (Fig. 14, Profile A). As pointed out by Emery (1962), this sample is not a true beach sand but was collected because of the intertidal position of the spring.
A sample taken from Campanaya Point (Station 20; see Table 8, Sample No, 26) is composed entirely of the skeletal remains of carbonate-secreting reef organisms. A qualitative inspection of other thin, patchy accumulations of beach material from various parts of this sector shows them to be similar in composition to the Campanaya Point sample.

Reefs and Other Subtidal Features

Sea-Level Benches — Along this sector, true developing fringing reefs are virtually absent. Most of the shoreline is bordered by cut benches of various widths (Figs. 37 & 47). At many locations, these benches look like fringing reefflat platforms, especially when viewed from the air (Fig. 40), a resemblance which led to the erroneous mapping of fringing .reef platforms on the U. S. Geological Survey Pati Point and Dededo 1:2,000 quadrangle maps (1968). A small discontinuous section of actual fringing reef platform has developed at Janum Point on a downfaulted section of coast (Fig. 37). Even though a developmental fringing reef is generally absent, there are local regions where structural accumulation of incrustate limestone is taking place, forming minor topographic features.

A general condition found wherever benches form is the presence of considerable wave assault, for even at low tide the bench platform is usually kept awash by wave action. A rich growth of encrusting and soft benthic algae covers the seaward face and upper surfaces of the bench platform. Occasional periods of calm lasting for several days and associated with minus tides which coincide with strong sunlight cause mass mortality along the bench.

The shoreline benches are at most places cut into the lowest-lying terraces or headlands, forming platforms ranging in width from a few feet at rocky headlands to a hundred feet or more where low, gentle sloping terraces border the shore. The shoreward boundary of the bench consists of a ledge 10–50 feet high with a prominent concave nip cut at the base (Fig. 47), the nip usually lying at the same general level as the cut bench platform. The maximum height of the overhang and the depth of the nip are somewhat governed by the amount of wave exposure the bench receives and by the degree of slumping or erosion which has occurred on the overhang. A variety of molluscs inhabit various parts of the nips, the most conspicuous being small limpets and chitons. Penetrating filamentous and larger benthic algae live in and on the rocky surfaces of the nip.

The bench platform generally has an irregularly scalloped margin (Fig. 43), the indentations being erosional features commonly aligned with joints and fissures which cut through the limestone ledge at the backside of the bench platform. At some locations these structural joints are widened into chutes and fissures which traverse the entire bench platform and penetrate the bench ledge some fifty feet or more (Fig. 48). Blowholes are a common feature where cracks are partially roofed over. Removal of sections of the platform by slumping and wave action also adds to the irregularity of the bench margin. The seaward edge and the face of the bench are usually cut into a series of grooves and spurs which are more closely spaced than the marginal scallops, giving the bench a toothed appearance. Like the scalloped indentations, fissures and chutes, the grooves are usually aligned down the steep seaward bench face to depths of perhaps 30 feet; they may also extend seaward many tens of feet (Fig. 49). The floor of a groove may be smooth or irregular, and the walls straight, crooked or forked; the groove may contain large rounded boulders and blocks. Some grooves are V-shaped, others U-shaped or even wider at the bottom than the top. Blocks slumped from the bench margin or headland cliff faces often lodge in the groove-and-spur system at the seaward margin of the bench, thus adding to the generally irregular topography.

The upper surface of the bench platform can be divided into two zones. The first is the seaward edge, which is r nearly always elevated by a series of rimmed terraces and pools (Figs. 43 & 47). In some cases, the height of this outer zone is 2–3 feet higher than the inner part. If the degree of wave assault on the bench is high, the number of the step-like series of rimmed terrace pools increases, and the heights of the terrace rims and depths of the pools will be greater. Landward of the elevated, outer margin is usually found the wider and lower moat zone, a region of impounded water. The surface of the moat is divided into a subrectangular series of pools, the rims being at nearly the same general level as the moat water. Water depth in moat pools ranges from a few inches to 23 feet. Fishes, molluscs, holothurians, and a few corals live in some of the larger pools of the moat.

Rich mats of algae form the dominant biological communities on bench surfaces. In general the dominance of encrusting calcareous algae is greater on the seaward margin and face of the platform, whereas soft benthic algae are more common on the inner platform.

The wider cut benches have thin accumulations of unconsolidated sediments on the floors. These sediments may be a foot or more thick in cracks and crevices in the moat. Table 11 gives the textural characteristics for reef sediments at station localities 22 1/2 and 29.

Seaward-Slope Zone — True developmental reef-front and reef-margin zones are not found to any extent along this sector. The cut bench face dips seaward at some places very irregularily; at other places it leads rather smoothly down into the seaward slope zone (Figs. 23 & 47).

Following is a description of the subtidal features observed along a traverse located about midway between Anao and Lafac Points (see Fig. 23), A cut bench about 75 feet wide, consisting of an inner moat and an outer section of rimmed terrace pools, occupies the shoreline. Surge channels and fissures cut across the bench platform and landward grade into the structural joints and fractures of the bordering cliff face. In a seaward direction, the surge channels and fissures grade into the massive spur-and-groove system of the bench face, this system dipping rather steeply for 50–75 feet and then flattening out to a gentle slope at the 100foot level, about 150 feet farther seaward. The grooves are flat-floored, smooth, and abraded near the bench face. Large rounded boulders line the floors of the grooves in most places. Depths of the grooves range from 15 to 25 feet. Between the grooves, local patches of coral form such developmental features as knobs, knolls, and pinnacles. These relief structures are densely covered with encrusting and plate-like growths of *Millepora platyphylla* and corymbose *Acropora* coral colonies. Red-colored encrusting coralline algae are abundant on the bench face and groove walls. Large blocks of limestone which have broken away from the shoreline cliffs lie at the base of the steep bench face. These also are covered with calcareous algae and coral growths.

Seaward the grooves and channels diminish in depth and width, finally becoming shallow fissures or cracks in the ocean floor. Intervening knobs and mounds of coral growth are more dense than near the bench face. At about the 70–80 foot level, the shallow grooves grade into sand-floored channels, 10–50 feet wide, separated by long ridges of coral development. Most of the ridges have a vertical relief of 6–15 feet and continue seaward to well beyond the 125-foot level. The dominant corals growing on these ridges are *Porites*, *Acropora*, and *Astreopora*.

The above traverse is typical of much of this sector. At other places, the gradual seaward dip of the floor from the base of the bench face is interrupted by a flattened terrace (Fig. 47). Other places with welldeveloped submarine terraces 60-feet or shallower in depth are indicated in Fig. 37.

Offshore slopes of this sector investigated by Emery (1962) are shown in profiles 17 through 23 (Figs. 28, 29). Four main submarine terraces are recognized on the slopes of this sector, the mean depths being 55, 105, 195, and 315 feet as follows. Profiles 17, 19, and 21 show terraces at 55 feet, profiles 17 through 23 show terraces at 195 feet, and profiles 17, 22, and 23 show terraces at 315 feet. (Most of the profiles shown in Fig. 28 start at too great a distance from the shoreline to show the narrow, shallow, inshore terraces.

Development, Use Patterns, Culturally Important Areas, and Unique Features

This rugged section of coastline is largely uninhabited, except for occasional local "ranches" on a few of the wider terraces. Much of the forest and other vegetation appears to be relatively undisturbed. Highway 15 borders the upper margin of the plateau from Mangilao to Andersen Air Force Base (Figs. 1, 36). A few dirt roads and jeep trails lead from the highway to the lower terrace levels at Huchunao, Sasajyan, and Janum Point. The AAFB boundary includes the coastal region of this sector north of Anao Point to Tagua Point. The remainder of the coastal region here is of private or Government of Guam ownership.

Four sewer outfalls are located along the coast of this sector. One, from the Mangilao district, empties into the ocean from the terrace cliff at Iates (Fig. 42); another, from the Marbo Annex of AAFB, empties onto the sea-level bench south of Campanaya Point, and two from AAFB terminate at the top of the coastal cliff between Anao and Lafac Points (Figs. 50, 51).

The Hawaiian Rock Company operates a ready-mix cement plant and quarries various types of limestone aggregates from the coastal plateau margin and terraces at the Huchunao District, between Fadian Point and Taguan Point. Several talus slopes composed of waste rock mark the cliff face at the Hawaiian Rock quarry sites and along the upper terraces of the Fadian District. Similar talus scars are evident at places along the coastal cliffs at Andersen Air Force Base. Hawaiian Rock maintains a seashore picnic area in the Huchunao District.

With the exception of the relatively rare fruit bat, *Pteropus marianus*, there are no rare or endangered plants or animals known along the coastal region of this sector. Fruit bats are occasionally seen on the forested cliffs and steep slopes along the coast, particularly along the northern part of the sector which borders Andersen Air Force Base.
Little fishing is done along this sector since the region is relatively inaccessible and on the windward side of the island.

The coastal area bordering Andersen Air Force Base, between the shoreline and upper cliff-line, was set aside by the U. S. Air Force in 1973 as a forest and wildlife preserve. Other than the archaeological sites shown in Fig. 34, there are no other known culturally important areas located in the sector.

Sector II

Physiography

This coastline (Figs. 9, 35, 52a, 52b) bounds the northern plateau westerly from Tagua Point to Tarague Channel, then northwesterly to Ritidian Point (the northernmost part of Guam), and finally southwesterly to Falcona Beach. Other than slight indentations, there are no embayments along this 10-mile sector. Limestone cliffs and associated steep slopes, several levels of elevated limestone terraces, low coastal terraces composed of beach deposits, white sand beaches, and a broad fringing reef-flat platform border most of the coast. This sector is delimited from Sector I mainly by the presence of these beaches and the broad fringing reef-flat platform. The upper cliff margin has a general elevation of about 500 feet along the entire sector, Mount Machanao being the highest place (602 feet), becoming lower from Mount Machanao south to the cliffline above Falcona Beach. This reduction follows the general tilt of the northern plateau, which dips to the southwest, elevation differences caused by tilting being less pronounced along the northeast- and north-facing coastlines because they lie in a line more or less parallel to the Adelup fault line (Fig. 6).

Small sections of rocky headlands and coast border the shoreline at Mergagan, Pajon and Achae Points, and at several other places between Uruno and Falcona Beaches (Figs. 53a, 53b). Well-developed terraces separate the remainder of the shoreline from the coastal cliffs along the sector, the most extensive being the broad series of terraces, as wide as 3,600 feet, which stretch from Tagua to Mergagan Points. Between Mergagan and Pajon Points, a terrace up to 1,x+00 feet wide separates the shoreline from the coastal cliffs; another with a maximum width of 1,000 feet borders the cliffs and shoreland from Pajon Point around Ritidian Point to Achae Point. Between Uruno Point and Falcona Beach the terrace is narrow, steep-sloped, and interrupted by sections of low rocky headlands. The terraces between sea level and 100 foot elevation are the widest and best-developed along the entire sector. A particularly good series of these terraces and nips can be seen where the Route 3 highway cuts across the steep coastal slope between Achae Point and Ritidian Beach.

The limestone plateau land of this sector is developed upon and is part of the same uplifted barrier-reef complex as that described in Sector I. Solution ramparts are developed on the upper rims of the limestone cliffs at many places. The Tarague beach road exposes a good cross section of a solution rampart bordering the upper rim of the coastal cliffs between Mergagan and Tagua Points. The cliff faces are cut by long vertical fractures, joints, and fissures (See Fig. 7b). Dense recrystallized limestone sheathes the cliff faces. Drip stone formations are particularly abundant in nips and sea caves located on the cliff faces around Ritidian Point.

Geology

The coastal cliffs, steep slopes, and higher terraces are comprised of various limestone facies of the Mariana limestone formation except for a small exposure of Barrigada limestone (Tbl) located on the steep slopes above Tarague Beach. Unconsolidated beach deposits (Qrb) cover most of the lowest coastal terraces except for a few isolated patches of reef facies limestone (QTmr) at Mergagan, Pajon, and Achae Points, and at two sections between Uruno Point and Falcona Beach (See Figs. 7b, 7f, 54, and 55).

Reef facies (QTmr) of Mariana limestone cap all the upper coastal cliffs bordering the sector except for the section about 1,200 feet long above Tarague Beach capped with detrital facies (QTmd). Generally, detrital facies are found at the zone lying between the plateau cliffs and the unconsolidated coastal terraces. Reef facies form thin lenses on the upper surfaces of many of the coastal terraces, beginning at and patchy from Mergagan Point northward to Ritidian Point. From Ritidian Point southward to the end of the sector, the reef facies lens forms a continuous band except for a section below Mount Machanao, where it divides into three bands, each occupying the upper surface of a series of step-like terraces there.

Soils

Two soil types and two miscellaneous land types are found along the coastal region of this sector (See Figs. 56a, 56b).

Shioya soil (Unit 12) is found in the upper horizon of the unconsolidated beach deposits along the low coastal terraces. It forms a narrow zone along the entire sector except where headlands, steep rocky slopes, or Guam clay border the shore.

Guam clay (Unit 1) forms a discontinuous band between the unconsolidated coastal lowlands and the steep rock land along the coastal cliffs. It also occurs on the upper plateau land along the coastal cliffs from Ritidian Point southward to the end of the sector. It is most extensive along the broad terrace at Tarague District, where the unit reaches a maximum width of 2,600 feet. An elongated patch about three quarters of a mile longs also occurs on each side of Ritidian Pointy the longer of these extending 4,200 feet by 750 feet wide. Another lengthy strip occurs from Falcona Beach to a region 3,000 feet north of the rocky headland at Uruno Point. At two locations along this strip the Guam clay unit extends to the shoreline. This soil is generally very patchy and thin except where local pockets form in depressions and fissures.

Steep limestone rock land (Unit 13f) is the most extensive land unit along this coast, forming a band along the entire sector and including all the steep slopes, cliffs, and higher terraces which border the lower terraces of Guam clay and Shioya soil. The unit extends to the shoreline for a considerable stretch along the coast, midway between Uruno Point and Ritidian Point. Soil is generally absent on this type of rock land except for local patches in depressions, solution pipes and holes, and fissures.

Gently sloping limestone rock land (Unit 13b) occurs on the upper plateau land bordering the coastal cliffs. Soil is very thin and patchy on this unit, generally less than two or three inches thick, except for local accumulations in holes and fissures where the thickness may be greater.
Additional descriptions of the various soil units and land types are given in Tables 5 and 6.

Engineering Aspects of Geology and Soils

The engineering aspects of geology are described in Chapter III (See also Fig. 12b). Engineering aspects of soils are summarized in Tables 5 and 6.

Vegetation Zones

The vegetation units (zones) along this sector are mapped in Fig. 33b. A general description of the vegetation units is given in Chapter III.

Hydrology

There are no streams developed on the plateau bordering this sector (Figs. 10, 13). The limestone is permeable to rainwater which moves rapidly downward to the zone of saturation, thence more slowly in a lateral direction to points of discharge along the beaches. Water escaping from the lens system along these beaches is a coon sight, particularly at low tide when the discharge forms small rivulets in the sand.

This sector of the coast lies entirely within the ground water subarea 3a (Fig. 13). The general chloride content of the water tapped by wells ranges from about 30 to 1400 ppm.

Near Tarague Channel are three springs (Fig. 52a)—each at an altitude of 20 feet above datum in a limestone sinkhole extending to the basal water table-having recent histories of use as water supply. Records for Tarague Spring No. 1 from July, 1945, to Feb., 1946, (Ward and Brookhart, 1962) show a pumping rate of 80–110 gpm with a chloride content ranging from 250–354 ppm. Taragué Spring No. 2 was formerly used by the military for water supply, but no chloride or pumping records are available. The third and largest, Tarague Spring No. 4, was developed about 1947 by the U.S.A.F. for military use. The pumping rate from 1953 through 1956 was 1,100 gpm, and the chloride content ranged from 320 to 830 ppm from April, 194, to August 1956 (Ward and Brookhart, 1962). Table 15 gives the chemical analysis of the water from Tarague Spring No. 4.

Beaches and Rocky Shorelines

Rocky shorelines (See Figs. 7b, 53a, 53b) occur as small rocky headlands at Mergagan Point, Pajon Point, and at several short stretches between Uruno Point and Falcona Beach (Figs. 54, 55). Well-developed beaches occupy most of the shoreline along the sector. Beach samples collected and analyzed by finery (1962) from six locations along this sector (Fig. 17, Stations 12–17, and Table 7) indicate that these beach sands are entirely bioclastic. No insoluble residue was found in any of the samples. The lack of such residue is not unusual, as there are no streams developed on the limestone plateau (Fig. 10) which could carry silt or clay deposits to the shores. For example, a sample taken from Tarague Beach (See Table 8, Sample No. 15) is composed entirely of organic carbonate material of reef origin, 50 per cent of which are coral fragments. Inspections at other localities along this sector reveal a beach composition similar to that at Tarague Beach.

At several locations, seaward-sloping beach rock is found at the shoreline along the sector. The beach deposits from Tagua Point to Tar ague Beach (Fig. 57) consist of a thin veneer over an irregular limestone platform. From Tagua Point to Tarague Channel, low linear projections of limestone protrude upward through the beach deposits at the shoreline and continue in some places to the strand vegetation zone. From Tarague Beach to Tarague Channel (Fig. 58), the beach consists of sand and scattered patches of solution-pitted, raised limestone. In terms of recreation beaches with a wide zone of clean sand free of remnant limestone-the best stretches of beach deposits are located at Tarague Beach (Fig. 59), Jinapsan Beach, the beaches on both sides of Ritidian Point (Figs. 60, 61), and a section of beach south of Achae Point.

Reefs and Other Subtidal Features

Intertidal Zone — Most of the intertidal zone (Figs. 53a, 53b) along this sector consists of unconsolidated bioclastic beach deposits. Beach rock is found at isolated locations and is particularly abundant and well-developed along the beaches near Ritidian Point. Remnant patches of raised limestone are scattered along the shore from Tagua Point to Tarague Beach (Figs. 57, 58, 59). Near Tagua Point, the beach consists mostly of sand with occasional remnant patches of limestone which forms low ridges cutting across the beach zone and reef-flat platform. Near Tarague Channel the remnant patches of limestone are more numerous and have a greater relief.

Fringing Reefs — Windward reef-flat platforms 200–750 feet wide fringe the entire sector. Two shallow channels cut through the reef-flat platform—one at Ritidian and another at Tarague (Fig. 52a). Ritidian Channel actually consists of a 600-foot-wide section of the reef flat, reef margin, and reef front cut by a series of wide channels and holes. Strong seaward-flowing rip currents are present in these channels when longshore currents generated by water piled onto the reef-flat platform by wave action returns to the sea in them. Tarague Channel is narrower (it is about 100 feet wide) but more defined where it cuts through the outer edge of the reef-flat platform (Fig. 58). Strong rip currents also develop in this channel. Neither channel is similar to the deep navigable channels located at the mouths of rivers along the southeast coast (Sector 12). The northern channels, are navigable at best only during periods of calm and then by small craft with shallow draft.

The fringing reef platforms along this sector can be roughly divided into three physiographic types. The first consists of a reef-flat platform on which the inner reef-flat subzone is poorly defined. The platform surface has numerous scattered remnant patches of supratidal limestone and thin, patchy unconsolidated sediments. Living corals are restricted to pools and depressions which retain water during low tides. The reef margin consists of a massive convex type of algal ridge cut by surge channels (Fig. 57). This type of reef-flat platform is found from Tagua Point, where the cut-bench type of shoreline abruptly changes into a reef-flat platform, to Tarague Channel (Fig. 57).

The second type of platform begins at Tarague Channel and continues to Ritidian Channel. Along this section, the reef flat has a well-defined inner reef-flat subzone. In general, this section has fewer remnant patches of limestone from Tarague Channel to Tarague Beach and is nearly devoid of such patches from Tarague Beach to Ritidian Channel. The inner reef-flat zone contains considerable sediment and boulder accumulation. Living corals are much more abundant here than on the platform east of Tarague Channel. At places along Jinapsan and Ritidian Beaches, staghorn *Acropora* forms dens, flat-topped thickets which grow upward to the low-tide level. A massive, convex type of algal ridge is developed along this section and the margin contains numerous open pools behind it. At Jinapsan Beach, 54 species of corals were counted in a series of five of the open reef-flat pools.

Following is an excellent general description of these two reef-flat types and offshore zones (Tracey et al., 196., pp. A79–A81):

> A well-developed windward reef 200 to 700 feet wide extends about 6 miles from Ritidian Point to Tagua

Point. An offshore terrace along this coast slopes gently seaward from the reef front at a depth of 15 to 25 feet to a depth of 50 to 90 feet at some distance from the reef. The outer edge of the terrace in most places breaks gradually rather than sharply toward the steep outer slope, as can be seen in fathometer profiles 14 through 17 of Emery (1963) [Figs. 28, 29]. Near the reef front the surface of the terrace is rough and broken, but beyond a distance of 50 to 100 feet it is comparatively smooth. It is pitted with irregular holes or hollows ranging in diameter and depth from a few inches to a few feet and is partly covered by pink encrusting calcareous algae. The surface of the terrace is cut by long sinuous channels ranging from 2 to 8 feet deep and from a few feet to as much as 20 feet wide. Some are continuous with the grooves and surge channels that cut the reef front and margin. Deeper channels are partly filled with coarse gravel and boulders, and in some places the surface of the pavement is littered with accumulations of coarse sand and gravel although generally it is clean and bare. Large blocks as long as 7 feet, and 2 to 3 feet wide and thick, have broken from the reef front and are scattered here and there.

The reef front along most of Tarague and Jinapsan Beaches is formed of rough knobby algal pillars and buttresses rather irregularly aligned perpendicular to the reef edge. The reef margin is a massive algal ridge cut by surge channels. Some channels of Jinapsan Beach in particular are more than 200 feet long and are broken by numerous pools 6 to 20 feet wide and 5 to 10 feet deep. The channels and pools are formed by growth and coalescence at the reef surface of algal knobs, pillars, and buttresses similar to those now forming the reef front. Edges of channels and pools are formed of actively growing coralline algae, and sides are covered by luxuriant growths of coral. Inner parts of the channels and pools are partly filled or choked by gravel and debris, but near the reef margin the channel bottoms are clean and worn. Obviously, erosion is strong at the very edge of the reef where algal growth is greatest, but perhaps more obviously the general pattern of the reef (See Fig. 62) has resulted from filling of the pools and channels near their landward ends by debris and by coral growth, from healing of the channels by algal growth on the reef surface, and from seaward extension of the reef front by growth of algal knobs and pillars on the terrace.

Most of the outer reef flat between the surge channels is covered with coral colonies. The inner reef flat is a rough, hummocky surface covered with sand and gravel on which grow large clusters and patches of coral.

A shallow channel about 100 feet wide cuts the reef near Tarague. East of the channel the reef margin is a massive algal ridge cut by surge channels. Numerous limestone remnants 3 to 4 feet high lie behind the algal margin, and large remnants 6 to 8 feet above the reef flat are found near shore. These remnants possibly represent a reef that grew during the "6-foot" sea, in which case they would be patches of Merizo limestone; more probably they represent ledges of Mariana limestone truncated to their present level when the sea stood 6 feet or more higher than at present and later eroded to form separate remnant blocks.

The reef flat east of the channel is more hummocky and irregular than that to the northwest, and contains fewer coral patches. This section of the long reef line has more indication of erosion and much less of growth than the section along Jinapsan Beach.

Currents along the Ritidian-Tagua reef are especially strong and varied, depending on the wind and size of the swells. In times of high trade winds and high surf, they may become dangerous to swimmers near shore. The currents on the reef are driven by the head of water piled onto the reef margin by the waves. Much of this water returns seaward through the surge channels, but during a series of high waves the water remains several feet higher on the reef than it is on the ocean. Most of this water tends to escape through the central channel, causing strong longshore currents toward the channel that may reach speeds of 4 to 6 knots. At any one place the nearshore currents are exceedingly irregular, for the water on the reef flat is piled high by series of large waves on the reef margin first to one side, then to the other of the point

> of observation, resulting in a longshore current of several knots, first in one direction, then in the other.
>
> The water level on this reef at any stage of the tide is particularly dependent upon the height of the waves striking the reef. During especially strong swells the water on the reef may be as much as 4 feet higher than it is at the same stage of the tide in calmer weather.

The third type of fringing reef borders the coast from Ritidian Channel south to Falcona Beach. The reef flat near Ritidian Channel is about 750 feet wide and gradually narrows to about 150 feet at Falcona Beach. The reef flat lacks the well-developed moat found from Ritidian Channel southeast to Tarague Channel.

From Ritidian Channel southwest to Achae Point, the reef flat is particularly barren and flat from the algal ridge to the beach, corals being found only where shallow pools retain water at low tide. Between Achae and Uruno Points, a shallow moat near the beach contains some massive corals which form microatolls, but the thickets of staghorn *Acropora* corals generally are absent. The outer reef-flat zone along part of the sector is mostly exposed at low tide. Sediment accumulation is thin and patchy except in the shallow moat between Achae and Uruno Points.

A narrow cuesta-type of algal ridge forms an elevated hummocky region at the reef margin (Fig. 61). This ridge is solid and massive and is cut by short shallow surge channels. There is no room-and-pillar development at the reef margin and reef front zone comparable to that found on the southeast side of Ritidian Channel. The reef front is cut by a groove-and-spur system along most of the section, although at some locations considerable development of coral-algal knobs and bosses is taking place on the upper surfaces of spurs. The reef front appears to be somewhat in equilibrium as far as outward growth and erosion are concerned. The 55-foot submarine terrace is present along most of the section, but it is narrow and irregular. At some places there seem to be relic features such as grooves and channels at the seaward margin of the terrace which resemble a sunken reef-margin system.

The outer part of the reef front, submarine terrace, and seaward slope zone was heavily infested by *Acanthaster planci* in 1969 along this entire sector. Most of the reef-building corals were killed in all three fringing reef zones as a result of predation by these starfish (Figs. 30–32). Wave and surf action prevented intensive starfish damage in the reef margin and inner part of the reef front zones. Rich coral growth is more or less restricted to this narrow wave-assaulted region at the pre sent time. Recent surveys show that recolonization of the dead coralla surface by calcareous red algae in the reef front zone has maintained the structural integrity of the colonies. New coral growth from planula settlement and small patches which survived the initial starfish predation was also evident in the affected zones during this survey.

Reef Flat Sediments — Emery (1962) analyzed the textural characteristics of reefflat sand samples at four localities along this sector (Fig. 17, Stations 12–16). Table 11 gives the median diameter and Trask sorting coefficients for the reef sands in a seaward direction from the low-tide shoreline at 100 yard intervals.

Offshore Slopes — Offshore slopes of this sector investigated by Emery (1962) are shown in the graphic presentations of his fathogram profiles in Figs. 28 and 29 (Profiles 14–16). There are terraces at 55, 105, and 195 feet. Most of the profiles started at too great a distance from the shoreline to show the narrow, shallow, inshore terraces.

Development, Use Patterns, Culturally Important Areas, and Unique Features

The entire coastal land of this sector lies within U. S. military reservation boundaries except for two small sections—one at Jinapsan Beach and the other below Achae Point (Figs. 1, 52a, 52b). This steep coastal land is for the most part uninhabited by permanent residents, but several "local" ranch-type, temporary dwellings are located along a private part of the sector between Achae Point and Falcona Beach.

Highway 3 borders the upper margin of the coastal cliffs from Falcona Beach to Achae Point, where it then descends the steep slopes to a military communication station at Ritidian Beach. Several acres of land have been cleared at the military station. Another unimproved road branches off from Highway 3 and terminates at the cliff edge at Ritidian Point. No roadways lead to the privately owned strip of land at Jinapsan Beach. A U. S. Air Force road leads down the steep slopes to the broad terrace in the Tarague District. A network of small roads leads to a pumping station, a rifle range, and a recreation beach area. The principal recreation beaches are located at Tarague Beach (Fig. 59) and at a beach east of the Tarague Channel.

Most of the coastal land is densely covered with forest vegetation and coconut groves. A large area on the upper plateau is the location of the U. S. Air Force Northwest Field, but the land bordering the coastal cliffs along the sector is relatively undisturbed and remains heavily forested (Fig. 63). A rare endemic plant on Guam, *Serianthes nelsonii*, is found on the upper plateau limestone forest which borders the coastal cliffs around Ritidian Point. Discovered by Peter Nelson about 1916

(Stone, 1970), it has been found since then by very few other people. A large specimen was observed from a helicopter during this survey of the coast at Ritidian Point. Fruit bats (*Pteropus marianus*) are also found in the forested plateau land and along the steep coastal cliffs and terraces. No other rare or endangered species of plants or animals are known from the coastal region of this sector.

Some sport fishing, spear fishing, and SCUBA diving are conducted from the shore, mostly by military personnel and their dependents, as the area is not readily accessible to the civilian population.

Sector III

Physiography

The four-mile sector between Hilaan Point and Falcona Beach is developed upon the uplifted limestone plateau land (Figs. 9, 35, 64, 65). The coastal region is represented by the former peripheral barrier reef and by steep seaward slopes, modified by intermittent faulting, local slumping, and various sea-level fluctuations. The shoreline forms a long, shallow, indentation with several small embayments which are actually shallow regions more or less contained upon the small fringing reef platforms which extend out to the heads of the bays. Haputo Beach, the largest of these small bays, is about 1,000 feet long by 250 feet wide. Limestone cliffs and steep slopes border the entire sector (Fig. 65), which is delimited from the adjacent ones because the coastal zone lacks the wide limestone and unconsolidated beach terraces and a continuous fringing reef platform of the latter. This sector is primarily bordered at the shoreline by cut sea-level benches similar to those of Sector I.

Elevation of the cliffs range from 500 feet at Falcona Beach to 340 feet at Ague Point, the general decrease of the plateau margin following the southwest tilt of the Machanao Block (Fig. 6). Irregularity of the cliffline south of Pugua Point occurred because of movement along the Pugua fault line (Figs. 7a and 66). The only extensive terrace along the steep coastal slopes is south of Pugua Point and is probably related to the fault zone. Narrow terraces and nips are found at many locations along the sector, and at places solution ramparts are on the upper rims of the limestone cliffs.

Dense recrystallized limestone sheathes the cliff faces which are cut by long vertical fractures, joints, and fissures. Drip stone formations are common where cliffs are overhanging and at zones where nips and sea caves are found.

Geology

The limestone cliffs, steep rocky slopes, and sea-level benches are comprised of reef (QTmr) and detrital (QTmd) facies of the Mariana limestone formation, except for sections of beach deposits (Qrb) at the head of the small bay at Haputo Beach and at a small section opposite the offshore patch reef (Figs. 7a, 7b, 7f, 11, 66). A cap of reef facies limestone forms a peripheral band along the upper plateau cliff margin, except where the Pugua fault line cuts through the cliff face. Below this cap the cliff faces and steep slopes are comprised of detrital reef facies except for a narrow belt of pure reef facies limestone along the shoreline. This limestone veneers the cut benches and lower raised terraces. This thin veneer was probably deposited secondarily on the raised terrace surface during one of the earlier sea stands.

Soils

Two soil types and a single miscellaneous land type are found along the coastal region of this sector (Fig. 67, and Tables 5, 6).

Guam clay (Unit 1) is located on the plateau land bordering the coastal cliffs and on a small terrace located at the Pugua fault line below Pugua Point. Shioya soils (Unit 12! are found in the upper horizon of the unconsolidated beach deposits at Haputo Beach.

Steep limestone rock land (Unit 13f) makes up the remainder of the sector, comprised of limestone cliffs, steep slopes, and terraces located between the coastal cliff margin and the shoreline.

Engineering Aspects of Geology and Soils

The distribution of the tree engineering geology units which occur in this sector is presented on the engineering geology map, Figs. 12a and 12b. Engineering aspects of soils are summarized in Tables 5 and 6, which are to be used in conjunction with the soil map (Figs. 12a, 12b, 67).

Vegetation Zones

The vegetation zones in this sector are mapped in Figs. 33a and 33b. A general description of the vegetation units is given in Chapter 1.

Hydrology

No streams are developed on the limestone plateau bordering this sector (Fig. 10). Rainwater percolates downward through the limestone to the lens system and then moves laterally to the shore, flowing into the sea. Underwater springs are common, particularly where joints and fissures are prominent along the rocky shoreline. This sector lies entirely within the ground water subarea 3a (Fig. 13).

Beaches and Rocky Shorelines

The coast along this sector consists of rocky shores except for a small section at Haputo Beach and a small area opposite the patch reef (Figs. 68, 69, 70). Sea-level cut benches border much of the shoreline. At places large angular blocks, broken loose from the steep rocky slopes and cliffs above, rest at the shoreline. Some of these blocks have been in the same places for periods of time sufficient for nips in them to have developed at various levels. The rocky shore along this sector is similar to that described for Sector I except for the presence of wide terraces and reduced vegetation at the latter.

A beach sample (Fig. 17) collected and analyzed by Emery (1962) at Haputo Beach consisted predominantly of coral-algal-shell debris (See also Tables 7 and 8).

Reefs and Other Subtidal Features

True fringing reefs are absent for the most part along this sector except for narrow platforms which extend outward to the mouths of the small embayments below Haputo and Ague Points. Another small section is found opposite the small offshore patch reef between Falcona Beach and Pugua Point (Figs. 68, 69, 71).

Cut Benches — Most of the shore along this sector is bordered by cut benches (Fig. 70) similar to those described for Sector I. In general, however, these benches are not as wide nor are the cut platforms as high in relation to mean sea level, and the moat zone and the development of rimmed terrace pools is reduced. Also, the salt-spray zone of reduced vegetation is narrower (compare Figs. 49 and 65). These differences result primarily from the reduced wave assault found along the west facing shorelines and to the predominance of an offshore wind. Much of the wave assault along this sector is refracted, particularly swells from around Ritidian Point.

Reef Flat Zones — Reef-flat platforms are poorly developed along this sector. Most have developed across the small embayments and are narrow with eroded reef-margin and reef-front zones (Fig. 68).

Submarine Terrace and Seaward Slope Zones — The cut benches and limited reef-flat platform are bordered at most places by submarine terraces (Fig. 68). The bench platforms and the steep seaward faces are cut by surge channels, cracks, and fissures. Along most of the sector the bench face dips steeply and then flattens out 10–20 feet forming narrow submarine terraces with gently seaward-sloping surfaces. Coral growth on such a bench face and submarine terrace constitutes a coral community rather than an accretional fringing-reef complex. The gently sloping submarine terrace dips steeply downward at the 40–60-foot depth to the seaward slope zone.

The steep bench face and inner part of the submarine terrace are characterized by a massive spur-and-groove system. Many of the grooves are 20 feet deep with smooth, eroded, vertical-to-overhanging walls. The floors are also smoothly eroded, strewn with rounded boulders. The grooves widen at places into large holes 20–50 feet in diameter. Potholes with large rounded boulders are common on the submarine terrace where deep grooves are present. The surfaces of the massive spurs and intervening regions between the grooves and holes are relatively smooth compared to the same zones on a developing fringing reef. Local clusters of corals produce scattered growth features such as knobs, mounds, and pinnacles. Along the bench face and inner part of the submarine terraces, large pinnacles develop as the grooves branch and rejoin, leaving isolated pillars. Development of topographic, coral-growth features such as mounds, knobs, and ridges is more common on the seaward slope zone than on the submarine terrace zone. Shallow channels cut down and across the seaward slope to a second terrace which starts at the 100–125 foot level.

The percentage of living coral covering the substrate of the submarine terrace and seaward slope zones along this sector has been greatly re duced by *Acanthaster planci* predation (Figs. 30–32). Soft corals have recolonized extensive areas on the seaward slope zone near Pugua Point. Scleractinian coral recovery in this region is similar to that described by Randall (1973c) at Tanguisson Point.

Offshore Patch Reef — A patch reef, 1,000 feet in diameter, lies about 1,200 feet offshore between Falcona Beach and Pugua Point (Fig. 66). The upper surface of this reef is usually awash, but during periods of calm and lower spring tides, parts of it may be exposed. The region is popularly known as "Double Reef" by local boatmen and fishermen and is surrounded by a developmental reef front and a submarine terrace zone which extend a considerable distance north of the patch and to the fringing platform shoreward (Fig. 68). A sandy-floored channel lies south of the patch reef, and a series of sand-floored holes 20–50 feet deep and coral ridges with nearly the same amount of relief are located shoreward and northward on the submarine terrace (Fig. 66). Coral diversity and development was very luxuriant in this region prior to *Acanthaster planci* (starfish) damage during the 1968 and 1969 infestation period (Chesher, 1969).

A unique dendrophyllid coral, *Tubastraea aurea*, is found in a small submarine cave located at the head of a little cove below Ague Point (Fig. 71).

This bright orange coral has worldwide distribution and is very common on nearly all the Micronesian islands. On Guam, its distribution is very limited, and to date it has been reported only from Apra Harbor and Manell Channel.

Development, Use Patterns, Culturally Important Areas, and Unique Features

The coastal cliffs, steep slopes, and narrow terraces along this sector are uninhabited. Most of the coastal region lies within the boundaries of the U. S. Naval Communication Station, Finegayan Military Reservation, and the U. S. Federal Aviation Agency Headquarters (Fig. 1), although a small section south of Falcona Beach is privately owned. Naval Communication facilities are located on the plateau land bordering the coastal cliffs between Haputo and Pugua Points. An unimproved road follows the plateau border from Pugua Point to the region above Falcona Beach intersecting with Route 3 (Fig. 64). A section of road borders the cliffline above Haputo Beach, and a jeep trail winds down steep coastal slopes at the Pugua fault line to the terrace below. Federal Aviation Agency dependent housing (Oceanview) borders the plateau cliff at Ague Point.

The shallow offshore terraces located around the patch reef south of Falcona Beach (Figs. 66, 68) is a favorite place for boaters to anchor smallcraft, and fish or scuba dive. The rocky benches and associated spur-and-groove system along this sector are reported to be good spiny lobster-fishing grounds.

Other than the archaeological sites shown on Fig. 34 there are no known culturally important areas or unique features along the coast of this sector.

Sector IV

Physiography

The three-mile sector between Hilaan Point and Fafai Beach is distinguished by narrow fringing-reef platforms from the cut-bench-bordered Sector III and the broad reef flat of Tumon Bay of Sector V to the south. There are no embayments along this sector although long, shallow indentations are found north and south of Tanguisson Point. Limestone cliffs, steep slopes, and low-lying terraces border the shoreline (Figs. 35, 72, 73).

Prominent headlands at the shoreline at Bijia, Amantes, Tanguisson, and Hilaan Points are generally higher than 300 feet. Broad terraces, some a thousand feet wide, of unconsolidated beach deposits are located north and south of Tanguisson Point. These terraces are, at most places, bordered by a low belt of solution-pitted emergent limestone along the shore (Fig. 74). Abroad sandy terrace is found at Fafai Beach (Fig. 75) between the high rocker headland at Bijia Point and the low limestone ridge about a thousand feet to the south (Fig. 76).

The limestone plateau land of this sector is developed upon the same uplifted peripheral barrier reef complex as that described for Sectors I–III. Solution ramparts are found on the upper rims of the limestone cliffs at several places. The cliff faces and steep slopes are cut by nips and narrow terraces from various sea-level stands. Joints and fissures are also prominent at these headlands. They are especially noticeable on the cliff face at Amantes Point (Figs. 77, 86). Large blocks of limestone dislodged from the steep slopes and cliffs have come to rest on the shoreline and reef flat platform at some places (Fig. 80).

Geology

The coastal cliffs and steep rocky slopes bordering this sector consist of reef and detrital facies of the Mariana limestone formation (Fig. 7a). Reef facies (OTmr) caps the coastal cliffs and veneers the low coastal terraces of emergent limestone. Detrital facies (QTmd) is exposed on the steep coastal slopes, and underlies the low rocky terraces and cap of reef facies limestone on the plateau cliff margin.

Unconsolidated beach deposits (Qrb) veneer the broad terraces north and south of Tanguisson Point and south of Bijia Point (Fig. 78). The thickness of the beach deposits on these terraces exceeds 15 feet south of Hilaan Point, where a sand excavation site exposes a vertical section near the beach.

Soils

Two soil types and two miscellaneous land types are found along this sector (Fig: 79).

Guam clay (Unit 1) forms a narrow strip along the landward side of the unconsolidated terrace north of Tanguisson Point and along a broad strip south of Bijia Point, the northern end of a broad curving belt of this soil from the Tumon Bay coastal terrace to the south. Guam clay is more extensively found bordering the upper limestone plateau cliff margin from Hilaan Point southward, nearly to Amantes Point.

Gently sloping limestone rock land (Unit 13b) occupies the remainder of the plateau cliff margin, from the region where the Guam clay ends southward to Bijia Point.

Sandy Shioya soils (Unit 12) are developed on the unconsolidated beach deposits of the low terraces north and south of Tanguisson Point and on the terrace south of Bijia Point.

Steep limestone rock land (Unit 13f) makes up the limestone cliffs, headlands, and steep rocky slopes which border the entire sector. The unit also includes three low projecting points of emergent limestone along the coast; one is at Hilaan Point, another is at Tanguisson Point, and the third forms a long limestone ridge bordering the south edge of Fafai Beach (Fig. 76).

Engineering Aspects of Geology and Soils

The engineering aspects of geology and soils are described, summarized, and mapped in Fig. 12a, and Tables 5 and 6.

Vegetation Zones

The vegetation units (zones) along this sector are mapped on Fig. 33a. Figure 82 shows dense strand vegetation developed at the edge of a beach located north of Tanguisson Point. Figure 83 shows a dense coconut grove developed on a sandy terrace between Tanguisson Point and Hilaan Point.

Hydrology

There are no streams developed on the limestone plateau bordering this sector (Fig. 10). The limestone rocks and beach deposits are permeable to rainwater, which moves rapidly downward to the zone of saturation and then laterally toward the shoreline, escaping along the beach and rocky headlands from the freshwater lens system. Such water is especially noticeable at low tide, when it forms numerous rills in the beach sands. From Tanguisson Point northward the sector lies within the ground water subarea 3a and from Tanguisson Point southward it lies within subarea 3d (Fig. 13).

Beaches and Rocky Shorelines

The rocky coastline (Figs. 7a, 78) consists of limestone headlands at Hilaan, Tanguisson, Amantes, and Bijia Points, and at the limestone ridge south of Faifai Beach. Low terraces of rough solution-pitted limestone occur along the shore north and south of the NCS swimming beach (Figs. 73, 74) and north of Tanguisson Point, Steep rocky slopes and large blocks of limestone (Fig. 80) occupy the remainder of the shoreline where beaches are not developed.

Beaches are developed along the shoreline at three locations. The most extensive beach lies between Amantes and Tanguisson Points (Fig. 73), although strips of emergent limestone resembling beach rock and a small rocky point north of ACS swimming beach interrupt the beach sands at places. The second most extensive beach lies between Tanguisson and Hilaan Points (Fig. 81). It also is interrupted by rocky points and narrow strips of emergent limestone. The third beach lies between Bijia Point and a limestone ridge bordering the north shore of Tumon Bay.

Beach samples were collected and analyzed by Finery (1962) at three locations along this sector (Fig. 17, Stations 8–10). The beach sands from this sector are entirely of bioclastic material of reef origin (Table 7).

Reefs and Other Subtidal Features

This entire sector is bordered by fringing reef-flat platforms (Fig. 78). The reef flats range in width from the narrow 50–75-foot-wide eroded platform at Amantes Point headland to the 1,000-foot-wide platform north of Tanguisson Point (Figs. 73, 77). Much of the reef-flat zone along this sector is exposed at low tides and the low-tide inner reef-flat moat is discontinuous and shallow when present. At places, remnant pinnacles of solution-pitted limestone are found. At Hilaan Point a large sandfloored hole, 500 feet long and about 10 feet deep, occurs where the reef flat narrows and grades into the cut benches of Sector III (Fig. 78).

Some sections of the reef margin, reef front, and submarine terrace zones along this sector show evidence of erosion, whereas at other sections these zones possess developmental features, showing signs of reef growth. The eroded front and submarine terrace zones are similar to those described along Sector III.

Tanguisson Point Study Area — The relatively narrow developing fringing reef between Amantes and Tanguisson Points has been studied and monitored since 1969 as part of an effort to determine the effects of natural and man-induced changes on a tropical reef (Jones and Randall, 1973). This section of the coast is bordered by steep slopes and limestone cliffs, and the reef has a westerly exposure to the sea (Figs. 73, 84, 85). A series of three permanent transects were established and a vertical reef profile showing the reef zones was compiled (Fig. 19).

Intertidal Zone — The intertidal zone bordering the transect locations is composed of bare limestone with the exceptions of a sandy section at NCS swimming beach and several other small sandy sections between Transects B and C. At Transect B this zone is 40 m wide and consists of limestone ridges, knobs, and pinnacles separated by numerous interconnecting channels which are relatively flat-floored and at about the same general level as the reef flat itself. The upper halves of the emergent structures are exposed during high tide and are deeply solution-pitted. Relief of these structures ranges from about 1 m at the shoreward side to 20 cm on the seaward side, where the structures grade into the reef flat. Several smaller patches of emergent structures are found near Transect C also.

Unconsolidated sediments are scarce along the bare rocky regions except for local patches of coarse gravel and boulders. Sediments at the two beach areas are mostly sand, largely composed of worn foraminiferan tests. At low tide, fresh water can be seen escaping from the intertidal zone, and at sandy locations such water forms small rills similar to those described at Gognga Beach (Emery, 1962).

Reef-Flat Zone — The outer, seaward part of the reef flat is slightly elevated with respect to the inner, shoreward section and, at low tide, is often exposed while the inner part retains water. On this basis, the reef flat is divided into two subzones—an outer reef-flat subzone exposed during low tide and an inner reefflat subzone or moat always covered by water at low tide.

Inner Reef-Flat Subzone — The inner reef-flat subzone is poorly developed at Transects A and C and is absent altogether at Transect B. During low tide at Transects A and C, a few shallow, irregularly-shaped pools and a depressed zone north of Transect C retain water and constitute the moat of the inner reef flat. The floors of these pools contain coarse gravel, boulders, and scattered emergent limestone patches. At NCS Beach water is retained at low tide, but this retention is caused partly by dredging and blasting and does not represent natural conditions.

Outer Reef-Flat Subzone — This subzone is more extensive than the inner reef-flat area and represents most of the reef platform. At Transect B, where no inner reef flat occurs, the outer reef flat extends from the reef margin to the intertidal zone and is 60 meters wide. At Transects A and C the subzone is 50 and 90 meters wide, respectively.

At low tide, the exposed platform is a flat pavement with very little relief. A few small shallow pools 10–50 cm deep are widely scattered over the surface. Sediments are scarce and accumulate only in these pools. An algal turf covers most of the surface and contains many foraminifera.

Reef Margin Zone — Always awash, even at low tide, the reef margin at Tanguisson Point is slightly elevated, being about 20 cm above the outer reef-flat level, and forms a low, poorly developed algal ridge, the development of which is greatest at Transect B. Observations immediately seaward of Transect B show that the degree of reef front slope is less than at Transects A or C, a condition causing greater surf and thereby enhancing algal ridge development. The width of the reef margin is fairly uniform and ranges from 20 to 30 m at the transect locations.

The seaward edge is very irregular and is cut at right angles by short surge channels—1–3 m wide, 2–4 m deep, and as long as 20 m—some of which coalesce at the upper margins, forming cavernous tunnels beneath the reef margin platform, generally opening at intervals along the fusion zone into pools and open cracks. In cross-section, most surge channels are wider at the bottom than at the upper margin perhaps because of growth at the upper regions and abrasion at the bases, which contain large, rounded boulders. Most boulders, however, do not show evidence of constant movement, as they are usually encrusted with red algae and small coral growths. They are probably moved about only during typhoons and other storms. Surge channels are separated by lobate elevations of buttresses which slope seaward toward the reef-front zone. The upper surfaces of the buttress are very irregular with knobs and pinnacles, and in many places are honeycombed with numerous interconnecting holes.

Reef Front Zone — The width of the reef front ranges from 70 m at Transect A to 60 m at Transect C. Submarine channels near the reef margin are 2–6 m deep and commonly branch into several secondary channels, wider at the bottoms than at the tops, and are relatively flat-floored, with large round boulders, coarse sand, and gravel scattered along their lengths. Some submarine channels widen into holes 5–15 m in diameter, large boulders covering the floors. Submarine buttresses slope seaward from 10–15° and are extremely irregular on the upper surfaces, by development of coral-algal knobs, bosses, and pinnacles. On the seaward half of this zone, these prominences may have a relief as great as 2–3 meters.

Submarine Terrace Zone — The first submarine terrace represents a noticeably flattened region when compared to the reef front and seaward slope zones, and ranges in width from 40 m at Transect C to 110 m at Transect B. The shoreward margin of this zone begins at the 6-meter contour but its seaward margin, where the steep seaward slope begins, is at the 10–15 m contour. Relief of the surface features ranges from 1–2 m. Occasional coral mounds or pinnacles attain a relief of 3 m. Shallow channels as much as a meter in width and depth cut the surface here and there. Sediments in localized patches, in holes, in cracks, and in shallow channels consist mostly of rounded boulders, coarse sand, and gravel.

Seaward Slope Zone — At the seaward margin of the Tanguisson Point submarine terrace, the degree of slope abruptly increases and sharply differentiates the seaward slope from the terrace. The width of this zone at the three transect locations averages 70 m. The steep seaward slope flattens into a second submarine terrace at about the 100–125 foot depth. This second terrace probably corresponds to the 105-foot submarine terrace at Tumon Bay (Emery, 1962).

Distinct linear sediment tracks can be traced from the upper part of the slope to the second submarine terrace below. Although the depth of the sediments was not measured at the second terrace, visual observations with SCUBA equipment revealed a considerable accumulation at the base of the slope.

A conspicuous feature of the second submarine terrace is the rising of scattered coral knolls from the sandy terrace floor at 40–45 m, the relief being as much as 10 meters.

Development and Use Patterns, Culturally Important Areas, and Unique Features

From NCS Beach northward, the coastal land along this sector is within the boundaries of military reservations (Figs. 1, 72). South of NCS Beach, the coastal land below the plateau cliffline is of Government of Guam or private ownership, and the plateau land above and inland from the cliffline is within military reservations (Fig. 1).

Roadways reach the low-lying regions at NCS and Faifai Beaches. Residential dwellings are found only in the Fafai Beach region.

An oil-fired, steam, electric generating facility is located on the low unconsolidated terrace immediately south of NCS Beach (Figs. 73, 84, 85). At present, this facility has a total generating capacity of about 52 megawatts. An intake channel cuts across the reef-flat platform to the reef margin zone to supply condenser-cooling water for the generating plant. Heated effluent water is released at the shoreline about 100 yards south of the intake channel. The biological impact caused by this generating facility is described in a study by Jones and Randall (1973).

Naval Communications Station (NCS) maintains a swimming and picnic area at NCS Beach (Fig. 85). The Government of Guam has a park located at the upper margin of the cliffline at Amantes Point (Fig. 86). At present, Fafai Beach is being developed, and several hotels are under construction in the area. Of historical interest, there is a World War II Japanese gun installation which attracts tourists at the north end of Fafai Beach.

A unique feature of the first low terrace south of Hilaan Point is the presence of a small open pool of water, about 75 feet in diameter. This pool is located at the base of the steep slopes which border the landward side of the terrace and appears to have formed as a result of cave collapse. Another unique feature of the rocky terrace and slopes around this water pool is the small but nearly pure stand of *Merrilliodendron megacarpum*, a relatively rare tree on Guam. No other rare or endangered plants or animals are, at present, known from the coastal region along this sector.

This section of the coastline is more accessible to SCUBA divers, skin divers, spear and net fishermen, and other beach-oriented activities than the rugged coast of Sector III to the north. The relatively remote sandy beaches and rocky headlands along this sector provide some of the finest scenery, picnicking, climbing, hiking, and other beach-related activities to be found on the island.

Other than the archaeological sites shown on Fig. 34, there are no other known culturally important or unique areas along the coastal region of the sector.

Sector V

The two-mile-long coastline between Ypao Point and Fafai Beach forms a broad, concave embayment known as Tumon Bay. It is delimited as Sector V from the coastal regions to the north and south by the presence of a broad fringing reef-flat bordered at both ends by low limestone cliffs, 15–30 feet high at the south end and 60–80 feet high at the north end (Figs. 35, 87, 88). Ypao Point forms a prominent headland more than 200 feet high. A generally broad terrace borders the reef-flat shoreline between the rocky cliffs north and south. The terrace consists of unconsolidated beach sands except for an elevated rocky stretch of limestone between Ypao and Naton Beaches, and a rocky headland between Naton and Gognga Beaches (Figs. 89 and 90). At Ypao Beach the terrace is extensive, about 1,000 feet wide, but widens considerably, to more than 2,000 feet at places along Naton Beach, and then narrows suddenly to a mere band at Gognga Beach. Steep limestone slopes border the entire landward side of this terrace. The upper margin of these slopes consists of north Guam plateau land (Fig. 9), the edge of which, slopes from 200 feet high at the north end to 100 feet at the south end of the sector.

Geology

The cliffs at the north and south ends of the reef flat, the rocky headland between Gognga and Naton Beaches, and the low rocky terrace between Ypao and Naton Beaches are composed of detrital limestone facies (QTmd) of the Mariana limestone formation. Reef facies (QTmr) caps the cliffline at the north end of the reef flat and behind Ypao Beach (Fig. 7c).

Beach deposits (Qrb) form a thick veneer over the limestone at Ypao, Naton, and Gognga Beaches. Sand quarries, well-boring logs, and construction-site excavations show the terrace deposits in some places to be thicker than 30 feet.

A fault cuts through the south end of the reef flat and cliff face at Ypao Point. Several channels cut through the reef margin in the fault zone, and a vertical sea cliff cuts across the reef front and submarine terrace.

Soils

Two soil types and ,a single miscellaneous land type are found along this coastal region (Fig. 91). Guam Clay (Unit 1) is found on the low-lying limestone terraces and along the high plateau land bordering Tumon Bay. Shioya soil (Unit 12) is found on the unconsolidated terraces at Ypao and Naton Beaches. Steep limestone rock land (Unit 13f) is found between the high plateau land and the low coastal terraces and along the cliffs and slopes bordering the north and south ends of the Tumon Bay reef flat.

Engineering Aspects of Geology and Soils

The engineering aspects of geology and soils are mapped, described, and summarized in Fig. 12a and Tables 5 and 6.

Vegetation Zones

The vegetation units (zones) along this sector are mapped in Fig. 33c.

Hydrology

There are no streams on the limestone plateau along this sector, which lies entirely within groundwater subarea 3d (Fig. 13). Rain water percolates downward to the zone of saturation and then moves laterally to the shore, where it escapes continually along the beach and rocky shorelines through intertidal and subtidal holes, cracks, and fissures. Along the unconsolidated beaches, it forms rills in the sand. Emery (1962) measured the discharge of water along a 150-foot section of Gognga Beach at 1.5 cfs.

A basal tunnel (Tumon Maui) was excavated at the base of the steep limestone plateau slope (Fig. 87) in 1947 by the Corps of Engineers, U. S. Army. The tunnel extends 1,000 feet beyond the pump sump, and the water level ranges between +1–2 feet. The monthly pumpage rate from June, 1953 to Dec., 1955 is given in Table 16, and the chloride content is given for various times between April, 1947, and August, 1956, in Table 17.

Several wells, most of which are now abandoned, were dug and drilled into the water table on the terrace along Naton Beach. The drillers' log gives some indication of the depth of sand encountered. Well No. 10 produced beach sand from 0–14 feet and coral and sand from 14–33 feet. Well No. 11, 19 feet deep, was dug in loose sand and coral. Well No. 27 was dug into sand and coral to a depth of 21 feet, the drillers' log showing sand from 0–8.5 feet and coral rock from 8.5–21 feet. The log from Well No. 54 shows that it was dug in limestone to a depth of about 20 feet.

Beaches and Rocky Shorelines

The north and south ends of Tumon Bay consist of rocky cliffs with well-developed sea-level nips cut at the bases and a +6-foot nip present along much of the cliff face (Figs. 88, 92). At places along the south end of the reef-flat platform, a narrow fossil bench separates the sea-level nip from the +6-foot nip. Large blocks of limestone have broken loose from the cliff at several places along the north cliff face and a large sea cave is located at reef-flat level along this face.

A narrow rocky headland with angular limestone blocks scattered along the base lies between Gognga and Naton Beaches. Recently, more blocks and rock debris have been pushed over the cliff face to the shoreline below by construction activities (Fig. 90). A low, irregular, solution-pitted limestone outcrop occupies a narrow strip of shoreline between Naton Beach and Ypao Beach (Fig. 88).

Unconsolidated beach deposits make up most of the shoreline along this sector, the principal ones being at Gognga, Naton, and Ypao Beaches. From a recreational point of view these beaches are among the finest on the island. The sand deposits are deep and extensive, and a sandy-floored moat, deep enough for swimming, borders the entire beach front.

Beach samples collected and analyzed by finery (1962) at three locations along Tumon Bay are free of nonbioclastic contaminants, two of the samples being composed predominantly of coral and shell fragments (Fig. 17, Stations 5–7; Tables 7 and 8).

Reefs and Other Subtidal Features

The fringing reef flat along this sector (Figs. 18, 93) is a broad, crescent-shaped, limestone platform 3,5I+0 m long on the concave seaward margin. It is relatively uniform in width, ranging from 460 m at Gognga Beach to 480 m at Naton Beach. Tumon Bay itself was probably formed by large-scale slumping (Tracey et al., 1964), an action which would provide a wide, shallow platform upon which the Tumon fringing reef could develop and explains the general absence of wide reef platforms along other sections of the northwest coast (See Fig. 35). At Ypao and Gognga Points, the fringing reef width narrows to 50 m and 100 m, respectively.

Intertidal Zone — Along the more seaward exposed regions at either end of the bay, the intertidal zone consists of bare limestone with welldeveloped seawall indentations called "nips" (Figs. 92, 93). The remainder of the beach consists principally of unconsolidated sand and coral-algal mollusc rubble. A considerable fraction of the sand portion from the unconsolidated beach material consists of foraminiferan tests, which are transported from the reef-flat zone by wave action and currents.

Reef-Flat Zones — At Tumon Bay the seaward part of the flat limestone platform, which extends from the intertidal zone to the wave-washed reef margin, is slightly elevated with respect to the inner shoreward section; consequently, at low tide, it is often exposed while the moat retains water (Figs. 18, 93).

Inner Reef-Flat Subzone — This region of the Tumon Bay reef flat, the moat, is considerably wider than the outer reef-flat subzone, ranging in width from 380 to 350 m. Unconsolidated sediments vary in thickness from a meter or more near the beach to a thin veneer of less than a centimeter near the outer reef flat. Local areas of bare reef rock are common, especially where this subzone grades into the outer reef flat subzone. Sand, gravel, coral-algal-mollusc rubble, and small boulders make up the sediment composition. Sand and gravel are more common along the inner half, and coral-algal mollusc rubble and boulders become more abundant as the outer reef flat is approached. The entire sub zone is relatively flat with a few cracks, holes, low mounds of rubble, and shallow bowl-shaped depressions, the general relief being usually less than 50 cm. The deepest water on the inner reef flat occurs at the mid-point, about 150 m from shore.

Outer Reef-Flat Subzone — This subzone of the Tumon reef flat varies considerably in width and is exposed during lower tides, when it emerges as a flat limestone pavement with very little relief. Near the boat channel opposite Naton Beach the outer reef flat disappears completely because of several shallow channels which occur. Unconsolidated sediments are nearly absent along the outer, seaward part of this region except in small, widely scattered, shallow pools a few centimeters deep where sand, gravel, boulders, and reef rocks perhaps a meter high accumulate. The inner, shoreward part usually has scattered boulders over the surface, and large boulder tracts form in some areas (Fig. 94) where the outer reef flat grades into the moat. The sources of these boulders are the reef margin and reef front, where rocks and living corals are broken loose and worked shoreward by typhoon and other storm waves. A large accumulation of such boulders has formed the basis for the small islet which is developing on the outer reef flat between Naton and Ypao beaches (Figs. 93, 95).

The surface of the limestone "pavement" is usually covered with a turf-like mat of filamentous algae. Foraminifera are abundantly distributed throughout this algal mat and are the main source of the buff-colored sand found on the reef flat and beach.

The depth of the water over the outer reef flat at high tide varies be-cause of elevation differences. The section between the boat channel and the shallow channel immediately seaward of the small islet seems to be depressed with respect to the sections opposite Ypao and Gognga beaches. Since there are no streams opposite or shoreward of these channels to account for their origin, this depressed section may have formed because of a local faulting or slumping of the reef margin and outer reef flat. Several patches of remnant limestone composed of solution-pitted pinnacles and knobs are found on the outer reef flat near Ypao Point. These features are probably remnants of a former reef platform of higher elevation.

Reef Margin Zone – At most places along the Tumon Bay reef margin, algal ridge development is very poor or—more often—absent. The reef margin varies in width from 30–40 m, the seaward edge being very irregular and cut at right angles by short surge channels 1–3 m wide, 2–4 m deep, and as long as 20 m. Some channels coalesce and fuse at the upper margins, forming cavernous channels beneath the platform. Most of these channels open at intervals along the fusion zone into pools and open cracks. In cross-section, most surge channels are wider at the bottoms than at the upper margins, a condition which may be due partly to growth at the upper regions and to abrasion at the bases, which contain large, rounded boulders. Most boulders, however, do not show evidence of constant movement because most are encrusted with red algae and small coral growths. These boulders are probably moved about only during typhoons and other storms. Surge channels are separated by lobate elevations called buttresses which slope seaward toward the reef-front zone. The upper surfaces of the buttresses are very irregular with knobs and pinnacles and in many places are honeycombed with numerous interconnecting holes. The inner half of the reef margin, like the outer surface, is irregular because of the presence of small knobs, pinnacles, holes, and pools. Shallow extensions of the longer surge channels cut through the inner half of this zone and terminate in small pools 1–2 m deep.

Reef-Front Zone — The width of the reef-front zone along Tumon Bay is variable and ranges from 60 m at the northern end to 80 m along the more windward, southern end. Generally, the 6-m submarine contour coincides with the seaward limit of this reef front, and although a reef-front slope may be contiguous with that of the seaward-slope zone, at most locations along Tumon Bay these two zones are separated by a flattened region called a submarine terrace (Figs. 18, 93). Submarine channels near the reef margin are 2–6 m deep and commonly branch into several secondary channels which are usually wider at the bottoms than at the tops and are relatively flat-floored, with large round boulders, coarse sand, and gravel scattered along the lengths (Fig. 26). Some submarine channels widen into holes 5–15 m in diameter with large boulders covering the floors. Submarine buttresses slope seaward from 10°–15° and are extremely irregular on the upper surfaces with coral-algal knobs, bosses, and pinnacles (Fig. 27). At the seaward half of this zone, these various prominences may be as high as 3–4 m.

Submarine Terrace Zone — At Tumon Bay the terrace begins at the 6-m contour and extends seaward, more or less, to the 18 m contour, where a sharp increase in the degree of slope marks the beginning of the seaward slope (Figs. 18, 93). Coral mounds and pinnacles, on the inner half of the terrace (Fig. 96), give its surface a topographic relief similar to that of the outer reef-front zone. Relief on the seaward half of the terrace is generally less, ranging from 1–2 m, but occasionally scattered coral knolls and knobs may have a relief as great as 4 m. A few shallow channels, about 1 m deep, cross the zone at right angles and usually connect with deeper channels on the seaward slope. The floors of these grooves are covered in places by thin layers of sand and gravel. A large fraction of the sediments found on the terrace is derived from various species of *Halimeda,* a green calcareous alga, and foraminiferan tests.

Seaward Slope Zone — At Tumon Bay this zone begins where the low-angled submarine terrace abruptly increases in steepness. At the transect locations, the slope ranges from 30° to 60° and averages 80 m in width. At 30–35 m deep, the slope flattens, forming a second submarine terrace (Fig. 18). The width of the second submarine terrace was not measured, but it probably corresponds to the 32-m submarine terrace found by Emery (1962) in several reef-profile soundings around the island. Grooves and V-shaped valleys, many of which are contiguous with those of the outer part of the submarine terrace, cut across the seaward slope and terminate at the beginning of the second terrace. These features are controlled by, and probably represent, remnants of a submerged reef-front buttress-and-channel system developed during a previous ocean stand. Even though the degree of slope is greater than that of the submarine terrace, the accumulation of sediments is greater in pockets, holes, valleys, and channels of this zone. Distinct linear sediment tracts can be traced from the upper part of the slope to the second terrace below. Although the depth of the sediments was not measured at the second terrace; visual observations made with SCUBA equipment reveal a considerable accumulation at the base of the slope.

Topographic surface relief is much less on the slope than on the first submarine terrace. The reef front, submarine terrace, and the seaward slope zones along Tumon Bay supported a rich growth of reef corals prior to the *Acanthaster planci* infestations of 1967 and 1969. A total of 146 coral species were reported from this sector before the infestation (Randall, 1973 a). Of the total number, 139 species representing 31 genera were hermatypic scleractinian corals, 2 species representing 2 genera were ahermatypic scleractinian corals; and 5 species representing 3 genera were nonscleractinian corals.

Acanthaster planci predation has killed not only most of the corals in the submarine terrace and seaward slope zones but also most of those in the reef margin and reef front zones along the northern half of the sector as well. Reduced wave assault along the northern half has allowed greater coral damage. The southern half of the sector receives more wave assault because the reef margin is oriented toward the north. Greater wave assault reduced *A. planci* activity in the southern reef margin and reef front zone, permitting a narrow band of living corals to be left there (See Figs. 30–32).

Offshore Slopes — Emery (1962) made one offshore profile along this sector which shows two narrow submarine terraces, one 55 feet deep and the other 195 feet deep (Figs. 28, 29-No. 9). Actually the 55-foot terrace is well developed, very irregular, and much wider than indicated in Fig. 28 because the profile was started nearly 250 yards offshore.

A sharp break occurs along the submarine terrace at the southern end of the sector where a fault, presumably a seaward extension of one mapped by Tracey (196) at Ypao Point, cuts across the reef platform (Figs. 7c, 93).

Development and Use Patterns, Culturally Important Areas, and Unique Features

Residential and commercial enterprise are developed extensively along most of this sector, for much of Guam's hotel development is located along the Tumon Bay shoreline. The steep limestone slopes and cliffs bordering the southern part of the bay are a backdrop for the hotel which adjoins Ypao Beach, a public park with a dredged submarine area (Figs. 93, 100). The cliffline seaward of the hotel is undeveloped and is covered with a limestone forest community (Fig. 98). Hotel development and scattered residential dwellings occupy the remaining shoreline between Ypao and Gognga Beaches. A monument to the martyred Father Diego Luis de Sanvitores is located at the north end of Naton Beach (Fig. 99). The high limestone ridge and sea cliff between Gognga and Fafai Beaches are relatively undisturbed at the present time (Fig. 97).

Tumon Bay reef flat itself is a popular region for net fishing, spear fishing, snorkeling, shelling, and reef walking. The deeper waters seaward of the reef margin are also popular for SCUBA diving and spear fishing. Small sailboards and even motor-powered boats are used on the reef-flat waters at high tide.

A network of improved and unimproved roads occupy the lower terraces between the shoreline and the steep plateau land (Fig. 87). Route 1 borders the upper plateau margin.

Sector VI

Physiography

This one-and-three-quarter mile sector is a convex section of rocky coastline between Tumon and Agana Bays. Limestone cliffs, sea-level benches, and narrow reef flats occupy the entire shoreline (Figs. 35, 101, 102). The upper cliff margin ranges in elevation from 200 feet at Ypao Point to 100 feet at Oca Point. Although a narrow, poorly defined terrace breaks the cliff face at places, particularly along the southern half of the sector, there are no wide terraces.

Geology

The limestone cliffs and plateau land here are part of the Mariana limestone formation. Reef facies (QTmr) limestone caps the upper part of the cliffs, and detrital facies (QTmd) makes up the loner part. A fault offsets the northern part of the cliffline along Tumon Bay, and the cliff face along the entire section is cut by joints, fractures, and fissures (Fig. 7c).

Soils

Guam clay (Unit 1) is found on the upper surface of the limestone plateau. Limestone rock land (Unit 13f) consisting of the steep slopes and cliff faces forms a narrow band along the entire sector. The band widens at the north end where a section of the plateau is offset by a fault zone (Fig. 103). Gently-sloping rock land (Unit 13b) forms a narrow band along part of the upper cliff border.

Engineering Aspects of Geology and Soils

The engineering aspects of geology and soils are described, summarized, and mapped in Fig. 12c and Tables 5 and 6.

Vegetation Zones

The vegetation units (zones) along this sector are mapped in Fig. 33c.

Hydrology

The entire sector lies within the ground water subarea 3d, for no streams are developed on the limestone plateau (Figs. 10, 13). Rainwater percolates downward through the porous limestone, and fresh water escapes from the lens system near sea level. A fresh water refraction zone is particularly noticeable along the bench where joints and fractures are prominent on the cliff face.

Beaches and Rocky Shorelines

Rocky shores border the entire sector (Fig. 104). A small patch of beach sand and boulders is found at the base of the steep rocky slope along the northern end where a narrow reef-flat platform fringes the coast. A prominent sea-level nip is cut into base of the cliff along most of the sector, and at places, the +6-foot nip is well developed. Vegetation is lacking along the lower part of the sea cliffs, and the limestone surface is very irregular. The exposed rocky surfaces are solution pitted and cut into sharp-crested pinnacles and knobs. Large limestone blocks which have broken away from the cliff face are found scattered along the bases of the cliffs and benches.

Reefs and Other Subtidal Features

Fringing Reef — A narrow reef-flat platform borders the limestone cliffs at either end of the sector, grading into a cut-bench platform near Oca and Ypao Points (Figs. 102, 104). The reef flat is pavement-like with very little relief. The following descriptions of the reef-flat and offshore zones were made along a transect bearing N. 10° W. from a large limestone block located at the base of the cliff which borders the north end of the region (Fig. 102).

Beach and Intertidal Zones — This zone consists of a limestone cliff base bordered by a band of coarse sand and gravel, twenty-five feet wide and interspersed with large boulders and blocks of limestone which are probably derived from the cliff face. All the rock of this region is solution pitted and dark gray in color. The narrow sand-gravel band forms a thin veneer over the limestone platform, which is less than two feet thick. The beach deposits are composed of comminuted pieces of coral, coralline algae, foraminiferan tests, mollusc shells, and skeletal fragments from other organisms which possess hard parts. During high tide and normal wind conditions, translatory waves reach the cliff base, in which a well-developed nip is being cut at sea level. Limpets and an occasional chiton are found attached to the rocky surface of the nip and to large blocks of limestone which lie at the edge of the beach. Grapsid crabs are numerous along the rocky nip and on the large boulders. Nerites are clustered in small cracks and cavities in the rocks. No corals are found in this zone.

Inner Reef-Flat Zone — This zone is narrow, only 50 feet wide. The shoreward section is cut by low ridges and shallow troughs formed by the scouring action of beach sand and gravel being moved back and forth by waves at high tide. At low tide, the depth of water ranges from a few inches where it grades into the outer reef flat to one foot in shallow pools and open cracks near the beach. The floors of the pools and cracks contain sand, gravel, and a few coral boulders.

Associated with the sandy regions are four species of holothurians. Both soft and calcareous algae are abundant, especially on the flat rocky areas where *Cladophoropsis* forms a dense mat. *Padina* grows along the rocky sides of the small pools and on submerged rocks in the deeper parts of the area. Small, scattered nodules of a branched, crustose red alga are found on the more barren areas of the flat. Three species of corals representing two genera were found in this area. *Porites lutea* forms small subspherical colonies and an occasional larger, flat-topped colony which is dead on the upper surface because of exposure at low tides. Interspersed among the *Porites* colonies are two species of *Pavona* which form low cushion-shaped coralla with a foliaceous, branching growth form.

<u>Outer Reef-Flat Zone</u> — This zone, 125 feet wide, is barren of corals except for one small pool 3–4 inches deep which contains a small, green-colored *Porites* growing out from the side of the wall. The region is almost completely covered by an algal mat of *Cladophoropsis* and loose pieces of *Boodlea*. Interspersed throughout and under this mat is a great variety of organisms, the dominant form being a stellate species of Foraminifera whose tests, which have been worked across the reef flat by wave action, give the beach sands their characteristic buff color.

<u>Reef-Margin Zone</u> — The reef martin, 50 feet wide at Ypao Point, is dominated by a narrow, elevated, cuestal algal ridge (Fig. 102) composed of lobate spurs which rise 1–2 feet above the general level of the outer reef flat. The spurs alternate with surge channels, and the upper margins of the spurs have a tendency to form a shelf which overhangs the surge channels at the seaward ends.

The seaward half of the spurs 3s covered with encrusting red algae, the shoreward half by a short mat of soft benthic algae. No corals are found on the upper surfaces of the spurs, but limpets and other gastropods are abundant. The surge channels are the same lengths as the raised spur lobes and slope from the crests seaward about 15° to the edge of the algal ridge, where they are 5–8 feet deep. These channels are free of sediments and boulders, and the wall surfaces and floors are entirely covered by some various types of encrusting organisms. These are small, scattered corals of encrusting, branching, and massive growth forms but particularly abundant here are encrusting red algae, the zone of which ends abruptly at the heads of the channels which is the limit of wave height at low tide.

Water oscillates back and forth in the surge channels at both high and low tide. As each wave advances, there is a seaward rush of water as the trough approaches, then a shoreward rush of water as the crest enters the channel mouth. Every few minutes, a series of high waves send surges of water or spray over most of the algal ridge.

Reef Front Zone — The reef front here is 50–75 feet wide and is cut along the entire width by submarine grooves. The floors of the grooves are relatively flat or slope very gently seaward, whereas the surge channels slope more steeply and at the reef front margin drop off almost vertically to the flat-bottomed floors of tile grooves. The grooves near the margin are relatively clean but usually contain some pockets of coarse gravel and large boulders. There is evidence of scouring at the very bottoms of the grooves but not on the sides, which are almost completely covered by encrusting organisms. Calcareous red algae are again the dominant growth along the walls, although some sections contain large coral-covered areas. The seaward ends of the grooves either grade out level with the submarine terrace slope or end abruptly in potholes which contain lame rounded boulders several feet below the level of the terrace slope. Between the grooves, extensions of the reef-margin spurs slope downward to the submarine terrace floor. These spurs are round on the upper surfaces and are relatively free of corals except at the seaward ends, where clusters of corals frequently develop. The upper surfaces of the spurs are predominantly covered by encrusting calcareous algae, and much of that region is riddled with borings made by a pink-spined sea urchin and the large slate-pencil sea urchin. The water at the bases of the spurs is 10–15 feet deep.

Submarine Terrace Zone — The submarine terrace is 200 feet wide and slopes very gently from a depth of 10–15 feet at the bases of the reef front spurs to 25 feet at the seaward edge where it drops off steeply to the seaward slope zone.

The shallower end of the terrace has scattered corals on the surface, and as the water deepens both the size and frequency of the colonies increase. Calcareous red algae are still very abundant and give the entire terrace a light pink color, but branching forms of coral are dominant.

Sea-Level Benches — The remainder of the sector is bordered by a narrow cut bench (Figs. 104, 105), described as follows by Tracey et al. (1964). "A limestone cliff forms the coastline from Saupon Point to Ypao Point. Along this headland no true fringing reef exists; rather the cliff is bordered at sea level by a cut bench 6 to 20 feet wide. The bench ranges in altitude from about mean sea level in lee exposures to about 4 feet above mean sea level along the most exposed part of the headland and resembles some of the 'water-level benches' described by Wentworth (1938, Figs. 2 and 3). The inner edge of the bench terminates at a notch in the cliff, and in places the cliff completely overhangs the bench to form a roof 5 to 8 feet above it. The floor of the bench is remarkably flat, but it contains small pools separated by low hummocks and is covered by a thin carpet of soft algae. The outer edge of the bench drops off steeply, is irregular and blocky, and is only thinly coated with pink calcareous algae."

Offshore Slopes — The offshore slopes along this sector are very similar to those described for the sections of shoreline bordered by cut benches along Sector III.

Emery (1962) made one offshore profile along this sector (Figs. 28, 29, No. 9) which indicates one terrace at 195 feet depth and another, very narrow one, at 315 feet. Although this profile does not indicate a shallower terrace, a well-pronounced but narrow 55-foot-deep terrace is present along most of the shoreline of this sector. Large limestone blocks found on the submarine terrace floor have broken loose from the adjacent cliffs and headland.

Development and Use Patterns, Culturally Important Areas, and Unique Features

The upper plateau land bordering the coastal cliffs is extensively developed along the entire sector. Guam Memorial Hospital and staff housing occupy the cliffline along Ypao Point. Residential dwellings cover much of the remainder (Figs. 101, 102, 106).

A sewage outfall empties onto the bench between Saupon And Ypao Points. The benches are inaccessible except at low tides during times of no wave or swell action. Near Saupon Point a privately-owned concrete stairway and observation platform has been built part way down the steep limestone slope and cliff face.

No other known culturally important areas or unique features are known from this sector.

Sector VII

Physiography

This sector, located along the north-facing coastline of the central part of the island, includes all of the coastal region between Oca Point and Cabras Island (Figs. 35, 107a, 107b). Approximately seven miles long, this coastline is delimited from the cut benches bordering Sector VI to the north, and from the Cabras-Island-Apra-Harbor complex of Sector VIII to the west, by fringing reef-flat platforms which range from the narrow fringe of about 75 feet at Adelup Point to the 3,000-foot-wide reef flat between Asan Point and Piti Bay. The average width of the platforms is about 2,000 feet.

Limestone plateau land and low unconsolidated terraces border the sector from Oca to Adelup Points. Volcanic highlands, isolated stretches of limestone, and low coastal terraces of unconsolidated beach deposits, alluvium, and artificially filled land border the sector from Adelup Point to Cobras Island. Swamp and marshland separate the northern limestone plateau from the southern volcanic highlands (Fig. 107a). This coastal region, is drained by six rivers, four of which drain volcanic mountain land, and two the hilly argillaceous land of central Guam (Fig. 10).

Two islands are found along this sector. Alupat Island is limestone and has a relief of 50–60 feet. Camel Rock, also limestone, is an islet about 20–25 feet high.

Three prominent peninsulas are situated along this sector. The largest is Asan Point, an isolated limestone ridge about 120 feet high. A low unconsolidated beach terrace makes up the northern half of this point (Fig. 108). The second-largest peninsula is Paseo de Susana Park, a triangular mass artificially made by a landfill on the Agana reef flat (Fig. 109). Adelup Point, the third and smallest peninsula, is a thumbshaped projection of limestone with a relief of more than 40 feet (Fig. 110).

Three bays are located along the coast of this sector. Agana Bay is a broad embayment between Oca Point and Adelup Point. Asan Bay is a shallow embayment between Adelup Point and Asan Point. Piti Bay is located between Asan Point and the mouth of Tepungan Channel, which formerly connected the east end of Apra Harbor lagoon with the Philippine Sea.

Geology

The coastline is bordered by several members and facies of the Mariana limestone formation, beach deposits, alluvium, and man-made filled land (Fig. 7c)

Mariana limestone borders small sections of coast, detrital facies (QTmd) being found at the northern end, from Oca Point to Dungcas Beach, the coastal cliff there being capped with reef facies (QTmr). Alupat island also appears to be composed of detrital facies. Reef facies (QTmr) makes up Adelup Point and Cobras Island. Argillaceous limestone (QTma) borders the rocky ridge on the west side of Asan Point.

Artificially, filled land (Qaf) makes up the causeway between Cobras Island and Schroeder Junction as well as the Paseo de Susana Park peninsula at Agana. Except for Adelup Point and Paseo de Susana Park, the entire shoreline from Dungcas Beach to the tip of Asan Point is bordered by low terraces of unconsolidated beach deposits (Qrb). A narrow band of these deposits borders the low alluvial terrace (Qal) from Hoover

Beach to the mouth of the Taguag River. A low coastal terrace composed of alluvium (Qal) borders the shoreline from the Taguag River to the rocky coast on the west side of Asan Point.

The Tamuning-Yigo fault zone forms a prominent scarp cliff from Trinchera Beach to Adelup Point (Figs. 6, 7e). Low terraces of unconsolidated beach material are deposited mostly upon the downfaulted platform of this zone. The fault scarp is interrupted by the Agana River and Agana Swamp. Alifan limestone (Tal) is exposed in the lower part of cliff scarp behind the city of Agana.

Soils

A complex group of soils and land types are present along this sector, particularly along the western part; where volcanic hills, alluvium, and several different limestones outcrop along the shore (Figs. llla, lllb).

Guam clay (Unit 1) is developed on detrital facies of the Mariana limestone plateau land which borders the eastern and northern parts of the sector.

Steep limestone rock land (Unit 13f) is found at Cabras Island, Adelup Point, the fault scarp behind Agana and Tamuning, and along the shoreline from Oca Point to Dungcas Beach.

The sandy Shioya soil (Unit 12) is developed on the beach terraces from Dungcas Beach to the Fonte River and from Adelup to Asan Points. Another stretch of this unit is found along the beach terrace at Hoover Park.

Pago clay (Unit 9) borders the shoreline at the Fonte and Matgue River mouths and is also developed on the shoreward part of the low terrace on the east side of Assn Point.

Inarajan clay (Unit 10) borders the alluvial terrace from the Taguag to the Matgue Rivers. It is also developed on the inner part of the alluvial terrace occupied by the village of Asan.

Yona clay (Unit 5) is found on the steep, argillaceous limestone ridge located on the west side of Asan Point. The limestone ridge immediately south of the Asan Point ridge is also part of this unit.

Alupat Island consists of steep rocky land (Unit 13f).

Engineering Aspects of Geology and Soils

The engineering aspects of geology and soils are mapped, described, and summarized in Fig. 12c and Tables 5 and 6.

Vegetation

The natural vegetation along the coastline of this sector is largely disturbed (Fig. 33c). The cliff facies at Oca Point, the steep slopes on the west side of Asan Point, and Alupat Island still retain plant communities somewhat resembling the natural vegetation found on the cliffs and steep-sloped coasts of Sectors III and IV.

Hydrology

Six rivers drain the argillaceous limestone land and volcanic highland along this sector (Figs. 10, 107a, 107b). The section of coast from the north side of Agana Swamp is bordered by nonargillaceous limestone plateau land and has no riverdrainage system.

The Agana River drains the hilly argillaceous limestone land and Agana Swamp. The present mouth of this river is on the east side of the Paseo de Susana Park. Before the park area was filled in, the river mouth and a section along the Agana boat basin channel were part of the same drainage system.

The Fonte River is developed partly upon hilly argillaceous limestone land and partly upon the volcanic highland region to the southwest.

The Asan, Matgue, Taguag, and Masso Rivers all originate in and drain the volcanic highland region to the south.

The coastal area along this sector lies within five different groundwater areas and subareas (Fig. 13). See Table 22 for gaging records of the Agana, Masso, and Fonte Rivers.

Beaches and Rocky Shorelines

Sandy beaches and alluvium predominate along this coast, rocky shorelines being restricted to Alupat Island, the north end of Tumon Bay, Adelup Point, the vest side of Asan Point, and the east end of Cabras Island (Figs. 112a, 112b). The causeway between Cabras Island and Hoover Beach is filled land and that shoreline consists mostly of rip-rap for stabilization along the seaward side. Paseo de Susana Park is also filled land, and the shoreline there consists of rip-rap along the east and west sides and of concrete and rip-rap along the seaward-facing point.

All the limestone shorelines have prominent sea-level nips cut at the bases, and usually a well-developed +6-foot nip is alto present. Large limestone blocks which have broken loose from the ridge on the west side of Asan Point are scattered along the adjacent reef-flat platform.

Emery (1964) analyzed beach samples from four locations along this sector (Fig. 17, Locations 1–4). The sandy beaches from Dungcas Beach to Anigua are composed of nearly 100 per cent bioclastic deposits of reef origin (Table 7, Location 4). The remaining beaches, from Anigua to Cabras Island, contain varying amounts of nonbioclastic deposits (Table 7, Locations 1–3). Beach deposits near river mouths which have drainage basins in or partly in the volcanic highlands contain high percentages of inorganic material. Beach deposits intervening between the rivers draining these volcanic highlands contain lower percentages of nonbioclastic material. Beaches bordering the alluvial deposits west of Asan Point have a high clay content and are soft and mucky in places, particularly after heavy rainfall.

Water seepage from the lens system is common along the beaches bordered by the limestone plateau land.

Reef and Other Subtidal Features

Intertidal Zone — Unconsolidated beach deposits make up most of the intertidal zone. Concave nips are cut in bases of the limestone cliffs and terraces which border the few rocky regions.

Fringing Reefs — Broad reef flats border the entire sector (Figs. 112a, 112b). Several channels cut completely or partially through the reef platform at places. The Agana Boat Channel runs from the Boat Basin along the west side of the Paseo de Susana Park to the sea (Fig. 109). Along the inner reef-flat zone, the channel averages about 6–8 feet in depth and then increases steadily to about 60 feet where it cuts through the reef-front zone. Another channel cuts partially through the reef platform at Asan Bay (Fig. 113). At Piti Bay the reef margin is cut with several partial channels, giving it a very irregular outer edge (Fig. 114). Tepungan Channel cuts completely through the inside of the reef platform between the east end of Cabras Island and Schroeder Junction. Before the causeway and Piti Power Plant were constructed, Tepungan Channel and Piti Channel were a single channel which connected the east end of Apra Lagoon with the Philippine Sea.

An inner-reef flat zone occurs along most of the fringing reef platforms of this sector. Impounded water in the moat is 1–3 feet deep during low tides, when the outer reef flat is often exposed. The moat floor is covered with sand and coralalgal rubble at most places. Thickets of "staghorn" *Acropora* are common in the sandyfloored parts of the moat. The outer, exposed reef-flat zone is floored with pavement-like reef limestone. Corals are generally absent except where shallow pools retain water. Boulder debris is common where the inner reef-flat and outer reefflat zones intergrade.

Following is a description of the reef-flat platform made by Tracey et al. (1964) along a traverse east of the Paseo de Susana Park (Figs. 112a, 115).

Reef margin (0–50 ft.) - The margin is exposed at low tide. It is composed mostly of algal rock whose surface is about one-third covered by living corals, such as *Pocillopora*, *Acropora*, and *Millepora*, and one-third by living encrusting algae, such as *Porolithon*. The remaining third of dead algal rock is covered by thick bunches of articulate coralline algae and large masses of green soft algae.

Reef flat (50–2,125 ft.) - For convenience, this reef flat is divided into three zones, which will be called the algal, coral, and sand zones.

The algal zone (50–325 ft.) is the highest part of the reef and appears to form a broad truncated rock pavement behind the reef margin. It is completely exposed at lowest tides. About 25 per cent of the surface is covered by smaller nodular patches of living red coralline algae, and the rest by green algae, including *Halimeda*, and pockets of gravel and abundant foraminiferal sand. Rubble and large blocks of coral are scattered over the inner part of the zone.

The coral zone (325–1,025 ft.) is depressed slightly below the outer reef flat and is covered by several inches of water at extreme low tide. The floor is a truncated rock pavement veneered in some places with foraminiferal sand. The dominant feature of the zone is the abundance of coral patches 6 in. to 1 ft. high, separated by depressed sandy areas. The outer 50 ft. is covered by large clusters chiefly of Pavona and staghorn *Acropora* 3 to 10 ft. in size, on a bottom of sand and packed coral gravel. The inner 400 ft. is covered by smaller and scattered clusters of *Acropora* on an increasingly sandy bottom.

The sand zone (1,025–2,125 ft.) is gradational from the preceding zone. Corals are small and scattered at the outer part of the zone, but they are absent near the shoreline. The dominant features of the zone are the thick sand cover over most of the area and the water depth of 1 to 1.5 ft. at extreme low tide. In effect, the zone is a moat between the coral zone and the shore. About 600 ft. from shore a shallow part of the zone is floored by rock covered thinly by sand or by a mat of clusters of rubbery soft corals. Spiny sea urchins are abundant, as are several kinds of holothurians. The zone continues to the sand beach.

Seaward of Tracey's reef-platform traverse, the reef front, submarine terrace, and seaward slope zones are very similar to those described for Tumon Bay (Sector V).

Between the Paseo de Susana Park and Adelup Point the reef-flat platform is similar in most respects to those just described on Tracey's reef traverse except for the sediment composition. Reef-flat sediments in the eastern half of this part of the sector are composed primarily of bioclastic deposits. Those on the western half are contaminated with nonbioclastic mud and other materials of nonreef origin derived from the Fonte River, which empties onto the reef flat near Adelup Point. *Enhalus acoroides* beds are present on the contaminated western half and absent from the eastern half (Fig. 116).

Figure 117 is a vertical profile through the fringing reef about 1,000 feet west of the Agana boat basin. The reef-flat zones along the profile are similar to those described above for the platform east of the Paseo de Susana Park. At the reef margin, a low convex algal ridge is developed. The inner part is an irregular surface of small knobs, ridges and pinnacles. The outer part consists of a surge-channel-and-buttress system. The surge channels are rather short and do not penetrate the margin to any great extent.

The reef front zone consists of a submarine-channel-and-buttress system constituting a seaward extension of the reef margin surge channels and buttresses. The point where these structures terminate marks the seaward boundary of the reef front zone. Alive coral region is located in the reef margin and inner reef-front zones.

A wide submarine terrace borders the reef front along this part of the sector. Most of the corals are dead on this terrace, but judging from the many intact coralla remaining, there was a rich and diverse assemblage of corals growing here before they were presumably killed by *A. planci*. The terrace surface is very irregular with knobs, mounds, and ridges of former coral development. Relief of these topographic features is usually less than 3–4 feet, but occasional knobs and mounds may have a relief of 10–15 feet.

The submarine terrace slope breaks abruptly at the seaward slope zone, forming a steep-to-vertical-walled scarp (Fig. 117). A second submarine terrace interrupts the steep seaward slope at 150–180 feet.

Between Asan and Adelup Points the reef-flat platform and inner reef-flat subzone are narrower, and the moat is shallower than in the Agana Bay section. Unconsolidated sediment accumulation is less, and the arborescent *Acropora* beds are replaced for the most part by microatolls of *Porites*. The offshore zones along Asan Bay are similar to those described along Agana and Tumon Bays. A strong, seaward-flowing rip current is usually present during high tide in the channel which partially cuts through the reef platform near Asan Point (Fig. 113).

Between Asan Point and Cabras Island the reef margin is very irregular and cut by several embayments. The reef flat east of Tepungan Channel contains many small and several large pools 10–25 feet deep. The largest pool is about 500 feet long. Offshore, the submarine terrace is extremely variable in width and surface topography. At places reef patches and pinnacles have a relief of 40 feet or more. Much of the submarine terrace floor is composed of unconsolidated sediments where embayments cut the reef margin.

Offshore Slopes — Emery (1962) made four offshore profiles along this sector (Figs. 28, 29, Nos. 4–7). Profiles 6 and 7 show a 55 foot-deep terrace. This terrace is also present at profiles 4 and 5, but finery's soundings were started too far from the reef edge to detect it. The 105-foot-deep terrace is present at profiles 4 and 5. The 315-foot-deep terrace is present in profile 5 and is probably present in profiles 6 and 7 but does not show up in the latter two because these profiles were terminated at depths shallower than 300 feet. Profile 4 shows a very steep average slope (38°) beyond the 105-foot-deep terrace.

Development and Use Patterns, Culturally Important Areas, and Unique Features

Most of the coastal region along this sector is an extensive urban area, largely occupied by the city of Agana and the villages of Tamuning, Asan, and Piti. The cliffline and steep slopes south of Oca Point, Alupat Island, the steep limestone ridge on the west side of Asan Point, and the east end of Cabras Island are the only areas not developed (Figs. 107a, 107b).

Route 1 follows much of this shoreline. The Government of Guam maintains parks between Route 1 and the shoreline along Trinchera Beach, along a stretch from the Agana Boat Basin to Anigua, and at a section west of Asan Point. Padre Palomo Park and a U. S. Naval Cemetery occupy a small sector of the beach east of the Agana River mouth. The largest park along the sector is the land-filled, former reef-flat area, now the Paseo de Susana peninsula.

The Government of Guam operates a small-boat harbor, the Agana Boat Basin, which has been dredged out of the inner reef-flat at the southwest corner of the Paseo de Susana Park (Fig. 118). The Agana Boat Channel runs along the west side of the Paseo from the boat basin to the reef margin and provides a passage for boats to the Philippine Sea.

Adelup Elementary School is located on Adelup Point (Fig. 110), and the U. S. Naval Hospital Annex occupies the east side of Asan Point. The reef flat immediately in front of the hospital has been altered somewhat into a swimming beach. A Filipino Patriot Monument is on the beach at the Hospital Annex. A U. S. Landing Monument stands on the beach at the head of Asan Bay east of the Hospital Annex (Fig. 108).

Hoover Park and USO Beach are located along the beach at Piti Bay. A causeway connects Cobras Island with Guam at Schroeder Junction, where Route 11 intersects Route 1. A canal borders the west side of the causeway and cuts through the east end of Cobras Island to bring seawater to the Piti Electric Power Plant facility. Tepungan Channel and the canal meet at the point where they enter the plant. Seawater from these two sources is used for condenser cooling in the power plant. Water, heated during this process, is then discharged into Apra Lagoon via the Piti Channel (Fig. 119).

The reef flats along this coastline and Agana Boat Channel are the most intensively fished regions of the island. It is common to see pole fishermen lined along the Paseo de Susana Park fishing in the Agana Channel. The depressed reef flat and small channel at the head of Asan Bay provide another popular pole-fishing area. Both gill-net and thrownet fishing are common sights on the wide reef flats. Entire families ran be seen at times working their gill nets. Some shell-fishing for clams is done in the sandy-floored parts of the reef flats, particularly at the north end of Agana Bay.

Sport diving and spear fishing are also popular along this sector. Ease of access and the variety of reef habitats available make the whole area a popular place for skin diving, sport diving with SCUBA equipment, and spear fishing. The deep reefflat holes and irregular reef-margin embayments at Piti Bay are one of the most popular SCUBA diving areas on the island.

The Agana sewer outfall crosses the wide fringing reef-flat about 1,000 feet west of the Agana Boat Basin (Fig. 107a).

Sector VIII

Physiography

Sector VIII includes all of Apra Harbor, the northern coast of Orote Peninsula, Cobras Island, and Glass Breakwater, which rests upon the shallow Luminao reef flat and submerged Calalan Bank (Figs. 35, 120). The region is roughly triangular, approximately 4.5 miles from Orote Island to Route 1.

Apra Harbor is a deep-water lagoon bounded on the north by the long, curving Glass Breakwater and Cabras Island, a narrow limestone island 1.7 miles long with a maximum elevation of slightly more than 60 feet. The southwest corner of Cabras Island is altered considerably by land filling and docking facilities. The Glass Breakwater (Fig. 124) is built upon a shallow reef-flat platform, Luminao Reef and a submerged coral bank, Calalan Bank. Luminao Reef itself extends 1.6 miles from Cabras Island, the upper surface about the same elevation as the fringing-reef platforms along the main part of the island. The Calalan Bank trends from the western tip of Luminao Reef to the deep Apra Harbor channel at the tip of Orote Peninsula. The bank is about 1.2 miles long, and if the breakwater structure is disregarded, the upper surface of the bank is about 20 feet deep.

The eastern part of the lagoon is bordered by volcanic mountain land, hilly dissected limestone land, and along the shore by alluvial coastal lowland (Fig. 9). This shoreline has been extensively modified by construction and land-filling activities; the long peninsula south of Piti Channel, Polaris Point, and a section north of Abo Cove have all been created by land fill (Fig. 7c): Shallow reef flats, holes, and patch reefs occur between Polaris Point and Piti Channel. The inner harbor has been extensively altered by dredging, construction, and landfills (Figs. 120, 121).

The southern part of the lagoon is bordered by the limestone plateau land of Orote Peninsula, the low-lying eastern end of which has been altered by land fills and construction activities. Orote Island, at the tip of Orote Point, has an elevation of more than 140 feet. The coast from Orote to Adotgan Points is a sheer cliff about 200 feet high. The remainder of the plateau land between Adotgan and San Luis Points forms steep slopes and cliffs along the lagoon coast. The upper margin of the plateau land along this stretch ranges in elevation from 200 feet at Adotgan Point to 100 feet at San Luis Point. The harbor entrance at Orote Point is the only opening to the sea from the lagoon. Piti and Tepungan Channels at the east end of the lagoon, at one time provided a natural channel to the sea but have since been separated by the causeway between Cabras Island and Hoover Beach (Fig. 122).

Five rivers which drain the adjacent volcanic mountain land empty into the lagoon along the east side, and small indentations occur along the eastern coastline of the lagoon at the mouth of the Laguas River and at the Abo Cove.

Geology

Cabras Island, Orote Island, and Orote Peninsula are reef facies (QTmr) of the Mariana limestone formation. Faults have displaced several sections of the limestone cliff at Orote Point, forming Orote Island and a low platform along the base of the cliffline between Orote and Adotgan Points.

Much of the shoreline around Apra Lagoon is artificially filled land (Qaf), including Glass Breakwater, the site of Commercial Port facilities at the southwest corner and the disturbed seaward side of Cabras Island, the peninsula south of Piti Channel, Polaris Point, a section of coast north of Abo Cove, and extensive region bordering the west side of the inner harbor, and the eastern end of Orote Peninsula, which borders the outer harbor (Fig. 7c).

Alluvium (Qal) borders the entire eastern shoreline except where landfills have been made and where there is a small band of beach deposits along the Piti Channel area.

