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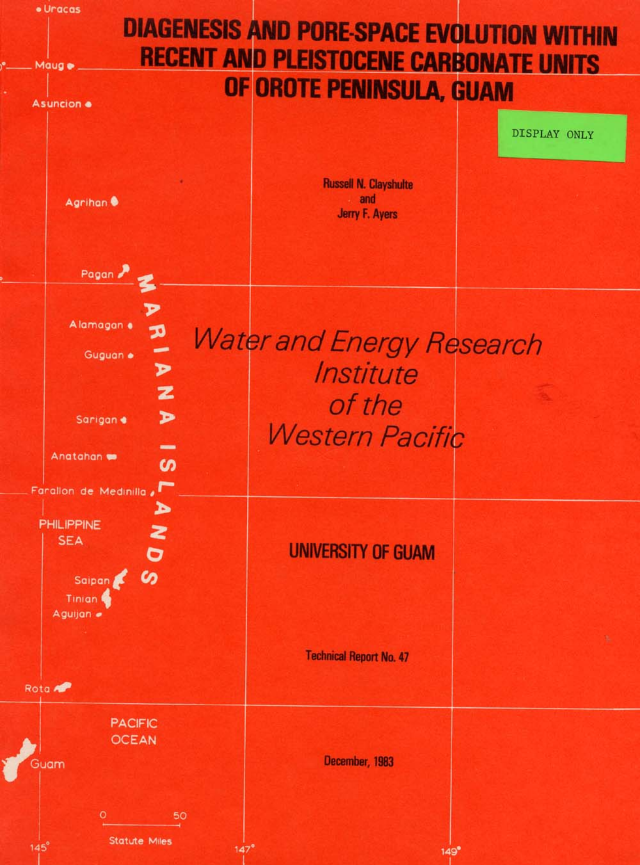

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Project Completion Report

for

PRELIMINARY STUDY OF DIAGENESIS AND PORE-SPACE EVOLUTION
IN THE PLIO-PLIESTOCENE LIMESTONES OF GUAM

Project No. A-025-Guam, Agreement No. 14-34-0001-2112

Principal Investigator: Russell N. Clayshulte

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ABSTRACT

The Mariana limestone on Orote Peninsula has undergone diagenetic modification under marine phreatic, freshwater and freshwater vadose conditions. Marine diagenetic modification from internal sediment fill, submarine cementation and borings have produced partial to complete occlusion of primary interparticle porosity. Marine sediments are lithified by cements similar to those found in the modern reef complex. Within the freshwater phreatic environment, nearly all interparticle porosity is occluded with some secondary porosity generation. There has also been preferential dissolution of, primarily, aragonitic clasts, which creates distinctive moldic porosity. There is only minor diagenetic alternation within the freshwater vadose environment.

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INTRODUCTION

General

Groundwater yield has been identified as a major water-research priority area for Guam (Five-Year Research and Development Plan, Water and Energy Research Institute (WERI), University of Guam, 1980). Accordingly, WERI has adopted as a policy that its "major program effort on Guam is devoted to groundwater". Specifically, the WERI program effort has as its focus the geology of the northern (limestone) aquifer, sea-water intrusion and dispersion phenomena, and computer modeling. In relation to this list there are other subjects of obviously needed research (e.g. the general behavior of the fresh-water lens, and the size, configuration and dynamics of the associated transition zone). The common denominator of all these areas of research is an understanding of the occurrence of porosity and permeability of limestones. The research described here is intended to make an initial thrust toward acquiring that understanding.

Purpose and Scope of Study

The primary purpose of this study was to determine, by petrologic examination of core samples, how diagenesis has affected water-bearing properties of Guam limestones. Specific objectives of the study were to:

1. Classify the limestones on the basis of composition and texture;

2. Identify the various carbonate facies represented in the sample suite;

3. Classify porosity types observed in megascopic and microscopic examination of samples;

4. Describe cement-porosity relationships within the various facies; and,

5. Relate the diagenetic properties exhibited by the sample suite to hydrologic and hydrogeologic environments.

In order to achieve these objectives, the scope of study included the following:

1. Megascopic examination of relevant features exhibited by the carbonate samples;

2. Microscopic examination of thin sections from carbonate samples; and,

3. Application of staining techniques to determine minerology.

Location and Description of Study Area

Orote Point, situated at the northwestern end of Orote Peninsula, is located along the southwestern coastline of Guam (Figure 1). Orote Peninsula forms the southern boundary of Apra Harbor, which is a natural lagoon. Orote Point in conjunction with the end of the Glass Breakwater, form the harbor entrance. The Glass Breakwater is an artificial boulder fill built on the Apra lagoon barrier reef complex. The only existing entrance to the lagoon is at Orote Point.