Alifan limestone (Tal) borders the shoreline along the south side of Abo Cove and at Gabgab Beach.

Beach deposits form a narrow band between Orote Island and the down-faulted platform at Orote Point.

Soils

Five soil types, two miscellaneous land types, and a variable unit, including the artificially made land, comprise the soils bordering this sector (Fig. 123).

Guam clay (Unit 1) occurs on the limestone plateau land on Orote Point. Gently sloping limestone rock land (Unit 13b) borders the plateau cliff margin from Orote Point to Adotgan Point. Steeply sloping limestone rock land (Unit 13f) makes up Orote Island, the steep coastal land from Orote Point to San Luis Point, and Cabras Island.

Artificially made land (Unit 14) makes up the filled land around the inner harbor area, the Glass Breakwater, the commercial dock area along the southwest side of Cabras Island, and the long peninsulas south of Piti Channel.

Chacha and Saipan clays (Unit 4) are developed on the argillaceous limestones along the southern shoreline of the inner harbor.

Muck (Unit 11) and Inarajan clay (Unit 10) occur along most of the east side of the lagoon except for the filled land areas. Shioya soil (Unit 12) is developed on the narrow strips of beach deposits which border the shoreline along the Piti Channel and Hoover Beach region.

Engineering Aspects of Geology and Soils

The engineering aspects of geology and soils are described, summarized, and mapped in Fig. 12c and Tables 5 and 6.

Vegetation Zones

The vegetation units (zones) along this sector are mapped in Fig. 33c.

Hydrology

Five rivers drain the volcanic mountain land to the east of Apra Harbor and empty into the lagoon along the eastern border (Fig. 120). Three of them—the Sasa, Laguas, and Aguada—empty into the outer harbor, and two—the Apalacha and Atantano—empty into the inner harbor. Orote peninsula consists of porous limestone, and no streams exist upon its surface (Fig. 10).

Small swampy estuaries are located at the mouths of these rivers, the most extensive being at the mouth of the Atantano River. Mangrove swamps are found at all the river mouths (Fig. 125) and are particularly well developed at the estuaries and adjacent coastal regions at the Sasa and Atantano River mouths (Fig. I28). A unique mangrove swamp is located on the south side of the Atantano River mouth, where a nearly pure stand of *Avicennia alba* dominates the region.

Ground water subarea 5b borders the eastern side of the sector, and the limestone plateau land of Orote Peninsula consists of groundwater subarea 5a (Fig. 13). See Table 22 for gaging records of the Atantano River.

Beaches and Rocky Shorelines

The shoreline has been greatly disturbed along the northern border of the lagoon. Glass Breakwater is constructed of large limestone blocks and smaller-sized rip-rap through which dye-charged water passes freely. Most of the lagoon side of Cabras Island consists of Commercial Port facilities or has been greatly altered by other construction activities. Much of the shoreline along the seaward side of Cabras Island has been altered by quarrying. A natural rocky shore is found along the eastern tip of Cabras Island. A causeway connects Cabras Island and Guam at the northeast corner of the lagoon (Fig. 122). Local patches of beachlike deposits occur at several places along the lagoonward eastern half of the breakwater (Fig. 125).

The lagoon's eastern border has a strip of beach deposits north and south of the Piti Power Plant, most of which have been disturbed by various construction activities. A network of causeway-jetties and man-made islands occupies the region between Cabras Island and Dry Dock Island peninsula. Alluvium and mangrove swamps border most of the remaining shoreline along the east side (Figs. 126, 127), except for the land-filled areas at Polaris Point and a section north of Abo Cove.

The shore along the west side of the inner harbor is occupied by port facilities of the U. S. Navy (Fig. 121), as is the shore east of San Luis Point. Some natural rocky shoreline is found at Orote Island and from Orote Point east to San Luis Point. At Orote Point and Orote Island, sea-level benches are cut into the more exposed rocky coasts. Nips are common in this region. Some beach deposits are found along the down-faulted section of limestone between Orote Island and the high cliffs of Orote Point.

Reefs and Other Subtidal Features

The seaward side of Cabras Island is bordered by a narrow fringing-reef platform, on the reef margin and reef front zones of which is developed a prominent spur-and-groove system. The Luminao Barrier Reef extends west of Cabras Island (Fig. 124), forming a wide, shallow reef also cut by a groove-and-spur system; in places, considerable reef-building is apparently taking place. The submerged Callalan Bank extends southwest from the west end of Luminao Reef, its upper surface submerged to depths of 15–25 feet. Glass Breakwater is built partly upon this submerged bank and partly upon the southern edge of the Luminao reef-flat platform (Fig. 125). The lagoon side of Luminao Reef and Cabras Island has for the most part been altered by dredging, filling, and construction, prior to which Piti and Tepungan Channels were connected and formed a natural outlet at the northeast corner of Apra Lagoon (Fig. 122). A well-developed 20–50 foot submarine terrace is generally present on both the lagoon and seaward sides of the northern Cabras Island-Luminao Reef-Callalan Bank border of Apra Lagoon.

The eastern side of Apra Lagoon consists of two extensive land-filled peninsulas, a complex fringing reef, and extensive dredged areas. Along the northern half is a greatly altered, shallow reef-flat platform upon which the Dry Dock Island Peninsula was largely built (Figs. 122–126). South of Dry Dock Island Peninsula to Polaris Point, the fringing reef platform is very irregular and consists of a complex of holes and coral patch reefs and ridges (Figs. 125, 126), the general relief of which ranges from 5 to 50 feet. Much of the coral in this area is dead because of dredging and construction activities. Polaris Point is an extensive area, filled onto what was probably a southern extension of the above-described fringing reef complex.

Inner Apra Harbor is occupied mostly by the U. S. Naval Port facilities (Fig. 121) and has been extensively dredged and otherwise altered by construction. The only portion not so changed is the mangrove area at the mouth of the Atantano River (Fig. 128). SCUBA diving in the inner harbor revealed some living *Pocillopora* and *Porites* corals on the wharf and dock structures.

The south side of Apra Lagoon is bounded by Orote Peninsula. A fringing reef platform borders the entire shoreline except at the land-filled eastern end (Fig. 125). The reef-flat platform is widest on the down-faulted platform at Orote Island. A well-developed reef front extends from the east end of Orote Island to Adotgan Point, where wave assault is high at the mouth of the Apra Harbor Channel. Since the construction of Glass Breakwater, the remainder of the fringing reef east of Adotgan Point receives considerably less wave and swell action. The 55-foot deep submarine terrace is narrow and intermittent along this section, and shallower terraces 15–30 feet deep occur here and there.

The lagoon slope is steep and well pronounced except where the perimeter has been disturbed by dredging or filling. In general, the steep slope levels out onto the lagoon floor at 100–125 feet in the outer harbor, the deep area being bounded by the Callalan Bank on the west, Luminao Reef on the north, Orote fringing reef on the south, and by a series of patch reefs known as Western Shoals and Jade Shoals on the east (Fig. 125). The lagoon floor in this region averages deeper than 100 feet, maximum depth being in excess of 160 feet at the western end near the deep Apra Harbor Channel. The depth in the channel itself is slightly less than the maximum lagoon depth.

Coral growth and development are rich and varied where the lagoon has not been disturbed by dredging or filling, especially along the Orote Peninsula fringing reefs. The only records of several species of corals are from outer Apra Harbor lagoon. Extensive beds of solitary fungiid corals are found on the lagoon slope and floor along Callalan Bank and Luminao Reef. Some patch reefs have been dredged to depths safe for shipping, and coral growth has been reduced, but deep-water species are still abundant on the rubble slopes. Coral growth is also well developed and diverse on the shoal patch reef located at the eastern end of the outer harbor.

On the seaward side of Callalan Bank, Luminao Reef, and Cabras Island, most of the corals have been killed by *Acanthaster planci* predation (Figs. 30, 31, 32). A narrow band of living corals has survived in the reef margin and inner reef-front zones.

Development and Use Patterns, Culturally Important Areas, and Unique Features

This entire sector lies within the boundary of the Apra Harbor Naval Reservation (Fig. 1). Most of the shoreline has been developed by the U. S.

Navy on the south and east sides of the lagoon and by the U. S. Navy, Government of Guam, and commercial enterprise on the north side.

The Piti Power Plant is located at Schroeder Junction. Another power plant is under construction on Cabras Island directly across Piti Channel from the first facility. The Cabras Island Plant will, when completed, (the Piti Power Plant already does) draw cooling water from the Philippine Sea via the Tepungan Channel and Piti Canal. Tepungan Channel was recently enlarged to handle the greater volume of cooling water to be needed for the Cabras Island facility. Piti Canal has been cut through the east end of Cabras Island and is channelized alongside the causeway between Cabras Island and Guam, to the Piti Power Plant.

The west end of Cabras Island is the site of the Government of Guam Commercial Port and various other commercial enterprises. Glass Breakwater extends westward from the west end of Cabras Island, and on the lagoon side are the sites of the U. S. Navy Ammunition Wharf, Mobil Fueling Pier, and various other pier facilities. An abandoned seaplane ramp is located at the east end of Glass Breakwater (Pier C) and is presently being used by the public as a boat-launching facility. The Marianas Yacht Club is located in a small embayment between the seaplane ramp and the west end of Cabras Island (Fig. 120). Highway 11 traverses the length of Cabras Island, and an unimproved roadway continues on to the western end of Glass Breakwater. The seaward side of Cabras Island is greatly disturbed by quarrying. The only part of the island not extensively developed and disturbed is the eastern tip, beyond the Piti Canal cut (see Fig. 122).

Between Piti Channel and Dry Dock Peninsula, a shallow-water area is partially enclosed by a series of causeways and small elongated islets. Dry Dock Peninsula is developed extensively on the west end, but much of the shoreline along the remainder of the landfill is occupied by shrub vegetation on the north side and by mangroves on the south side. Mangrove vegetation continues southward along the coast from Dry Dock Peninsula to Polaris Point, where it trends westward. The western end of Polaris Point is extensively developed by the U. S. Navy, but on the south side mangrove vegetation again becomes prevalent along the coast to Wharf X (Figs. 120, 127). A few mangroves grow along the shore at Abo Cove. Route 1 runs somewhat inland along the east side of the lagoon, except at the mouth of Laguas River and Abo Cove. The alluvial coastal lowland between the highway and shore along this region is, for the most part, swampy and marshy. Where rivers cross the alluvial lowland, these wetlands extend farther inland and in some cases lie east of Route 1. The estuaries formed by rivers which empty into the lagoon along the east side are small and shallow, and eels (*Anguilla marmorata*) are caught in some of them. Land crabs are also trapped in the mangrove swamps bordering this area. The west side of the inner harbor is occupied by wharves and the Ship Repair Facilities of the U. S. Navy (Figs. 121). Orote Peninsula occupies the south side of the outer harbor and is extensively developed along the eastern half by the U. S. Navy. Fort Santa Cruz Site is located at the eastern end of the peninsula along the channel between the inner and outer harbors (Fig. 120). Several small-boat channels and an enclosed salt-water pond extend inland along this region at Sumay. Sumay Cemetery and Japanese Caves are located near the head of the above larger boat channel. A Navy beach and picnic area is located at Gabgab Beach (Fig. 120). The shoreline from Gabgab Beach to Orote Point is relatively undeveloped, including a sandy beach on the down-faulted platform between Adotgan Point and Orote Island. The Fort Santiago Site is located in the upper plateau land at Adotgan Point.

The outer harbor has several sunken ships which are favorite places for SCUBA divers to investigate. The scuttled *S.M.S. Cormoran* and the torpedoed *M. V. Tokai Maru* lie within a few tens of feet of each other at the edge of the slope lagoonward of the seaplane ramp on Glass Breakwater (Ward, 1970). Several other vessels are sunk alongside Glass Breakwater on the Callalan Bank.

Apra Harbor is a deep-water lagoon which, even though greatly altered by construction and dredging, contains a rich and diverse biocoenosis of reef corals and associated species. The rare reef coral genus *Pectinia* is found in Apra Harbor only in deep waters. *Tubastraea* is another rather rare coral in Guam and is found in greatest abundance in the reduced-light habitats of the deep lagoon area.

Sector IX

Physiography

This sector, located along the seaward coast of Orote Peninsula, extends from Orote Island southwest to Neye Island (Fig. 129) and consists of sea cliffs except for a small section at Tipalao Bay. This stretch of coastline is unique and is found at no other place on Guam, for the cliffs lack a fringing reef platform or a cut sea-level bench.

Figure 130 is an aerial view taken from the southwest which shows the overall physiography. Orote Peninsula is a limestone plateau which is tilted to the east (Fig. 6). This tilt probably occurred at least partly because of hinge movement along the Cabras Fault Zone (Tracey et al., 1964). Structurally, this fault separates the Orote block from the Tenjo block to the east.

The sea-cliff face is steep-sloped to vertical and at places is overhanging. The frequent large joints and fractures have been eroded into wider open cracks and chutes (Fig. 131). Occasional large blocks have spalled from the cliff face, and the over-all appearance is irregular and blocky. The limestone surface is smooth and compact on the vertical and overhanging cliff faces where secondary deposition of calcite has occurred. On the steeply inclined faces, the limestone surface is solution pitted and eroded into irregular pinnacles and sharp crests.

The cliff margin continues relatively uninterrupted from Orote Point to a low notch about 3,500 feet north of Apuntua Point (Fig. 132). The cliffline continues south of this low region to Tipalao Bay, where a small beach interrupts it (Fig. 133). A small limestone peninsula and a rocky islet, Neye Island, border the south side of Tipalao Bay (Fig. 134).

The cliffline margin slopes to the southeast from slightly higher than 200 feet at Orote Point to about 40 feet at the low notch north of Apuntua Point. From the notch southward, the cliffline increases again in elevation to 151 feet at Apuntua Point itself. Neye Island and the north side of Tipalao Bay are both about 60 feet high.

Geology

The entire coastline of this sector, including Neye Island, is composed of Mariana limestone reef facies (QTmr), except for a small region of unconsolidated beach deposits (Qrb) located at the head of Tipalao Bay (Fig. 7c).

A narrow down-faulted platform separates Orote Island from Orote Point at the Apra Harbor Channel. The strikes of prominent joint zones along the cliffline are shown in Fig. 7c.

Soils

Two soil types and two miscellaneous land types are found in this sector (Fig. 135).

Guam clay (Unit 1) forms a thin rocky soil along the coast at the low notch north of Apuntua Point. It is also found along the coast on the north side of Tipalao Bay.

Steep limestone rock land (Unit 13f) borders the south side of Tipalao Bay, Neye Island, a broad section north and south of Apuntua Point, and a narrow band from the low notch area to Orote Point. The band of plateau land bordering the cliffline from Orote Point southeastward to the low notch area is gently sloping limestone rock land (Unit 13b).

Sandy Shioya soil (Unit 12) is developed on the unconsolidated beach deposits at the head of Tipalao Bay.

Engineering Aspects of Geology and Soils

The engineering aspects of geology are mapped, described, and summarized in Fig. 12c and Tables 5 and 6.

Vegetation Zones

The vegetation units (zones) in this sector are mapped in Fig. 33c.

Hydrology

There are no streams developed on the limestone plateau land of Orote Peninsula (Fig. 10). The limestone is porous, and the water percolates downward to the zone of saturation near sea level. Fresh water escapes along the rocky shoreline, particularly in the zones of joints and fractures.

This sector lies completely within ground-water subarea 5a (Fig. 13).

Beaches and Rocky Shorelines

The entire shoreline of this sector consists of irregular rocky cliffs, except for a small stretch of beach deposits at the head of Tipalao Bay (Figs. 7c, 136). A prominent sea-level nip is cut at the base of the cliff in most places, except where large blocks have been recently wedged out by erosion (Fig. 131). Many sea-level joints and fractures in the cliff face have been widened by erosion into open cracks and fissures. At some places the intertidal zone has been honeycombed by solution where fresh water escapes from the porous limestone plateau land of Orote Peninsula.

There is a general absence of a cut-bench platform along this sector. Possibly, structural movements of the Orote block (Fig. 6) postdate the northern limestone block movement, and sufficient time has not elapsed for a bench to develop. A large seacave is found in the cliff face just north of Tipalao Bay (Fig. 133).

Unconsolidated beach deposits and beach rock border the shoreline at Tipalao Beach (Fig. 136). Figure 17 shows the location of a beach sample collected by Emery (1962) in this sector, and Table 7 gives the characteristics of the sample.

Reefs and Other Subtidal Features

No fringing reefs border this sector except for a small platform which has developed across Tipalao Bay (Fig. 133). The submarine zone consists of steep to precipitous slopes which generally flatten out, forming terraces, at 60–105 feet deep. Large angular blocks which have broken loose from the cliff face are scattered along this terrace. Some of these blocks have a relief of more than 50 feet.

The rocky slopes are covered with widely scattered coral colonies, most of which are small. There are very few coral-growth developmental features, such as ridges, knobs, and pinnacles. *Pocillopora* species dominate the wave-agitated upper part of the slope, and a more diverse community of corals occupies the deep parts of the slope and 105-foot terrace. Soft corals and crinoids are locally abundant on the large blocks which have come to rest on this terrace. A short algal turf covers much of the lower slope surface, whereas encrusting reef algae are more common on the upper slope surfaces where small submarine caves, holes, and cracks are also found. These habitats of reduced light are particularly rich with encrusting calcareous algae.

A large deep hole called the "Blue Hole" opens up on the 60-foot terrace (Fig. 129). This shaft is continuous to the 250-foot level, where it opens outward onto a steep slope.

Emery (1962) shows two offshore profiles in this sector (Figs. 28, 29, Nos. 1, 40). Profile No. 1 shows the 315-foot terrace at Orote Point, Profile No. 40, the 105- and 315-foot terraces at Neye Island.

Development and Use Patterns, Culturally Important Areas, and Unique Features

The coastal land of this sector lies within the U. S. Naval Apra Harbor Reservation (Fig. 1). The steep cliff faces and steep slopes are for the most part inaccessible.

The Navy has some cables which enter the water at Apuntua Point. This is a former garbage disposal site. The low cliff area north of Apuntua Point is the site of a solid-waste dump (Fig. 132), and a considerable amount of scrap metal and concrete and rock rubble have accumulated on the submarine slope at this location. North Tipalao and South Tipalao Naval dependent housing borders the plateau land around Tipalao Bay. An abandoned airfield is a conspicuous feature of the Orote Peninsula from the air. The U. S. Coast Guard LORAN station is located on the western tip of Orote Peninsula (Figs. 129, 130). A sewer outfall empties onto the rocky shoreline at the north side of Tipalao Bay.

<u>Sector X</u>

Physiography

This 10-mile sector borders the southwest coast of Guam between Orote Peninsula and Cocos Barrier Reef (Figs. 137a, 137b). The coastline consists mainly of the steep mountainous land of southern Guam, drained by many rivers which carry fresh water and silt to the fringing reef platforms (Figs. 9, 10). The coastline is irregularly cut by projecting points of land and by river embayments. At most places, the coast is fringed by limestone reef-flat or truncated volcanic-rock platforms.

Eight limestone islets are scattered along the coast from Orote Peninsula to Facpi Point. All except Anae Island are located on the surface of the shallow, fringing reef-flat platforms. The shoreline here is bordered by low isolated patches of limestone, unconsolidated beach deposits, low coastal alluvial land, and, near Facpi Point, by steep-sloped volcanic mountain land. A low coastal plain bounds the area from Dadi to Taelayag Beaches.

From Taelayag Beach to Cocos Barrier Reef the coast is bordered by steep-sloped, greatly dissected, weathered mountain land, by rocky volcanic headlands, and by isolated patches of alluvium and beach deposits at the heads of bays. A low narrow band of emergent limestone is found at most of the shoreline along these features of the southern half of the sector.

General elevations along the coast are +60 feet at Neye Island, 20 feet at Orote Peninsula, less than 20 feet along the low coastal plain from Dadi to Taelayag Beaches, +20 feet at Alutom Island, +40 feet at Anae and Facpi Islands, 215 feet at Facpi Point, 200 feet at Achugao Point, 160 feet at Chii Point, 200 feet at Pinay Point, 288 feet at Fouha Point, 247 feet at Chalan Anite Point, 77 feet at Lalas Rock pinnacle, 127 feet at Fort San Jose Ruins, 146 feet at Fort Soledad Ruins, 209 at Mamatgun Point, less than 20 feet along the Bile Bay coastal plain, and less than 20 feet at the mouths of the alluvial valley floors where the Sagua, Asmafines, Sella, Cetti, La Sa Fua, Umatac, and Toguan Rivers reach the coast.

The entire sector is fringed by reef-flat platforms ranging from 2,600 feet wide near Bangi Point to less than 100 feet wide at truncated volcanic headlands along the southern half of the sector (Figs. 138a, 138b). In general the reef-flat platforms are wider along the low coastal plain from Dadi to Taelayag Beach on the east side of Anae Island. Channels cut completely or partially through the fringing reef platforms at the mouths of some of the larger rivers, particularly along the southern half of the sector.

The coastline forms prominent embayments at Agat, Sella, Cetti, Fouha, Umatac, Toguan, and Bile Bays. The reef-flat margin forms small embayments in the fringing reef platforms at the village of Agat, Chalingan Creek, Nimitz Beach Park, and Taleyfac River.

This coastline is well protected from the easterly trade winds by Orote Point on the north and by Cocos Barrier Reef on the south. Except for rare periods when the winds or swells are westerly, this section of Guam's coast receives less wave assault than any other.

Geology

Limestone borders the northern end of the sector and is found at several isolated stretches between Bangi and Apaca Points (Figs. 7c, 7d). The reef-flat islets and offshore Anae Island are also composed of limestone. Limestone of the Agana argillaceous member of the Mariana formation (QTma) borders small sections of coastline near Dadi Beach and Gaan Point. The small reef-flat islets and offshore Anae Island between Apaca and Facpi Points are also composed of Agana argillaceous limestone.

Alifan limestone (Tal) borders a three-quarter-mile section along Togcha Beach and Apaca Point.

Isolated narrow bands of low-lying limestone, generally less than three feet high, are mapped as Merizo limestone (Qrm) along the coast from Taelayag Beach to the Cocos Barrier Reef. A narrow, low-lying band of unmapped solution-pitted limestone also borders the shoreline in much of this region. It is similar in all respects to Merizo limestone and probably should be considered equivalent.

Except for isolated stretches of limestone, the coastline between Taelayag and Dadi Beaches is predominantly bordered by beach deposits (Qrb) and alluvium (Qal). Other sections of coastline bordered by narrow bands of beach deposits and alluvium are located north and south of Facpi Point, Sella Bay, Pinay Point, the north shore and head of Cetti Bay, Fouha Bay, the head and south side of Umatac Bay to Toguan Bay, and along most of Bile Bay.

Unweathered, dark basaltic rock and red-colored clay derived from weathered volcanic rock of the Umatac formation border the coastline from Taelayag Beach south to the Cocos Barrier Reef. In much of this area, the inner parts of the fringing reef-flat platforms are composed of dark basalt which has been truncated to mean low sea level (Fig. 7d). The outer parts of these basalt platforms are veneered in most places by recent deposits of reef limestone. At places the volcanic rocks and weathered clay slopes border the shoreline, and at other places beach deposits and alluvium thinly veneer the volcanic rocks.

Soils

Two soil types (Units 1 and 4) and one steep rocky land type (Unit 13f) have developed on the limestone rock which borders the northern part of the sector. Three soil types (Units 9, 10, 12) occur upon the alluvial and beach deposits which border various parts of the entire sector. Three other soil types (Units 6, 7, 8) are developed upon volcanic rocks bordering the shoreline along the southern half of the sector and the inland slopes along the northern half (see Figs. 139x, 139b, and Tables 5 and 6).

Guam clay (Unit 1) appears on the limestone plateau land of Orote Peninsula at the northern end of the sector. Steeply sloping limestone rock land (Unit 13f) makes up Neye Island and the cliffs bordering the shoreline of Orote Peninsula. Chacha and Saipan clay (Unit 4) is developed on the argillaceous Alifan and Mariana limestones located south of Apaca and Gaan Points, respectively.

Pago clay (Unit 9) exists on the alluvial valley deposits at the mouth of the Sagua, Asmafines, Sella, and Umatac Rivers and on the low-lying coastal alluvium from Machadgan Point to Cocos Barrier Reef. Inarajan clay (Unit 10) occurs on the inner part of the alluvial coastal plain from the Namo River south to Taelayag Beach. It is found also on the alluvial valley deposits at the mouth of the Cetti and La Sa Fua Rivers. Shioya soil (Unit 12) is developed on the beach and on alluvial deposits along the shoreline from Dadi Beach to Nimitz Beach Park except for a small section of Chacha and Saipan clay south of Gaan Point. A small patch of Shioya soil is located along the shoreline north of Facpi Point and along the beach on the north side of Fouha Bay.

Atate clay (Unit 6) is found on the volcanic slopes bordering the alluvial coastal plain in the northern part of the sector and on the high volcanic ridgetops and gently sloping land south of Umatac Bay and the Toguan and Pigua Rivers in the southern part. Agat and Asan clays of Unit 7 are developed on the volcanic hilly upland land, and a variant of these (Unit 8) appears on the steep, dissected mountain land along the southern part of the sector from Taelayag Beach to Cocos Barrier Reef.

Engineering Aspects of Geology and Soils

The engineering aspects of geology are mapped, described, and summarized in Figs. 12c, 12d, and Tables 5 and 6.

Vegetation Zones

The vegetation zones along this sector are mapped on Figs. 33c, 33d.

Hydrology

Numerous short streams and tributaries ending in 21 stream mouths drain the steep volcanic slopes on the western side of the southern Guam coastal mountain ridge (Figs. 10, 138a, 138b). Streams are absent along that part of the sector bordering the limestone plateau land of Orote Peninsula. Most of these short rivers have steep gradients to the sea and lack well-defined estuaries.

Gaging and other discharge-measurement stations are or were located on many rivers and streams along this sector (see Figs. 137a, 137b). Tables 18, 19, 20, 21, and 22 give a summary of the gaging and other discharge records for the rivers and streams. These tables were taken from Ward and Brookhart (1962) and the Geologic Survey Water Supply Paper 1937 (1971), which provide more detailed records (see fables 18, 19, 20, 21, 22).

The northern part of this sector, bordered by limestone plateau land, is in the groundwater subarea 5a, and the alluvial coastal region from Apaca Point south to a point midway between Bangi Point and Nimitz Beach Park is in subarea 5b. The remainder of the coastal region is within the volcanic mountain land subarea 6a (Fig. 13).

Beaches and Rocky Shorelines

Beach deposits dominate the shoreline from Dadi to Taelayag Beaches (Fig. 138a). Beach samples collected and analyzed by Emery (1962) at four locations (Fig. 17, Stations 52–55; Tables 7, 8) along this part of the sector have a nonbioclastic fraction ranging from 2 to 39 per cent. Samples collected from the close proximity of river mouths contain the highest fractions of nonbioclastic volcanic material, 20 to 39 per cent; those collected some distance from river mouths range from 2 to 8 per cent.

Other beach deposits are located along the shoreline at Sagua Beach, from Facpi Point to Achugao Point, at the head of Sella Bay, from Pinay Point to a rocky headland along the north side of Cetti Bay, at the head of Cetti Bay, at Chalan Point, and at the head of Fouha Bay (Figs. 138x, 138b). Beach samples collected at Cetti and Fouha Bays have nonbioclastic fractions of 11 and 74 per cent, respectively (Emery, 1962; see Fig. 17, Stations 49, 50; Table 7).

Alluvial deposits border the shoreline between Finile Creek and the Gaan River, the southern part of Taelayag Beach, at the mouths of the Sagua and Asmafines Rivers, the south side of Umatac Bay, between Machadgan and Mamatgun Points, along the north side of Toguan Bay, and along Bile Bay Figs. 7c, 7d). Emery's (1962) four samples (Fig. 17, Stations 45–48; Table 7) range in nonbioclastic composition from 6 to 91 per cent.

The rocky shorelines are composed of limestone along Orote Peninsula, at Apaca Point, at a short section south of Gaan Point, and along the shorelines of all the reef-flat and offshore islets between Tipalao Bay and Facpi Point. Volcanic rocks form rocky shorelines between Taelayag Beach and the Sagua River, at Facpi Point, from Achugao Point to Chalan Anite Point, along the south side of Fouha Bay to the head of Umatac Bay, at Machadgan, Mamatgun Points, and along a short section south of the Toguan River (see Figs. 138a, 138b). At places narrow bands of Merizo limestone border the seaward edge of the beach and alluvial deposits from Sagua Beach south to Mamaon Channel.

Reefs and Other Subtidal Features

Intertidal Zone — From Orote Peninsula to Taelayag Beach, the intertidal area consists mostly of unconsolidated beach or alluvial deposits. A few rocky zones are found where limestone borders the shoreline (Figs. 138a, 138b, 140).

Rocky shorelines are more common from Taelayag Beach to Cocos Barrier Reef (Fig. 141). At Achugao and Fouha Points, elevated bench-like platforms are cut into volcanic rocks. Low-lying narrow bands of limestone border much of the intertidal shoreline along the southern part of the sector. The band is solution-pitted and dissected into pinnacles and ridges, usually less than three feet above the general level of the bordering reef-flat platform (Fig. 142). An almost continuous band of this limestone borders the sector from Umatac Bay to Bile Bay. Other isolated stretches occur intermittently between Sagua Beach and Umatac Bay.

Fringing reefs — The fringing reef platforms north of Taelayag Beach are composed entirely of reef limestone and are considerably wider than those to the south. From Sagua Beach to Cocos Barrier Reef, the fringing reefs are for the most part truncated basalt platforms with outer fringes of limestone. Here and there limestone completely veneers the volcanic platform, and at a few places the entire platform is composed of truncated volcanic rock (Fig. 143). Basaltic inliers protrude through the limestone at places, and near river mouths rounded volcanic boulders are incorporated into the limestone matrix.

Numerous rivers transport silt, mud, sand, gravel, and other organic debris to the fringing reef platforms and inshore water mass along this sector. The reef platforms are cut partially to completely through by channels on the north side of Nimitz Beach and at the mouths of the Taleyfac, Madofan, Asmafines, Sella, Cetti, La Sa Fua, Umatac, and Toguan Rivers (Figs. 138a, 138b). Regardless of the periodic discharge of silt-laden fresh water at these river mouths, rich and diversified coral communities grow on the outer channel margins, walls, reef margin, and in the reef front zones. Coral communities which have developed in and adjacent to river channels are obviously adjusted to the periodic influx of silt and fresh water.

Much of the reef-flat platform is exposed during low tide. The reef margin usually lacks any algal ridge development but is at places regularly cut by short surge channels. Where the platform consists entirely of volcanic rock, the margin is cut by irregular cracks and fissures. Here and there are large re-entry channels which appear to be erosion features. The reef margin and reef front zones are particularly irregular along a half-mile section immediately north of the Nimitz Beach Park Channel because of re-entry channels and large sand-floored holes.

Basaltic sea stacks occur on the fringing reef platforms at Sella and Fouha Bays (Figs. 144, 145). The stack at Fouha Bay, Lalas Rock, is 77 feet high. Numerous dikes cut the basaltic platforms from Sagua Beach to Mamatgun Point. At places, the dikes are truncated to the same level as the reef platform, but at other sites they stand up in relief from a few inches to 5–6 feet. A swarm of dikes is found at Facpi Point (Fig.

Reef development is intermittent and inconsistent along this sector. At places, the reef front and shallow submarine terrace zones show considerable evidence of reef growth and development, and at other places, these zones represent old erosion surfaces with a coral community type of development.

A prominent submarine terrace borders most of the fringing reef platforms. The depth of the inner part of the terrace is variable and ranges from less than 10 feet to 2530 feet. At some places, the outer edge of the terrace breaks sharply at the seaward slope zone 20–60 feet deep, and at other places, it gradually slopes seaward to depths of 150 feet or more.

At Agat Bay, the submarine terrace is wider than 3,000 feet in spots and consists of extensive sand-floored areas with intermittent, irregular rocky zones. Several small patch reefs extend to the low-tide surface opposite the reef margin at Dadi Beach. The reef margin and reef front zones near these patch reefs consist of rich coral growth. The submarine buttress-and-channel development along the reef front zone contains a margin of coral pinnacles, knobs, and bosses. Of particular note in this region are large colonies of the "blue coral," *Heliopora coerulea*, and many rounded, pink-colored clumps of a ramose coralline alga up to several feet in diameter.

From Rizal Beach to the south side of Agat Village, the reef margin and reef front zones show little growth and development. Live coral zones are scattered and patchy, the most conspicuous being large and variably-colored ramose *Pocillopora* colonies, many 3 feet in diameter. The submarine terrace in this region has extensive sand-floored areas. Several prominent rocky submarine mounds are located on the terrace offshore from the Pelagi Islets.

From Agat Village south to a re-entry channel a half-mile north of the Nimitz Beach Park, the reef margin and reef front zones show good coral growth and evidence of considerable reef development. The submarine terrace is narrower here, and, in contrast to the reef front and margin zones, lacks good developmental features such as coral mounds and pinnacles. It is nevertheless well covered by encrusting *Montipora* corals. At Alutom Island (Fig. 147) an irregular sea-level bench is cut into the limestone along the exposed seaward side.

At Nimitz Park Beach Channel, the submarine terrace widens and consists of coral ridges and sandy-floored holes as deep as 60 feet. Coral growth is rich and diverse in this region, and some colonies reach unusually large sizes on the walls of the holes.

The Anae Island patch reef (Fig. 140) and adjacent shallow submarine terrace, which lies between it and the fringing-reef platforms along Nimitz Beach Park area, are rich coral development zones, supporting coral mounds, pinnacles, and ridges separated by sandy-floored channels and holes. The relief of some of these coral mounds is 30–40 feet. The upper surfaces of some coral mounds and ridges are 15–30 feet deep.

South of the Anae Island patch reef, the irregular coral mounds and sandy-floored terrace grade into a rocky-floored region with a scattered coral community type of growth. There is no break along the terrace to the seaward slope zone; instead, it gradually slopes seaward to depths greater than 150 feet. The submarine terrace narrows along Dadi Beach and then widens around Facpi Point. South of Facpi Point, the submarine terrace is irregular in width. At Fouha Point, the 55-foot-deep terrace is more than 3,000 feet wide. Other wide submarine terraces are located at Pinay and Mamatgun Points. Coral growth on these terraces consists of a community of scattered colonies. Reef development is restricted to local patches, mounds, and pinnacles. Submarine topography from Facpi Point to Toguan Bay seems to reflect the general slope and pattern of the bordering coastal mountain valleys and spurs. The presence of a buttress-and-channel system, pinnacles, knobs, and mounds in the shallow wave-agitated waters of the reef margin and reef front zones is evidence that reef accretion and development are taking place.

The 55-foot-deep submarine terrace from Toguan Bay to Cocos Barrier Reef is very irregular in width, and is for the most part narrower than that found to the north. There is a shallow terrace with rich coral growth 10–25 feet deep along most of this section. The shallow terrace is separated from the 55-foot terrace by a steep-to-precipitous slope. This slope is cut by fissures and chutes, and resembles a sunken reef margin zone. Coral diversity, especially on the steep slope separating these two terraces, is greater along this short stretch of reef than anywhere else on Guam.

Offshore Slopes — Offshore investigations by Emery (1962) reveal submarine terraces at 55 feet, 195 feet, and 315 feet. The profiles made off Alutom Island and Facpi Point were started too far from shore to detect the presence of the shallower 55-foot terrace (see Figs. 28, 29, Nos. 35–37).

Development and Use Patterns, Culturally Important Areas, and Unique Features

From Orote Point to Taelayag Beach the coastline is extensively developed. Route 2 borders the alluvial coastline along this section. South Tipalao Naval Dependent Housing, Rizal Beach, and other Naval facilities border the coast lying within the Orote Peninsula Naval Reservation (Figs. 1, 137a). Many residences and much commercial development are found on the coast in this part of the sector, especially in the village of Agat (Fig. 147).

South of Taelayag Beach, Route 2 parallels the coastline well inland to the village of Umatac (Fig. 143). This section of coast is bounded by the steep mountain slopes of southern Guam, and except for Umatac, there are few houses and little commercial development. A short ,jeep trail borders the coast somewhat inland from Taelayag Beach to the Sagua River. Another ,jeep trail traverses the steep mountain slope from Route 2 at the Achugao District to the shore between Chii Point and the Agaga River (Fig. 137b).

From Umatac Route 4 goes overland to Toguan Bay and then follows the coast to the village of Merizo. Except for a few homes, the coast is relatively undeveloped from the mouth of Umatac Bay south to the Bile River except for a few residential dwellings. South of the Bile River, the coastline is extensively developed,

Several historical sites and monuments are located along the coast here. There is a U. S. Landing monument at the junction of Routes 2 and 12, an old Spanish bridge at the mouth of the Taleyfac River, another Spanish bridge (Fig. 148) near an oven at the mouth of the Sella River, Fort San Jose (Ruins), Fort Santo Angel (Ruins) (Fig. 143) on the bluffs north of Umatac Bay, Magellan monument at the head of Umatac Bay, and Fort Soledad (Ruins) on the bluff south of Umatac Bay. Cemeteries are located along the coast north of the Togcha River, at Agat, at Umatac on the south side of the bay, and on the north side of Route 4 near Merizo (Figs. 137a, 137b).

Nimitz Beach Park, a public swimming beach and park (Fig. 149), includes a deepwater channel on the north side used for small-boat access to the Philippine Sea, by snorkelers, and by skin and SCUBA divers.

Shallow reef flats border the seaward side of the park. The Government of Guam maintains a roadway park strip northward along the shore from Nimitz Beach Park to Chaligan Creek, which is used for picnicking and gives the public access to the broad reef flats north of Nimitz Beach Park. A military beach and park is located at Rizal Beach.

The coastline here is bordered by highways and receives considerable usage by the public. The less accessible coastline along the sector is used by the general public very little, except for those who can gain access by small boats. Commercial tours are available to certain spots along the undeveloped coastline. The coastline from Anae Island to Toguan Bay, with its rugged mountain background, small protected bays, and shallow reef flats, is certainly one of the more scenic coastal areas of Guam.

Sector XI

Physiography

This sector includes the Cocos Barrier Reefs and enclosed Cocos Lagoon, Cocos Island, and the coastal region lying between the mouth of Mamaon and Manell Channels (Figs. 150, 151). The triangular lagoon is enclosed by barrier reefs nearly three miles long on the northwest side and three-and-a-half miles long on the south side, and by two-and-a-half miles of steep mountainous land and alluvial coastal low land on the northeast side. The Geus River forms a broad alluvial valley which trends northeasterly from the head of Mamaon Channel. Several rivers form alluvial valleys and a broad coastal plain at the head of Manell Channel. Two deep channels connect the lagoon waters with the open sea: Mamaon Channel opens to the Philippine Sea, and Manell Channel opens to the Pacific Ocean.

Three islands are located on the barrier reef. Cocos Island, slightly longer than a mile, lies along the west end of the south barrier reef. A second small, sandy island has developed on the lagoon side of the barrier reef, 1,000 feet east of Cocos Island. Babe Island, an elongated low strip of barren raised limestone, lies on the south barrier reef midway between the east end of Cocos Island and Manell Channel.

Cocos Lagoon, excluding the barrier reefs, has an area of 2.8 square miles, The area of the barrier reefs and lagoon together is 3.9 square miles. Disregarding the deep Mamaon and Manell Channels, the deepest part of the lagoon is about 45 feet.

Emery (1962) divided Cocos Lagoon and associated barrier reefs into five physiographic units: reef, lagoon hollow, reef bar, channels, and nearshore shelf (See Fig. 152).

Geology

Cocos Lagoon and its barrier reef probably developed on a basement of the Umatac formation (Tracey et al., 1964). The basic shape of the reef supports the idea that part of the Umatac formation dropped along the Cocos fault, which strikes almost parallel to both the Talofofo fault zone and the Adelup fault (Fig. 6).

The landward margin of the lagoon (Fig. 7d) is bordered by a low, narrow, coastal plain composed of alluvium along the Mamaon Channel. This shelf widens into a broad alluvial valley at the head of the channel and then narrows again at Joatan Point. A low-lying section of argillaceous limestone of the Mariana formation (QTma) forms a small point on the north side of Achang Bay. A broad, swampy, alluvial plain, composed mostly of volcanic clay and muck (Qal), borders Manell Channel and Achang Reef.

Babe Island (Fig. 153) is composed entirely of a low strip of raised, solution-pitted Merizo limestone (Qrm) 1–3 feet higher than the general reef-flat level. Merizo limestone similar in elevation and lithologic characteristics to that at Babe Island also forms a low band on the seaward side of Cocos Island (Fig. 154). The lagoonward side of Cocos Island is composed of unconsolidated beach deposits derived from the nearby barrier reefs.

Soils

The most extensive soil type along this shoreline is Inarajan clay, (Unit 10) which is developed on the low coastal plain bordering the lagoon (Fig. 155). A small section of Agat clay is found along the shoreline near the mouth of Mamaon Channel.

Atate-Agat clay (Unit 6) and Agat-Asan clay (Unit 8) are found somewhat inland on the volcanic slopes bordering the coastal plain. Pago clay (Unit 9) is found on the upper alluvial valleys of the Geus and Manell Rivers. Shioya soil (Unit 12) is developed on the unconsolidated sediments of Cocos Island. Rocky land types (Unit 13f) are found on the low strip of raised limestone at Babe Island. Although not mapped, the solution-pitted band of limestone located on the seaward side of Cocos Island should be grouped with Unit 13f.

Engineering Aspects of Geology and Soils

The engineering aspects of geology are mapped, described, and summarized in Fig. 12d and Tables 5 and 6.

Vegetation Zones

The vegetation zones along this sector are mapped in detail in Fig. 33d. Mangrove communities border the shoreward side of Cocos Lagoon from Joatan Point to Balang Point. Some scattered patches of mangrove are found near the mouth of the Geus River (Figs. 156, 157, 158).

Hydrology

The volcanic slopes bordering this sector are intricately dissected by streams. The Geus River basin drains the largest area along the sector, emptying into the lagoon at a small embayment at the head of Mamaon Channel (Figs. 150, 157; see also Tables 22, 23 for discharge data for this river).

Tochog Creek and Manell River empty near the head of Manell Channel at Achang Bay (Fig. 158).

The volcanic mountain land bordering the east side of the lagoon lies within the ground water subarea 6a (Fig. 13).

Beaches and Rocky Shorelines

The shoreline along Cocos Lagoon is bordered mostly by alluvium. Near the mouth of the Geus River and at Achang Bay, the shores are mud flats and mangrove swamps (Fig. 156).

Unconsolidated beach deposits border the lagoonward side of Cocos Island, and a low, rocky, solution-pitted band of limestone bounds the seaward side (Fig. 154). Babe Island consists entirely of low pinnacles of solution-pitted limestone (Fig. 153). The small islet about 1,000 feet east of Cocos Island is composed entirely of unconsolidated beach deposits.

Cocos Lagoon and Barrier Reefs

The following description of the Cocos Lagoon and barrier reefs has been summarized from Emery (1962).

Topography — The topography of the floor of Cocos Lagoon is known chiefly from some 3,000 sonic soundings made in 1945 by sound boats of *U.S.S. Bowditch* (AGS 4) (See Fig. 152).

The lagoon consists of five main physiographic units. Closest to land is nearshore shelf, apparently merely a seaward continuation of the small coastal plain bordering the lagoon. Its slope is gentle from the shore to depths of about 5 feet at its outer margin, which varies in width from less than 100 feet off Merizo to about a quarter-of-a-mile off Joatan Point. At its eastern end and extending to the deep channel of Achang Bay, the shelf separates the reef from the shores, forming an area that is 1–2 feet deeper than a normal reef flat. Near the middle is a large indentation of the shore where the Geus River empties. A small mangrove swamp is present along the shore of this indentation.

The outermost physiographic unit of the lagoon is the barrier reef itself, which averages about 300 yards in width, except at the northern end where it is blunt and some 600 yards wide, possibly because of better growth conditions along the side of Mamaon Channel. The outer edge of the reef is a low algal ridge. Near its southern tip is Cocos Island, a mass of sand and gravel 0.11 miles square, nowhere more than about 10 feet high. Because all the material seen above high tide is unconsolidated, it is believed that the island owes its origin to waves and currents which have transported sediment along and across the reef. An example of the transporting ability of large waves was presented by Typhoon Allyn of November 17, 1949, which destroyed Navy installations at the west end of the island, carried away part of the eastern quarter-mile of the island, removed a small islet just north of the east end, and built another small islet farther north (Fig. 150).

Between the nearshore shelf and the north end of the reef is the deep Mamaon Channel. This is fairly straight, a mile long within the reef, 100–200 yards wide, and about 100 feet deep where it passes through the reef (Fig. 151). Soundings show a continuation to depths of at least 400 feet about 1,100 yards out from the reef. The current in the channel flows outward strongly at ebb tide, and either inward or outward weakly at flood tide. The channel may owe its origin to its having been the chief original means of exit from the lagoon of fresh water brought by streams.

The fourth physiographic unit is a shallow reef bar in the northern half of the lagoon, which separates the nearshore shelf and channels from the main part of the lagoon (Fig. 152). Most of the top of this reef bar is less than 10 feet deep, and it consists largely of branching coral (Figs. 151, 159). Its position and distance from shore indicate that it may originally have been a fringing reef, now cut off from the open sea by the building up of the present barrier reef on which Cocos Island sits. Blasting operations for easier navigation in Mamaon Channel may have produced minor modifications of this area.

The fifth physiographic unit is the deep "lagoon hollow." Its southern part is a gently undulating surface generally less than 10 feet deep, but the northern part against the reef bar is deep and irregular. Here are 3 main holes, with depths of 34, 40, and 43 feet.

General Sediment Composition and Distribution — Most of the lagoon hollow is floored by a broad expanse of sand, with few or no rocky masses. The shallow southern part of the area, except near the shore of Cocos Island, is 100 per cent sandy bottom. Similarly, sand covers the shallow eastern part of the reef bar and the nearshore shelf. Most of the nearshore shelf and those parts of the lagoon near the reef are between 50 and 100 per cent sand, whereas the seaward side of the reef and most of the reef bar are less sandy. The embayment of the nearshore shelf contains some mud mixed with the sand. Practically all bottom material other than sand is either dead or living coral. The ratio of dead to living coral varies widely and unsystematically. The most striking expanse of living coral is found at the entrance of Mamaon Channel. Other large areas of living coral, mostly *Porites*, are present along both sides of the channel off Merizo and atop the reef bar. Very different corals, less branching and more massive, form the reef surface and the areas ,just lagoonward of the reef.

To simplify the picture of sediment distribution, the samples were classed as fine sand and silty foraminifers, *Halimeda* debris, and corals according to the most abundant constituent. Calcareous red algae and shells were omitted, because they were chief constituents in few or none of the samples. The results plotted in chart form are easier to visualize than separate charts of each constituent (Fig. 160).

In summary, it is evident that detrital sediments from the land—insoluble residue fractions—are not carried far into the lagoon. The chief foraminifera are heavy ones which live on the reef, and after death of the organisms, the empty tests collect on the beaches inshore of the reefs. *Halimeda* evidently live best in the areas receiving new water from Mamaon Channel, for their debris is most abundant there. Madreporarian corals and calcareous red algae form the bulk of the sediment bordering the reef. The finest sediment from comminuted organic remains collects in the deeper areas of presumed quieter water, where organic growth is less rapid probably because less sunlight reaches the bottom. Thus, coarse debris is not available locally, and only the finer sediment is carried there by currents from distant areas of growth.

A rough value for the overall composition of the present lagoon floor and adjacent reef and beaches can be obtained by totaling the areas of the various constituents shown by Fig. 161. If the samples had been evenly distributed over the lagoon floor, the same result would be obtained by averaging together the composition of all 251 samples. In fact, approximately the same values were obtained when this method was used (Table 24). The results from both methods show that the contribution by animals is about twice that of plants.

Chemical composition — Table 10 shows the chemical composition of sediment samples from Cocos Island, Achang Bay, Cocos Lagoon, and Mamaon Channel.

Barrier and Fringing Reefs

The following account of the reefs of Cocos Lagoon area has been summarized, in part, from Tracey et al. (1964).

The reefs and lagoon together with Cocos Island on the southeastern reefs form an atoll-like environment about 4 miles square (Figs. 150, 151, 156). The seaward reef margin from Manell Channel to Mamaon Channel is 6 ½ miles long.

Fathometer profiles (Emery, 1962; see Figs. 28, 29, Nos. 32–34) show that outer slopes are steep on the east and moderate on the west. No definite break in the eastern slope at 60 feet was recorded, although that starts at a depth of 60 feet, only 550 feet from the reef edge. Observations on both the sides of the reef revealed a flat, shallow terrace about 50 feet deep and at least 100 yards wide on the east side and a terrace which slopes gently from a depth of about 50 feet near the reef front to 80 or 90 feet several hundred yards away on the west side.

From Manell Channel almost to Cocos Island, the barrier reef flat is more than 3,000 feet wide and is the broadest reef on the island (Fig. 151).

The reef front is rounded and not marked by grooves. Along Cocos Island the reef front is cut by conspicuous grooves which cross the algal ridge to form surge channels. The outer reef flat is mostly exposed at low tide and contains tracts or bands of rubble. The inner reef flat is exposed at low tide near Manell Channel but is covered by 2–5 feet of water east of Cocos Island. A broad, shallow, sand shelf covered by several feet of water forms the lagoon reef margin.

The northwestern reef has a rounded, lobate margin. In aerial photographs, the reef front shows numerous elongate hollows parallel to the reef, probably torn by storm waves.

Following is a description of the northwest barrier reef taken from Tracey et al., 1964 (Traverse 4, pp. A89–A90). See Fig. 156, Transect A, for the transect location.

> Outer slopes — The outer slopes were not examined although Emery's (1962, pl. 1) profile was made just beyond the line of the traverse (Figs. 28, 29, No. 34). It shows the outer edge of a terrace at 90-feet depth about 400 yards from the edge of the reef.
>
> Reef front and terrace — The reef front, about 150 feet wide, and the inner part of the terrace were examined by swimming. No measurements were made, but approximate profile is shown (Fig. 20). The front slopes moderately seaward from the submerged margin at a depth of 2 feet to the terrace at a depth of nearly 50 feet. Beyond this, the broad shelf formed by the terrace dips gradually to a depth of 90 feet at the outer edge. The outer part of the terrace, seen from a glass-bottom boat, is a rough, flat floor cut by narrow cracks which are partly filled with rounded boulders and rubble. Near the reef front are erosional channels and hollows 3 feet or more wide and 3–6 feet deep, also partly filled with boulders. Hollows in the floor contain debris, but most of the terrace is bare rock on which corals grow only sparsely.
>
> The lower part of the reef front is cut by irregular erosional channels 3 feet or more wide and 3–6 feet deep, partly or nearly filled with well-rounded boulders. Many varieties of coral cover perhaps 10 per cent of the reef front. The upper part of the reef front contains more numerous but much narrower erosional grooves. Corals and calcareous algae form a rough, irregular surface.

Reef margin — This poorly defined zone, about 100 feet wide, consists of a broad, slightly convex, debris-covered surface containing much small coral and knobby coralline algae on the seaward side.

Outer reef flat — This barren surface, about 200 feet wide and visible on aerial photographs, is covered with packed debris which consists mostly of subrounded boulders of coral. Few coral colonies are present, and pink calcareous algae coats parts of the rock surfaces.

Inner reef flat — About 900 feet wide, this broad zone contains abundant small colonies on the outer part which grow on a rubble and gravel floor. Lagoonward, the size and the height of the colonies increase, and the composition of the floor changes from gravel to sand. Soft green algae and articulate algae are abundant. The inner part of the zone is a broad band of staghorn *Acropora* in thickets 1–2 feet high.

Lagoon shelf — The shelf is an almost barren zone 500 feet wide of medium and fine-grained sand containing foraminifera and abundant *Halimeda* segments. Coral patches are rare. The zone is about 4 feet deep at low tide near the inner reef flat and about 6 feet deep near the lagoon edge.

Development and Use Patterns, Culturally Important Areas, and Unique Features

The coastal region along Cocos Lagoon is extensively developed and altered from its natural condition. The village of Merizo occupies most of the shoreline, residential and commercial development being especially concentrated along the portion bordered by Mamaon Channel. The deep water of Mamaon Channel provides access to both the Philippine Sea and the main body of Cocos Lagoon. Access to Cocos Lagoon is made possible by the deeper water over the reef bar zone (Fig. 152) along the southwest side of the channel. Several marinas and piers are located along the narrow fringing reef shelf between the shore and Mamaon Channel.

The density of residential and commercial development diminishes from the Geus River southeastward to Achang Bay. Route 4 is situated somewhat inland along this region (Fig. 150), and mangroves have developed a narrow fringe along the shore in many places (Fig. 157).

The deep-water Manell Channel provides access to the Pacific Ocean, but the broad, shallow reef flat bordering the west side of the channel prevents communication to the main body of Cocos Lagoon, except for small-draft boats at high tide (Fig. 162). There is little development along the shoreline bordering this channel. Mangroves are extensively developed along the shore around Achang Bay, southeast to the mouth of the Suyafe River.

Abandoned facilities of a U. S. Coast Guard LORAN Station occupy the western third of Cocos Island (Fig. 154). The remainder of the island is privately owned and currently a tourist attraction.

The protected waters of Cocos Lagoon are used for small boats, sailboats, glass-bottom boat excursions, water skiing, snorkeling, skin diving, and shell collecting, and the deep channels are used for SCUBA diving. Excursion boats transport picnickers, beachcombers, and swimmers to and from the beaches of Cocos Island. Many tourists use the marina facilities along Mamaon Channel.

Government-regulated fish traps are located at various places on the shallow subtidal parts of Cocos Lagoon (Fig. 163).

Sector XII

Physiography

This sector is located along 17 miles of the southeast coast of Guam, extending southward from Taogam Point to Manell Channel. It is exposed to the easterly tradewinds, like Sector I to the north, but differs in that it is bordered predominately by fringing reef-flat platforms and has numerous streams and rivers which carry silt and mud to the coastal regions (Figs. 10, 164a–164c) .

A limestone plateau borders the sector from Taogam Point to Nomna Bay (Fig. 7e). Intermittent stretches of limestone, low alluvial river-valley floors, and dissected volcanic slopes border the sector from Nomna Bay to Manell Channel.

Along the limestone plateau land, the coastal region consists of steep slopes and clifted headlands, which are set back somewhat at places from the shoreline by lower-lying limestone terraces of various widths. Prominent headlands are found at Taogam Point (120 feet), Pago Point (315 feet), Tagachan Point (+200 feet), Tartuguan Point (300 feet), Ypan Point (100 feet), Asquiroga Cliff (413 feet), Matala Point (100 feet), Asiga Point (334 feet), and Jalaiha Point (220 feet). Low-lying terraces separate these coastal cliffs from shoreline at the south end of Pago Bay (2,000 feet wide), from Ylig Bay to Tartuguan Point (1,000 feet wide), between Tartuguan and Ypan Points (3,000 feet wide), between Matala and Asiga Points (600 feet wide), from Asiga Point to Nomna Bay (1,000 feet wide), between Nomna Point and Inarajan Bay (1,400 feet wide), and between Agfayan and Ajayan Points (1,600 feet wide).

Prominent bays and river gaps cut through the limestone plateau at Pago, Ylig, and Talofofo Bays. From Nomna Bay to Manell Channel, the coastline is bordered by alluvium and unconsolidated beach deposits at Nomna, Pauliluc, Inarajan, and Agfayan Bays, and from Atao Beach to Balang Point. Rough, irregular limestone terraces, generally lower than 100 feet, are found between Nomna and Pauliluc Bays, between Pauliluc and Inarajan Bays, on the south sides of Inarajan and Agfayan Bays, and at Aga and Malilog Points. Prominent bays are found at Pauliluc, Inarajan, Agfayan, and Ajayan Bays.

The village of Yona sits on the plateau land between Pago and Ylig Bays. Talofofo village is situated somewhat inland on the plateau west of Mana Bay, and Inarajan occupies the southern shore of Inarajan Bay.

Fringing reef-flat platforms border most of the shoreline. Narrow cut benches have developed at some headlands where fringing reef flats are absent. River channels cut completely through the reef flat at Pago, Ylig, Talofofo, Pauliluc, Inarajan, Agfayan, and Ajayan Bays. River channels cut partly through the reef flat Togcha River at Mana, Asanite, Aga, Asgadao, and Sumay Bays, and at Malilog Point. Nine islets are located on the fringing reef flat platform between Inarajan Bay and Manell Channel.

Only four rivers have cut through the limestone plateau land from Pago Bay south to Nomna Bay, whereas 13 rivers and creeks reach the shoreline along the remaining southern coast.

Geology

The sector is bordered by a limestone plateau from Taogam Point to Nomna Bay (Figs.6,7c–7e). Reef facies (QTmr) of the Mariana limestone formation caps much of coastal limestone cliffs, slopes, and headlands. It also veneers some of the low-lying coastal terraces. Reef facies occurs in isolated patches from Pago Bay to Talofofo Bay and is a continuous coastal band on the terraces bordering the coast from Talofofo Bay to Nomna Bay. The limestone terraces at Aga and Malilog Points and the reef-flat islets scattered along the southern coast are also composed of Mariana limestone reef facies.

The inner part of the limestone plateau along this sector is composed of the argillaceous limestone member of the Mariana formation (QTma). Coastal deposits of the same limestone occur along the inner part of Pago Bay, in narrow strips on both sides of Ylig Bay, from Tartuguan Point south to Talofofo Bay, and at four intermittent sections between Nomna Bay and Acho Point.

Fore-reef facies of the Mariana limestone (QTmf) borders both side of the Togcha River, and a small patch is exposed inland on the band terrace at Mana Bay.

Beach deposits (Qrb) are found at the head of Pago Bay, north and south of Tagachan Point, at the head of Ylig Bay, at a long strip from Ylig Point to Asanite Point, along Ypan Point, at the head of Talofofo Bay, at four isolated patches between Matala Point and Nomna Bay, at the heads of Nomna, Pauliluc, and Agfayan Bays and at a long section from Agfayan Point to Balang Point.

Alluvium (Qal) is found bordering the coast or immediately behind the coastal beach deposits (Qrb) at all the river mouths. Extensive deposits are found at the Talofofo and Inarajan River valleys and along the coastal plain at Balang Point.

Structurally, several faults and fault zones have modified the coastline here (Figs. 6, 7c–7e). The Adelup fault trends along the Pago River valley. Prominent joints along the cliffline at Pago Point (Fig. 165) mark the location of this fault zone in the coastal limestone along the coast. Talofofo Bay marks the location of the prominent Talofofo fault zone. According to Tracey et al. (1960), the upper cliffline at Talofofo Bay has been offset by faults (Fig. 166). Several faults have lowered a triangular section of the coast between Dongua and Aga Points.

Soils

Soil patterns are complex and varied along this sector because of the presence of the many kinds of rocks exposed along the coast (Figs. 167a–167c; Tables 5 and 6).

The most extensive type of soil is Shioya limesand (Unit 12), which borders the unconsolidated shoreline of Pago Bay, and is found at the head of Ylig Bay, along a broad coastal strip from Ylig Point to Asanite Bay, at the head of Gayloup Cove at Talofofo Bay, intermittently from Asiga Beach to Jalaiha Point, in a small finger-like extension inland at Guaifan Point, at the heads of Inarajan and Agfayan Bays, and at a long strip of varying width between Agfayan Point and Balang Point.

Steeply sloping limestone rock land (Unit 13f) is extensively found along the limestone plateau land, forming the steep slopes and cliffs at the north end of Pago Bay, from Pago Point south to the head of Ylig Bay, at the south side of Ylig Bay, at Ypan Point, on both sides of Talofofo Bay, from Matala Point south to Asiga Point, at a small patch at Nomna Point, at Jalaiha Point, in small sections at the mouth of Inarajan Bay, and on the limestone islets scattered over the reef platform between Inarajan Bay and Balang Point.

Inarajan clay (Unit 10) is developed on the alluvial valley floors of all the river mouths along this sector.

Chacha and Saipan clays (Unit 4) are developed on the gently sloping argillaceous limestone, and Yona clay (Unit 5) is developed on the ridge tops and more steeply sloping argillaceous limestone along the sector. These clays form extensive areas lying between the volcanic slopes bordering the limestone plateau to the west and the seaward cliffs.

Guam clay (Unit 1) borders the upper cliff margins and coastal terraces along the limestone plateau land and along the coast south of Jalaiha Point.

Gently sloping limestone rock land (Unit 13b) forms a small section south of Pago Point, and Pago clay (Unit 9) occurs in the upper parts of the alluvial valley floors of the larger rivers and borders the coast at Nomna Bay.

Various Atate, Agat, and Asan clays appear inland on the volcanic slopes bordering the southern part of the sector.

Engineering Aspects of Geology and Soils

The engineering aspects of geology are mapped, described, and summarized in Figs. 12c–12e and Tables 5 and 6. Engineering aspects of soils are summarized in Table 5 (description of soils) and Table 6 (soil drainage and erosion).

Hydrology

From Manell Channel to Agfayan Bay the coastline is bordered by volcanic mountain slopes and low-lying alluvial plains. This region lies within the ground water subarea of 6a (Fig. 13). Seven permanent rivers and streams and several intermittent ones reach the coast lying within this ground water subarea. The low-flow partial discharge data for the Ajayan and Agfayan Rivers are presented in Table 22.

From Agfayan Bay northward to the Pago River, the coast is bordered mostly by a belt of limestone which bounds the eastern foothills of the southern Guam mountains (Figs. 7c–7e, 13). This stretch of coast lies within two ground water subareas. Subarea 5c forms a narrow strip along the shore, bordered inland by a wider strip which extends westward to the volcanic mountain land. This long stretch, in contrast to the southern part of the sector bordered by ground water subarea 6a, has only seven rivers which reach the coast. A few intermittent streams occur in the southern part of the coast bordered by subarea 5c, where the limestone belt attenuates and becomes discontinuous. Discharge rates for the rivers along this part of the sector are considerably greater than for those along the southern part, except for the Ajayan and Agfayan Rivers. Tables 25 through 30 show discharge records for the Inarajan, Pauliluc, Talofofo, Ugum, Ylig, and Pago Rivers, respectively. Additional low-flow partial discharge records are given in Table 22 for the Asalonso River.

The remainder of the sector, from the Pago River to Taogam Point, is bordered by argillaceous limestone of the streamless northern plateau and lies within the ground water subarea 3b.

Short estuaries are developed on the Ajayan, Agfayan, Pauliluc Rivers. Intrusion of marine waters into these rivers is minimal.

More extensive estuaries are developed on the Inarajan, Talofofo, Ylig, and Pago Rivers. Table 31 gives salinity and depth measurements for them.

Beaches and Rocky Shorelines

Unconsolidated beach materials accumulate more extensively along sections of the coast bordered by wide reef-flat platforms, whereas parts of the coast bordered by narrow reef-flat platforms generally have intermittent patches of beach deposits separated by rocky shorelines (Figs. 168a–168c).

Beach deposits have accumulated at the heads of all the bays along this sector, except at Inarajan Bay, and form a wide coastal terrace from Ylig to Asanite Points. Equally wide terrace deposits border the slopes from Agfayan Point to Balang Point. Between Nomna Bay and Matala Point and between Pago and Tagachan Points, beach deposits form narrow, isolated stretches along the narrow reef flats and adjacent raised limestone terraces and rocky headlands.

Beach samples collected by Emery (1962) here (Fig. 17, Stations 22–39; Tables 7, 8, 9) have a nonbioclastic fraction ranging from 0 to 91 per cent. Samples collected near the mouths of rivers tend to have the lowest bioclastic fractions because of the insoluble volcanic material brought to the shoreline by rivers and streams (Fig. 169).

Rocky shorelines border less than half of this sector. Prominent rocky headlands are found at the north and south ends of Pago Bay, from Pago Point to Ylig Bay, at the south side of Ylig Bay, at the north and south sides of Talofofo Bay, at Asiga Point, and at Agfayan Point (Figs. 38, 165, 166, 168a–c, 170, 171).

Rocky terraces form step-like tiers of solution-pitted, pinnacled limestone along much of the shoreline bordered by limestone plateau land. The elevation of these terraces, in respect to the general level of the present sea-level reef-flat platforms, varies from place to place. The height above sea level of the lowest terrace is usually less than 3 feet; the next and most common terrace is usually around 5–6 feet; a third occurs 10–15 feet above sea level; and a fourth, somewhat variable, irregularly-surfaced terrace is found between 25 and 40 feet. Higher terraces occur at various levels farther inland along the coastal plateau land. Nips are cut into the rocks where limestone cliffs and headlands border the shoreline.

Fringing Reefs and Offshore Slopes

The following description of fringing reefs along this sector was taken, in part, from Tracey et al. (1960).

The southeastern coast of Guam is bordered by wide windward reefs. Broad reef flats and prominent algal margins are found at Pago Bay, from Tagachan Point to Asanite Point, and from Agfayan Point to Manell Channel. Narrow reefs, rimmed terraces on the reef margins, and cut benches along clifted headlands which average 6 feet above low-tide level, predominate from Pago Point (Fig. 165) to Tagachan Point and from Asanite Point to Agfayan Point. The coastline includes a number of bays at the mouths of principal streams as well as channels and breaks in the reef where small streams emerge (Figs. 168a–168c).

Fathogram profiles compiled along this sector of the coast by Emery (1962), show that the outer slope ranges in steepness from less than 10° to as much as 45° (Figs. 28, 29; Nos. 24–31). A shallow submerged terrace is broad and well defined. Six of the eight profiles show definite breaks to the outer slope 60 ± feet deep, and from less than 400 to more than 1,500 feet from the reef margin.

The reef front and reef margin here show the greatest variety and development of any on Guam. East-facing reefs from Pago Bay to Nomna Bay show prominent spurs separated by deep grooves, which in many places cut the reef margin to form long surge channels (Figs. 170, 172). The margin is a broad, low, algal ridge backed by a wide reef flat ranging in width from 400 to more than 2,000 feet. Near the reef margin is a truncated rock pavement containing moderately abundant corals. Large clusters and tabular masses of coral are common in places on the sandy inner reef flat, but generally, the size, variety, and abundance of corals are much less than on the wide western reefs.

Southeast-facing reefs from Nomna Bay to Manell Channel show notable development of rimmed terraces and pools in some places (Figs. 22, 171). Elsewhere occurs a most unusual growth of algal bosses and knobs which coalesce to form a honeycomb or room-and-pillar structure on the reef flat (Fig. 173). Headlands contain benches and nips at varying altitudes above sea level (Fig. 165).

Following is a description of the reef features taken from Tracey et al., 1964 (Traverse 3, pp. A87) of a measured traverse located about half-a-mile south of the Ylig River, some 500 feet south of Ylig Point.

> Outer slope (not examined) — Two of Emery's (1962) fathometer profiles—north and south, respectively, of the traverse—indicate that the edge of the terrace is at a depth of 60 feet nearly 300 yards beyond the reef edge (Figs. 28, 29; Nos. 25, 26).
>
> Reef front and terrace (roughly 800 feet) — The inner part was examined in 1953 by S. O. Schlanger

using an aqualung. The terrace slopes very gently from the base of the reef front at a depth of 20–30 feet to the outer edge at a depth of 60 feet. The outer part of the terrace is a nearly flat rock pavement cut here and there by straight, narrow, nearly vertical fissures at angles to the reef edge. The rock pavement is coated with calcareous algae and contains scattered small colonies of coral. Between the base of the reef front and the outer flat terrace is a rough zone about 150 feet wide cut by large, irregular cracks and eroded hollows 2–8 feet deep which are filled with reef rubble. Large blocks as much as 8 feet in diameter lie on the pavement or fill the holes. The reef front is cut by surge channels which do not appear to be related to the cracks and fissures on the terrace.

Reef Margin — The margin, about 100 feet wide, has as its chief feature a low algal ridge about 30 feet wide of porous coralline algae and coral. Surge channels cut through the margin for 20–50 feet, although a few are more than 100 feet long. They are 6–8 feet deep and 5–10 feet wide. Small open pools, partly roofed over, are found near the landward ends of the channels, similar to those near Tartuguan Point. Between pools, the inner part of the reef margin is formed mostly of packed fragments of dead coral thickly covered with soft brown and green algae and less than 10 per cent calcareous red algae.

Outer reef flat — The flat is about 200 feet wide and is just exposed at lowest tides. This is a flat, comparatively smooth area with scattered small corals, such as *Pocillopora* and *Acropora* at the outer edge, which is cut by narrow channels 1–2 feet deep. The bottoms of the channels are covered with sand, and living corals grow on the side. The sizes of the channels and shallow pools increases shoreward.

Inner reef flat — The inner flat is about 1,000 feet wide and is covered with water at low tide. The sandy floor of the pool areas increases shoreward to form the dominant area of the reef. Corals form colonies of flat-topped clusters 1–2 feet wide near the outer edge of the zone, increasing shoreward in size to 10 feet or more, but decreasing in number. They stand 6 inches to 1 foot above the sandy, irregular floor of the reef.

Other fringing reef areas — The reef north of Agfayan Bay, 2,000 feet south of Inarajan, is cut in limestone deposited upon a volcanic conglomerate on the Bolanos pyroclastic member of the Umatac formation and preserves both nips and eroded surfaces probably relating to former stands of the sea. A remnant of Mariana limestone 15 or more feet high stands near the seaward margin of the reef and is responsible for the preservation of the forms and surfaces described (Fig. 171).

The reef margin consists of several horizontal surfaces (Fig. 22), the lowest being level with the top of the reef flat about mean-tide level, nearly 2 feet above lowest tides. This surface is coated with abundant corals and calcareous and soft algae. Two higher surfaces are cut in the remnant of Mariana limestone about 4-1/2 and 5 feet above the level of the reef flat. These surfaces extend along the reef for several hundred feet and are about 100 feet in maximum width. Both contain rimmed pools a few inches deep and 5–10 feet in diameter.

An unusual form of reef margin occurs from Ajayan to Agfayan Bays and is especially well shown near Aga Point (Fig. 173). Algal knobs and bosses 5–15 feet in diameter and 5–20 feet apart grow from a shoal floor 10–15 feet deep. These bosses mushroom at the surface, and landward they merge to form a room-and-pillar type of reef. Open pools on the reef flat are 10–20 feet in diameter and 5–10 feet deep. They are connected beneath the reef flat by arched channelways, and in places they are abundant and close together.

The area along this coast containing algal bosses apparently are places where the reef has dropped several feet by faulting relative to each side. In some places, the line of faulting is obvious on the reef surface (Fig. 173). The down-dropping results in a submerged platform shallow enough for algal knobs to grow abundantly to the surface, whereas the up-faulted sides have comparatively poorly developed algal ridges containing few surge channels. The down-faulted reef flat contains many pools, and coral and algal growth is abundant on the reef surfaces. The up-faulted reef flat is barren rock truncated to sea level. At the shoreline, the down-faulted areas contain sandy beaches, and the adjoining areas are flat expanses of pitted limestone 3–5 feet above the level of the reef. These areas of limestone may have been truncated during an earlier-sea stand such as the "6-foot" or they may represent recent reef flats lifted above the present one by faulting, which dropped the algal boss-and-pool areas.

Reef-Flat Sediments — Reef flat sediments were studied in detail at Achang and Pago Bay Reefs by Emery (1962). Following is a summarized description of these studies.

Achang Reef — The inner half of the reef flat is dominantly sand, in part covered by patches of the ribbon-like *Enhalus* (Fig. 174). Abundant mounds of sand 1–3 feet in diameter and several inches high are made by burrowing activities of echiuroid worms. The outer half of the reef and the areas bordering the deep channel of Achang Bay consist chiefly of coral, reef rock, and algal pavement, with sand occurring only in pockets or as a thin mat on the surface. Samples of the sand from both inner and outer halves of the reef flat were examined microscopically, and the percentages of detrital grains, foraminifera, shells, *Halimeda* debris, coral, calcareous red algae, and fine sand and silt were determined. The distribution of these constituents atop the reef surface proved to be monotonously uniform and dominated by comminuted coral (Fig. 175). *Halimeda* debris presents the greatest variation; the highest concentrations are on the deep reef flat west of Achang Bay, and the lesser ones are near the reef edge, along part of the deep channel, and at some beaches. Fine sand and silt are abundant only in the deep channel and its head. Detrital grains average 25 per cent in the beach samples but are rare beyond 200 feet from shore.

Pago Bay — The sediments of the reef flat at Pago Bay are not dominated by any one constituent, but contain approximately equal percentages of several kinds of organic remains (Figs. 17—Stations 22 ½; 29, 39 1/2—176, 177, 178, and Tables 10, 11). Foraminiferal sand is most abundant, 10–20 per cent, about midway across the southern reef and at some of the beaches. Shells are about twice as abundant as foraminifera and have a similar distribution, though they are slightly nearer the outer edge of the reef. Fine sand and silt presents a pattern of decreasing concentration outward from the mouth of Pago River and is virtually absent on the reef flat. This material, evidently contributed by Pago River, is of volcanic origin and not bioclastic, as is the rest of the reef-flat sediment. *Halimeda* debris is most abundant, 20–35 per cent, along the middle and inner half of the reef flat, somewhat shoreward of the zone of maximum concentration of shell fragments. Coral, over-all the most abundant constituent, comprises 20–30 per cent of most samples on the shoreward half of the reef and more than 40 per cent near the reef edge. Calcareous red algal debris, more abundant at Pago Bay than elsewhere, has a concentration and distribution similar to that of coral debris.

Development and Use Patterns

The southeast shoreline is more extensively developed than other coasts of Guam, principally because the physiography of this sector makes the coastal areas more accessible.

The University of Guam Marine Laboratory is located at the north end of Pago Bay (Fig. 179). A small housing development is located about midway along the Pago Bay shoreline (Fig. 176), and the adjacent beach has been cleared for a picnic area. The shoreline along the southern part of Pago Bay is relatively undisturbed.

The rugged coastline from Pago Point to Tagachan Point is mostly undisturbed (Figs. 165, 170). A jeep trail leads to a small beach area, Marine Hole, north of Tagachan Point, used by picnickers and swimmers. The north side of Ylig Bay is being developed as a condominium-beach resort area (Fig. 180). Togcha Cemetery is located on the sandy terrace south of Ylig Bay (Fig. 164a).

The coastline from the south side of Ylig Bay to Togcha Channel is relatively undeveloped. It receives considerable usage, though, by picnickers, swimmers, fishermen, skin and SCUBA divers, and sun bathers because of the easy access via a network of jeep trails leading from Route 4 to the beach (Fig. 164a). Togcha Channel, near the mouth of Togcha River, cuts almost through the reef platform (Fig. 181) and with its vertical to overhanging walls is an interesting diving and snorkeling location.

From Togcha Bay to Talofofo Bay, parts of the coastline are developed by residential dwellings and unimproved roads and jeep trails (Fig. 164a). A public park is located at Ypan Beach. Jones Beach is privately owned. A small cemetery is located midway between Tartuguan Point and Mana Bay. Unimproved roads, jeep trails, and Route 4 where it borders a small bay south of Asanite Point, provide access for many people to this stretch of coastline. From Ypan Point to the head of Talofofo Bay, the coastline is bordered by rugged limestone terraces and cliffs and is undeveloped.

A public beach park occupies the head of Talofofo Bay, a favorite surfing area (Fig. 182).

From the south side of Talofofo Bay to Inarajan Bay, the coast is undeveloped. Route 4 runs inland on the high limestone plateau land which borders this part of the sector. Several private roadways give access to Paicpouc Cove, a beach south of Matala Point, Perez Beach at Nomna Bay, and Pauliluc Bay (Figs. 164b, 164c, 166, 183).

Some primitive drawings are located on the walls of a small sea cave a short distance north of Guaifan Point. A detailed account of these drawings is given by Hendrickson (1968).

The village of Inarajan is situated on the south shore of Inarajan Bay (Fig. 184).

A small public park and swimming pool has been constructed from natural tide pools at the south edge of Inarajan Village (Fig. 185). A cemetery is located along the road at Asgon Point (Fig. 164c). The remainder of the coastline from Inarajan to Manell Channel is more extensively developed. Route 4 borders the shoreline along most of this region providing easy access to the coast and fringing reef flats. Residences, small farms, and ranch dwellings are widely scattered from Agfayan Bay to Manell Channel. This section of coast and fringing reef receives considerable use by fishermen, snorkelers, skin divers, and picnickers. Some fish traps are placed on Achang Reef near Manell Channel.

CHAPTER V

SENSITIVITY OF THE COASTAL ENVIRONMENT TO THE ACTIVITIES OF MAN

On small island settings the ratio of coastline to total land area is high, tending to increase the degree of shoreline use and development. This is especially true when the interior part of the island is mountainous, as in the case with southern Guam. Guam is also undergoing rapid development at the present time, and land is being utilized at a frantic rate as was discussed in Chapter I. Less coastal development has occurred in northern Guam, because the northern coastal plateau region consists of steep rocky slopes, cliffs, and much of it is occupied by military reservations. The southeastern, southern, and parts of the southwestern coasts are not heavily populated, and with the exception of the Merizo area there is correspondingly less coastal development. Most of the population of Guam is located in the central part of the island, particularly on the western coast, where most of the coastal development is presently found. Rapid growth of Guam, though, is placing increased demands on this already developed coastline and other less developed areas elsewhere are being considered. Most significant of this development is the various kinds of land use which irrevocably change the original or natural status of the coast by residential or commercial development.

The steep slopes, cliffs, narrow rocky terraces, and sea level benches bordering Sectors I, II, III, IV, VI, IX, and parts of X and XII are rugged coastal regions of great natural beauty. These regions are not ideally suited for residential or commercial development and much of it should be left in its natural condition. Many of these slopes and terraces, particularly those along Sectors I and II, support forest communities which are less disturbed and in a condition which is more nearly like that found before habitation of the island by man. Development of these steep coastal areas for residential development would reduce the amount of already scarce undisturbed land on the island and also create problems of sewage disposal and access. Sewage must either be discharged into the marine waters on these windward coasts or be lifted to the much higher elevation of the upper limestone plateau level and then integrated into the island sewerage system. Because of steep gradients involved along these coasts; roadways and water and power lines would be expensive and difficult to build and service. Plateau land bordering these coastal slopes (Land Unit 13b) would be more suited for residential development, as a considerable amount of it has already been disturbed and is much too rocky and lacks good soil development for agricultural use.

Coastal land is being utilized in the Tumon Bay area (Sector V) for tourist development. Along this bay shore a proliferation of hotel building is taking place. The beaches along Tumon Bay are some of the finest to be found anywhere on the island. Much of the natural beauty of this shoreline can be preserved if developers would utilize the natural shoreline strand vegetation as much as possible. Introduction of exotic plants along the shore will result in their being damaged by salt spray and wave runup during severe storms, whereas the natural vegetation would be more resistant. Exotic vegetation should be reserved for areas more removed from the shoreline unless of salt-resistant species.

Wharf, docking facilities, and marinas are utilizing the shoreline and inshore waters of the Apra Harbor area (Sector VIII). These facilities will undoubtedly be expanded in the near future. Some dredging will probably be necessary also. Even though there has been considerable alteration in the subtidal parts of Apra Harbor, a rich and varied biocoenosis of marine life is found there. With careful planning in regard to development, the destruction of this biologically rich area can be prevented, and much of it can remain and be compatible with harbor development. The largest expanse of mangrove community on Guam is found along the landward side of both inner and outer Apra Harbor. Examination of this community shows that it is in a stage of accretional development in many areas that were previously disturbed, especially along the land-filled regions of Dry Dock Peninsula and Polaris Point. The protected waters of Apra Harbor also make it an ideal place for small craft mooring. Marina development in this area is generally lacking, though, because of little to no private or Government of Guam land ownership in that area.

Merizo and adjacent Cocos Lagoon (Sector XI) are undergoing rapid development at the present time. A considerable volume of tourist traffic, via boats to Cocos Lagoon and Cocos Island, has developed in this region. There has been distinct increase in marina facilities to handle this traffic. Most of the development has taken place along the deep Mamaon Channel at the northeast corner of the lagoon. Most of the shoreline along this region is densely populated and developed and is considerably altered from its original state. The shoreline along the southeastern part of the lagoon is relatively undisturbed and is mostly occupied by mangrove communities.

A shallow fringing shelf borders the landward side of Cocos Lagoon, which necessitates dredging for marine development so boats can gain access to the deep adjacent waters of Mamaon and Manell Channels.

Cocos Lagoon is a unique shallow water lagoon and possess certain kinds of arborescent coral development which are not found elsewhere on the island. These arborescent coral communities are not developed along the landward side of the lagoon as this region receives a considerable silt load from the streams and rivers which drain the bordering volcanic highlands. The protected waters of the lagoon does make the development of marinas there more attractive, and if continued development is warranted, then it should be more or less restricted to the landward side of the lagoon adjacent to the deep Mamaon and Manell Channels.

Other activities which perturb the present status of the coastal environment

1. Dredging

Dredging in subtidal waters increases the load of sediment and dissolved organic and inorganic materials in the water column within the immediate area of disturbance and may also effect other regions by currents carrying these waters to other adjacent or nearby areas. The subtidal communities in the western part of Sector VII, the shoreward parts of Sectors VIII and XI, and Sectors X and XII are somewhat adjusted to silt and turbid water from the surface drainage of numerous rivers and streams which occur there. The remaining sectors are bordered by limestone plateau land and, thus, lack surface drainage to their shorelines. It is in these sectors which lack surface drainage that are probably more sensitive to silt and turbid water from dredging activities. Even in the silt-adjusted area, though, the communities might be very precariously adjusted and could be affected just as easily as those in the nonsilt-adjusted regions when stressed by additional siltation from dredging operations. Whenever dredging is contemplated in an area, the communities present should be assessed and currents studied to determine the probable movement of the dredge spoil and recommendations should be made accordingly.

2. Excessive siltation because of removal of natural cover in river drainage basins

This type of activity effects subtidal areas which are subject to surface drainage by rivers and streams to the shoreline. On Guam this region is confined more or less to coastal areas of Sectors VII through XII. This type of silt is especially harmful because of the large amounts of fine clay and mud which are carried to the coast, especially if the rivers or streams debouch in the relatively quiet waters of bays, estuaries, or enclosed lagoons. Particularly damaging, is the removal of natural cover by earth-moving construction equipment in areas where weathered volcanic soils are present.

Fires, whether natural or deliberately set, also increase runoff and silt to the coastal areas where surface drainage is present. This is not as much a problem on the limestone plateau land of northern Guam, because there are no surface streams, and the natural limestone forest communities there are less subject to burning.

3. Freshwater runoff from storm drains to coastal areas

Freshwater normally escapes rather continuously at sea level from the Ghyben-Herzberg lens system along Sectors I through VI and IX and parts of VII, VIII, and XII. Subtidal communities are adjusted to this relatively slow and continual discharge, but when drains concentrate and increase the volume during rain storms, there may be considerable damage by reducing the salinity in the localized area. Storm drain water is also usually high in bacterial content and at times washes toxic substances, which have accumulated on the drainage surfaces, into the coastal regions.

4. Sewage Outfalls

The use of ocean outfalls, particularly in land-scarce insular regions, is common practice which may have an adverse effect on the water quality and inshore communities. Ocean outfalls should ideally be placed in water deep enough to assure adequate mixing of the effluent with the sea water and along coasts where currents are favorable to carry the sewage-entrained waters offshore. Except for localized regions, the inshore currents around Guam are very poorly known, especially on the windward coasts of Sectors I, II, and XII. Tides, ocean currents, wind patterns, sea conditions, and submarine topography are some of the factors which determine current patterns, and these should be carefully evaluated, preferably over an annual cycle, before selecting an ocean outfall site. Ocean outfall pipe is usually buried in the substrate which removes the benthic communities present. These disturbed regions usually recover and are recolonized by marine organisms with time,

5. Thermal ocean outfalls from power plants

Aside from the initial disturbance to the benthic community by laying the outfall pipe, heated water, when discharged into deep enough water and properly diffused to bring the water close to ambient temperature, produces less perturbation of the inshore communities than many other forms of disturbance. Changes in the marine environment are almost certain, though, when the thermal effluent is discharged in a manner which raises the inshore water temperature above the range in which the marine communities present are adjusted. As with ocean sewer outfalls, a site should be carefully evaluated in terms of currents. Again, the poor knowledge of current patterns around Guam necessitate a careful study before selecting a site for discharge.

6. Solid waste disposal.

This form of disturbance occurs along the coastline in both terrestrial and subtidal environments. In terrestrial environments, especially along the cliffted coastal sectors, there is a tendency to push unwanted earth, rock, and trash material over the cliff edge onto the steep slopes and terraces below. This practice produces ugly scars and destroys the original faunal and floral communities found along the coastal regions. There are numerous borrow-pits on the island in which this waste earth and rock material could be dumped. These steep-sloped coastal areas and cliffs along Sectors I through VI, IX, and XII are relatively undisturbed and, at present, contain the best preserved limestone forests.

Dumping of solid wastes in shallow marine waters covers the original benthic communities present and provides a different surface substrate. Solid wastes also commonly contain toxic substances which could be harmful to marine communities. There is some discussion of dumping certain solid wastes into shallow marine waters to provide artificial reef-like habitat areas for fishes and other marine animals. Before waste disposal of this manner is used, a careful study should be made as to the location of such sites. Sites for solid waste disposal should be selected in areas which are devoid of reef development and hard substrate marine communities. Sandy-floored terraces, which lack rich marine communities, should be considered.

7. Tourism

Attracting tourists to Guam is at present a rapidly developing economic base for the island. At present much of this tourist traffic is from Japan. Guam's geographic setting, which is relatively close to Japan, certainly has a bearing on the attractiveness for tourists coming to Guam, as well as the allure of a tropical island with its sandy beaches, coral reefs, and clear blue waters. Most of these latter features are best found and expressed in the undisturbed areas away from commercial and residential development. If Guam is to continue fostering tourism as an economic base, then it would be wise to maintain and preserve as much of the natural beauty and serenity of the island as possible. Most hotel development is being developed on coastal land particularly in regions that have good adjacent beaches. Most of the reef-flat areas along these beaches are shallow and at low tide are in some cases exposed or partly exposed. In many areas this condition has been alleviated by dredging of the reef-flat platform. Dredging removes the present marine benthic substrates and communities and substitutes it for another deeper water habitat. Although this type of dredging does not remove marine environments permanently, it does alter them considerably from their original condition.

Tourism increases greatly the number of reef gleaners and walkers, shell and coral collectors, and small boat traffic. The exact impact of this type of activity and harvest from the shallow reef flat areas is not known but observations in these areas over a period of time reveal a distinct reduction of, at least, macro-molluscs, such as *Lambis lambis*, and the colorful blue starfish *Linckia laevigata*, which were formerly abundant in these regions. Corals are also being harvested from the reefs around Guam and sold to tourists. Again there are no data available to determine whether or not this type of harvest is greater than the annual growth and accretion of corals.

CHAPTER VI

ACKNOWLEDGMENTS

We would like to thank the Department of the Army Corps of Engineers for providing the financial support for this project (No. DACW84-72-C-0015).

Our appreciation goes to the U. S. Navy for providing helicopter support for aerial photography and for providing photos of Cocos Lagoon and the fringing reef platform at Aga Point. This helicopter support was arranged through Mr. Dave Hotaling of the Department of Education, who also generously supplied many of the aerial photos used in the survey. Thanks again goes to Mr. Dave Hotaling and Mrs. L. Hotaling for critically reading the final draft of the manuscript.

Marine technicians Ted Tansy, Rodney Struck, Frank Cushing, Tom Cepeda, Pat Beeman, and Modesto Salas were very helpful and efficient in field operations, maintenance of equipment, and in the construction of special apparatus.

During the literature search and review phase of the project a special thanks goes to Mrs. Emilie G. Johnston and Mr. Albert L. Williams, from the Micronesian Area Research Center, and to Dr. Lucius G. Eldredge of the Marine Laboratory for their help in finding and providing difficult-to-find literature. Dr. Eldredge was also always willing to discuss various aspects of the project and to give advice whenever asked.

We very much appreciate Mrs. Joann Eldredge's laborious task of reading and editing the lengthy first draft of the manuscript.

Many photos used in this survey were provided by Mr. H. T. Kami of the Guam Fish and Wildlife Department, for which we are very grateful.

For the many hours spent at the drafting table drawing maps, we thank graduate student Randy Herold. Other graduate students who helped with field support for the project were Jennifer Chase and Mike Gawel. Graduate student Bill FitzGerald also was very helpful in processing film and printing photos for the project.

We wish to thank many of the landowners around Guam and the U. S. Navy and U. S. Air Force who generously gave us permission to cross their property so we could gain assess to many coastal areas around Guam.

Much appreciation goes to Augusto Terlaje for the administrative handling of the many grant details.

A special thanks goes to Mrs. Teresita Balajadia and Mrs. Mary Mariano of the Marine Laboratory administrative staff for typing the manuscript and cheerfully accepting the many changes which took place between the first and final drafts.

There have been many people which were helpful in some way or another to the project, we have failed to record, and to all of you we thank you.

CHAPTER VII

LITERATURE CITED

Anon. 1971. Interim report of the February 1971 Current and Ecological Survey of Guam. U. S. Naval Oceanographic Office (1971).

Badon Ghyben, W. 1889. Nota in verband met de voorgenomen put boing nabij Amsterdam. Koninkl. Inst. Ing. Tijdschr., 1888–89, The Hague. 21 pp.

Blumenstock, D. I. 1959. Climate. *In* Military Geology of Guam, Mariana Islands, Intelligence Division, Office of the Engineer, Headquarters, U. S. Army Forces Pacific. 282 pp.

Caroll, D., and J. C. Hathaway. 1963. Mineralogy of selected soils from Guam, with a section on description of soil profiles, by C. H. Stensland. U. S. Geol. Surv. Prof. Pap. 403F:F1–F53.

Cheney, D. P. 1971. *Acanthaster planci*. Resurvey of Guam. Mimeographed report submitted to the Governor of Guam, Marine Laboratory, University of Guam. 7 pp.

Chesher, R. H. 1969. Destruction of Pacific Corals by the sea star *Acanthaster planci*. Science 165:280–283.

Cloud, P. E., Jr., R. G. Schmidt, and H. W. Bruke. 1956. General Geology, Part I of Geology of Saipan, Mariana Islands. U. S. Geol. Surv. Prof. Pap. 280-A:1–126.

Cole, W. S. 1963. Tertiary larger Foraminifera from Guam. U. S. Geol. Surv. Prof. Pap. 403-E:1E–28E.

Cox, L. M. 1904. The island of Guam. Am. Geog. Soc. Bull. 36(7):385–395.

Emery, K. O. 1938. Rapid method of mechanical analysis of sands. J. Sed. Petrology. 8:105–111.

Emery, K. O., J. T. Tracey, Jr., and H. S. Ladd. 1954. Geology of Bikini and nearby atolls. Part 1, Geology in Bikini and nearby atolls, Marshall Islands. U. S. Geol. Surv. Prof. Pap. 260-A:1–265.

Emery, K. O. 1962. Marine Geology of Guam. U. S. Geol. Surv. Prof. Pap. 403-B:1B–76B.

Fosberg, F. R. 1959. Vegetation. *In* Military Geology of Guam, Mariana Islands. Intelligence Division, Office of the Engineers, Headquarters, U. S. Army Forces Pacific. 282 pp.

Fosberg, F. R. 1960. The vegetation of Micronesia, 1. General descriptions, the vegetation of the Mariana Islands, and a detailed consideration of the vegetation of Guam. Am. Mus. Nat. Hist. Bull. 64(1):1–76.

Herzburg, A. 1901. Die wasserversorgung einijer Nordseebader. J. Gasbecleuchlung V. Wasserversorgung, Jarg, 44, Mimich.

Jones, R. S., and R. H. Randall. 1971. An annual cycle study of biological, chemical, and oceanographic phenomena associated with the Agana ocean outfall. University of Guam, Marine Laboratory Technical Report No. 1. 67 pp.

Jones, R. S., and R. H. Randall. 1973. A study of biological impact caused by natural and man-induced changes on a tropical reef. University of Guam, Marine Laboratory Technical Report No. 7. 184 pp.

Johnson, H. J. 1964. Fossil and recent calcareous algae from Guam. U.S. Geol. Surv. Prof. Pap. 403G:G1-Gro.

Johnston, E. G., and A. L. Williams. 1973. Bibliography relative to the development of water resources Territory of Guam. University of Guam Micronesian Area Research Center. Special Pub. No. 1.

Kellogg, C. E., and F. D. Davol. 1949. An exploratory study of soil groups in the Belgian Congo. Inst. Nat. Pour 1' Etude Agron. Congo Belge, Ser. Sci. 46:1–61.

Kim, S. 1972. Guam 1972 challenging the seventies. Dept. of Commerce, Govt. of Guam. 64 pp.

May, H. G., and S. O. Schlanger. 1959. Engineering Geology. *In* Military Geology of Guam, Mariana Islands. Part II, Engineering aspects of geology and soils. Intelligence Division, Office of the Engineer, Headquarters, U. S. Army Forces Pacific. 282 pp.

McCracken, R. J. 1957. Soils. *In* Part 2, Petrology and soils of Geology of Saipan, Mariana Islands. U. S. Geol. Surv. Prof. Pap. 280-D:189–207.

Osborne, D. 1947. Archaeology of Guam: A Progress Report. Am. Anthropol. 49(3):518–524.

Osborne, D. n.d. Archaeology. Unpublished manuscript on Guam Sites, Univ. of Washington. 55 pp.

Pacific Islands Engineers. 1948. Historical reviews of the Meteorology, Seismology, Oceanography, and Geology of Guam, with references (4 vols.). Prepared for U. S. Dept. of the Navy, Bureau of Yards and Docks, contract Noy-13626 (unpublished).

Pacific Island Engineers. 1951. Interim report on ocean current studies- island of Guam.

Randall, R. H. 1971. Tanguisson-Tumon, Guam, reef corals before, during, and after the Crown-of-Thorns starfish (*Acanthaster planci*) predation. M.S. Thesis, University of Guam. 119 pp.

Randall, R. H. 1973a. Reef physiography and distribution of corals at Tumon Bay, Guam, before "crown-of-thorns" starfish, *Acanthaster planci* (L.) predation. Micronesica 9(1):119–158.

Randall, R. H. 1973b. Distribution of corals after *Acanthaster planci* (L.) infestation at Tanguisson Point, Guam. Micronesia 9(2):213–222.

Randall, R. H. 1973c. Coral reef recovery following extensive damage by the crown-of-thorns starfish, *Acanthaster planci* (L.). Publ. Seto Mar. Biol. Lab. (Proc. Second Internat. Symp. Cnidaria) 20:469–489.

Reed, E. K. 1952. Archaeology and history of Guam. National Park Service, US Department of the Interior. Washington, D. C. 133 pp.

Reinman, F. M. 1968. Guam prehistory: A preliminary field report. pp. 41–50. *In* I. Yawata and Y. H. Sinoto. Prehistoric culture in Oceania, a symposium. Bernice P. Bishop Museum Press.

Repetti, W. C. 1939. Catalogue of earthquakes felt in Guam. 1825–1938. Weather Bureau Manila, Seismol. Bull. (Jan.–June). pp. 27–43.

Royal Meteorological Observatory. n.d. 70 years' typhoon tracks, 1884–1953. Hong Kong (pre-publication copies of charts).

Schlanger, S. O. 1964. Petrology of the limestones of Guam, with a section on petrography of the insoluble residues, by J. C. Hathaway and Dorothy Carroll. U. S. Geol. Survey Prof. Pap. 403-D:D1–D52.

Spoehr, A. 1957. Marianas prehistory: Archaeological survey and excavations on Saipan, Tinian and Rota. Fieldiana: Anthropology. 48 pp.

Stark, J. T. 1963. Petrology of the volcanic rocks of Guam, with a section on trace elements in the volcanic rocks of Guam, by J. I. Tracey, Jr., and J. T. Stark. U. S. Geol. Surv. Prof. Pap. 403-C:C1–C32.

Stearns, H. T. 1941. Shore benches on north Pacific islands. Geol. Soc. Am. Bull. 52(6):773–780.

Stearns, H. T. 1945. Eustatic shorelines of the Pacific. Geol. Soc. Am. Bull. 56(11):1071–1078.

Stensland, C. N. 1959. Soils. *In* Military Geology of Guam, Mariana Islands. Intelligence Division, Office of the Engineer, Headquarters, U. S. Army Forces Pacific. 282 pp.

Stone, B. C. 1970. The flora of Guam. Micronesica 6:1–659.

Thompson, L. 1932. Archaeology of the Marianas Islands. B.P. Bishop Mus. Bull 100:1–78.

Thompson, L. 1940. The function of latte in the Marianas. Jour. Polynesian Soc. 49(195):447–465.

Todd, R. 1966. Smaller Foraminifera from Guam. U. S. Geol. Surv. Prof. Pap. 403I:I1–I41.

Tracey J. I., Jr., C. H. Stensland, D. B. Doan, H. G. May, S. O. Schlanger, and J. T. Stark. 1959. Military geology of Guam, Mariana Islands. Part I, Description of terrain and environment. Part II, Engineering aspects of geology and soils. U. S. Army, Chief of Engineers, Intelligence Div., Headquarters. U. S. Army Pacific (Tokyo). 282 pp.

Tracey, J. I., Jr., S. O. Schlanger, J. T. Stark, D. B. Doan, and H. G. May. 1964. General geology of Guam. U. S. Geol. Surv. Prof. Pap. 403-A:A1–A104.

Trask, P. D. 1932. Origin and environment of source sediments of petroleum. Houston, Texas, Gulf Publ. Co. 323 pp.