Orote Peninsula is a cliff-bounded plateau which slopes toward the southeast. The highest elevations are along the western perimeter in the vicinity of Orote Point and are in excess of 200 feet. In general, the physiography of the peninsula resembles that of the prominant limestone plateau of northern Guam.

The geology of Orote Peninsula is dominated by the various facies of the Mariana limestone. Older rocks of the Alifan limestone crop out along a short section of the shoreline near Gabgab beach. Alluvium and artificial fill overlie carbonate units in lower-elevation regions toward the southeast. Narrow recent fringing reefs occur along the harbor perimeter of the peninsula. There is no fringing reef development along the cliff bounded southwestern exposure.

BACKGROUND

Guam is the largest, southernmost, and most populated of the Mariana Islands. Consistent with its tropical, island-arc setting, the geology of Guam is dominated by Tertiary volcanics and contemporaneous younger carbonates (Figure 1). In the southern half of the island, Eocene and Miocene volcanic rocks form a dissected upland which is fringed along the coast and is in part overlain by a cap of Miocene and younger limestones. In the northern half of the island, the limestones form a broad plateau bounded by cliffs 200 to 600 feet high. These northern limestones rest on a volcanic basement which rises to the surface to form isolated "Mounts" at three localities within the plateau.

Since the mid-1960's, groundwater of the northern limestone plateau has been recognized as the principal source for water supply. As outlined by Ward et al.(1965) and Mink (1976) and later by Camp, Dresser, and McKee, Inc. (1982), groundwater of the plateau occurs as a complex Ghyben-Herzberg system ("basal water" of local reports). In this system fresh recharge-supplied water rests on underlying groundwater of seawater composition. The "interface" between these two water bodies occurs well below sea level in accordance with their respective densities. In the vicinity of the "Mounts", there is so-called "para-basal" water. This water occurs where the limestone-basement contact intersects the "interface" and fresh groundwater rests directly on the volcanic rocks.

Limestones of Guam

What is known of the limestones of Guam comes from two U.S. Geological Survey Professional Papers resulting from fieldwork done in the early 1950's. Tracey et al. (1964) give an overview of the island geology describing the geologic succession, structure, geomorphology, present-day sedimentary environments, and a 1:50,000-scale geologic map. Schlanger (1964) studied the limestones of Guam and gives petrographic details. Based on his analysis of thin sections, and drawing on biotic and lithic comparisons between the ancient rocks and the modern sediments of Guam, Schlanger interprets the depositional environment(s) of each mapped limestone. The depositional environments (depositional facies) he identifies are reef-wall, back-reef lagoon, and fore reef (Table 1); these facies represent various components of a "reef complex" similar to the close-to-shore depositional setting of today.

Although this early work preceded "the prodigious expansion and diversification of carbonate sedimentology since the mid-1950's" (Bathurst, 1971, p. vii), it does form an important framework on which to build. The stratigraphic units are mapped (Tracey et al., 1964) and the paleontologic (foraminiferal) criteria for their identification are published (Cole, 1963; Todd, 1966). (See Table 2 for larger foraminifera zones in limestones of Guam). Further, the constituent depositional facies are identified, and the lithic and faunal means of recognizing them are known from the work of Schlanger (1964).