Tsuda, R. T. 1970. *Acanthaster planci*, crown-of-thorns starfish. Resurvey of Guam. Mimeographed report submitted to the Governor of Guam, Marine Laboratory, University of Guam. 7 pp.

Tsuda, R. T. (compiler). 1971. Status of *Acanthaster planci* and coral reefs in the Mariana and Caroline Islands, June 1970 to May 1971. Technical Report No. 2, Marine Laboratory, University of Guam. 127 pp.

U. S. Air Force, Air Weather Service. n.d. Uniform summary of surface weather observations, Guam, Mariana Islands, Harmon Field, for period July, 1945–Sept., 1949, less Jan. 1946–June, 1946, May, 1948 (IBM copy).

U. S, Geological Survey Water Supply Paper. 1971. Surface water supply of the United States, Part 16. Hawaii and other Pacific areas. Geological Survey Water Supply Paper 1937. 710 pp.

U. S. Navy, Chief of Naval Operations, Aerology Branch. n.d. Summary of monthly aerological records, Guam, Naval Air Station, Sept., 1945–Feb., 1946, May 1947–Dec., 1952, revision 1 (IBM copy).

Vlerck, I. M. van de, and R. E. Dickerson. 1927. Distinctions among certain genera of Foraminifera, for the field geologists of the East Indies, Jour, Paleontology. 1(3):185–192.

Ward, H. T. 1970. Flight of the Cormoran. Vantage Press, New York. 175 pp.

Ward, P. E., S. H. Hoffard, and D. A. Davis. 1965. Hydrology of Guam. U. S. Geol. Surv. Prof. Pap. 403-H:H1–H23.

Ward, P. E., and J. W. Brookhart. 1962. Military geology of Guam, Mariana Islands, Water resources supplement. Intelligence and Mapping Division, Office of the Engineer, Headquarters, U. S. Army Pacific. 182 pp.

Wentworth, C. K. 1938. Marine bench-forming processes-water-level weathering. Jour. Geomorphology. 1(1):6–32.

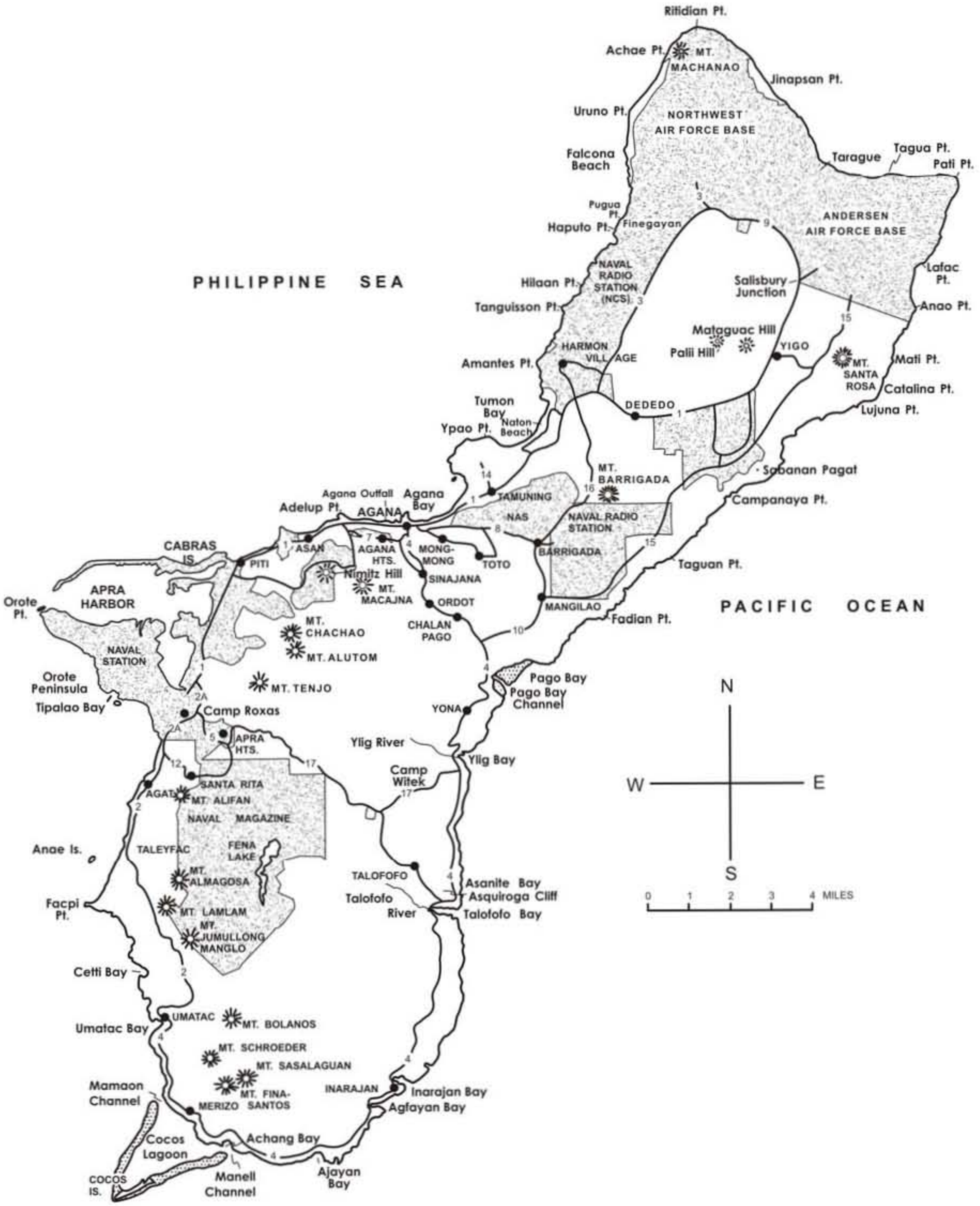


Figure 1. General location map of Guam, showing military reservation boundaries, major highways, villages, mountains, and other place names.

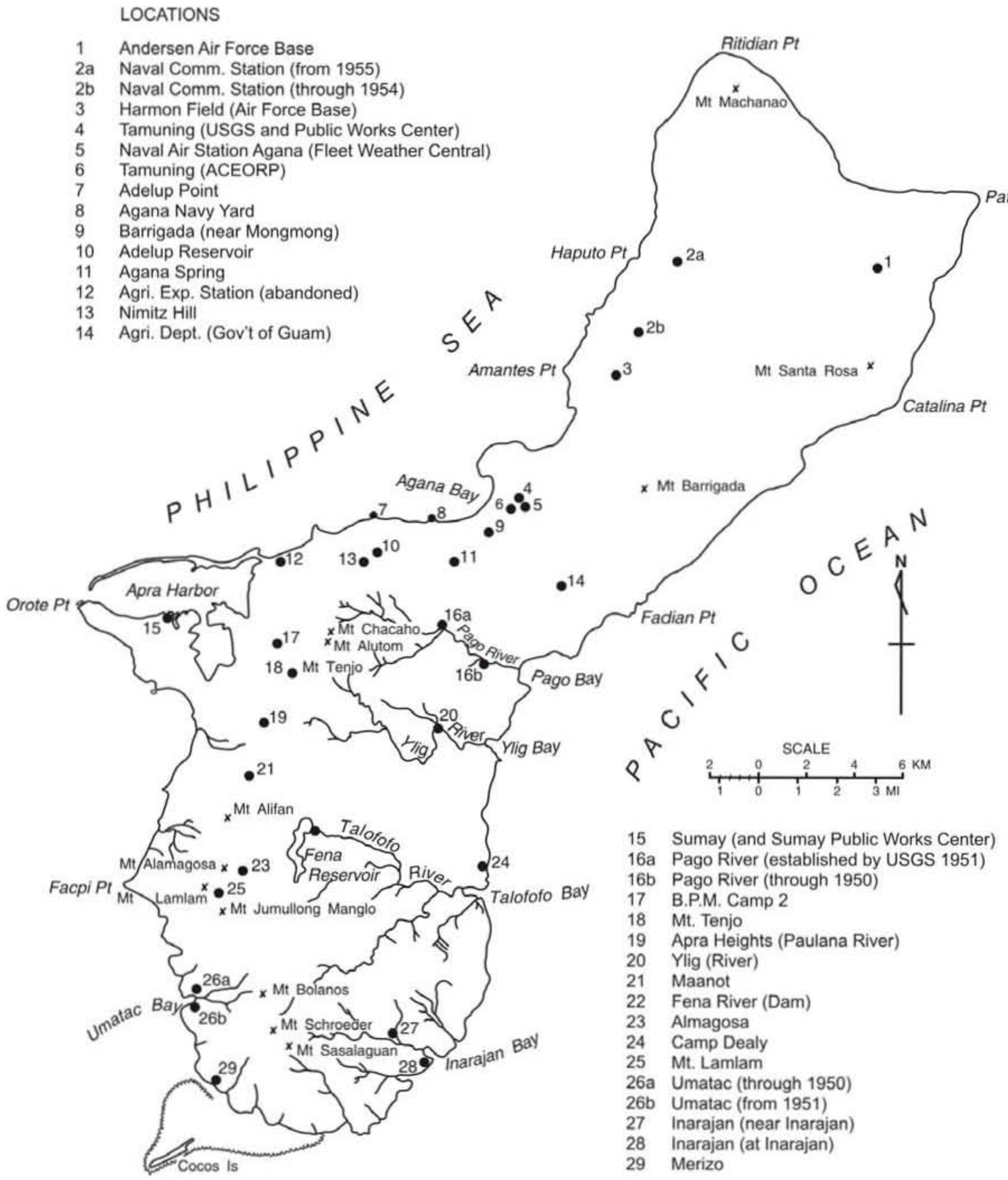


Figure 2. Locations of weather stations, Guam. Figure taken from Blumenstock (*In* Tracey et al., 1959).

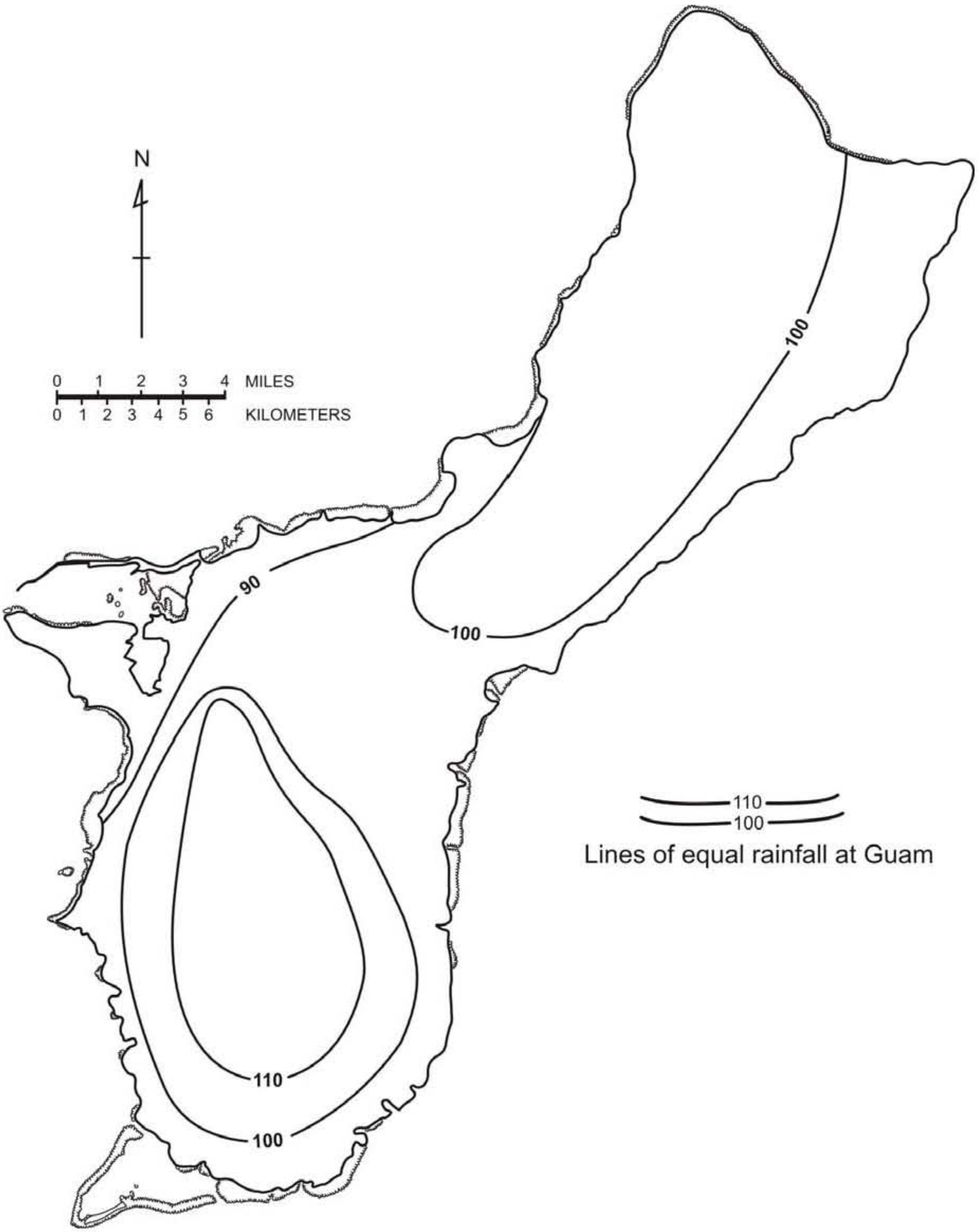


Figure 3. Mean annual rainfall at Guam. Figure taken from Blumenstock (*In* Tracey et al., 1959).

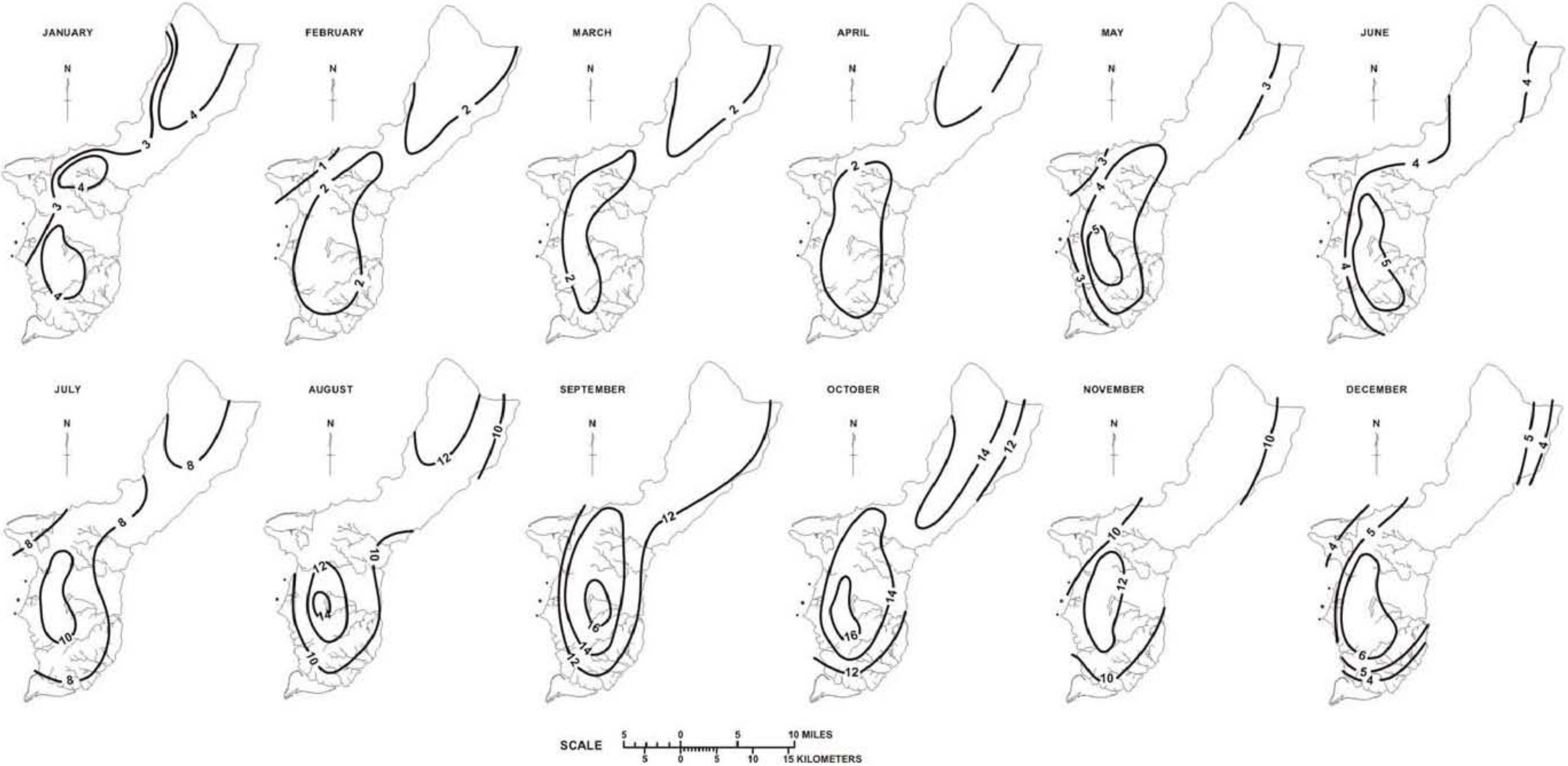


Figure 4. Median monthly rainfall at Guam (in inches). Figure taken from Blumenstock (*In* Tracey et al., 1959).

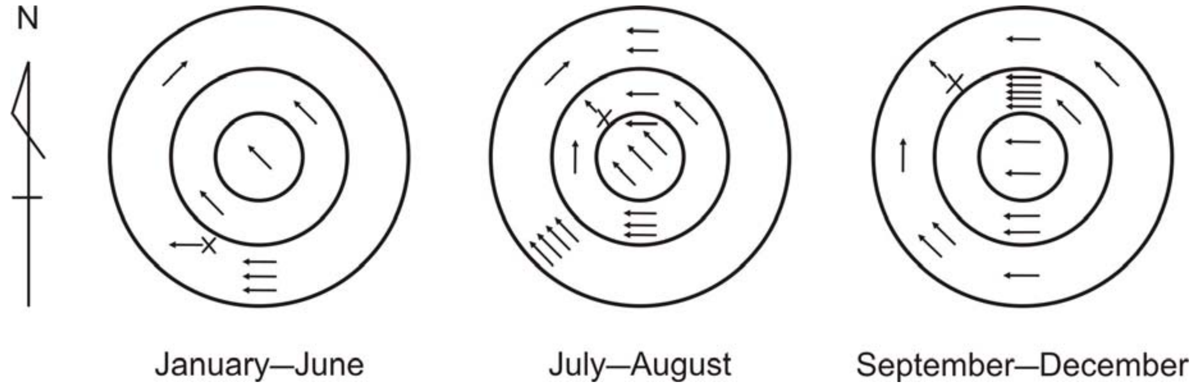
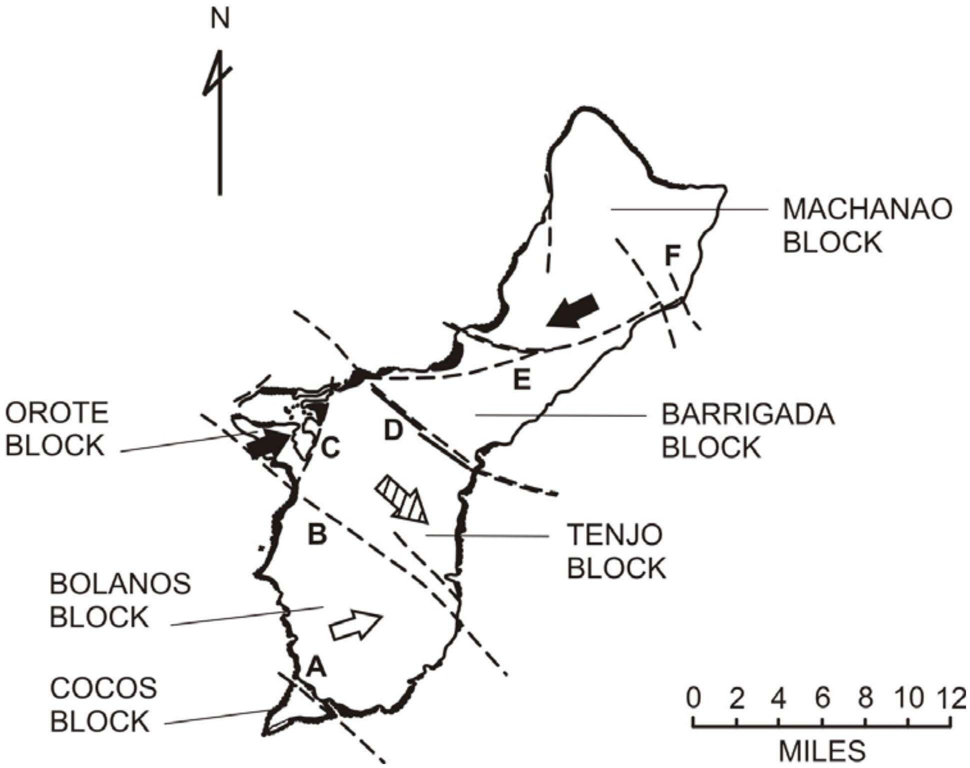


Figure 5. Typhoons in the vicinity of Guam, 1924–1953[1/], showing direction from Guam of each and direction of movement of each at time of closest approach to Guam. Each arrow represents a typhoon and shows direction of typhoon movement to nearest 1/8th point of compass. X indicates point of typhoon origin. *Inner circle* contains arrows for typhoons crossing Guam; *middle ring*, for typhoons passing 1–60 nautical miles from Guam; and *outer ring*, for typhoons passing 61–120 nautical miles from Guam. Within the two outer rings, distance of arrow from center of inner circle is not significant; direction of arrow from center of inner circle shows direction from Guam to nearest 1/8th point of compass. Figure taken from Blumenstock (*In* Tracey et al., 1959).

[1/] Compiled from Roy. Met. Obs., Hong Kong, Charts of Typhoons Tracks.



EXPLANATION

Fault mapped on Guam

Inferred fault mapped on Guam and offshore extensions of both mapped and inferred faults

Topographic dip of structural blocks

Black arrows indicate tectonically tilted block; white arrow indicates slope due to primary depositional dip; slashed arrow indicates slope due to combination of circumstances.

A – Cocos fault
B – Talofofo fault zone
C – Cabras fault
D – Adelup fault
E – Tamuning-Yigo fault zone
F – Faults bounding the Santa Rosa horst

Figure 6. Structural subdivisions of Guam. Figure modified from Tracey et al. (1964).

LEGEND FOR GEOLOGIC MAPS
(Figures 7a – 7e)

Qaf – Artificial fill

Qrb – Beach deposits

Qrm – Merizo limestone

Qal – Alluvium

Mariana limestone:
Qtmr – Reef facies
Qtmd – Detrital facies
Qtmm – Molluscan facies
Qtmf – Fore-reef facies
Qtma – Agana argillaceous member

Tal – Alifan limestone
Tt – Talisay member

Tj – Janum formation

Tbl – Barrigada limestone

Tb – Bonya limestone

Umatac formation:
Tuf – Facpi volcanic member
Tum – Maemong limestone member
Tub – Bolanos pyroclastic member
Tud – Dandan flow member

Alutom formation:
Ta – Alutom formation
Tam – Mahlac member

– Reef margins and reef flats

Contact
Dashed where approximately located, gradational or inferred.

? U D

Fault, showing dip
Solid where definitely located; dashed where approximately located; dotted where concealed. Queries indicate uncertainty as to existence of fault. Arrows show relative movement. U, upthrown side; D, downthrown side.

Brecciated zone
Crushed and brecciated zone in limestone. Zone may grade into joint and fault zones along its strike, and into massive, structureless rock perpendicular to its strike.

Thrust fault
Dashed where inferred. T, indicates upper plate.

Legend continued on next page:

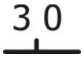
Legend for Geologic Maps (Continued)

Anticline

Showing crestline and bearing and plunge of axis.

Syncline

Showing position of trough and bearing and plunge of axis.



Strike and dip of beds.

Strike and dip of joints.

Strike of vertical joints

A line of joint symbols indicates a prominent joint or structural lineament, along which unbrecciated limestone is cut by a dominant set of joints in which solution has produced deep fissures bounding elongate, pinnacled ridges or along which volcanic rocks are cut by recognizable structural lines that show as a series of knobs and ridges crossing topographic trends or as fine fissures. In places, drainage patterns and valley-wall alignments are determined by these lines. Minor movement as the zone may have occurred, but significant stratigraphic displacement is not shown.

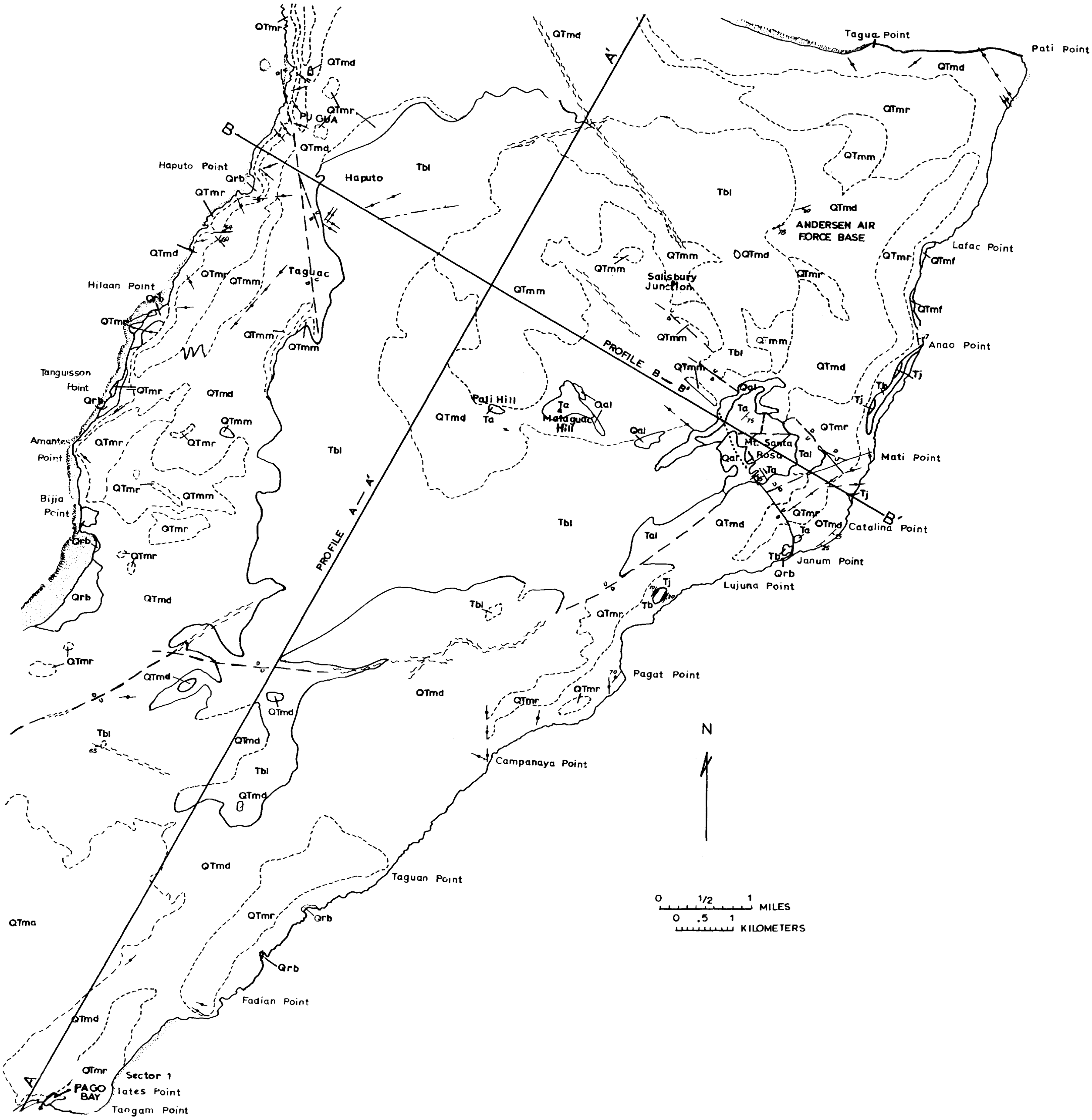


Figure 7a. Geologic map for Sectors I, III, and IV. Legend for maps is on pages 181–182; profile sections are shown on Figure 7f. Map modified from Tracey et al. (1964).

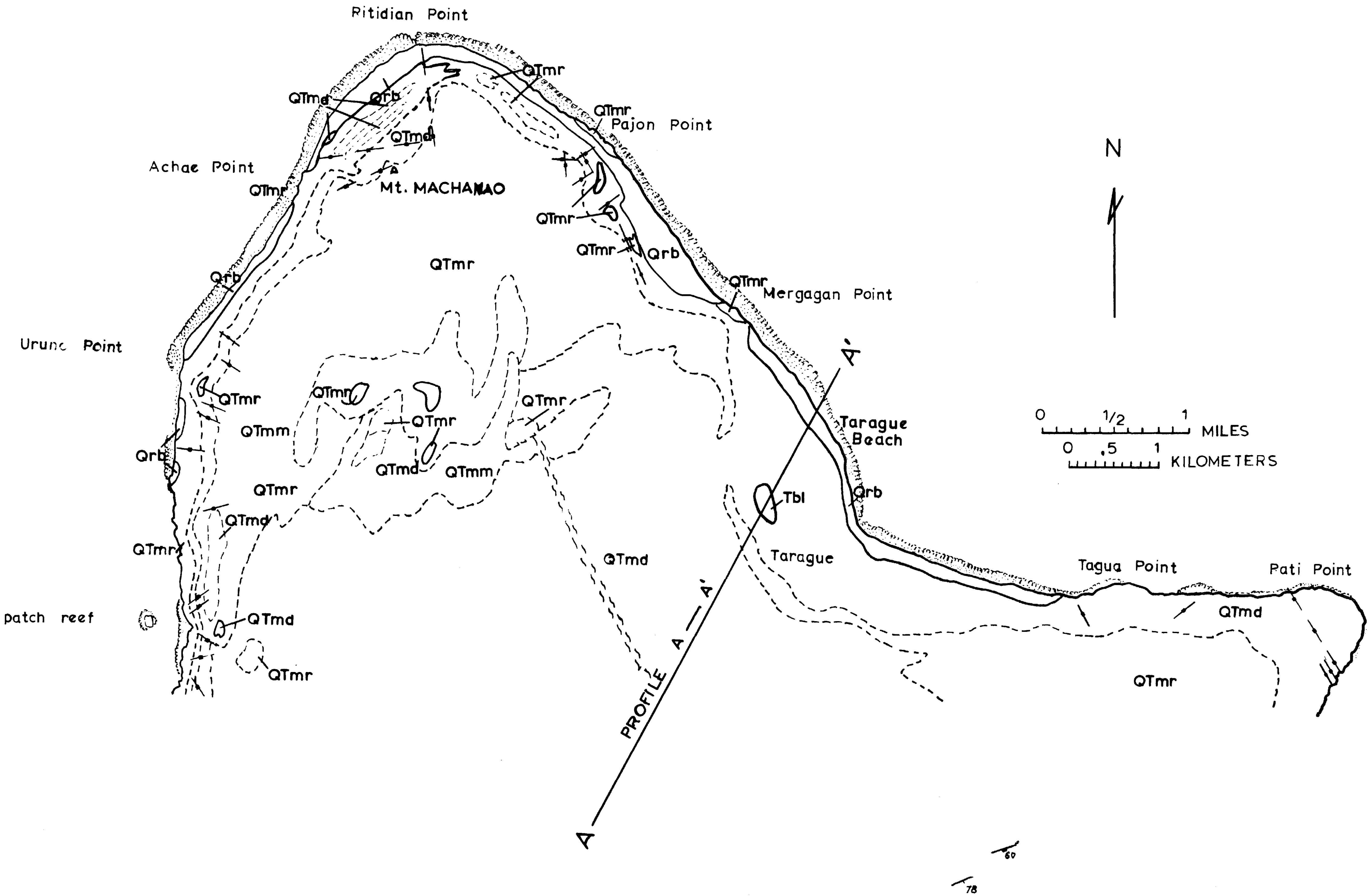


Figure 7b. Geologic map for Sector II. Legend for map is on pages 181–182; profile sections are shown on Figure 7f. Map modified from Tracey et al. (1964).

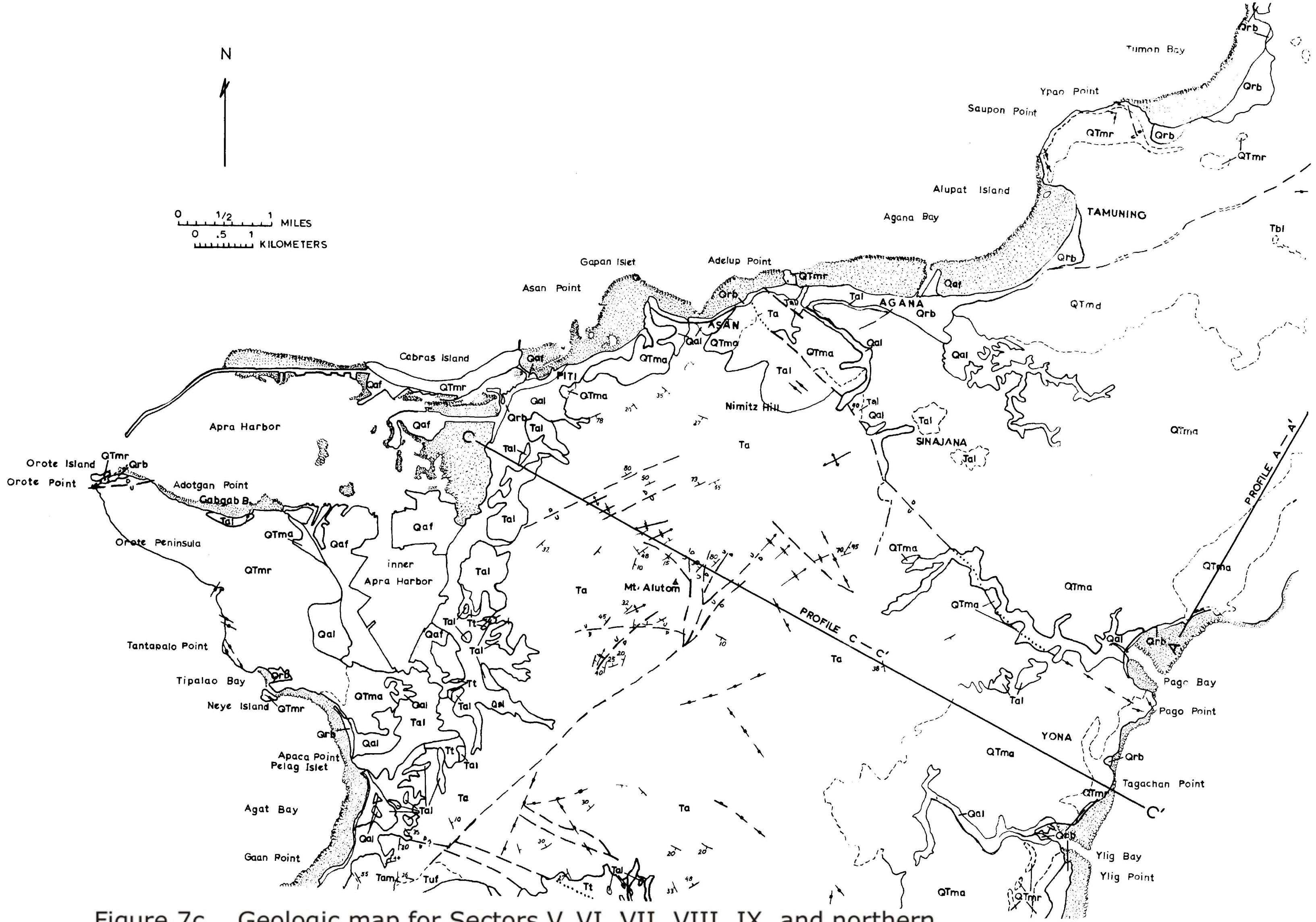


Figure 7c. Geologic map for Sectors V, VI, VII, VIII, IX, and northern part of X and XII. Legend for map is on pages 181–182; profile sections are shown on Figure 7f. Map modified from Tracey et al. (1964).

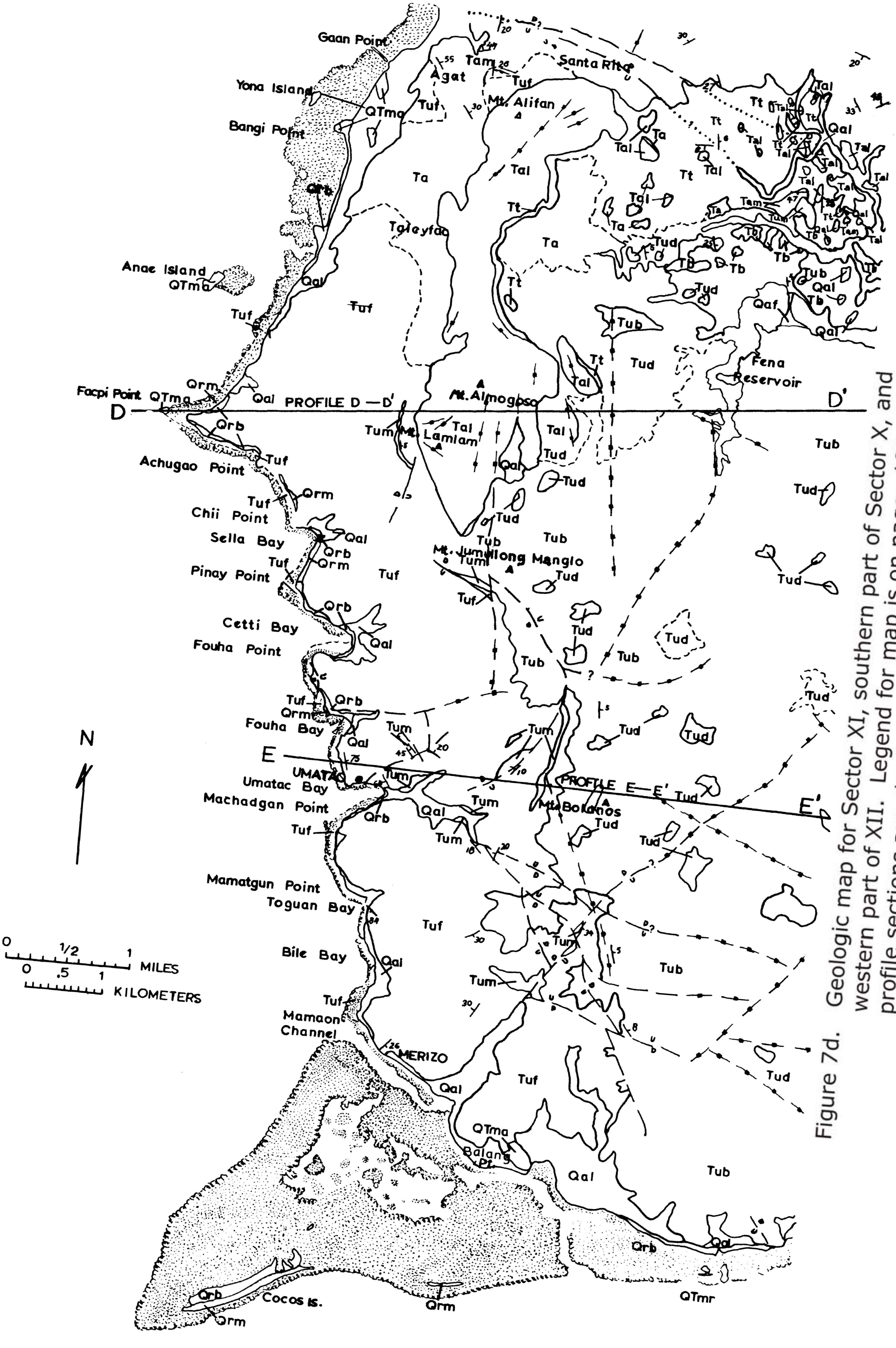


Figure 7d. Geologic map for Sector XI, southern part of Sector X, and western part of XII. Legend for map is on pages 181–182; profile sections are shown on Figure 7f. Map modified from Tracey et al. (1964).

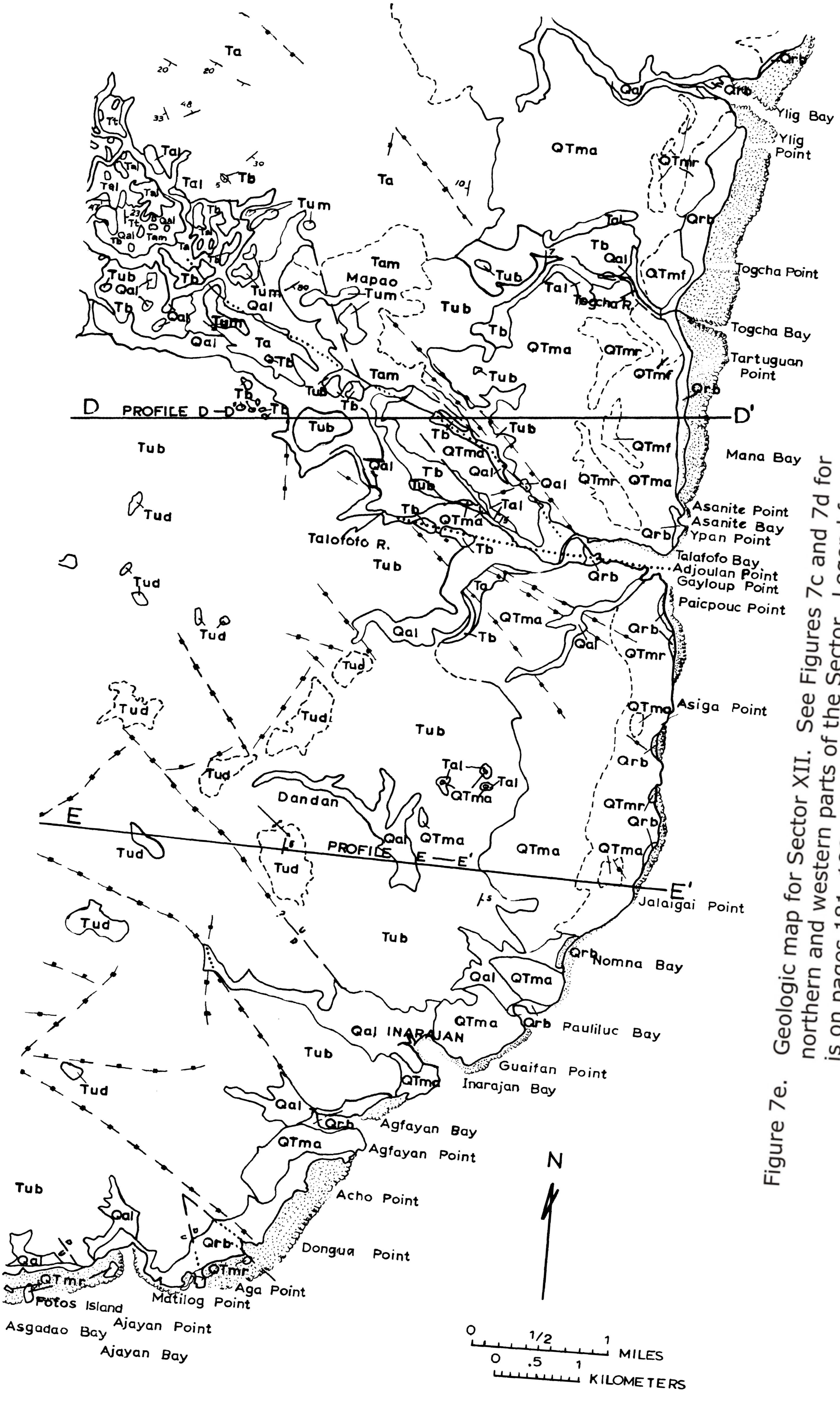


Figure 7e. Geologic map for Sector XII. See Figures 7c and 7d for northern and western parts of the Sector. Legend for map is on pages 181–182; profile sections are shown on Figure 7f. Map modified from Tracey et al. (1964).

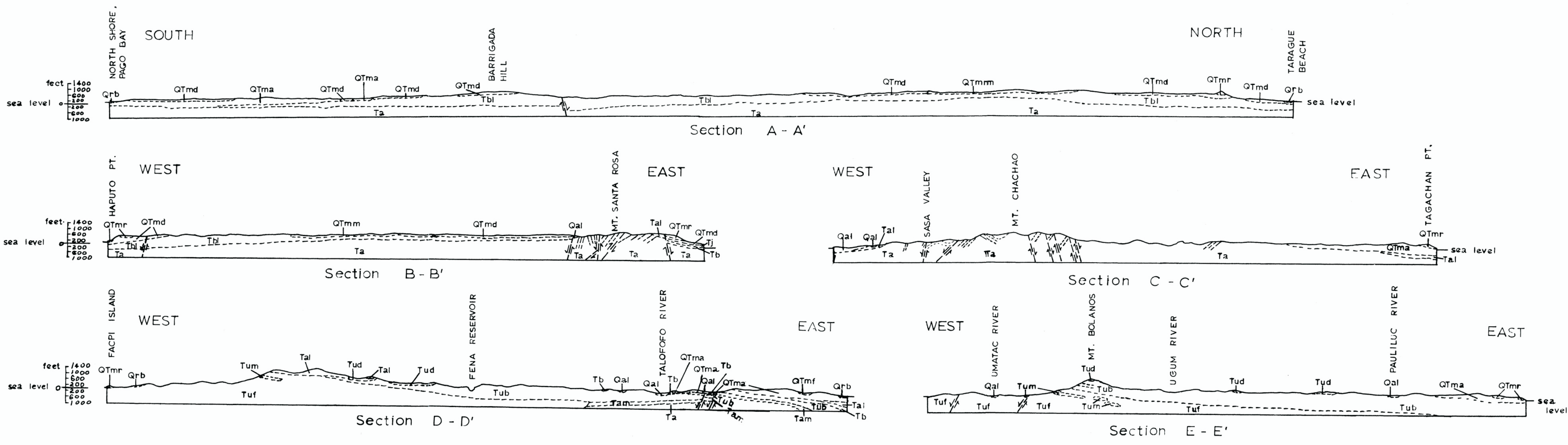


Figure 7f. Profile sections. See Figures 7a–7e for profile locations. Legend is on pages 181–182. Profiles modified from Tracey et al. (1964).

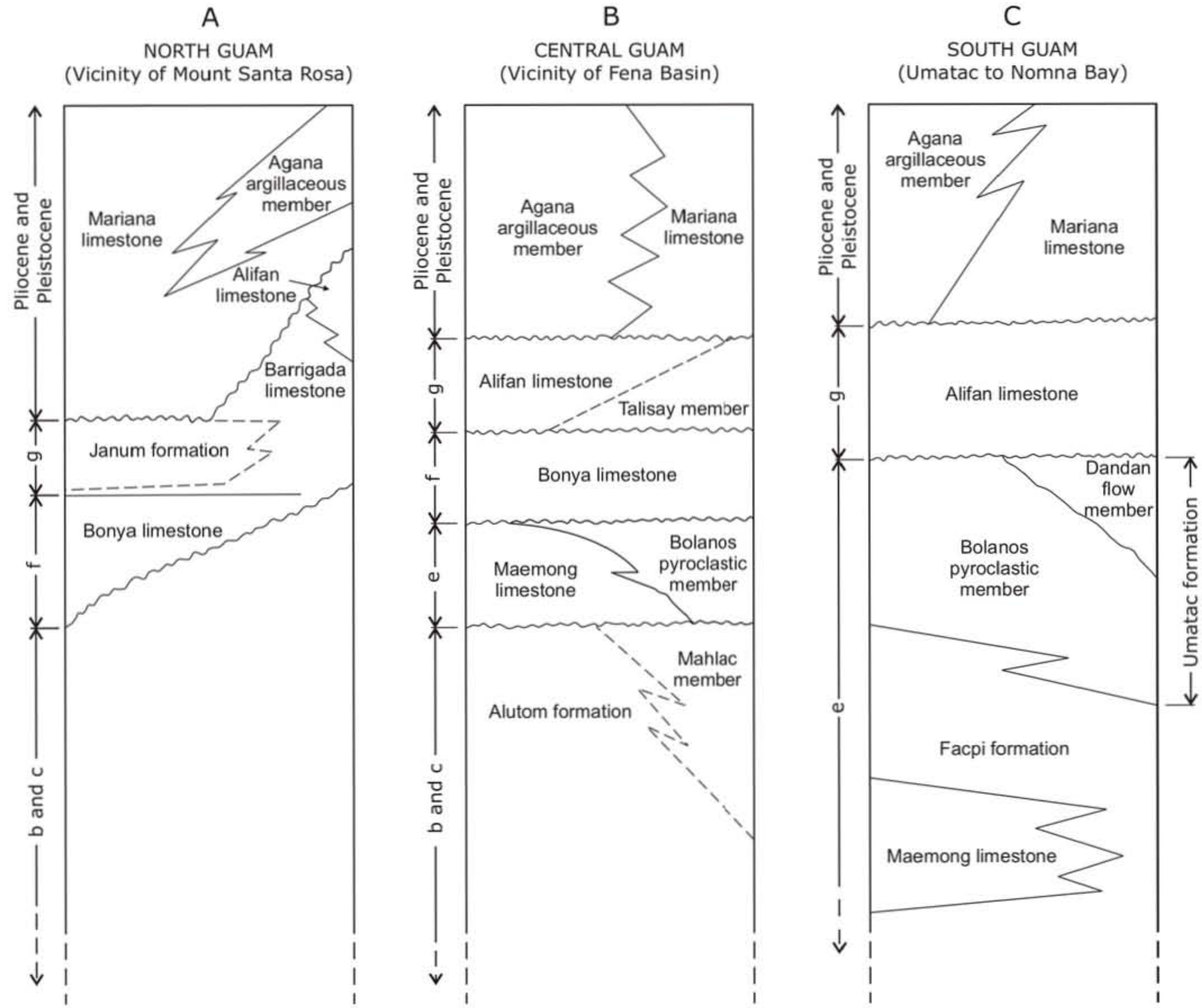


Figure 8. Stratigraphic sections for Guam. A, Generalized section of the north plateau. B, Generalized section in central Guam. C, Generalized section in south Guam. Thickness of formations vary widely within short distances. Letters in age column indicate correlation with Indonesian faunal zones of Van der Vlerk (1927). Figure taken from Tracey et al. (1964).

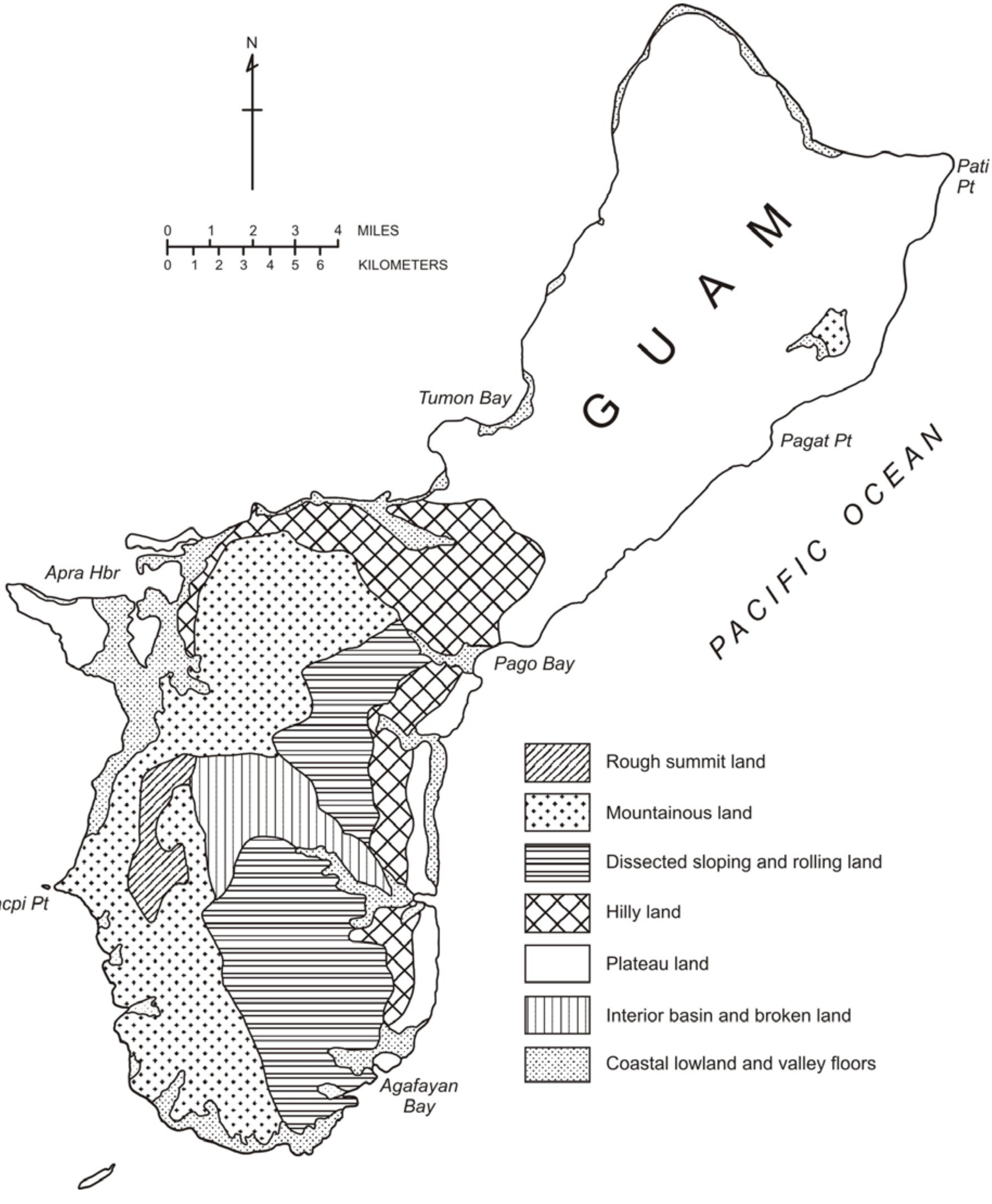


Figure 9. Physiographic divisions of Guam. Figure taken from Tracey et al. (1959).

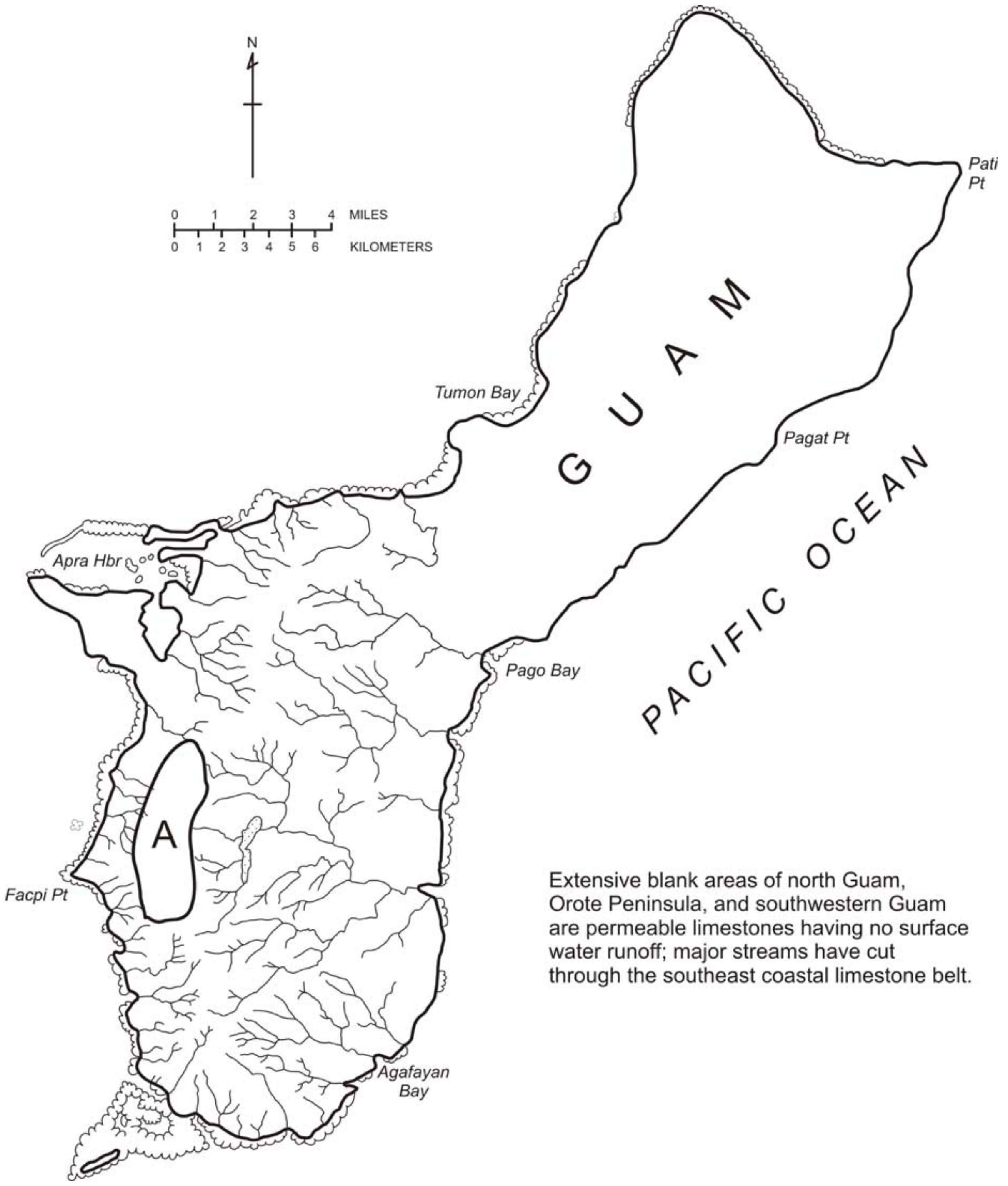


Figure 10. Drainage pattern of Guam. Not the absence of streams on the north plateau compared to the intricate system found in south Guam. Short streams of high gradient are found on the steep west slopes of south Guam, whereas longer low gradient streams with larger drainage basins are found on the east slopes of south Guam. A, is rough summit land. Figure modified from Tracey et al. (1959).

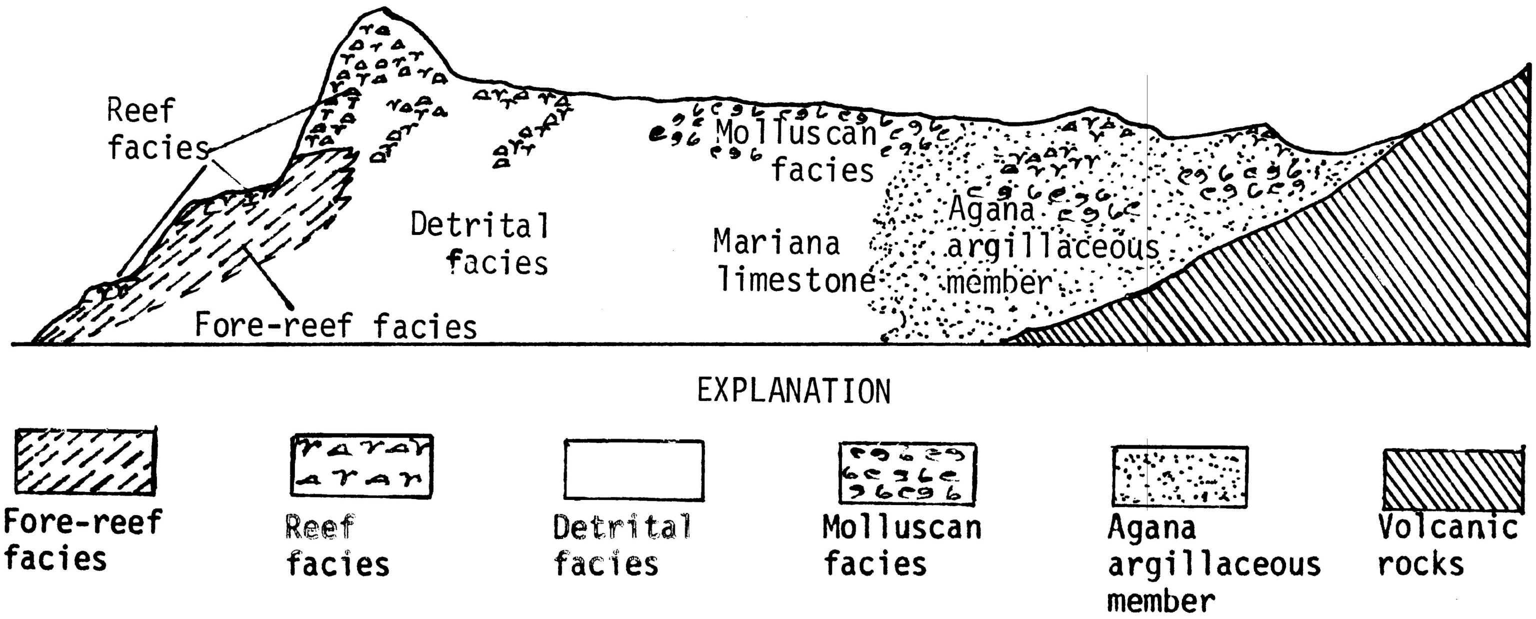


Figure 11. Relation of facies of the Mariana limestone. Diagrammatic section across limestone coast and cliffline to volcanic rock shows general distribution of reef, fore-reef, detritial and molluscan facies; and Agana argillaceous member. Figure taken from Tracey et al. (1964).

ENGINEERING GEOLOGY

EXPLANATION

Limestone Materials

1 - Compact Coralline Limestone. Massive, compact, recrystalized, white to light-brown limestone containing numerous coral heads in a hard, fine-grained algal matrix; includes some porous limestone and some limey rubble. Thick, irregular sheathings of Unit 1 occur on rugged coastal slopes, upon the seaward margins of porous limestones of Units 2 and 3. Excavation requires extensive drilling and blasting. This unit supplies very good cyclopean riprap, and crushed aggregate for base course, wearing course, and concrete. Large quarries are at Cabras Island and Fadian Point.

2 - Coralline Limestone And Rubble. Predominantly white to reddish-brown coralline rubble in a loose to porous lithified limesand matrix. There are also scattered massive ledges and lenses of vuggy and compact coralline limestone, and large, irregular exposures of chalky limestone; vuggy limestone commonly is along the margins of Unit 1, and chalky limestone generally is in the central part of Unit 2 on the northern plateau. Most rocks of Unit 2 can be excavated by power equipment; drilling and blasting will expedite removal of the vuggy limestone. Unit 2 supplies very good base course and, if processed, aggregate for roads; extensively developed and utilized.

3 - Clayey Coralline Limestone And Rubble. Predominantly reddish-brown, clayey, rubbly coralline limestone. There also are scattered lenses and beds of porous, clayey limestone; 5 to 20% of the unit is disseminated clay in the rock, and clay filling cavities in the rock. Locally the rock is buried by soils as much as 50 feet thick. Volcanic rocks of Unit 4 and 5 dip under the rocks of Unit 3. Most of Unit 3 can be excavated with power equipment; drilling and blasting will expedite excavation in compact limestone and in well bonded rubble. Unit 3 supplies good to fair aggregate for fill and sub-base, and clay-coated aggregate; Limited development for material for local roads and fill, and many small quarries (mostly abandoned). Concealed caverns are common.

Volcanic Rock Materials

4 - Volcanic Tuff. Predominantly thick, bedded, fine-grained volcanic tuffs. There also are interbedded volcanic conglomerates and breccias, and interbedded lava flows. Fractures and joints are common; locally there is complex folding and faulting. Most hard rock on rolling uplands is buried under 50 or more feet of clay and soft clayey rotten rock; much hard rock is exposed on steep and rough broken land. Weathered rock can be easily excavated with hand tools and power equipment; drilling and blasting will expedite removal of hard rock. Rarely used for construction materials; provides poor fill and embankment; selected hard boulders and compact limestone may be suitable for sub-base and base courses. Roadbeds and foundations for heavy installations on weathered rock must have adequate drainage.

5 - Volcanic Conglomerate. Predominantly dark-gray, massive volcanic conglomerate with included limestone fragments. There also are massive and bedded, gray tuffaceous shales and sandstones. Rocks of Unit 5 are similar in character to those of Unit 4, but are less fractured and faulted. Much of Unit 5 is deeply weathered.

6 - Lava Flows. Upper part of the unit consists of basalt flows with interbedded massive and bedded tuffaceous shales, sandstones, and conglomerates; the lower part, of thick, moderately hard pillow basalts and dikes. There is some interbedded grayish limestone. Weathered rock can be easily excavated by hand and power tools; hard rock must be drilled and blasted. Much of the rock is deeply weathered to clay. Not used for construction materials, although hard dike rock is very good for crushed aggregate. Roadbeds and foundations, especially on weathered rock must have adequate drainage.

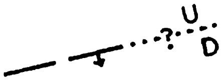
Unconsolidated Materials

7 - Beach Sands And Gravels. Predominantly discontinuous veneering beach and embayment deposits of unconsolidated limey granular materials. Materials include fragments of shells, corals, algae, and other reef materials. Volcanic detritus and clay are common constituents along volcanic rock coasts, and are major constituents of the mouths of rivers draining volcanic rock hinterlands. Beach materials above the water table can be easily excavated with hand tools and power equipment. Unit 7 supplies limesand for filler in coarse aggregate and blanket cover on clays. Active sand pits are at Tumon and Tarague embayments.

8 - Lagoonal Deposits. Limey, granular marine deposits 10 to 50 feet thick in the shallow basins of larger lagoons; generally contaminated by clay and organic material. Granular material ranges in size from silt to pebble and gravel to large coral boulders as much as 10 feet in diameter; average size is sand and gravel, or cobbly gravel. Can be easily excavated with dredging equipment and dragline. Significant reserves are at Apra Harbor and Cocos Lagoon and probably in embayments along the southeast coast; used extensively around Apra Harbor for fill.

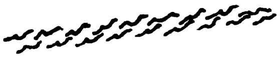
9 - Alluvium. Predominantly clayey sediments 5 to 150 feet thick in nearly all valley bottoms and on gently sloping alluvial fans and earthy floors in large basins in limestone terrain. Subsoils are varicolored clays and silts, generally firm to plastic when moist, soft, and plastic and sticky when wet, hard and cracked when dry; topsoils are dark colored and contain much organic matter. Water table ranges in depth from a few feet near the coast to a few tens of feet inland. Clays are viscous and soupy in saturated zones. Dry earth material can be easily excavated by hand tools and power equipment; heavy equipment bogs down in wet seasons when flooding is common. Clayey materials are generally unsuitable for construction uses.

F - Artificial Fill And Made Land.



FAULT, SHOWING DIP

Dashed where approximately located; dotted where concealed. Question mark indicates inferred fault. U, upthrown side; D, downthrown side.



BRECCIATED ZONE

Zone of many intersecting, closely spaced fractures. The rock in places comprises angular fragments in a friable matrix. Zone may grade along its trace to joint and fault zones, and at depth, to massive, structureless rocks.

THRUST FAULT

Dashed where inferred. T indicates upper side of fault.

ANTICLINE

Showing location of structural ridge. Single arrow at end indicates direction of downward inclination of the structure.

SYNCLINE

Showing location of structural trough. Single arrow at end indicates direction of downward inclination of the structure.

STRIKE AND DIP OF INCLINED JOINTS

STRIKE OF VERTICAL JOINTS

QUARRY OR PIT

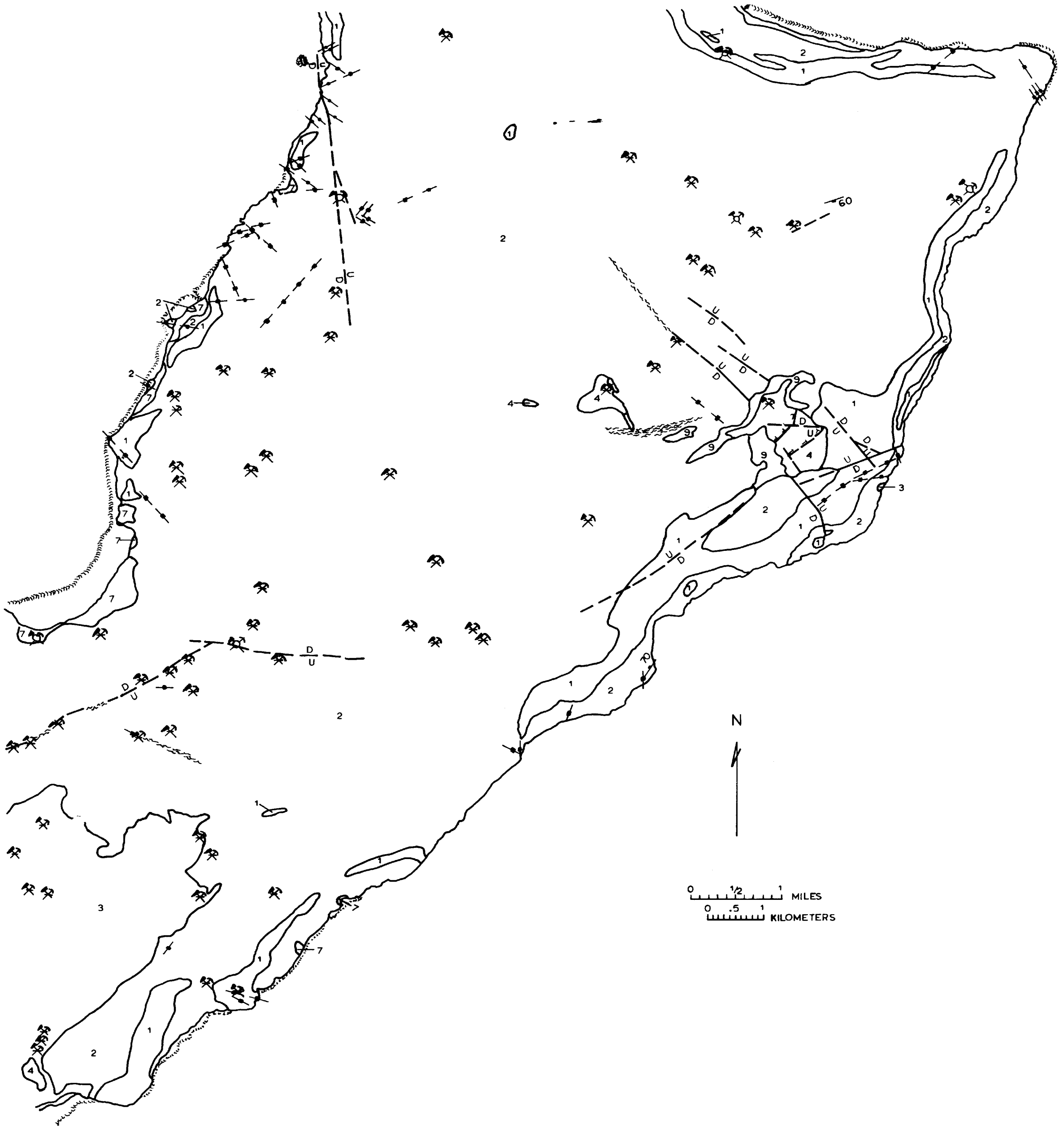


Figure 12a. Engineering geology map for Sectors I, III, IV, and V. A map legend and explanation for the geology map units (1–9) is given on pages 193–195. To be used in conjunction with Tables 5 and 6 (pages 373–376). Map modified from Tracey et al. (1959).

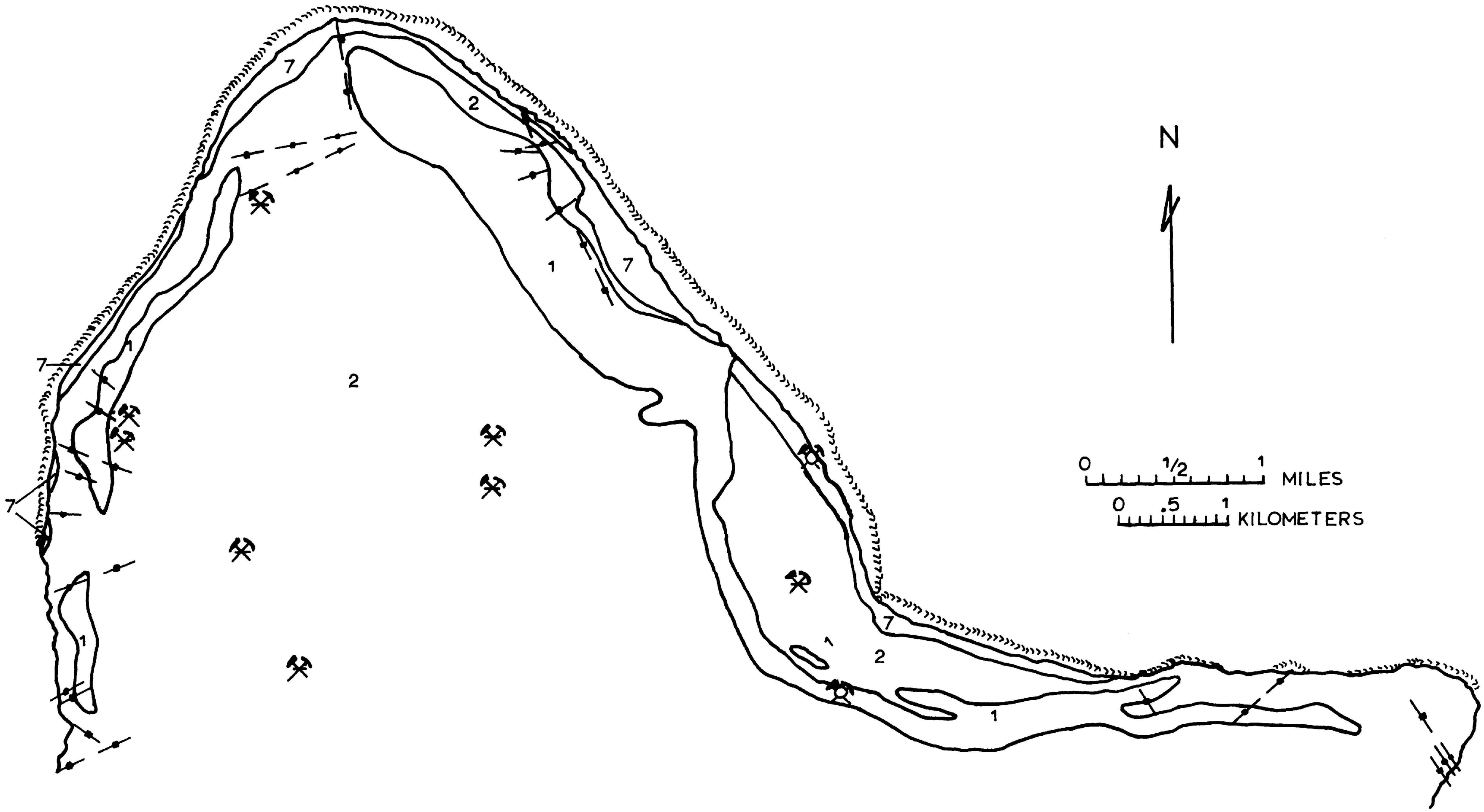


Figure 12b. Engineering geology map for Sector II and northern part of Sector III. A map legend and explanation for the geology map units (1–9) is given on pages 193–195. To be used in conjunction with Tables 5 and 6 (pages 373–376). Map modified from Tracey et al. (1959).

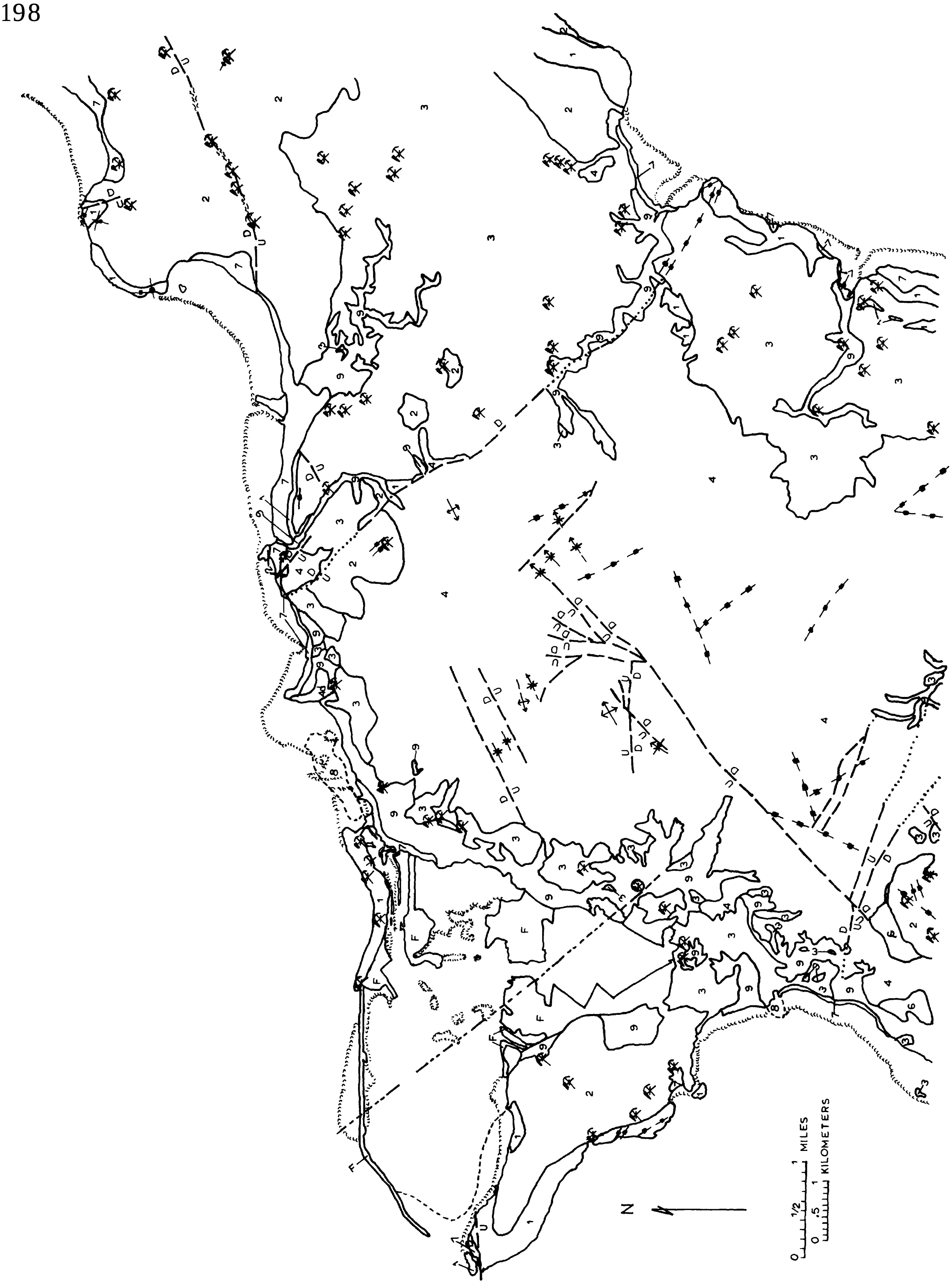


Figure 12c. Engineering geology map for Sectors VI, VII, VIII, IX, and the northern parts of X and XII. A map legend and explanation for the geology map units (1–9) is given on pages 193–195. To be used in conjunction with Tables 5 and 6 (pages 373–376). Map modified from Tracey et al. (1959).

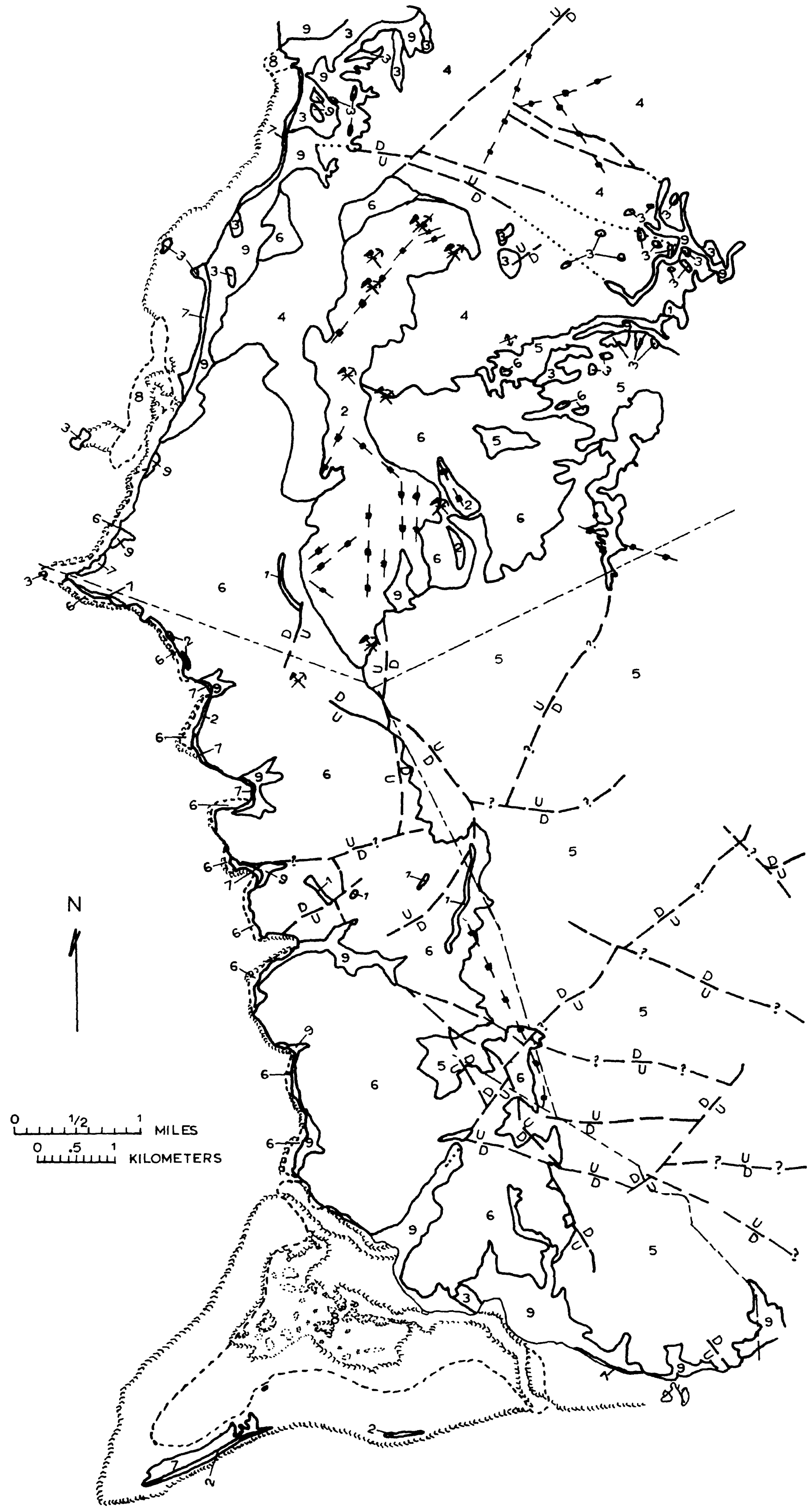


Figure 12d. Engineering geology map for Sectors X (see 12c for northern part), the southern tip of Sector XII, and Sector XI A map legend and explanation for the geology map units (1–9) is given on pages 193–195. To be used in conjunction with Tables 5 and 6 (pages 373–376). Map modified from Tracey et al. (1959).

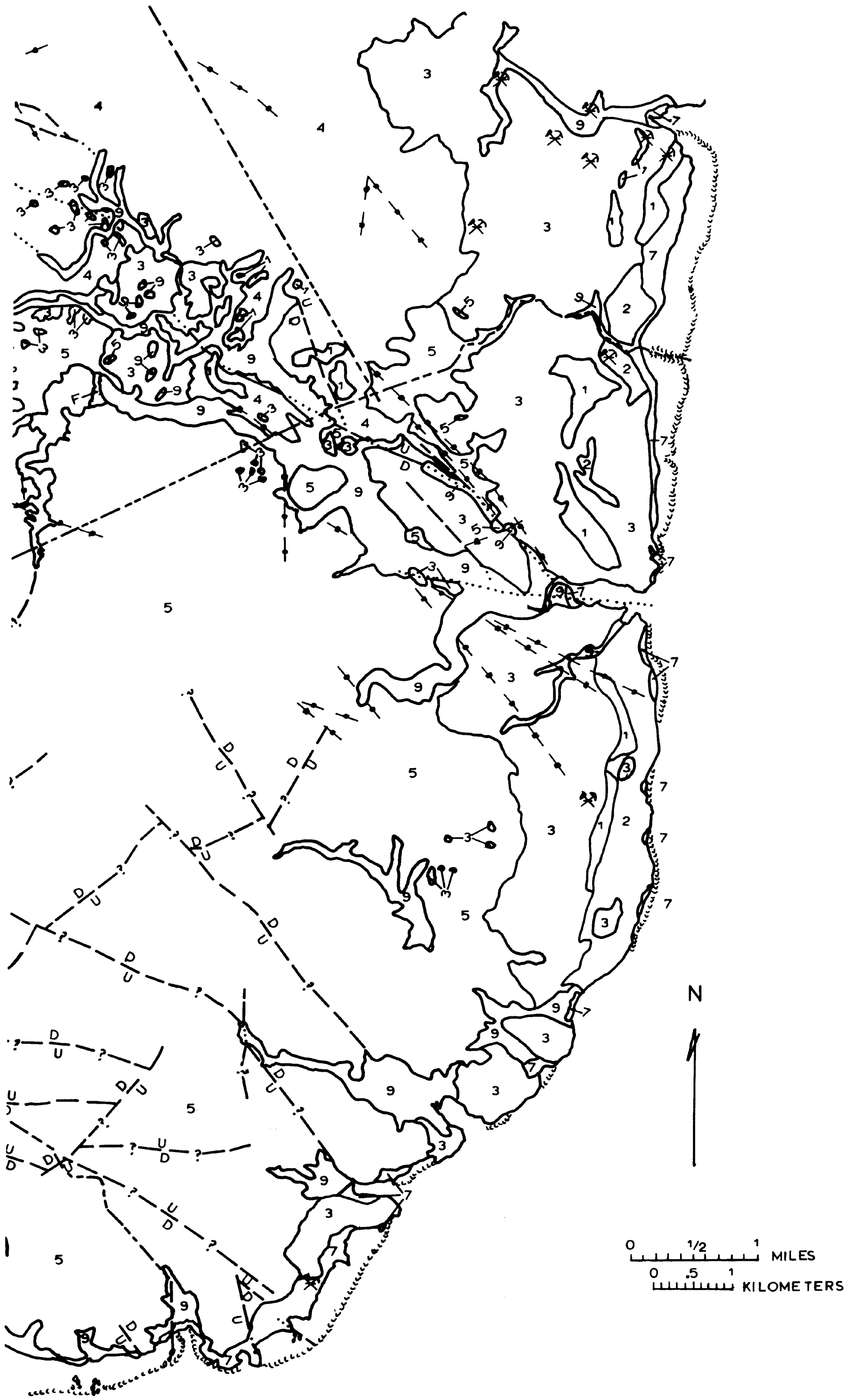


Figure 12e. Engineering geology map for all but the northern and western parts of Sector XII (see Figures 12c and 12d for the northern and southern parts). A map legend and explanation for the geology map units (1–9) is given on pages 193–195. To be used in conjunction with Tables 5 and 6 (pages 373–376). Map modified from Tracey et al. (1959).

EXPLANATION FOR GROUND-WATER AREAS (FIG. 13)

1

Area underlain by limestone containing ground water that stands 5 to 7 feet above sea level. Limestone has high permeability and yields water readily to drilled wells and tunnels. Locally, especially near boundary with area 7, relatively impermeable volcanic rock and non- calcareous sediments underlying the limestone may be present above sea level. Most of the water has a chloride content less than 100 ppm, but heavy pumping of wells may cause intrusion of sea water and an increase in salinity

2

Area underlain by limestone containing ground water that stands 3 to 7 feet above sea level. Limestone has high permeability and will yield water readily to drilled wells and tunnels. Most of the water has a chloride content less than 250 ppm, but heavy pumping of wells probably will cause sea-water intrusion and an increase in salinity

3a 3b 3c 3d

Area underlain by limestone containing ground water

In subarea 3a the limestone has high permeability, and the water table stands 1 to 5 feet above sea level. Chloride content of the water ranges from 30 ppm in interior parts of the subarea to more than 1,000 ppm in coastal parts. Heavy pumping of most wells will cause sea-water intrusion and an increase in the salinity of the water. Janum Spring which is at sea level on the eastern shore, has a discharge ranging from 1 to 3 mgd and a chloride content of about 30 ppm

In subarea 3b the water table stands 1 to 5 feet above sea level, and when undisturbed by pumping, the water contains 30 to 400 ppm of chloroide. Sea-water intrusion and large increases in salinity occur when wells are pumped at rates greater than 50 to 100 gpm

In subarea 3c the limestone has lower permeability than the rock in other parts of area 3, and the height of the water table ranges from about 1 foot above sea level in coastal parts to about 20 feet in interior parts. The water generally contains less than about 40 ppm of chloride, but the salinity may rise in heavily pumped wells. Agana Spring yields water having a chloride content of 30 to 40 ppm and has an average flow greater than 1 mgd

In subarea 3d the water table stands 1 to 4 feet above sea level, and when undisturbed by pumping, the water has a chloride content ranging from 30 to more than 1,000 ppm. The limestone yields water readily to wells and tunnels, but pumping causes intrusion of sea water, and most wells yield water having more than 500 ppm of chloride

Explanation For Ground-Water Areas (Fig. 13). Continued.

4a 4b

Area consisting of limestone caps on hills of volcanic rock. The limestone contains thin bodies of high-level ground water that are perched on relatively impermeable volcanic rocks. The water discharges at springs at the edges of the limestone caps. Flow of the springs varies greatly with seasonal rainfall

5a 5b 5c

Area in coastal parts of southern Guam underlain by limestone, alluvium, and beach deposits containing ground water. Most of the water is brackish. Locally, deposits of alluvium may contain water having less than 500 ppm of chloride, but the yields are low. The limestone and beach deposits have generally high permeability

6a 6b

Area underlain by volcanic rock and noncalcareous sediments, which contain large amounts of ground water but have very low permeability, and by limestone, which contains only meager amounts of ground water

The water-bearing materials of subarea 6a are largely volcanic rock and associated sediments. Height of the water table ranges from a few feet above sea level in coastal lowlands to several hundred feet in interior highlands. Wells have low yield and high drawdown. Average specific capacity of wells is about 1 gpm per foot of drawdown. Numerous small springs and seeps occur in valleys

Subarea 6b is underlain by limestone that rests on a steeply dipping surface eroded in volcanic rock and noncalcareous sediments. Meager amounts of ground water may occur locally perched on the volcanic rock, but most of the limestone is dry

7

Area underlain by permeable limestone that lies above sea level on relatively impermeable volcanic rock and noncalcareous sediments. The limestone contains little or no ground water. Wells drilled into volcanic rock would have very low yields.

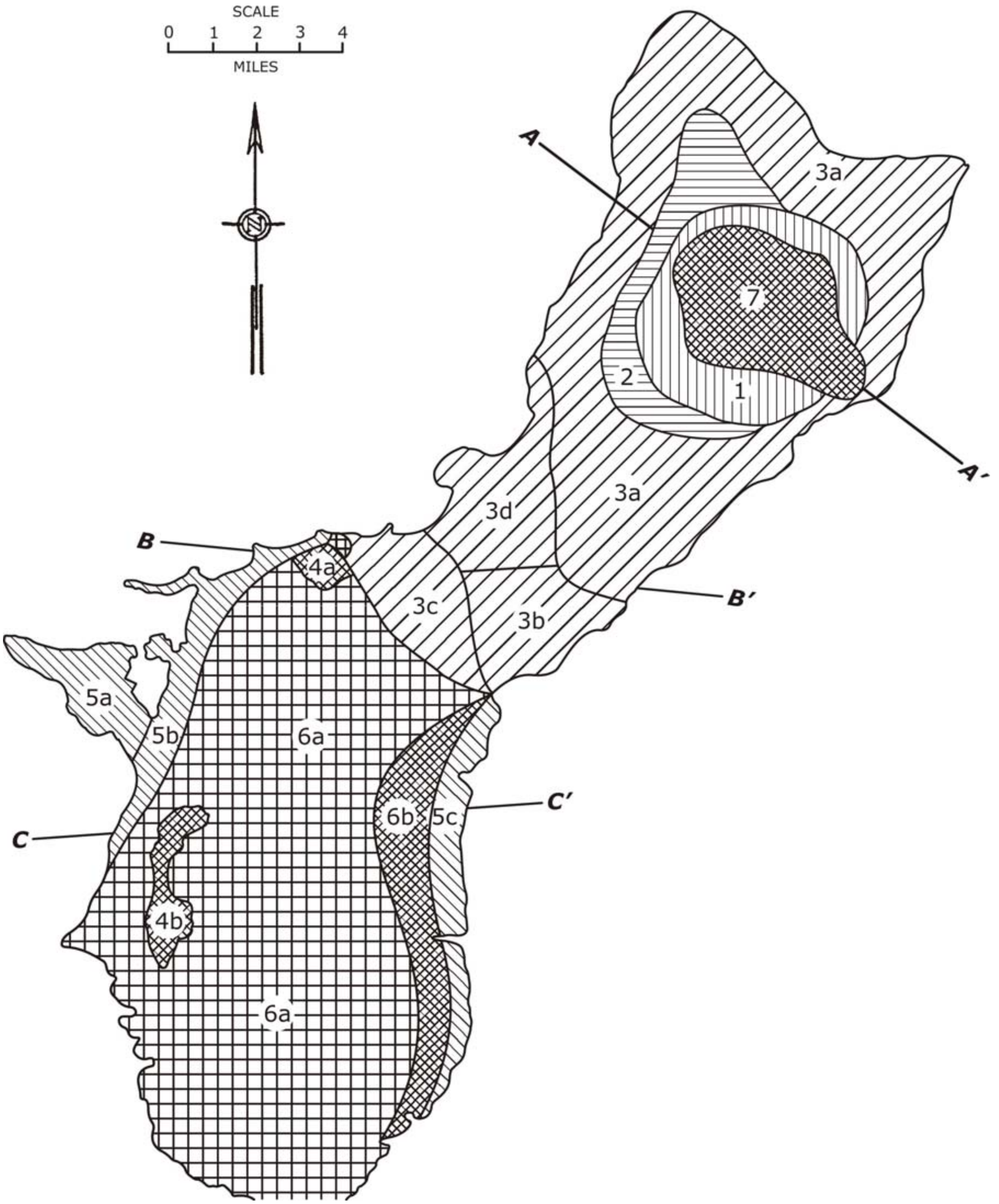


Figure 13. Map showing ground-water areas in Guam, and the locations of geologic sections shown in Figure 14. An explanation legend is given on the two preceding pages. Figure taken from Ward and Brookhart (1962).