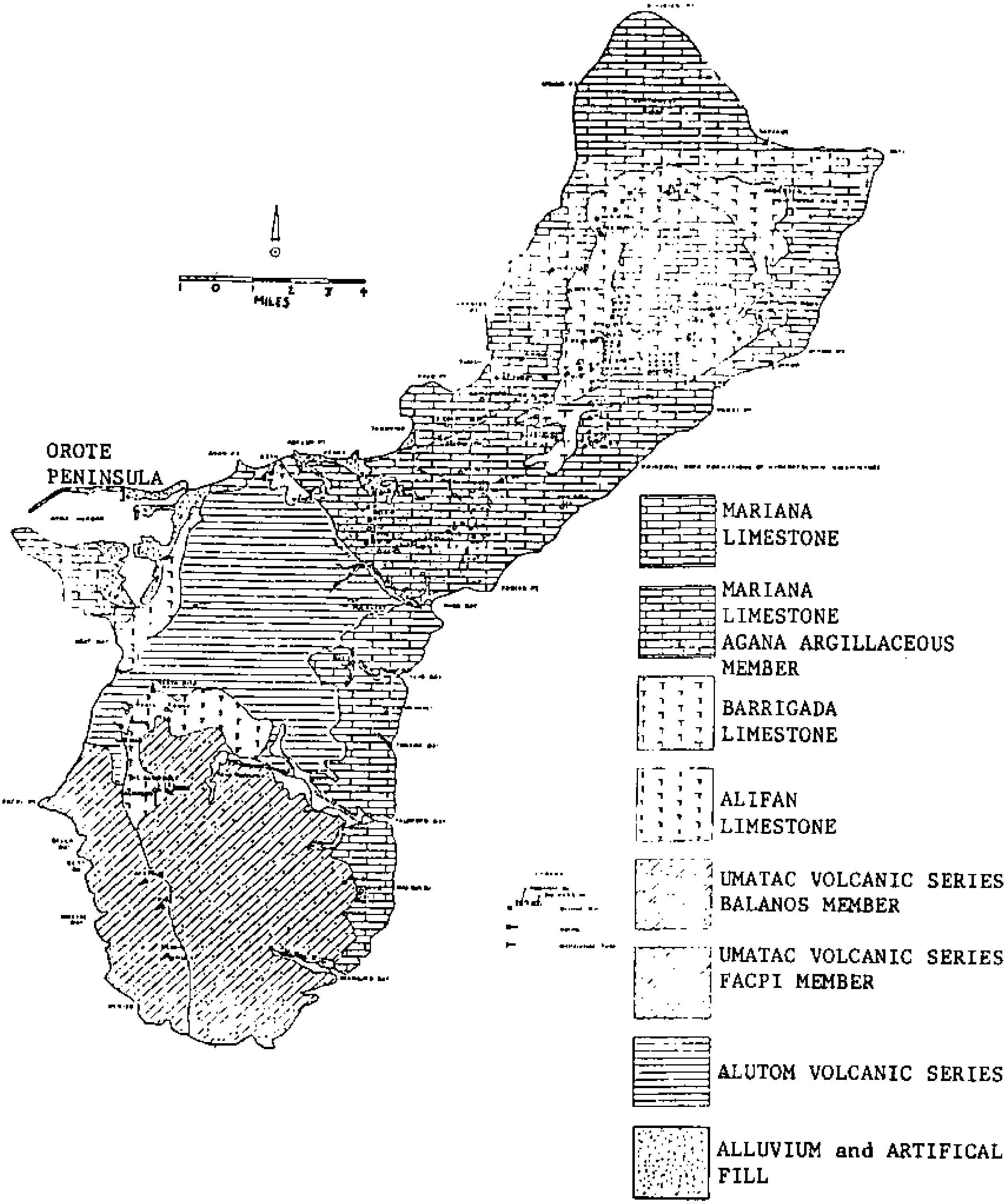

Figure 1. General Geology of Guam.

Table 1. Limestones of Guam (Schlanger, 1964).

PETROLOGIC CLASSIFICATION

I. Incrustate limestone ("Boundstones" or "biolithites" of modern classifications).

Crustose coralline algae (e.g., Lithothamnium), encrusting foraminifera (e.g., Homotrema), binding growth-position coral heads forming framework). Interstices filled with foraminifera tests and skeletal debris (molluscs, corals, algae).

II. Particulate limestone.

Skeletal debris. Sand-sized and larger particles. Fragments of coralline algae, molluscs, corals, foraminifera, etc. Whole foraminifera and molluscs. Varying amounts of carbonate mud.

A. Coquinite ("biosparudite"), when well sorted fossil debris, coarser than sand size. Microcoquinite ("biosparite") when sand-sized particles.

B. Paracoquinite and microparacoquinites ("fossiliferous packstone"). Like coquinite but with interstitial mud. Intact framework.

C. Breccia ("poorly sorted wackestone or packstone"). Unsorted fossil debris in mud. Both intact and disrupted framework.

D. Coquinoid limestone ("fossiliferous wackestone"). Mostly mud. Whole, unsorted fossils.

E. Mudstone ("mudstone" or "biomicrite"). More than 75% mud. Whole, unsorted fossils.

III. Metasomatic limestone.

Limestone which has been wholly or partly replaced. Rare.

STRATIGRAPHY AND FACIES

Alifan Limestone

Age: Late Miocene; locally Pliocene
Occurrence: Caps volcanics in southern and central Guam. Occurs near mounts in northern Guam.
Reef-wall facies: Incrustate limestones and coral-rich breccias.
Lagoon facies: Coral-molluscan coquinoid limestones; foram-algal microparacoquinites; mudstones. Mud fraction exhibits granoblastic-textured spar formed during recrystallization of original mud ("neomorphism", see Bathurst, 1975); inclusions of original mud.
Off-reef, shallow-water facies: Microparacoquinites. Rotalia (foram) abundant.

Table 1. Continued.

Barrigada Limestone

Age: mostly Pliocene
Occurrence: Ring-shaped area 6 miles in diameter, 1 mile wide, in northern limestone plateau.
Reef-wall facies: Not recognized.
Lagoon facies: Not recognized.
Off-reef, shallow-facies: Foraminiferal mudstones, microcoquinites, and microparacoquinites. Cycloclypeus abundant, a fore reef foraminiferan.

Mariana Limestone

Age: Pliocene and early Pleistocene
Occurrence: More than 80% of the surface and cliff exposures of the northern limestone plateau. The surface of the northern plateau is a relatively undisturbed depositional surface of the reef complex mapped as the Mariana Limestone. The formation includes an Agana Argillaceous Member bordering the volcanics. Tracey et al. (1963) separately map: reef, detrital, molluscan, and forereef facies. Their reef facies occurs in the coastal cliffs and encircles, for the most part, their detrital and molluscan facies of the interior of the plateau. The forereef facies is on seaward slopes of the cliffs.
Reef-wall facies: Incrustrate limestone, with many coral heads. Spaces between corals filled with well-cemented skeletal debris. Corals recrystallized to calcite, but retain structure. Primary and secondary voids, some partly filled with spar; vuggy porosity, perhaps locally as much as 10%.
Lagoon facies: Coral-rich breccias, Halimeda-rich paracoquinities, and molluscan coquinoid limestones. Irregular lithification patterns. Halimeda largely still present as aragonite. Multiple generations of cement, some including aragonite precipitation. Molluscs remain largely as casts and molds. Corals recrystallized to calcite.
Forereef facies: Thin-bedded friable, foraminiferal microcoquinite forming apron-like wedges that dip away and lie seaward of and topographically below the reef facies. Includes many worn tests of reef-dwelling foraminifera. Facies identified from Cycloclypeus, a forereef foraminiferan.

Merizo Limestone (not studied by Schlanger, 1964)

Age: Recent - ca. 3500 years, radiocarbon date on Tridacna shell
Occurrence: Low-lying coastal exposures along southwest Guam and scattered localities elsewhere along coast. Forms bench. Veneers planed-off volcanics in Southern Guam.
Reef facies: Closely packed coral heads, many in positions of growth, with well cemented matrix of sediment that weathers away so that corals stand out in relief (Tracey et al., 1964, p A51).

Table 2. Foraminiferal zones in limestone units of Guam.

Limestone Unit	Foraminiferal Zone	Age
MERIZO	*Baculogypsina sphaerulata* *Gypsina vesicularis* *Homotrema rubrum* *Sporadotrema cylindricum*	Holocene
MARIANA	*Calcarina spengleri* *Amphistegina lessonii* *A. radiata* *Cycloclypeus carpenteri*	Pleistocene and Pliocene
BARRIGADA	*Cycloclypeus postindopacificus* *Operculina lucidisutura* *O. rectilata* *Gypsina* spp. Globigerinid zone (Janum formation)	Upper Miocene (Tg)
ALIFAN	*Rotalia atjehensis* *Miogypsina cupulaeformis* *Cycloclypeus*-*Operculina* group	Upper to Mid Miocene (Tf to Tg)
BONYA	*Cycloclypeus* group *Rotalia* group	Lower Miocene (Tf)
MAEMONG	*Heterostegina borneenis* *Miogypsina dehaartii*	Lower Miocene (Te)

Geology of Limestone Porosity

The evolution of limestone porosity involves as a starting point a sediment with high (primary) porosity which is both interparticle (spaces between, e.g., skeletal grains) and intraparticle (borings and skeletal holes within, e.g., corals). In an aquifer, the material is a vastly different rock: a limestone in which much or all of the primary porosity is occluded or totally filled and there is new (secondary) porosity which is vuggy (typically fossil molds) and-or cavernous or micro-cavernous (solution channels and tubes) (see, e.g., Choquette and Pray, 1970).

Diagenetic transformation from loose sediment to limestone with moldic and cavernous permeability occurs when the marine-formed sediments are exposed to circulation of meteoric waters. At least four processes are involved:

a. The conversion of a sediment consisting of metastable marine phases (aragonite and Mg-calcite) to a stable mineralogy;

b. Precipitation of calcite (cementation, hence lithification) by waters held in saturation with one of the marine phases and hence in supersaturation with the less soluble calcite;

c. Bulk solution of the entire rock by entrance and passage of aggressive groundwater; and

d. Enhanced cementation ("induration") due to increase in saturation state of calcite, usually by a lowering of $P(CO_2)$ of the groundwater.