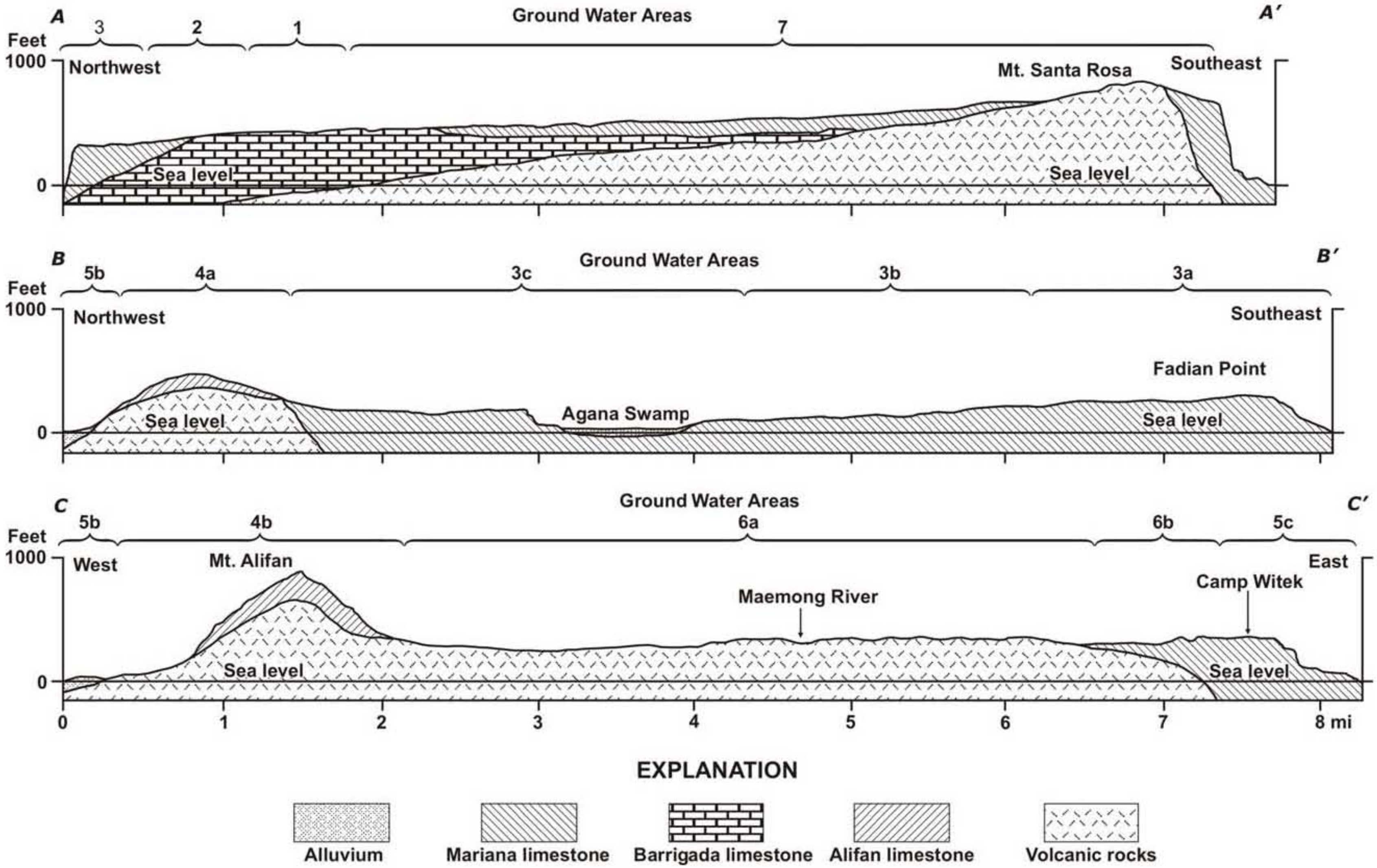
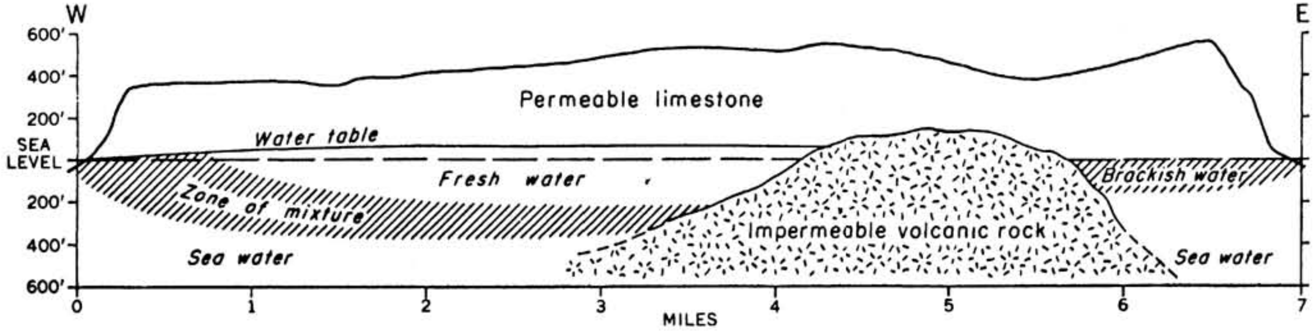


Figure 14. Geologic sections in the ground-water areas of Guam. Locations of the sections are shown in Figure 13. Figure taken from Ward and Brookhart (1962).



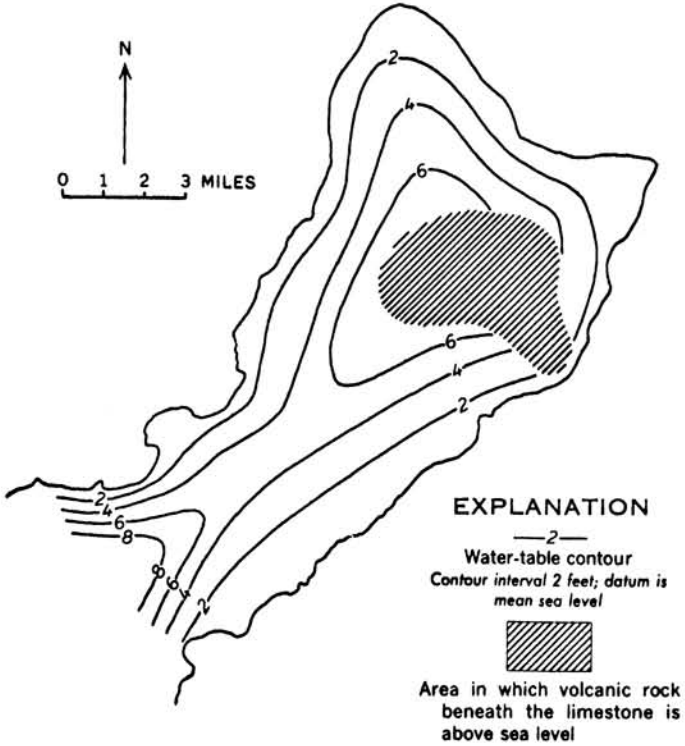


Figure 15 (at left). Approximate height of the water table in limestone in northern Guam. Figure taken from Ward et al. (1965).

Figure 16 (above). Occurrence of the fresh-water lens in limestone in northern Guam. Figure taken from Ward et al. (1965).

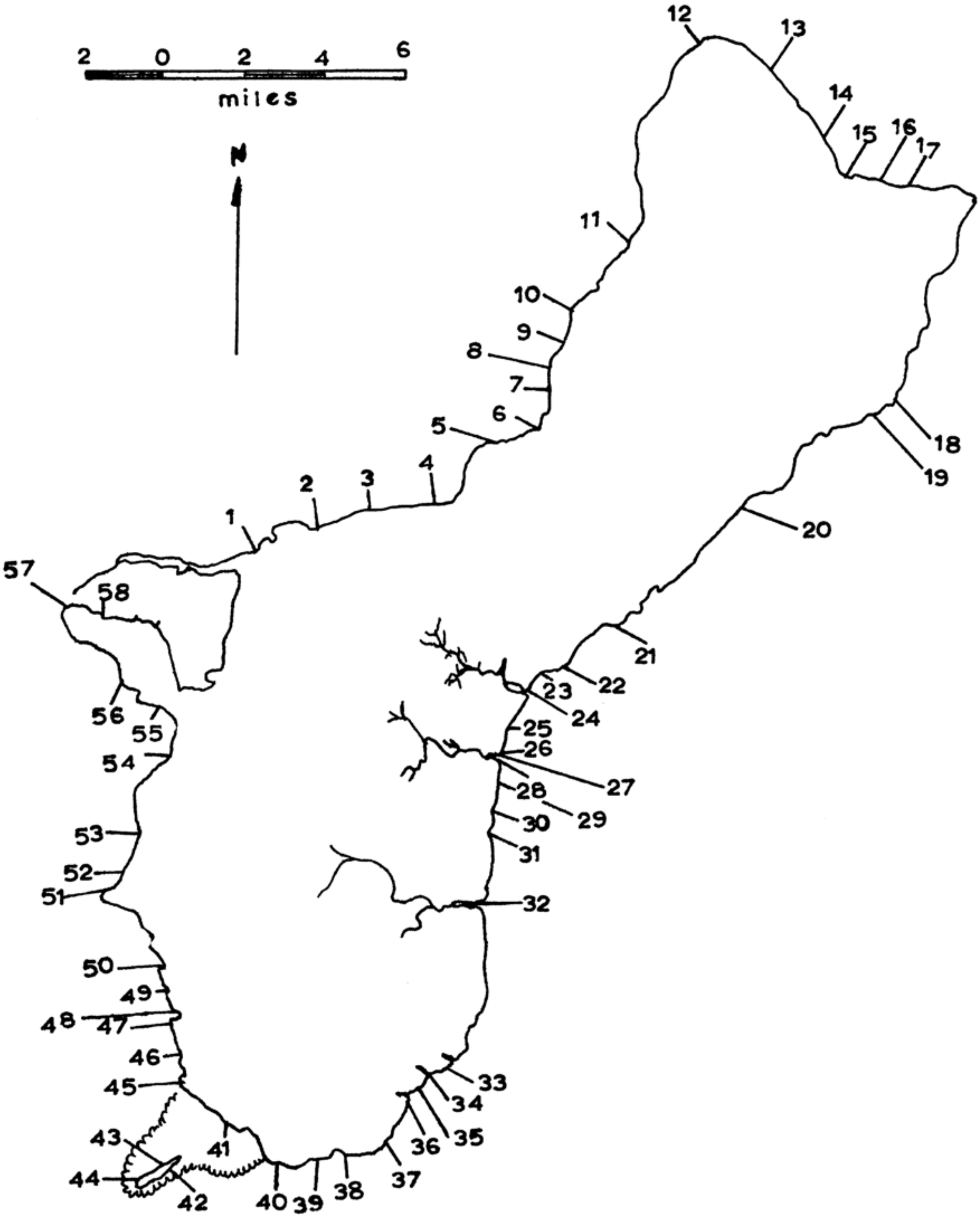


Figure 17. Locality numbers of beach-sand samples collected by Emery (1962). Map taken from Emery (1962).

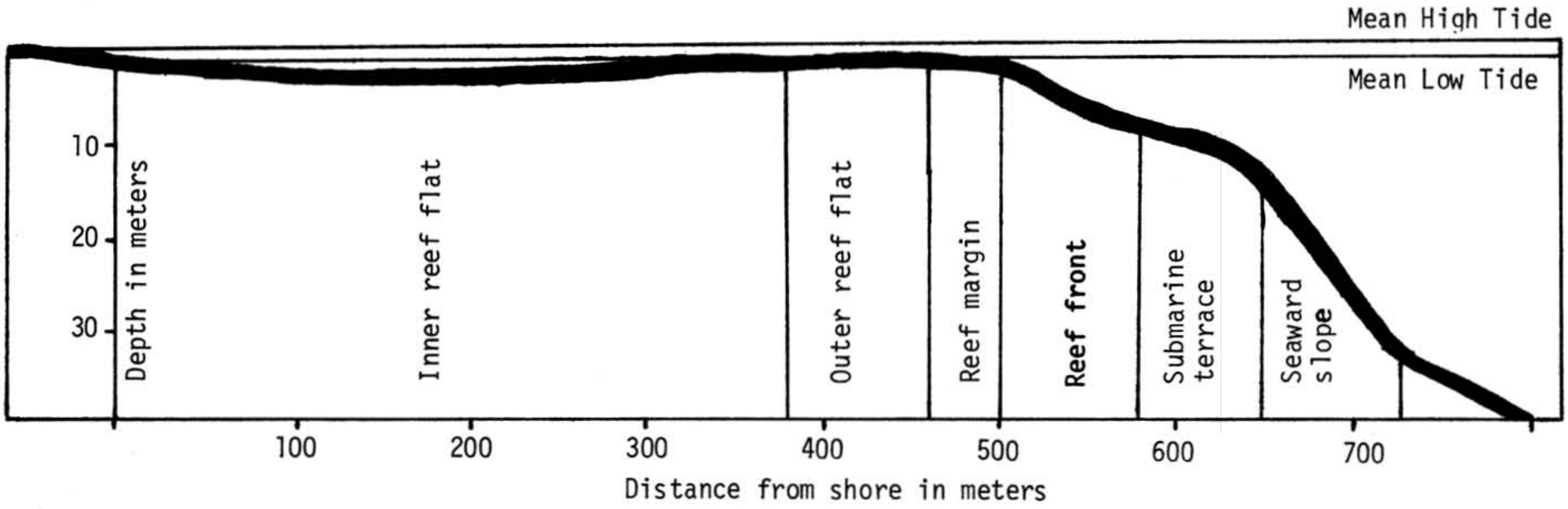


Figure 18. Vertical profile of the fringing reef at Naton Beach, Tumon Bay. The flattened region seaward of the seaward slope is the beginning of a second submarine terrace. For location of profile see Figure 88. Vertical exaggeration X5.

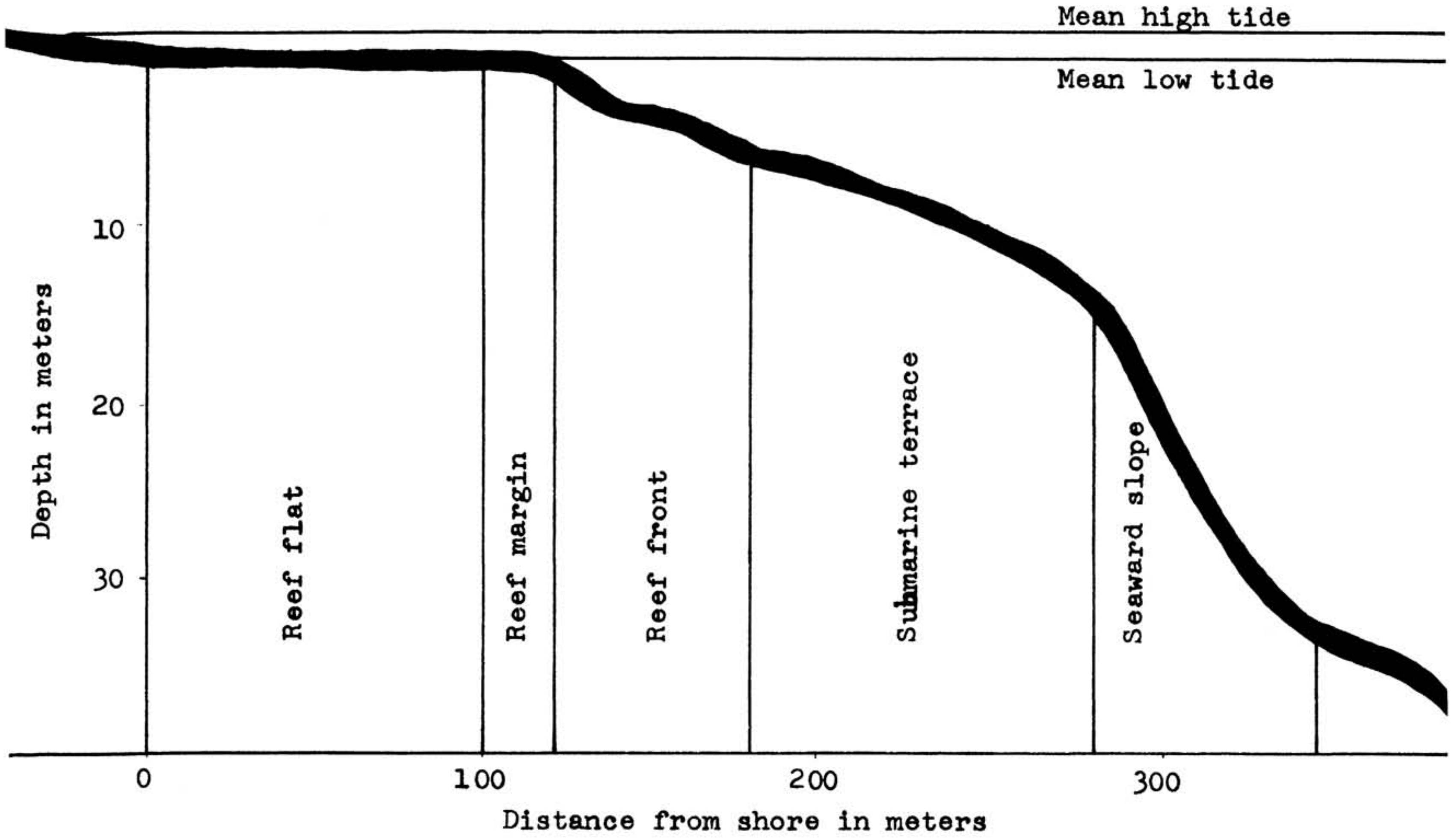


Figure 19. Vertical profile of the fringing reef at Tanguisson Point (Transect B). The flattened region seaward of the seaward slope is the beginning of a second submarine terrace. For location of profile see Figures 78 and 84. Vertical exaggeration X5.

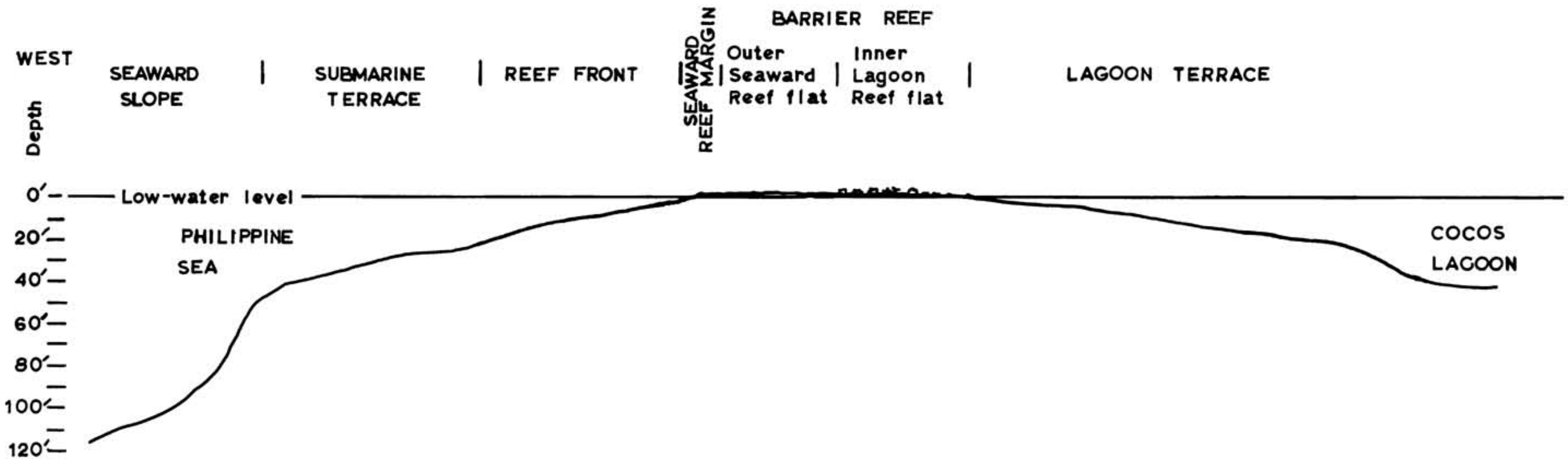


Figure 20. Vertical profile (A) of the western Cocos Barrier Reef. Horizontal distance not to scale. See Figure 156 for location of profile.

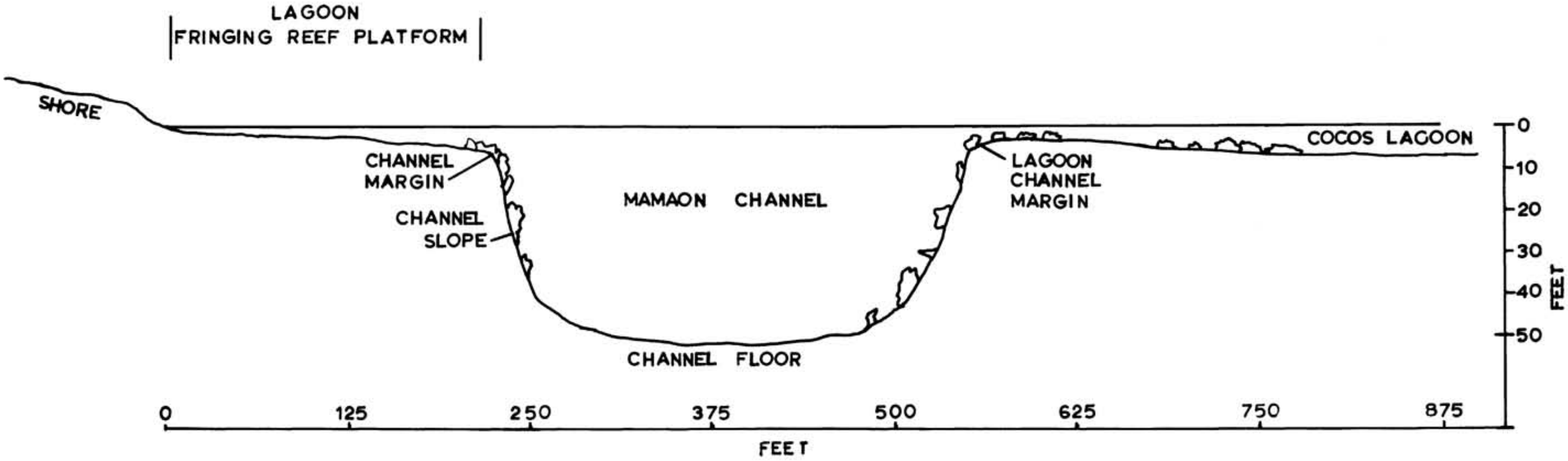


Figure 21. Vertical profile (B) of a lagoon fringing reef and deep channel. For location of profile see Figure 156.

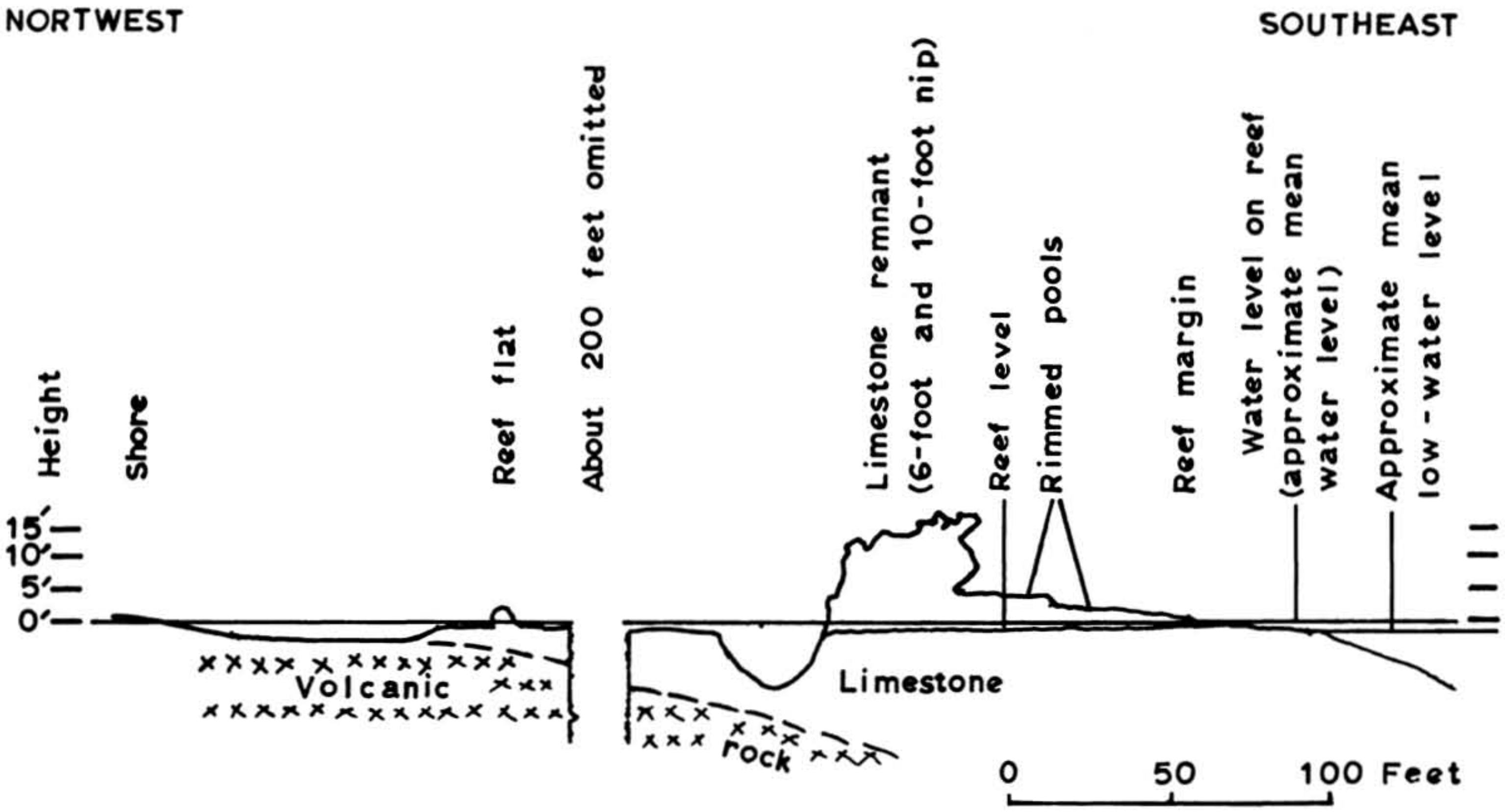


Figure 22. Vertical profile of a fringing reef at Agfayan Bay. See Figure 168c for location of profile. Figure from Tracey et al. (1964).

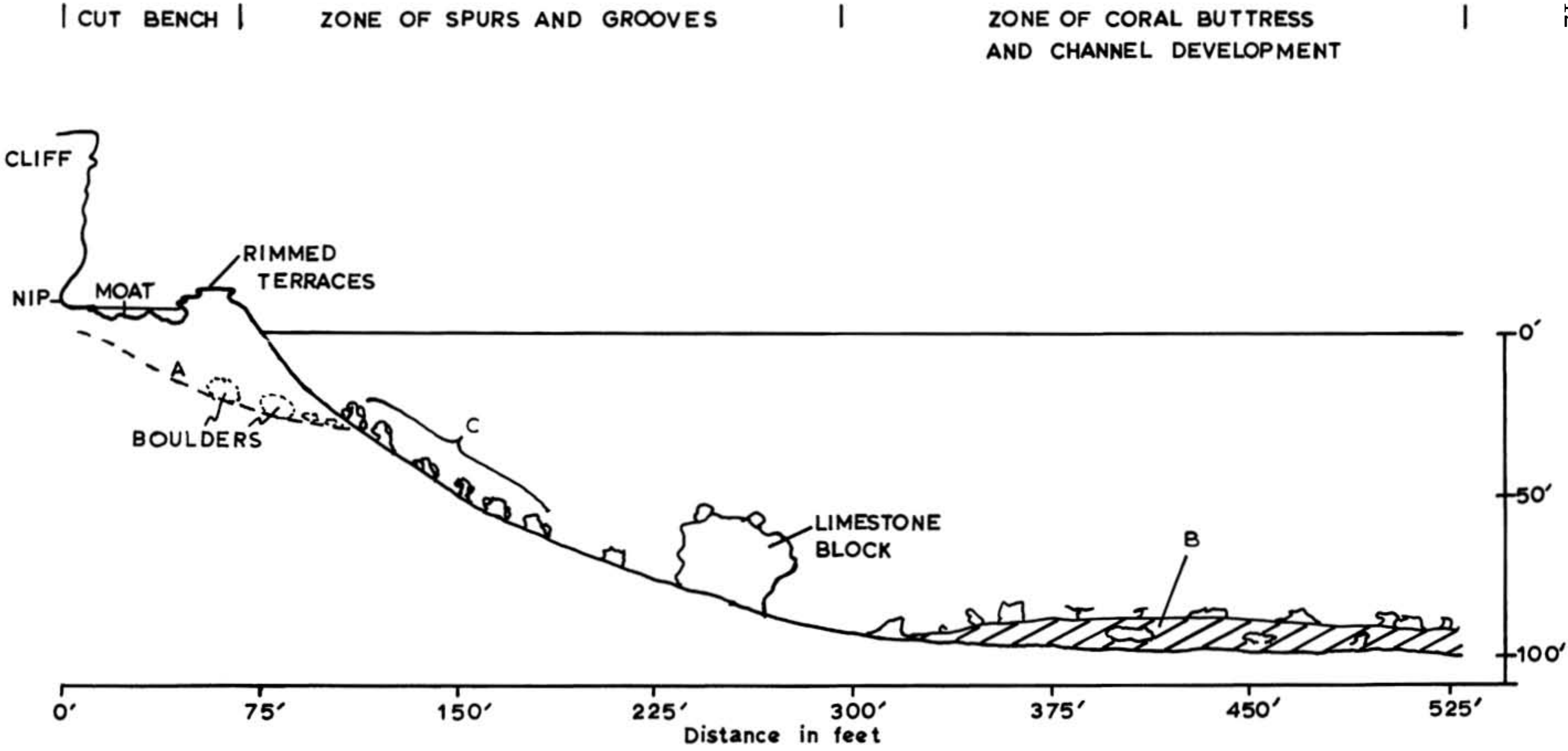


Figure 23. Vertical profile of a cut bench platform and offshore slope at Lafac Point (for location see Fig. 37). Point A is the floor level of the grooves and fissures that cut the bench platform, Point B is a ridge of coral development, and Point C is coral knolls and mounds.

Figure 24. Honeycombed reef margin. Numerous interconnecting holes permeate the seaward margin of this buttress at Pago Bay.

Figure 25. Algal ridge development at Pago Bay.

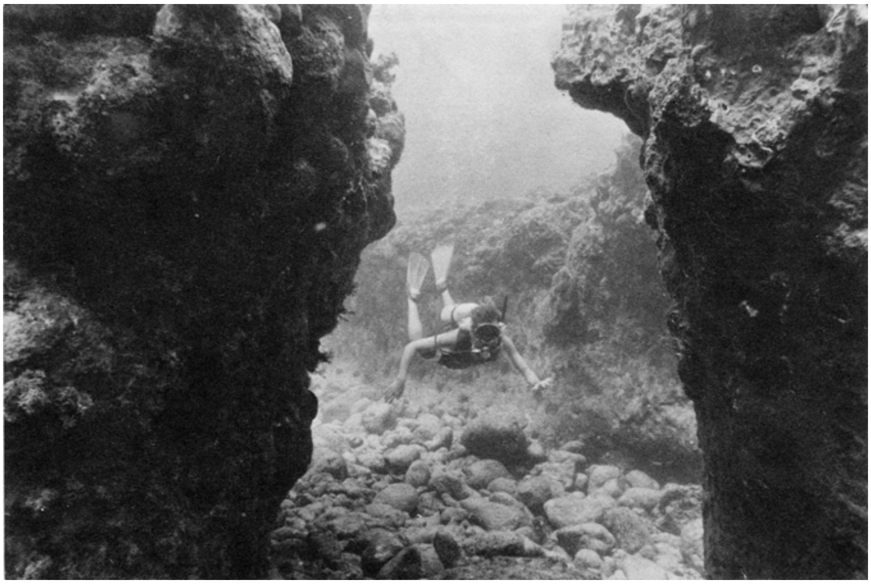


Figure 26. Submarine channels in the reef front zone a Tumon Bay.

Figure 27. Reef front buttress and channel development at Tumon Bay. The flat-topped bosses in the foreground and background are specialized regions of intensive coral-algal growth.

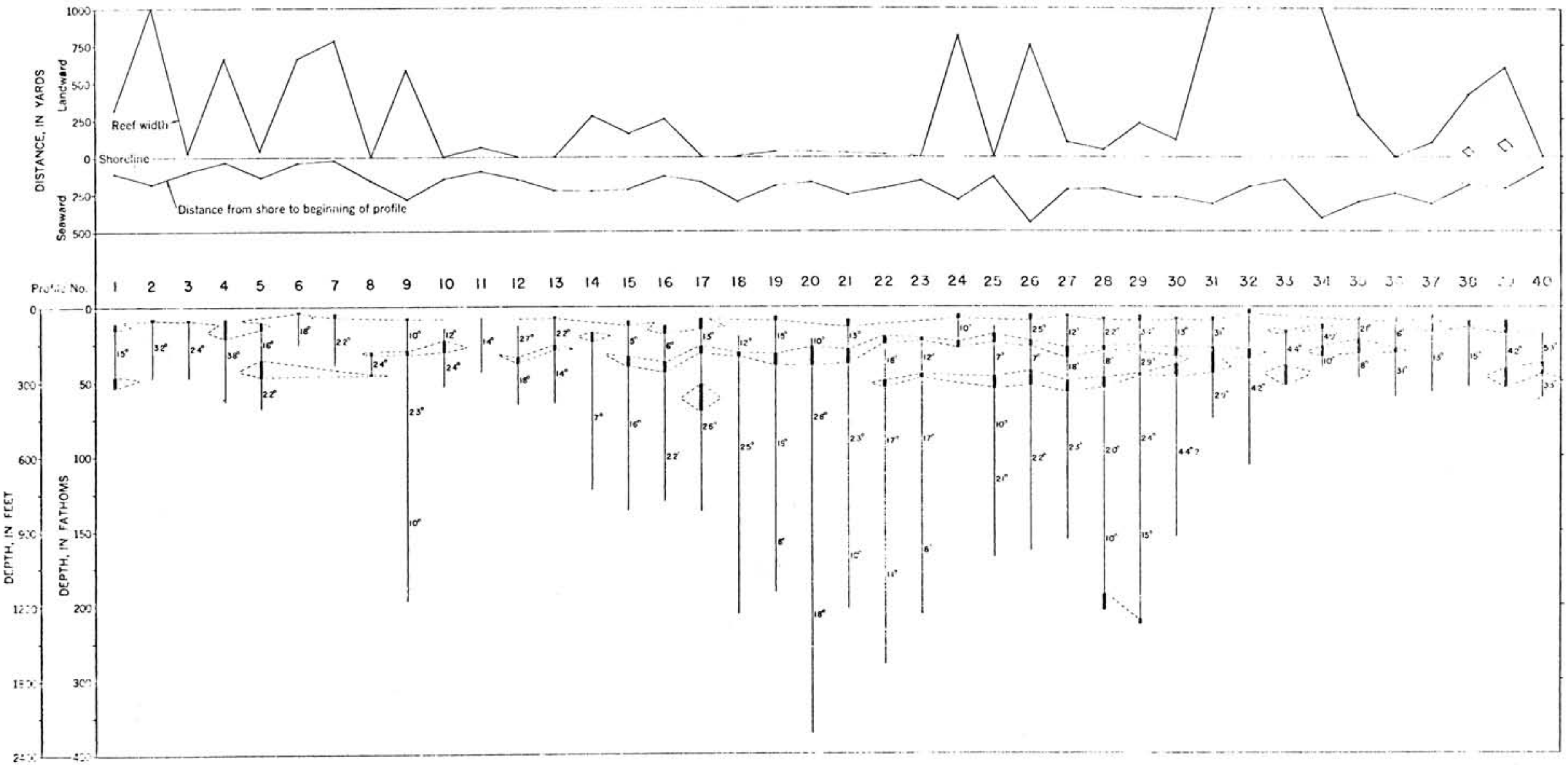


Figure 28. Graphical interpretation of Emery's (1962) offshore profiles. In lower half, wide lines indicate depth of flattenings or terraces; narrow lines indicate the depth range sounded but which contained no terraces. The average steepness is indicated by degrees for the steps between terraces. The upper half shows the distance of the inner end of the surrounding profile from the reef edge or other shoreline. The width of the reef opposite the profile is indicated to a maximum of 1,000 yards. See Figure 29 for profile location. Figure from Emery (1962).

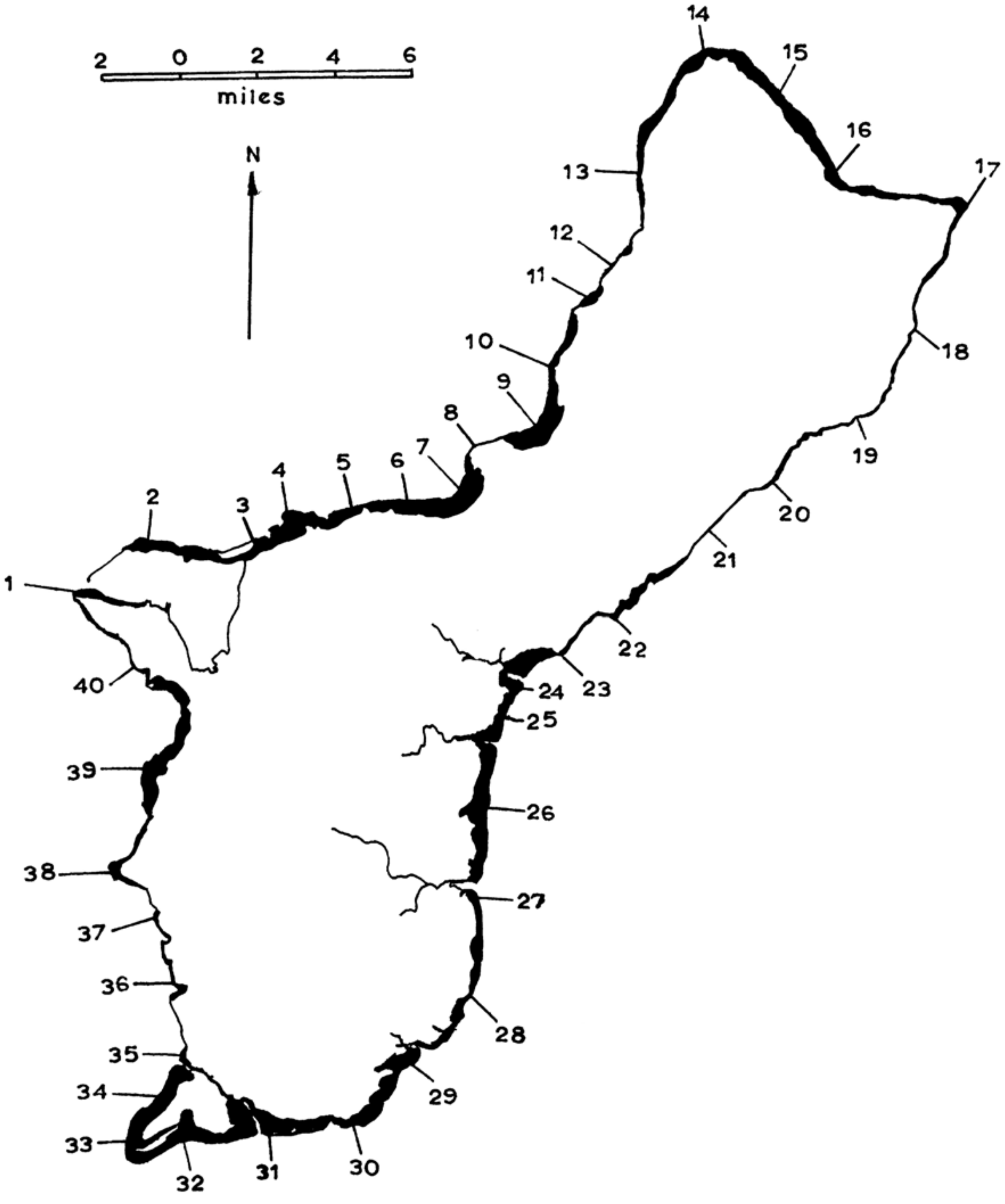


Figure 29. Location of Emery's (1962) offshore profiles (1 40). Black areas represent fringing reef flat and barrier reef flat platforms.

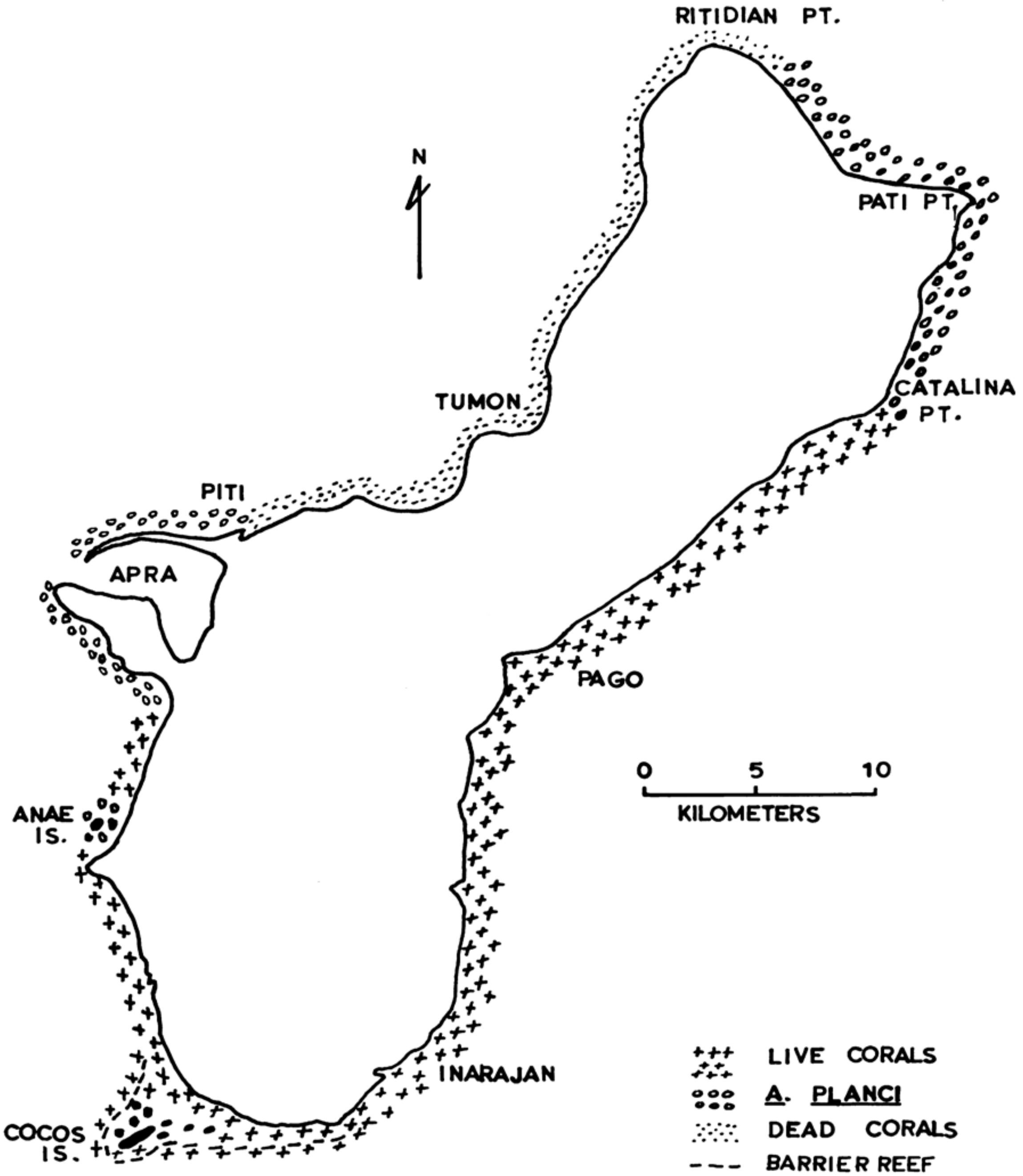


Figure 30. Status of *Acanthaster planci* and coral conditions on Guam during Summer, 1969. Figure taken from Tsuda (1971).

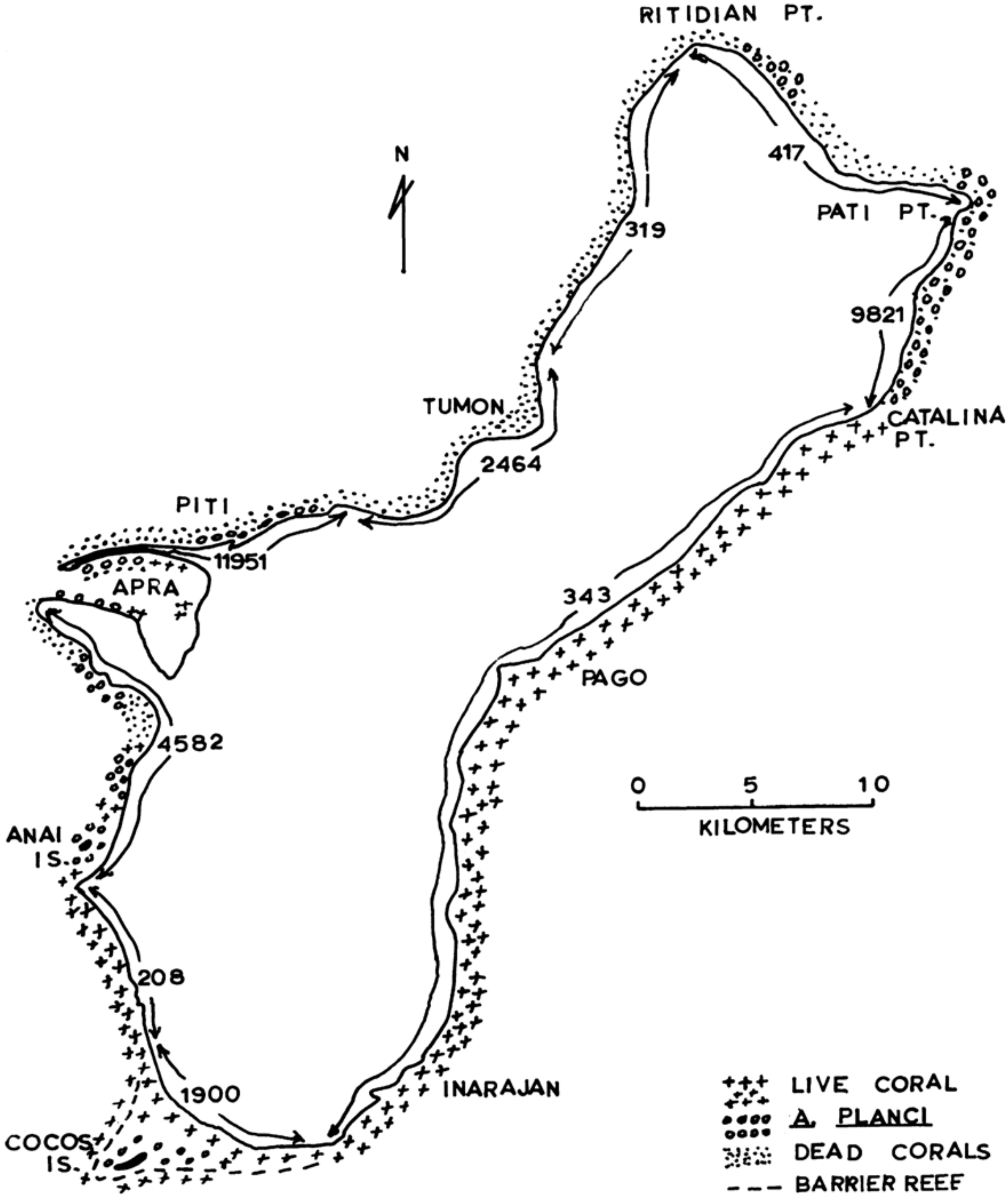


Figure 31. Status of *Acanthaster planci* and coral conditions on Guam during Summer, 1970. (Note: Numbers represent starfish killed between 1969 and August 1970 in different areas). Figure taken from Tsuda (1971).

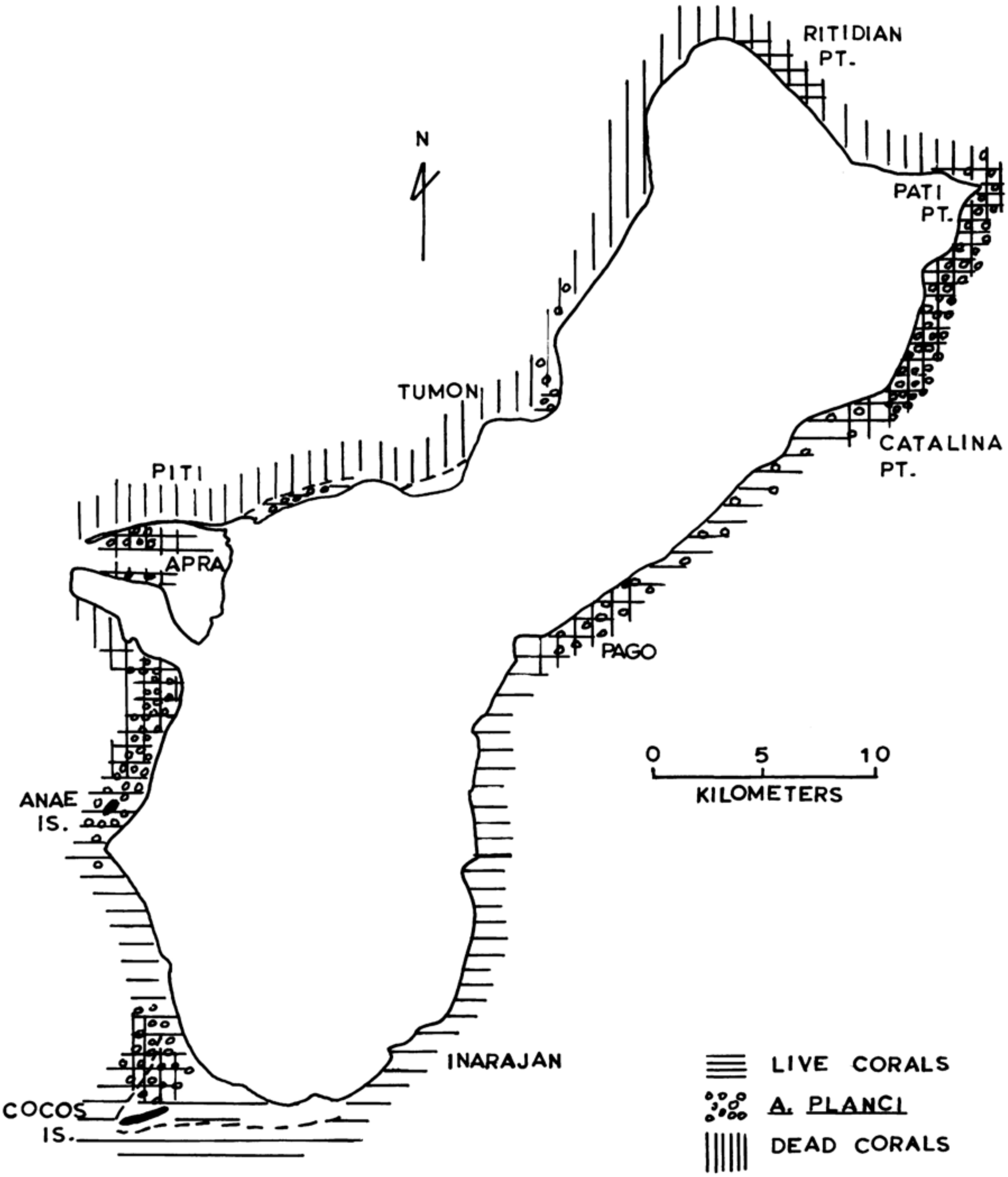


Figure 32. Status of *Acanthaster planci* and coral conditions on Guam during April 1971. Figure taken from Tsuda (1971).

VEGETATION MAPS

Explanation of Units

Forest Vegetation

1 - Mixed Forest on Limestone Plateaus and Cliffs. Basically a moist broad-leafed evergreen forest mostly dominated by wild breadfruit (*Artocarpus* or "dugdug") and banyan (*Ficus*); in some large areas, by screw-pine (*Pandanus*), or locally by other species. Varies to a dense scrub on edges and faces of cliffs and near the sea; where once cleared and abandoned or where badly damaged by war activities, it is principally a dense scrub forest of hibiscus and other secondary trees with scattered large dead or half-dead trunks towering above the general level of growth. Canopy irregular, up to 75 feet high; trees 6 inches or more in diameter are fairly closely to widely spaced; undergrowth sparse where forest is little disturbed to very dense where disturbance has been great. Concealment generally good; cover fair to poor. Some temporary construction timber available, but generally short and of poor quality.

2 - Mixed Forest on Volcanic Soil in Ravines and on Limestone Outcrops in Valleys. Basically a moist broad-leafed evergreen forest dominated locally by hibiscus or by screw-pine (*Pandanus*), rarely by wild breadfruit (*Artocarpus* or "dugdug"); usually very mixed, commonly containing betel palm (*Areca*) and with breadfruit scarce or absent; varies commonly to a dense scrub of limon-de-china (*Triphasia*) or to patches of reef marsh or hibiscus scrub. Coconut occasional to locally common. Stature generally low (seldom over 40 feet), canopy dense to irregular, large trees locally common and closely spaced; undergrowth generally dense, usually spiny. Concealment generally good; cover fair to usually poor. Some temporary construction timber of poor quality available locally. Unit may include small areas of savanna.

Swamp And Marsh Vegetation

3 - Swamp Forest. Mangrove and *Nypa* swamps locally near the sea, principally in river valley mouths, changing upstream to a mosaic of stands of *Barrinqtonia racemosa*, hibiscus, hibiscus and *Pandanus*, and reeds (*Phraqmites*). Stature is about 50 feet and canopy is continuous where *Barrinqtonia* is dominant; elsewhere stature is much lower and canopy may be continuous, irregular, or absent. Undergrowth very dense, except in *Barringtonia* stands. Substratum usually mucky and unstable. Concealment good; cover fair to absent. Little or no construction timber.

4 - Reed Marsh. Pure stands of reeds or canes (*Phragmites karka*) on wet ground or in standing water. Canes as much as one-half inch in diameter, 6 to 18 feet tall, very closely spaced. Concealment fair; cover lacking.

221

Grassland And Woody Or Herbaceous Vegetation And Cultivated Or Open Ground

5 - Savanna. Mosaic of several kinds of grassland and herbaceous vegetation and erosion scars with shrubs and tangled ferns. Swordgrass (*Miscanthus*) dominant over large areas. Small ironwood (*Casuarina*) trees scattered in many parts, locally forming sparse woodland. Swordgrass very dense, extremely difficult to traverse on foot, leaves likely to lacerate skin; areas of other vegetation easy to traverse. Concealment poor or lacking; cover lacking. Timber lacking. Unit may include small areas of ravine forest.

6 - Secondary Thicket And Cultivated Ground. Extremely variable vegetation resulting from long-continued disturbance by man; usually on argillaceous limestone. Fine mosaic of patches of forest, usually dominated by breadfruit; coconut groves, bamboo clumps, patches of scrub or shrub forest, home sites, small cultivated fields and patches, pastures, and very large areas of tangantangan (*Leucaena glauca*) thickets. Undergrowth very dense and spiny locally; marshy places common. Trees over 6 inches in diameter common and closely spaced in patches of breadfruit forest and coconut groves; trees less than 6 inches in diameter very abundant in other types of vegetation except that of cultivated fields and pastures. Concealment locally good or locally lacking; cover locally fair or locally lacking. Some poor quality construction timber available.

7 - Coconut Plantation. Vegetation commonly dominated by coconut trees, often planted in rows; trees 10 to 30 feet apart. Canopy 50 to 75 feet high, usually incomplete. Undergrowth usually dense, often very dense, sometimes spiny. Concealment good; cover fair. Coconut logs available.

8 - Predominantly Open Ground And Pasture. Open cultivated ground, pastureland, dwellings, and thickets. Concealment usually lacking; cover lacking. No timber.

9 - Bare Ground And Herbaceous To Shrubby Vegetation At Military Installations. Bare ground, tall grass, weed patches, and shrubby growth, changing constantly. Vegetation usually not a very significant feature. Usually affords little or no obstruction, little concealment, no cover, and no timber.

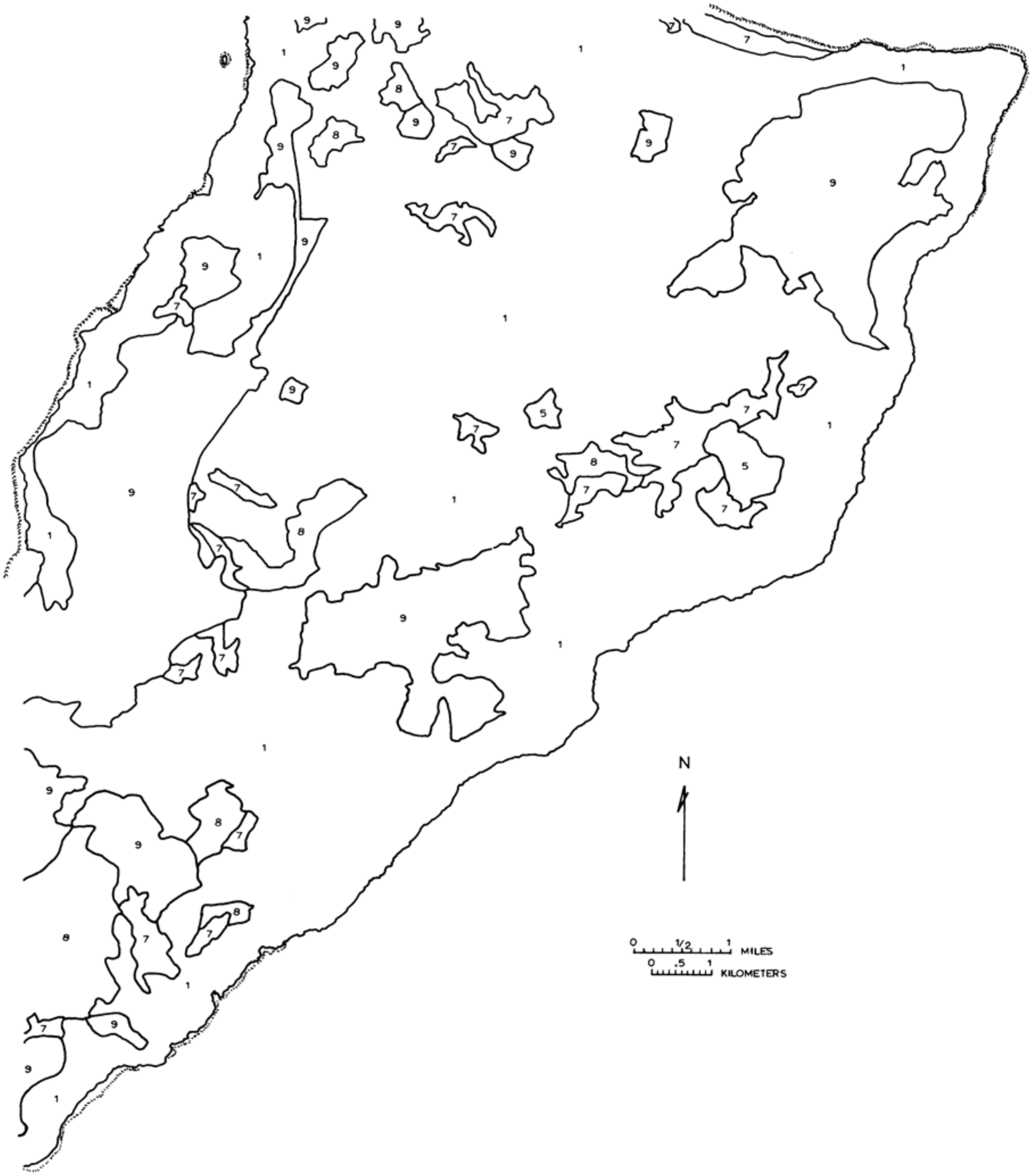


Figure 33a. Vegetation map for Sectors I, III, and IV. Legend explanation for vegetation units (1–9) are given on pages 220–221. Map and legend from Fosberg (*In* Tracey et al., 1959).

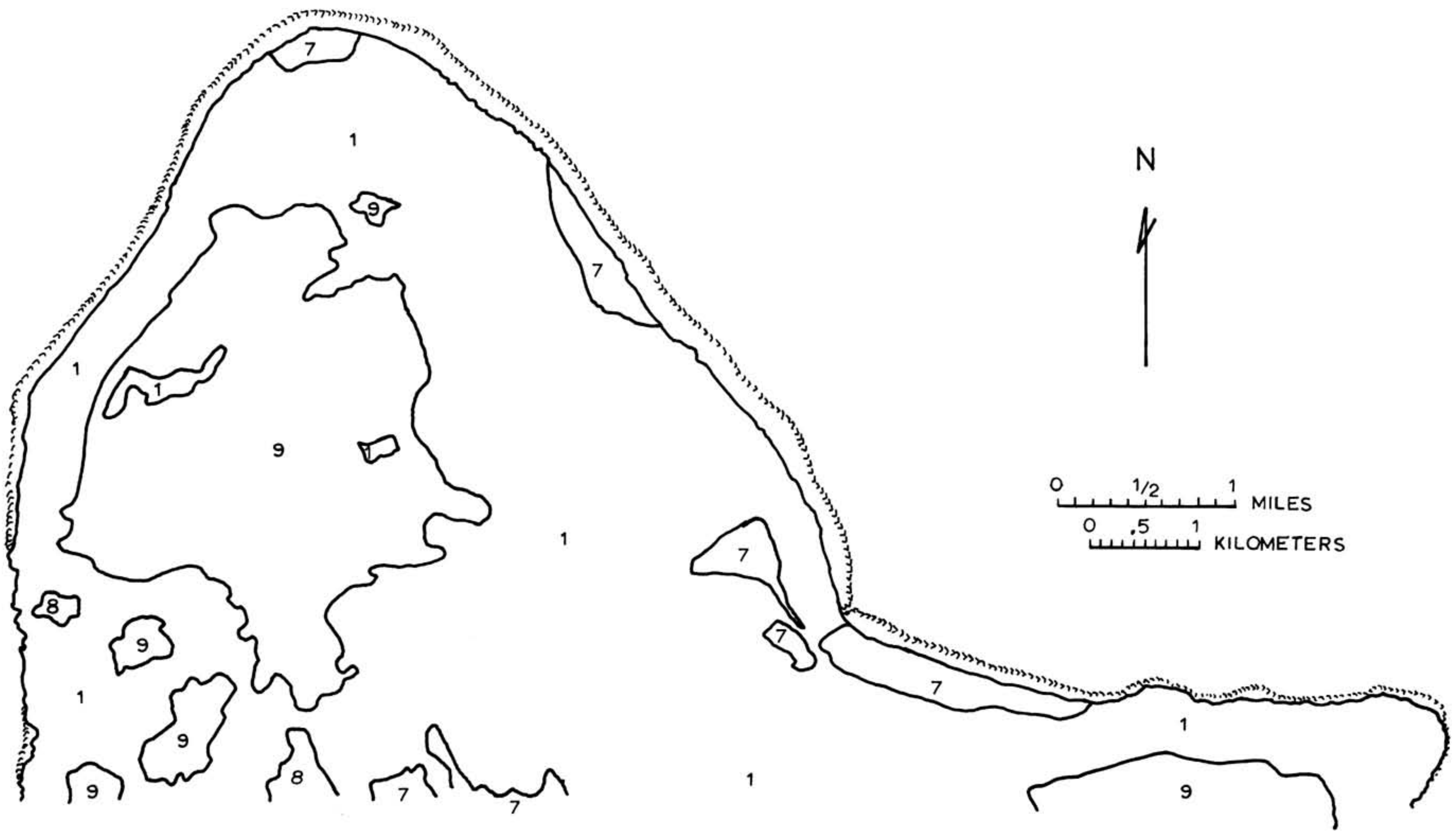


Figure 33b. Vegetation map for Sector II and northern part of Sector III. Legend explanation for vegetation units 1–9 are given on pages 220–221. Map and legend from Fosberg (*In* Tracey et al., 1959).

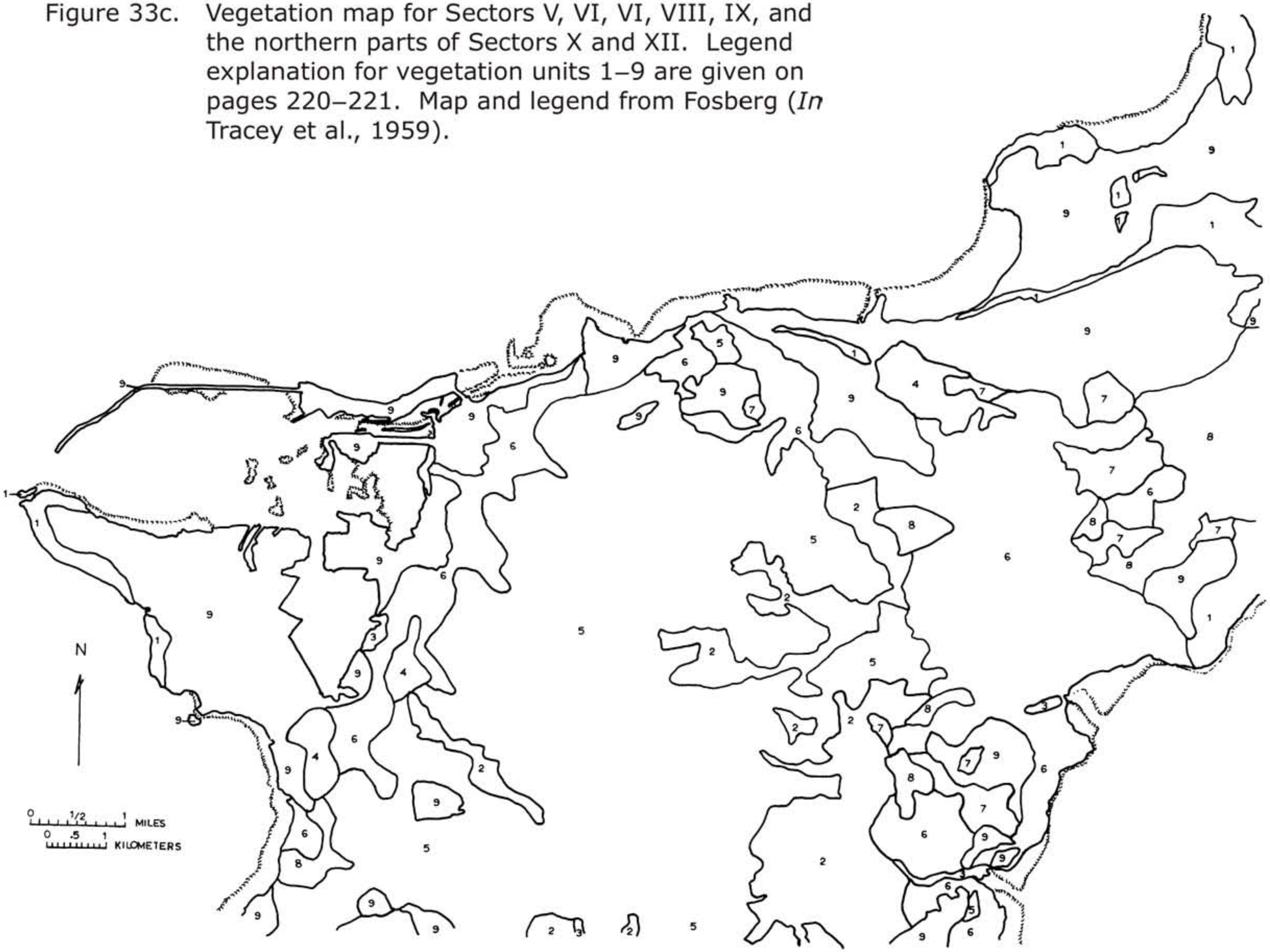


Figure 33c. Vegetation map for Sectors V, VI, VI, VIII, IX, and the northern parts of Sectors X and XII. Legend explanation for vegetation units 1–9 are given on pages 220–221. Map and legend from Fosberg (*In* Tracey et al., 1959).

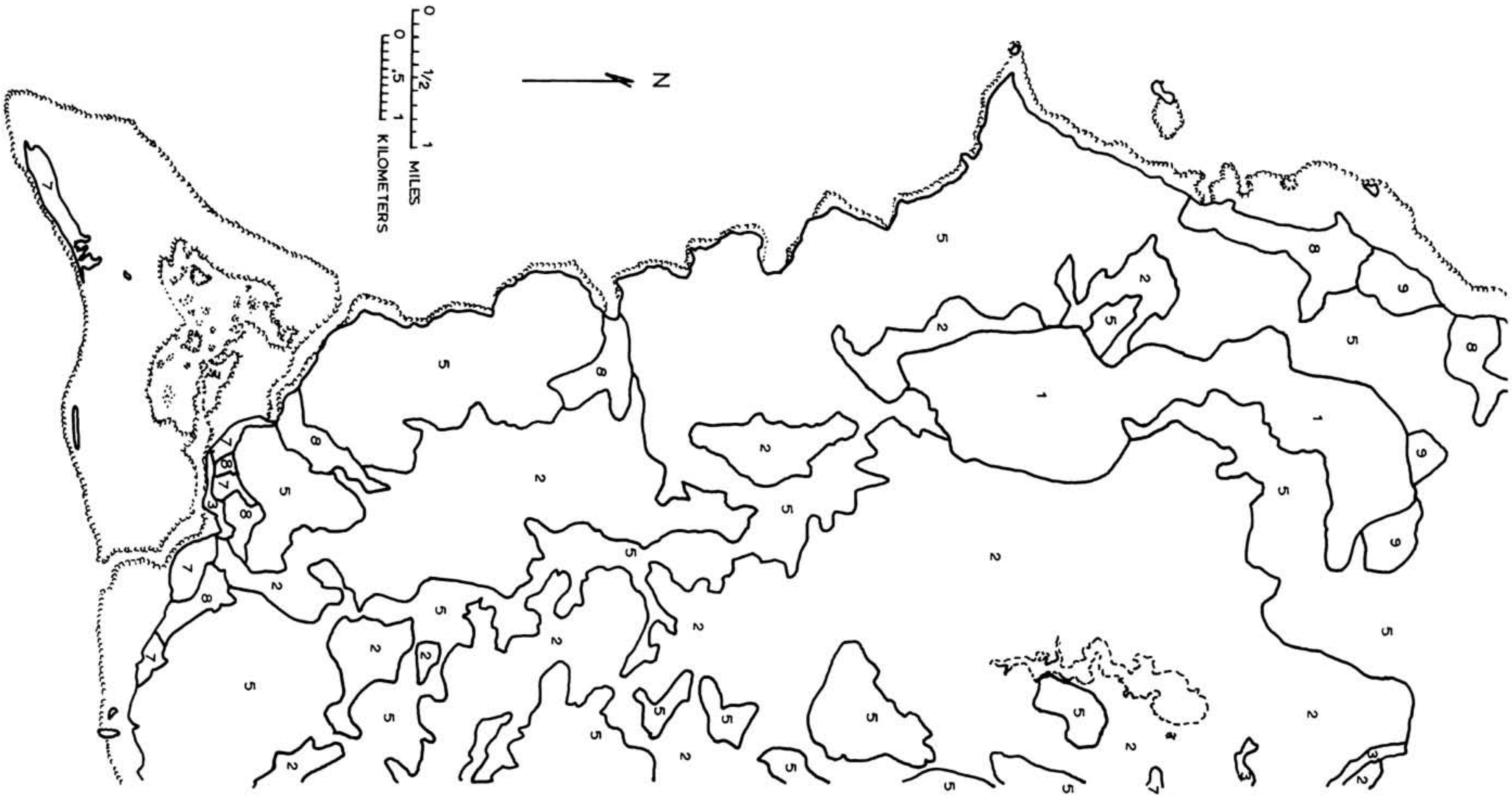


Figure 33d. Vegetation map for Sector X (see Figure 33c for northern part), the southern tip of Sector XII, and Sector XI. Legend explanation for vegetation units 1–9 are given on pages 220–221. Map and legend from Fosberg (*In* Tracey et al., 1959).

Figure 33e. Vegetation map for Sector XII (see Figure 33c for northern part and Figure 33d for southern tip. Legend explanation for vegetation units (1–9) are given on pages 220–221. Map and legend from Fosberg (*In* Tracey et al., 1959).

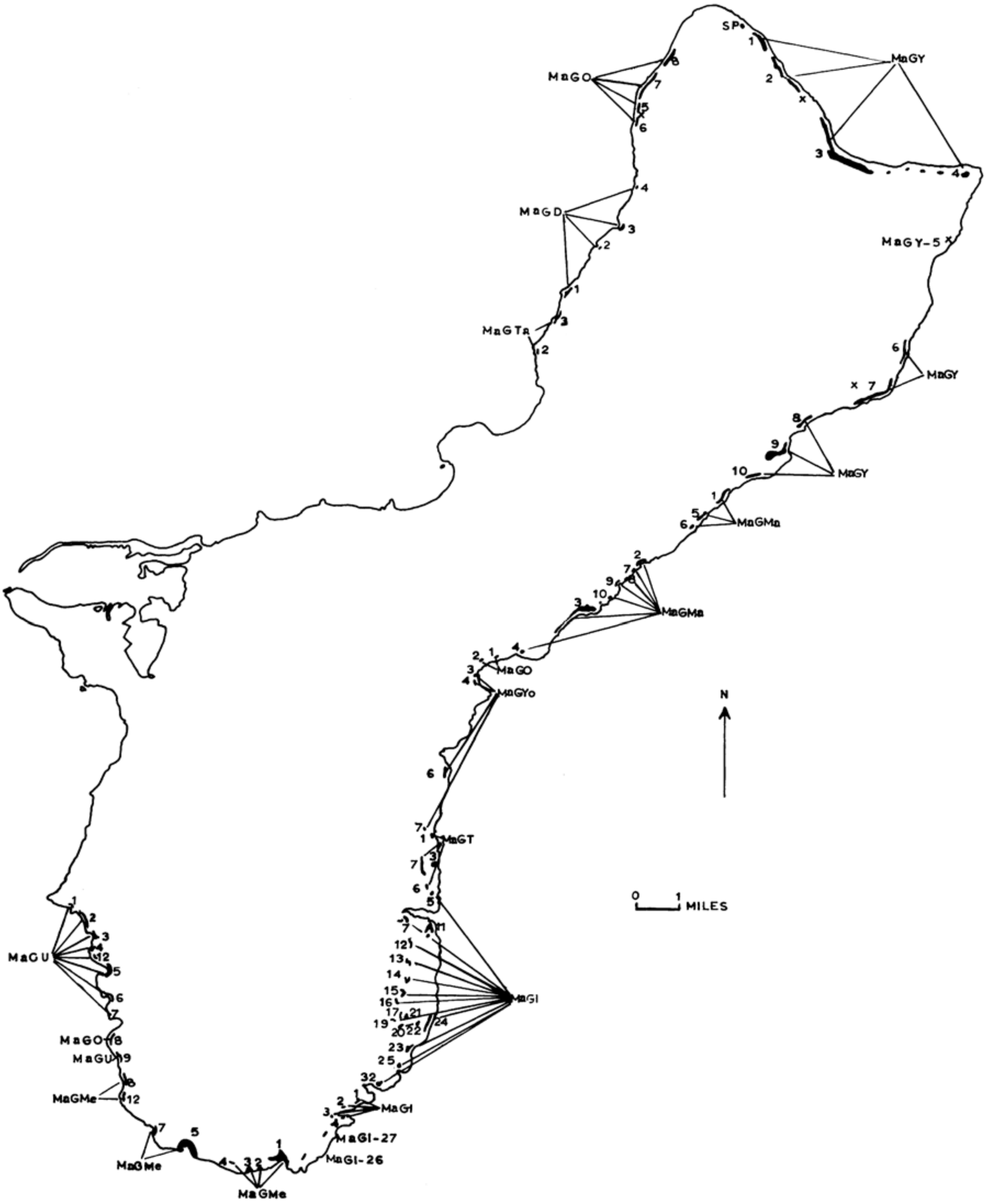


Figure 34. Archaeology sites of Guam. Map modified from Reinman (unpublished manuscript.

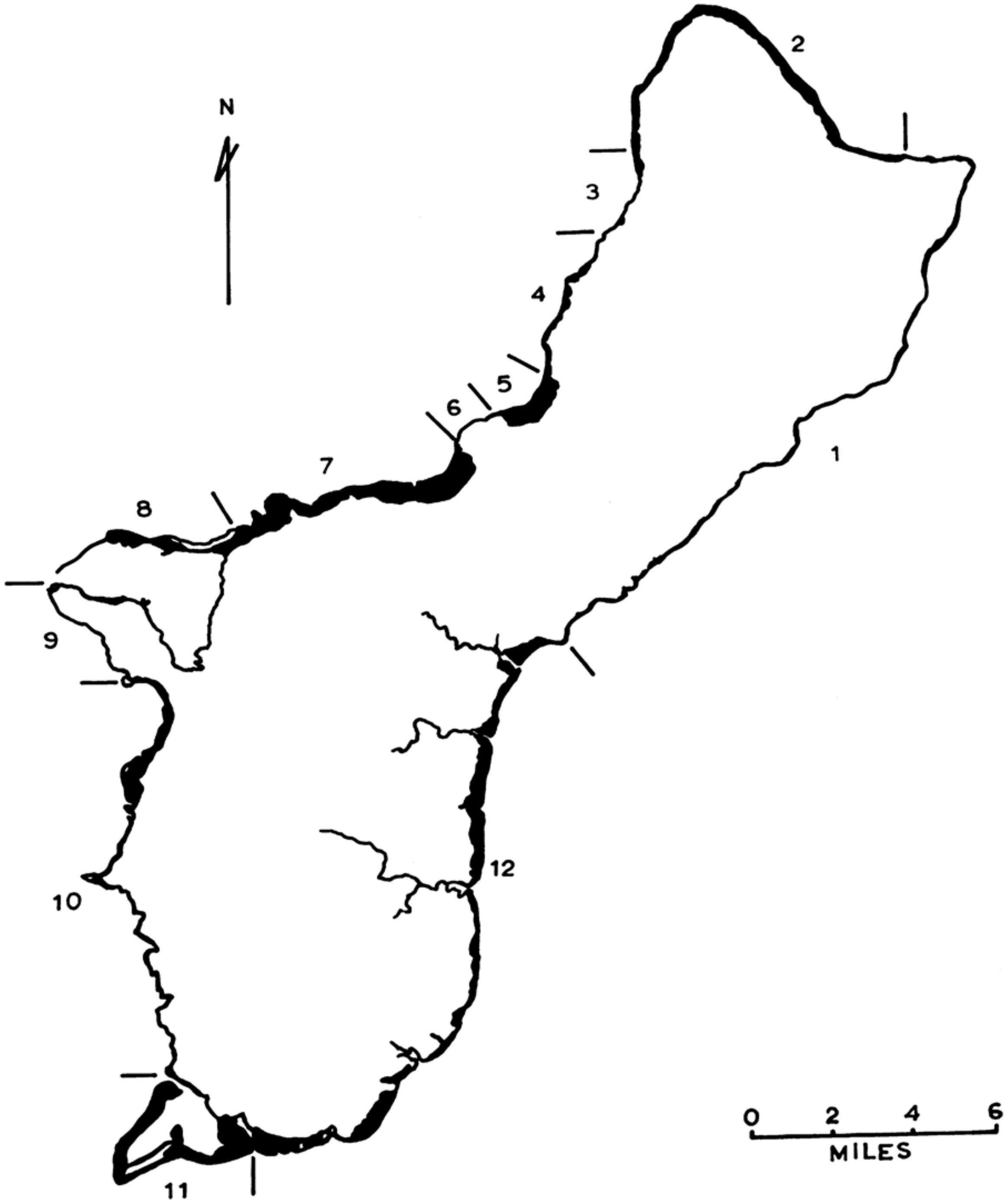


Figure 35. Map of Guam showing sector boundaries and fringing and reef flat areas (shaded regions).

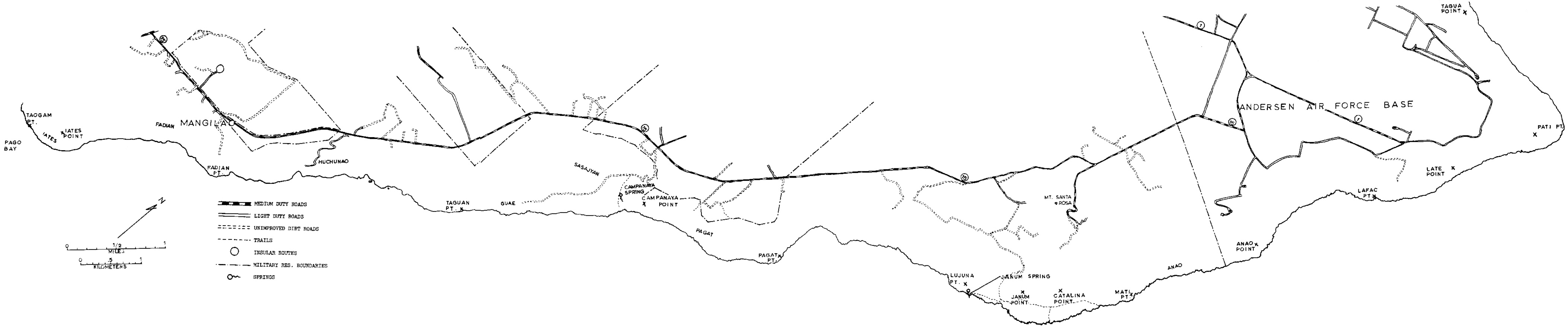


Figure 36. General location map for Sector I.

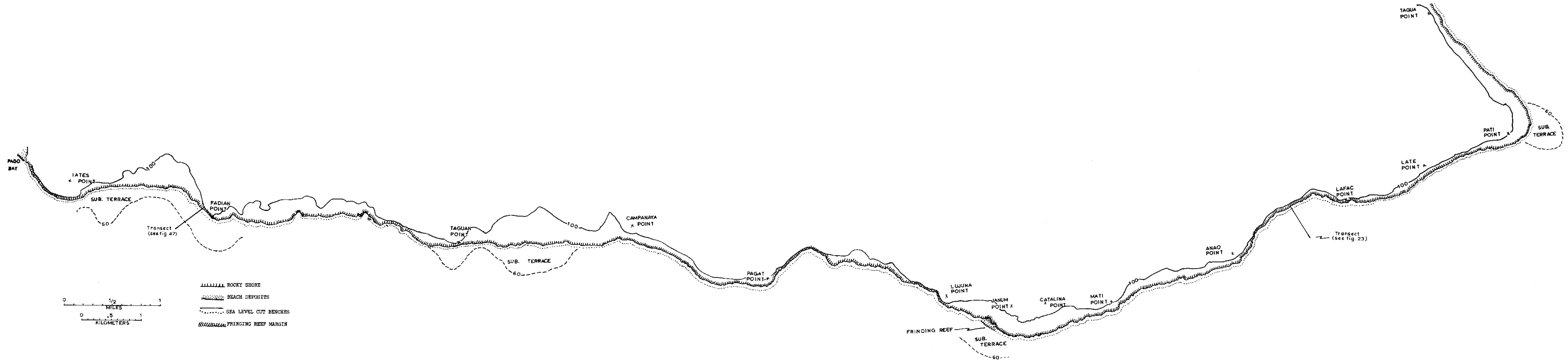


Figure 37. Map showing the 100–foot coastal contour (solid line), rocky shorelines, beach deposits, sea-level cut benches, fringing reef-flat platforms (stippled region seaward of shoreline), reef margin, submarine terraces, and the 60–foot submarine contour (dashed line) for Sector I. Lack of sounding data prevented the plotting of submarine contours for most of the coastline along this sector.

Figure 38. Limestone headland southwest of Iates Point. Sea level and+6-foot nips are visible at the left foreground and +6-foot and +40–50-foot nips are visible in background. Large reef blocks rest on the reef flat and offshore terrace which have eroded from the cliff face.

Figure 39. Taguan Point, showing several levels of terraces.

Figure 40. Broad terrace between Taguan Point and Campanaya Point (Sasajyan District). A narrow cut bench fringes the shoreline along this coast.

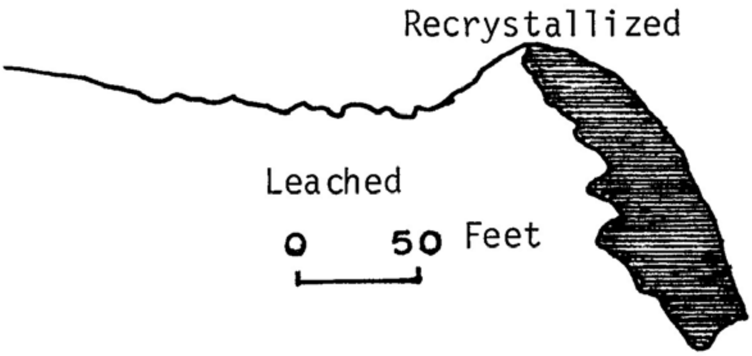


Figure 41. Sketch of rampart and moat. Solution of limestone behind the cliff and deposition of calcite along the cliff face results in a “case-hardened” rampart backed by a solution depression or moat. Figure taken from Tracey et al. (1964).

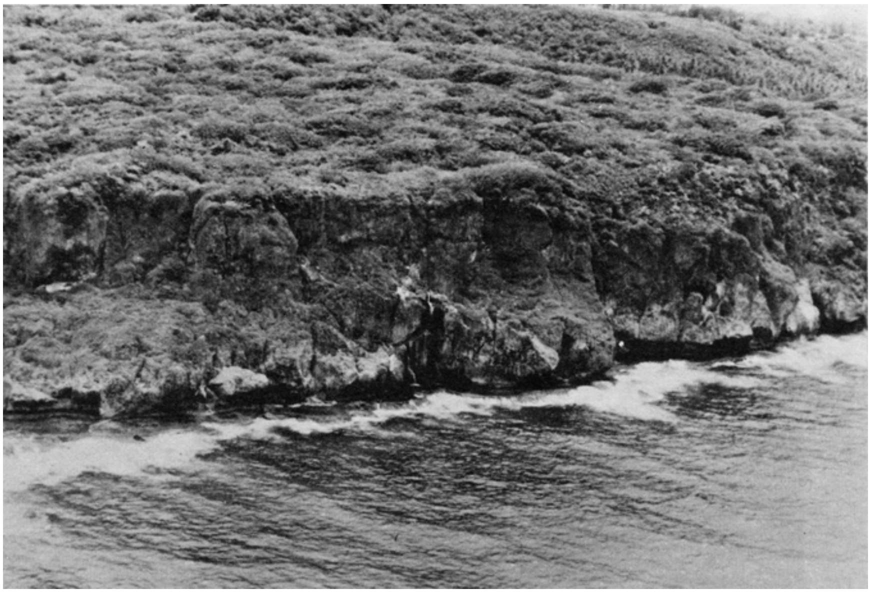


Figure 42. Cliff face below Iates Point cut by cracks and fissures. Sewer outfall if visible in center of cliff.

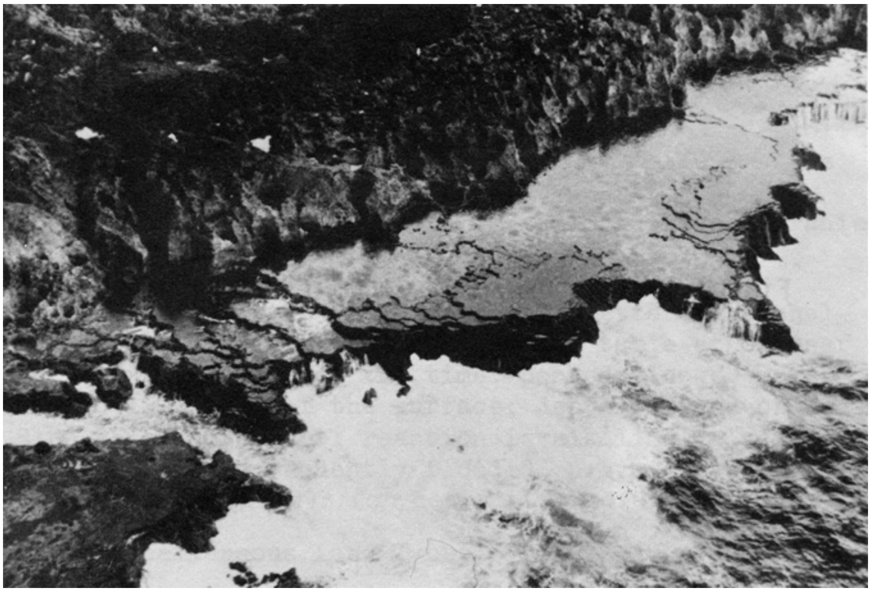


Figure 43. Scalloped margin of cut bench at Pati Point. At left fissures cut completely through the bench. Tiers of rimmed terraces are visible on the outer part of the bench platform.

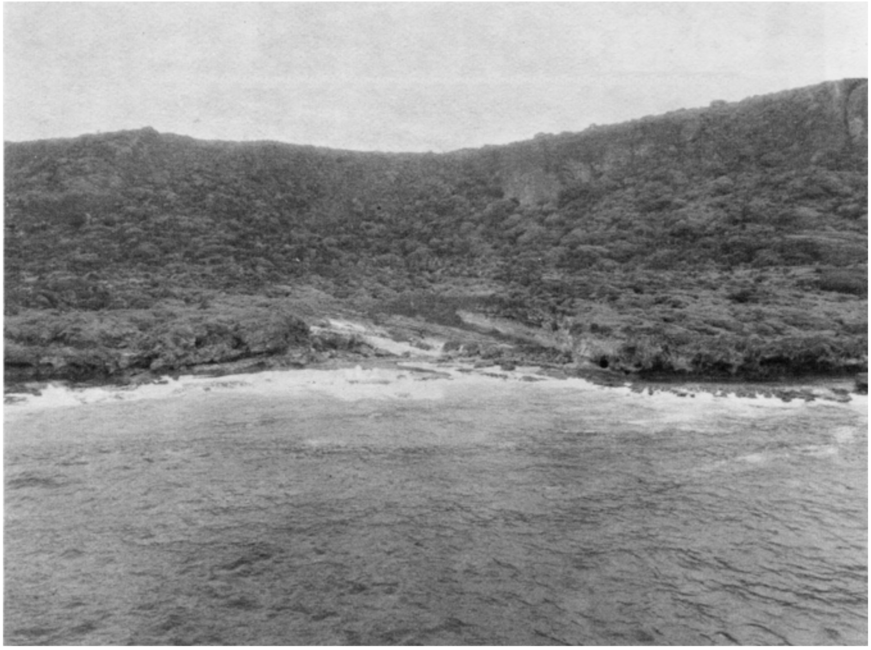


Figure 44. Exposure of Janum limestone at Catalina Point.

SOILS EXPLANATION FOR SECTOR I

Upland Soils (On Limestone)

1 - Guam Clay. Reddish, granular, permeable Latosol; generally very shallow (less than 12 inches), but has some pockets or narrow troughs of deep soil; prevailing surface gradient 1 to 8 percent.

3 - Chacha-Saipan Clays. Yellowish-brown, firm clay (Chacha), and red firm clay (Saipan); neutral to acid reaction; Latosolic intergrades. These soils with convex surfaces are 1 to I0 feet deep; with concave surfaces they are 10 to 60 feet deep; prevailing surface gradient 1 to 8 percent.

4 - Saipan-Yona-Chacha Clays. Chacha-Saipan clays with a shallow brownish Lithosol (Yona clay) on many of the narrow convex ridge-tops and steep slopes; soil depth similar to Unit 3, except Yona clay which generally grades into clayey limestone at about 12 to 2) inches below surface; reaction of Yona clay is thus alkaline or calcareous; prevailing surface gradient 8 to 25 percent.

Upland Soils (On Volcanic Rocks)

6 - Atate-Agat Clay, Rolling. Remnant benches or small mesas of an old red, granular, porous, acid Latosol (Atate clay) with deep reddish, mottled, plastic to hard clay C horizon, pale yellow, olive, or gray in lower part; and its truncated counterpart (Agat clay) with similar C horizon of saprolitic clay, ranging in depth from a few feet to about 100 feet, and averaging about 50 feet; prevailing surface gradient of Atate clay is 1 to 8 percent, and of Agat clay 8 to 15 percent.

7 - Agat-Asan-Atate Clays, Hilly. Atate-Agat clays and a dark grayish-brown Regosol (Asan clay) developed in more severely truncated saprolite (similar to lower part of C horizon described in Unit 6); soil depths similar to those of Unit 6, except Asan clay which ranges from a few feet in depth to generally less than 50 feet; prevailing surface gradient 15 to 50 percent.

Soils of Coastal and Valley Flats

10 - Inarajan Clay. Similar to Pago Clay but lower, wetter, and shallower (thins out on coastal sands and bedrock); water table at or near the surface (within 30 inches) most of the time; poor drainage, mottlings (gray) within 6 to 12 inches of the surface; depth to sand or bedrock ranges from 3 to 25 or more feet; reaction is alkaline in water saturated zone; poorly drained; frequently flooded; prevailing surface gradient 0 to 1 percent.(see page 293 for description of Pago Clay).

Miscellaneous Land Types

13b - Limestone Rock Land, Gently Sloping. Patches of thin (generally less than 2 or 3 inches) reddish or brownish granular clay among exposures of limestone bedrock, pinnacles, boulders, and fragments, which make up more than 25 percent of entire unit area and more than 75 percent of local areas; prevailing surface gradient 2 to 15 percent.

13f - Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical.

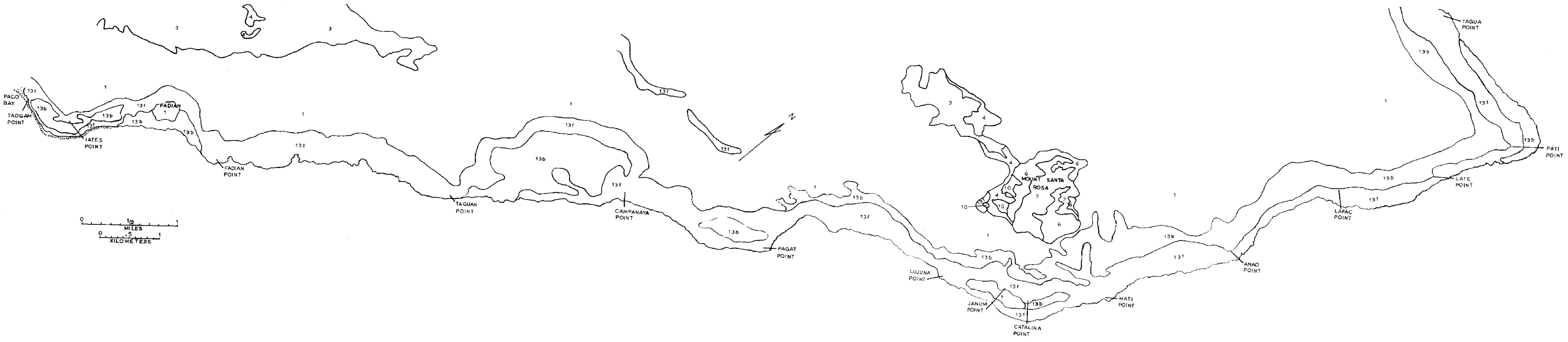


Figure 45. Sector I soil map. See Tables 5 (Pages 373–374) and 6 (Pages 375–376) for additional soil descriptions. Soils explanation legend is on opposite facing page.

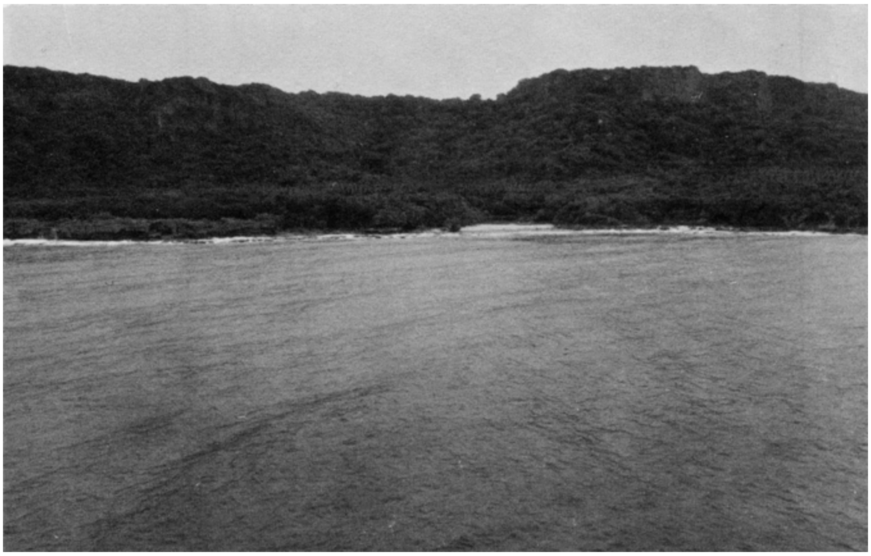


Figure 46. Small section of beach deposits at Janum Point.

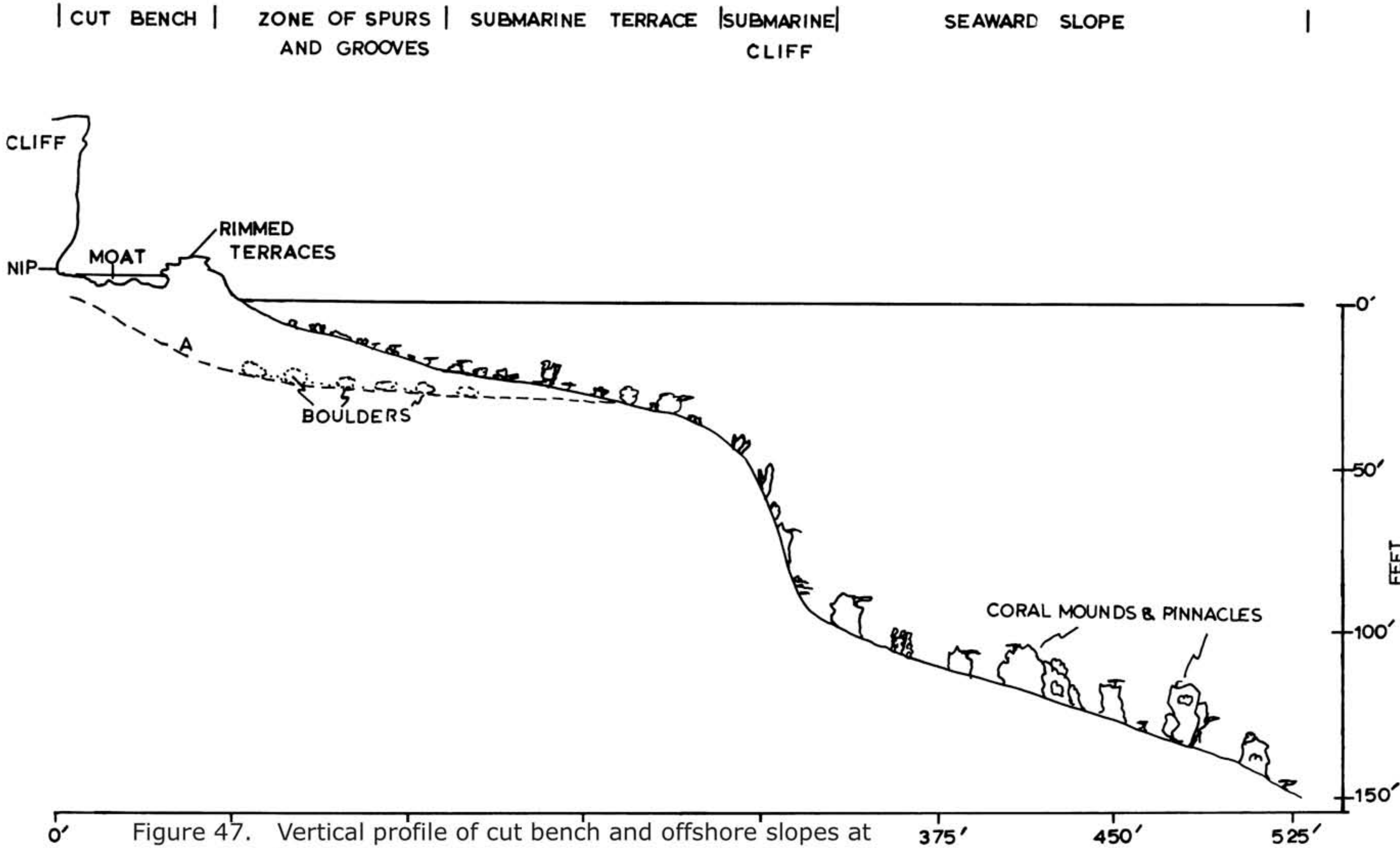


Figure 47. Vertical profile of cut bench and offshore slopes at Fadian Point. Point A represents the floor level of grooves and fissures that cut through the bench platform.