The first process is largely responsible for moldic porosity in young limestones. Aragonite dissolves in one of the first conversion steps and leads to permeable zones. The occurrence of these zones depends on the size and abundance of aragonitic organisms (corals, molluscans, green algae), which is dependent on the depositional environment. Process (c) leads to cavernous porosity and highly permeable zones, which are obviously related to the diagenetic (hydrologic or paleohydrologic) environment. Low porosity and permeability result from the second (b) and fourth (d) processes. Occurrence of process (d) is a function of diagenetic environment. The extent to which process (b) leads to a tight young limestone is in large part dependent on the original percentage of aragonitic mud (which converts to a crystal mosaic of calcite: neomorphism, which may involve both processes (a) and (b); (Bathurst, 1971), which also depends on the depositional environment).

These processes create and destroy porosity and permeability when a calcareous sediment is flushed by groundwater and are localized in accordance with the groundwater-flow system. Processes (a) and (b) are probably more-or-less pervasive, so long as aragonite is present. The effectiveness of these processes (that is, the extent to which molds are formed and the aggregate cemented) appears related to major hydrologic environment (vadose versus phreatic zone) and, within the saturated zone, probably to the ground-water flux. Bulk dissolution appears to be favored in three important environments: (a) at the water table where waters of differing $P(CO_2)$ are mixed; (b) where groundwater enters directly from a CO_2-source such as a marsh; and (c) where high-CO_2, calcite-saturated groundwater mixes with seawater in a well-washed transition zone peripheral to the fresh ground-water body. Process (d) is one of a down-gradient, close-to-the-water-table, generally close-to-shore environment.

Relevance to Groundwater of Oceanic Islands

The importance of understanding the occurrence and developmental history of permeability in an insular limestone aquifer is well illustrated by the results of hydrogeologic investigations in Bermuda.

Bermuda is a small island, 20 square miles, and only 1.5 miles wide at maximum. With its large, affluent population (60,000) and highly developed tourist industry (500,000 tourists/year), there is a seemingly continual water-shortage problem. The Bermuda Government's strategy is to use the fresh and brackish groundwater as the initial supplement to the traditional roof-top catchments, in order to forestall use of desalination as it becomes increasingly more viable economically, Bermuda's fresh-water lenses are small and delicate with a maximum water table elevation of about 1.2 feet. Bermuda, however, has long been the subject of state-of-the-art carbonate research, especially in diagenesis (e.g., Land et al., 1967; Land 1970; Bathurst, 1971, Chapter 8) and the resultant knowledge of the limestone formed a basis for groundwater exploration (Vacher, 1974). It was soon learned that the Bermudian lenses occur in two laterally adjacent formations of differing extent of diagenetic alteration, and that the older formation, on the average, is an order of magnitude more permeable than the younger. Second-order permeability variation of the saturated zone is related to proximity to marshes and shoreline. This permeability variation exerts a profound control on all features and behavioral patterns of the fresh-water lenses that are relevant to exploration (Vacher, 1978; Vacher and Ayers, 1980). These features and patterns include magnitude and distribution of head, extent to which tidal and other sea-level variations penetrate inland, thickness of the transition zone (the upper half of which diminishes the fresh-water thickness calculated from head), and thickness of the fresh-water column. Knowledge of the permeability variation has subsequently guided development and management, through control of local drawdown and hence upconing, which obviously must be minimized.

Groundwater research in Bermuda has culminated in a computer model that treats time-dependent behavior, including extractions, in an island of any shape and of non-homogeneous permeability (Ayers, 1980; Ayers and Vacher, 1983). The model was successful only because there was extensive time-series data from observation wells to use for calibration, and a good understanding of the hydrologically relevant features of the limestones, particularly their permeability variation. The model has been used as a basis of overall development planning and management, with the result that the small lenses can yield up to some 60% of their annual recharge.

Ecology of Modern Reefs

From a geological perspective, the coral reef is a complex association of calcareous frame-building organisms, associated flora and fauna, and biogenic sediments. Scleractinian corals and calcareous algae provide the hard substratum essential to the existence of other reef-dwelling organisms. An extensive portion of the hard-substratum surface area of coral reefs lies within crevices and cavities of the framework. These interstices are occupied by an associated fauna and flora of sedentary organisms which contribute to reef cementation (e.g. foraminifera, bryozoans, polycheates). The coral reef biotype also consists of epifauna and epiflora, which are associated parasites, commensals and symbionts, and mobile fauna of nektonic species. Ecologically, the coral reef is an essentially steady-state oasis of organisms which are characterized by high population densities, intensive calcium metabolism and complex nutrient chains. The tropical coral reef complex is the resultant of its' nutrient chains and their diversification products, as well as the past history of the reef and surrounding area.

Constructive and destructive forces help shape reef complexes. These forces include both biological and physical factors. Boring by algae, sponges, mollusks and worms is a major destructive force of reef framework. Grazing by fish and ingestion of living coral by echinoderms (e.g. starfish Acanthaster) can cause considerable destruction and alternation of reef features. There are numerous physical factors which modify reef structures: wave action, currents, slumping, sea level changes, sedimentation, erosion, natural runoff, tectonics, chemical precipitation, and man-induced perturbations.

The major taxonomic groups associated with recent reefs of Guam which contribute to the fossil record are shown in Table 3. A working list of marine organisms from Guam, which includes only studied taxa, has been compiled by the University of Guam, Marine Laboratory (1981). There are many taxa with poor records that have not been studied or barely studied from Guam and Micronesia; among these are sponges, bryozoans, polychaete worms, boring bivalves, vermetid gastropods and many arthropods.

The major reef-building group is the Coelenterates, of which the scleractinians are by far the most important and form the major basis for interpretations of coral paleoecology (Dodd and Stanton, 1981). Scleratinians are major contributors to both in situ reef framework and reef detrital development in the shallow water environments around Guam. These are 19 scleratinian families on reefs around Guam and 267 species (Table 4). Different environments have characteristic coral communities which develop in response to variable environmental conditions. Although there have been no major published papers on the corals of Guam, there are numerous environmental impact surveys which have identified corals and their zonation. An assessment of coral zonation at the Glass Breakwater barrier reef complex was made by Randall (1982). This study determined to species level the distribution and community structure of corals within the reef-flat and upper reef slope environments. Randall has conducted many coral surveys throughout the Indo Western Pacific which deal with coral ecology, distribution and zonation. These surveys are available as technical reports from the University of Guam, Marine Laboratory.

Table 3. Major taxonomic groups associated with recent reefs of Guam which contribute to the fossil record.

Corals	Scleractinia	19 families, 267 species
	Hydrocorals	2 families, 9 species
	Octocorallia	7 families, 33 species
	Antiniaria	3 families, 6 species
Benthic Algae	<u>Halimeda</u>	10 species
	Corallinaceae	26 species
Foraminifera (nearshore, shallow water)	benthonic	28 families, >160 species
	sedentary	11 species
	planktonic	1 family, 5 species
Gastropoda	(recent reefs)	99 families, >950 species
	Vermetidae	4 genera
Bivalvia	(recent reefs)	13 families, 26 species
	boring species	6 genera
Polychaeta (worms)	Annelids	13 families, 37 species
	Sedentarida	9 families, >10 species
Echinodermata	Crinoidea	3 families, 7 species
	Asteroidea	9 families, 25 species
	Ophiuroidea	6 families, 18 species
	Echinoidea	8 families, 17 species
	Holothuroidea	6 families, 29 species
Anomuran Crustaceans	(recent reefs)	5 families, 56 species
Bryozoans	(Pacific distribution)	38 families, 102 species
Diatoms	(recent reefs)	12 families, 83 species
Sponges	Clionidae	1 family, unknown

Table 4. Genera of coral in recent reefs of Guam.

	FAMILY	GENERA	NO. SPECIES
Scleractinia	(19 families, 267 species)		
	Astroceniidae	Stylocoeniella	2
	Thamasteriidae	Psammocora	11
	Pocilloporidae	Stylophora	1
		Seriatopora	3
		Pocillopora	11
		Madracis	2
	Acroporida	Acropora	37
		Astreopora	5
		Montipora	30
	Agariciidae	Pavona	17
		Gardineroseris	2
		Leptoseris	11
		Pachyseris	1
	Siderastreidae	Coscinaraea	3
	Fungiidae	Cycloseris	5
		Fungia	9
		Herpolitha	1
		Polyphyllia	1
		Halomitra	1
		Parahalomitra	1
		Podabacia	1
	Micrabacia	Micrabacia	1
		Stephanophyllia	1
	Poritidae	Goniopora	7
		Porites	18
		Stylaraea	1
		Alveopora	3
	Faviidae	Favia	8
		Favites	3
		Oulophyllia	1
		Goniastrea	2
		Platygyra	2
		Leptoria	1
		Hydnophora	3
		Montastrea	2
		Plesiastrea	1
		Diploastrea	1
		Leptastrea	4
		Cyphastrea	3
		Echinopora	1
	Rhizangiidae	Culicia	1
	Oculinidae	Madrepora	1
		Neohelia	1
		Galaxea	2
		Acrhelia	1

Table 4 Continued.