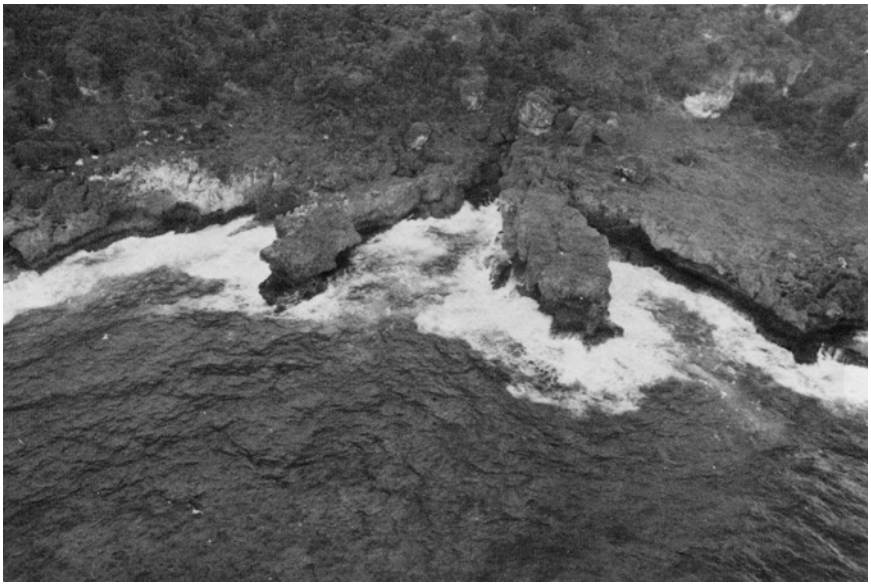


Figure 48. Bench and adjacent cliff cut by wide fissures near Pati Point.

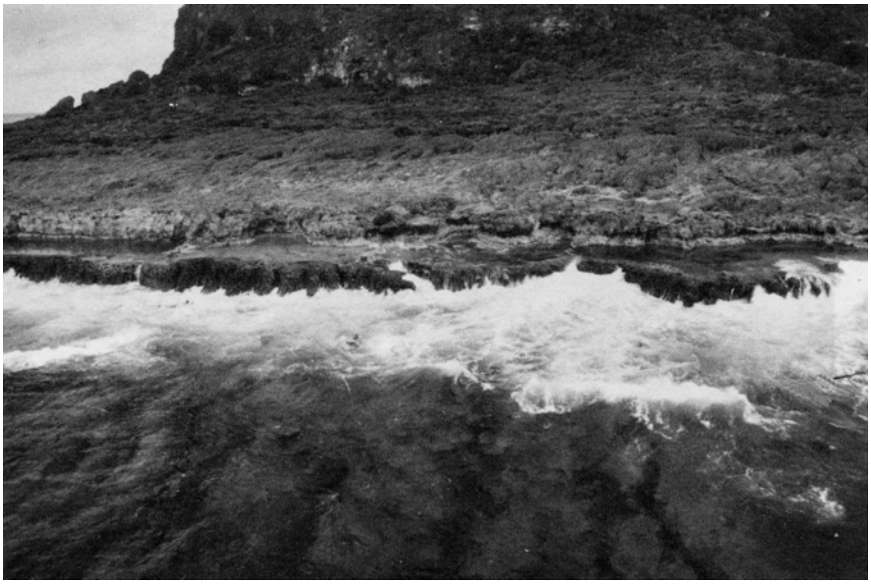


Figure 49. Bench between Pati Point and Tagua Point, showing grooves and spurs extending seaward from the bench face.

Figure 50. Sewer outfall near Anao Point.

Figure 51. Sewer outfall near Lafac Point.

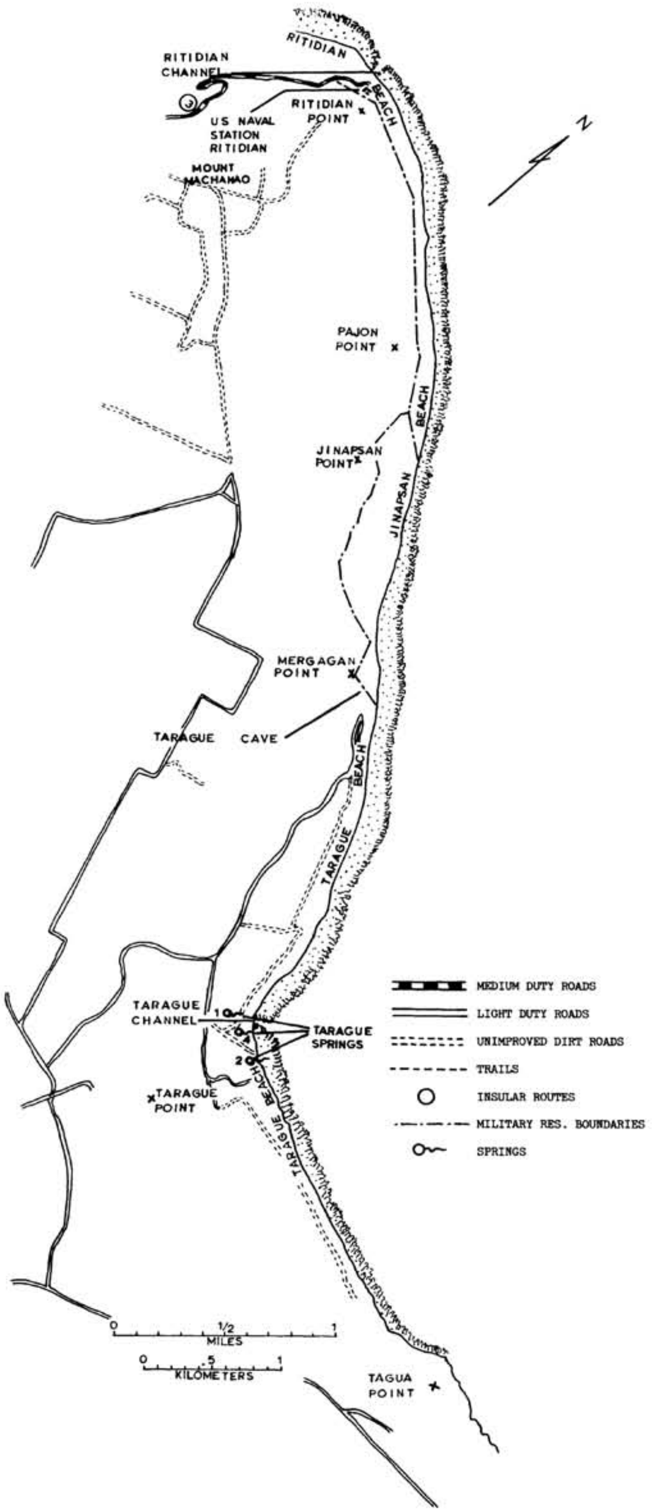


Figure 52a. General location map for the eastern part of Sector II. See Figure 52b for the remainder of Sector II (western part).

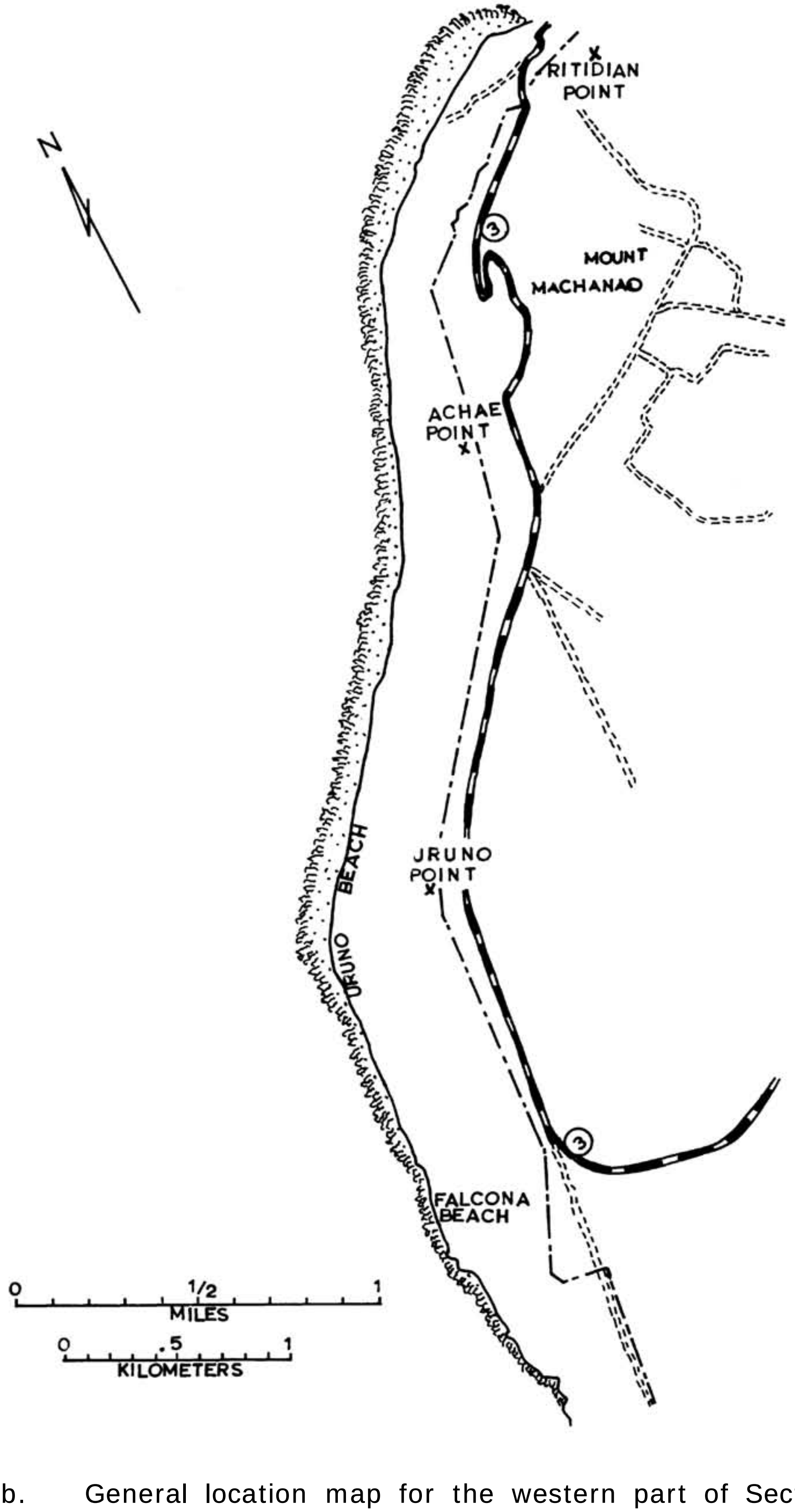


Figure 52b. General location map for the western part of Sector II. See Figure 52a for the remainder of Sector II (eastern part) and map legend.

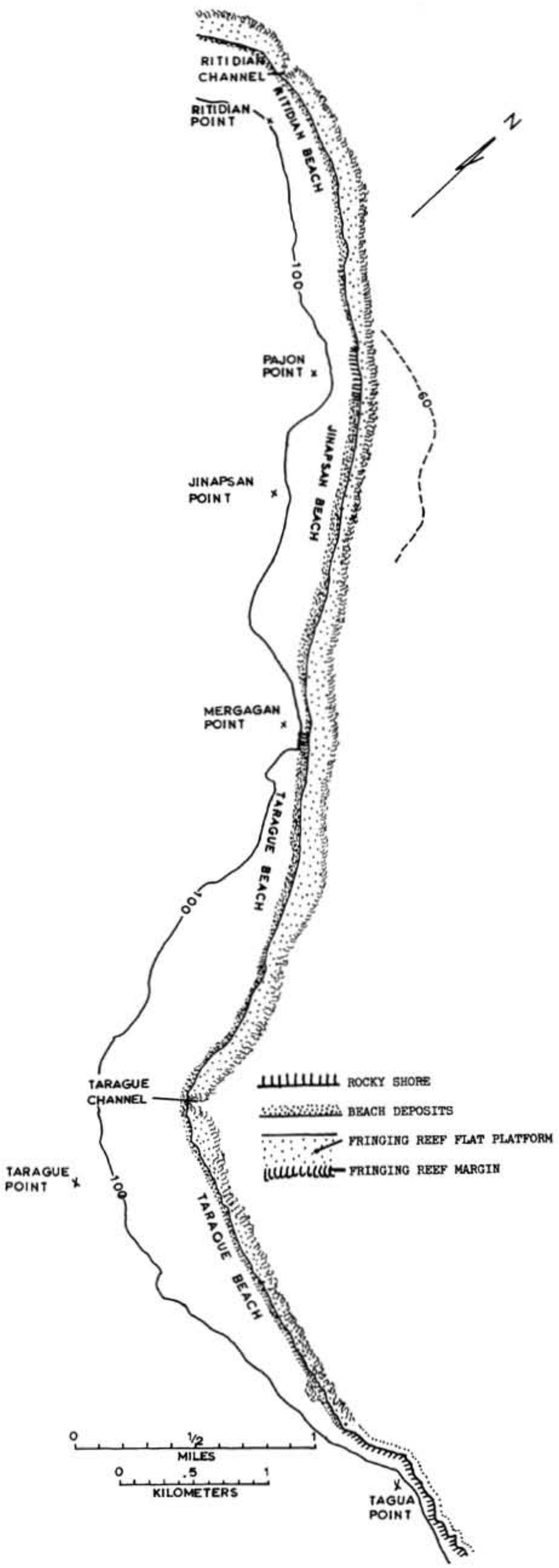


Figure 53a. Map showing the 100-foot coastal contour (solid line), rocky shorelines, beach deposits, fringing reef-flat platforms (stippled region seaward of shoreline), reef margin, and the 60-foot submarine contour (dashed line), where known, for Sector II (eastern part). See Figure 53b for remainder (western part) of Sector II.

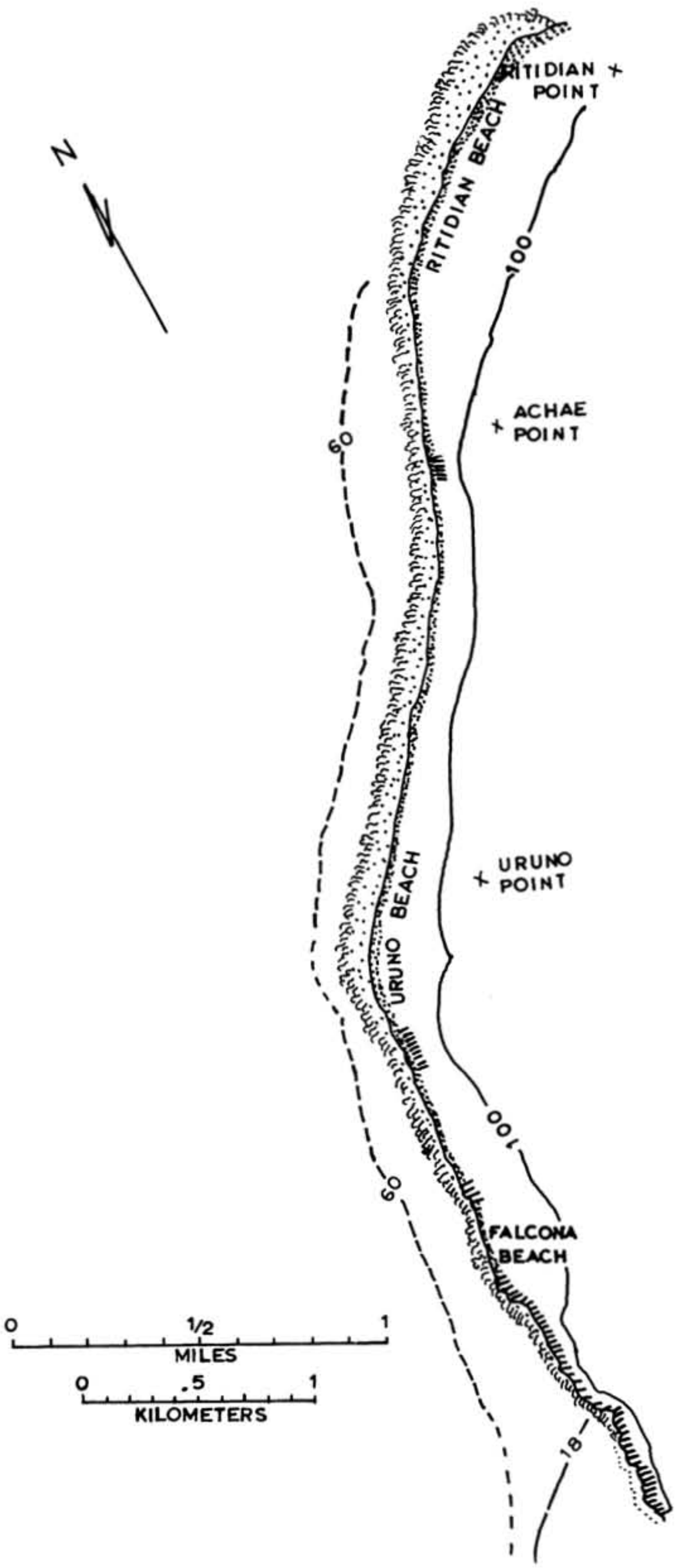


Figure 53b. Map showing the 100-foot coastal contour (solid line), rocky shorelines, beach deposits, fringing reef-flat platforms (stippled region seaward of shoreline), reef margin, and the 18-foot (solid line) and 60-foot submarine contour lines, where known, for Sector II (western part). See Figure 52a for remainder (eastern part) of Sector II and map legend.

Figure 54. Fringing reef flat and bench deposits at Mergagan Point. Tarague Beach lies behind the rocky point in the foreground.

Figure 55. Narrow terrace and irregular rocky headland at Achae Point.

SOILS EXPLANATION FOR SECTOR II

Upland Soils (On Limestone)

1 - Guam Clay. Reddish, granular, permeable Latosol; generally very shallow (less than 12 inches), but has some pockets or narrow troughs of deep soil; prevailing surface gradient 1 to 8 percent.

Soils of Coastal and Valley Flats

12 - Shioya Soils. Pale brown to white, fine-, medium-, or coarse-grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Miscellaneous Land Types

13b - Limestone Rock Land, Gently Sloping. Patches of thin (generally less than 2 or 3 inches) reddish or brownish granular clay among exposures of limestone bedrock, pinnacles, boulders, and fragments which make up more than 25 percent of entire unit area and more than 75 percent of local areas; prevailing surface gradient 2 to 15 percent.

13f - Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical.

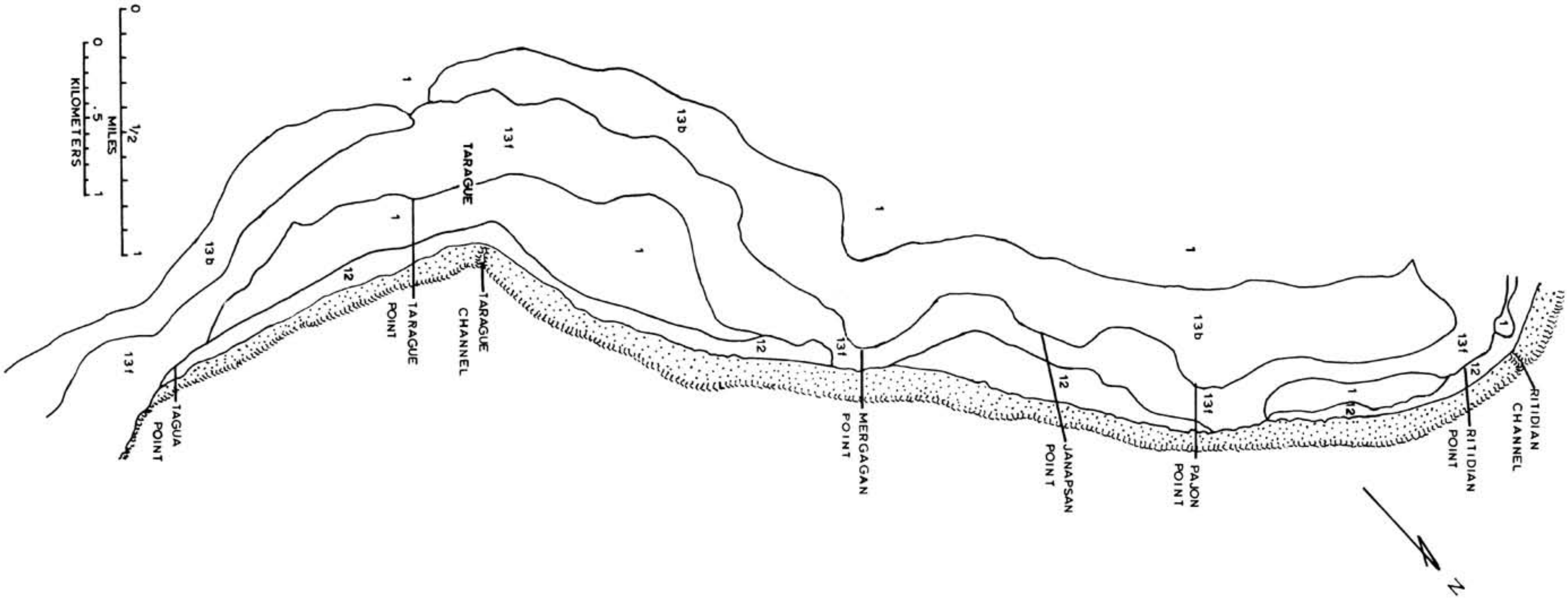


Figure 56a. Sector II soil map (eastern part). The soil unit explanation legend is on the opposite facing page. See Tables 5 (pages 373–274) and 6 (pages 375–376) for additional soil unit descriptions and characteristics.

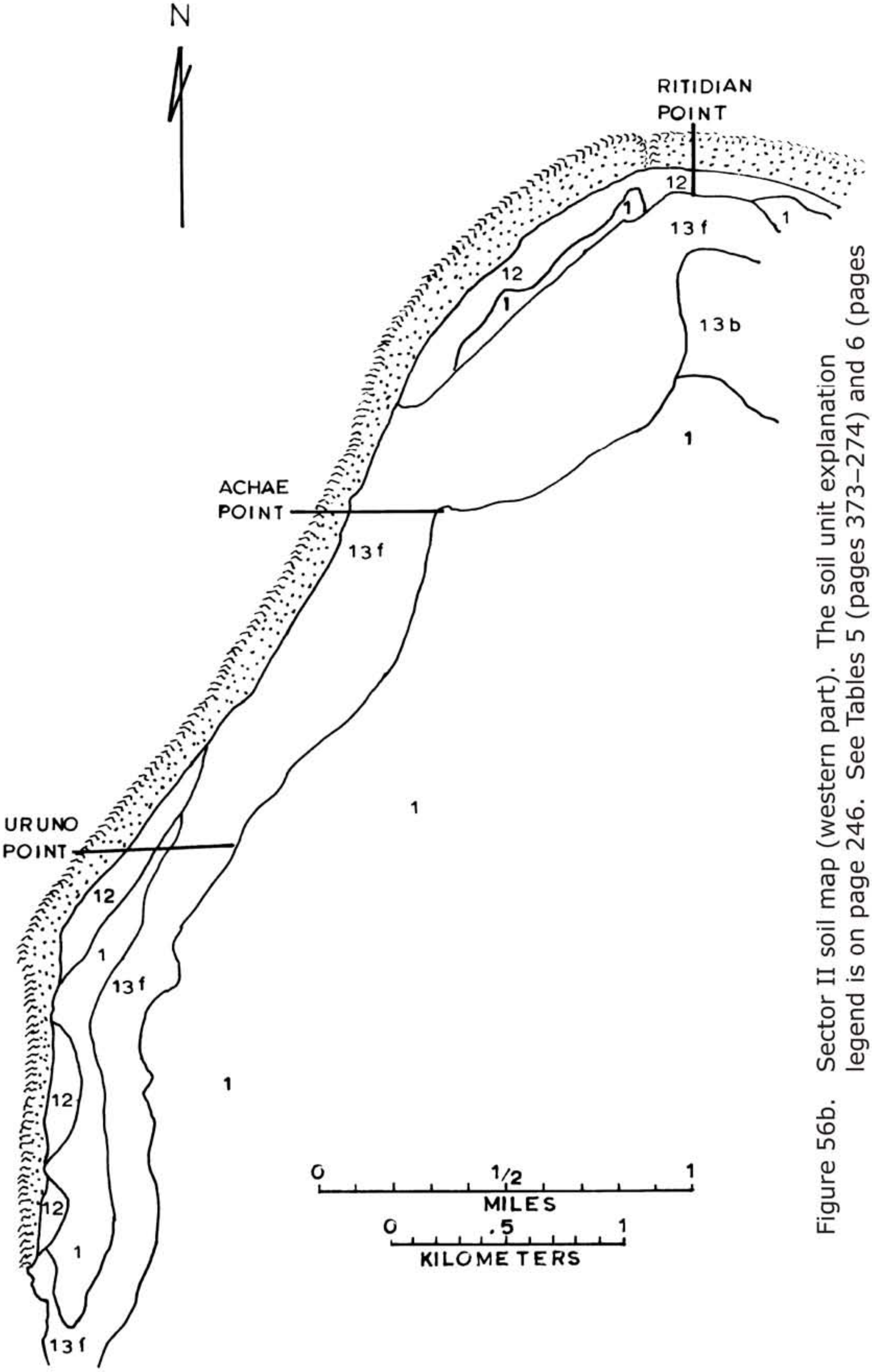


Figure 56b. Sector II soil map (western part). The soil unit explanation legend is on page 246. See Tables 5 (pages 373–274) and 6 (pages 375–376) for additional soil unit descriptions and characteristics.

Figure 57. Fringing reef platform looking toward Tagua Point from Tarague Channel.

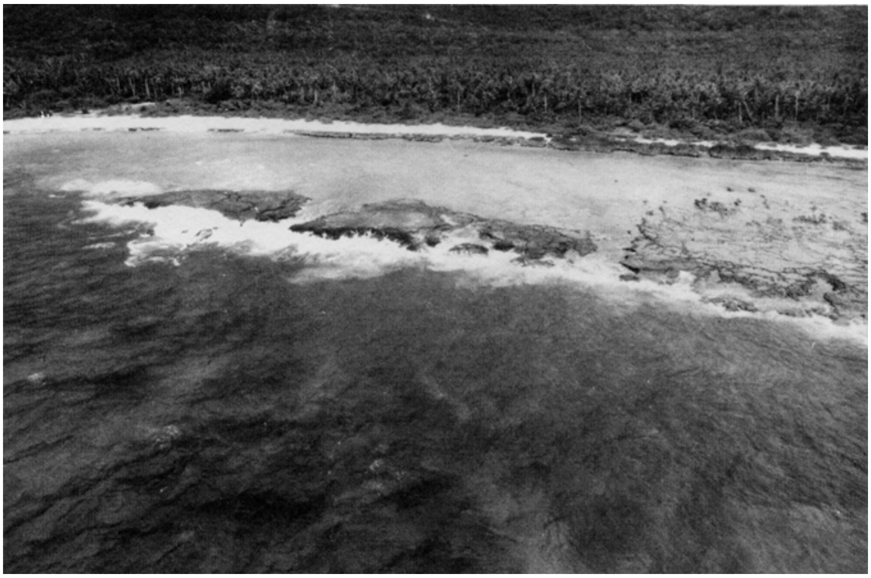


Figure 58. Tarague Channel is at the left, and a massive algal ridge dominates the reef margin. The beach along this sector consists of beach sand with scattered solution-pitted limestone remnants.

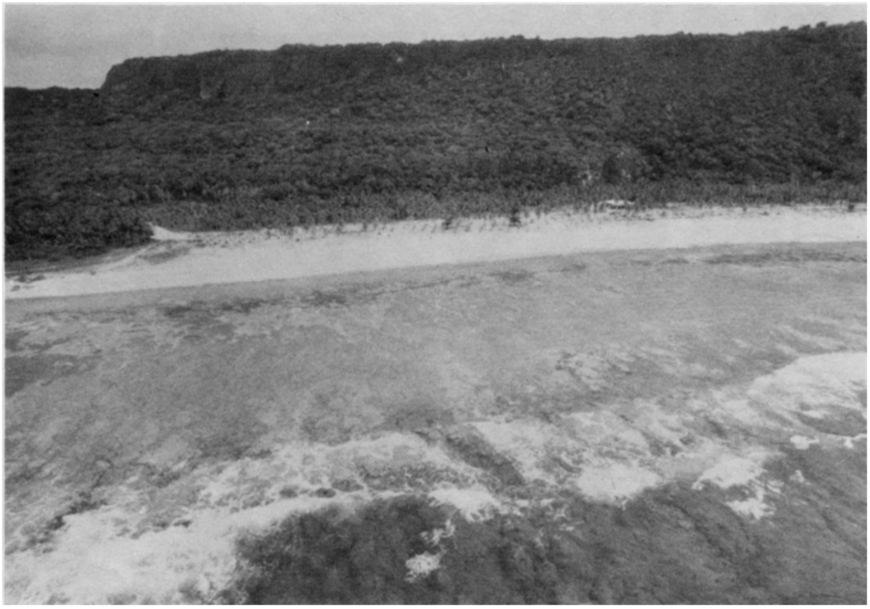


Figure 59. Tarague Beach.

Figure 60. Fringing reef flat on east side of Ritidian Point. Reef margin (convex type) is exposed. Ritidian Channel is located at the right where a break in the reef margin occurs.

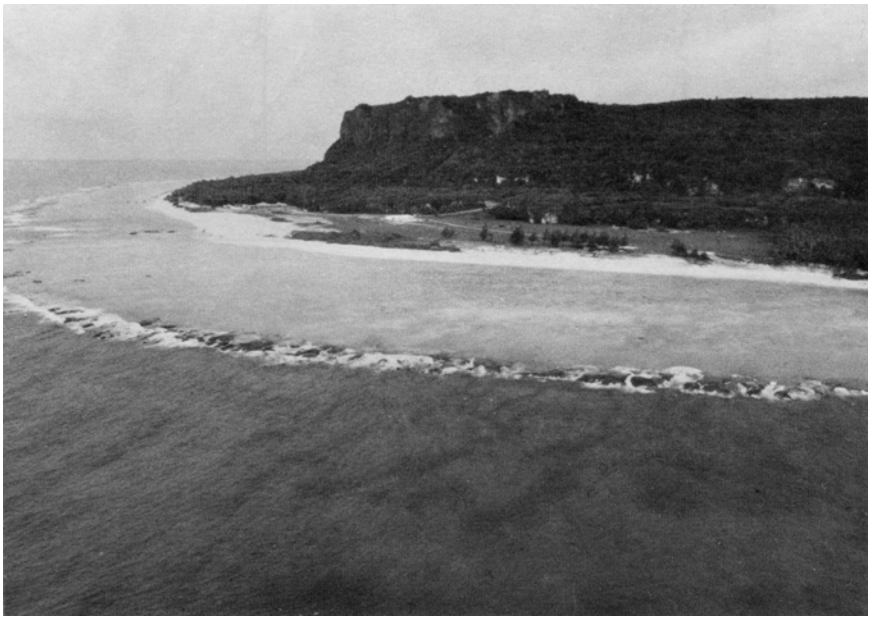


Figure 61. Fringing reef on west side of Ritidian Point. Wide reef flat with reef margin (cuesta type) is exposed. Ritidian Channel is shown at the left.

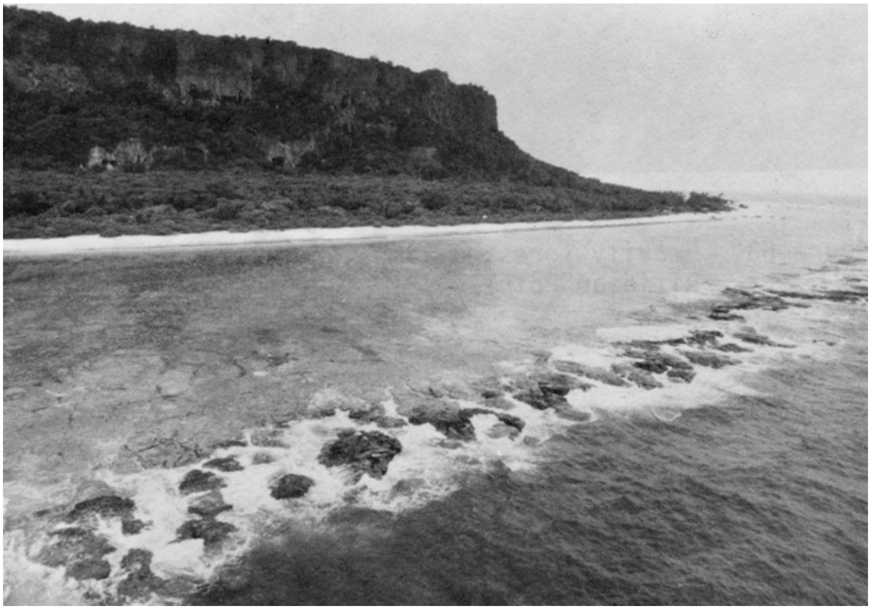


Figure 62. Fringing reef flat east of Ritidian Point with moat and convex algal ridge.

Figure 63. Heavily forested limestone plateau near Ritidian Point.

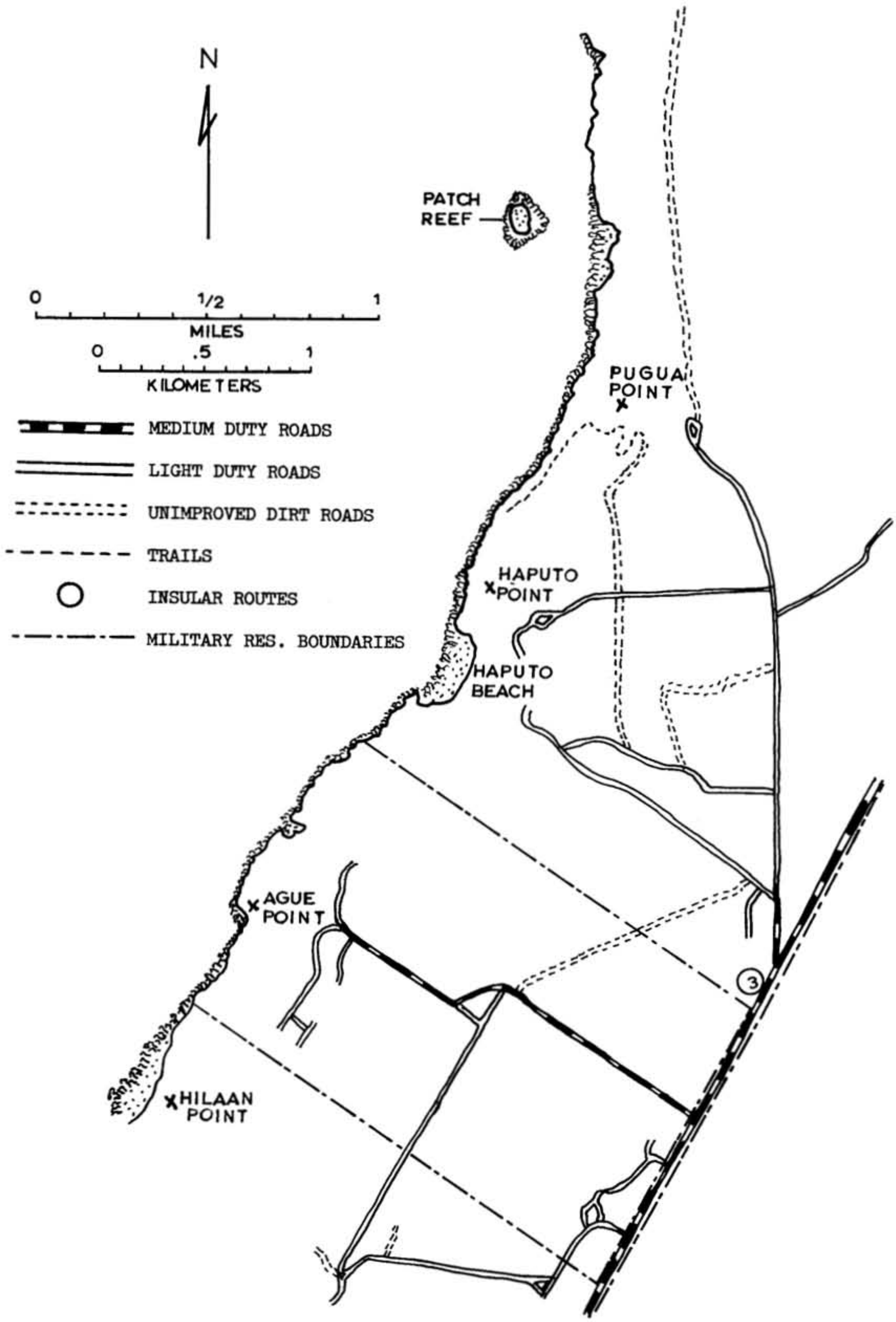


Figure 64. General location map for Sector III.

Figure 65. A view of Sector III toward the north from Haputo Point.

Figure 66. Coastline and patch reef along Sector III. Pugua fault offsets the cliffline at the right.

SOILS EXPLANATION FOR SECTOR III

Upland Soils (On Limestone)

1 – Guam Clay. Reddish, granular, permeable Latosol; generally very shallow (less than 12 inches), but has some pockets or narrow troughs of deep soil; prevailing surface gradient 1 to 8 percent.

Soils of Coastal and Valley Flats

12 – Shioya Soils. Pale brown to white, fine-, medium-, or coarse-grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Miscellaneous Land Types

13f – Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical. (see page 246 for description of Unit 13b).

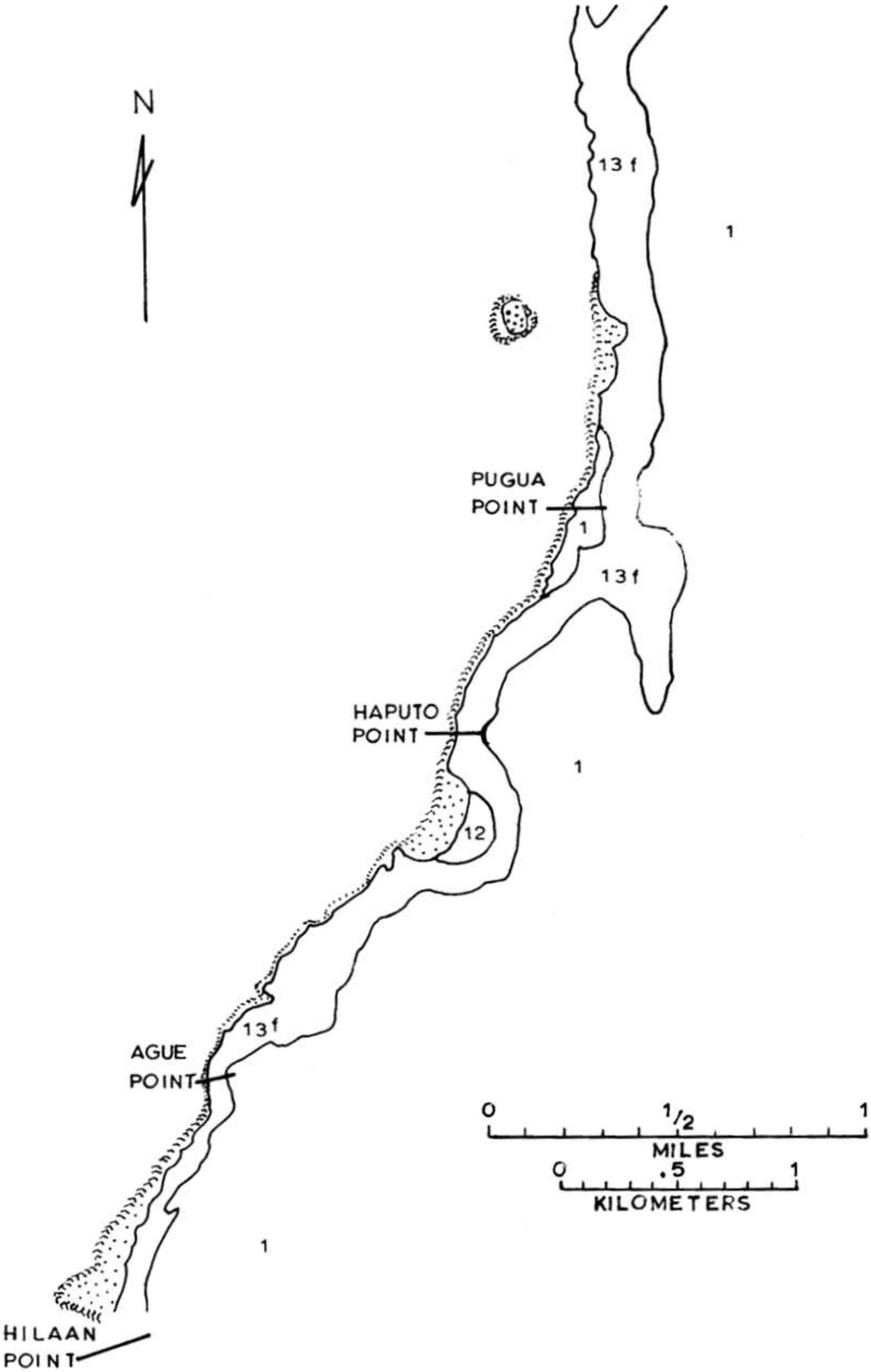


Figure 67. Sector III soil map. Soil unit explanation legend is on page 255. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil unit descriptions. Fringing reef-flat areas are stippled.

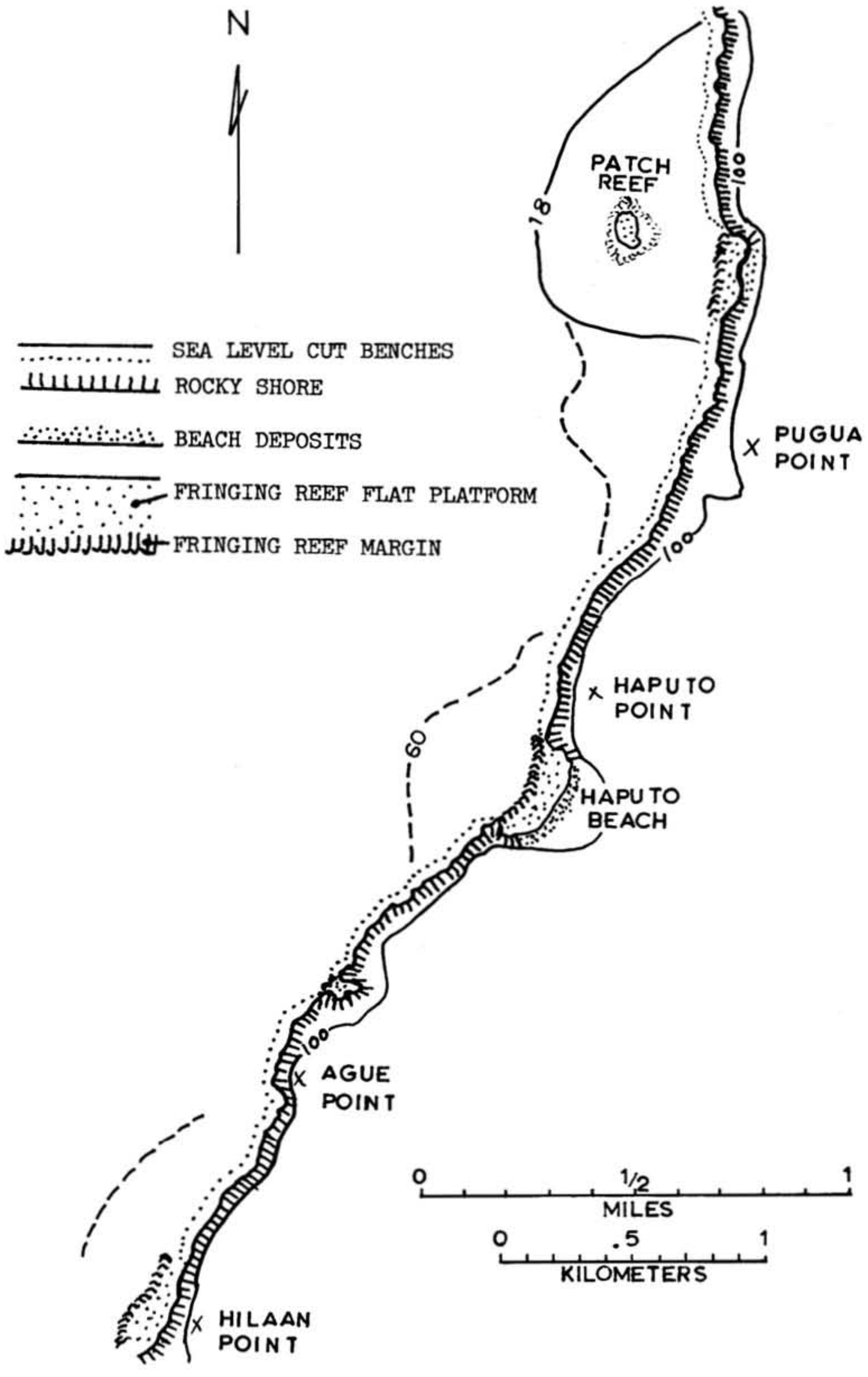


Figure 68. Map showing the 100-foot coastal contour (solid line), rocky shorelines, beach deposits, cut benches, fringing reef-flat platforms (stippled region seaward of shoreline), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for Sector III.

Figure 69. Narrow reef-flat platform located along the coast of Sector III.

Figure 70. Narrow benches and prominent nip cut the shoreline at sea level. A view, looking toward Uruno Point.

Figure 71. Small cove north of Ague Point.

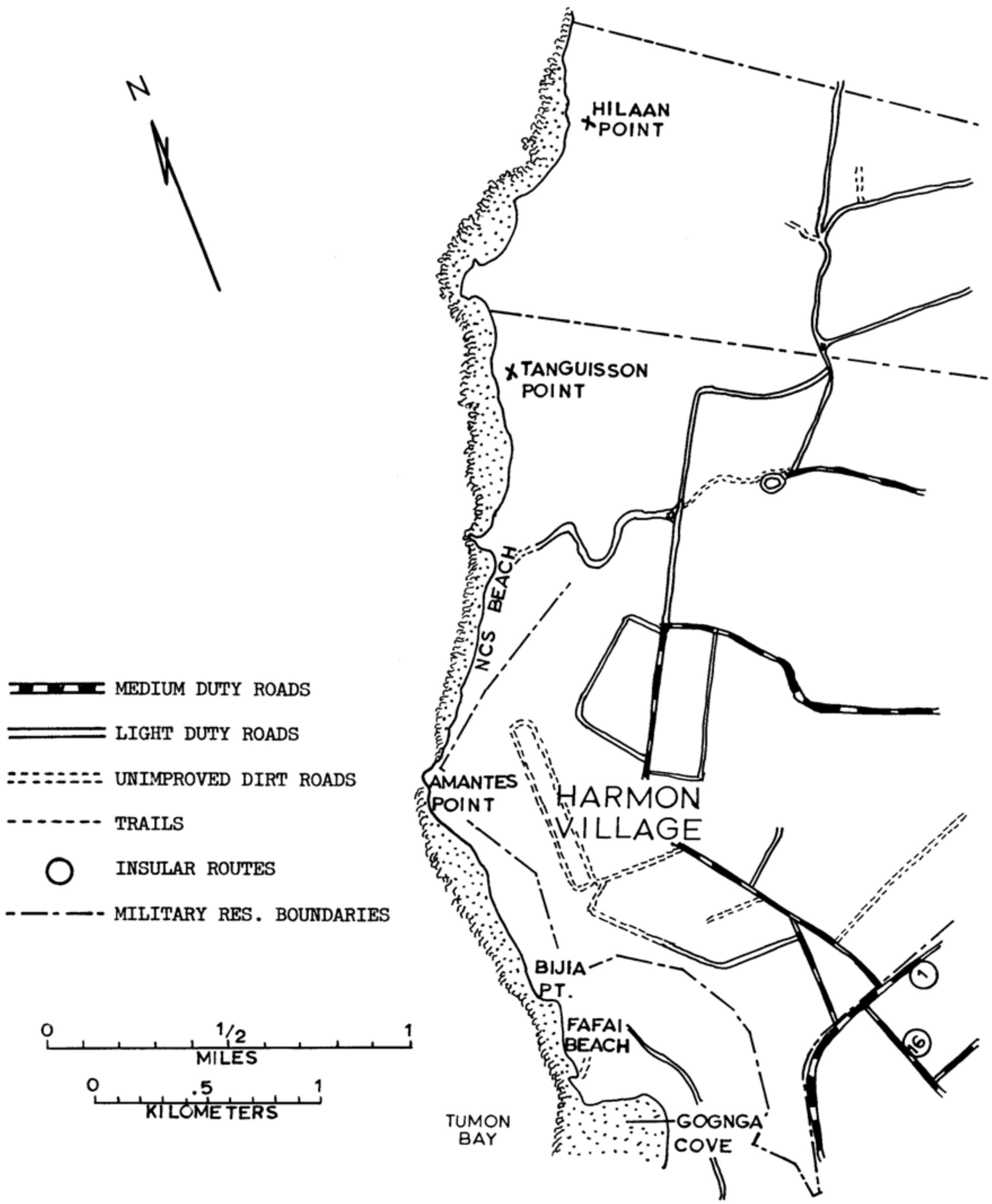


Figure 72. General location map for Sector IV.

Figure 73. Aerial view southward of Sector IV from Hilaan Point to Amantes Point. Tumon Bay is in the background. Tanguisson Power Plant is located on an unconsolidated terrace north of Amantes Point. The broad sandy area just north of the Power Plant is the NCS swimming beach.

Figure 74. Solution-pitted emergent limestone along the shoreline south of Tanguisson Point.

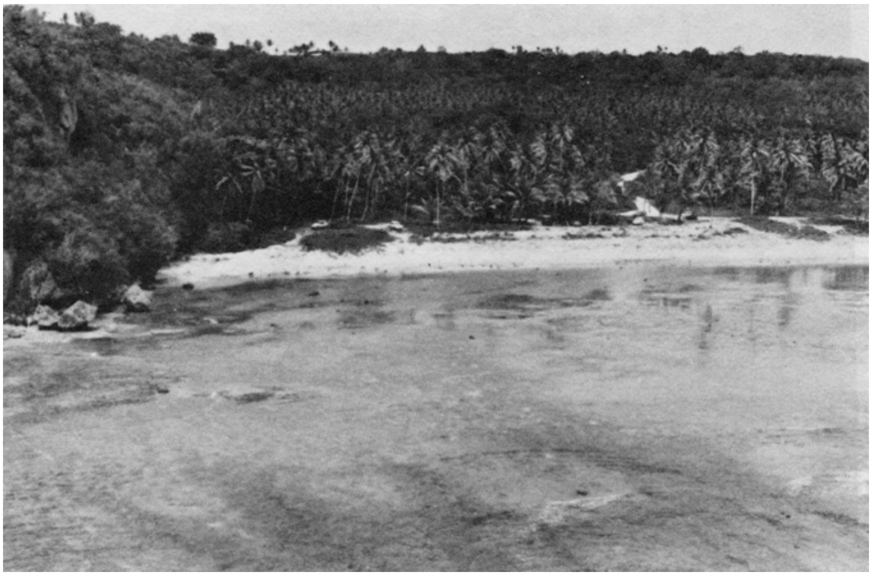


Figure 75. Faifai or “Gun” Beach, located at the southern edge of Bijia Point headland.

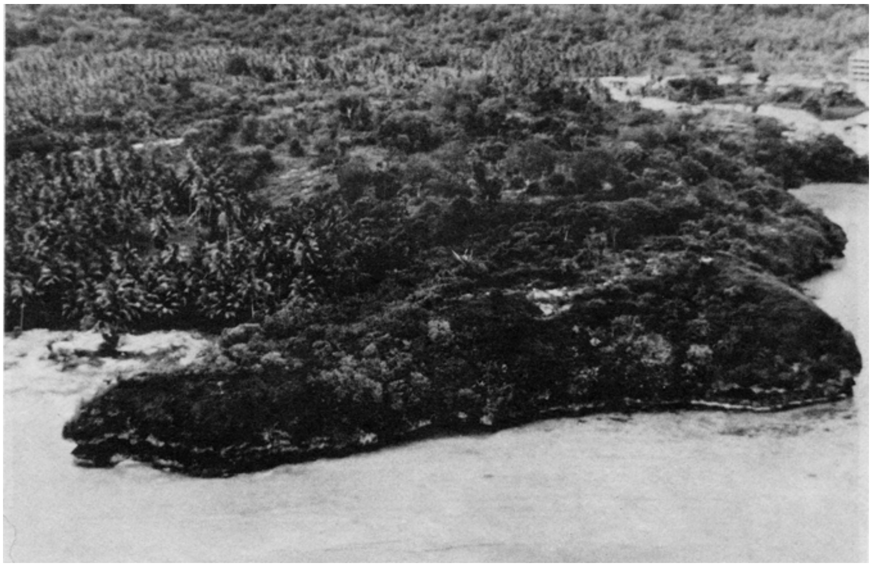


Figure 76. Low limestone ridge separating Faifai Beach to the left and Tumon Bay to the right.

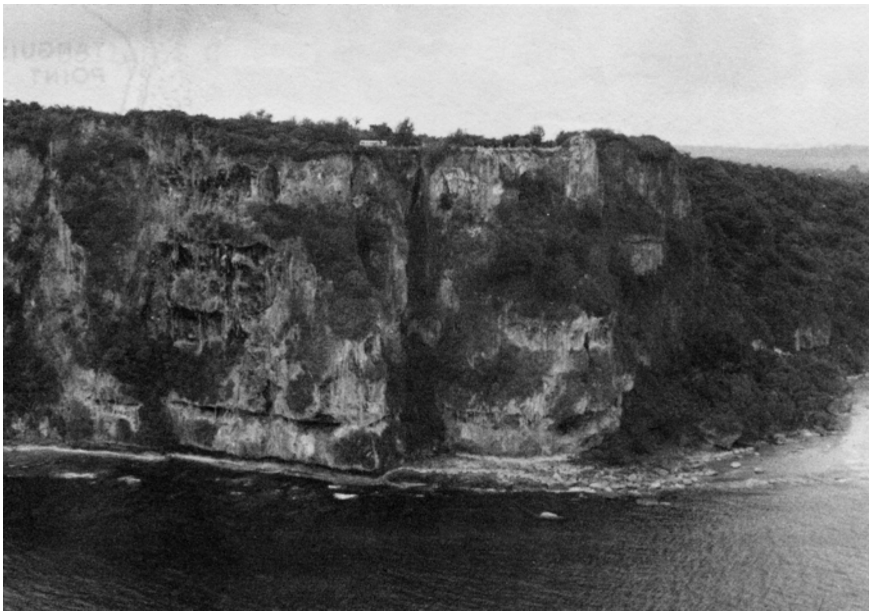


Figure 77. Amantes Point headland. Note the nips cut on the cliff face at various levels and the very narrow reef platform.

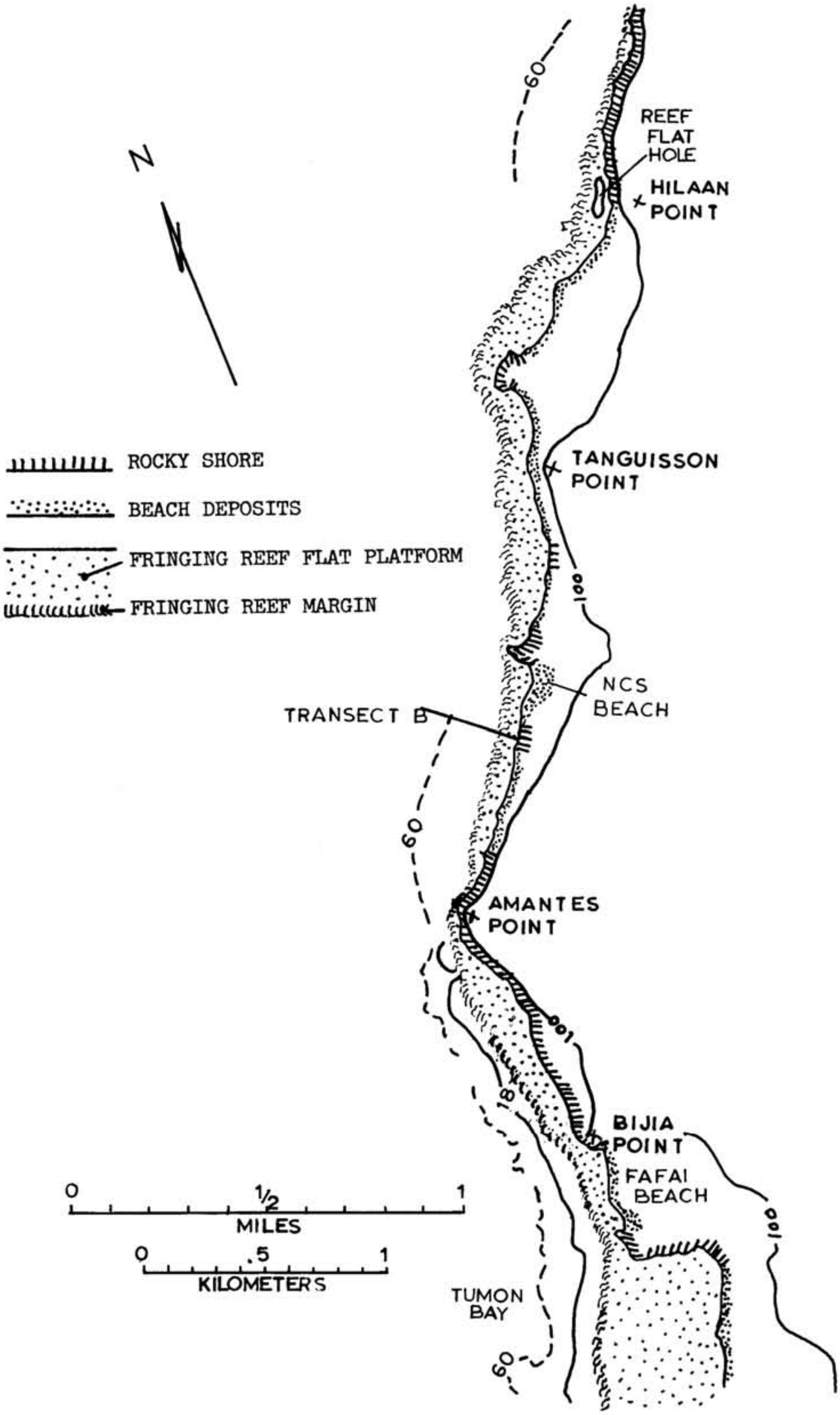


Figure 78. Map showing the 100-foot coastal contour (solid line), rocky shorelines, beach deposits, fringing reef-flat platforms (stippled region seaward of shoreline), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for Sector IV. See Figure 19 for profile of Transect B.

SOILS EXPLANATION FOR SECTOR IV

Upland Soils (On Limestone)

1 – Guam Clay. Reddish, granular, permeable Latosol; generally very shallow (less than 12 inches), but has some pockets or narrow troughs of deep soil; prevailing surface gradient 1 to 8 percent.

Soils of Coastal and Valley Flats

12 – Shioya Soils. Pale brown to white, fine-, medium-, or coarse- grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Miscellaneous Land Types

13b – Limestone Rock Land, Gently Sloping. Patches of thin (generally less than 2 or 3 inches) reddish or brownish granular clay among exposures of limestone bedrock, pinnacles, boulders, and fragments, which make up more than 25 percent of entire unit area and more than 75 percent of local areas; prevailing surface gradient 2 to 15 percent.

13f – Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical.

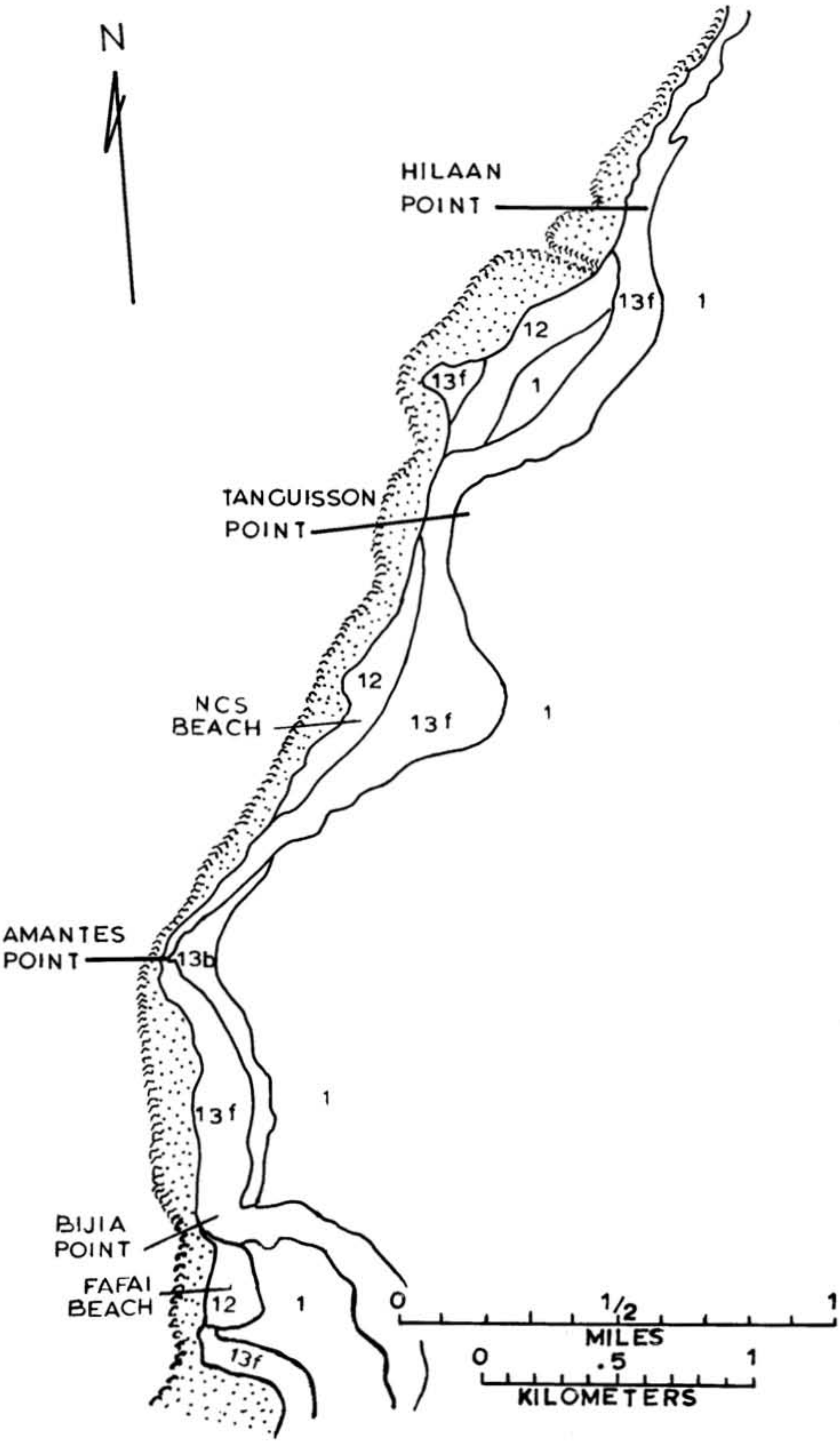


Figure 79. Sector IV soil map. The soil unit explanation legend is on page 265. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil unit descriptions. Fringing reef-flat areas are stippled.

Figure 80. Steep cliff, dislodged blocks of limestone, and fringing reef flat platform at Tanguisson Point.

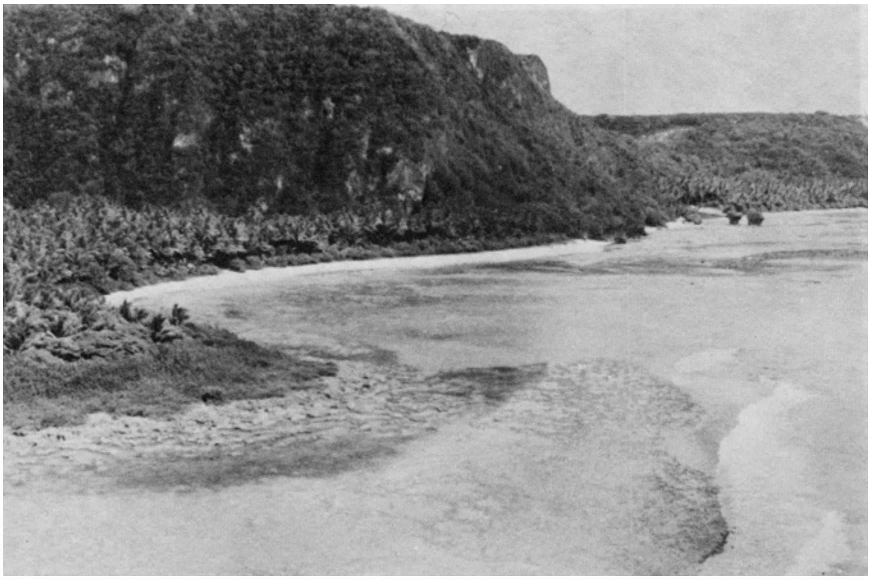


Figure 81. Sandy beach between a rocky point near Hilaan Point and Tanguisson Point in the background.

Figure 82. Strand vegetation along beach between Tanguisson and Hilaan Points.

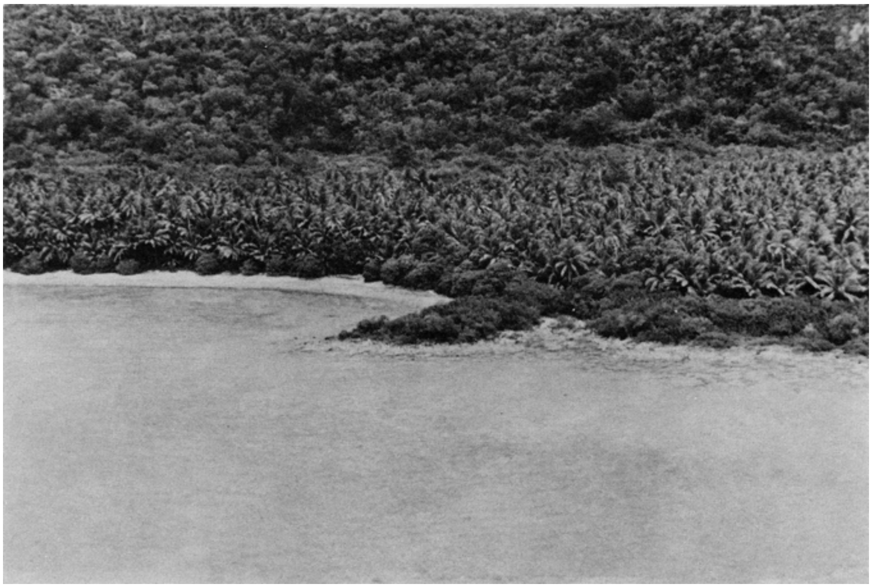


Figure 83. Coconut grove bordering the strand vegetation zone shown in Figure 82.

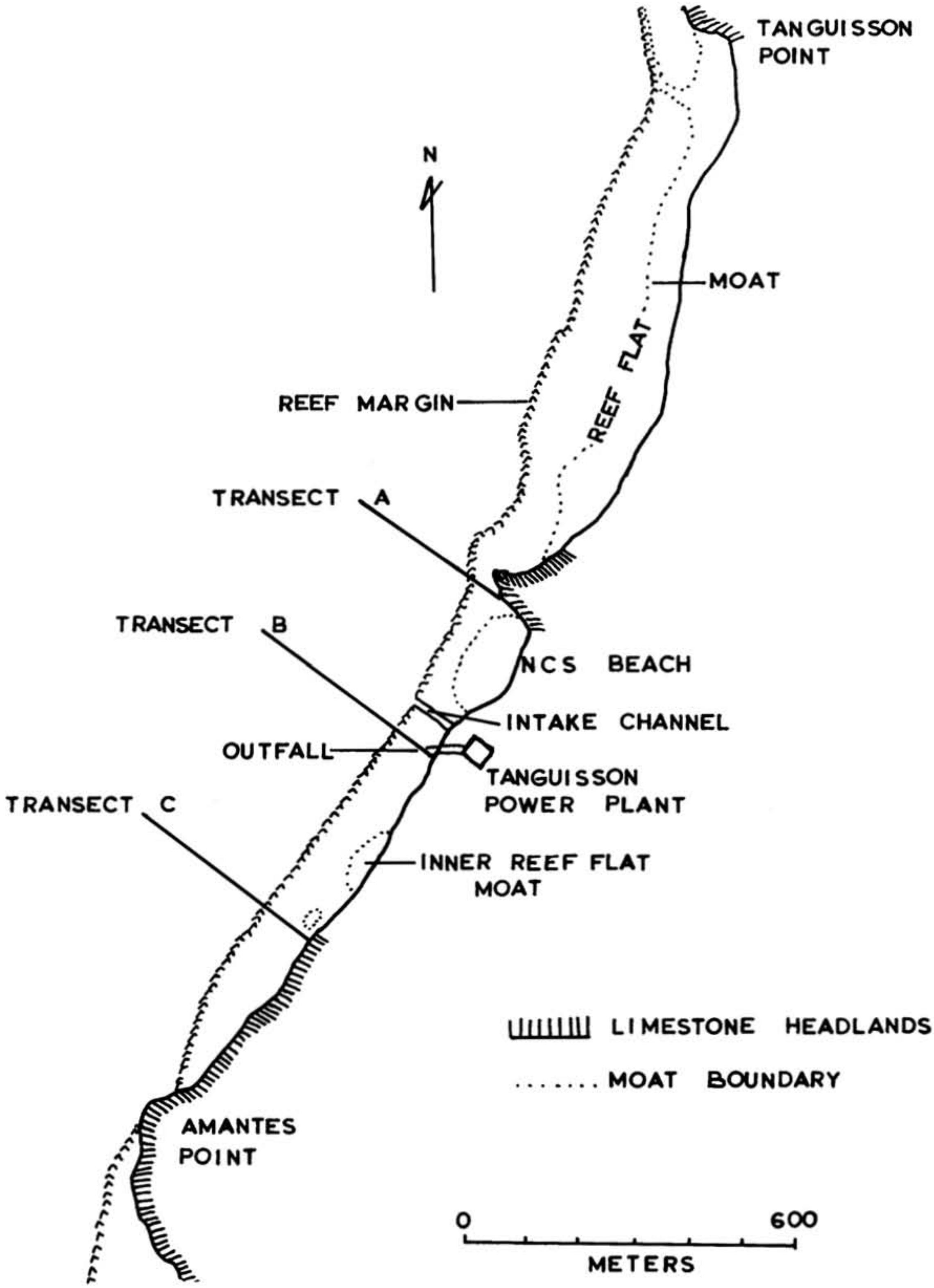


Figure 84. Fringing reef map showing the three permanent transects at the Tanguisson Power Plant. See Figure 19 for profile at Transect B.

Figure 85. Aerial view of Tanguisson Point Power Plant showing an intake channel which cuts across the reef platform and an outfall which empties onto the reef-flat shoreline. Naval Communications Station Beach is to the left.

Figure 86. Amantes Point (Two Lovers' Leap) Park located on the margin of a prominent headland. See Figure 77 for an overall view. Joints and fissures cut the face of the cliff.

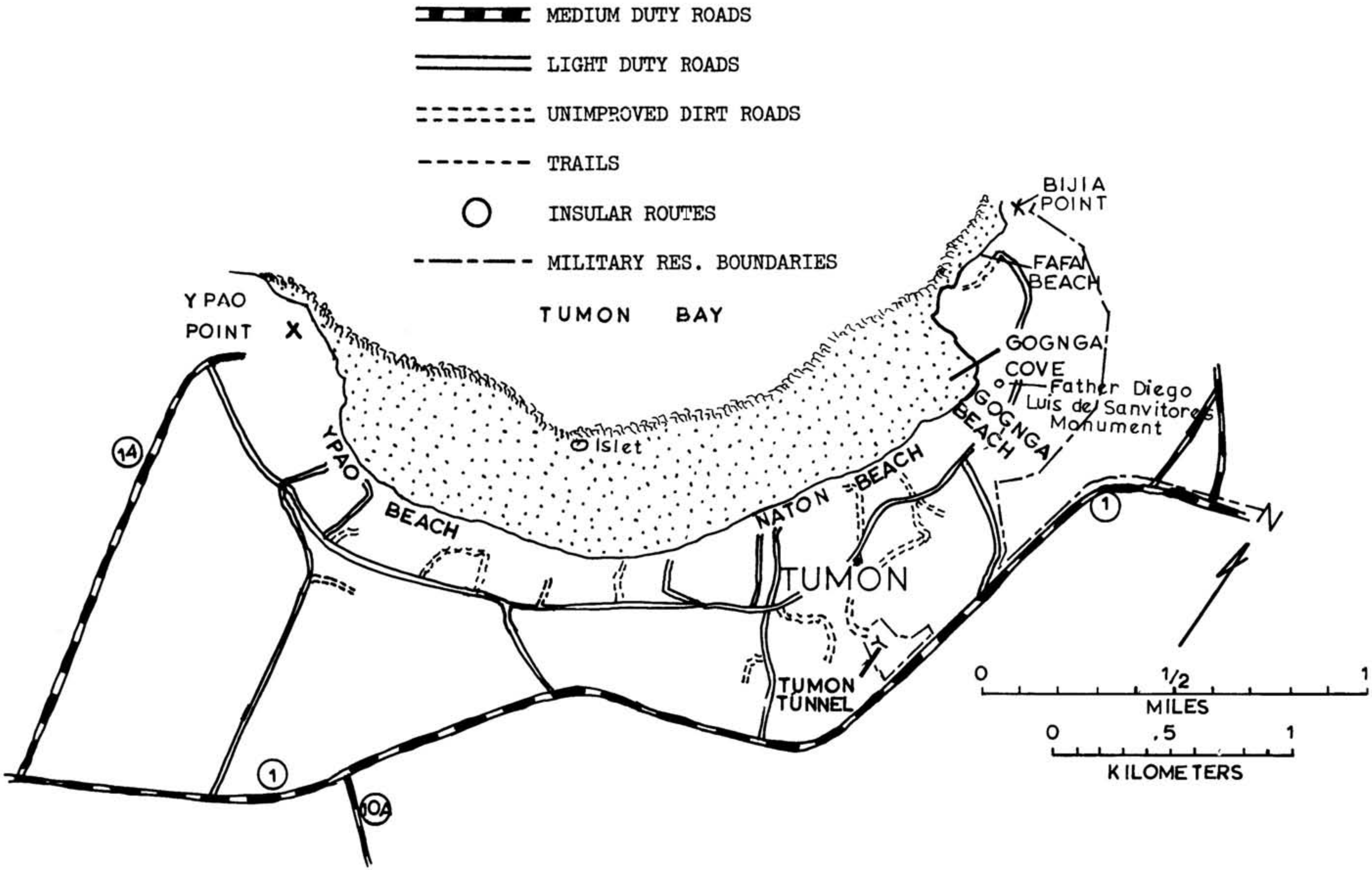


Figure 87. General location map for Sector V.

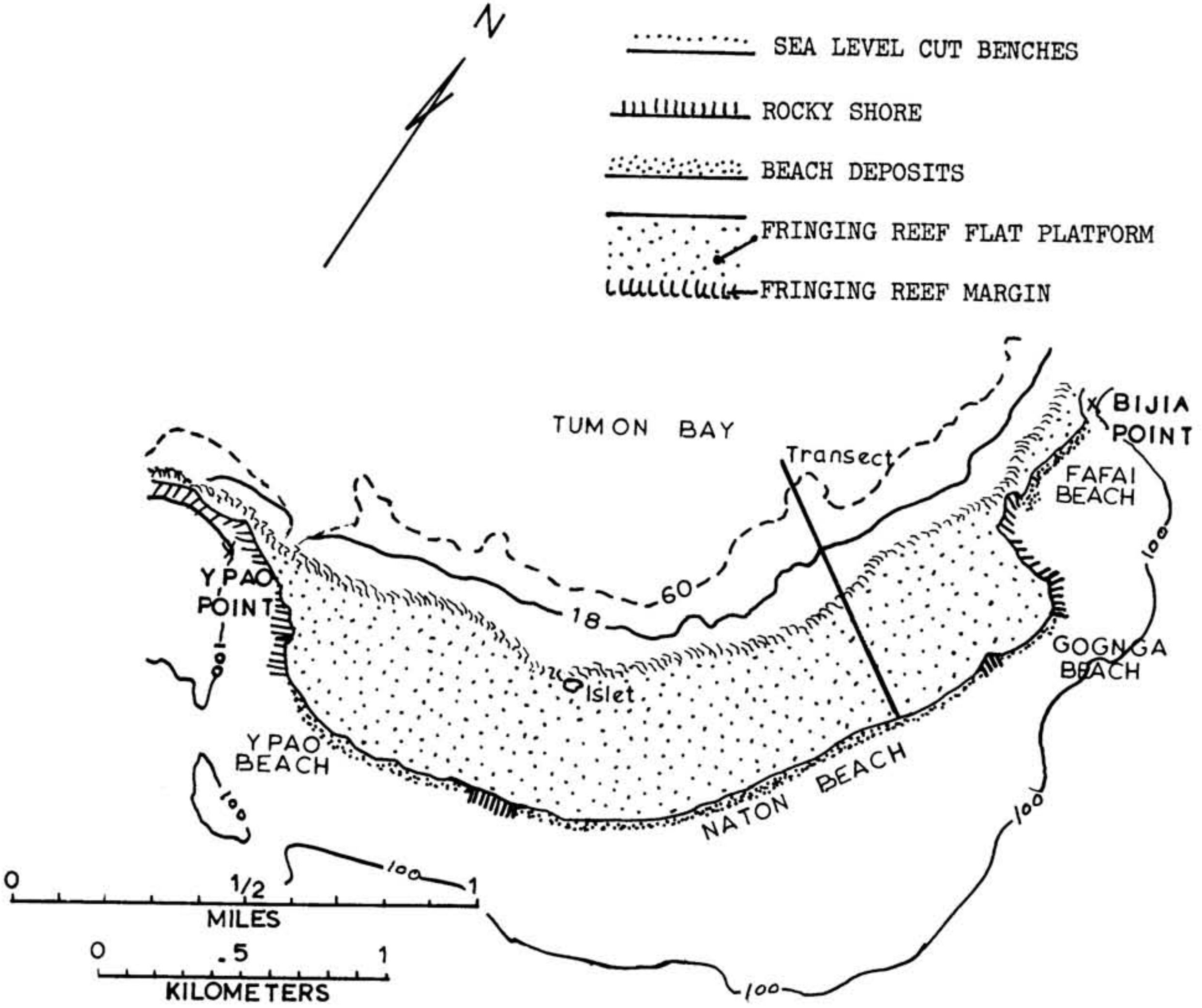


Figure 88. Map showing the 100-foot coastal contour (solid line), rocky shorelines, beach deposits, fringing reef-flat platforms (stippled region seaward of shorelines), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for Sector V. See Figure 18 for profile at Naton Beach.

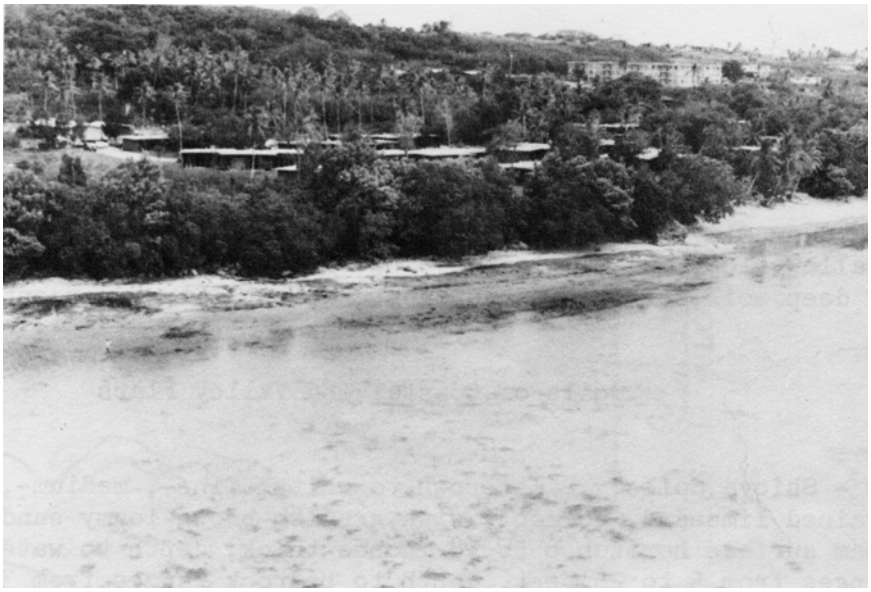


Figure 89. Rocky shoreline between Ypao and Naton Beaches. Continental Travel Lodge forms a cluster of low hotel units behind the shoreline.

Figure 90. Rocky headland between Naton and Gognga Beaches. The Towa Reef Hotel is under construction in the background.

SOILS EXPLANATION FOR SECTOR V

Upland Soils (On Limestone)

1 – Guam Clay. Reddish, granular, permeable Latosol; generally very shallow (less than 12 inches), but has some pockets or narrow troughs of deep soil; prevailing surface gradient 1 to 8 percent.

Soils of Coastal and Valley Flats

12 – Shioya Soils. Pale brown to white, fine-, medium-, or coarse- grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Miscellaneous Land Types

13f – Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical. (see page 246 for description of Unit 13b).

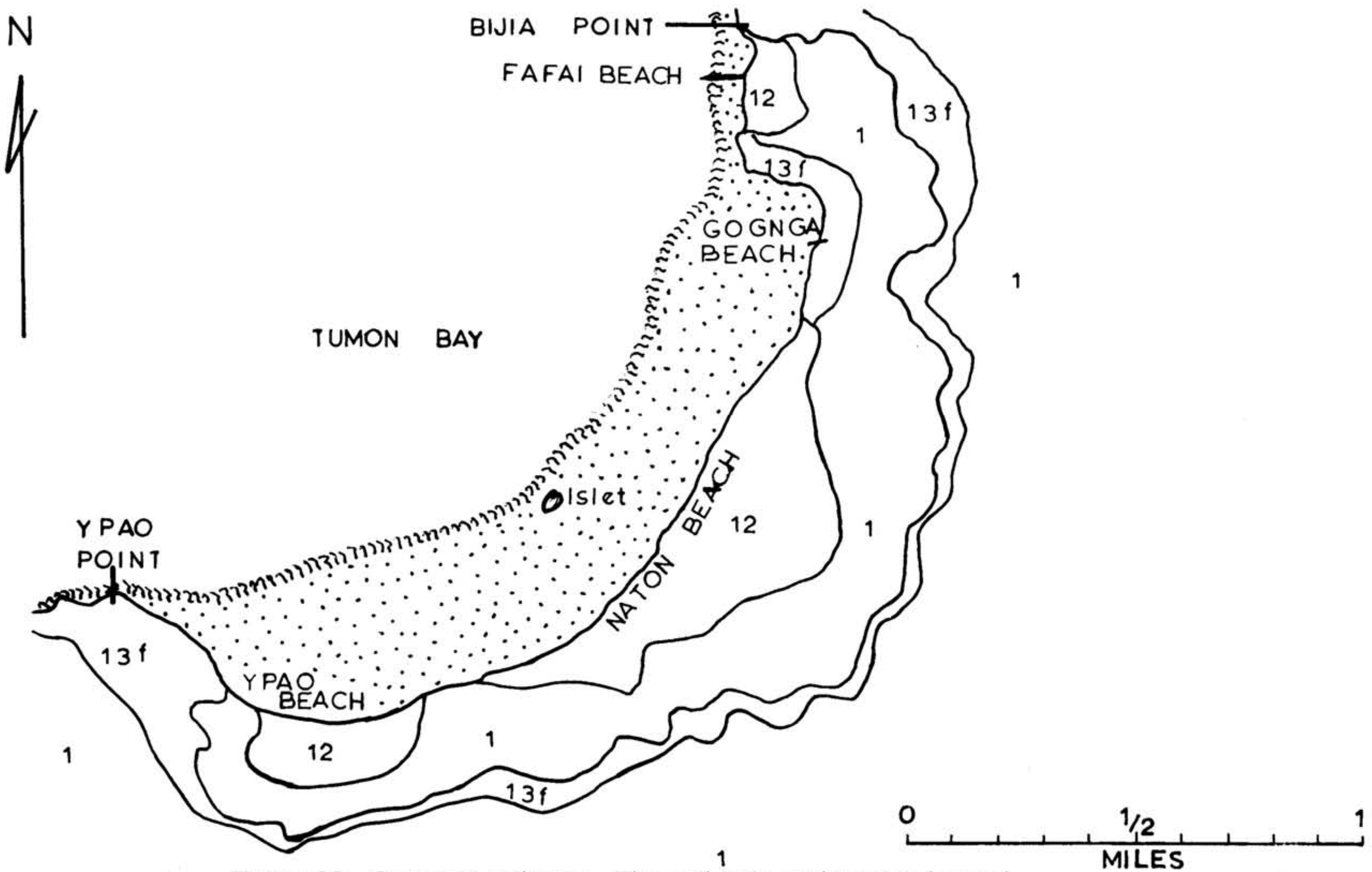


Figure 88. Sector V soil map. The soil unit explanation legend is on page 274. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil unit descriptions. Fringing reef-flat areas are stippled.

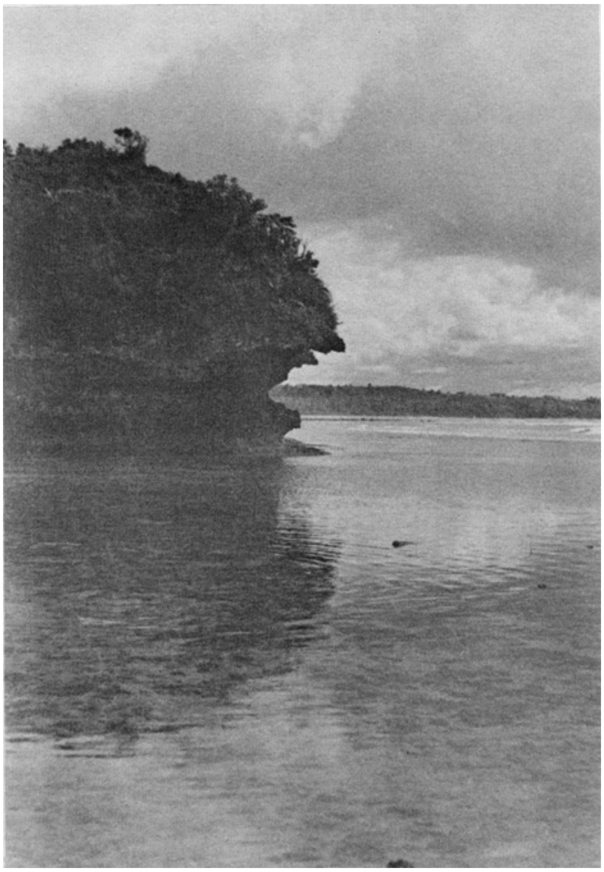


Figure 92. Sea-level and +6-foot nips cut in limestone headland at the north end of Tumon Bay.

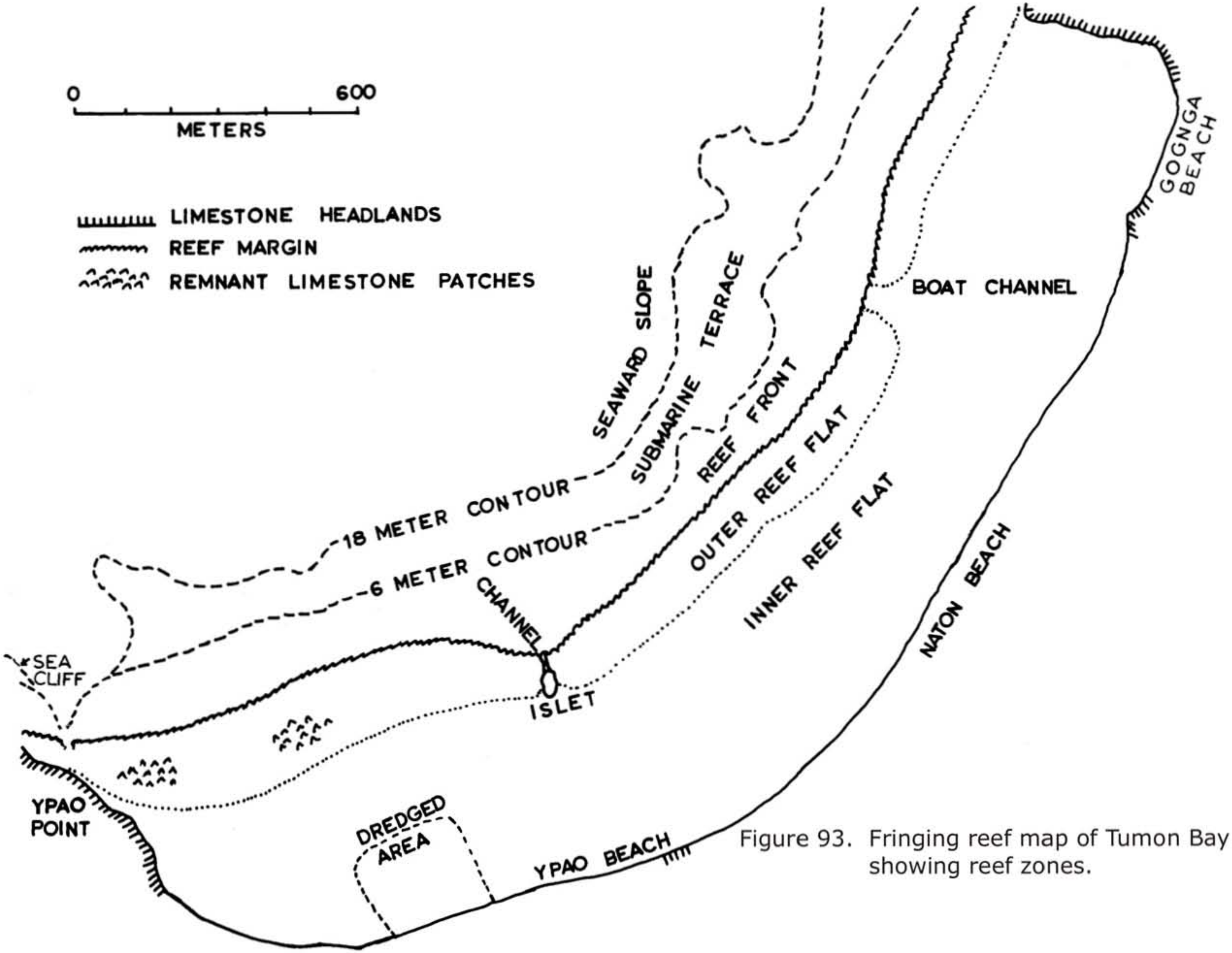


Figure 93. Fringing reef map of Tumon Bay showing reef zones.

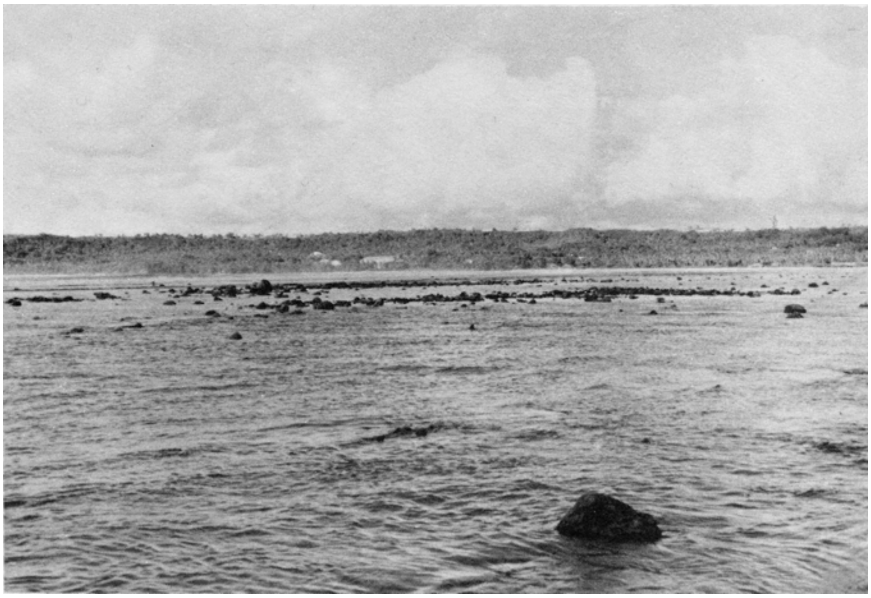


Figure 94. Boulder accumulation at the boundary of the inner and outer reef-flat zones.

Figure 95. Boulder accumulation and small islet at the seaward edge of the Tumon Bay reef-flat platform.

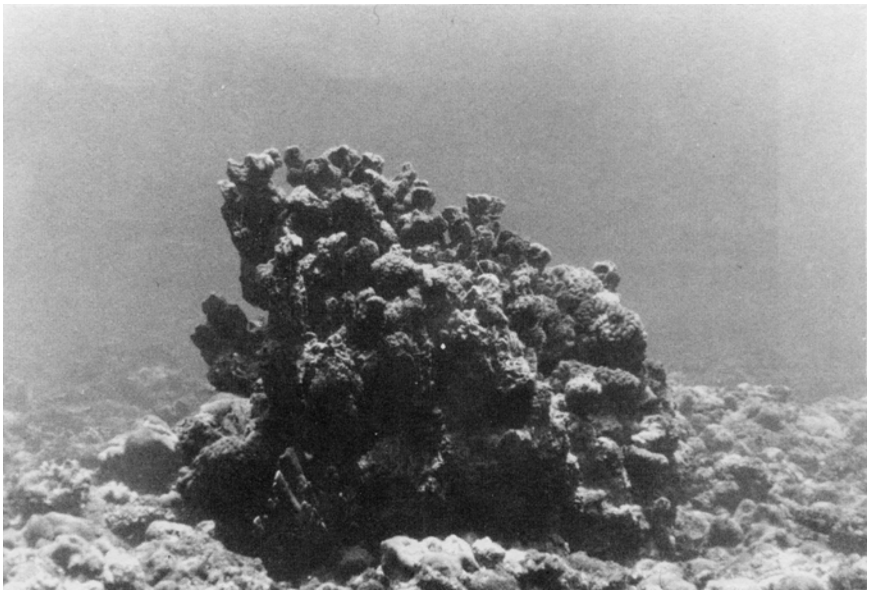


Figure 96. Coral mound on the submarine terrace zone at Tumon Bay.

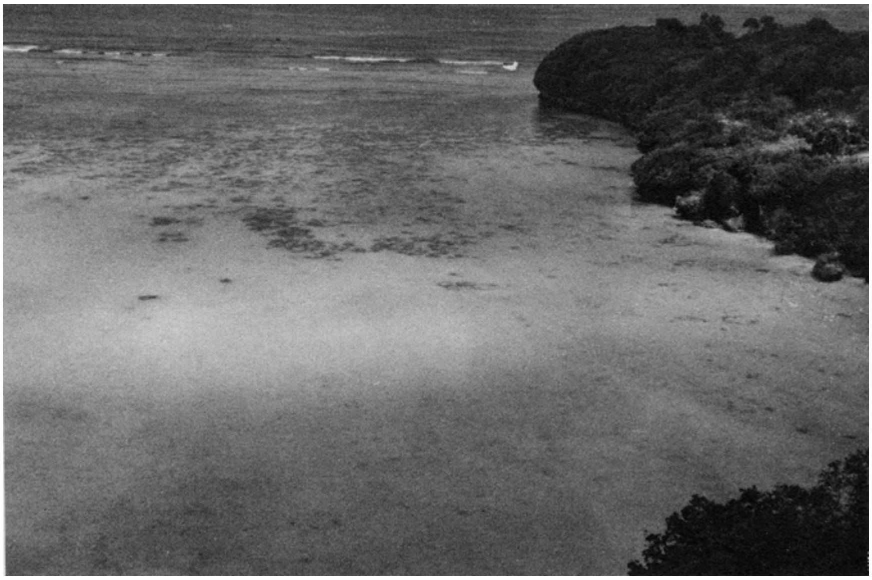


Figure 97. A relatively undisturbed limestone ridge borders the north end of Tumon Bay.