Merulinidae	Merulina	2
	Scapophyllia	1
Mussidae	Parascolymia	1
	Acanthastrea	2
	Lobophyllia	4
	Symphyllia	1
Pectiniidae	Echinophyllia	1
	Mycedium	1
	Pectinia	1
Anthemiphylliidae	Anthemiphyllia	1
Caryophyllidae	Caryophyllia	4
	Paracyathus	2
	Deltocyathus	1
	Polycyathus	1
	Heterocyathus	1
	Desmophyllum	1
	Dactylotrochus	1
	Euphyllia	2
	Plerogyra	1
Flabellidae	Flabellum	2
Dendrophyllidae	Balanophyllia	2
	Dendrophyllia	3
	Endopsammia	1
	Tubastrea	1
	Heteropsammia	1
	Turbinaria	1
Hydrocorals (2 families, 9 species)		
Milleporidae	Millepora	4
Stylasteridae	Stylaster	2
	Conopora	1
	Distichopora	2

The family coralinaceae includes most of the recent carbonate secreting red algae. There are generally two groups of coralline algae which can be distinguished by growth form: (1) encrusting or crustose habit; and (2) articulated-segmented forms. The crustose coralline algae are a major component of modern tropical coral reefs. These coralline algae have developed a large variety of growth forms which include laminated encrustations, nodules, massive knobs and branching growths. The recent crustose coralline algae from Guam include 15 species from 9 genera (Gordon et al., 1976). This study included a floristic account and coralline distribution in relation to environmental factors. The common corallines of Guam with zonational occurrence and depth range are presented in Table 5. The most important coralline is Porolithon onkodes because it is the major reef margin cementing algae and it has a wide distribution range from reef-flat to submarine terrace. Another important species is Lithophyllum moluccense, which is also abundant and has a wide distribution range. Common reef flat species are Neogoniolithon frustescens and Sporolithon schmidtii. The dominant crustose coralline on the submarine slope below 70 feet is Mesophyllum erubescens. A floristic study of cenozoic calcareous algae has been made of fossil and recent species from limestone formations on Guam (Johnson, 1964). Johnson (1964) describes 82 species of calcareous algae from 16 genera. Calcareous algae, primarily crustose corallines, are identified from limestone formations which have been stratigraphically dated by means of foraminifera. Different limestone formations on Guam have characteristic flora, which are similar to those found on Saipan (Johnson, 1957). In Saipan, there are 88 species/groups of calcareous algae from 18 genera, with most species found as fossils. The floristic accounts of calcareous algae in both studies are based mainly on thin-sections.

There is a conspicuous foraminifera component in sediment deposits and adhering to the reef framework at Apra Harbor. Benthonic foraminifera are the dominate species associated with shallow water and intertidal sediment deposits with only rare occurrences of planktonic species. Adherent foraminifera readily occur on natural substrates of the fringing and barrier reef complexes. There is a minimum of 150 species of living larger and smaller foraminifera, representing three suborders and 28 families, which can be found in lagoon, on the reef-flat, and upper reef slope environments (>60m) (Clayshulte, 1981a).

Few foraminifera studies have been conducted on Guam's reefs and off-shore areas. A review of off-shore dredging activities prior to 1952 was presented by Emery (1962). The foraminiferal component of sediments dredged near the Apra Harbor entrance at depths to 3,000 ft. was not specifically determined, although foraminifera were identified as a major sediment constituent. The Tertiary larger foraminifera were determined by Cole (1963). Foraminifera were recorded in a 21-fathom sample collected at a Guam anchorage of the "Albatross" expedition (Cushman and Todd, 1972). Todd (1966) examined the smaller foraminifera from Guam and reported over 400 species, ranging in geologic time from upper Eocene to Recent. The distribution and recruitment of sedentary foraminifera in the families Homotrematinidae and Acervulinidae were studied on the leeward coast of Guam including the Luminao Barrier Reef by Clayshulte (1981b).

Table 5. Zonational occurrence and depth range of recent calcareous algae of Guam. The table was adapted from Gordon et al. (1976).