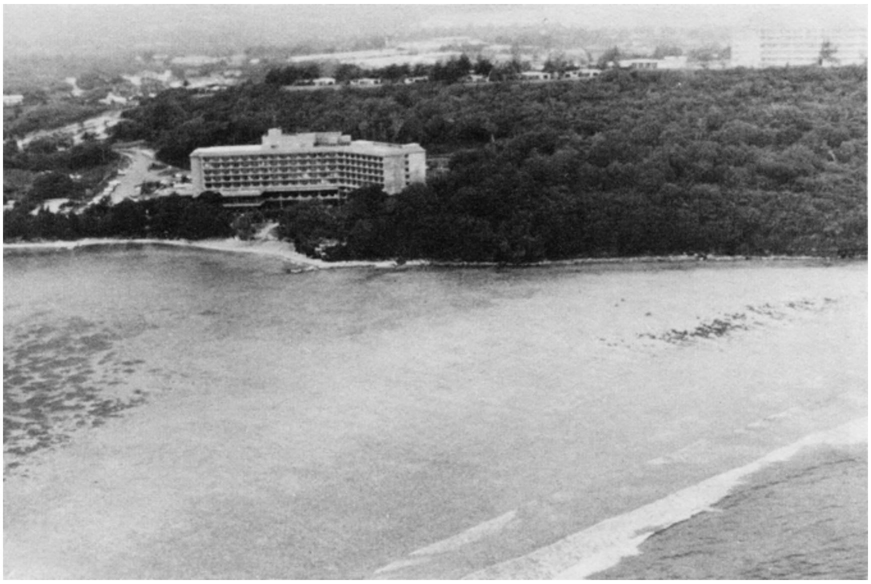


Figure 98. Hilton Hotel and steep limestone slopes and cliffs border the south end of Tumon Bay.

Figure 99. Naton Beach and Father Diego Luis de Sanvitores Monument at the north end of Naton Beach.

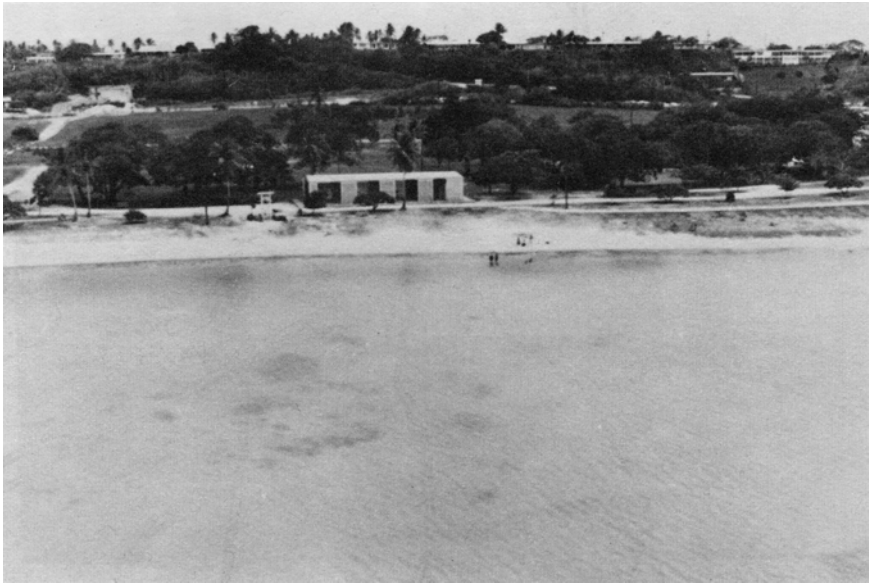


Figure 100. Ypao Public Beach at the south end of Tumon Bay.

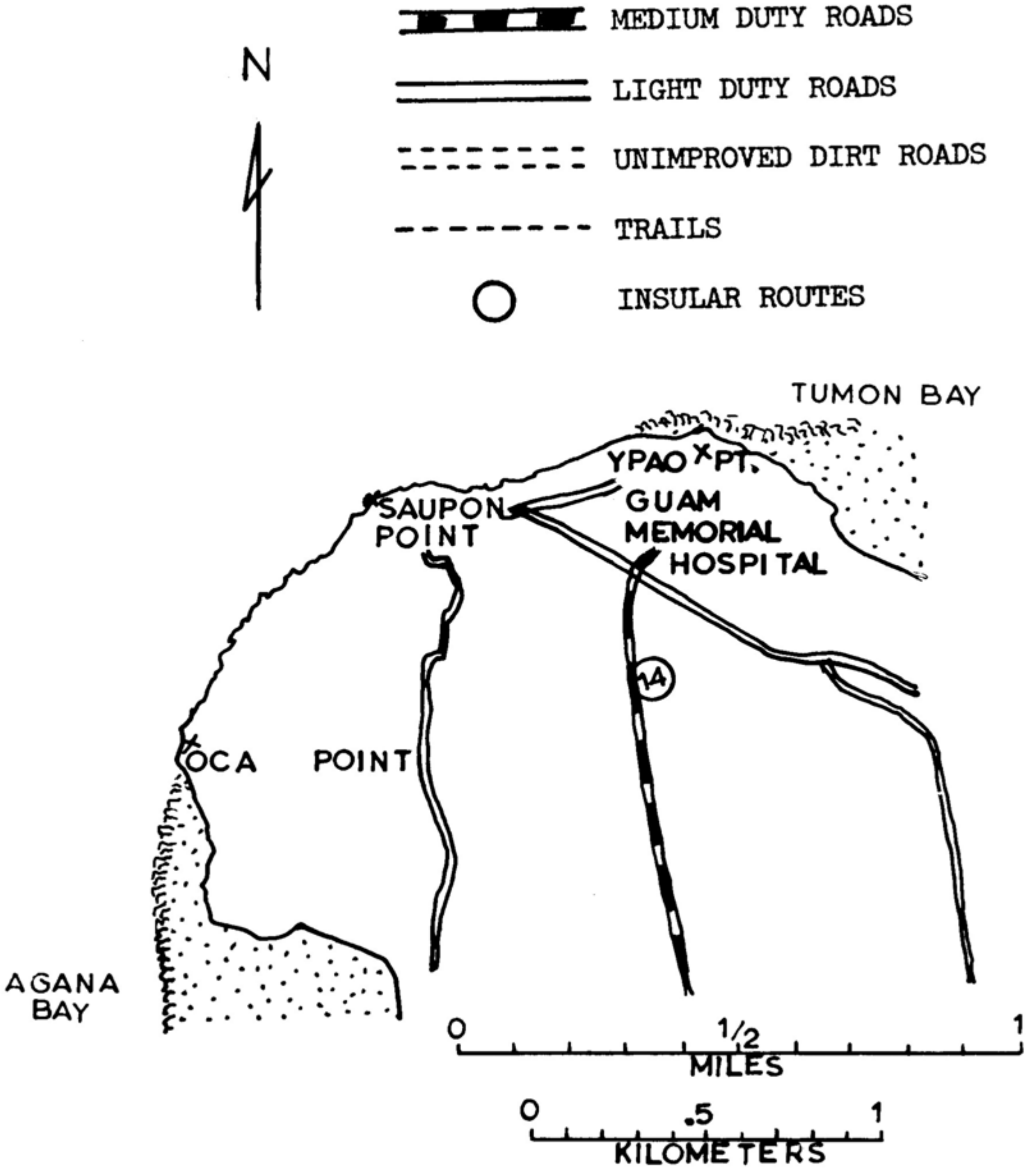


Figure 101. General location map for Sector VI.

Figure 102. The narrow reef flat at Ypao Point grades into a narrow cut bench. On the plateau above is the Guam Memorial Hospital. Note large limestone block from which reef-flat transect was made.

SOILS EXPLANATION FOR SECTOR VI

Upland Soils (On Limestone)

1 – Guam Clay. Reddish, granular, permeable Latosol; generally very shallow (less than 12 inches), but has some pockets or narrow troughs of deep soil; prevailing surface gradient 1 to 8 percent.

Soils of Coastal and Valley Flats

12 – Shioya Soils. Pale brown to white, fine-, medium-, or coarse-grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Miscellaneous Land Types

13b – Limestone Rock Land, Gently Sloping. Patches of thin (generally less than 2 or 3 inches) reddish or brownish granular clay among exposures of limestone bedrock, pinnacles, boulders, and fragments, which make up more than 25 percent of entire unit area and more than 75 percent of local areas; prevailing surface gradient 2 to 15 percent.

13f – Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than I00 percent, with many scarps or cliffs nearly vertical.

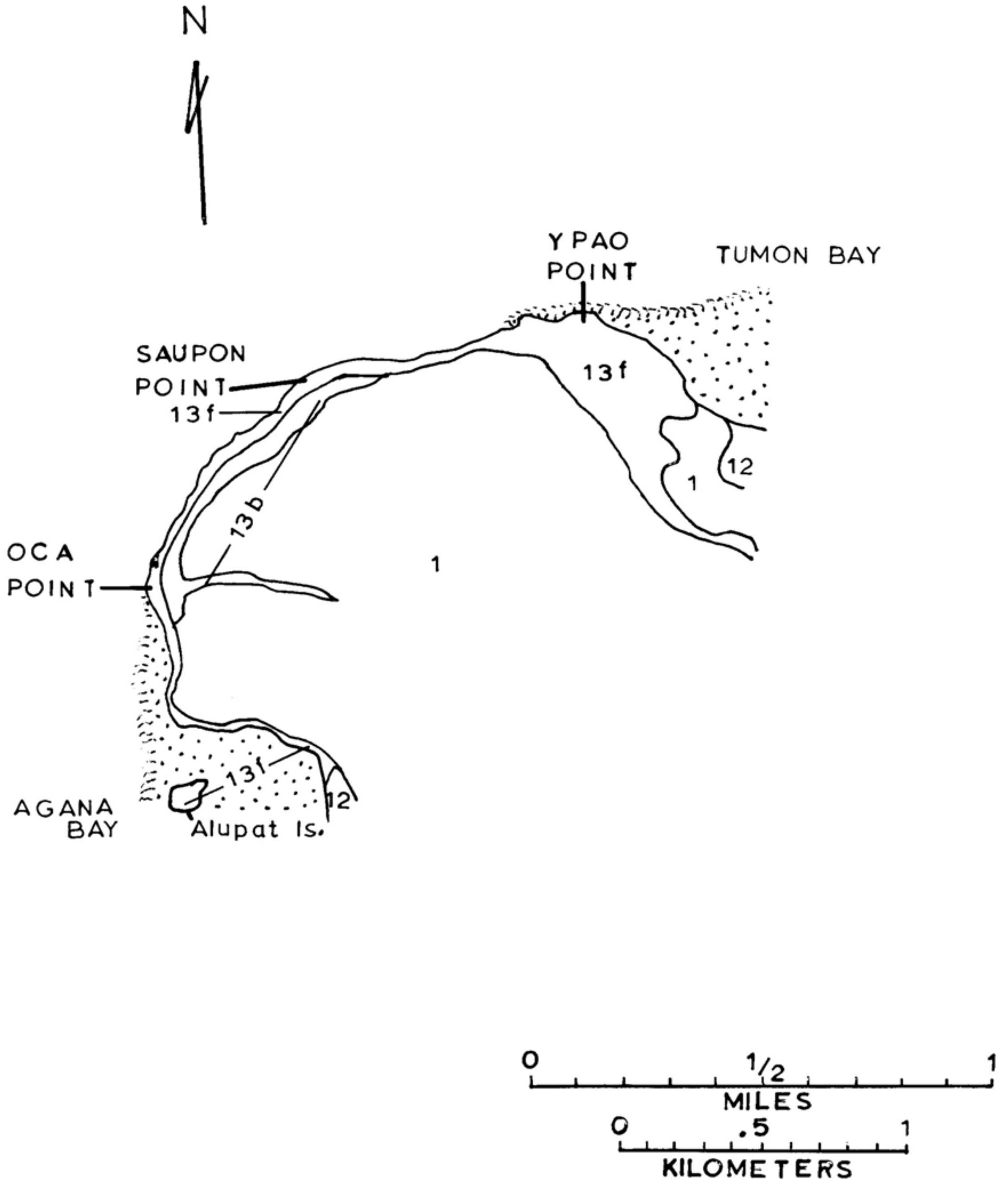


Figure 103. Sector VI soil map. The soil unit explanation legend is on page 284. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil unit descriptions. Fringing reef-flat areas are stippled.

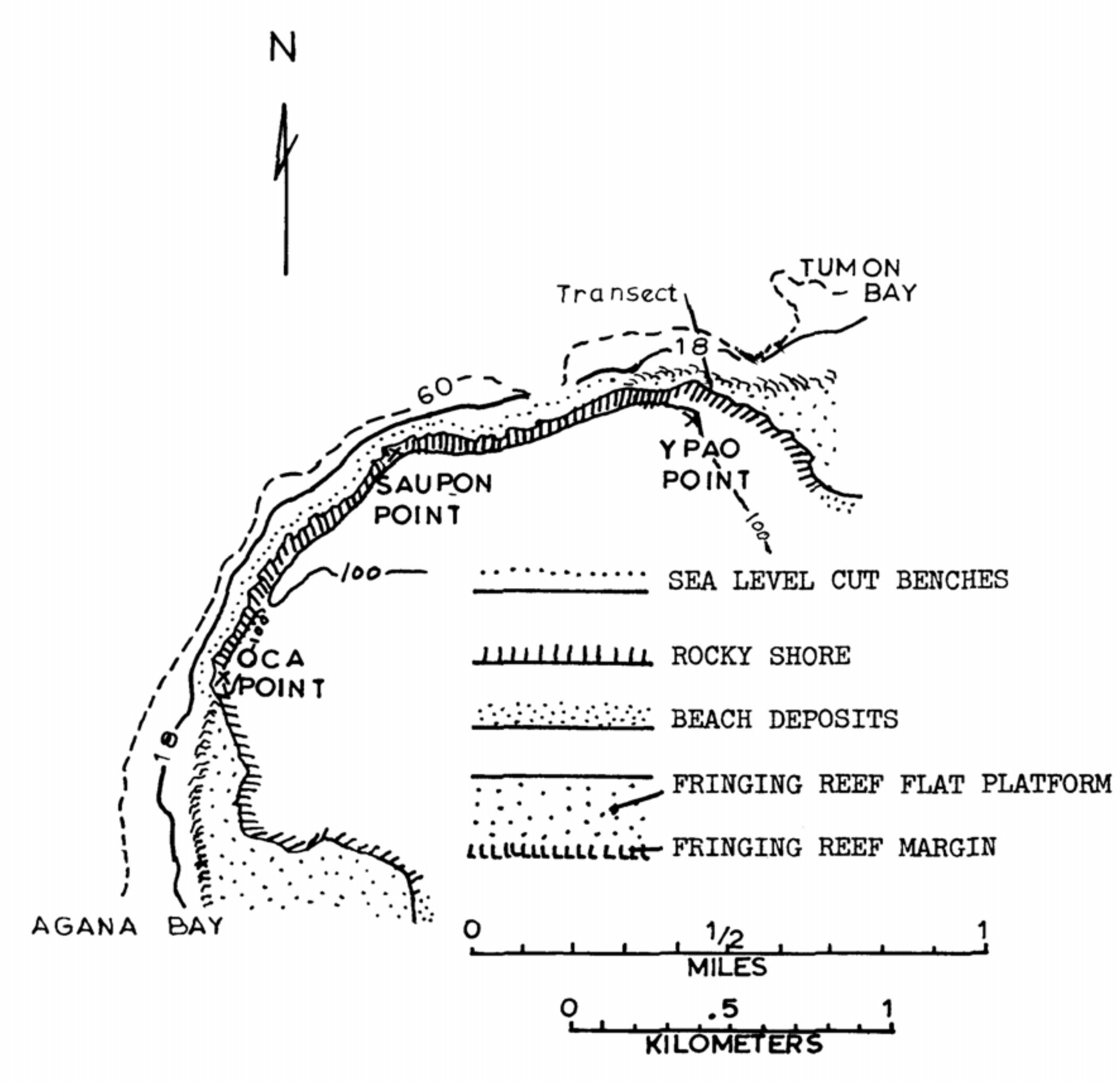


Figure 104. Map showing the 100-foot coastal contour (solid line), rocky shorelines, cut benches, fringing reef-flat platforms (stippled region seaward of the shoreline), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for Sector VI.

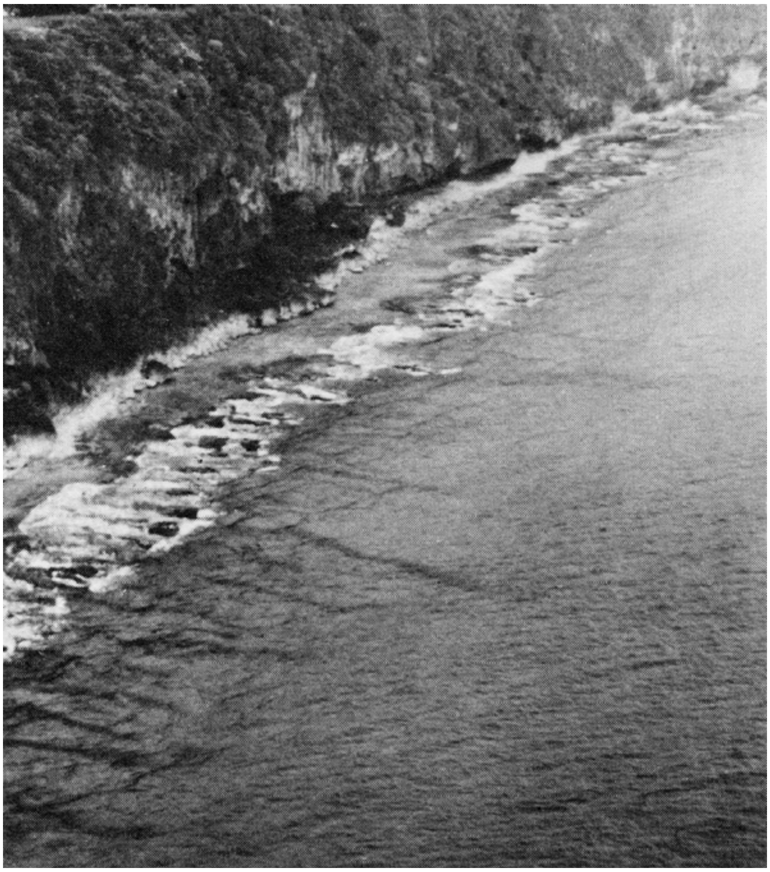


Figure 105. Bench and concave nip cut into the rocky headland along Sector VI. A spur and groove system is visible just seaward of the surf zone.

Figure 106. Residential housing between Saupon and Oca Points on the limestone plateau land bordering the cliffs along Sector VI. Agana Bay and Alupat Island are visible in the background.

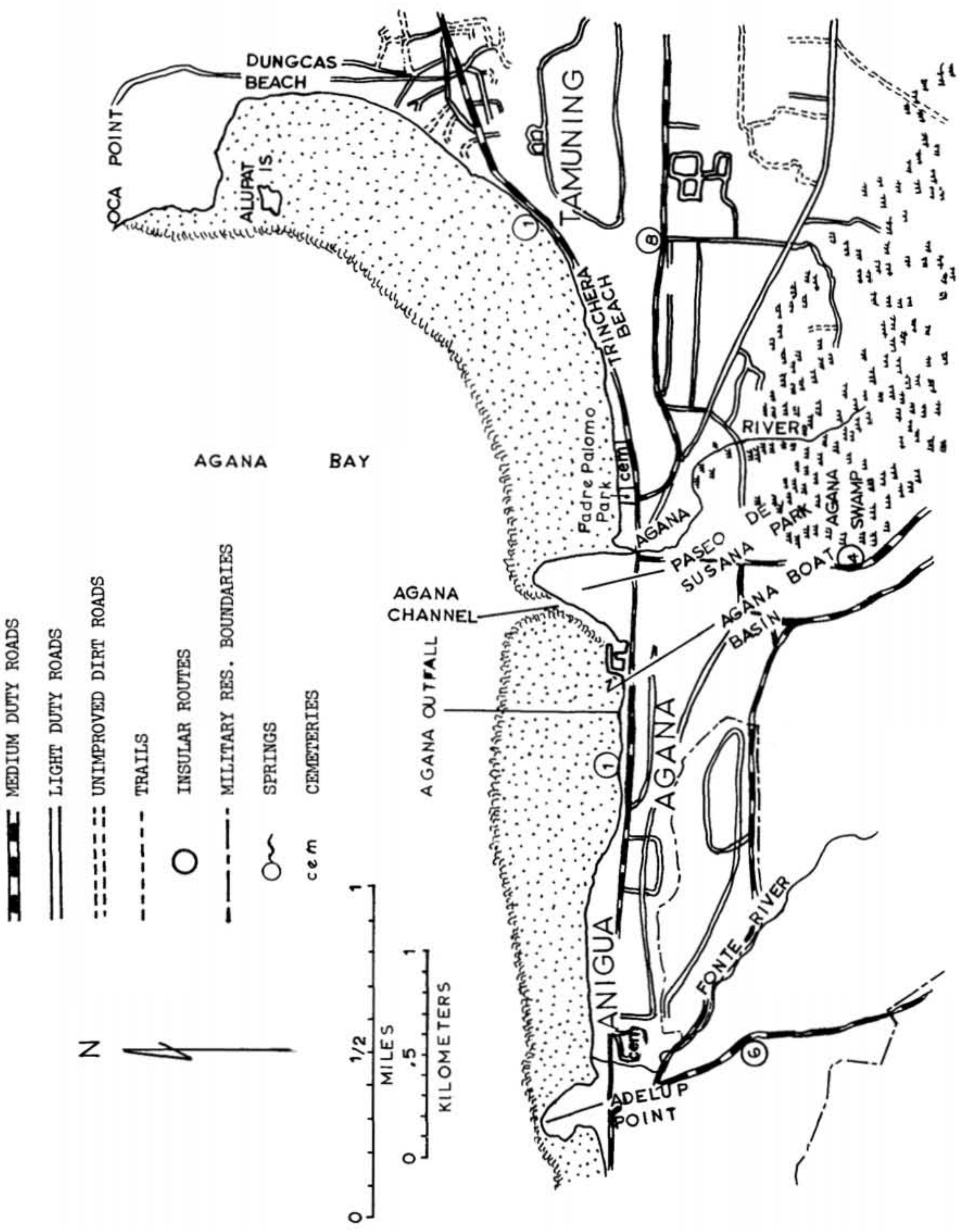


Figure 107a. General location map for the eastern part of Sector VII. See Figure 107b for the remainder (western part) of Sector VII.

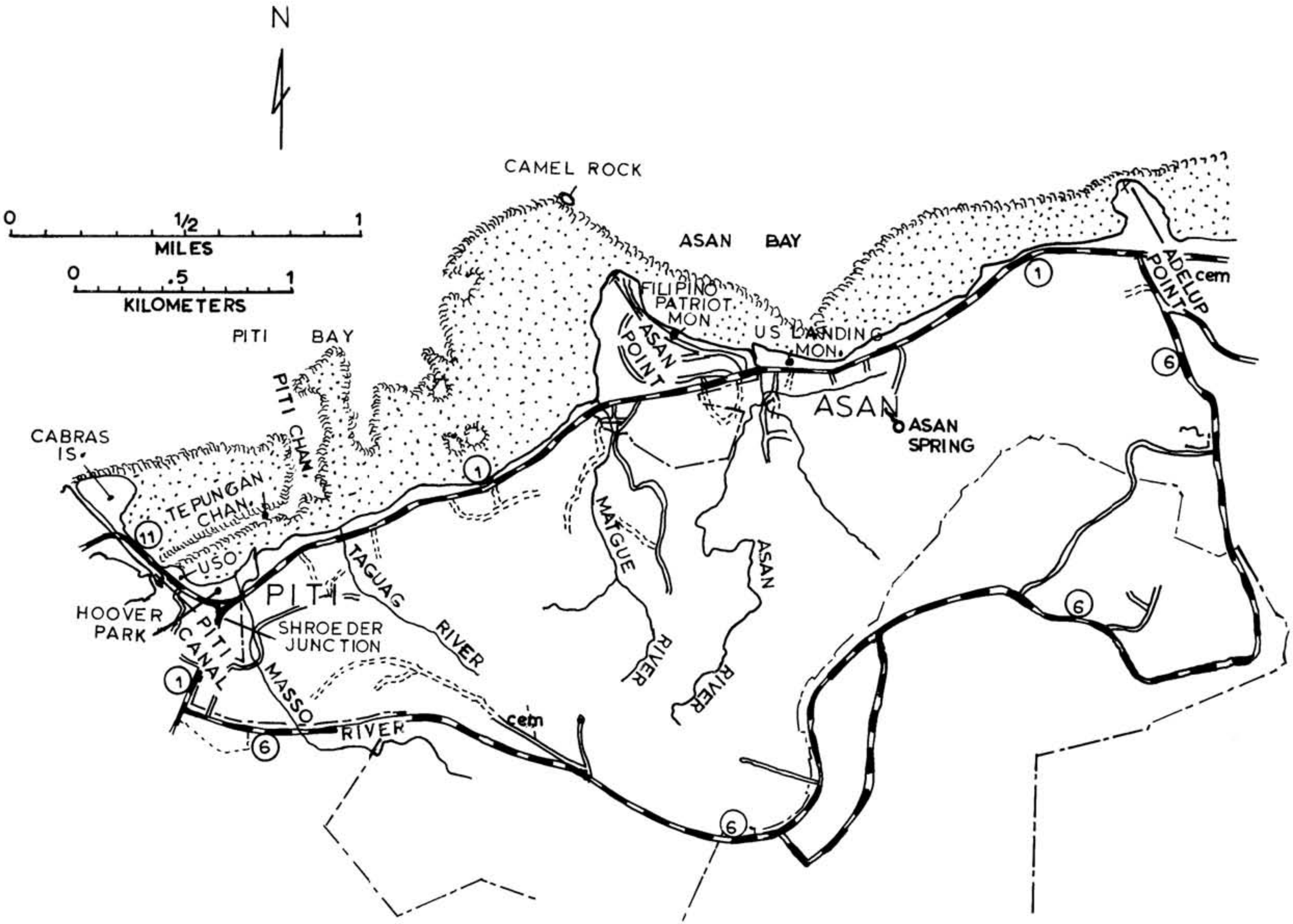


Figure 107b. General location map for the western part of Sector VII. See Figure 107a for the remainder (eastern part) of Sector VII and map legend.

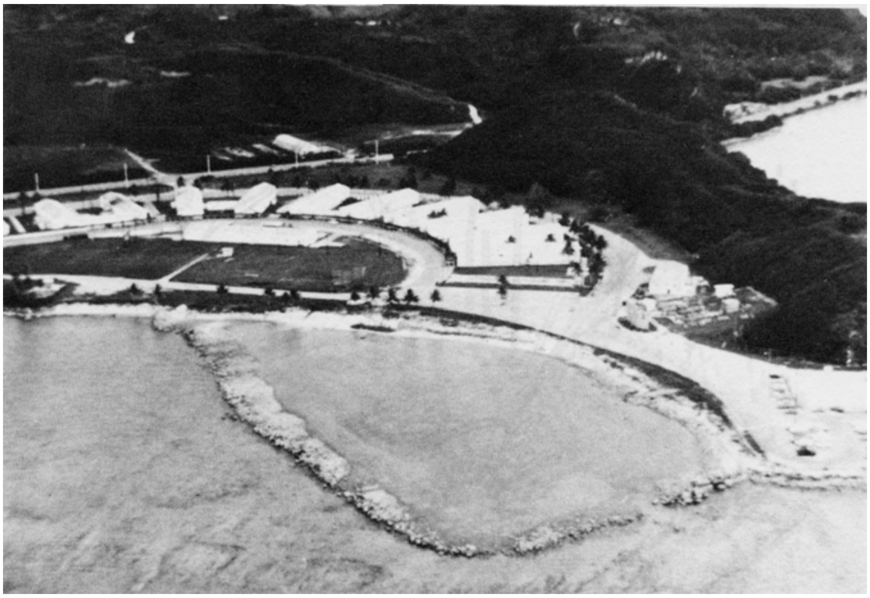


Figure 108. Asan Point. A forested limestone ridge occupies the south side of the Point, and the U.S. Naval Hospital Annex occupies the low terrace on the north side. A causeway partially encloses a swimming area in the foreground.

Figure 109. Paseo de Susana Park occupies the triangular, man-made peninsula at Agana. The Agana Boat Basin and Channel are visible on the south side of the Park.

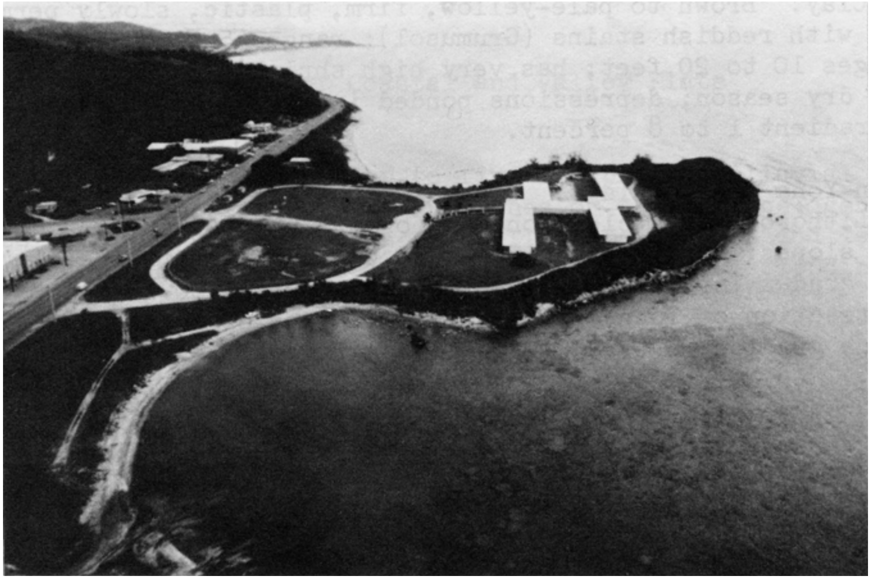


Figure 110. Adelup Elementary School occupies most of Adelup Point at Anigua.

SOILS EXPLANATION FOR SECTOR VII

Upland Soils (On Limestone)

1 – Guam Clay. Reddish, granular, permeable Latosol; generally very shallow (less than 12 inches), but has some pockets or narrow troughs of deep soil; prevailing surface gradient 1 to 8 percent.

2 – Toto Clay. Brown to pale-yellow, firm, plastic, slowly permeable, acid clay with reddish stains (Grumusol); ranges 5 to 30 feet in depth and averages 10 to 20 feet; has very high shrinkage and expansion (large cracks in dry season; depressions ponded in wet season); prevailing surface gradient 1 to 8 percent.

4 – Saipan-Yona Chacha Clays. Chacha-Saipan clays with a shallow brownish Lithosol (Yona clay) on many of the narrow convex ridge-tops and steep slopes; soil depth similar to Unit 3, except Yona clay which generally grades into clayey limestone at about 12 to 24 inches below surface; reaction of Yona clay is thus alkaline or calcareous; prevailing surface gradient 8 to 25 percent.(see page 235 for description of Unit 3).

5 – Yona-Chacha Clays. Yona clay is on most narrow convex ridge-tops and steep side slopes, with Chacha on intervening slopes; also small areas of shallow stony phase Saipan clay; depth of soil with convex surface is generally less than 2 or 3 feet, with concave surface it is generally more than 3 feet; slopes range from 25 to more than 100 percent but prevailing surface gradient is commonly 30 to 65 percent.

Upland Soils (On Volcanic Rocks)

6 – Atate-Agat Clay, Rolling. Remnant benches or small mesas of an old red, granular, porous, acid Latosol (Atate clay) with deep, reddish, mottled, plastic to hard clay C horizon, pale yellow, olive, or gray in lower part; and its truncated counterpart (Agat clay) with similar C horizon of saprolitic clay, ranging in depth from a few feet to about 100 feet, and averaging about 50 feet; prevailing surface gradient of Atate clay is 1 to 8 percent, and of Agat clay 8 to 15 percent.

7 – Agat-Asan-Atate Clays, Hilly. Atate-Agat clays and a dark grayish-brown Regosol (Asan clay) developed in more severely truncated saprolite (similar to lower part of C horizon described in Unit 6); soil depths similar to those of Unit 6, except Asan clay which ranges from a few feet in depth to generally less than 50 feet; prevailing surface gradient 15 to 50 percent.

Soils Explanation For Sector VII. Continued.

8 – Agat-Asan Clays And Rock Outcrop, Very Hilly To Steep. Chiefly of the truncated Latosol (Agat clay) and the Regosol (Asan clay) with some un-named dark grayish-brown Lithosols and scattered small areas of volcanic rock outcrop (basalt and bedded tuffs); depth to rock ranges from 0 to 50 or more feet and averages perhaps 20 to 35 feet; prevailing surface gradient 35 to more than 100 percent.

Soils of Coastal and Valley Flats

9 – Pago Clay. Brownish, granular to firm and plastic Alluvial clay, with gray mottling to within 24 to 30 inches of the surface; generally alkaline to neutral; soil depth is generally more than 10 and less than 150 feet; moderately well drained; subject to occasional flooding; prevailing surface gradient 1 to 3 percent.

10 – Inarajan Clay. Similar to Pago Clay but lower, wetter, and shallower (thins out on coastal sands and bedrock); water table at or near the surface (within 30 inches) most of the time; poor drainage, mottlings (gray) within 6 to 12 inches of the surface; depth to sand or bedrock ranges from 3 to 25 or more feet; reaction is alkaline in water saturated zone; poorly drained; frequently flooded; prevailing surface gradient 0 to 1 percent.

11 – Muck. Black to brown, soft muck and peat, with some clay and silt; depth to underlying material (chiefly limesand or shelly clay) ranges from 3 to 20 feet, averages 5 to 10 feet; alkaline reaction below the water table, which is generally at or near the surface; prevailing surface gradient is level or very nearly level.

12 – Shioya Soils. Pale brown to white, fine-, medium-, or coarse-grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Miscellaneous Land Types

13b – Limestone Rock Land, Gently Sloping. Patches of thin (generally less than 2 or 3 inches) reddish or brownish granular clay among exposures of limestone bedrock, pinnacles, boulders, and fragments, which make up more than 25 percent of entire unit area and more than 75 percent of local areas; prevailing surface gradient 2 to 15 percent.

Soils Explanation For Sector VII. Continued.

13f – Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical.

14 – Made Land. Artificial fill, chiefly of limesand and gravel; large boulders, rubble, cobbles, earth, trash, and scrap iron predominate locally; prevailing surface gradient 0 to 3 percent.

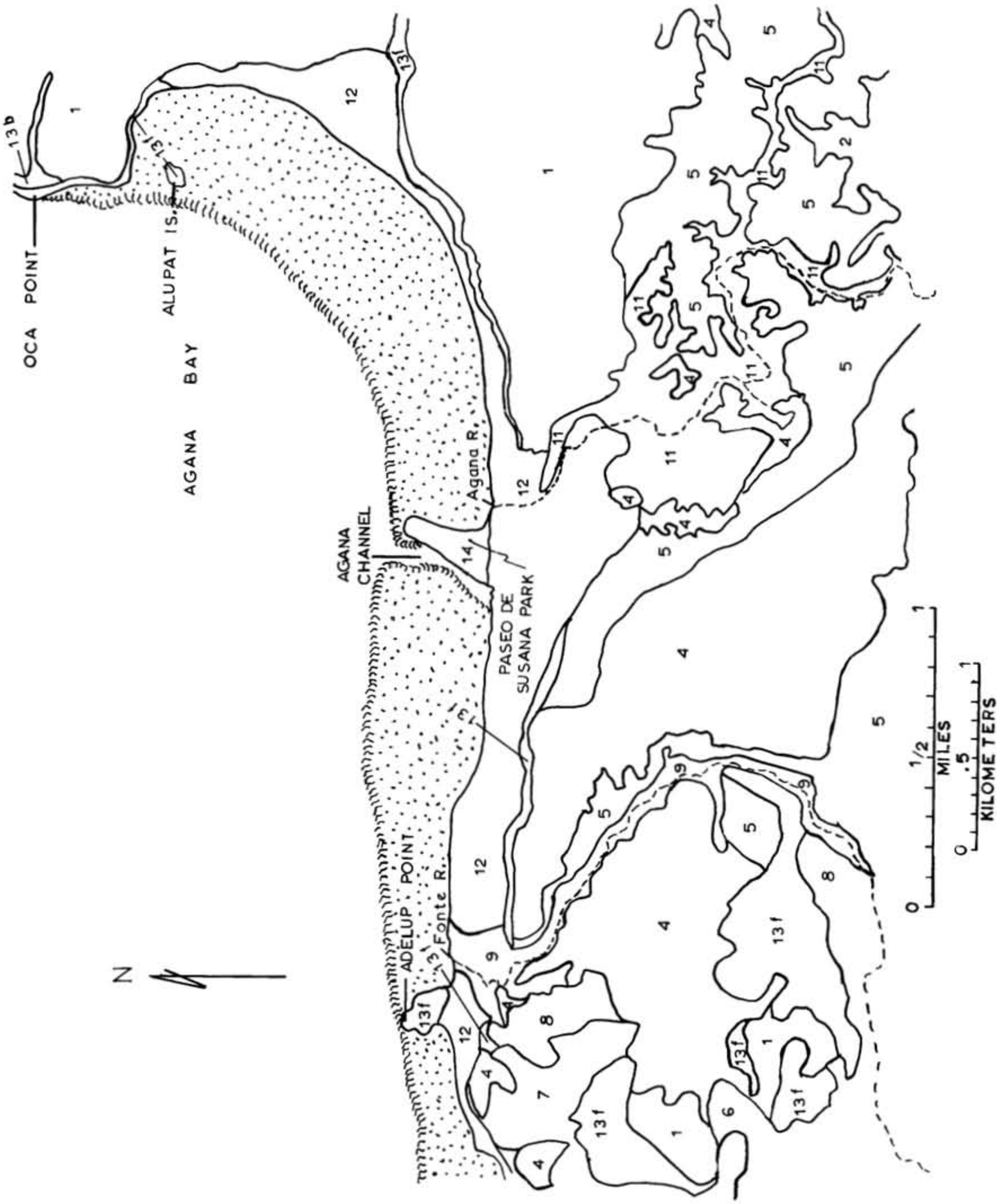


Figure 111a. Sector VII soil map (eastern part). The soil unit explanation legend is on pages 292–294. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil unit descriptions and Figure 111b for the remainder (western part) of Sector VII. Fringing reef-flat areas are stippled.

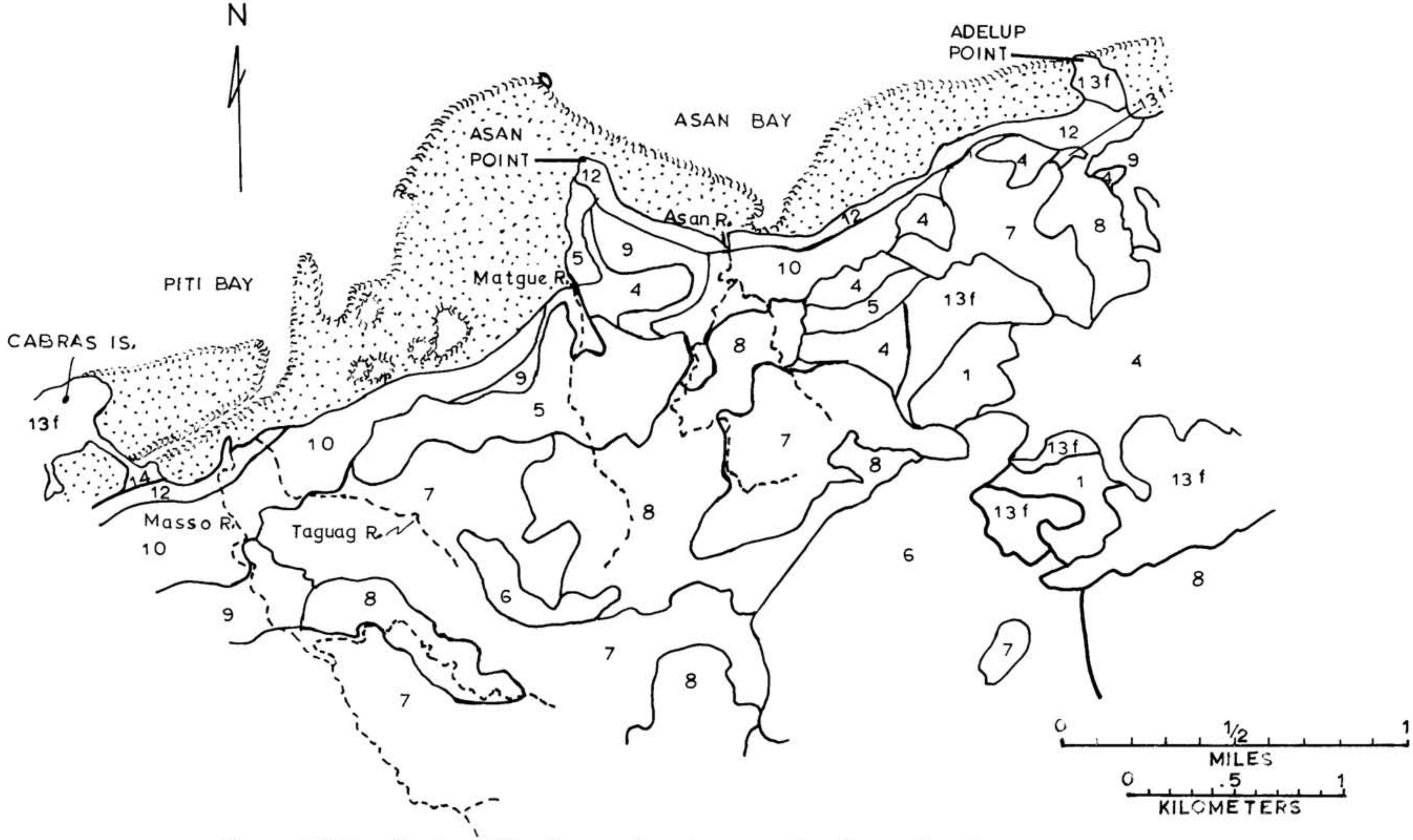


Figure 111b. Sector VII soil map (western part). The soil unit explanation legend is on pages 292n294. See Tables 5 (pages 373n374) and 6 (pages 375n376) for additional soil unit descriptions and Figure 111a for the remainder (eastern part) of Sector VII. Fringing reef-flat areas are stippled.

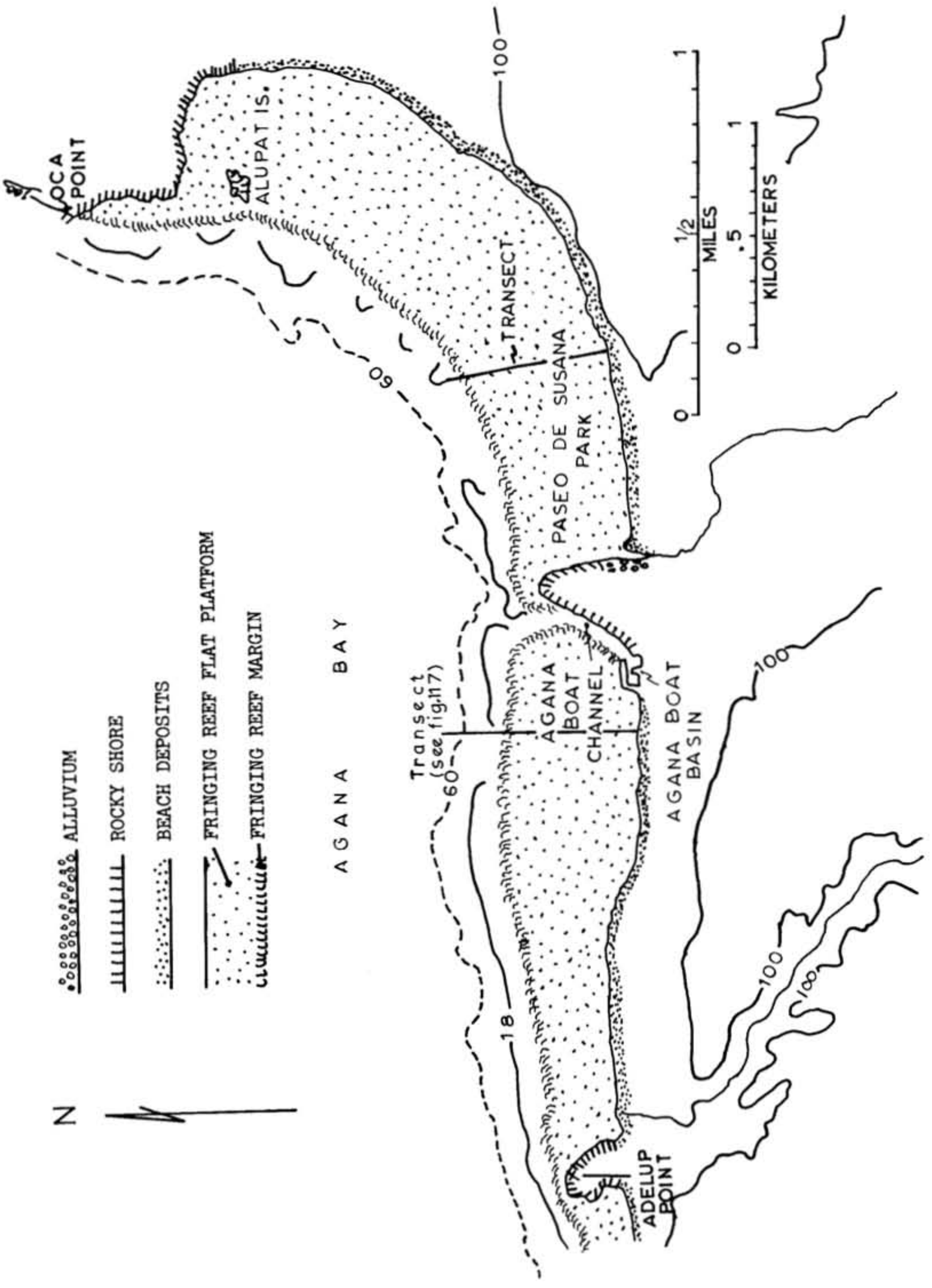


Figure 112a. Map showing the 100-foot coastal contour (solid line), rocky shorelines, beach deposits, alluvium, fringing reef-flat platforms, (stippled region seaward of shoreline), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for Sector VII (eastern part). See Figure 112b for the remainder (western part) of Sector VII. Emery's (1962) Transect No. 1 is shown east of the Paseo de Susana Park.

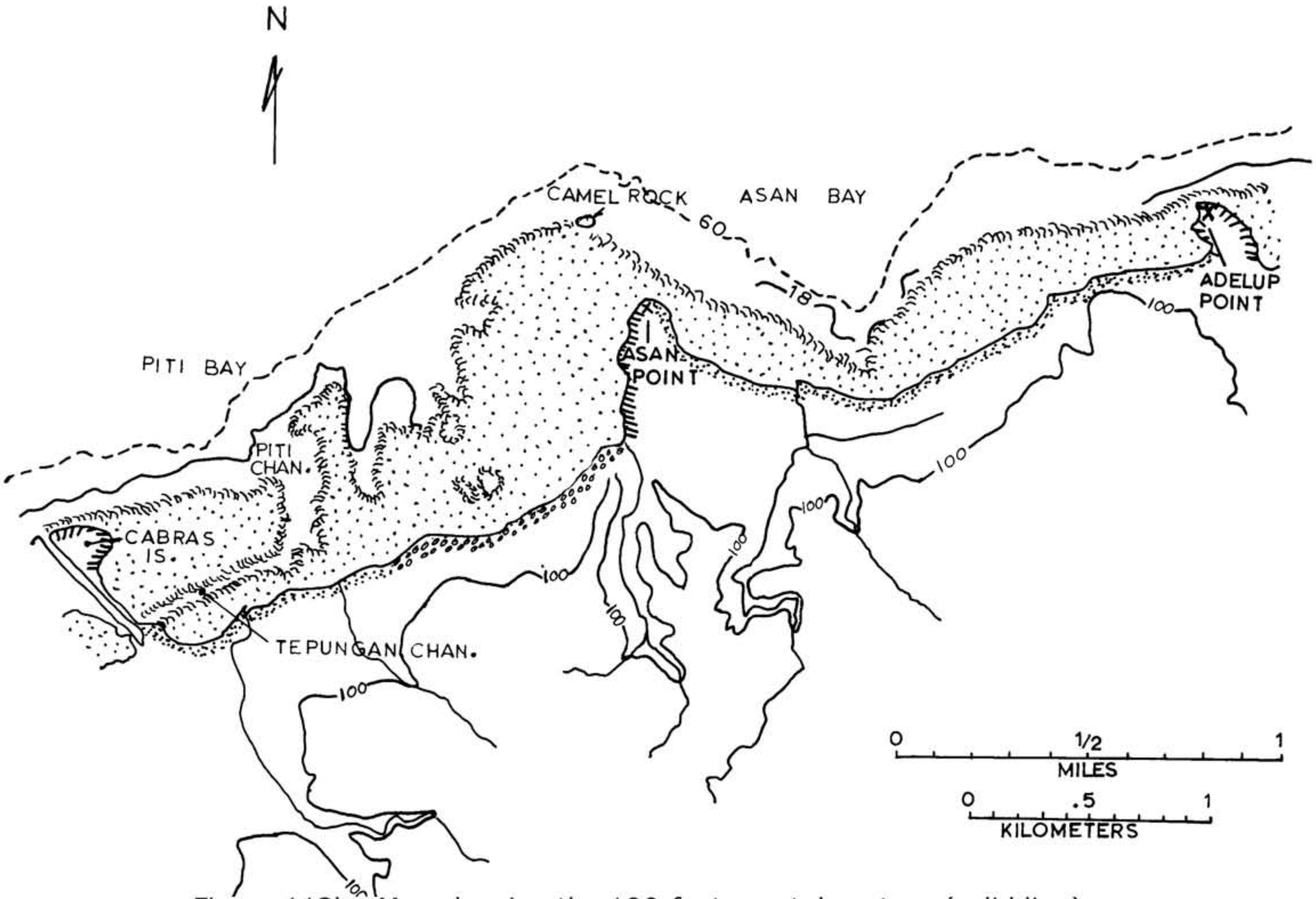


Figure 112b. Map showing the 100-foot coastal contour (solid line), rocky shorelines, beach deposits, alluvium, fringing reef-flat platforms (stippled region seaward of shoreline), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for Sector VII. See Figure 112a for the remainder (eastern part) of Sector VII and map legend.

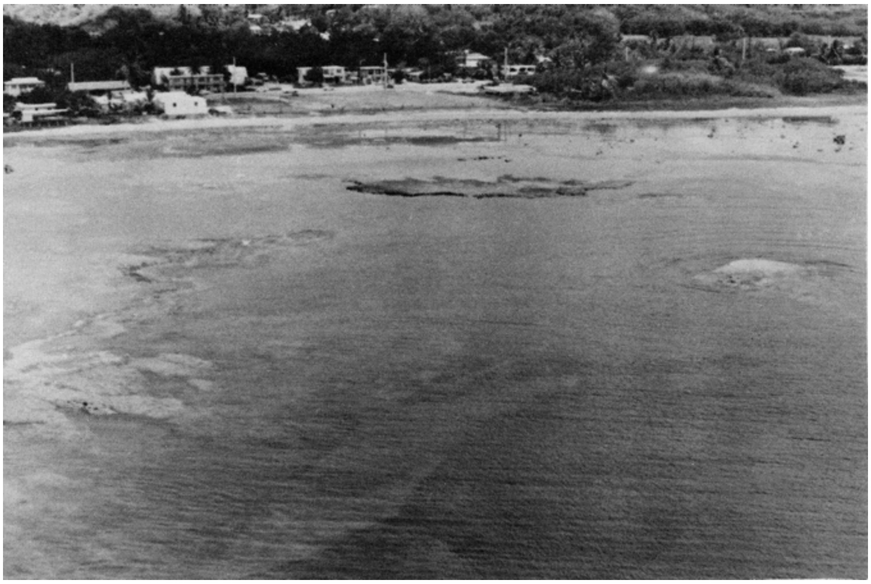


Figure 113. Channel cuts partially through the reef platform at the head of Asan Bay.

Figure 114. Piti Channel cuts partially through the reef-flat platform. The Tepungan Channel flows parallel to the shore from the left and joins Piti Channel.

Figure 115. Broad fringing reef-flat platform east of Paseo de Susana Park.

Figure 116. Broad reef-flat platforms west of Paseo de Susana Park. Circular regions are patches of *Enhalus acoroides*.

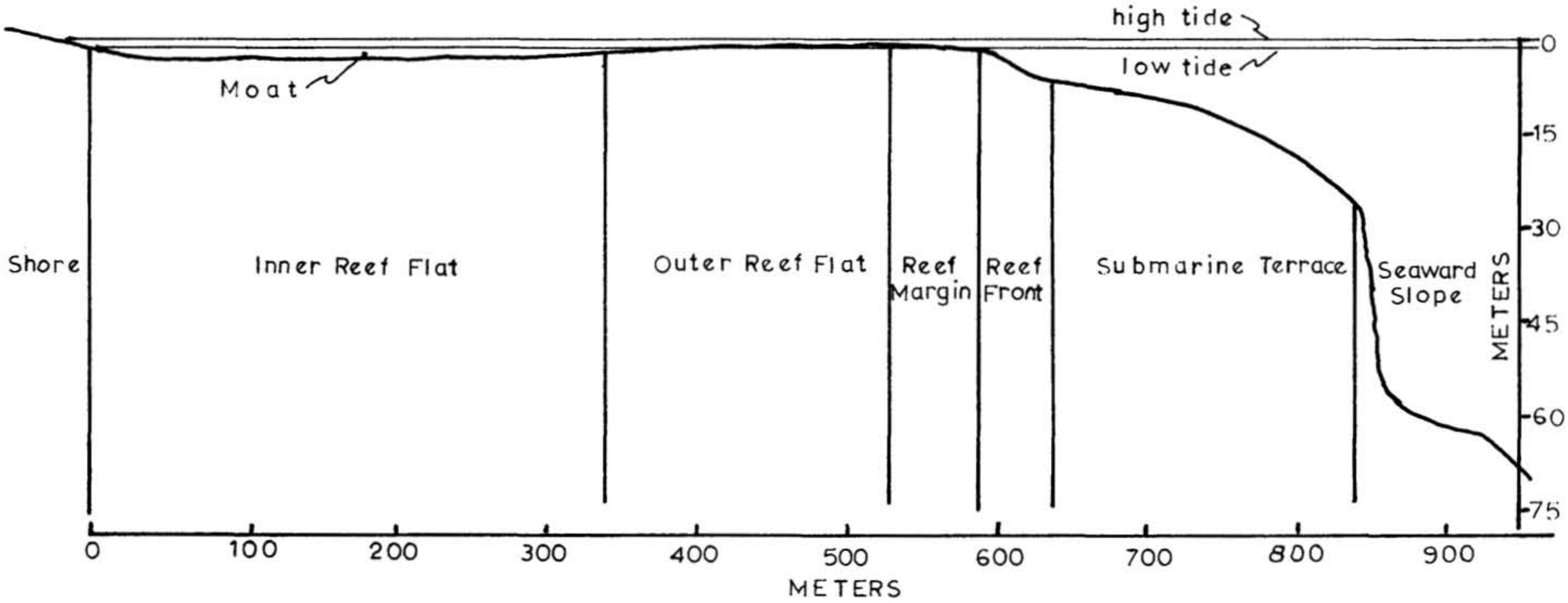


Figure 117. Reef profile about 1000 feet west of the Agana Boat Basin at the vicinity of the Agana Sewer Outfall. Figure taken from Jones and Randall (1971).

Figure 118. Agana Boat Basin.

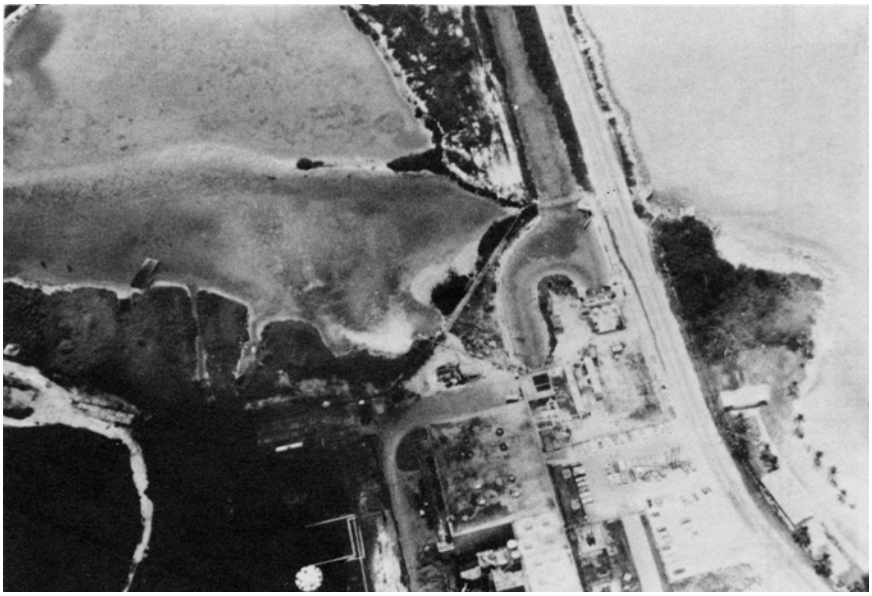


Figure 119. Aerial view of Piti Power Plant (center foreground), Piti Canal (parallel to causeway), Piti Channel (left of causeway), Tepungan Channel, and Hoover Park, USO (right side of causeway).

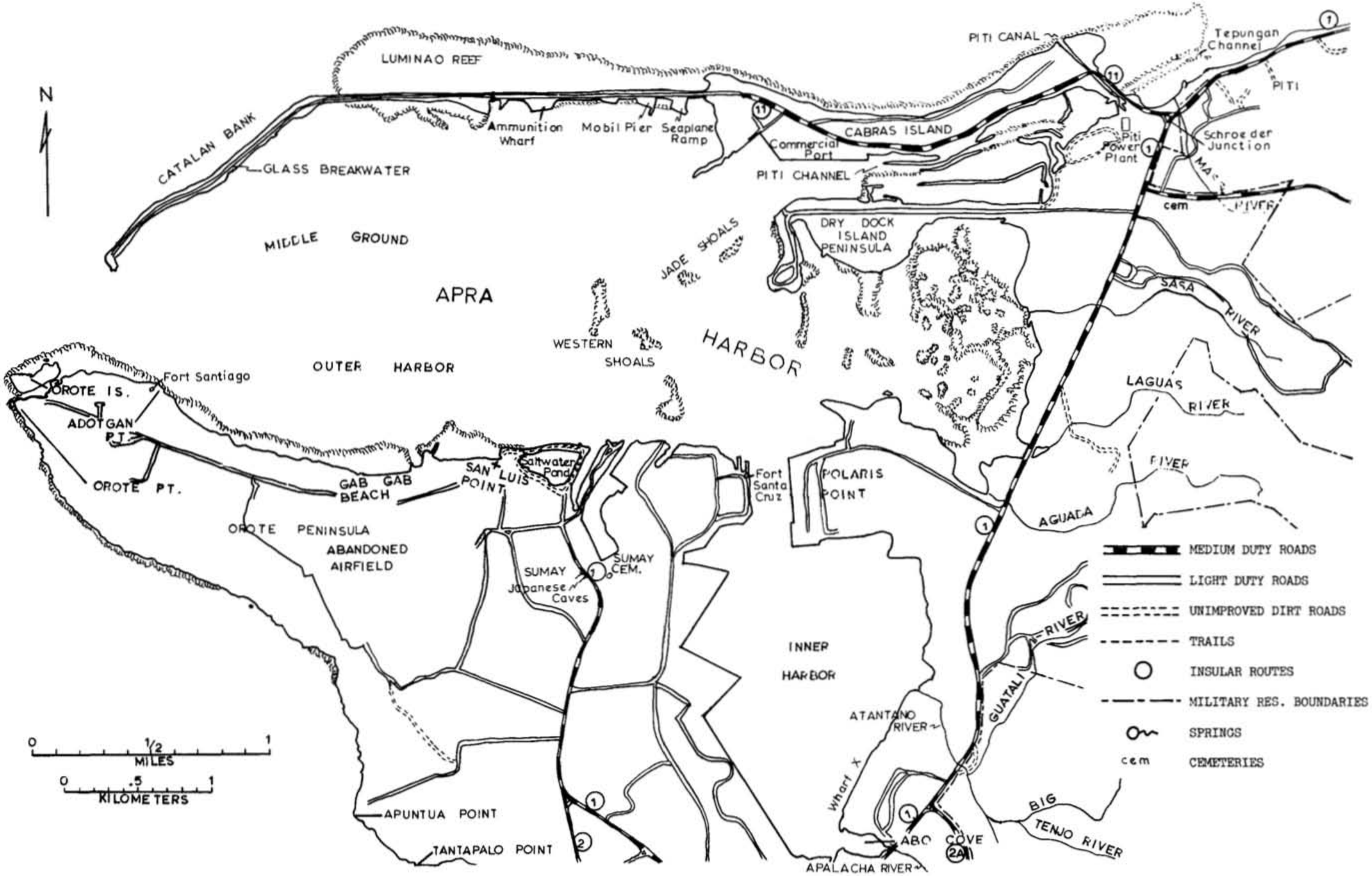


Figure 120. General location map for Sector VIII.

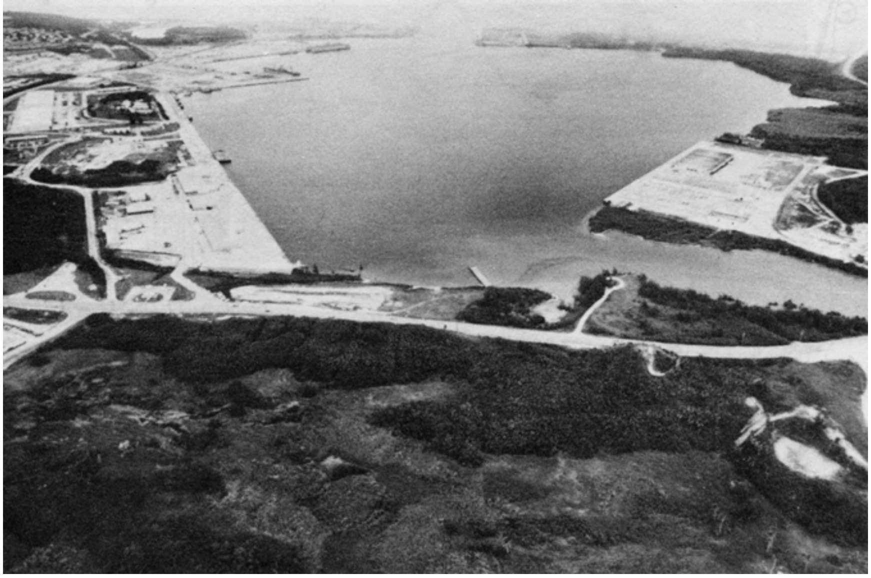


Figure 121. Inner Apra Harbor. Abo Cove is a small embayment in the southwest corner of the inner harbor area.

Figure 122. Eastern end of Apra Lagoon. Cabras Island and Glass Breakwater are in the background. Tepungan Channel is to the east of the causeway between Guam and Cabras Island and Piti Channel is to the west. Piti Canal cuts through the east end of Cabras Island.

SOILS EXPLANATION FOR SECTOR VIII

Upland Soils (On Limestone)

1 – Guam Clay. Reddish, granular, permeable Latosol; generally very shallow (less than 12 inches), but has some pockets or narrow troughs of deep soil; prevailing surface gradient 1 to 8 percent.

4 – Saipan-Yona-Chacha Clays. Chacha-Saipan clays with a shallow brownish Lithosol (Yona clay) on many of the narrow convex ridge-tops and steep slopes; soil depth similar to Unit 3, except Yona clay which generally grades into clayey limestone at about 12 to 24 inches below surface; reaction of Yona clay is thus alkaline or calcareous; prevailing surface gradient 8 to 25 percent. (see page 235 for description of Unit 3).

5 – Yona-Chacha Clays. Yona clay is on most narrow convex ridge-tops and steep side slopes, with Chacha on intervening slopes; also small areas of shallow stony phase Saipan clay; depth of soil with convex surface is generally less than 2 or 3 feet, with concave surface it is generally more than 3 feet; slopes range from 25 to more than 100 percent but prevailing surface gradient is commonly 30 to 65 percent.

Upland Soils (On Volcanic Rocks)

6 – Atate-Agat Clay, Rolling. Remnant benches or small mesas of an old red, granular, porous, acid Latosol (Atate clay) with deep, reddish, mottled, plastic to hard clay C horizon, pale yellow, olive, or gray in lower part; and its truncated counterpart (Agat clay) with similar C horizon of saprolitic clay, ranging in depth from a few feet to about 100 feet, and averaging about 50 feet; prevailing surface gradient of Atate clay is 1 to 8 percent, and of Agat clay 8 to 15 percent.

7 – Agat-Asan-Atate Clays, Hilly. Atate-Agat clays and a dark grayish-brown Regosol (Asan clay) developed in more severely truncated saprolite similar to lower part of C horizon described in Unit 6); soil depths similar to those of Unit 6, except Asan clay which ranges from a few feet in depth to generally less than 50 feet; prevailing surface gradient 15 to 50 percent.

8 – Agat-Asan Clays And Rock Outcrop, Very Hilly To Steep. Chiefly of the truncated Latosol (Agat clay) and the Regosol (Asan clay) with some un-named dark grayish-brown Lithosols and scattered small areas of volcanic rock outcrop (basalt and bedded tuffs); depth to rock ranges from 0 to 50 or more feet and averages perhaps 20 to 35 feet; prevailing surface gradient 35 to more than 100 percent.

Soils Explanation For Sector VIII. Continued.

Soils of Coastal and Valley Flats

9 – Pago Clay. Brownish, granular to firm and plastic Alluvial clay, with gray mottling to within 24 to 30 inches of the surface; generally alkaline to neutral; soil depth is generally more than 10 and less than 150 feet; moderately well drained; subject to occasional flooding; prevailing surface gradient 1 to 3 percent.

10 – Inarajan Clay. Similar to Pago Clay but lower, wetter, and shallower (thins out on coastal sands and bedrock); water table at or near the surface (within 30 inches) most of the time; poor drainage, mottlings (gray) within 6 to 12 inches of the surface; depth to sand or bedrock ranges from 3 to 25 or more feet; reaction is alkaline in water saturated zone; poorly drained; frequently flooded; prevailing surface gradient 0 to 1 percent.

11 – Muck. Black to brown, soft muck and peat, with some clay and silt; depth to underlying material (chiefly limesand or shelly clay) ranges from 3 to 20 feet, averages 5 to 10 feet; alkaline reaction below the water table, which is generally at or near the surfaces; prevailing surface gradient is level or very nearly level.

12 – Shioya Soils. Pale brown to white, fine-, medium-, or coarse-grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Miscellaneous Land Types

13b – Limestone Rock Land, Gently Sloping. Patches of thin (generally less than 2 or 3 inches) reddish or brownish granular clay among exposures of limestone bedrock, pinnacles, boulders, and fragments, which make up more than 25 percent of entire unit area and more than 75 percent of local areas; prevailing surface gradient 2 to 15 percent.

13f – Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical.

14 – Made Land. Artificial fill, chiefly of limesand and gravel; large boulders, rubble, cobbles, earth, trash, and scrap iron predominate locally; prevailing surface gradient 0 to 3 percent.

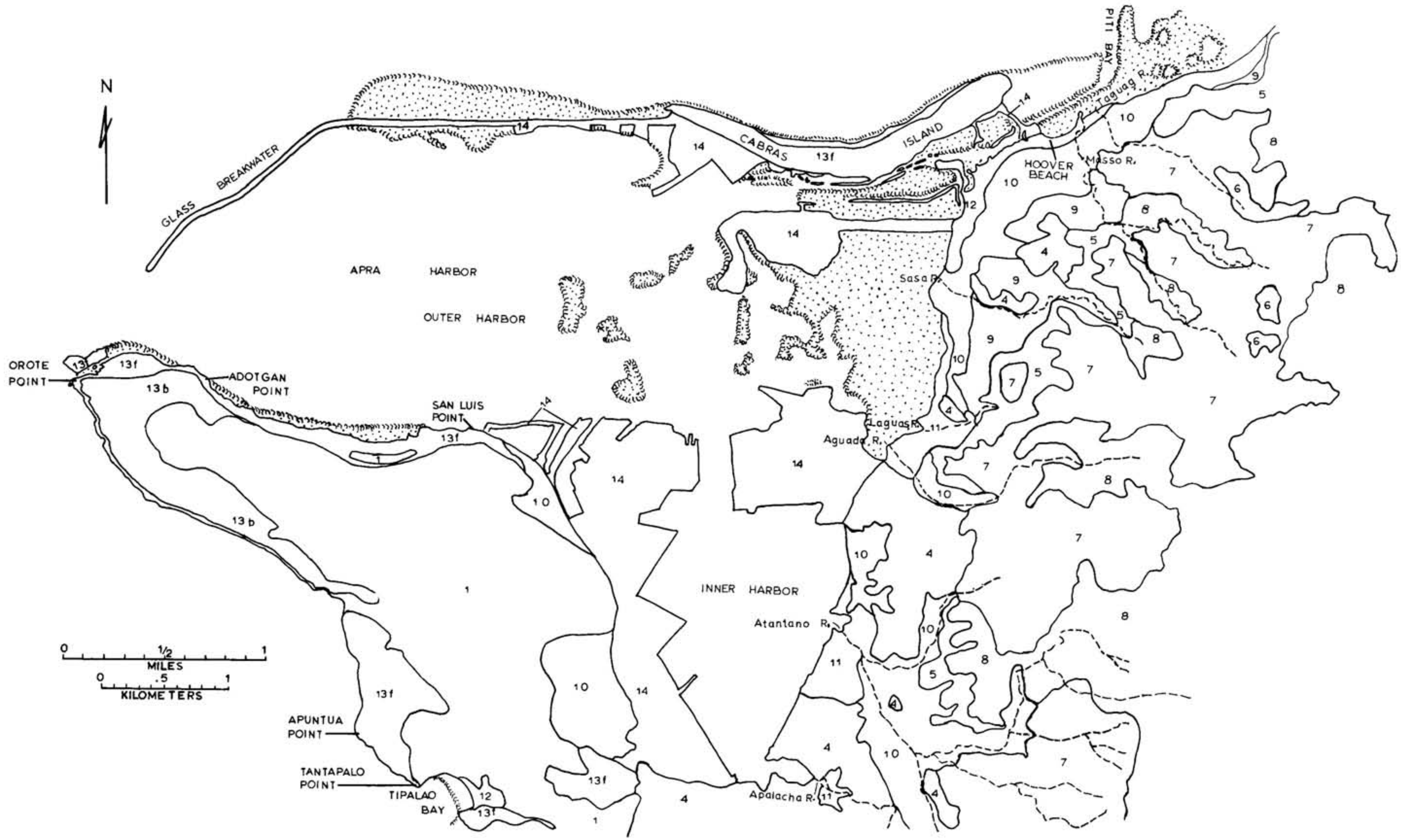


Figure 123. Sector VIII soil map. The soil unit explanation legend is one pages 305–306. See Table 5 (pages 373–374) and 6 (pages 375–376) for additional soil unit descriptions. Fringing and lagoon reef-flat areas are stippled.

Figure 124. Glass Breakwater. Orote Island and Peninsula are in the background. The Luminao Reef forms a broad platform on the seaward side of the breakwater.

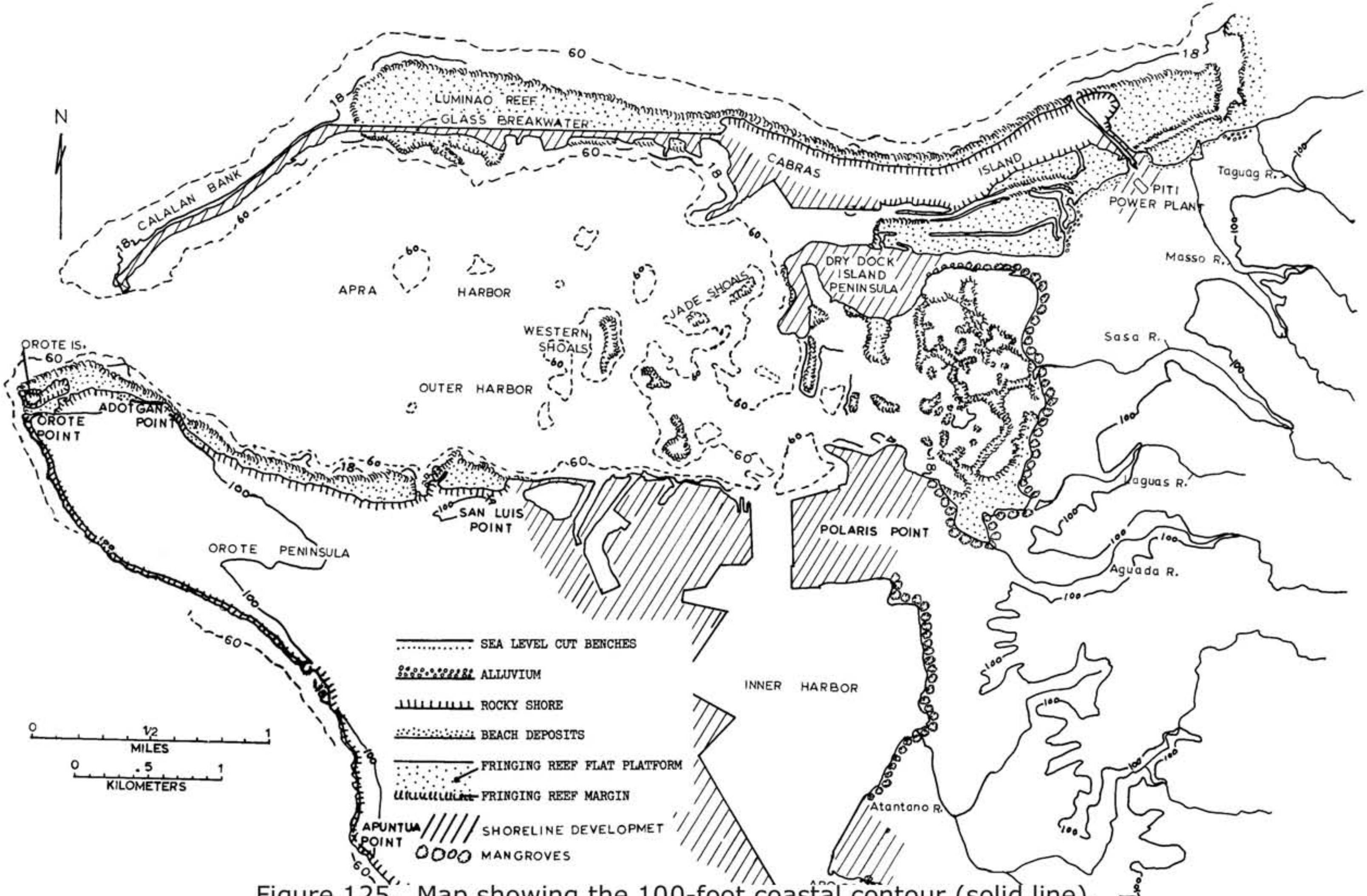


Figure 125. Map showing the 100-foot coastal contour (solid line), rocky shorelines, mangrove shorelines, beach deposits, alluvium, fringing reef and lagoon reef-flat platforms stippled region seaward of shoreline), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for Sector VIII.

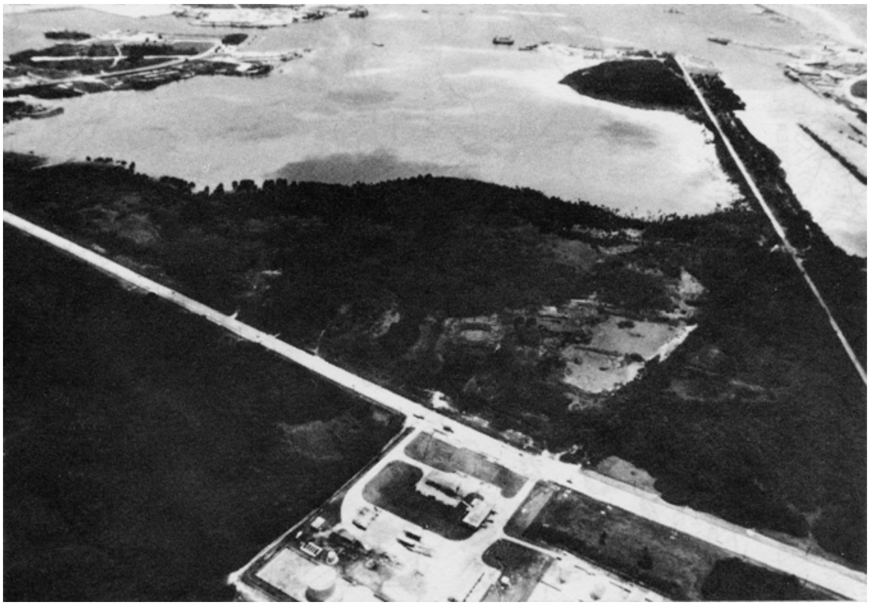


Figure 126. Eastern end of the Apra Lagoon between Dry Dock Peninsula on the right and Polaris Point on the left. Mangroves border much of the shoreline along this region.

Figure 127. Shoreline between Abo Cove and Polaris Point. Mangroves border much of this shoreline.

Figure 128. Mangroves at the mouth of Atantano River. The light-colored mangroves along the shoreline consist of a nearly pure stand of *Avicennia alba*.

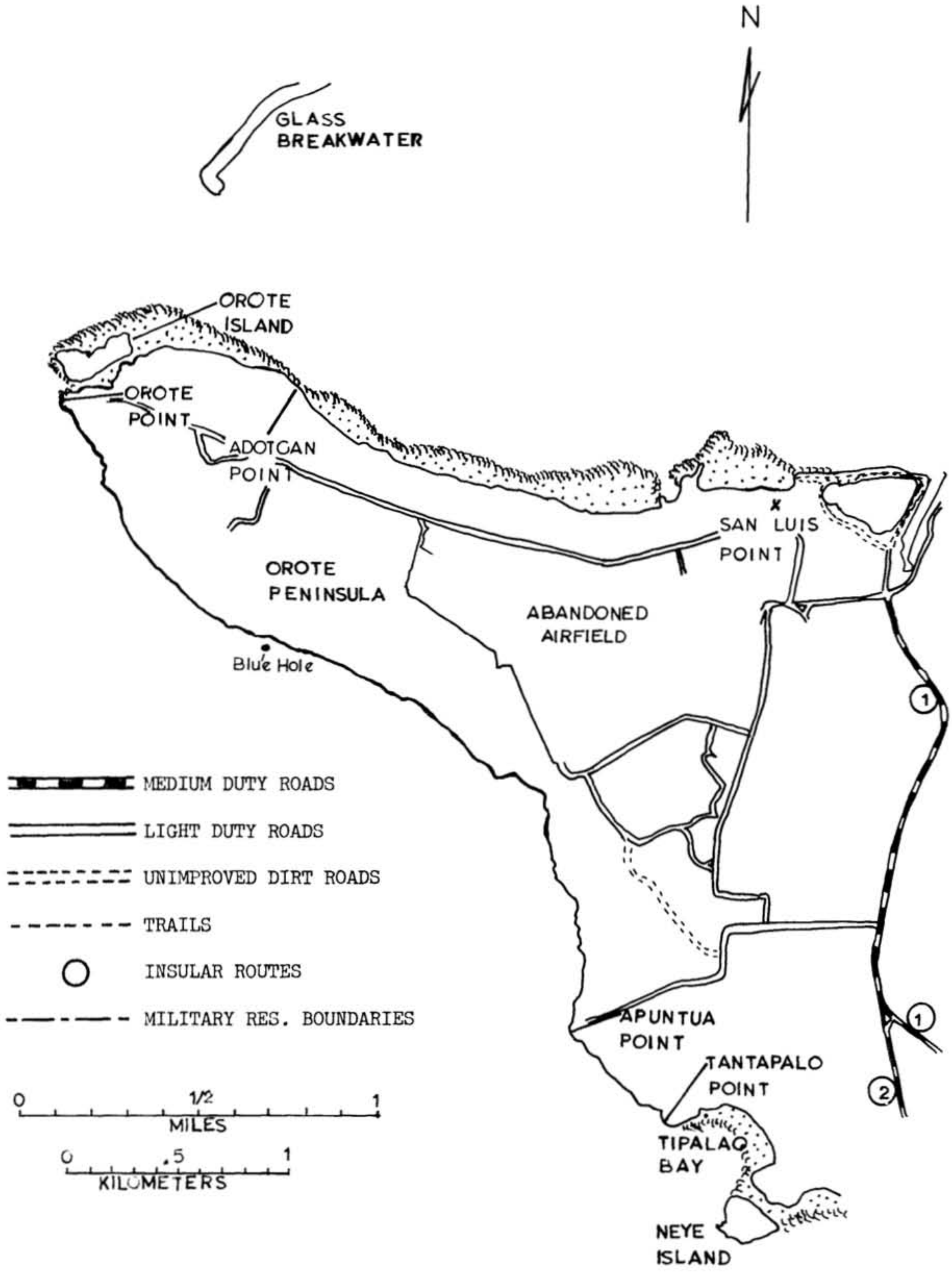


Figure 129. General location map for Sector IX.

Figure 130. Aerial view of Orote Peninsula. Facilities of the Naval Station occupy most of the peninsula. The dark areas (middle right and background) are patches of scrub vegetation, consisting mostly of *Leucaena leucocephala*, which has grown up in disturbed and abandoned parts of the peninsula.

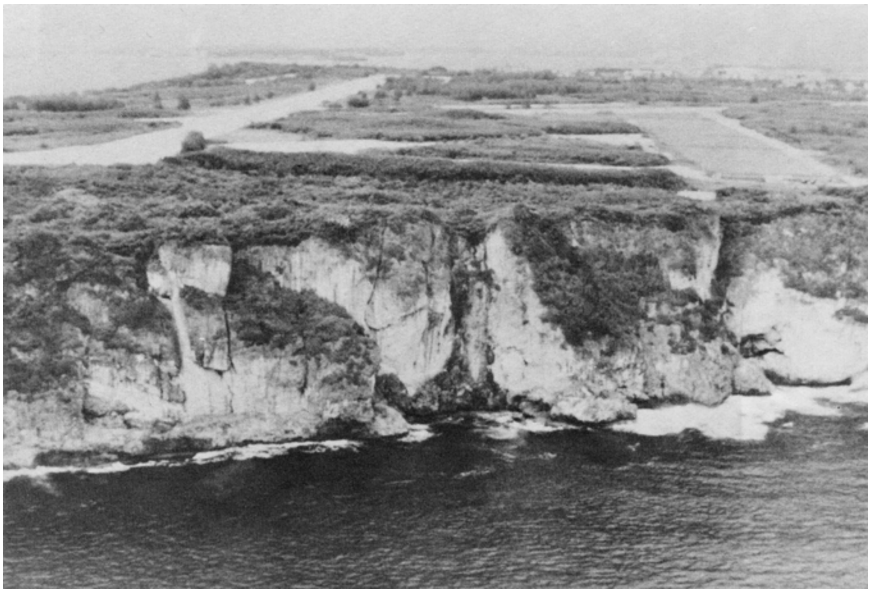


Figure 131. Sea cliff along Orote Peninsula, midway between Orote and Apuntua Points. Abandoned airfield is in the background. Joints, fissures, and fractures are visible on the cliff face.

Figure 132. Interruption of high sea cliff along Orote Peninsula. The region is used as a dump for solid waste materials, and considerable debris accumulation is visible at the shoreline.

Figure 133. A narrow reef-flat platform has developed across the bay. A sea cave is visible in the cliff face to the left.

Figure 134. Neye Island forms a small limestone islet at the south side of Tipalao Bay.

SOILS EXPLANATION FOR SECTOR IX

Upland Soils (On Limestone)

1 – Guam Clay. Reddish, granular, permeable Latosol; generally very shallow (less than 12 inches), but has some pockets or narrow troughs of deep soil; prevailing surface gradient 1 to 8 percent.

Soils of Coastal and Valley Flats

10 – Inarajan Clay. Similar to Pago Clay but lower, wetter, and shallower (thins out on coastal sands and bedrock); water table at or near the surface (within 30 inches) most of the time; poor drainage, mottlings (gray) within 6 to 12 inches of the surface; depth to sand or bedrock ranges from 3 to 25 or more feet; reaction is alkaline in water saturated zone; poorly drained; frequently flooded; prevailing surface gradient 0 to 1 percent. (see page 293 for description of Unit 9).

12 – Shioya Soils. Pale brown to white, fine-, medium-, or coarse-grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Miscellaneous Land Types

13b – Limestone Rock Land, Gently Sloping. Patches of thin (generally less than 2 or 3 inches) reddish or brownish granular clay among exposures of limestone bedrock, pinnacles, boulders, and fragments, which make up more than 25 percent of entire unit area and more than 75 percent of local areas; prevailing surface gradient 2 to 15 percent.

13f – Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical.

14 – Made Land. Artificial fill, chiefly of limesand and gravel; large boulders, rubble cobbles, earth, trash, and scrap iron predominate locally; prevailing surface gradient 0 to 3 percent.

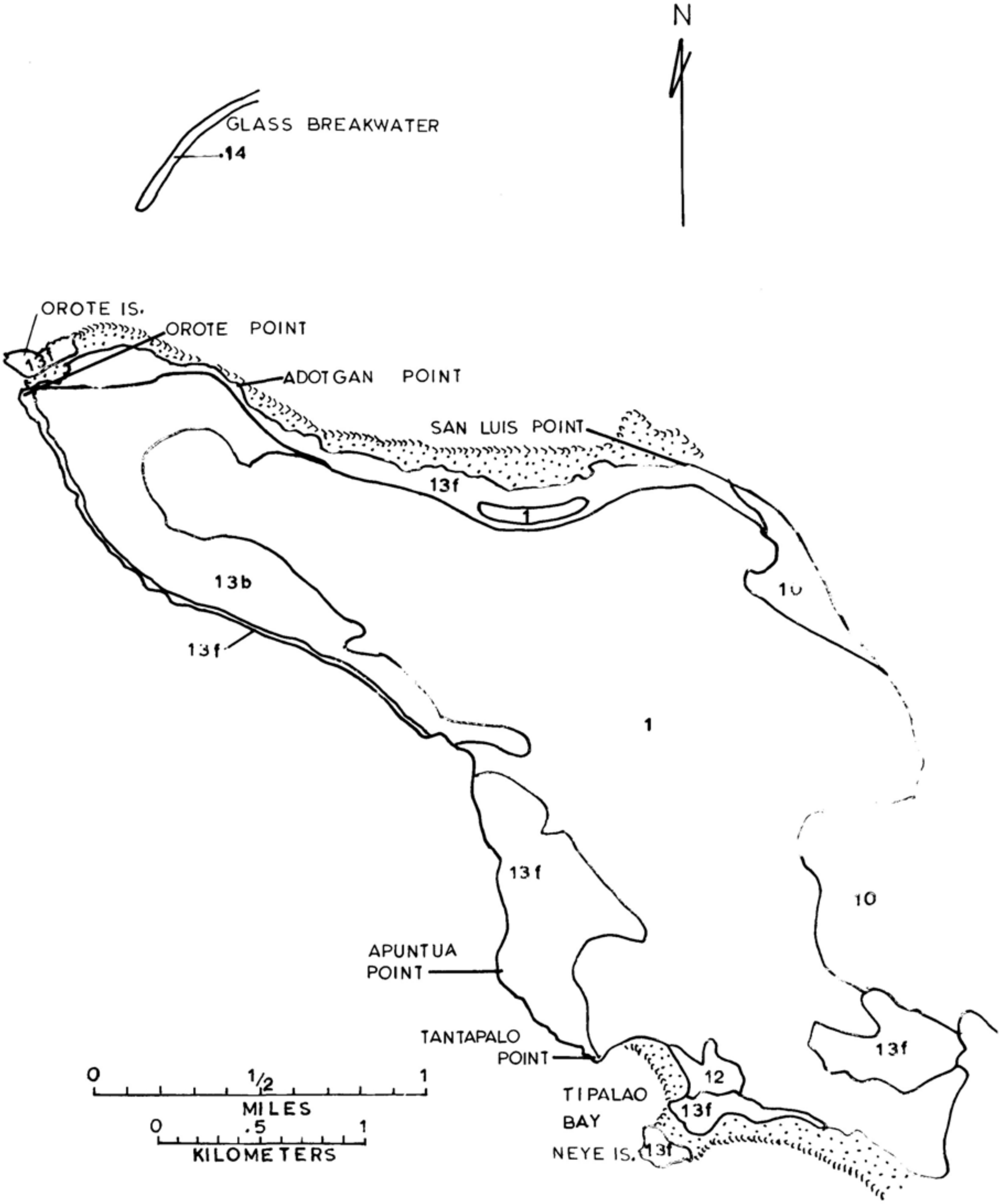


Figure 135. Sector IX soil map. Soil unit explanation legend is on page 316. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil unit descriptions. Fringing reef-flat areas are stippled.

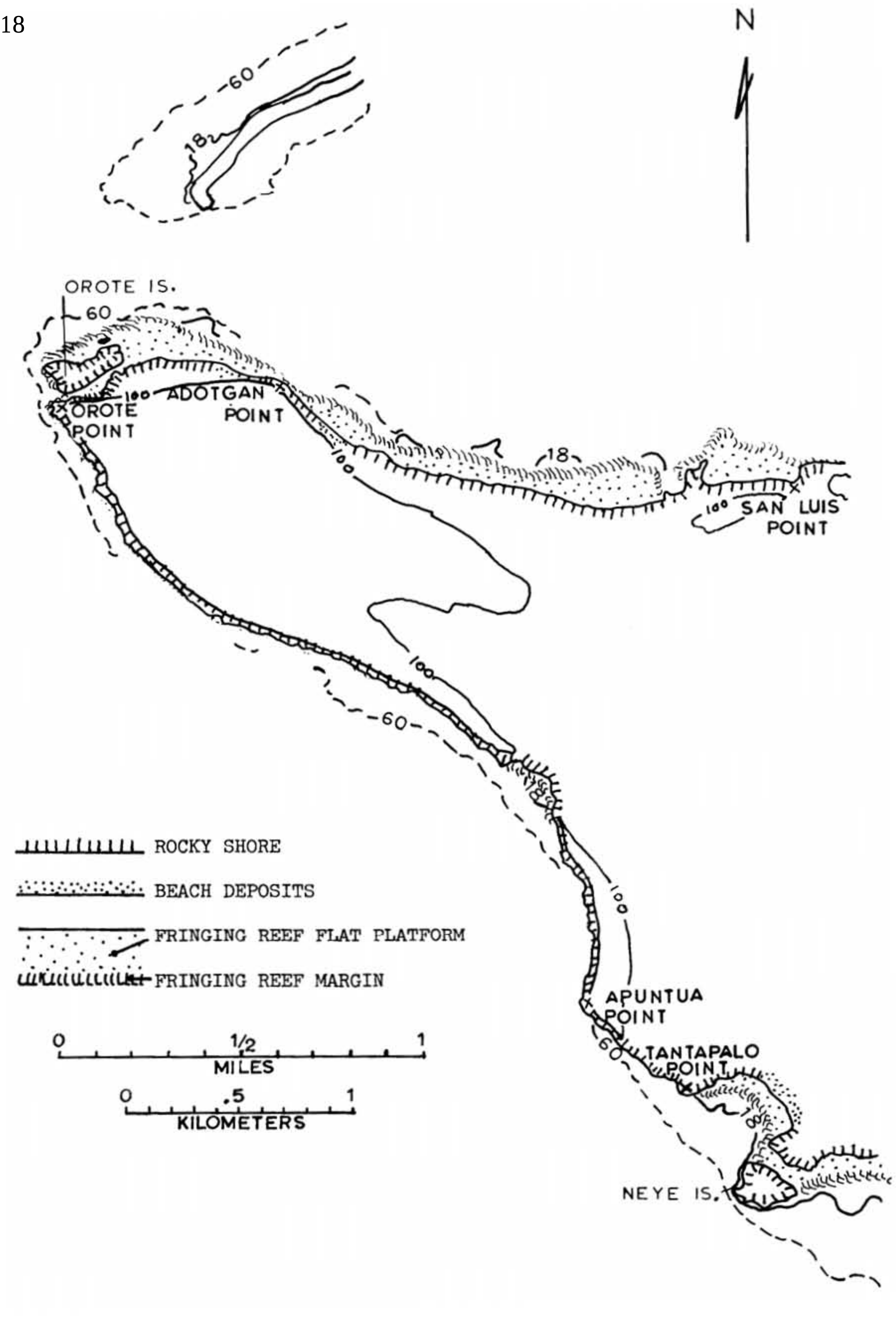


Figure 136. Map showing the 100-foot coastal contour (solid line), rocky shorelines, beach deposits, fringing reef-flat platforms (stippled region seaward of shoreline), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for Sector IX.

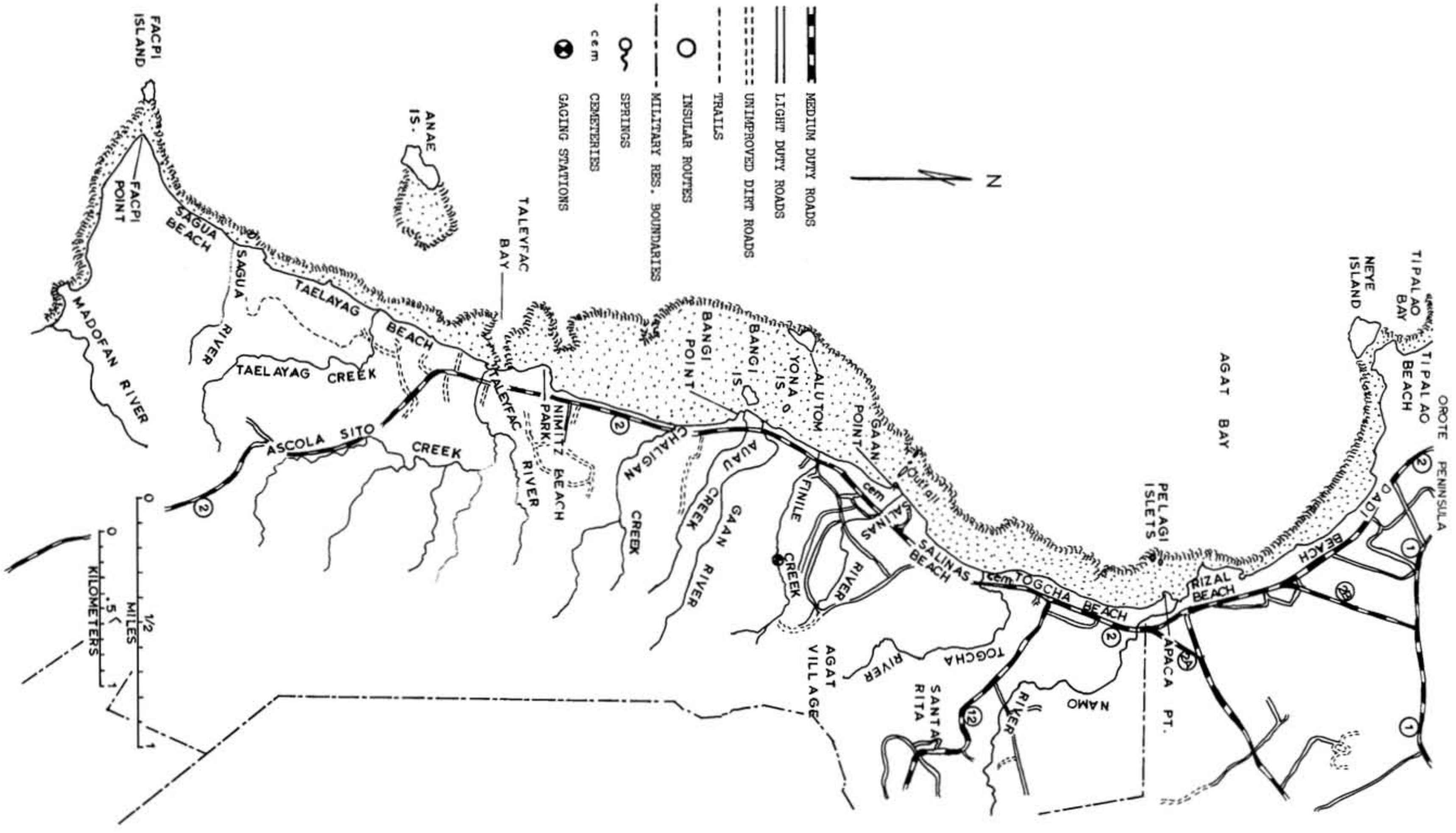


Figure 137a. General location map for the northern part of Sector X. See Figure 137b for the remainder (southern part) of Sector X.

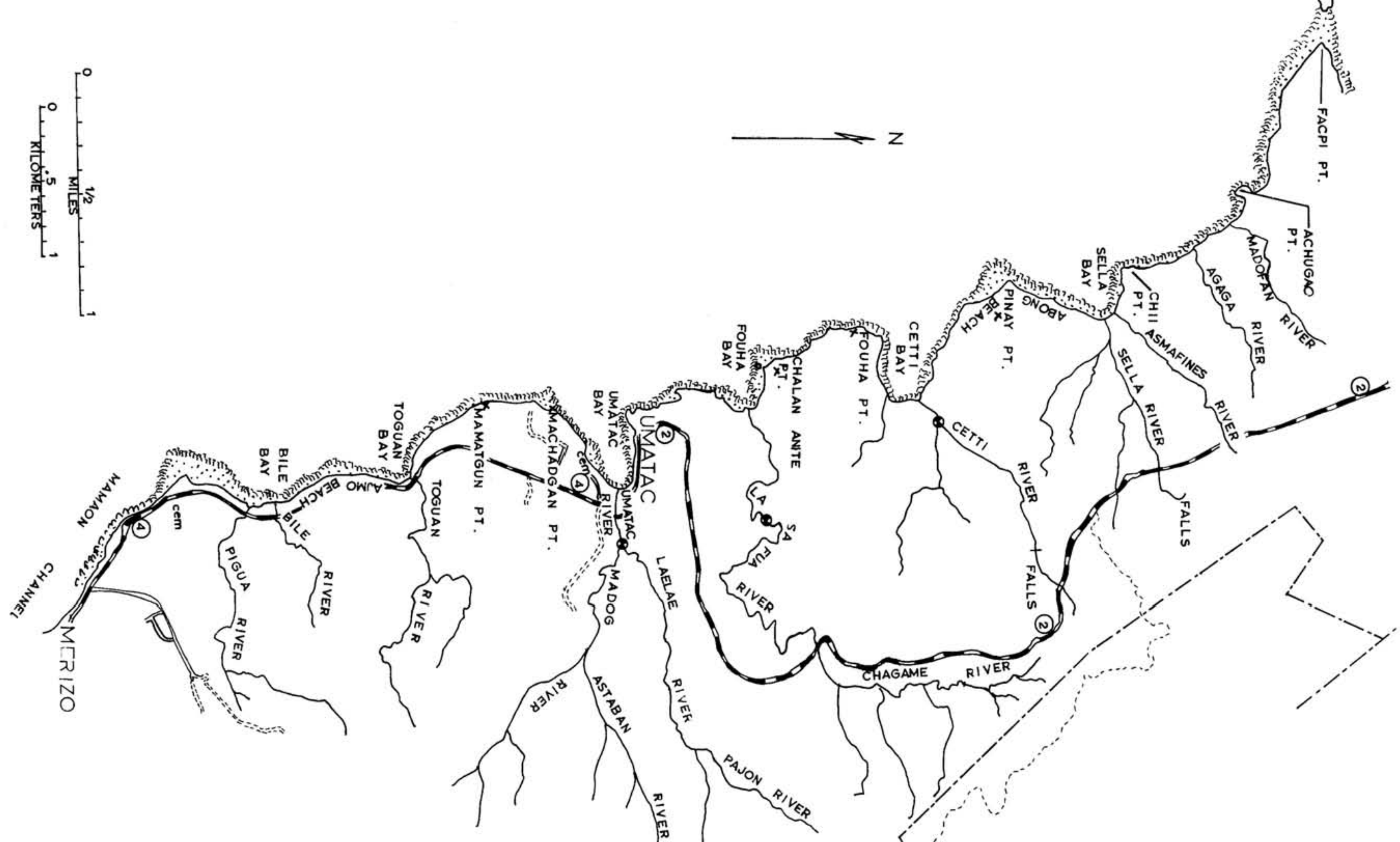


Figure 137b. General location map for the southern part of Sector X. See Figure 137a for the remainder (northern part) of Sector X and map legend.

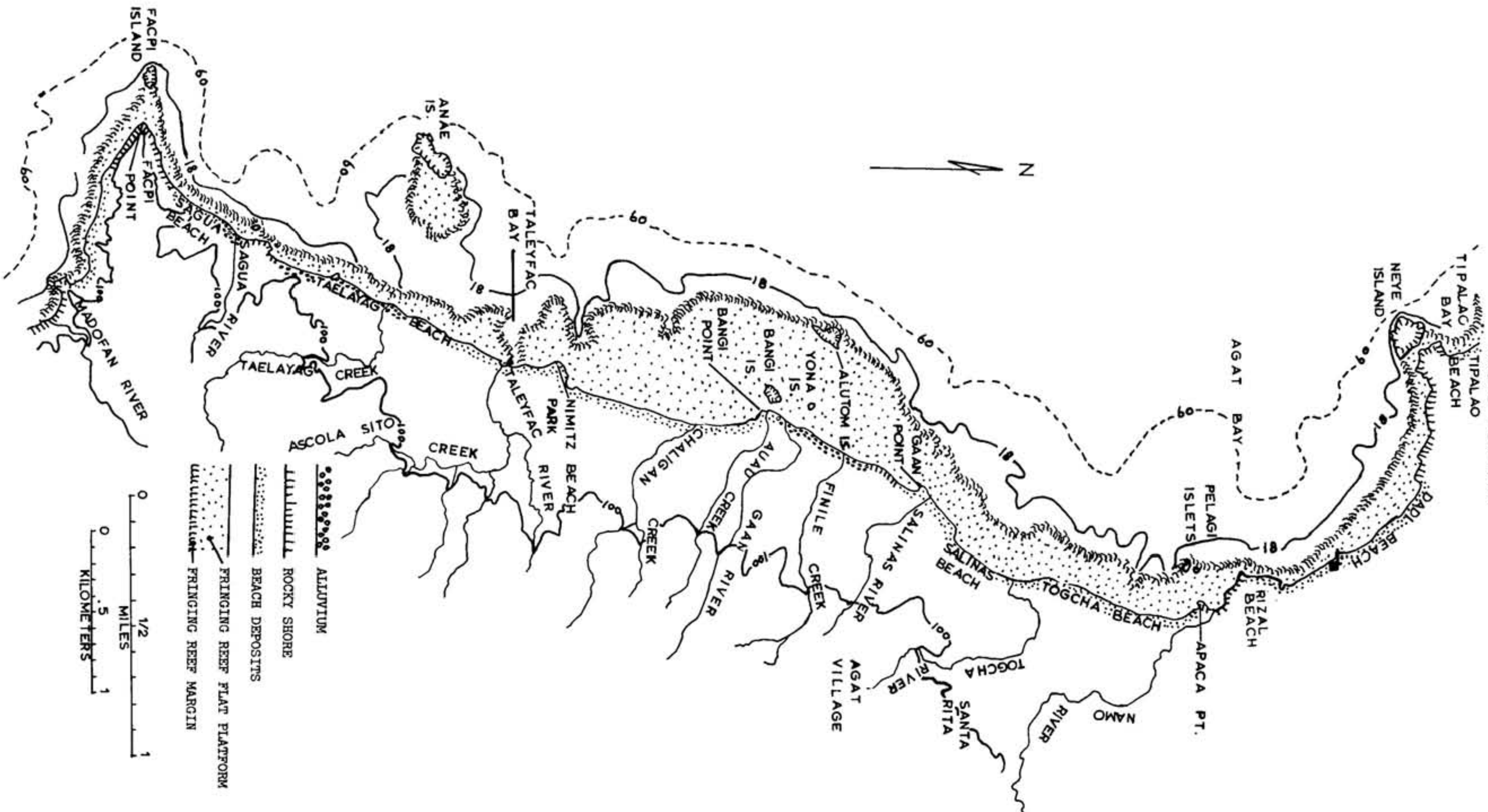


Figure 138a. Map showing the 100-foot coastal contour (solid line), rocky shorelines, beach deposits, alluvium, fringing reef-flat platforms (stippled region seaward of shoreline), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for the northern part of Sector X. See Figure 138b for the remainder (southern part) of Sector X.

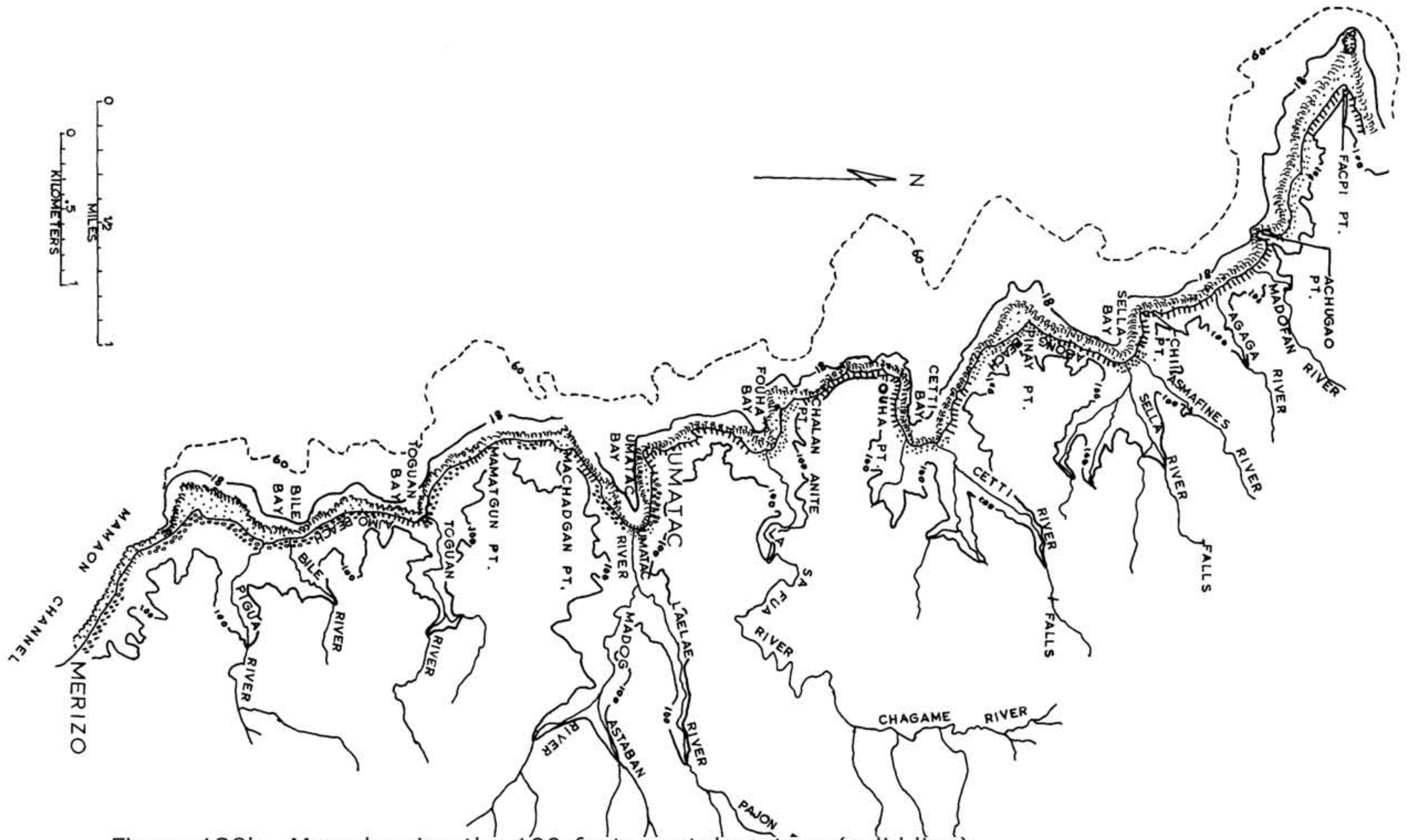


Figure 138b. Map showing the 100-foot coastal contour (solid line), rocky shorelines, beach deposits, alluvium, fringing reef-flat platforms (stippled region seaward of shoreline), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for the southern part of Sector X. See Figure 138a for the remainder (northern part) of Sector X and map legend.

SOILS EXPLANATION FOR SECTOR X

Upland Soils (On Limestone)

1 – Guam Clay. Reddish, granular, permeable Latosol; generally very shallow (less than 12 inches), but has some pockets or narrow troughs of deep soil; prevailing surface gradient 1 to 8 percent.

4 – Saipan-Yona-Chacha Clays. Chacha-Saipan clays with a shallow brownish Lithosol (Yona clay) on many of the narrow convex ridge-tops and steep slopes; soil depth similar to Unit 3, except Yona clay which generally grades into clayey limestone at about 12 to 24 inches below surface; reaction of Yona clay is thus alkaline or calcareous; prevail-
ing surface gradient 8 to 25 percent. (see page 235 for description of Unit 3).

5 - Yona-Chacha Clays. Yona clay is on most narrow convex ridge-tops and steep side slopes, with Chacha on intervening slopes; also small areas of shallow stony phase Saipan clay; depth of soil with convex surface is generally less than 2 or 3 feet, with concave surface it is generally more than 3 feet; slopes range from 25 to more than 100 percent but prevailing surface gradient is commonly 30 to 65 percent.

Upland Soils (On Volcanic Rocks)

6 – Atate-Agat Clay, Rolling. Remnant benches or small mesas of an old red, granular, porous, acid Latosol (Atate clay) with deep, reddish, mottled, plastic to hard clay C horizon, pale yellow, olive, or gray in lower part; and its truncated counterpart (Agat clay) with similar C horizon of saprolitic clay, ranging in depth from a few feet to about I00 feet, and averaging about 50 feet; prevailing surface gradient of Atate clay is 1 to 8 percent, and of Agat clay 8 to 15 percent.

7 – Agat-Asan-Atate Clays, Hilly. Atate-Agat clays and a dark grayish-brown Regosol (Asan clay) developed in more severely truncated saprolite (similar to lower part of C horizon described in Unit 6); soil depths similar to those of Unit 6, except Asan clay which ranges from a few feet in depth to generally less than 50 feet; prevailing surface gradient 15 to 50 percent.

8 – Agat-Asan Clays And Rock Outcrop, Very Hilly To Steep. Chiefly of the truncated Latosol (Agat clay) and the Regosol (Asan clay) with some un-named dark grayish-brown Lithosols and scattered small areas of volcanic rock outcrop (basalt and bedded tuffs); depth to rock ranges from 0 to 50 or more feet and averages perhaps 20 to 35 feet; prevailing surface gradient 35 to more than 100 percent.

Soils Explanation For Sector X. Continued.

Soils of Coastal and Valley Flats

9 – Pago Clay. Brownish, granular to firm and plastic Alluvial clay, with gray mottling to within 24 to 30 inches of the surface; generally alkaline to neutral; soil depth is generally more than 10 and less than 150 feet; moderately well drained; subject to occasional flooding; prevailing surface gradient 1 to 3 percent.

10 – Inarajan Clay. Similar to Pago Clay but lower, wetter, and shallower (thins out on coastal sands and bedrock); water table at or near the surface (within 30 inches) most of the time; poor drainage, mottlings (gray) within 6 to 12 inches of the surface; depth to sand or bedrock ranges from 3 to 25 or more feet; reaction is alkaline in water saturated zone; poorly drained; frequently flooded; prevailing surface gradient 0 to 1 percent.

11 – Muck. Black to brown, soft muck and peat, with some clay and silt; depth to underlying material (chiefly limesand or shelly clay) ranges from 3 to 20 feet, averages 5 to 10 feet; alkaline reaction below the water table, which is generally at or near the surface; prevailing surface gradient is level or very nearly level.

12 – Shioya Soils. Pale brown to white, fine-, medium-, or coarse-grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Miscellaneous Land Types

13f – Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical. (see page 235 for description of Unit 13b).

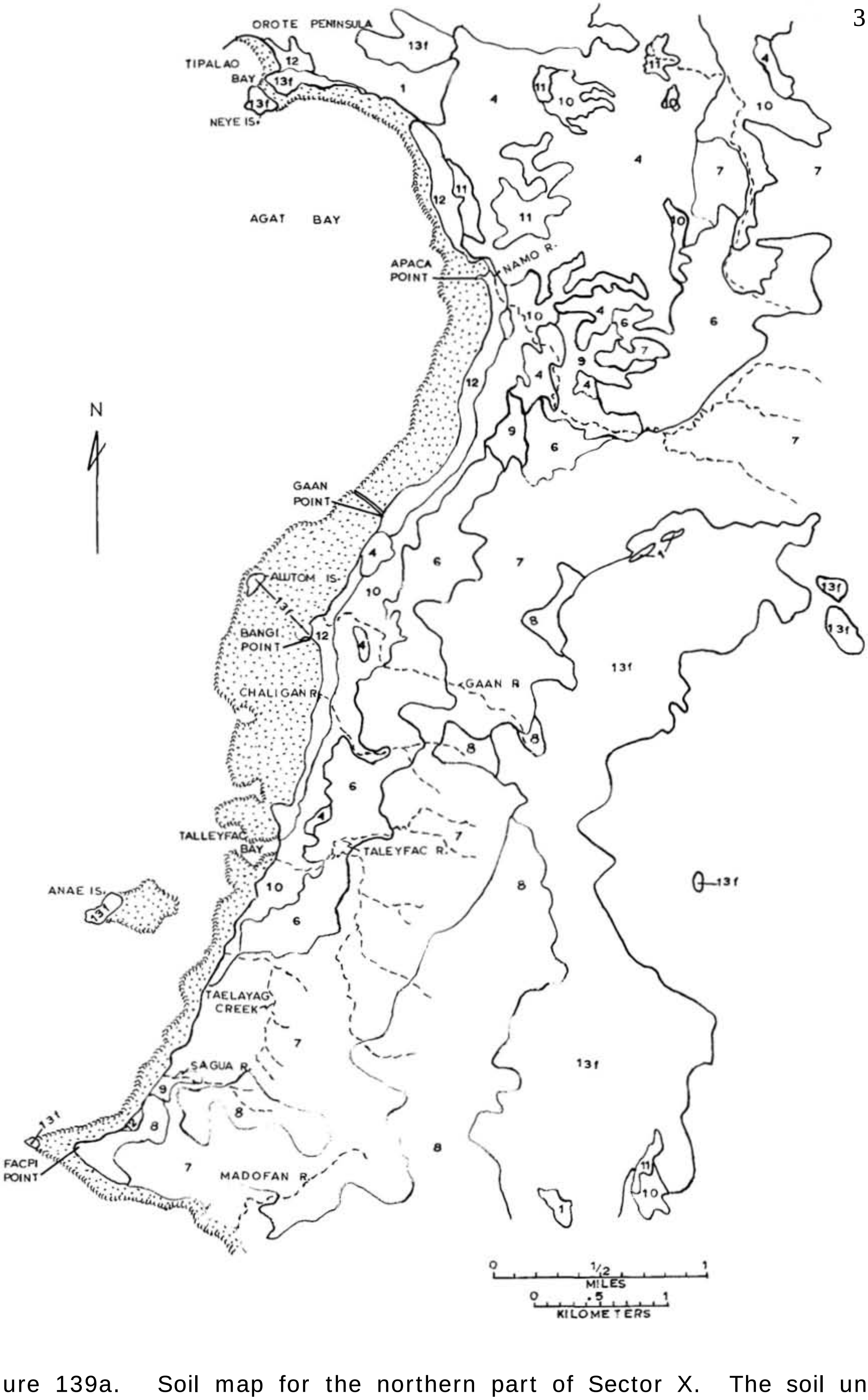


Figure 139a. Soil map for the northern part of Sector X. The soil unit explanation legend is on pages 323–324. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil unit descriptions and Figure 239b for the remainder (southern part) of Sector X. Fringing reef-flat areas are stippled.

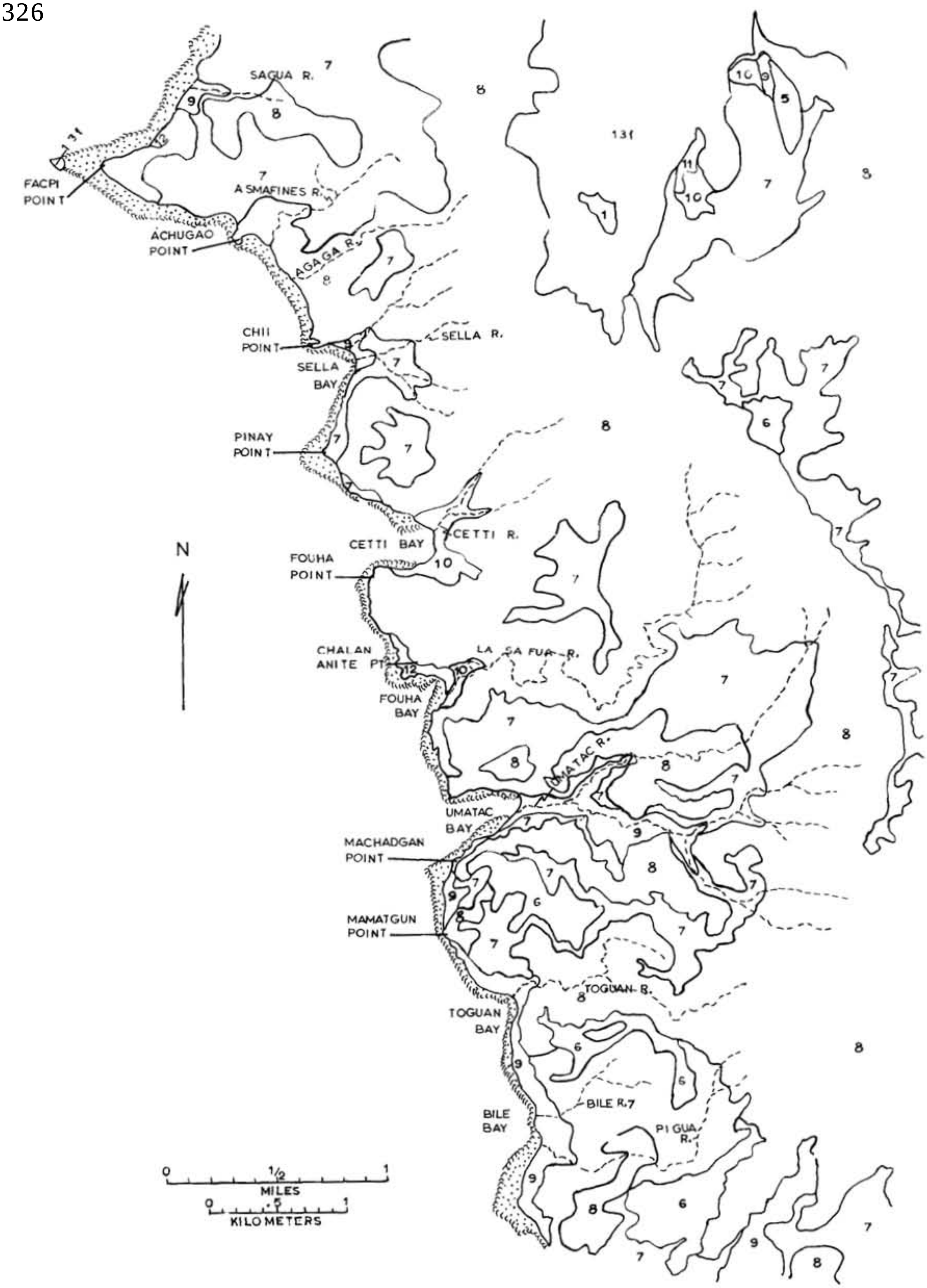


Figure 139b. Soil map for the southern part of Sector X. The soil unit explanation legend is on pages 323–324. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil unit descriptions and Figure 139a for the remainder (northern part) of Sector X and map legend. Fringing reef-flat areas are stippled.

Figure 140. Aerial view of the coastline from Facpi Point (foreground) toward Orote Peninsula. Anae Island and patch reef lies offshore of the reef flat platform. Other reef flat islets are visible in the background.

Figure 141. Aerial view of the coastline from Merizo (foreground) toward Facpi Point.

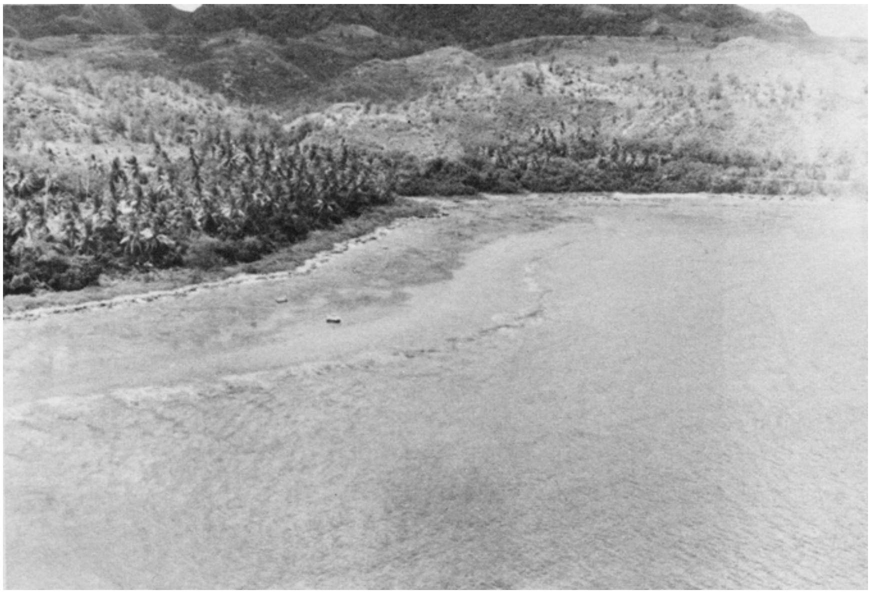


Figure 142. Narrow reef-flat platform at Toguan Bay. A low solution-pitted band of limestone borders the shoreline.

Figure 143. Umatac Bay. In the foreground the reef flat consists entirely of a truncated basalt platform. Fort Santo Angel (ruins) is located on the large rocky stack in the foreground.

Figure 144. Sella Bay. Chii Point frames the left side of the bay, and Ablong Beach, the right. A prominent basaltic sea stack borders the shoreline on the right.

Figure 145. Fouha Bay. Lalas Rock forms a basaltic sea stack at Chalan Anite Point (background), and a channel cuts through the reef flat to the mouth of the La Sa Fua River (foreground).

Figure 146. Facpi Point and Facpi Island. The reef flat here consists principally of a truncated volcanic platform. A prominent dike, offset by small echelon faults, parallels the shoreline between the right side of Facpi Point and the island.

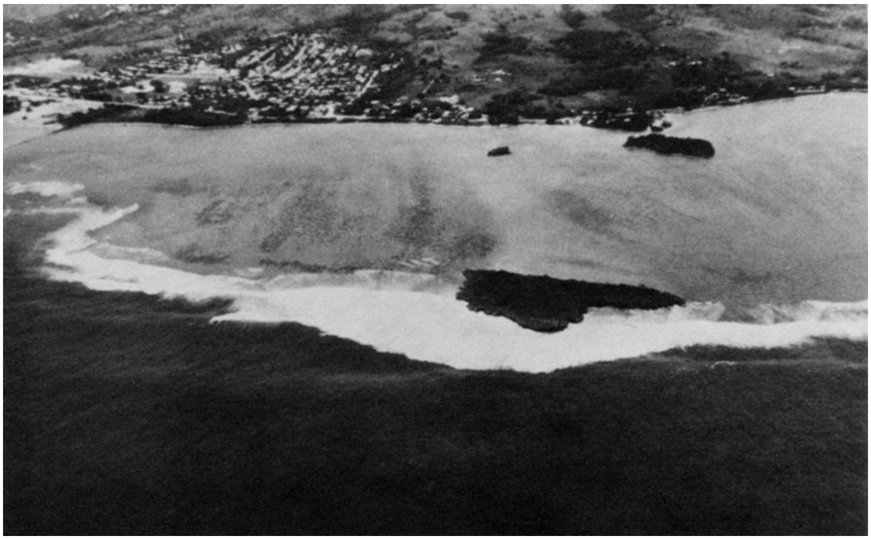


Figure 147. Reef-flat platform and islets at Agat Village. Alutom Islet is located at the reef margin, Bangi Islet (larger) and Yona Islet (smaller) are situated near the shoreline.

Figure 148. Sella Bay. An old Spanish bridge is visible at the mouth of Sella River. A truncated basalt and reef limestone platform fringes the entire shoreline of the bay.

Figure 149. Nimitz Beach Park. Nimitz Channel, on the left, and Talayfac River Channel, on the right, cut through the fringing reef platforms.

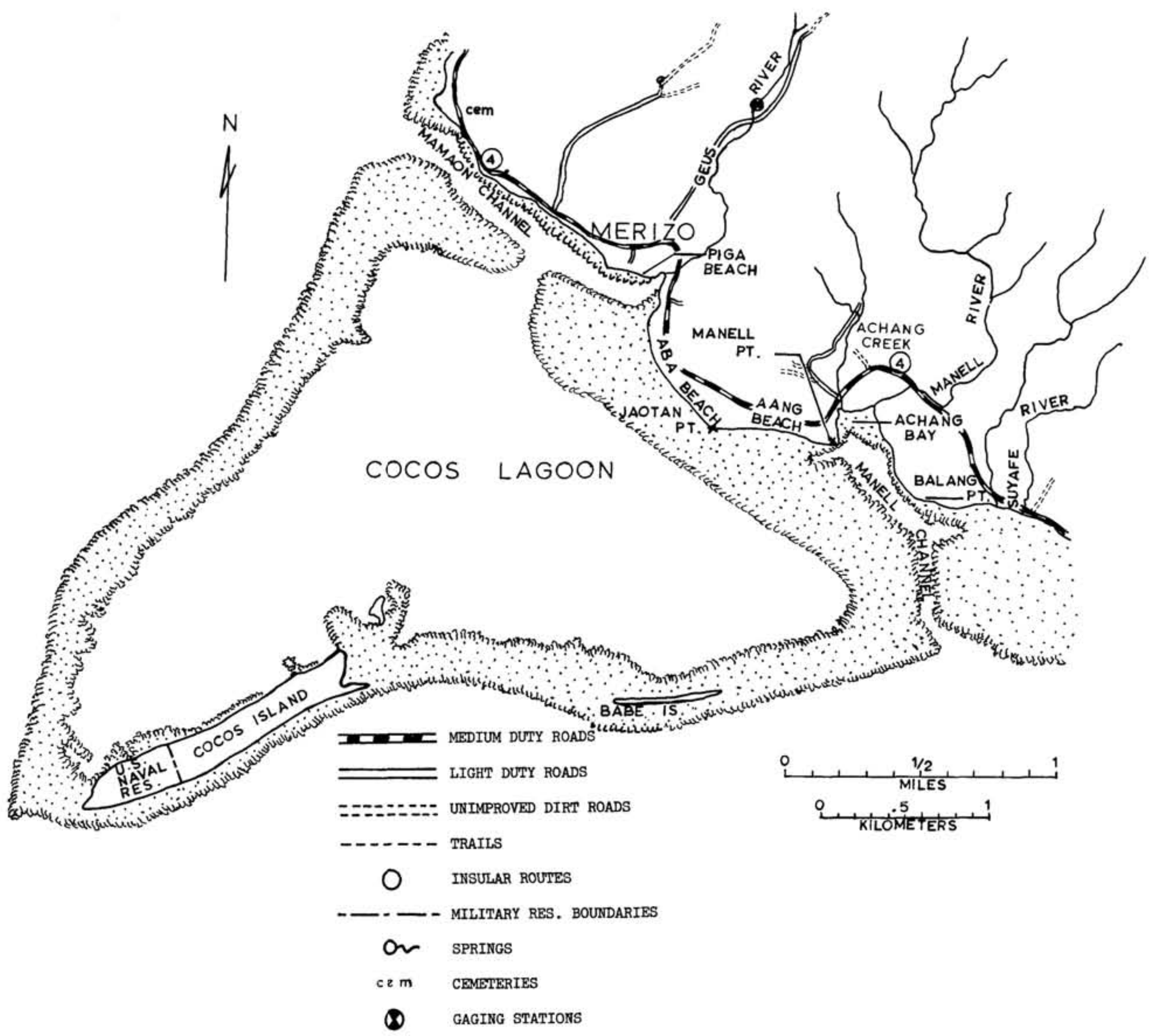


Figure 150. General location map for Sector XI.

Figure 151. Aerial view of Cocos Lagoon and barrier reef. The village of Merizo borders the landward side of the lagoon. Mamaon Channel cuts through the barrier reef at the upper right, and Manell Channel cuts through it at the lower right.

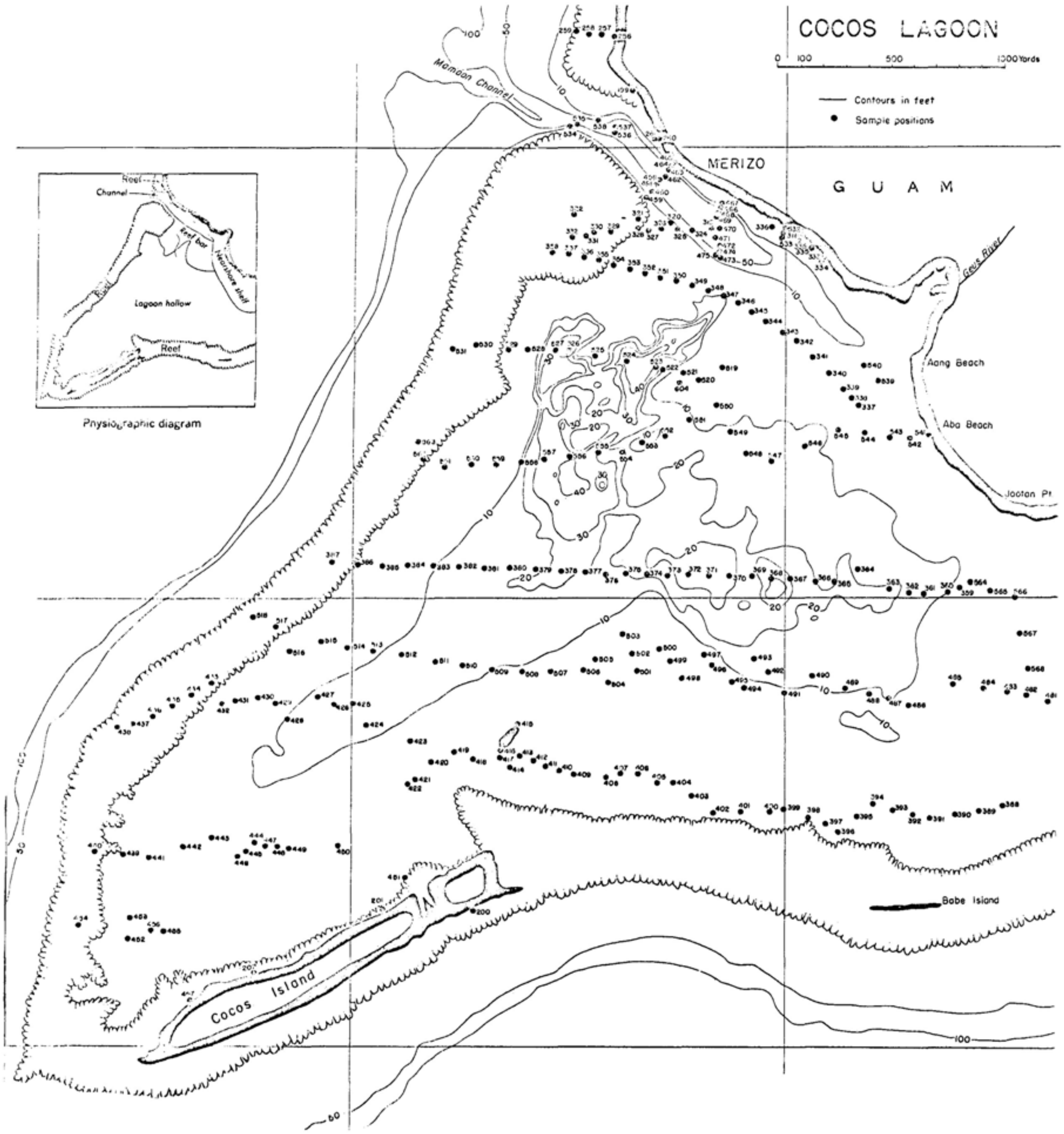


Figure 152. Topography map of Cocos Lagoon. Inset shows the location of the physiographic units. Map from Emery (1962).

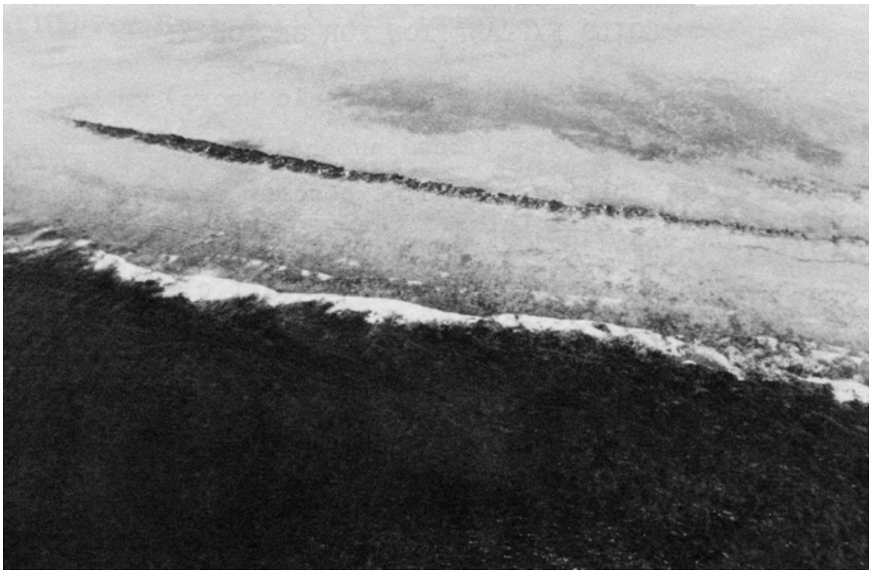


Figure 153. Babe Island consists of a low ridge of solution-pitted limestone on the south barrier reef of Cocos Lagoon.

Figure 154. West end of Cocos Island. The seaward side of the island is bordered by a low strip of solution-pitted limestone. An abandoned LORAN station is located at the western end of the island.

SOILS EXPLANATION FOR SECTOR XI

Upland Soils (On Volcanic Rocks)

6 – Atate-Agat Clay, Rolling. Remnant benches or small mesas of an old red, granular, porous, acid Latosol (Atate clay) with deep, reddish, mottled, plastic to hard clay C horizon, pale yellow, olive, or gray in lower part; and its truncated counterpart (Agat clay) with similar C horizon of saprolitic clay, ranging in depth from a few feet to about 100 feet, and averaging about 50 feet; prevailing surface gradient of Atate clay is 1 to 8 percent, and of Agat clay 8 to 15 percent.

7 – Agat-Asan-Atate Clays, Hilly. Atate-Agat clays and a dark grayish- brown Regosol (Asan clay) developed in more severely truncated saprolite (similar to lower part of C horizon described in Unit 6); soil depths similar to those of Unit 6, except Asan clay which ranges from a few feet in depth to generally less than 50 feet; prevailing surface gradient 15 to 50 percent.

8 – Agat-Asan Clays And Rock Outcrop, Very Hilly To Steep. Chiefly of the truncated Latosol (Agat clay) and the Regosol (Asan clay) with some un-named dark grayish-brown Lithosols and scattered small areas of volcanic rock outcrop (basalt and bedded tuffs); depth to rock ranges from 0 to 50 or more feet and averages perhaps 20 to 35 feet; prevailing surface gradient 35 to more than 100 percent.

Soils of Coastal and Valley Flats

9 – Pago Clay. Brownish, granular to firm and plastic Alluvial clay, with gray mottling to within 24 to 30 inches of the surface; generally alkaline to neutral; soil depth is generally more than 10 and less than 150 feet; moderately well drained; subject to occasional flooding; prevailing surface gradient 1 to 3 percent.

10 – Inarajan Clay. Similar to Pago Clay but lower, wetter, and shallower (thins out on coastal sands and bedrock); water table at or near the surface (within 30 inches) most of the time; poor drainage, mottlings (gray) within 6 to 12 inches of the surface; depth to sand or bedrock ranges from 3 to 25 or more feet; reaction is alkaline in water saturated zone; poorly drained; frequently flooded; prevailing surface gradient 0 to 1 percent.

12 – Shioya Soils. Pale brown to white, fine-, medium-, or coarse-grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Soils Explanation For Sector XI. Continued.

Miscellaneous Land Types

13f – Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical. (see page 235 for a description of Unit 13b).

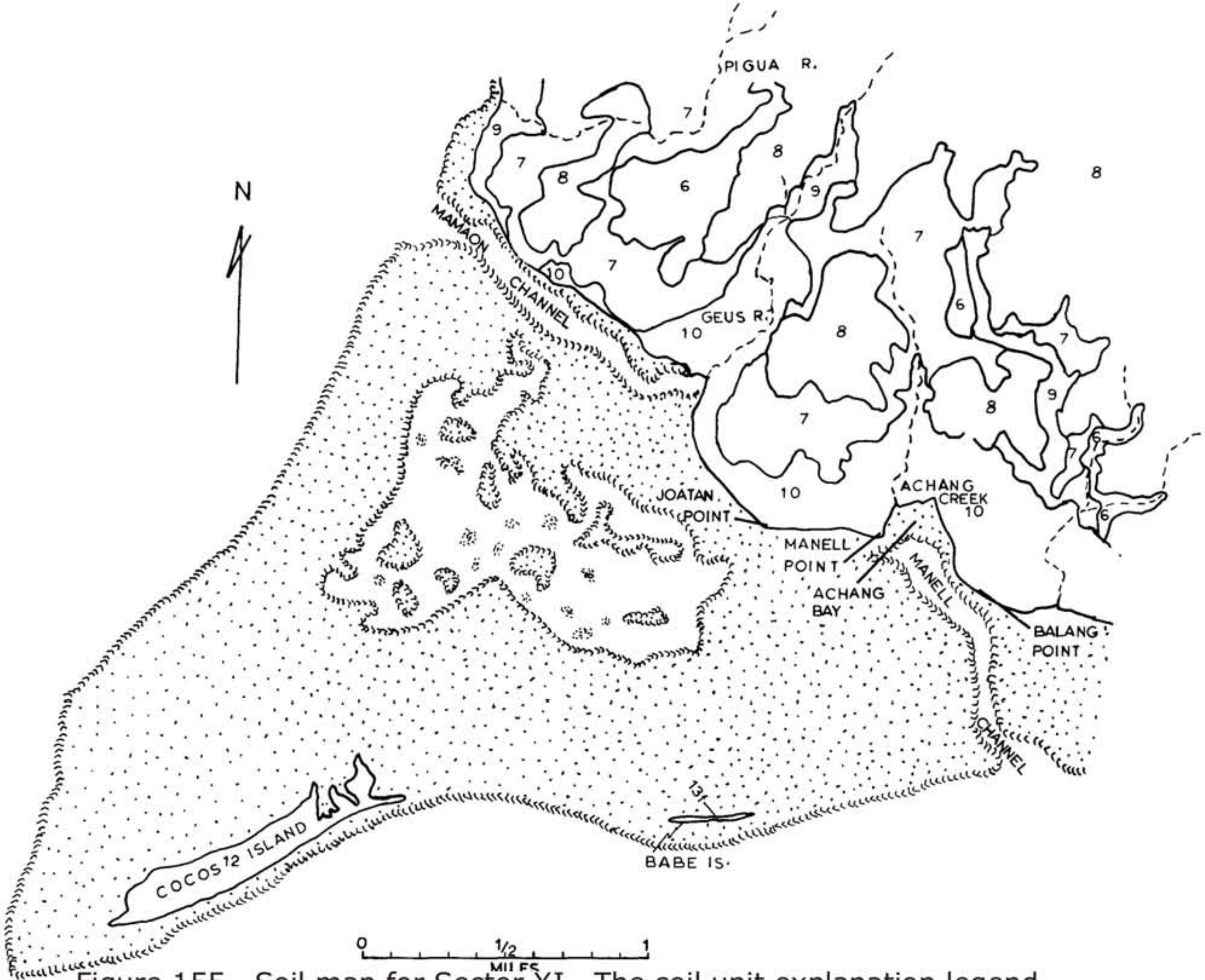


Figure 155. Soil map for Sector XI. The soil unit explanation legend is on pages 336–337. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil descriptions. Fringing and lagoon reef-flat areas are stippled.

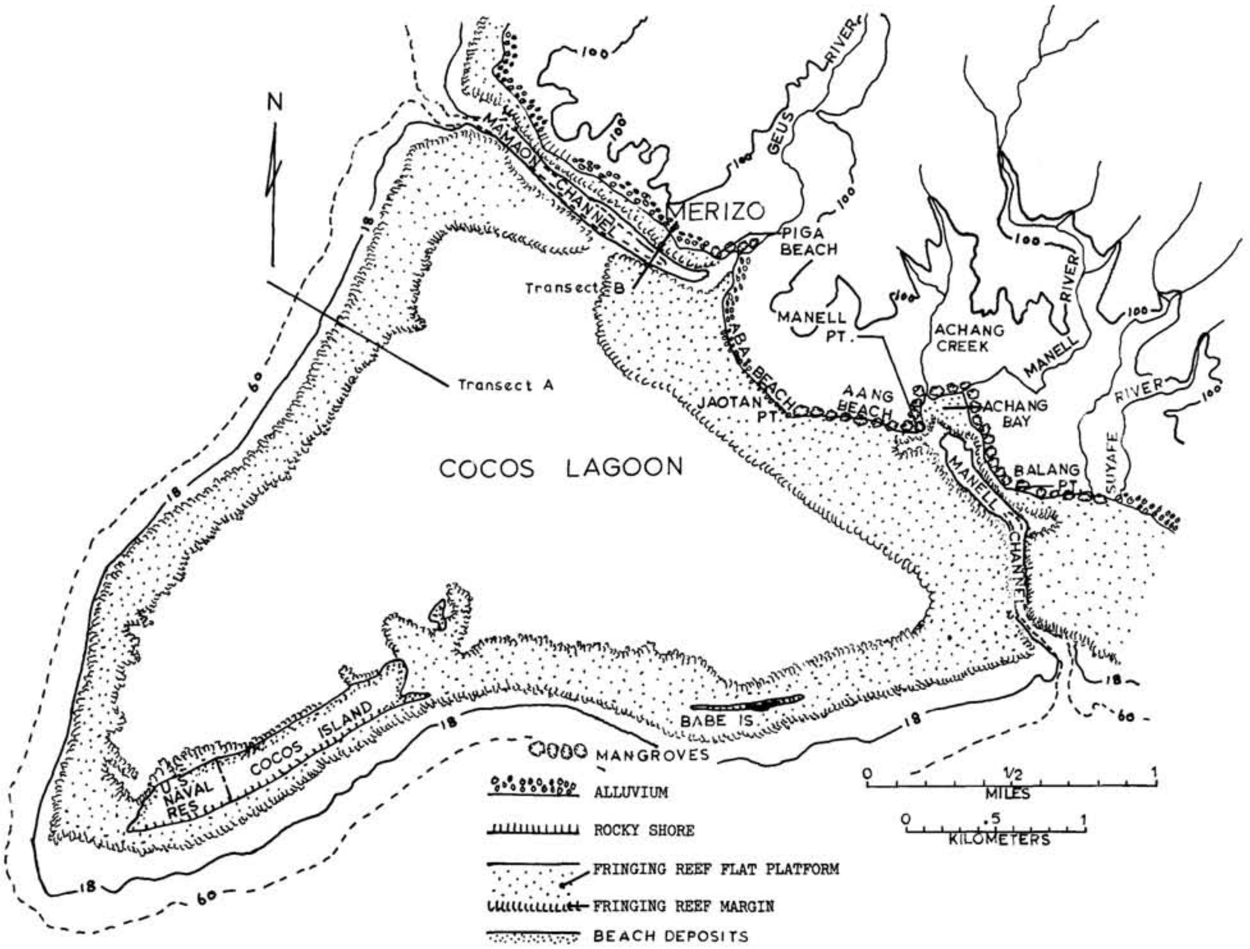


Figure 156. Map showing the 100-foot coastal contour (solid line), rocky shorelines, mangrove shorelines, beach deposits, alluvium, fringing and lagoon reef-flat platforms (stippled region seaward and lagoonward of shorelines) reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for Sector XI.

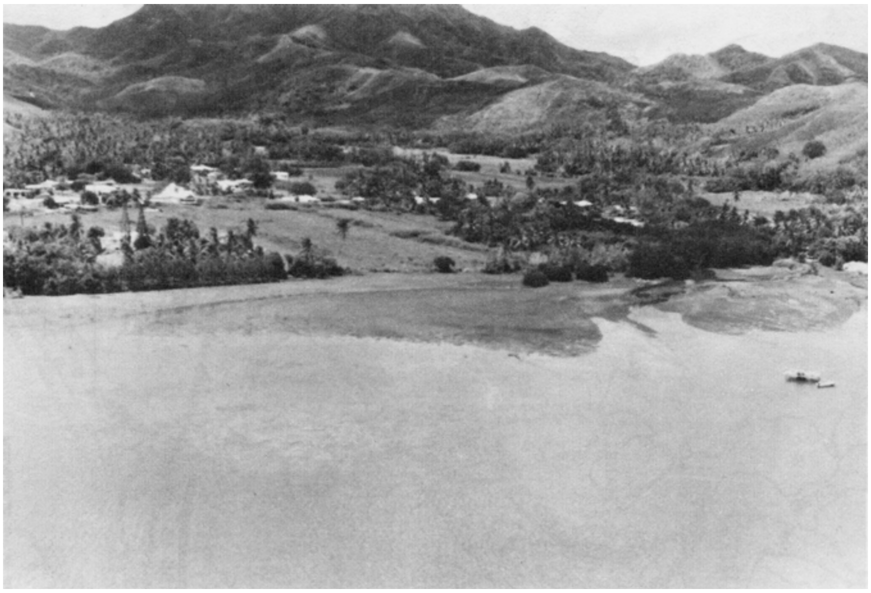


Figure 157. Mouth of the Geus River at the head of Mamaon Channel. Small patches of mangroves are located at the river mouth.

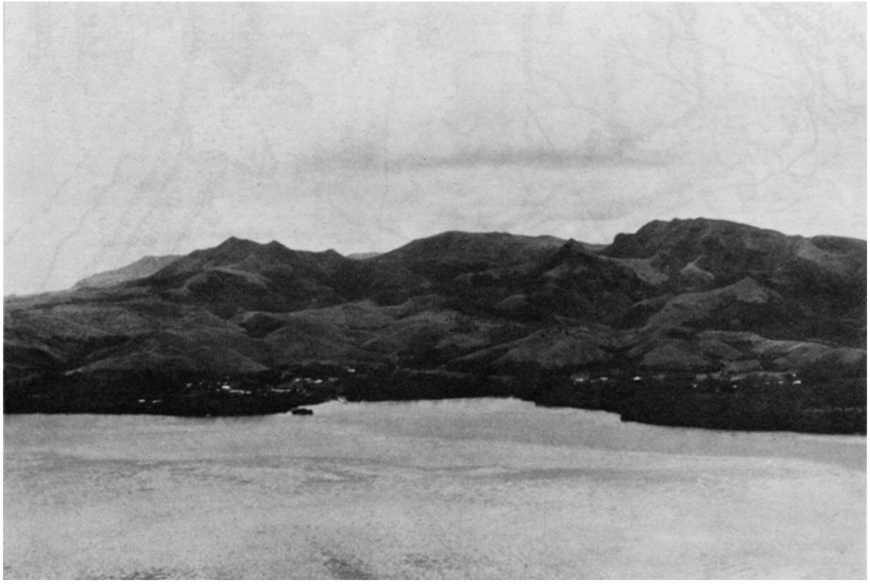


Figure 158. Achang Bay at the head of Manell Channel. The steep-sloped mountains of south Guam form the background. Mangroves occupy much of the shoreline along the bay.

Figure 159. Shallow reef-bar zone in the foreground separates the deeper part of the lagoon from Mamaon Channel. Dark areas in the reef bar are living coral patches and coral rubble.

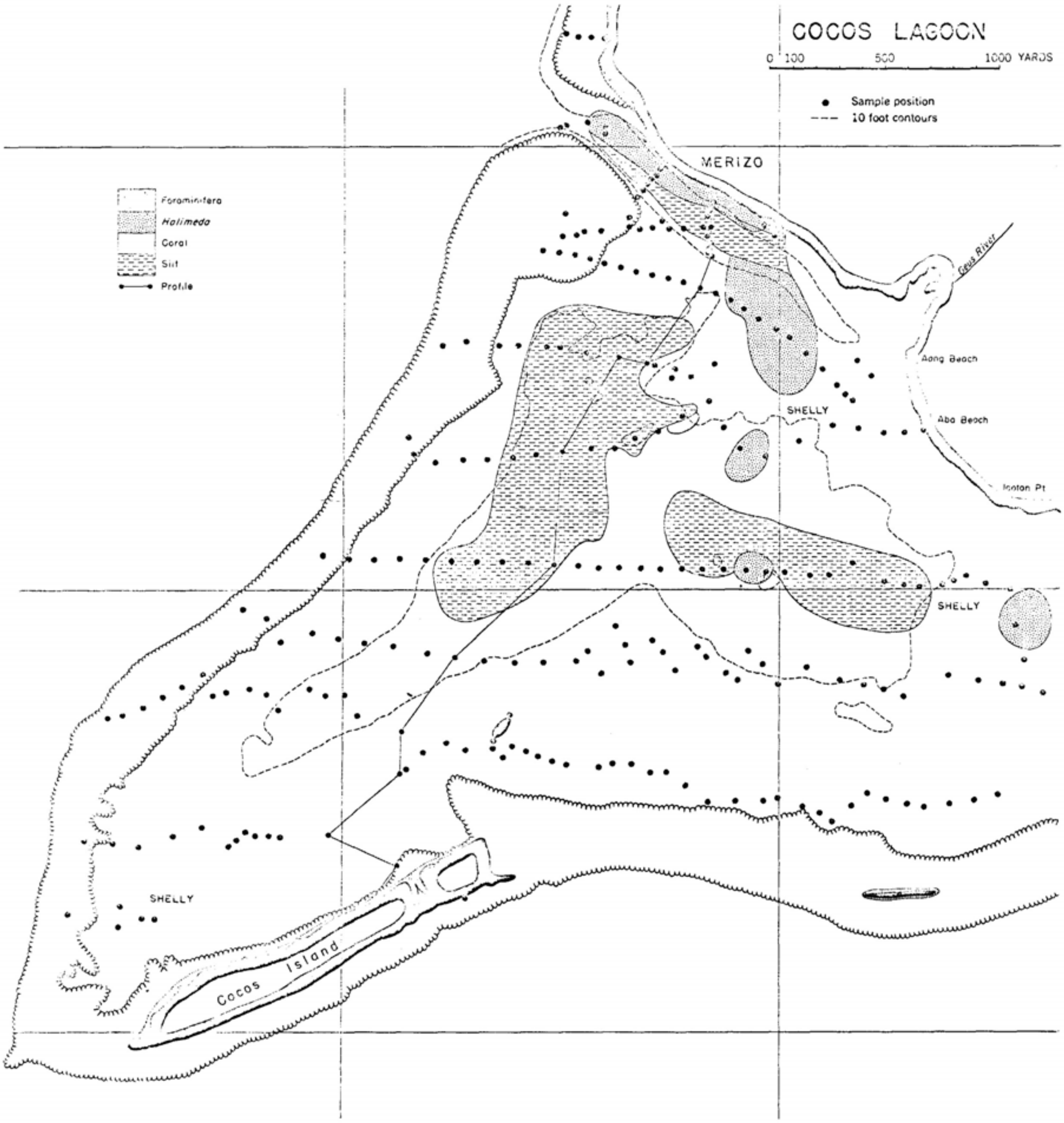


Figure 160. Generalized sediment map of Cocos Lagoon. Map from Emery (1962).

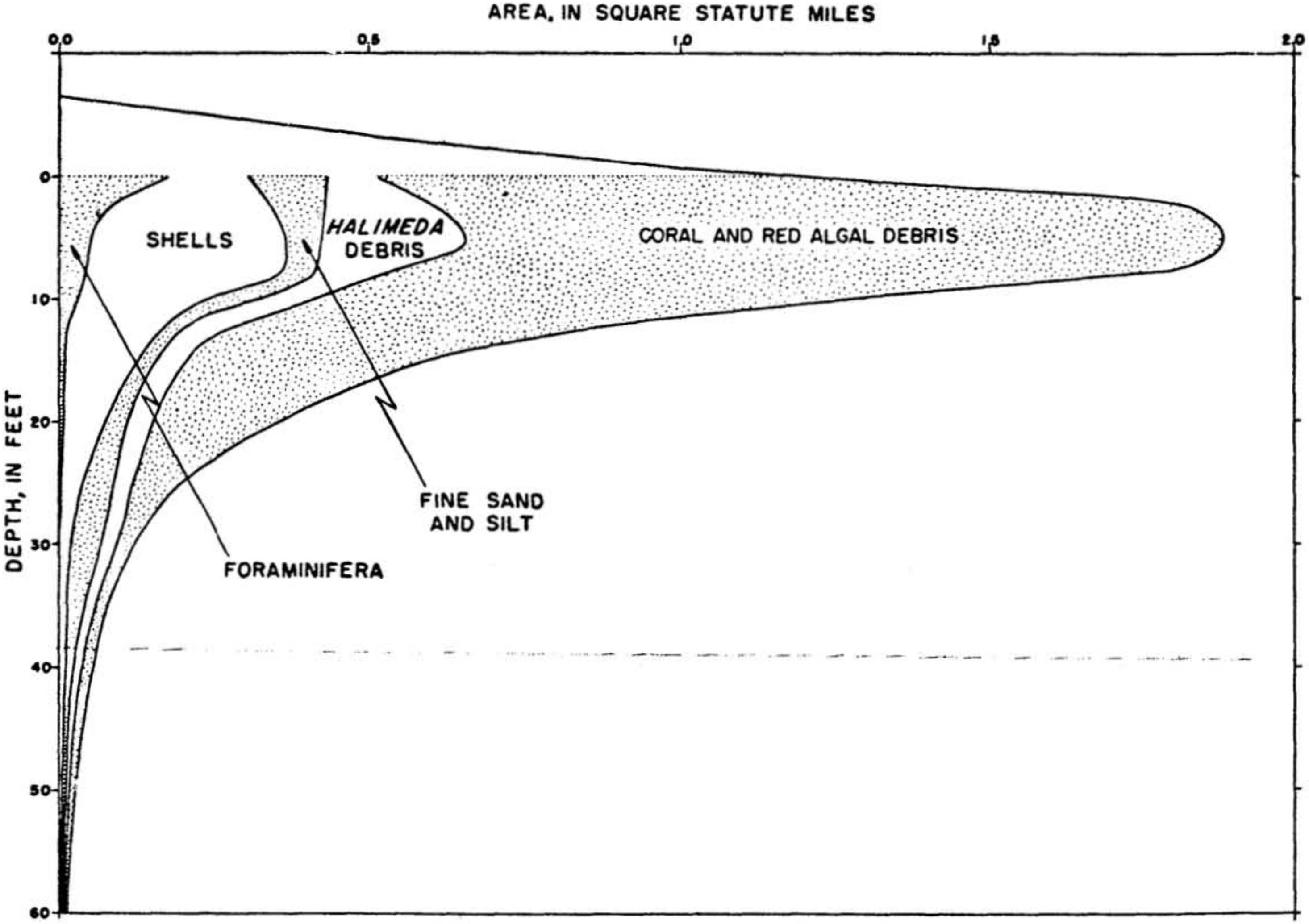


Figure 161. Vertical distribution of sediment composition corrected for actual area of the lagoon floor at various depths. From Emery (1962).

Figure 162. Manell Channel. The shallow reef flat left of the channel prevents passage of boats except at high tide. The depth at the mouth of the channel is about 100 feet. Achang Bay is in the background at the head of the channel.

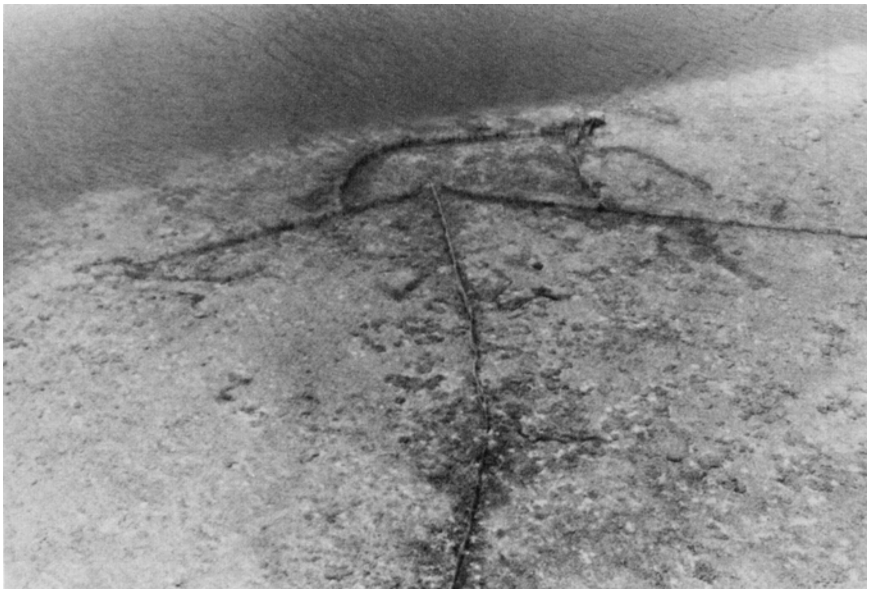


Figure 163. Fish trap on the lagoon side of Mamaon Channel near Merizo.

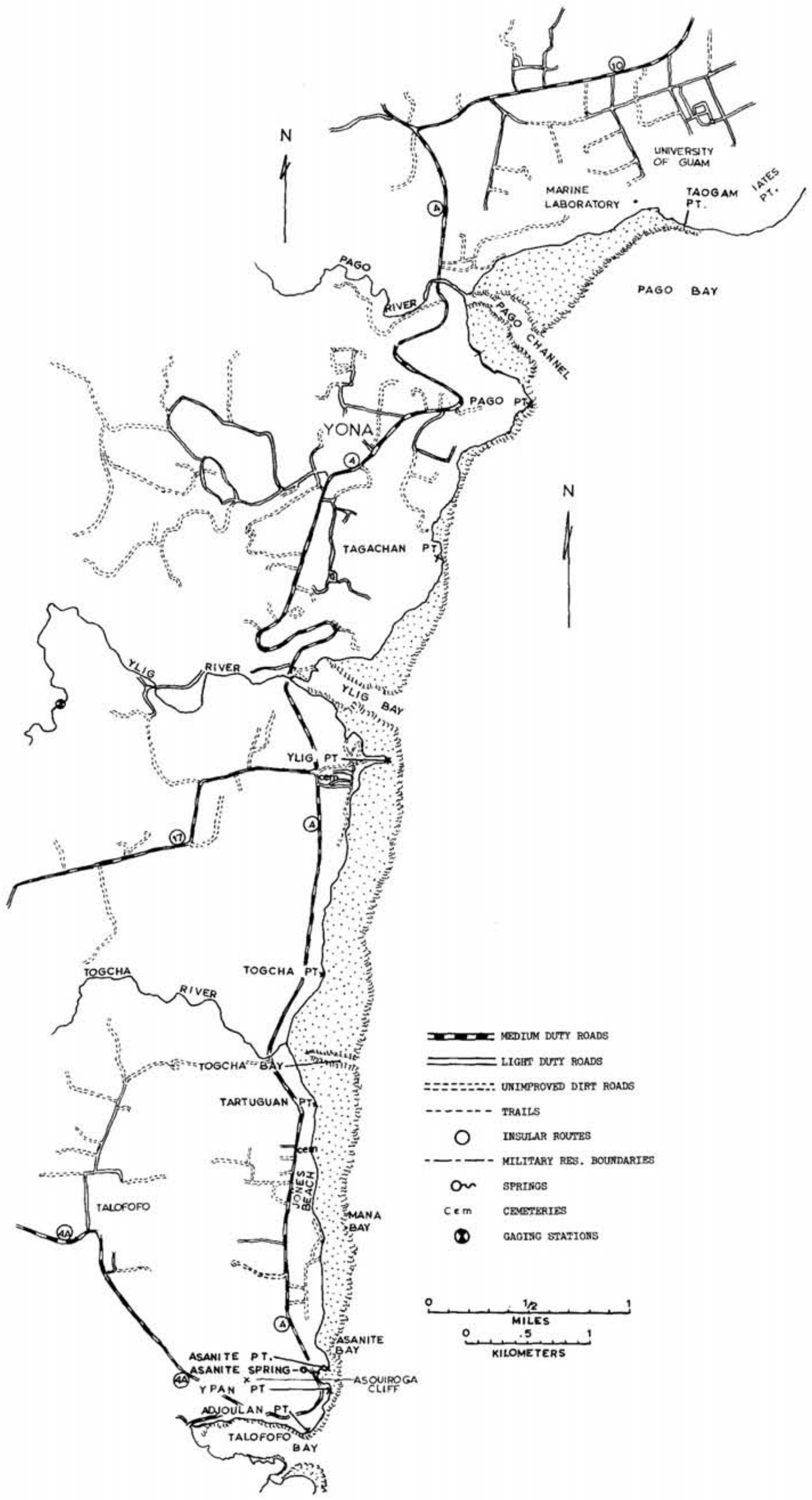


Figure 164a. General location map for Sector XII from Pago Bay to Talofofo Bay. See Figures 164b and 164c for the remainder of Sector XII.

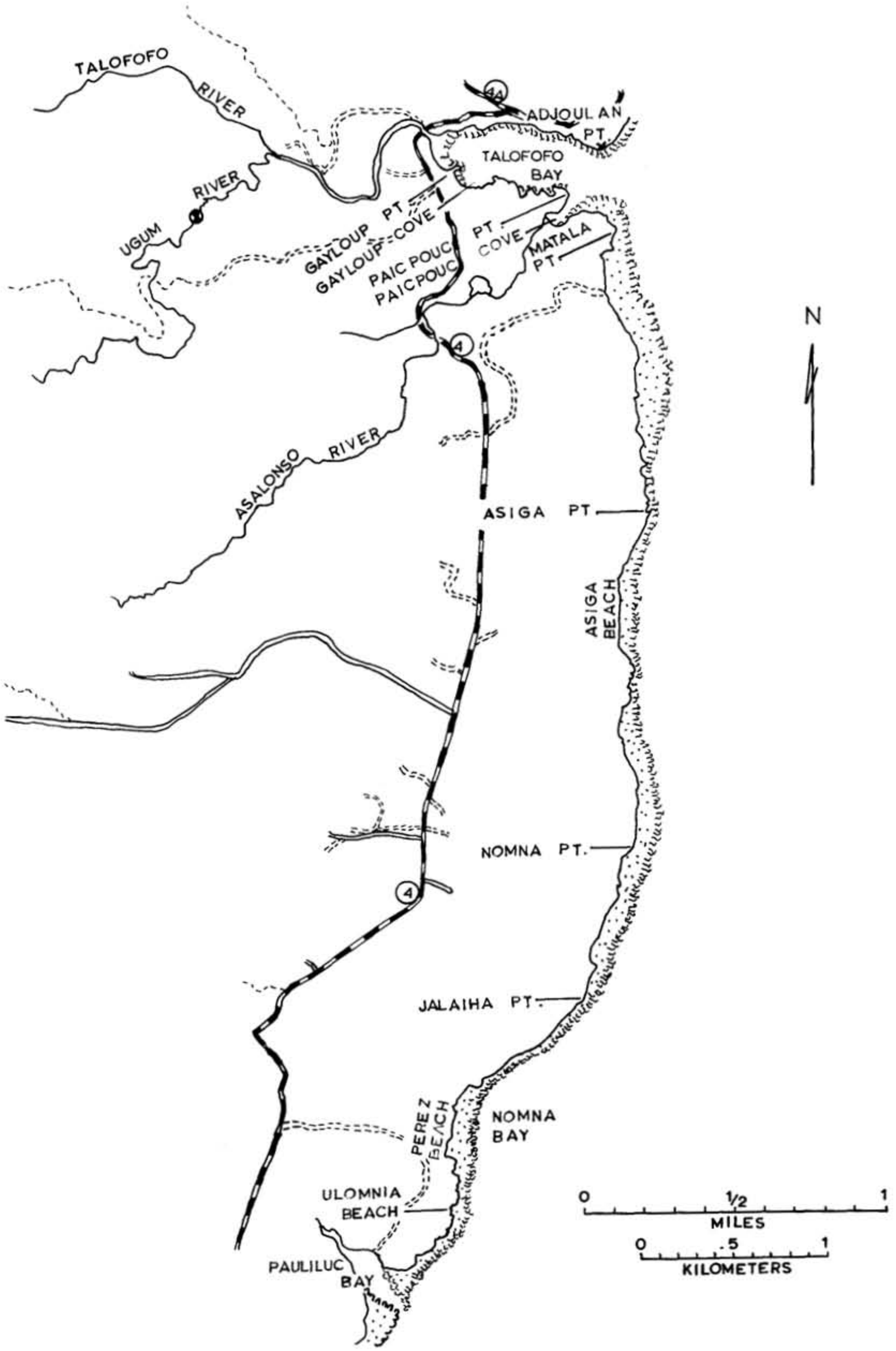


Figure 164b. General location map for Sector XII from Talofofo Bay to Pauliluc Bay. See Figures 164a and 164c for the remainder of Sector XII (map legend on Figure 164a).

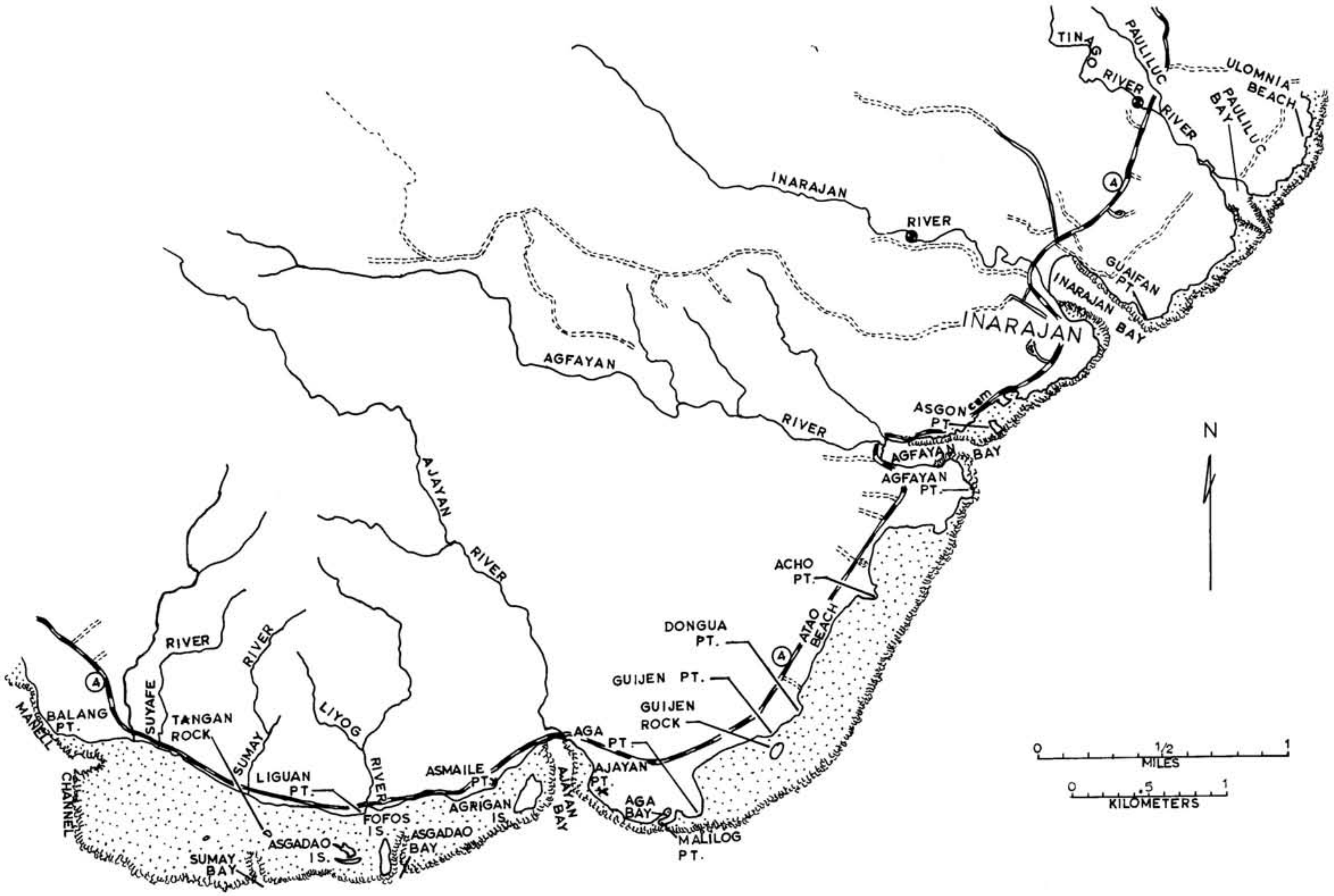


Figure 164c. General location map for Sector XII from Pauliluc Bay to Manell Channel. See Figures 164a and 164b for the remainder of Sector XII (map legend on Figure 164a).

Figure 165. Pago Point. Benches are cut into the base of the limestone cliffs. Fractures and joints are visible in the cliff face, which marks the east end of the Adelup fault zone.

Figure 166. Talofofo Bay. Paicpouc Bay forms a small secondary bay to the left at the mouth of the Asalonso River. Several levels of low-lying limestone terraces are visible at the mouth of Talofofo Bay to the right. The low cliffline on the left side of the bay has been offset by faults from the high cliffline on the right.

SOILS EXPLANATION FOR SECTOR XII

Upland Soils (On Limestone)

1 – Guam Clay. Reddish, granular, permeable Latosol; generally very shallow (less than 12 inches), but has some pockets or narrow troughs of deep soil; prevailing surface gradient 1 to 8 percent.

3 – Chacha-Saipan Clays. Yellowish-brown, firm clay (Chacha), and red, firm clay (Saipan); neutral to acid reaction; Latosolic intergrades. These soils with convex surfaces are 1 to 10 feet deep; with concave surfaces they are 10 to 60 feet deep; with concave surfaces they are
10 to 60 feet deep; prevailing surface gradient 1 to 8 percent.

4 – Saipan-Yona-Chacha Clays. Chacha-Saipan clays with a shallow brownish Lithosol (Yona clay) on many of the narrow convex ridge-tops and steep slopes; soil depth similar to Unit 3, except Yona clay which generally grades into clayey limestone at about 12 to 24 inches below surface; reaction of Yona clay is thus alkaline or calcareous; prevailing surface gradient 8 to 25 percent.

5 – Yona-Chacha Clays. Yona clay is on most narrow convex ridge-tops and steep side slopes, with Chacha on intervening slopes; also small areas of shallow stony phase Saipan clay; depth of soil with convex surface is generally less than 2 or 3 feet, with concave surface it is generally more than 3 feet; slopes range from 25 to more than 100 percent but prevailing surface gradient is commonly 30 to 65 percent.

Upland Soils (On Volcanic Rocks)

6 – Atate-Agat Clay, Rolling. Remnant benches or small mesas of an old red, granular, porous, acid Latosol (Atate clay) with deep, reddish, mottled, plastic to hard clay C horizon, pale yellow, olive, or gray in lower part; and its truncated counterpart (Agat clay) with similar C horizon of saprolitic clay, ranging in depth from a few feet to about 100 feet, and averaging about 50 feet; prevailing surface gradient of Atate clay is 1 to 8 percent, and of Agat clay 8 to 15 percent.

7 – Agat-Asan-Atate Clays, Hilly. Atate-Agat clays and a dark grayish- brown Regosol (Asan clay) developed in more severely truncated saprolite (similar to lower part of C horizon described in Unit 6); soil depths similar to those of Unit 6, except Asan clay which ranges from a few feet in depth to generally less than 50 feet; prevailing surface gradient 15 to 50 percent.

Soils Explanation For Sector XII. Continued.

8 – Agat-Asan Clays And Rock Outcrop, Very Hilly To Steep. Chiefly of the truncated Latosol (Agat clay) and the Regosol (Asan clay) with some un-named dark grayish-brown Lithosols and scattered small areas of volcanic rock outcrop (basalt and bedded tuffs); depth to rock ranges from 0 to 50 or more feet and averages perhaps 20 to 35 feet; prevailing surface gradient 35 to more than 100 percent.

Soils of Coastal and Valley Flats

9 – Pago Clay. Brownish, granular to firm and plastic Alluvial clay, with gray mottling to within 24 to 30 inches of the surfaces; generally alkaline to neutral; soil depth is generally more than 10 and less than 150 feet; moderately well drained; subject to occasional flooding; prevailing surface gradient 1 to 3 percent.

10 – Inarajan Clay. Similar to Pago Clay but lower, wetter, and shallower (thins out on coastal sands and bedrock); water table at or near the surface (within 30 inches) most of the time; poor drainage, mottlings (gray) within 6 to 12 inches of the surface; depth to sand or bedrock ranges from 3 to 25 or more feet; reaction is alkaline in water saturated zone; poorly drained; frequently flooded; prevailing surface gradient 0 to 1 percent.

12 – Shioya Soils. Pale brown to white, fine-, medium-, or coarse-grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Miscellaneous Land Types

13b – Limestone Rock Land, Gently Sloping. Patches of thin (generally less than 2 or 3 inches) reddish or brownish granular clay among exposures of limestone bedrock, pinnacles, boulders, and fragments, which make up more than 25 percent of entire unit area and more than 75 percent of local areas; prevailing surface gradient 2 to 15 percent.

13f – Limestone Rock Land, Steep. Similar to Unit 13b but consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical.

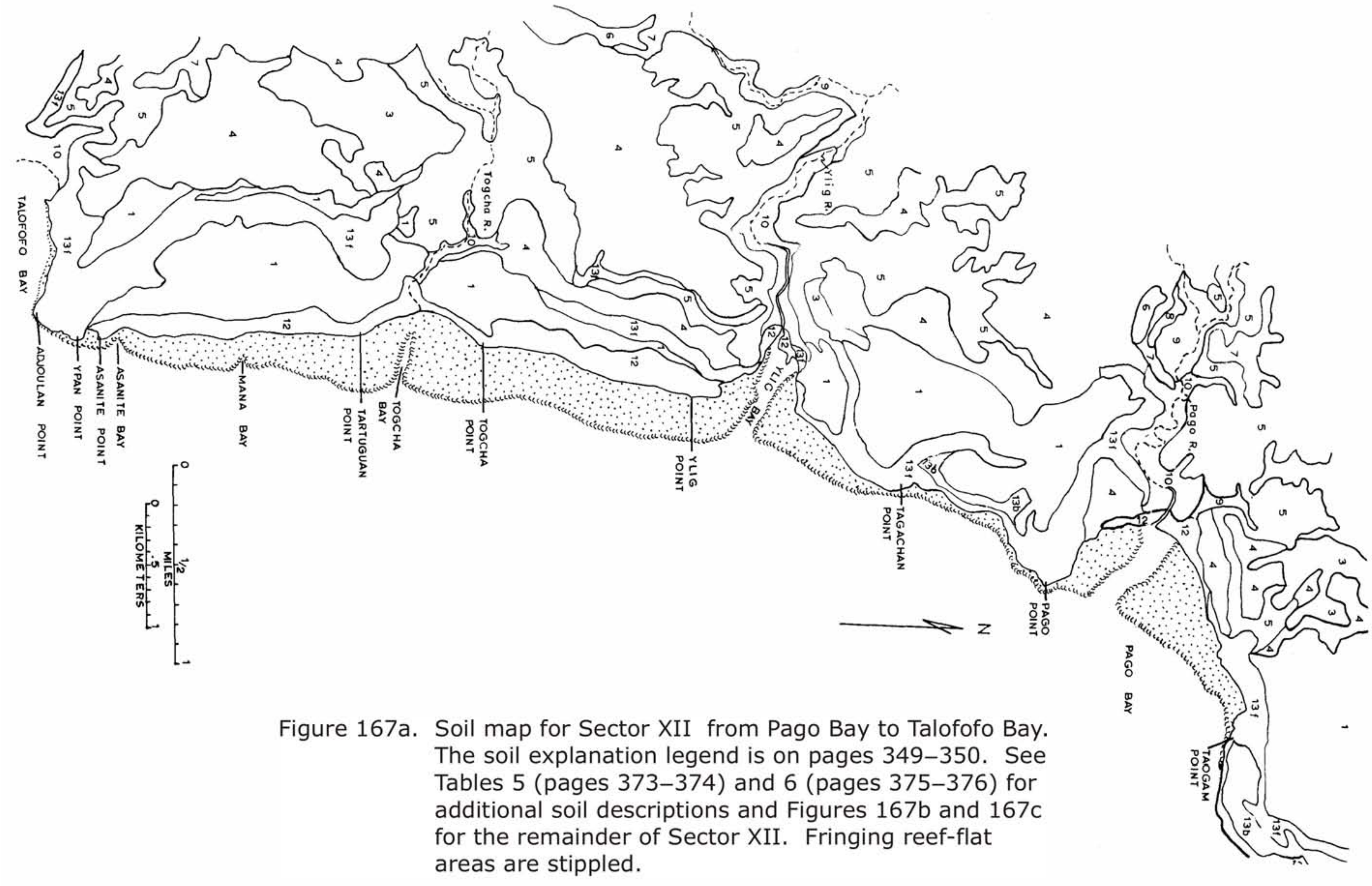


Figure 167a. Soil map for Sector XII from Pago Bay to Talofofo Bay. The soil explanation legend is on pages 349–350. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil descriptions and Figures 167b and 167c for the remainder of Sector XII. Fringing reef-flat areas are stippled.

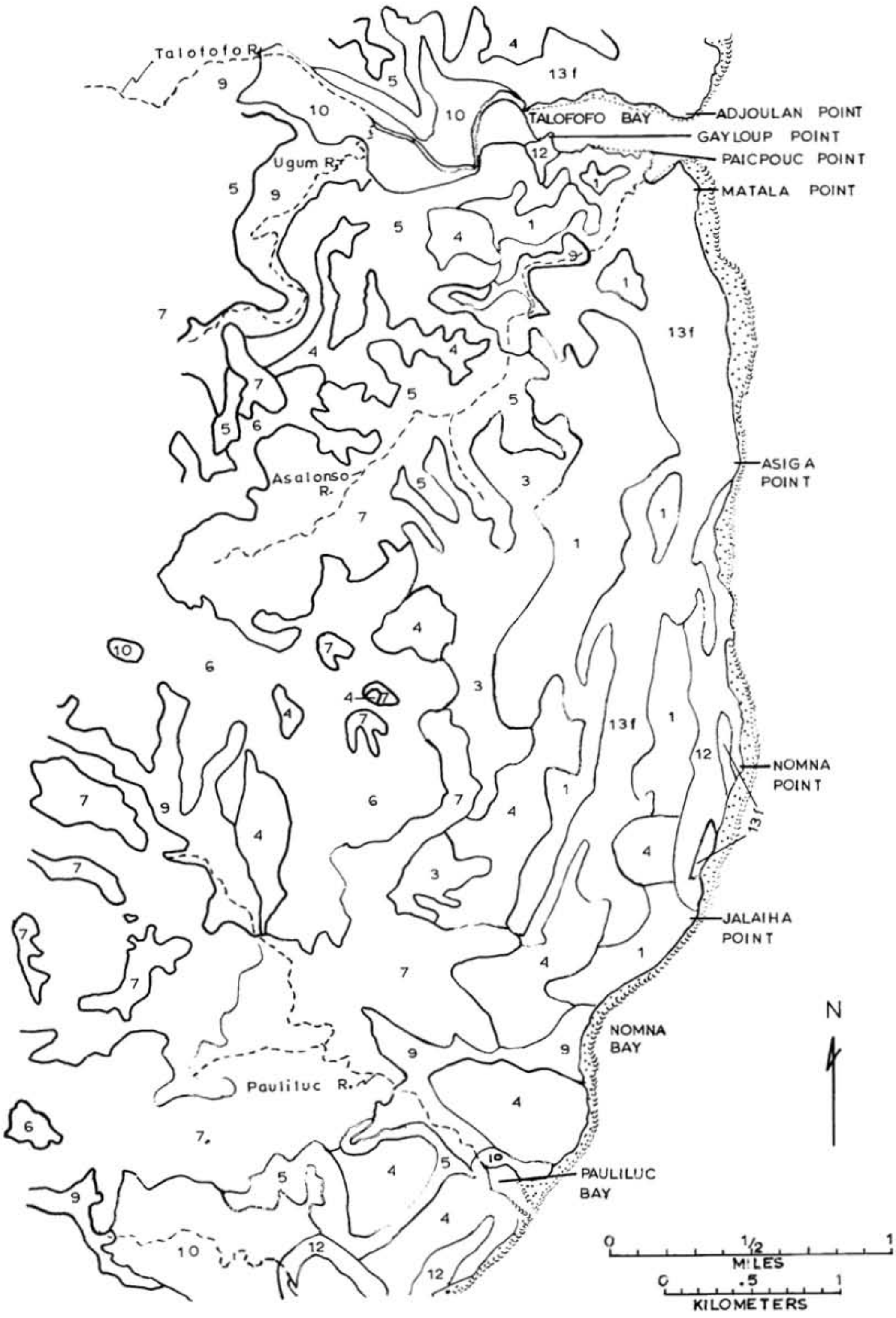


Figure 167b. Soil map for Sector XII from Talofofo Bay to Pauliluc Bay. The soil explanation legend is on pages 349–350. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil descriptions and Figures 167a and 167c for the remainder of Sector XII. Fringing reef-flat areas are stippled.

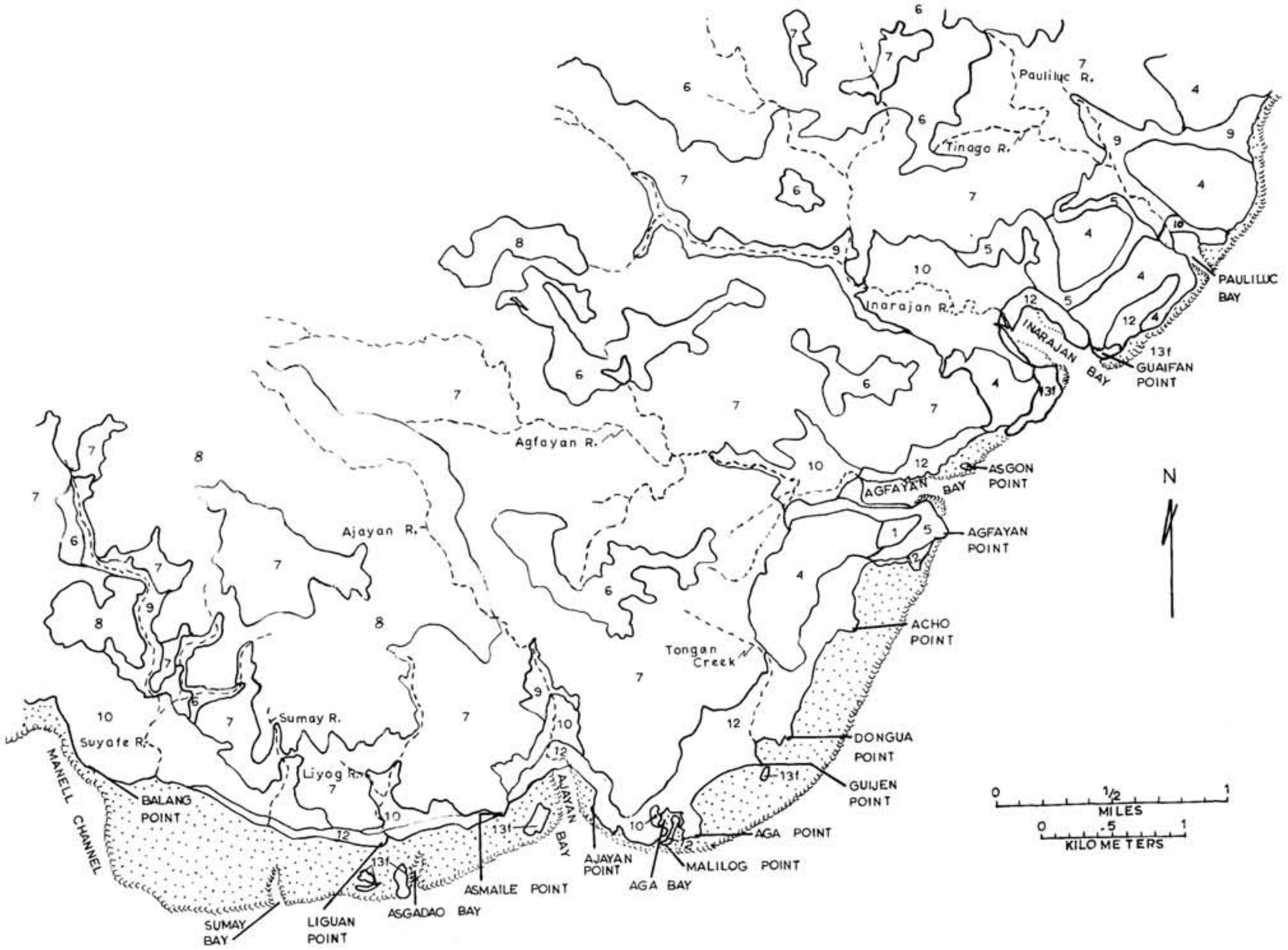


Figure 167c. Soil map for Sector XII from Pauliluc Bay to Manell Channel The soil explanation legend is on pages 349–350. See Tables 5 (pages 373–374) and 6 (pages 375–376) for additional soil descriptions and Figures 167a and 167b for the remainder of Sector XII. Fringing reef-flat areas are stippled.

Figure 168a. Map showing the 100-foot coastal contour (solid line), rocky shorelines, cut benches, beach deposits, alluvium, 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 for Sector XII from Pago Bay to Talofofo Bay. See Figures 168b and 168c for the remainder of Sector XII.

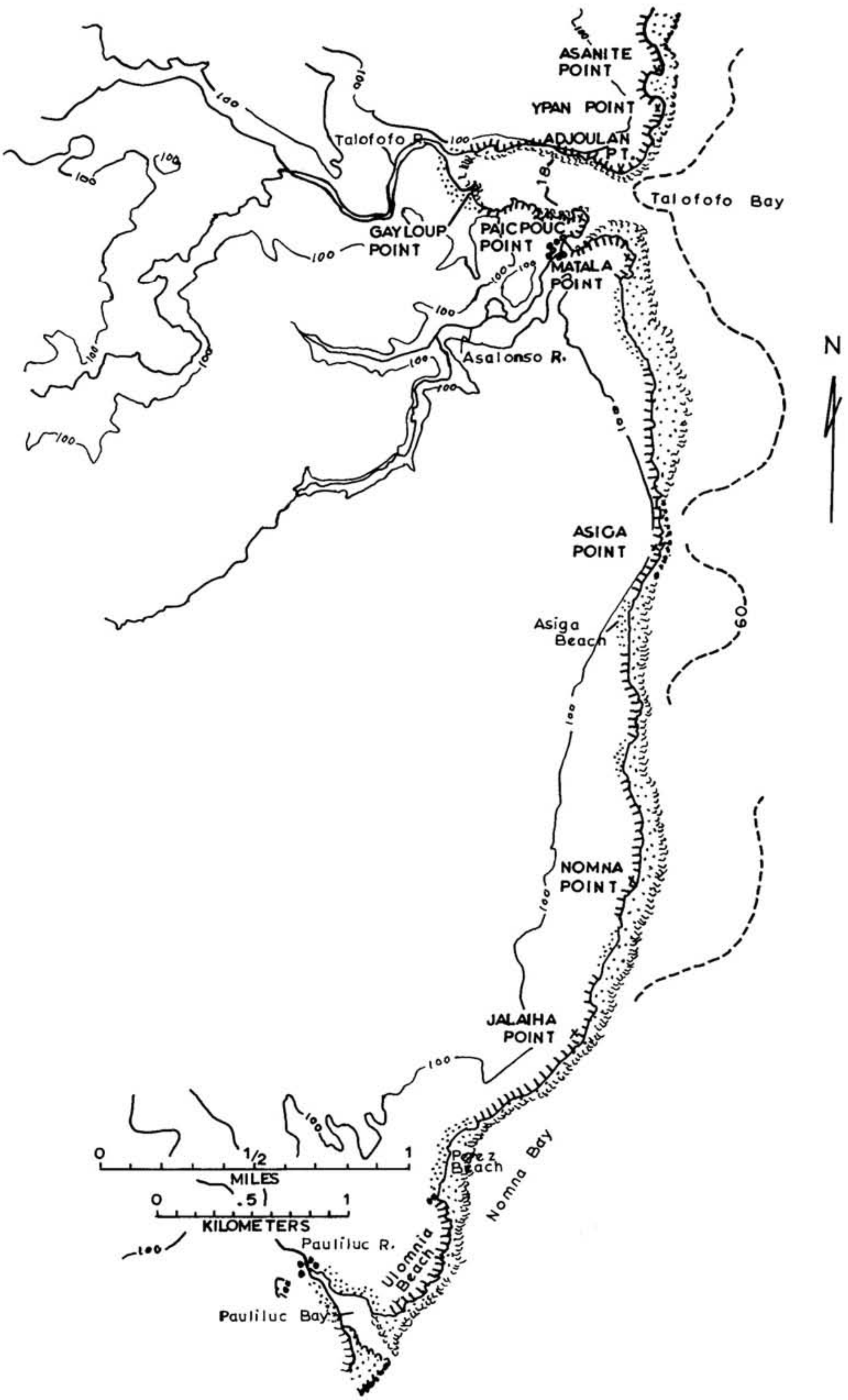


Figure 168b. Map showing the 100-foot coastal contour (solid line), rocky shorelines, cut benches, beach deposits, alluvium, fringing reef-flat platforms, (stippled region seaward of shoreline), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for Sector XII from Talofofo Bay to Pauliluc Bay. See Figures 168a and 168b for the remainder of Sector XII (map legend on 168a).

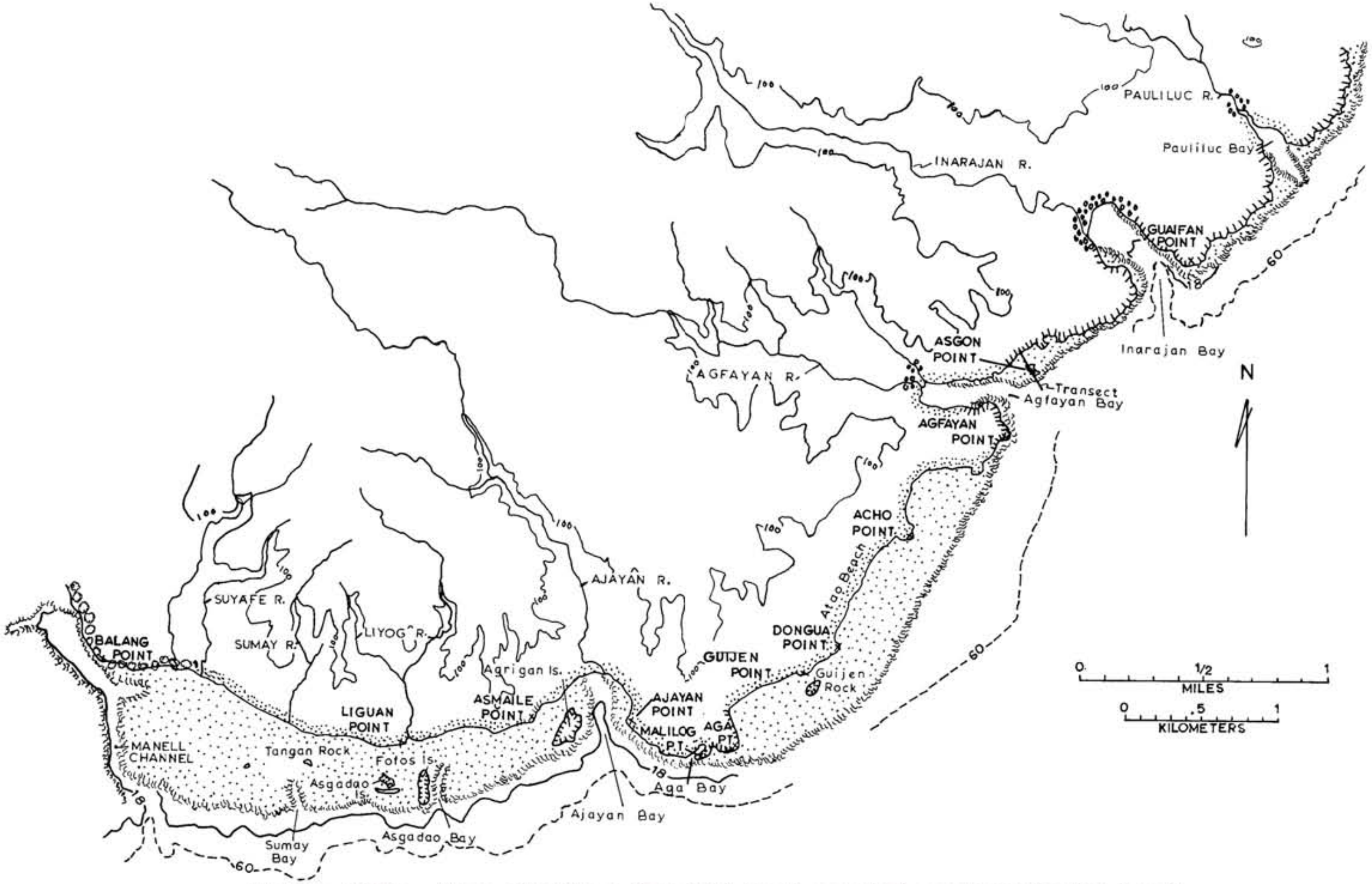


Figure 168c. Map showing the 100-foot coastal contour (solid line), rocky shorelines, cut benches, beach deposits, alluvium, fringing reef-flat platforms, (stippled region seaward of shoreline), reef margin, and the 18-foot (solid line) and 60-foot (dashed line) submarine contour lines for Sector XII from Pauliluc Bay to Manell Channel. See Figures 168a and 168b for the remainder of Sector XII (map legend on 168a).

Figure 169. Small alluvial fan of silt, sand, and gravel deposited on the reef platform at the mouth of the Sumay River.

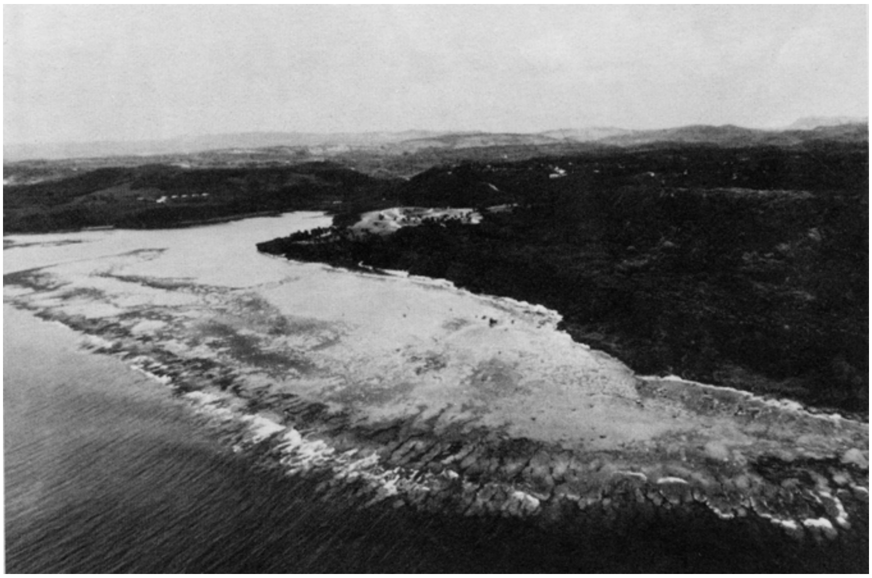


Figure 170. Reef flat and coastline between Ylig Bay (background) and Tagachan Point. A well developed buttress-and-channel system is found along the reef margin and reef front zones. A channel cuts completely through the reef platform at Ylig Bay.

Figure 171. Agfayan Bay. Small cut benches have developed at Agfayan Point on the left side of the bay and a Asgon Island on the right.

Figure 172. Broad reef-flat platform between Asanite and Mana Bays. The reef margin and reef front zones show a well-developed buttress-and-channel system.

Figure 173. Fringing reef platform from Aga Point on the left to Guijen Point at the right. A small channel marks the location of a fault which cuts across the reef platform at the lower left. The reef margin and reef front zones show room-and-pillar development by the formation of isolated coral-algal bosses in the reef front, which by continued growth, coalesce in the reef margin, forming cavernous surge channels, open pools, and new reef-flat surfaces.

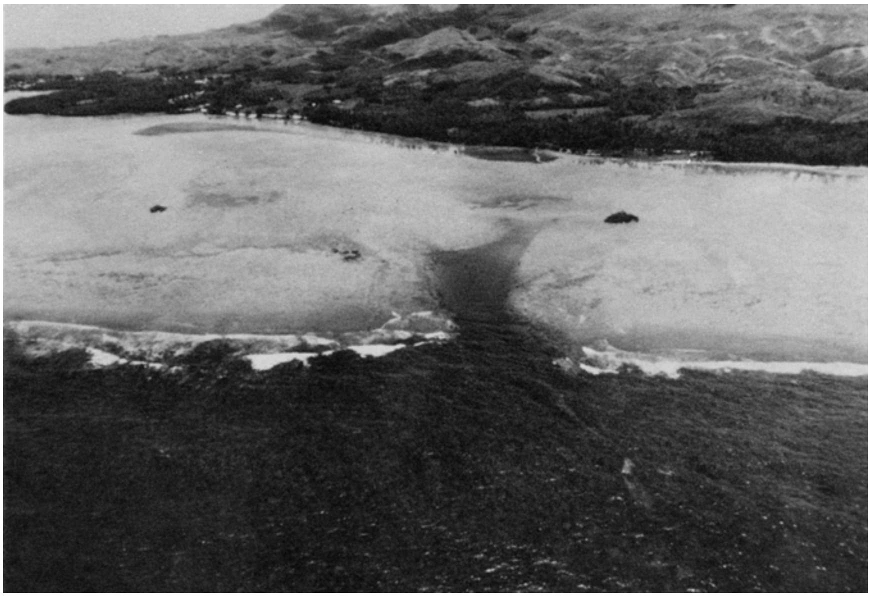


Figure 174. Achang Reef. This broad platform is located on the east side of Manell Channel. A fringing reef channel partially cuts through the reef platform opposite the mouth of the Sumay River.

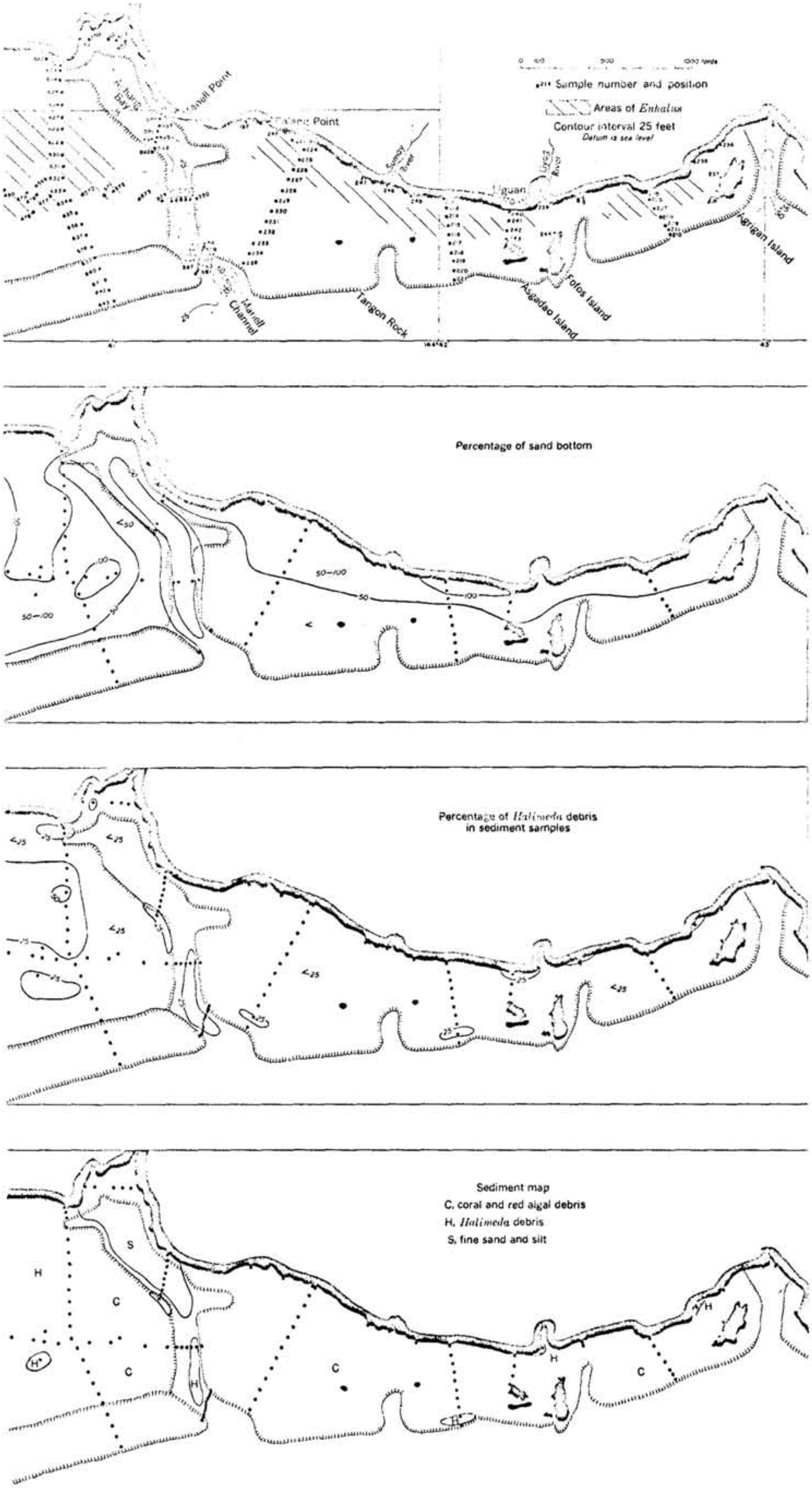


Figure 175. Achang Reef and Manell Channel surface composition. Figure from Emery (1962).

Figure 176. Pago Bay. Pago Channel cuts through the reef platform at the south end of the bay. A small housing development borders the bay shoreline in the foreground.

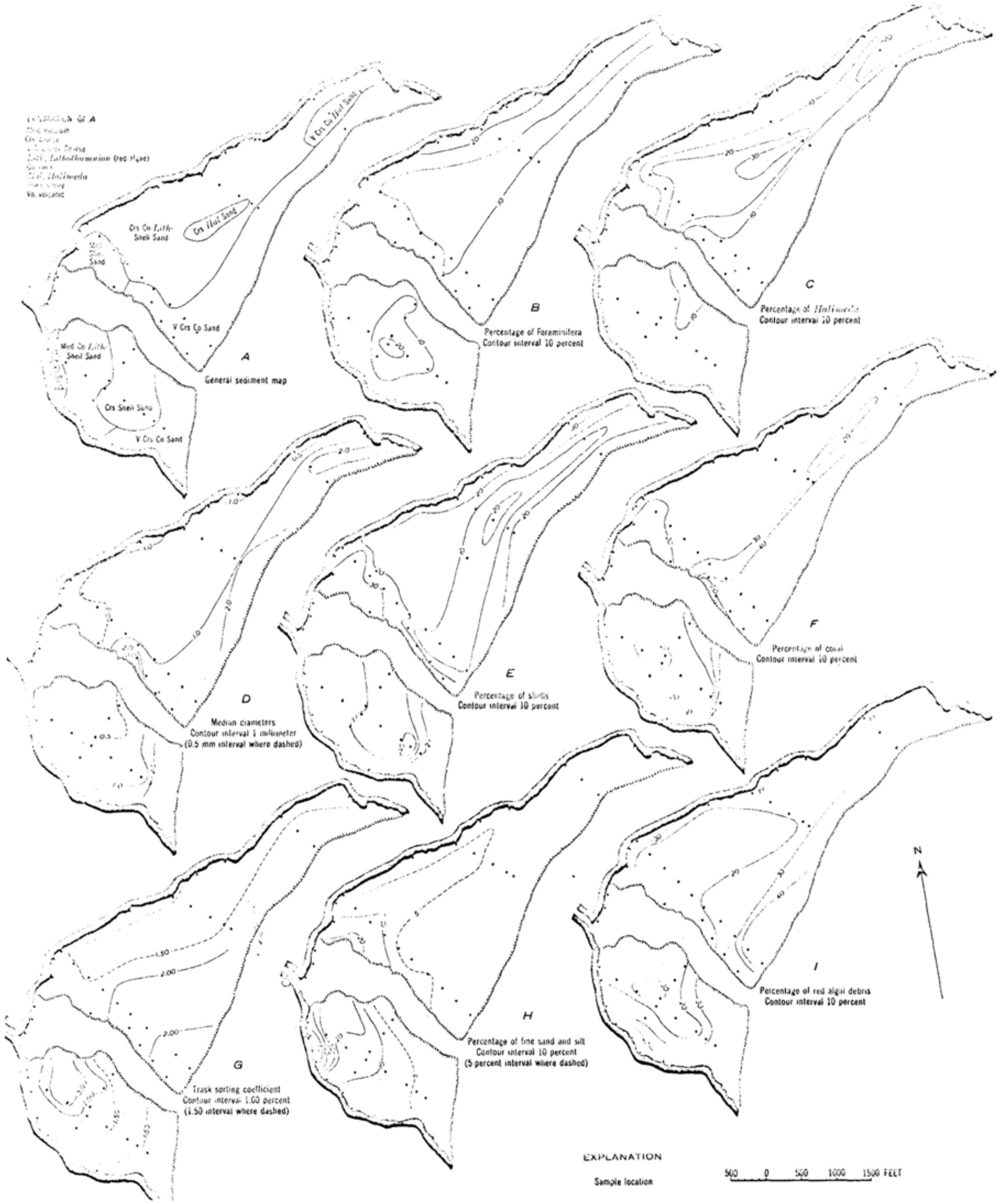


Figure 177. Pago Bay reef flat, composition and distribution of sediment. Figure from Emery (1962).

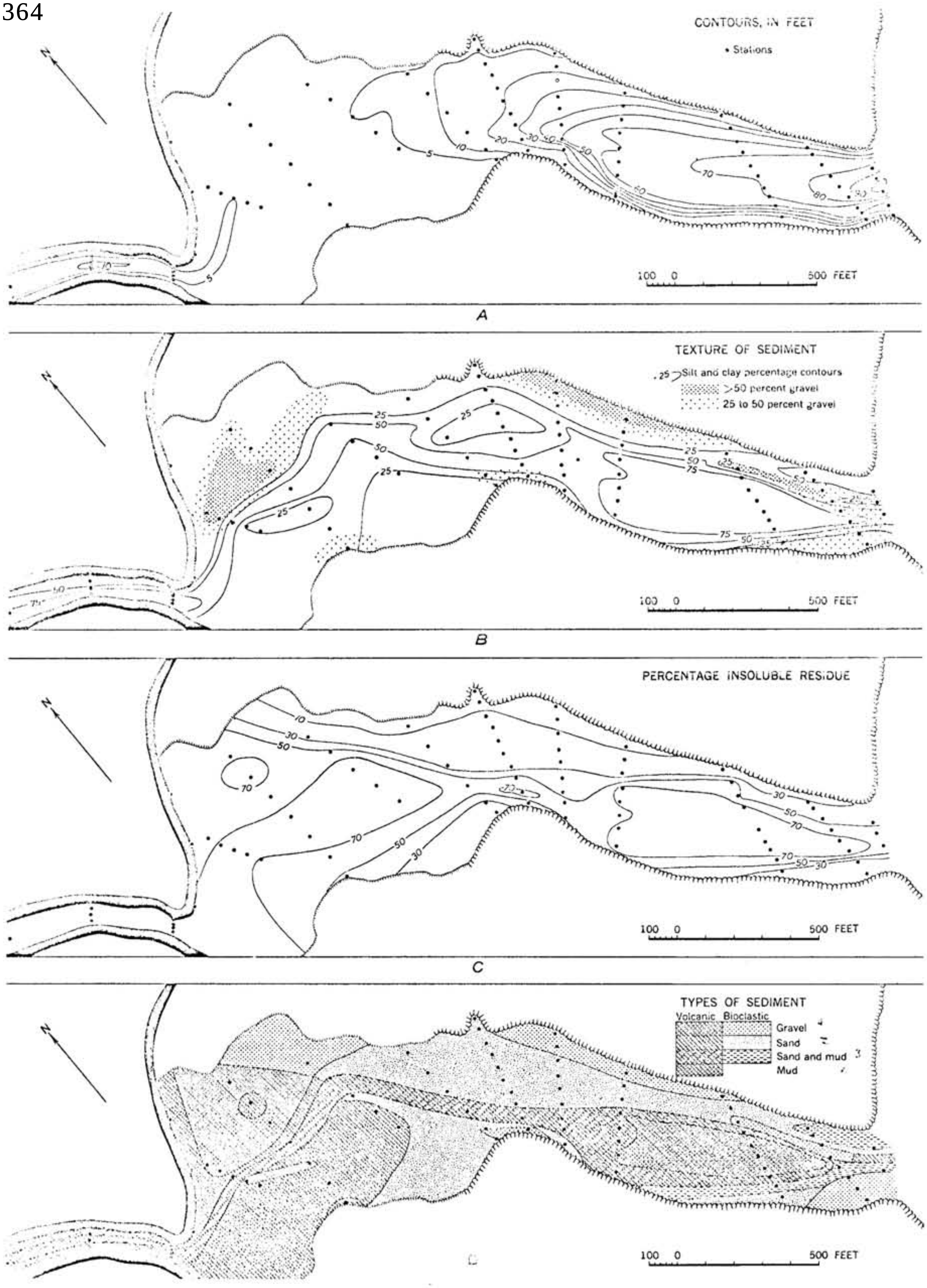


Figure 178. Pago Channel topography and sediment characterization. Figure from Emery (1962).

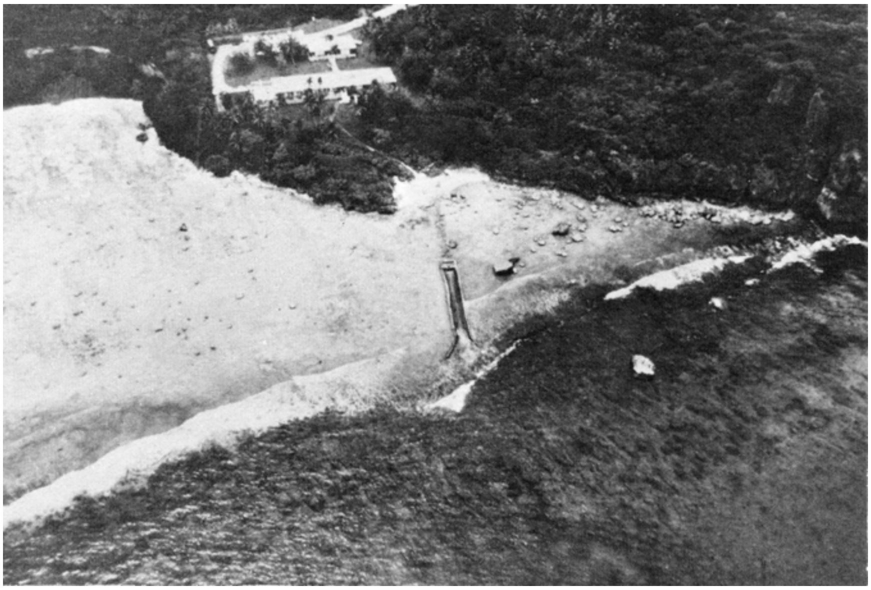


Figure 179. University of Guam Marine Laboratory at the north end of Pago Bay. The trough-like structure on the reef flat is a channel which leads to a sump for pumping seawater to the laboratory.

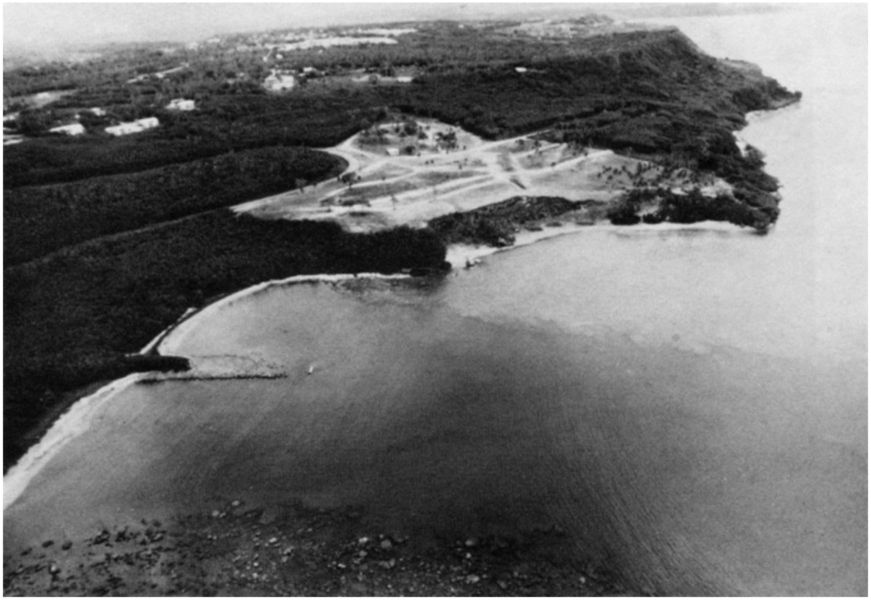


Figure 180. Ylig Bay. A resort development (under construction) occupies the north side of the bay. The channel (foreground) cuts completely through the reef platform to the mouth of the Ylig River at the lower left.

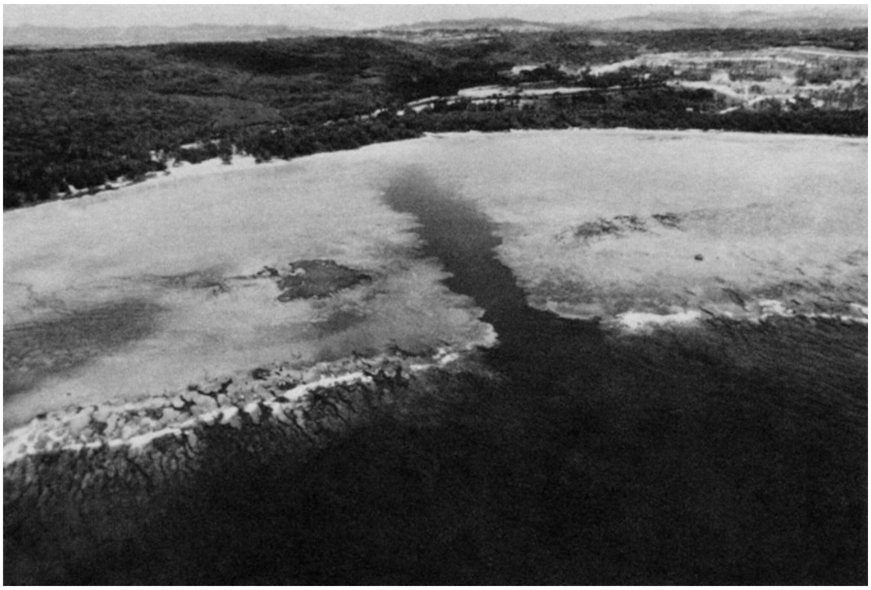


Figure 181. Togcha fringing reef channel. The dark areas to the left and right of the channel are remnant patches of supratidal limestone.

Figure 182. Talofofo Bay. The mouth of this bay allows swells and waves to enter, which develop into surfing waves in the shoal-water area in from of the wide bar which has formed across the head of the bay where the Talofofo River empties (Photo taken 1972).

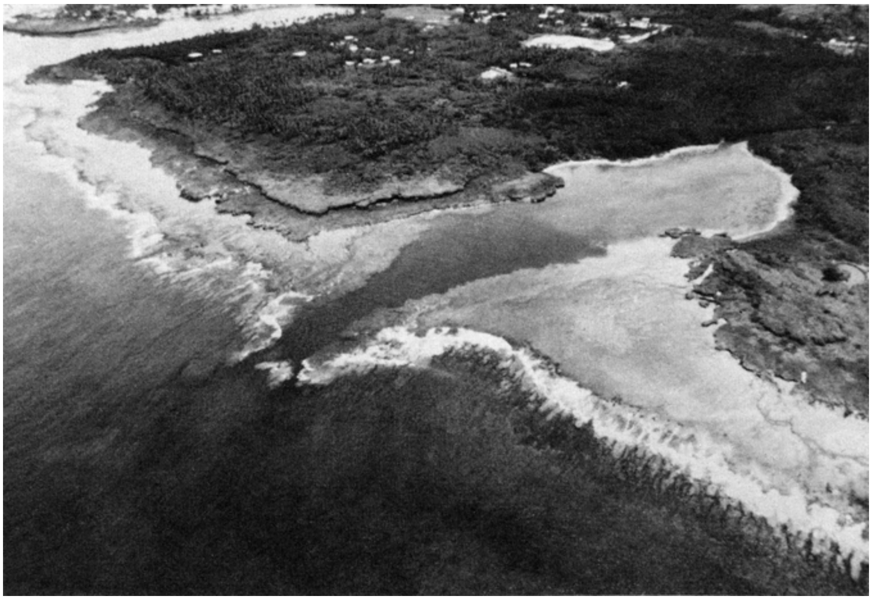


Figure 183. Pauliluc Bay. The fringing reef has nearly sealed off the main body of the bay from the open ocean. Note the various levels of raised limestone terraces on both sides of the bay.

Figure 184. Inarajan Bay. Limestone terraces flank both sides of the mouth of the bay.

Figure 185. Inarajan pool and park.

Table 1. Mean and extreme monthly temperatures: Sumay, Agana Navy Yard, and Agricultural Experiment Station. 1/ Table is from Blumenstock (*In* Tracey et al., 1959).

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	ANNUAL	Years of record
SUMAY														
Mean	79.2	79.2	80.2	81.5	82.3	82.5	81.4	81.0	80.8	80.8	81.1	80.4	80.9	26
Mean maximum	83.5	84.2	85.3	86.9	87.8	88.2	86.4	86.2	86.0	85.6	85.6	84.6	85.8	26
Mean minimum	74.8	74.1	75.0	76.1	76.8	76.8	76.3	75.9	75.7	75.9	76.6	76.1	75.8	26
Extreme max.	89.0	93.0	90.0	92.0	94.0	94.0	92.0	91.0	91.0	91.0	90.0	92.0	94.0	26
Extreme min.	68.0	64.0	68.0	70.0	71.0	72.0	70.0	71.0	70.0	69.0	69.0	70.0	64.0	26
AGANA NAVY YARD														
Mean	85.9	86.4	86.3	88.2	88.6	88.1	87.1	87.3	87.5	87.0	88.1	87.0	87.4	14
Mean maximum	94.4	95.3	96.0	95.1	98.0	96.1	96.5	96.8	97.1	98.1	97.4	96.4	96.4	14
Mean minimum	68.7	66.7	68.0	69.6	71.5	71.3	72.7	73.1	72.9	72.9	72.0	70.3	70.8	14
Extreme max.	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Extreme min.	–	–	–	–	–	–	–	–	–	–	–	–	–	–
AGR. EXP. ST.														
Mean	81.0	81.0	81.0	82.0	82.0	82.0	8I.0	81.0	81.0	81.0	82.0	81.0	81.0	15
Mean maximum	86.0	87.0	87.0	88.0	88.0	88.0	87.0	86.0	87.0	87.0	88.0	87.0	87.0	15
Mean minimum	75.0	74.0	75.0	76.0	77.0	77.0	76.0	76.0	76.0	76.0	76.0	76.0	76.0	15
Extreme max.	92.0	100.0	96.0	96.0	99.0	93.0	98.0	93.0	93.0	97.0	95.0	98.0	100.0	15
Extreme min.	65.0	68.0	69.0	70.0	71.0	72.0	68.0	69.0	69.0	64.0	69.0	68.0	64.0	15

1/ Data from U.S. Joint Army-Navy Study of Mariana Islands (JANIS No. 102) and U.S. Navy, Weather Summary for H. O. Publ. 273, both as quoted in Historical Review of the Meteorology of Guam, Pacific Islands Engineers 1948.

Table 2. Diurnal variations in relative humidity at Naval Air Station as shown by mean maximum and mean minimum relative humidities and their times of occurrence. 1/ Table from Blumenstock (*In* Tracey et al., 1959).

Month	Mean Maximum and Time of Occurrence 2/	Mean Minimum and Time of Occurrence 2/
January	85% -- 0100–0600	71% -- 1200–1500
February	85% -- 0300–0500	66% -- 1300
March	85% -- 0300–0600	66% -- 1200–1500
April	84% -- 0200–0600	66% -- 1300–1400
May	86% -- 0200–0600	69% -- 1200–1400
June	86% -- 0300–0600	69% -- 1300–1400
July	88% -- 0400–0600	71% -- 1200
August	89% -- 0400–0600	74% -- 1400–1500
September	89% -- 0500–0600	75% -- 1200–1300
October	89% -- 0500	75% -- 1100
November	87% -- 0200–0600	73% -- 1400
December	86% -- 010	71% -- 1400

1/ Chief of Naval Operations, Aerology Branch Summary of Monthly Aerological Records, Guam NAS, covering the periods 9/45-2/46 and 5/47-12/52.

2/ Standard time, 150° E. longitude.

Table 3. Wind direction frequencies (in percentages) at Naval Air Station and Harmon Field. 1/ Table from Blumenstock (*In* Tracey et al, 1959).

Month	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Calm
NAVAL AIR STATION																	
January	*	*	9	27	31	20	7	1	1	*	*	*	0	0	0	*	2
February	*	1	11	26	36	16	3	*	1	*	*	*	*	*	*	*	3
March	1	1	8	21	35	22	7	1	*	*	*	0	*	*	*	*	4
April	*	*	3	14	40	24	10	2	2	*	*	0	*	*	1	*	2
May	*	*	2	8	31	32	16	4	1	*	*	0	*	*	*	*	4
June	*	*	1	7	28	37	17	2	1	*	0	*	*	*	*	*	6
July	1	1	3	5	17	20	19	6	5	1	1	*	1	*	1	*	13
August	1	1	3	5	14	16	17	7	8	2	3	2	3	1	1	1	15
September	3	2	5	5	11	12	14	7	8	3	2	1	2	1	2	1	21
October	3	2	5	6	16	12	13	6	8	3	3	1	1	1	3	1	16
November	2	3	10	13	28	17	10	5	3	*	*	*	*	*	*	*	6
December	*	1	10	24	36	17	7	2	1	*	0	*	*	*	*	*	3
ANNUAL	1	1	6	13	26	20	12	4	3	*	1	*	I.	*	1	*	9
HARMON FIELD																	
January	*	*	1	23	41	19	5	1	1	*	*	0	0	0	0	0	9
February	*	1	6	26	47	10	2	*	*	*	*	*	*	0	*	0	8
March	0	*	1	14	65	12	2	*	*	*		0	*	0	*	0	5
April	*	*	1	8	54	28	3	1	*	*	*	0	*	*	1	*	4
May	0	0	*	5	49	32	8	1	*	*	*	0	0	0	0	0	3
June	*	*	*	6	41	33	10	2	1	*	*	0	*	0	0	0	6
July	*	*	3	5	26	16	11	4	7	3	4	2	4	1	2	*	13
August	1	1	2	4	19	13	14	3	4	5	6	3	4	1	4	1	17
September	2	2	4	3	11	10	13	7	6	6	5	3	3	1	4	2	22
October	1	1	4	6	16	11	8	3	6	5	5	3	3	2	3	2	22
November	*	1	4	13	35	15	6	3	3	1	1	*	*	1	1	1	15
December	*	*	2	25	50	11	3	*	*	*	0	0	0	0	0	0	8
ANNUAL	1	1	3	11	35	16	8	2	3	2	2	1	2	1	1	1	12

* Less than 0.5%, but more than 0%.

1/ Sources: Chief of Naval Operations, Aerology Branch, Summary of Monthly Aerological Records, Guam, NAS, 9/45 thru 2/46 and 5/47 thru 12/52; Dept. of the Air Force, Air Weather Service, Uniform Summary of Surface Weather Observations, Guam, Harmon Field, 7/45 thru 9/49 less 1/46–6/46, 5/58. Hourly obs. at both stations.

Table 4. Frequency of typhoons, tropical storms, and "possible typhoons" in the vicinity of Guam, 1924–1953. 1/ Table from Blumenstock (*In* Tracey et al., 1959).

Month	Storm Center Crossed Guam			Storm Center within 60 Miles of Guam 2/			Storm Center 60 to 120 Miles from Guam 2/			Monthly Total			
	Typhoon	Tropical storm	Probable typhoon	Typhoon	Tropical storm	Probable typhoon	Typhoon	Tropical storm	Probable typhoon	Typhoon	Tropical storm	Probable typhoon	All storms
January	0	0	0	0	0	0	1	0	0	1	0	0	1
February	0	0	0	1	0	0	0	0	0	1	0	0	1
March	1	0	0	0	0	0	1	0	0	2	0	0	2
April	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	1	0	0	2	0	0	3	0	0	3
June	0	0	0	0	0	0	1	0	0	1	0	0	1
July	3	0	0	2	0	1	4	0	4	9	0	5	14
August	1	1	1	5	0	3	3	0	4	9	1	8	18
September	2	0	0	2	1	4	4	0	3	8	1	7	16
October	0	0	1	2	0	3	1	0	6	3	0	10	13
November	0	0	1	3	2	1	1	0	2	4	2	4	10
December	0	0	0	1	0	0	1	0	1	2	0	1	3
Totals:	7	1	3	17	3	12	19	0	20	43	4	35	82
Grand Totals:		11			32			39					

1/ Compiled from Royal Met. Obs., Hong Kong, Charts of Typhoon Tracks

2/ Nautical miles

Table 5. Description of soils. To be used in conjunction with the sector soil maps and the engineering geology maps (Figs. 12a–12e). Taken from Plate 49 (*In* Tracey et al., 1959).

LAND TYPE	SOIL GROUP [1/]	BASIC SOIL COMPONENTS OF SOIL GROUPS		UNDERLYING ROCK [3/]		
	Corps of Engineers Classification	Basic Soil Unit	Descriptions	Depth to Rock [4/] (in ft)	Kind of Rock	Engr. Geol. Unit
LIMESTONE UPLANDS	Clayey silt (ML)	**1**	Reddish, granular, friable Guam clay. Generally shallow on limestone; some pockets or narrow troughs of deeper soil.	0.5–1.5 average 0.5–1.0	Porous white limestone	1, 2
		13b	Patches of thin, reddish or brownish, granular clay among pinnacles, boulders, small scarps, or bedrock exposures of Limestone rock land, gently sloping.	0–0.5		
		13f	Generally sparse, red to brown, granular clay among fragments, pinnacles, bedrock exposures, scarps, ridges, and high cliffs of Limestone rock land, steep.	0–0.5		
	Fat clay to silty clay (CH - MN) [2/]	**2**	Brown to pale yellow, firm, moderately plastic, acid Toto clay, generally deep on argillaceous limestone; high shrinkage and expansion in the clay.	5–30 average 10–20	Clayey limestone	3
		3	Yellowish -brown to strong brown, firm, plastic Chacha clay, and reddish, firm, plastic Saipan clay; neutral to acid; both moderately deep to very deep on argillaceous limestone.	Convex: 1–10 [6/] Concave: 10–20		
		4	Chacha and Saipan clays as in Unit 3, with very shallow, brownish, granular Yona clay on many narrow, convex ridgetops.	Convex: 1–10 Concave: 10–60		
		5	Shallow, brownish, granular Yona clay on most narrow, convex ridgetops; Chacha clay on intervening slopes; also small areas of shallow, stony phase Saipan clay.	Convex: 1–3 Concave: 3 or more		
VOLCANIC UPLANDS	Silty clay (MH) [2/] in upper part; sandy silt (SM) in lower part	**6**	Red, granular Atate clay (a Latosol); deep, reddish, mottled, plastic to hard C horizon, pale yellow, olive, or gray in lower part; and a truncated Latosol, Agat clay, with a similar C horizon. [5/]	10–100 average 50	Volc. tuff	6
		7	Agat clay (see above) and another truncated Latosol, Asan clay, with pale yellow, olive, or gray C horizon, plastic to hard and only slightly red in upper part; Atate clay sparse. [5/]	10–100 average 50	Tuff-congl.	7
		8	Chiefly Agat clay (a truncated Latosol) and Asan clay (a Regosol), with some dark grayish-brown Lithosols and small areas of rock outcrop, boulders, and cobbles.	0–50 or more average 20–35	Basalt flows and dikes	8
COASTAL AND VALLEY FLATS	Silty clay (MH) [2/]	**9**	Deep, noncalcareous, varicolored, firm, plastic Pago clay, with gray mottling below 24 to 30 inches; occasionally flooded; moderately to well drained.	10–150	Limesand, limestone, volc. rock	Any except 1, 2
		10	Shallow to deep, moderately firm and plastic Inarajan clay, neutral to alkaline; mottling below 12 inches; generally high water table; poorly drained, often flooded.	3–25 or more		
	Peat and highly organic silts (Pt)	**11**	Muck. Generally submerged, highly organic soils; silty muck and peat; contains 20 to 50% decomposed organic matter.	3–20 average 5–10	Limesand, limestone, volc. rock	Mostly 4, 9, 3
	Poorly graded sand, few or no fines (SP)	**12**	Pale brown to white, fine-, medium., or coarse-grained limesand called Shioya soils; contains some dark organic coloring and less than 10% fines in top 6 to 18 inches.	3–35	Limestone, volc. rock, sediments	Any
		14	Artificial till, chiefly limesand and gravel; large boulders, rubble, cobbles, earth, trash, and scrap iron predominate locally. Mapped as Made land.	2–25	Limestone, lagoonal or alluvial deposits	Any except 6, 7, 8

1/ Unified soil classification system, U.S. Army Corps of Engineers Tech. Memo 3-357, v. 1. 1953.
2/ Mechanical analyses did not correlate with other tests which designated the soil to thus group.
3/ See Engineering Geology tables, and map for descriptions and locations of the rock types.
4/ Refers to shape of the soil surface.
5/ The consistence of the clays ranges from moderately plastic (wet) through friable to firm (moist) to hard (dry).
6/ Rock is considered to be material whose hardness renders ineffective a 4-inch jeep-mounted auger designed for drilling in earth and saprolite.

Table 5. (Continued).

SOIL GROUP Corps of Engineers Classification	Basic Soil Unit	SOIL AREA (acres and % of island)	TOPOGRAPHY				VEGETATION	
			Prevailing Gradients of Soil Surface (in %)	Landforms	Average Local Relief (in ft)	Altitudes (meters)	Description	Timber
Clayey silt (ML)	1	48,030 35.40	1–8	High, undulating, southward-sloping plateau with steep seaward slopes, cliffs, and some low benches.	tens	10–350	Mixed forest; canopy irregular, up to 75 ft high; undergrowth sparse to dense; many large clearings.	Short, low quality; for temporary use only
	13b	3,390 2.50	2–15	Rocky, pinnacled rim of upland plateau, and some narrow coastal benches or terraces.	tens	0–350	Similar to Unit 1 above, but few large areas of bare or open ground.	
	13f	9,150 6.74	25–100 or more	Mostly seaward-sloping, steep rocky slopes, scarps. and cliffs.	hundreds	0–405	Similar to Unit 1 above, but few large areas of bare or open ground.	
Fat clay to silty clay (CH - MH)	2	155 0.11	1–8	Nearly level to sloping, micro-undulating ridgetops.	tens	20–55	Predominantly open ground, pastureland, dwellings, and thickets; a few coconuts; some areas occasionally cultivated.	None
	3	3,310 2.44	1–8	Undulating limestone upland (youthful karst).	tens	40–110	Open cultivated ground, pastureland, dwellings, and thickets, bare ground weeds and shrubby vegetation around military installations and towns.	None
	4	7,340 5.41	8–25	Rolling to hilly upland with flat-bottomed basins (moderate karst).	tens	30–170	Secondary thicket cultivated ground; bare ground weeds, herbs, and shrubs around built-up areas; coconut plantations; mixed forest on steep slopes.	Some poor quality; also coconut logs
	5	8,360 6.16	25–100 or more	Deeply dissected; narrow, steep-sided ridges and flat bottomed valleys and basins (mature karst).	tens or hundreds	3–260	Mixed forest; a few patches of large trees closely spaced; few over 50 ft high; canopy dense to irregular; undergrowth generally dense, spiny.	Some poor quality
Silty clay (MH) in upper part; sandy silt (SM) in lower part	6	8,400 6.20	1–15	Gently sloping ridgetops and adjacent swales; includes some steeper slopes near ravine heads.	tens	10–300	Savanna: grassland and herbaceous vegetation, with erosion scars, shrubs, and fern; swordgrass dense. Small ironwood trees in many places.	None
	7	23,760 17.50	15–50	Predominantly hilly upland, with some small areas of gently sloping ground.	tens or hundreds	0–370	Savanna, with mixed forest in some ravine heads or parts of valleys not repeatedly burned; undergrowth spiny.	Some poor quality locally
	8	15,020 11.09	35–100	Maturely dissected upland; very hilly to mountainous.	generally hundreds	0–390	Mixed forest in some ravines; stature low, canopy dense to irregular; undergrowth dense and spiny. Most ridges and slopes contain savanna.	Some poor quality, for construction
Silty clay (MH)	9	2,380 1.75	1–3	Narrow to moderately wide valley bottoms and alluvial fans.	few	Mostly 10–25	Varied locally: mixed forest, secondary thicket and cultivated ground; coconut plantations; open ground and pasture.	Some poor quality; also coconut logs
	10	2,320 1.72	0–1	Coastal flats and wide valley bottoms.	tenths	Mostly 0–10	Open ground and pasture; locally swamp forest, or dense growth of giant reeds or other marsh plants where almost continuously ponded.	None
Peat and highly organic silts (Pt)	11	520 0.38	0–1	Flat, depressional, ponded or mostly submerged areas.	tenths	Mostly 0–10	Heavy stands of large reeds (*Phragmites karka*) and scattered trees (*Hibiscus tiliaceus*).	None
Poorly graded sand, few or no fines (SP)	12	2,425 1.78	1–5	Discontinuous, low, narrow coastal terraces.	few	0–10	Coconut plantations; patches of mixed forest; scattered shrubs, herbs, vines, stands of low stiff grasses, and bare beach.	Coconut logs
	14	965 0.71	Nearly level	Shallow to deep artificial till extending coastal areas or budding up coastal flats.	very few	1–5	Mostly bare ground with buildings or installations; some scattered vines, shrubs, and thin grasses.	None

Table 6. Soil drainage and erosion characteristics to be used in conjunction with the sector soil maps and the engineering geology maps (Figs. 12a–12e). Taken from Plate 49 (*In* Tracey et al., 1959).

SOIL GROUP Corps of Engineers Classification	Basic Soil Group	PERMEABILITY COEFFICIENT 1/	WATER TABLE Position	NATURAL DRAINAGE Observed Rates Surface	 Internal
Clayey silt (ML)	1	Generally $k > 10^{-4}$	Generally just above sea level	Slow; no surface streams	Free to rapid
	13b				
	13f				
Fat clay to silty clay (CH - MH)	2	$k = 10^{-4}$ to 10^{-8}	50 to 175 ft below surface	Rapid to slow (water stands in microbasins)	Medium (before cracks swell shut) to very slow
	3		50 to 300 ft below surface	Rapid to medium	Medium
	4		At sea level or on underlying volcanic rocks	Rapid to medium	Medium
	5		At sea level or on underlying volcanic rocks	Rapid to medium	Medium
Silty clay (MH) in upper part; sandy silty (SM) in lower part	6	$k = 10^{-3}$ (near surface) to 10^{-8} (at depth)	2 to 100 ft below surface; average 50 ft	Slow to medium; rapid on exposed C horizon	Rapid in A and B horizons; slow in C horizon
	7		0 to 100 ft below surface; average 50 ft	Slow on concave surfaces; rapid on convex	Slow
	8		0 to 100 ft below surface	Rapid	Slow
Silty clay (MH)	9	$k = 10^{-4}$ to 10^{-8}	3 to 50 ft below surface; average 5 to 25 ft	Rapid to medium	Medium to slow
	10		0 to 15 ft below surface; average 0 to 5 ft	Medium to slow	Slow to very slow
Peat and highly organic silts (Pt)	11	$k > 10^{-6}$	0 to 1 ft below surface	Medium to slow	None; water table at or near surface
Poorly graded sand, few or no fines (SP)	12	Generally $k > 10^{-3}$	3 to 25 ft below surface	No surface flow	Rapid (above water table)
	14		5 to 25 ft below surface	Very slow to none	

1/ Permeability equations refer to any soil in the corresponding engineering classification, but are for generalized whole profiles and are based upon tests made on similar soils from other areas.

Table 6. (Continued).

LAND TYPE	SOIL GROUP: Corps of Engineers Classification	Basic Soil Unit	CONSTRUCTION DRAINAGE: Flooding and Erosion: Excavations	Flooding and Erosion: Embankments and Foundations	Subsurface Drainage: Excavations	Subsurface Drainage: Embankments and Foundations
LIMESTONE UPLANDS	Clayey silt (ML)	1, 13b, 13f	Heavy rains pond some depressions; dikes advisable	Flooding and erosion rare	Natural drainage adequate except during heaviest rains	Natural drainage generally adequate
	Fat clay to silty clay (CH - MH)	2	Low diversion dikes needed around excavations	Prevent concentration of surface water and soil saturation	Local ponding difficult to drain (wet soil expands)	Prevent soil saturation; install adequate drains
		3	Dikes or diversions needed	Turf and adequate culverts or weirs needed	Temporary ponding unless drains are installed	Drains needed at contacts of fill and natural earth
		4	Diversion dikes needed on uphill sides of excavations	Adequate weirs, spillways, and toe-drains needed	Temporary ponding in low areas unless drainage is provided	Drains needed at contacts of fill and natural earth
		5	Diversion dikes needed on uphill sides of excavations	Adequate weirs, spillways, and toe-drains needed	Natural drainage adequate for higher areas; low areas as in Unit 4	Prevent saturation of bearing area in low places; install adequate drains
VOLCANIC UPLANDS	Silty clay (MH) in upper part; sandy silt (SM) in lower part	6	Diversion dikes needed on uphill sides of excavations	Prevent ponding or channeling of surface drainage	Adequate subsoil drains required for depressions	Prevent saturation of fill/ subgrade contact zone in lower areas; install adequate drains
		7	Diversion dikes needed. Design for maximum runoff	Design for maximum runoff; avoid overflow or ponding	Perched water table in many low areas; seepage from hillsides	Prevent saturation at base of fill on low or sloping areas
		8	Extensive precautions needed; see Unit 7	Protection costly; design for maximum runoff	Perched water table in many low areas; seepage from hillsides	Prevent saturation at base of fill on low or sloping areas
COASTAL AND VALLEY FLATS	Silty clay (MH)	9	Occasional severe flooding; design for maximum runoff	Occasional severe flooding; design for maximum runoff	Seepage in some areas; pumping required below water table	Provide drains for subgrade above water table
		10	Frequent severe flooding; design for maximum runoff	Frequent severe flooding; design for maximum runoff	High water table; sheeting and pumping may be required	Excavate to sand or rock; use piling for foundations, and thick sub-base
	Peat and highly organic silts (Pt)	11	Remove peat; design for high water table and flooding	Remove peat; design for high water table and flooding	Remove peat; design for high water table	Design as for Unit 10
	Poorly graded sand, few or no fines	12, 14	Subject to typhoon floods and encroaching high seas	Subject to typhoon floods and encroaching high seas	Water table fluctuates rapidly; tight sheeting and pumping required	Keep subgrade confined

Table 7. Characteristics of beach sands. Taken from Emery (1962).

Beach locality	Sample	% Insoluble residue	Median diameters in mm		Trask sorting coefficient		Slope in degrees	
			Hiqh	Low	High	Low	High	Low
1	72	65	0.31	1.55				
2	69-70	11	.27	0.76	1.16	2.58	6.8	0.0
3	73	14	.16	-.-	1.50	-.-	-.-	-.-
4	66-67	0	.23	.64	1.22	1.91	7.2	-.-
5	63-64	0	.23	.89	1.38	1.83	7.1	5.1
6	59-60	0	.26	.64	1.33	1.33	7.7	4.0
7	56-57	0	.26	.34	1.60	2.22	5.7	
8	53-54	0	.26	.45	1.25	1.85	9.1	.0
9	50-51	0	.21	.79	1.23	5.34	8.4	.0
10	48	0	.45	-.-	1.15	-.-	-.-	-.-
11	83-84	0	.34	.61	1.25	1.91	15.0	1.7
12	41-42	0	.38	1.04	1.26	3.80	10.5	-.-
13	265	0	.54	-.-	1.69	-.-	-.-	-.-
14	45-46	0	.24	.38	1.13	1.10	12.4	.0
15	32-33	0	.26	.45	1.23	1.24	10.7	.0
16	27-28	0	.59	.38	1.36	1.50	11.9	.0
17	30-31	0	.35	.44	1.45	2.24	7.9	3.3
18	36-37	0	.70	.71	1.22	2.65	11.7	3.4
19	96	80	.01	-.-	-.-	-.-	-.-	-.-
20	26	0	1.03	-.-	1.52	-.-	-.-	-.-
21	24-25	1	.49	1.63	1.27	2.30	10.7	4.0
22	204	--	.39	-.-	1.17	-.-	-.-	-.-
23	22-23	49	.33	1.01	1.67	1.39	8.5	.0
24	21	78	.25	-.-	1.43	-.-	-.-	-.-
25	190	1	.47	-.-	1.18	-.-	-.-	-.-

Table 7. Continued.

26	20	-.-	.42	-.-	1.47	-.-	-.-	-.-
27	17-18	34	.33	.54	1.46	1.30	7.1	2.5
28	19	-.-	.18	-.-	1.09	-.-	-.-	-.-
29	12-13	2	.43	.60	1.33	1.54	6.0	.0
30	192	3	.21	-.-	1.16	-.-	-.-	-.-
31	193	0	.38	-.-	1.08	-.-	-.-	-.-
32	10-11	91	.21	.82	1.29	1.86	8.9	2.4
33	194	2	.77	-.-	1.42	-.-	-.-	-.-
34	8-9	86	.26	.35	1.29	1.24	10.0	2.2
35	195	2	1.56	-.-	1.72	-.-	-.-	-.-
36	7	39	.47	-.-	1.57	-.-	-.-	-.-
37	196	1	.35	-.-	1.58	-.-	-.-	-.-
38	6	51	.36	-.-	1.65	-.-	-.-	-.-
39	4-5	14	.57	.78	1.30	1.78	10.4	.0
40	197	42	.25	-.-	1.45	-.-	-.-	-.-
41	2-3	2	.54	1.14	1.27	1.88	5.0	3.1
42	200	0	.86	-.-	1.54	-.-	-.-	-.-
43	201	0	.45	-.-	1.28	-.-	-.-	-.-
44	202	0	.70	-.-	1.72	-.-	-.-	-.-
45	199	6	.47	-.-	1.25	-.-	-.-	-.-
46	198	74	.40	-.-	1.31	-.-	-.-	-.-
47	621	18	.70	-.-	2.16	-.-	-.-	-.-
48	1	91	.21	-.-	1.22	-.-	-.-	-.-
49	620	11	.87	-.-	1.56	-.-	-.-	-.-
50	612	74	.74	-.-	1.77	-.-	-.-	-.-
51	79	-.-	.79	-.-	-.-	-.-	-.-	-.-
52	77	20	.63	-.-	1.52	-.-	-.-	-.-
53	78-79	2	.63	.91	1.62	1.76	3.3	0
54	75	39	.15	-.-	1.58	-.-	-.-	-.-
55	81-82	8	.21	1.16	1.17	2.32	8.0	5.0
56	74	-.-	.40	-.-	1.17	-.-	-.-	-.-
57	263	0	.76	-.-	2.03	-.-	-.-	-.-
58	264	0	.98	-.-	1.53	-.-	-.-	-.-
	Mean values ---------------	2	.39	.73	1.34	1.86	8.4	0.0

Table 8. Composition of beach sands, in percent. Table from Emery (1962).

Beach locality	5	6	11	15	20	23	31	36	41	43	53
Sample	63	59	83	32	26	109	193	7	2	201	78
Organic carbonate	100	100	100	100	100	44.3	100	61.5	98	100	98
Foraminifera	5	1	2	1	1	2	12	1	0	58	2
Shells	25	38	10	20	44	15	30	38	39	5	50
Fine sand and silt	20	0	0	0	0	1	0	0	0	0	1
Halimeda debris	5	1	1	15	20	0	15	0	1	2	3
Coral	35	55	77	50	20	65	13	25	20	20	15
Calcareous red algae	10	5	10	14	15	17	30	35	40	15	27
Miscellaneous	0	0	0	0	0	0	0	1	0	0	2
Inorganic	0	0	0	0	0	55.7	0	38.5	2	0	2
Glass and Quartz	---	---	---	---	---	2.3	---	1.0	---	---	---
Feldspar	---	---	---	---	---	20.1	---	20.2	---	---	---
Serpentine	---	---	---	---	---	33.2	---	40.4	---	---	---
Biotite	---	---	---	---	---	.0	---	.2	---	---	---
Hornblende	---	---	---	---	---	7.6	---	18.4	---	---	---
Olivine	---	---	---	---	---	10.9	---	6.1	---	---	---
Augite	---	---	---	---	---	14.3	---	7.3	---	---	---
Magnetite	---	---	---	---	---	6.0	---	4.3	---	---	---
Spinel (picotite)	---	---	---	---	---	1.9	---	.6	---	---	---
Rock fragments	---	---	---	---	---	3.5	---	.5	---	---	---
Not determined	---	---	---	---	---	.2	---	1.0	---	---	---

Table 9. Composition of detrital beach sands—partial chemical analyses. Table from Emery (1962).

	Partial analysis in %	
Beach locality	23	36
Sample	199	7
SiO_2	50.2	46.4
Fe_2O_3	10.8	16.6
Al_2O_3	12.8	13.3
Cr_2O_3	.6	.2
CaO	7.8	7.9
MgO	9.8	8.6
K_2O	.3	.3
Na_2O	1.9	.9
	94.5	94.2

Table 10. Chemical composition of sediments. Table from Emery (1962).

C, coral; F, Foraminifera; Sh, shells; S, silt; H, *Halimeda*; fs, fine sand; A, red algae; L, limestone

	Beaches		Reef flats					Lagoon				Channels		Outer slopes				
	Agana Bay	Cocos Island	Agana Bay	Pago Bay		Achang Bay		Cocos				Pago	Ma-maon	Off Merizo		Off Ritidian		
Sample	63	201	89	302	649	635	602	503	407	464	556	469	141	607	611	660A	662	660B
Depth (feet)	0	0	2	2	2	2	2	3	6	36	45	79	21	115	315	810	1,170	810
Dominant constituent	C	F	C, Sh	C	C	C	S	C	Sh	H	fs, S	fs, S	S	C, red A	F, fs	F, H, fs	F, H	L
SiO_2	0.19	0.14	0.25	5.75	0.51	0.47	18.66	0.29	0.24	3.80	1.15	20.42	13.13	0.81	5.31	0.39	0.24	0.51
$(Al,Fe)_2O_3$	.11	.13	.15	4.24	.50	.52	14.31	.19	.13	2.89	.91	14.76	9.98	.75	4.58	.58	.27	.34
MgO	1.71	2.81	2.02	3.56	2.58	2.17	2.51	1.57	2.48	2.37	2.06	5.49	2.30	2.41	3.65	2.18	2.53	4.81
CaO	52.25	51.16	51.43	44.01	50.45	51.05	30.41	51.76	51.21	47.50	50.07	28.99	36.14	50.61	44.50	50.34	51.54	48.52
SO_3	.44	.46	.52	.40	.51	.48	.32	.48	.49	.48	.55	.31	.30	.49	.34	.52	.42	.49
P_2O_6	.09	.10	.11	.12	.12	.12	.15	.11	.14	.11	.12	.16	.09	.12	.11	.13	.12	.19
Ignition loss	44.93	45.10	44.86	40.95	44.57	44.19	31.37	44.66	44.77	42.63	44.04	28.13	35.73	44.20	40.81	44.69	44.73	44.45
Nitrogen	.003	.010	.003	.067	.044	.015	.100	.010	.018	.068	.036	.034	.074	.015	.015	.007	.010	.012
$CaCO_3$	93.2	91.3	91.8	-.-	90.0	91.2	-.-	90.6	91.5	-.-	89.5	-.-	-.-	90.5	-.-	90.0	92.1	86.8
$MgCO_3$	3.6	5.9	4.2	-.-	5.4	4.6	-.-	3.3	5.2	-.-	4.3	-.-	-.-	5.1	-.-	4.6	5.3	10.1

Table 11. Textural characteristics of reef flat sands. Table from Emery (1962).

Locality	Sample	Median diameter, in millimeters, for indicated interval, in yards				Trask sorting coefficient, for indicated interval, in yards			
		Shore (low tide)	100	200	300	Shore (low tide)	100	200	300
2------	70, 71---------------	0.76	1.50	------	------	2.58	3.21	------	------
4------	67, 68, 69, 88, 90---	.64	.45	0.66	0.35	1.91	1.44	1.65	1.97
5------	64, 65---------------	.89	.52	------	------	1.83	1.48	------	------
6------	6o, 61---------------	.64	.26	------	------	1.33	1.71	------	------
7------	57, 58---------------	.34	1.17	------	------	2.22	2.58	------	------
8------	54, 55---------------	.45	.92	------	------	1.85	2.32	------	------
9------	51, 52---------------	.79	.64	------	------	5.34	1.92	------	------
11-----	84, 85---------------	.61	1.44	------	------	1.91	1.8o	------	------
12-----	429 43---------------	1.04	.75	------	------	3.8o	1.53	------	
14-----	46, 47---------------	.38	.25	------	------	1.10	1.34	------	------
15-----	33, 34, 35-----------	.45	.25	1.60	------	1.24	1.43	4.41	------
16-----	28, 29---------------	.38	1.07	------	------	1.50	3.36	------	------
22½---	644 , 645, 649, 652---	.65	.67	.62	.76	1.6o	1.44	1.52	1.51
29-----	13, 14, 15, 16-------	.6o	.37	.74	.50	1.54	1.65	1.51	2.14
39½---	222, 224, 226, 228---	.48	.42	.54	.55	1.85	1.48	1.67	1.91
53-----	79, 80---------------	.91	.54	------	------	1.76	1.85	------	------

Table 12. Composition of reef flat sediments, in percent. Table from Emery (1962).

Reef	Number of samples	Forami-nifera	Shells	Fine sand and silt	*Halimeda* debris	Madre porarian coral		Calcareous red algae
Achang-------------	90	4	25	4	17		50	
Cocos---------------	26	1	18	1	7		73	
Agana---------------	12	6	32	5	6	41		10
Pago-----------------	30	8	24	3	8	31		26
Weighted average--------------------		4	24	4	13		55	

Table 13. Discharge data in millions of gallons for Janum Spring. Table modified from Ward and Brookhart (1962).

Mar. 27, 1952	1.23	July 2, 1953	1.55
Apr. 11	1.16	Sept. 21	2.24
June 10	1.34	June 1, 1954	2.20
July 9	1.30	June 18	2.31
Aug. 6	1.51	June 30	1.50
Sept. 4	1.34	Oct. 11	2.74
Apr. 14, 1953	1.25	June 4, 1955	1.50
May 14	1.37	Nov. 22	1.66
June 12	1.43	May 25, 1956	1.32

Table 14. Chemical analysis of water at Janum Spring. Results in parts per million. Table modified from Ward and Brookhart (1962).

Date	5-12-52	5-13-56
Analyst	USGS	USN
Silica (SiO_2)	6.2	6.1
Aluminum (Al)	-	.2
Iron (Fe)	.05	-
Calcium (Ca)	63	60
Magnesium (Mg)	17	21
Sodium (Na)	12	19 1/
Potassium (K)	.4	-
Bicarbonate (HCO_3)	272	284
Sulfate (SO_4)	4.8	5.2
Chloride (Cl)	20	28
Phosphate (PO_4)	.0	.1
Dissolved solids (Residue on evaporation at 180°C)	224	248
Hardness (as $CaCO_3$) (Calcium, Magnesium)	227	235
pH	7.3	7.2

1/Calculated as sodium plus potassium and expressed as sodium.

Table 15. Chemical analysis of water from Tarague Spring No. 4. Results are in parts per million. Table modified from Ward and Brookhart (1962).

Date	5-2-52
Analyst	USGS
Silica (SiO_2)	1.5
Aluminum (Al)	–
Iron (Fe)	0.08
Calcium (Ca)	92
Magnesium (Mg)	48
Sodium (Na)	380
Potassium (K)	13
Bicarbonate (HCO3)	238
Sulfate (SO4)	98
Chloride (Cl)	680
Phosphate (PO4)	.1
Dissolved solids (Residue on evaporation at 180°C)	1,470
Hardness as CaCO3 Calcium, magnesium)	427
pH	7.5

Table 16. Pumpage rate for Tumon Tunnel. Table from Ward and Brookhart (1962).

Pumpage
(million gallons)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1953	–	–	–	–		30.03	32.13	30.80	32.84	33.78	27.01	–
1954	31.00	25.24	28.43	25.74	28.77	30.58	30.35	32.67	34.06	35.97	36.27	–
1955	28.50	15.23	–	21.41	16.98	31.36	33.59	33.76	34.69	32.14	23.06	30.72

Table 17. Chloride content of water from Tumon Tunnel. Table from Ward and Brookhart (1962).

	Chloride (ppm)		
Apr. 23 , 1947	89	May 1955	128
May 12	114	Aug.	120
Apr. 16, 1951	112	Sept.	120
Mar. 1, 1953	80	Oct.	118
15	130	Nov.	128
Apr. 1	120	Dec.	120
May 19	140	Jan. 1956	118
July 16	140	Feb.	128
Jan. 8, 1954	120	Mar.	129
Feb. 3	130	Apr.	130
Mar. 10	125	May	128
Dec. 10	80	June	126
Mar. 1955	115	July 9	116
Apr.	144	Aug. 1	114

Table 18. Discharge records for the Finile River. Table from the Geologic Survey Water Supply Paper 1937 (1971).

Finile River at Agat

Location.— Lat 13°22'41"N., long 144°39'26"E., on right bank 0.4 mile upstream from estuary and 0.4 mile southeast of Agat School.

Drainage area.—0.26 sq. mi.

Records available.—April 1960 to September 1965.

Gage.—Water-stage recorder and concrete control. Altitude of gage is 20 ft (from topographic map).

Average discharge.—5 years, 1.59 cfs (1,150 acre-ft per year).

Extremes.—Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharge above base (170 cfs), April 1960 to September 1965

Date	Time	Discharge	Gage height	Date	Time	Discharge	Gage height	Date	Time	Discharge	Gage height
Sept. 2, 1960	1100	*153	2.53	Aug. 2, 1962	0430	*202	2.96	Sept. 9, 1953	1400	288	3.66
				Sept. 12, 1962	1330	177	2.76				
Oct. 19, 1960	1945	*261	3.39	Sept. 30, 1962	2230	171	2.71	Dec. 4, 1963	1100	*194	2.90
Aug. 13, 1961	2400	182	2.80					Sept. 20, 1964	1730	177	2.76
Sept.18, 1961	1800	184	2.82	Nov. 11, 1962	2400	214	3.06				
				June 3, 1963	1330	214	3.06	Oct. 5, 1964	1700	*123	2.23
Dec. 14, 1961	0800	186	2.83	June 6, 1963	1830	*314	3.77				

Annual minimum discharge, April 1960 to September 1965

Water year	Date	Discharge	Water year	Date	Discharge
1960	May 9, 14-16, 1960	0.11	1963	Several days	0.62
1961	Several days	0.39	1964	April 3, 8, 9, 1964	0.39
1962	June 24, 1962	0.11	1965	May 22, 23, 1965	0.22

1960-65: Maximum discharge, 314 cfs June 6, 1963 (gage height, 3.77 ft), from rating curve extended above 30 cfs on basis of slope-area measurement at gage height 3.66 ft; minimum, 0.11 cfs May 9, 14-16, 1960, June 24, 1962.

Remarks.—Records good except those above 60 cfs, which are fair. No diversion above station.

Table 19. Discharge records for the Cetti River. Table from the Geologic Survey Water Supply Paper 1937 (1971).

Cetti River near Umatac

Location.— Lat 13°18'58" N., long 144°39'21" E., on right bank 0.1 mile upstream from estuary and 1.3 miles northeast of Umatac School.

Drainage area.—0.72 sq. mi.

Records available.—February 1960 to September 1965.

Gage.—Water-stage recorder and concrete control. Altitude of gage is 10 ft (from topographic map).

Average discharge.—5 years, 4.44 cfs (3,210 acre-ft per year).

Extremes.—Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharge above base (800 cfs), February 1960 to September 1965

Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height	Date	Dis- Time	Gage charge	height
Sept. 21, 1960	1515	*835	4.23	Sept. 30, 1962	2230	*1, 400	6.12	Oct. 23, 1963	0630	884	4.40
Nov. 12, 1963	0830	829	4.22								
Oct. 19, 1960	1930	*1,420	6.19	Nov. 11, 1962	2400	*1,230	5.58	Dec. 4, 1963	1100	*1,130	5.24
Nov. 3, 1960	0400	829	4.21	Apr. 29, 1963	2030	968	4.68	Apr. 26, 1964	1230	806	4.11
Sept. 18, 1961	1700	1,120	5.21	June 1, 1963	0030	942	4.60	Sept.17, 1964	1330	1,030	4.90
Oct. 5, 1961	1030	890	4.42	Aug. 10, 1963	1230	1,100	5.12				
Dec. 14, 1961	0630	1,000	4.80	Sept. 9, 1963	1330	1,070	5.04	July 28, 1965	0400	*563	3.25

Annual minimum discharge, February 1960 to September 1965

Water year	Date	Discharge	Water year	Date	Discharge
1960	May 15, 1960	0.18	1963	Mar. 27-30, Apr. 2 , 1963	0.50
1961	Apr. 1, 1961	.46	1964	Feb. 29, Mar. 11, 1964	.11
1962	June 23, 1962	.26	1965	May 11, 1965	.03

1960-65: Maximum discharge, 1,420 cfs Oct. 19, 1960 (gage height, 6.19 ft from rating curve extended above 66 cfs by slope-area measurements at gage heights 1.78 and 6.19 ft; minimum, 0.03 cfs May 11, 1965.

Remarks.—Records good except those for period of indefinite stage-discharge relation, which are poor. No diversion above station.

Table 20. Discharge records for the La Sa Fua River. Table from Ward and Brookhart (1962).

La Sa Fua River near Umatac

Location.— Lat 13°18'25" N., long 144°39'45" E., on left bank 0.6 miles northeast of Umatac, 3.1 miles north of Merizo, and 5.5 miles south of Agat.

Drainage area.—1.93 sq. mi.

Records available.—April 1953 to June 1958.

Gage.—Water-stage recorder and concrete control. Altitude of gage is 130 ft (by barometer).

Average discharge.—5 years, 4.43 cfs.

Extremes.—Maximum and minimum discharges for the fiscal years 1954-1958 are contained in the following table:

Fiscal year	Maximum			Minimum		
	Date	Discharge (cfs)	Gage height (feet)	Date	Discharge (cfs)	Gage height (feet)
1953†	June 23, 1953	1.45	0.74	June 14, 1953	0.37	0.42
1954	Oct. 15, 1953	†1,050	5.47	(††)	.37	.42
1955	Sept. 6, 1954	‡610	4.62	May 6, 1955	.45	.46
1956	Sept.10, 1955	‡505	4.31	May 23,24, 1956	.35	.41
1957	Aug. 28, 1956	650	4.72	June 15, 16, 17 18, 1957	.39	.43
1958	Sept. 2, 1957	730	4.93	May 16, 19, 1958	.29	.38

† Period April to June.

‡ From rating curve extended above 13 cfs by test on model of station site.

†† July 9, Aug. 1, 1953, June 2-4, 20, 21, 1954.

1953-58: Maximum discharge, 1.050 cfs Oct. 15, 1953 (gage height, 5.47 ft), from rating curve extended above 13 cfs by test on model of station site; minimum, 0.29 cfs May 16, 19, 1958 (gage height, 0.38 ft).

Remarks.—Records good except those for periods of no gage-height record, which are poor.

Rating table, April 11, 1953, to June 30, 1958 (gage height, in feet, and discharge, in cubic feet per second)

0.4	0.33	1.3	5.6
.5	.55	1.5	13.0
.6	.85	2.0	55
.7	1.25	3.0	193
.8	1.75	4.0	405
1.0	2.95		

Table 21. Discharge records for the Umatac River. Table from the Geologic Survey Water Supply Paper 1937 (1971).

Umatac River at Umatac

Location.— Lat 13°17'45" N., long 144°39'50" E., on left bank 0.2 mile upstream from mouth, 0.3 mile southeast of Umatac, and 5.7 miles northwest of Inarajan.

Drainage area.—2.04 sq. mi.

Records available.—September 1952 to September 1965.

Gage.— Water-stage recorder and concrete control. Altitude of gage is 8 ft, revised (from topographic map). Prior to Oct. 16, 1953, at datum 0.62 ft higher.

Average discharge.—13 years, 8.60 cfs (6,230 acre-ft per year).

Extremes.—Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharges above base (1,200 cfs, revised), water years 1960-65

Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height
Nov. 29, 1959	1500	1,200	3.24	Aug. 31, 1962	0200	1,500	3.58	Oct. 4, 1963	0300	1,380	3.42
Aug. 20, 1960	0130	*1,490	3.53	Sept.30, 1962	2300	*3,470	4.94	Oct. 11, 1963	1800	1,880	3.87
								Oct. 23, 1963	0630	1,440	3.48
Oct. 19, 1960	1915	*1,460	7.04								
Jan. 14, 1961	1030	1,640	3.66	Nov. 11, 1962	2400	2,710	4,44	Nov. 7, 1963	1630	1,530	3.54
Sept. 2, 1961	0800	1,920	3.90	Apr. 29, 1963	0400	2,050	4.01	Dec. 4, 1963	1030	*3,920	5.22
Sept.18, 1961	1700	5,500	6.09	May 29, 1963	0600	1,300	3.33	May 19, 1964	2330	1,230	3.27
				June 1, 1963	0030	1,430	3.46	Aug. 20, 1964	1830	1,410	3.45
Oct. 5, 1961	1130	1,440	3.48	Aug. 24, 1963	1300	1,470	3.51	Sept.19, 1964	0730	1,700	3.72
Dec. 14, 1961	0600	2,160	4.07	Sept. 9, 1963	1430	2,040	3.98				
July 26, 1962	0030	1,650	3.67	Sept. 28, 1963	0400	1,240	3.28	Jan. 21, 1965	2230	*1,130	3.17

Annual minimum discharge, water years 1960-65

Water year	Date	Discharge	Water year	Date	Discharge
1960	June 23, 1960	0.20	1963	Apr. 24-26, 1963	1.5
1961	Apr. 21-24, May 5, 1961	1.2	1964	Mar. 11, 1964	1.1
1 62	June 23, 1962	.56	1965	June 1, 1965	.42

1952-65: Maximum discharge, 7,460 cfs Oct. 19, 1960 (gage height, 7.04 ft), from rating curve extended above 320 cfs on basis of slope-area measurements at gage heights 3.51 and 7.04 ft; minimum, 0.20 cfs June 23, 1960.

Remarks.–Records good. Upstream diversion at Piga Spring for domestic use at Umatac. Continuous records of rainfall are obtained at station.

Table 22. Discharge rates from low-flow partial-record stations. Table taken from the Geological Survey Water Supply Paper 1937 (1971).

Station Number	Station Name	Location	Drainage area (sq. mi.)	Period of record	Measurements Date	Measurements Discharge (cfs)
16-8072	Agana River at Agana.	Lat 13°28'25" N,, long 144°45' 11" E., 0.2 mile south of Leary Junction on Marine Drive and 0.2 mile east of the Guam Legislature building.	8.68	1962	2-19-62	1.01
					2-21-62	1.02
					3-30-62	.23
					5- 2-62	.52
					5-17-62	.33
16-8073	Fonte River at dam, near Nimitz Hill.	Lat 13°27'25" N., long 144°43' 34" E., at old diversion dam 0.4 mile south of Force Headquarters building on Nimitz Hill and 1.2 miles southeast of Asan.	.60	1961-65	3- 7-61	.39
					4-26-61	.24
					6- 6-61	.31
					3-20-62	.17
					4-27-62	.14
16-8077	Masso River at dam, near Piti.	Lat 13°27'21" N., long 144°41" 43" E., at end of penstocks on downstream side of dam, 0.5 mile southeast of Schroeder Junction, and 0.7 miles south of approximate center of Piti.	0.74	1962, 1964-65	4-12-62	.05
					5-15-62	.40
					3-25-64	.40
					3-23-65	.40
					4-28-65	.14
					6-10-65	.13
16-8079	Atantano River near Agat.	Lat 13°25'15" N., long 144°40'35" E., 500 ft upstream from highway bridge, 2.9 miles northeast of Agat School, and 5.6 miles northwest of Yana Catholic Church.	2.81	1958, 1960-62	3-20-58	c .82
					4-20-60	c .18
					5-24-60	c .51
					6-29-60	c 1.33
					3-17-61	1.31
					4-19-61	1.20
					6-22-61	2.18
					3-20-62	.61
					4-26-62	.66
					5-17-62	.84

Table 22. Continued.

Station Number	Station Name	Location	Drainage area (sq. mi.)	Period of record	Measurements Date	Discharge (cfs)
a 16-8085	Taleyfac River near Agat.	Lat 13°21'40" N. long 144°39'00" E., 800 ft upstream from bridge on Agat-Umatac road and 1.7 miles southwest of Agat School.	1.77	1959-65	3-10-61	1.50
					4-21-61	.91
					6-15-61	1.59
					3-20-62	.69
					4-26-62	.66
					5-17-62	.41
					3-27-63	1.03
					4-25-63	1.16
					3-25-64	.68
					3-23-65	1.38
					4-28-65	.41
					6-10-65	.39
16-8170	Toguan River near Umatac,	Lat 13°17'05" N., long 144°39'35" E., at highway bridge on Route 4, 1.0 mile south of Umatac Catholic Church	.48	1962, 1960-65	3- 9-61	.34
					4-20-61	.20
					6-16-61	.34
					3-15-62	.18
					4-25-62	.14
					5-15-62	.06
					3-27-63	.32
					4-23-63	.32
					3-31-64	.22
					3-24-65	.15
					4-29-65	.08
					6- 8-65	.07

Table 22. Continued.

Station Number	Station Name	Location	Drainage area (sq. mi.)	Period of record	Measurements Date	Measurements Discharge (cfs)
16-8200	Geus River above Siligin Spring tributary, near Merizo (formerly published as “above diversion”).	Lat 13°16'45" N., long 144°40'55" E., upstream from pipeline diversion to village of Merizo, 2.0 miles northeast of Merizo School.	.50	1960-65	3- 9-61	.22
					4-20-61	.19
					6-14-61	.20
					3-15-62	.16
					4-25-62	.13
					5-15-62	.10
					3-27-63	.22
					4-23-63	.18
					3-31-64	.13
					3-24-65	.12
					4-29-65	.08
					6- 8-65	.12
16-8207	Geus River below Siligin Spring tributary, near Merizo.	Lat 13°16'41" N., long 144°40'55" E., 1.6 miles northeast of Merizo School and 2.0 miles southeast of Umatac School.	.60	1962-65	3-15-62	.39
					5-15-62	.32
					4-23-63	.43
					3-31-64	.40
					3-24-65	.54
					4-29-65	.30
					6- 8-65	.28
16-8250	Ajayan River near Inarajan.	Lat 13°15'16" N., long 144°42'56" E., 2.4 miles southwest of Inarajan School and 3.8 miles southeast of Merizo School.	1.08	1962-65	5-24-62	0.15
					3-29-63	.39
					4-24-63	.24
					3-31-64	.21
					3-25-65	.16
					4-29-65	.11
					6- 9-65	.11

Table 22. Continued.

Station Number	Station Name	Location	Drainage area (sq. mi.)	Period of record	Measurements Date	Measurements Discharge (cfs)
16-8280	Agfayan River near Inarajan.	Lat. 13°16'03" N., long 144°43'42" E., 1.2 miles southwest of Inarajan School and 4.5 miles east of Merizo School.	1.67	1962-65	5-24-62	.17
					4-24-63	.43
					3-31-64	.41
					3-25-65	.25
					4-29-65	.13
					6- 9-65	.18
16-8420	Asalonso River near Talofofo.	Lat 13°19'41" N., long 144°45' 34" E., 300 ft downstream from highway bridge on Route 4 and 1.8 miles south of Talofofo School.	1.50	1952, 1961-65	3-22-61	.73
					4-24-61	.76
					6-23-61	.49
					3-21-62	.38
					4-27-62	.35
					5-16-62	.23
					3-29-63	.68
					4-24-63	.47
					3-26-64	.58
					3-31-65	.40
					4-30-65	.32
					6-16-65	.46

Table 23. Discharge records for the Geus River. Table from the Geologic Survey Water Supply Paper 1937 (1971).

Geus River near Merizo

Location. — Lat 13°16'15" N., long 144°40'40" E., on left bank 0.7 mile northeast of Merizo, 2.2 miles southeast of Umatac, and 4.7 miles west of Inarajan.

Drainage area.—0.95 sq, mi.

Records available.—April 1953 to September 1965.

Gage.—Water-stage recorder and broad crested weir. Altitude of gage is 60 ft (from topographic map).

Average discharge.—12 years, 3.36 cfs (2,430 acre-ft per year).

Extremes.—Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharges above base (350 cfs), water years 1960-65

Date	Time	Dis-charge	Gage height	Date	Dis- Time	Gage charge	height	Date	Time	Dis-charge	Gage height
Aug. 20, 1960	0100	427	2.81	Aug. 31, 1962	0130	372	2.72	Sept.28, 1963	0330	498	2.91
Sept. 19, 1960	0700	*514	2.93	Sept. 30, 1962	2300	*1,800	3.80	Oct. 4, 1963	0230	832	3.26
								Oct. 4, 1963	0230	832	3.26
Oct. 19, 1960	1930	*2,940	4.16	Nov. 11, 1962	a2400	1,310	b3.58	Oct. 11, 1963	1800	*1,040	3.41
Jan. 14, 1961	1000	469	2.87	Feb. 4, 1963	0900	772	3.21	Dec. 4, 1963	1030	992	3.38
Sept. 2, 1961	0730	642	3.06	Feb. 7, 1963	2400	506	3.92	May 12, 1964	0830	498	2.91
Sept.18, 1961	1700	2,460	4.00	Apr. 29, 1963	0400	1,140	3.48	May 19, 1964	2330	498	2.91
				May 29, 1963	0630	1,080	3.44	July 30, 1964	1200	514	2.93
Oct. 7, 1961	0700	390	2.75	June 1, 1963	0100	661	3.11	Sept. 5, 1964	2030	350	2.68
Dec. 14, 1961	0630	716	3.16	June 8, 1963	1730	530	2.95				
July 25, 1962	2400	570	3.00	Sept. 9, 1963	1330	*2,050	3.90	Jan. 21, 1965	2400	*408	2.78

a About. b From floodmarks.

Annual minimum discharge, water years 1960-65

Water year	Date	Discharge	Water year	Date	Discharge
1960	May 4, 5, 1960	a 0	1963	Apr. 20, 1963	0.28
1961	May 19, 1961	.20	1964	Mar. 25, 1964	.14
1962	Apr. 14, May 14, 1962	.12	1965	May 26, 1965	.06

a Part of each day.

1963-65: Maximum discharge, 2.940 cfs Oct. 19, 1960 (gage height, 4.16 ft), from rating curve extended above 66 cfs on basis of slope-area measurements at gage heights 4.00 and 4.16 ft; no flow for part of each day July 17, 1953, May 4, 5, 1960.

Remarks.—Records good. Water is diverted half a mile upstream for domestic use and at station for irrigation.

Revisions (fiscal years).—Revised figures of peak discharge for the fiscal years 1954 and 1959, superseding those published in WSP 1751), are given as follows:

Revised peak discharge.—1953-54: Aug, 11 (1400) 265 cfs. 1958-59: July 16 (0730) 274 cfs.

Table 24. Composition of lagoon sediments, in percent. Table from Emery (1962).

	Fo- rami- nifera silt	Shells	Fine sand and	*Halimeda* debris algae	Madre- porarian corals	Calcar- eous red
Guam (Cocos Lagoon):						
Simple average of all samples-----	2	16	11	9.5	40	16
Samples weighted by areas of depth zones-----------	3	15	8	11	45	18
Corrected for areas of coral seen from boat------------	2	11	5	8	60	14

Table 25. Discharge records for the Inarajan River. Table from the Geologic Survey Water Supply Paper 1937 (1971).

Inarajan River near Inarajan

Location.—Lat 13°16'40" N., long 144°44'15" E., on right bank 0.6 mile northwest of Inarajan and 4.9 miles east of Merizo.

Drainage area.—4.49 sq. mi. (revised).

Records available.—September 1952 to September 1965.

Gage.—Water-stage recorder and concrete control. Altitude of gage is 15 ft (from topographic map).

Average discharge.—13 years, 17.2 cfs (12,450 acre-ft per year).

Extremes.—Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharges above base (1,700 cfs, revised), water years 1960-65

Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height
Aug. 20, 1960	0300	(*)	12.31	Sept.30, 1962	2330	(*)	12.74	Oct. 11, 1963	1900	(*)	12.90
Sept. 3, 1960	0200	1,730	10.60	Oct. 23, 1963	0630	1,710	10.48				
Sept.18, 1960	0430	1,700	10.46	Nov. 11, 1962	2200	-	12.54	Dec. 4. 1963	1230	-	12.80
				Dec. 8, 1962	2300	-	12.30	May 19, 1964	a1130	-	b12.84
Oct. 19, 1960	2100	-	12.13	Feb. 4, 1963	0830	-	12.62				
Jan. 14, 1961	0600	-	11.84	Feb. 8, 1963	0030	-	a12.0	Jan. 1, 1965	0330	*1,790	10.88
Sept.18, 1961	1730	(*)	12.65	Apr. 29, 1963	0500	-	12.48	Jan. 21, 1965	2300	1,780	10.80
				May 29, 1963	0800	-	b12.82				
Oct. 5, 1961	1200	1,820	10.99	Aug. 9, 1963	2000	1,730	10.58				
Dec. 14, 1961	0700		12.51	Sept. 9, 1963	1400	(*)	12.68				

a About. b From floodmarks.

Annual minimum discharge, water years 1960-65

Water year	Date	Discharge	Water year	Date	Discharge
1960	Several days	1.2	1963	Apr. 26, 1963	3.4
1961	May 25, 1961	2.5	1964	Apr. 16, 1964	2.6
1962	May 12, 16, 17, 1962	1.4	1965	May 31, June 1, 1965	1.1

1952-65: Maximum gage height, 12.90 ft Oct. 11, 1963 (discharge not determined); minimum discharge, 0.99 cfs. July 14, 1959.

Remarks.—Records good except those for period of shifting control, which are fair. Stage-discharge relation not determined above gage height 11.0 ft owing to engaged overbank flow. Village of Inarajan diverts about 40,000 gallons a day above station for domestic use.

Table 26. Discharge records for the Pauliluc River. Table from the Geologic Survey Water Supply Paper 1937 (1971).

Pauliluc River near Inarajan

Location.— Lat 13°17'05" N., long 144°45'00" E., on right bank 0.3 mile upstream from mouth, 0.9 mile northeast of Inarajan, and 3.8 miles south of Talofofo.

Drainage area.—1.86 sq. mi.

Records available.—October 1952 to September 1965.

Gage.—Water-stage recorder and concrete control. Altitude of gage is 15 ft (from topographic map).

Average discharge.—13 years, 5.92 cfs (4,290 acre-ft per year).'

Extremes.—Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharges above base (400 cfs, revised), water years 1960-65

Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height
Aug. 20, 1960	0300	423	4.33	Sept. 1, 1962	1600	430	4.45	Oct. 4, 1963	0400	783	6.30
(a)	-	*536	4.98	Sept.30, 1962	2400	*1,520	9.48	Oct. 11, 1963	1900	*1,350	8.80
								Oct. 23, 1963	0730	570	5.21
Aug. 21, 1961	0030	449	4.56	Nov. 11, 1962	2300	1,220	8.24	Dec. 4, 1963	1130	593	5.33
Aug. 23, 1961	1230	646	5.61	Dec. 8, 1962	1730	463	4.64	May 19, 1964	2400	1,020	7.41
Sept.18, 1961	1800	*1,840	10.62	Feb. 4, 1963	0830	831	6.53				
				Feb. 7, 1963	2400	400	4.27	Jan. 1, 1965	0530	*461	4.63
Oct. 5, 1961	1230	558	5.15	Apr. 29, 1963	0430	555	5.13	July 28, 1965	0600	408	4.32
Dec. 14, 1961	0700	1,280	8.52	Aug. 9, 1963	2100	576	5.24				
July 25, 1962	2300	432	4.46	Sept. 9, 1963	1430	*1,260	8.40				

Annual minimum discharge, water years 1960-65

Water year	Date	Discharge	Water year	Date	Discharge
1960	Apr. 4, 7-12, 19, 1960	0.27	1963	Apr. 2 , 1963	1.0
1961	May 25, 1961	.65	1964	Mar. 10, 11, 1964	.81
1962	June 23, 1962	.39	1965	June 1, 1965	.43

1952-65: Maximum discharge, 2.980 cfs Oct. 15, 1953 (gage height, 13.11 ft), from rating curve extended above 210 cfs by logarithmic plotting; minimum, 0.16 cfs June 2, 1954, Apr. 27, May 1, 1955, May 18, 1956.

Remarks.—Records good except those for period of no gage-height record, which are poor. No diversion above station.

Table 27. Discharge records fob the Talofofo River, Table from the Geologic Survey Water Supply Paper 1937 (1971).

Talofofo River near Talofofo

Location.—Lat 13°21'05" N., long 144°43'50" E., on left bank 1.5 miles southwest of Talofofo and 5.3 miles north of Inarajan.

Drainage area.—16.2 sq. mi.

Records available.—November 1951 to June 1962 (discontinued).

Gaffe.—Water-stage recorder and steel weir. Altitude of gage is 20 ft (from topographic map).

Average discharge.—9 years (1952-61), 51.0 cfs (36,920 acre-ft per year).

Extremes.—Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharges above base (2,300 cfs), October 1959 to June 1962

Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height
Aug. 20, 1960	0500	*2,460	8.73	Aug. 25, 1961	1400	*3,200	9.27	Oct. 23, 1961	2400	2,310	8.61
				Sept.18, 1961	2130	3,060	9.17	Dec. 14, 1961	1030	*3,220	9.28
Oct. 20, 1960	0030	2,900	9.07								

Annual minimum discharge, October 1959 to June 1962

Water year	Date	Discharge	Water year	Date	Discharge
1960	May 28, 1960	1.1	1962	May 17, 1962	1.9
1961	May 5, 6, 1961	3.1			

1951-62: Maximum discharge, 8,560 cfs Oct. 15, 1953 (gage height, 12.69 ft), from rating curve extended above 340 cfs by test on model of station site; minimum, 0.52 cfs June 18, 1959.

Remarks.— Records good except those above 500 cfs, which are fair, and those for period of no gage-height record, which are poor. An average of about 10 cfs is diverted from Fena Reservoir and springs above station for municipal use.

Table 28. Discharge records from the Ugum River. Table from the Geologic Survey Water Supply Paper 1937 (1971).

Ugum River near Talofofo

Location.— Lat 13°20'00" N., long 144°44'55" E., on left bank 0.3 miles upstream from confluence with Talofofo River, 1.3 miles south of Talofofo, and 4.2 miles north of Inarajan.

Drainage area.—6.96 sq. mi. (revised).

Records available.—June 1952 to September 1965.

Gage.—Water-stage recorder and concrete control. Datum of gage is 3.23 ft above mean sea level

Average discharge.—13 years, 29.8 cfs (21,580 acre-ft per year).

Extremes.—Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharge above base (1,400 cfs), water years 1960-65

Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height
Aug. 20, 1960	0300	*1,350	9.95	Dec. 14, 1961	0800	*2,920	1.54	Oct. 4, 1963	0430	1,530	10.62
								Oct. 11, 1963	2000	3.660	11.68
Oct. 19, 1960	2300	*5,900	11.90								
Aug. 25, 1961	7300	2,020	11.36	Oct. 1, 1962	0030	*3,800	11.70	Oct. 23, 1963	0730	5,680	11.88
Sept.18, 1961	1900	4,200	11.74	Nov. 11, 1962	2300	2,300	11.45	Dec. 4, 1963	1330	*7,660	12.06
				Apr. 29, 1963	0530	1,710	11.02				
Oct. 5, 1961	1300	1,740	11.09	Sept. 9, 1963	1530	2,020	11.36	Jan. 1, 1965	0600	*1,140	8.78

Annual minimum discharge, water years 1960-65

Water year	Date	Discharge	Water year	Date	Discharge
1960	June 15, 1960	3.2	1963	Apr. 26, 1963	8.4
1961	July 30, Aug. 1, 1961	6.6	1964	Apr. 17, 18, 1964	5.6
1962	June 23, 1962	4.1	1965	July 18, 1965	1.1

1952-65: Maximum discharge, 7.600 cfs Dec. 4, 1963 (gage height, 12.06 ft), from rating curve extended above 910 cfs on basis of slope-area measurements at gage heights 11.30, 11.36, 11.87, and 11.90 ft; minimum, 1.1 cfs July 18, 1965.

Remarks.—Records good except those above 200 cfs, which are fair. No diversion above station.

Table 29. Discharge records from the Ylig River. Table from the Geologic Survey Water Supply Paper 1937 (1971).

Location.— Lat 13°23'20" N., long 144°45'00" E., on right bank 2 miles upstream from mouth, 2.1 miles southwest of Yona, and 5.8 miles south of Agana.

Drainage area.—6.58 sq. mi.

Records available.—June 1952 to September 1965.

Gage.—Water-stage recorder and concrete control. Altitude of gage is 20 ft (from topographic map).

Average discharge.—13 years, 28.2 cfs (20,420 acre-ft per year).

Extremes.—Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharges above base (2,000 cfs), water years 1960-65

Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height
Aug. 20, 1960	0200	2,580	13.12	Dec. 8, 1962	1800	3,930	17.32	Dec. 4, 1963	1300	4,140	17.84
Sept.12, 1960	0800	*2,950	14.32	Feb. 7, 1963	a1900	3,260	14.32	July 26, 1964	1400	2,200	11.84
				Apr. 28, 1963	a2200	3,790	16.86	Aug, 30, 1964	1200	2,640	13.35
Aug. 14, 1961	0130	2,310	12.22	June 6, 1963	2030	3,390	15.68	Sept.14, 1964	1400	3,850	17.04
Sept.18, 1961	2000	*3,000	14.40	Sept. 3, 1963	0900	2,340	12.32	Sept.19, 1964	0900	2,860	14.03
				Sept. 9, 1963	a1700	*4,900	b19.77	Sept.20, 1964	2100	3,560	13.07
Aug. 2, 1962	0630	3,230	15.20	Sept.23, 1963	1430	2,160	11.73				
								Sept.14, 1965	1260	*2,430	12.62
Nov. 11, 1962	a2300	2,970	14.38	Oct. 11, 1963	1930	2,850	14.00				

a About.

b From floodmarks.

Annual minimum discharge, water years 1960-65

Water year	Date	Discharge	Water year	Date	Discharge
1960	May 16-19, 1960	0.28	1963	Apr. 22, 26, 27, 1963	3.6
1961	May 5, 6, 1961	2.2	1964	Apr. 1, 2, 4, 1964	1.6
1962	Apr. 3, 4, 1962	1.5	1965	June 2, 1965	.50

Table 29. Continued.

1952-65: Maximum discharge, 4,900 cfs Sept. 9, 1963 (gage height, 19.77 ft, from floodmarks), from rating curve extended above 620 cfs on basis of slope-area measurements at gage heights 11.24 and 15.87 ft; minimum, 0.16 cfs June 18-22, 1959.

Remarks.—Records good except those for period of no gage-height record, which are fair. No diversion above station.

Revisions (fiscal years).—Revised figures of discharge, in cubic feet per second, for high-water periods in the fiscal years 1957-58, superseding those published in WSP 1751, are given herewith:

Oct. 12, 1956	296	Dec. 15, 1956	378	Oct, 7, 1957	269	June 14, 1958	271
Dec. 14	292	Oct. 6, 1957	360	Jan. 14, 1958	286		

Month	cfs-days	Maximum	Minimum	Mean	Runoff in acre-feet
October 1956	1,294.0	296	16.2	41.7	2,570
December	1,231.4	378	10.9	39.7	2,440
Calendar year 1956	–	378	.56	18.4	13,360
Fiscal year 1956-57	–	378	.36	19.6	14,220
October 1957	1,765.8	360	10.3	57.0	3,500
Calendar year 1957	–	731	.28	19.0	13,780
January 1958	575.4	286	5.5	18.6	1,140
June	558.93	271	.89	18.6	1,110
Fiscal year 1957-58	–	731	.28	20.6	14,890
Calendar year 1958	–	484	.56	23.9	17,320

Table 30. Discharge records from the Pago River. Table from the Geologic Survey Water Supply Paper 1937 (1971).

Pago River near Ordot

Location.— Lat 13°26'10" N., long 144°45'15" E., on left bank 0.8 mile south of Ordot, 2.5 miles south of Agana, and 3.6 miles southeast of Asan.

Drainage area.—6.17 sq. mi. (revised).

Records available.—September 1951 to September 1965.

Gage.—Water-stage recorder and concrete control. Altitude of gage is 25 ft (from topographic map).

Average discharge.—14 years, 25.5 cfs (18,460 acre-ft per year).

Extremes.—Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharges above base (2,700 cfs, revised), water years 1960-65

Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height
Nov. 5, 1959	2130	2,920	11.12	Aug. 2, 1962	0600	9,470	a18.87	Sept. 9, 1963	b0800	4,400	a14.70
Aug. 20, 1960	0200	*4,350	14.67	Aug. 20, 1962	1400	5,270	15.87				
Sept.12, 1960	–	3,730	13.24	Sept.30, 1962	2300	9,300	a18.76	Oct. 4, 1963	0100	3,720	13.22
								Oct. 11, 1963	1630	3,220	11.98
Nov. 30, 1960	–	2,800	10.78	Nov. 11, 1962	2230	3,610	12.94	Dec. 4, 1963	1230	3,710	13.20
July 11, 1961	1400	2,920	11.10	Dec. 8, 1962	b1900	*5,320	a15.94	May 13, 1964	0330	*4,000	13.90
Aug. 14, 1961	0200	3,470	12.60	Feb. 7, 1963	2000	3,650	13.04	July 26, 1964	1460	3,810	a13.44
				Apr. 28, 1963	0830	2,800	a14.15	Aug. 29, 1964	1630	3,290	12.15
Oct. 23, 1961	2130	2,980	11.30	June 6, 1963	1800	3,680	13.12	Nov. 17, 1964	1000	*3,350	12.30

a From floodmarks. b About.

Annual minimum discharge, water years 1960-1965

Water year	Date	Discharge	Water year	Date	Discharge
1960	June 12, 1960	0.18	1963	Apr. 24-27, 1963	2.1
1961	May 6, 1961	1.7	1964	Mar. 30 to Apr. 2, Apr. 5, 1964	1.3
1962	Mar. 29 to Apr. 5, 1962	.90	1965	May 31 to June 2, 1965	.18

1951-65: Maximum discharge, 9,470 cfs Aug. 2, 1962 (gage height, 18.87 ft, from floodmarks), from rating curve extended above 320 cfs on basis of slope-area measurements at gage heights 13.22, 15.07, and 18.87 ft; no flow June 5-7, 10-23, 1959.

Revisions.— Figures of maximum discharge for the fiscal years 1954 and 1958 have been revised to 6.080 cfs Oct. 15, 1953 (gage height, 16.76 ft) and 5,490 cfs Oct. 28, 1957 (gage height, 16.13 ft, superseding those published in WSP 1751.

Remarks.—Records good except those for periods of no gage-height record. which are poor. No diversion above station.

Table 31. Salinity and depth measurements at the Inarajan, Talofofo, Ylig and Pago Rivers.

	INARAJAN RIVER		TALOFOFO RIVER		YLIG RIVER		PAGO RIVER	
Station Number S=Surface/B=Bottom	Depth (ft.)	Salinity ‰	Depth (ft.)	Salinity ‰	Depth (ft.)	Salinity ‰	Depth (ft.)	Salinity ‰
1S		*		4.437		28.865		30.015
B	6' 0"	26.040	9' l0"	30.579	5' 10"	31.475	7' 6"	32.525
2S		*		2.861		28.575		28.659
B	4' 6"	23.155	6' 7"	28.689	4' S"	30.364	7' 3"	30.687
3S		*		3.053		28.407		27.343
B	3' 0"	18.870	6' 7"	29.331	6' 4"	29.757	8' 6"	32.533
4S		*				27.867		26.843
B	4' 0"	20.587	11' 6"	27.924	7' 0"	30.283	8' 4"	32.378
5S		*		*		27.108		26.673
B	3' 0"	15.540	8' 2"	30.291	10' 1"	30.591	8' 1"	32.296
6S		*				26.956		25.839
B	5' 0"	20.276	8' 2"	30.029	11' 5"	31.328	8' 2"	32.378
7S		*				26.529		24.224
B	3' 10"	7.228	13' 1"	30.541	9' 10"	32.335	10' 7"	32.257
8S				*		26.039		24.025
B			9' 0"	29.684	11' 5"	31.800	9' 7"	32.424
9S				*		25.877		23.088
B			9' 10"	30.141	10' 7"	32.145	10' 4"	31.142
10S				*		24.964		22.913
B			7' 5"	28.022		31.521	10' 5"	32.382
11S				*				–
B			11" 6"	29.022			7' 10"	–
12S								
B			6' 7"	29.419			upstream	31.158

*Indicates values with conductivity less than .1000