		Zonational Occurrence				
	Depth Range	Reef Flat	Reef Margin	Reef Front	(20m) Terrace	(40M) Slope
Fosliella farinosa	3m	x				
Lithothamnium asperulum	3m	x				
*neogoniolithon conicum**	3m					
N. frutescens	3m	x				
Lithoporella pacifilca	to 10m			x	x	
Sporolithon schmidtii	to 10m	x			x	
Hydrolithon reinboldii	to 15m	x			x	
Porolithon onkodes	to 20m	x	x	x	x	
Lithophyllum kotchyanum	to 25m			x		x
Neogoniolithon fosliei	to 30m	x	x	x	x	x
N. pacificum	to 35m					x
Lithophyllum moluccense	to 40m	x	x	x	x	x
mesophyllum mesomorphum	to 40m	x				x
M. erubescens	5-40m				x	x
Lithoporella melobesioides	12-40m				x	x

*This species found in Cocos Lagoon, depth less than 10m.

Dominate benthonic foraminifera associated with barrier and fringing reefs at Apra Harbor are *Baculogypsina*, *Marginopora*, *Heterostegina*, *Amphistegina* and *Elphidium*. These genera are typical reef-flat forms or very shallow-water forms (Emery, 1962; Todd, 1966; Tracey et al., 1964). Living specimens of *Marginopora vertebralis* are uncommon on the reef-flat platforms and abundant between the 45 feet and 100 feet terraces. *Amphistegina lessonii* is rare in reef-flat sediment deposits. Specimens are relatively common in sediments below 50 feet. *Elphidium advena* and *Heterostegina depressa* are relatively uncommon in shallow sediments but were common in a mud sample collected at a depth of about 1000 feet off the Glass Breakwater. There is a characteristic foraminiferal assemblage associated with these deeper slope sediments. These deep water forminifera include *Amphistegina bicirulata*, *A. lobifera*, *Spiroclypeus* spp. and a *Cycloclypeus-Operculina* complex. The benthonic foraminifera *Baculogypsina sphaerulata* is a species common to and dominant in the foraminifera assemblage of some Indo-Pacific reef-flat environments (Boltovskoy and Wright, 1976). On Guam, *B. Sphaerulata* can be a major contributor of sand-sized particles and is characteristic of high energy reef-flat environments.

Characteristic components of the crypotfaunal assemblage residing in cavities and interstices of the reef framework are foraminifera. These framework-associated species can be significant contributors to bioclastic sediments and important cementing agents (Hanzawa, 1957; Loeblich and Tappan, 1964). Recent foraminifera from the families Acervulinidae and Homotrematinidae characteristically attach themselves permanently to reef-associated substrata by means of a cement which persists after death of the animal. As a result of this attachment, species from these families are conspicuous components of the cryptofaunal assemblage of Cenozoic reef systems.

In particular, adherent foraminifera are an important component of the cryptofaunal communities on hard substrata in different reef zones around Guam. They are found in fringing reef, barrier reef, lagoon and coral community environments. Previous records (Brady, 1884; Clayshulte, 1981b; Cole, 1963; Cushman and Todd, 1972; Todd, 1966) indicate that the adherent foraminifera associated with Guam's reefs are *Homotrema rubrum* (Lamarck), *Gypsina globula* (Reuss), *G. vesicularis* (Parker and Jones), *G. plana* (Carter), *Miniacina miniacea* (Pallas), *Sporadotrema cylindricum* (Carter), *S. rubrum* (d'Orbigny), *Carpenteria proteiformis* (Göes), *C. utricularis* (Carter), *C. monticularis* (Carter), *Acervulina inhaerens* (Schultze), *Planogypsina squamiformis* (Chapman), and *Sphaerogypsina globulus* (Reuss).

Although adherent foraminifera occupy only about 1% of substratum surface area, they are important biofoulers. On reef-flat and reef margin substrates they can be the major cryptofaunal component and occupy as much as 50% of cryptic surface areas. Since foraminifera tests remain attached to reef substrata after the animals die, adherent foraminifera do make a small contribution to the overall coral reef carbonate accretion and can be useful as paleoecology indicators of reef environments.

MATERIALS AND METHODS

An opportunity to study Guam's carbonate geology presented itself when a number of cores became available to WERI. Thirty-two cores were acquired from the Officer in Charge of Construction (Navy) with the aid of the U. S. Geological Survey (Guam field office). Originally, the cores were obtained through drilling operations as part of a construction-site evaluation for an ammunition wharf at Orote Point, Apra Harbor (C.E. Maquire, Inc., 1977; 1979).

Recent reef (and associated facies) and Mariana limestone were represented in the core material from Orote Peninsula. Borings, which made 4 inch cores, were taken from recent reef environments (water borings) and from raised Mariana limestones (land borings) of Orote Island and Peninsula (Table 6). Core depths ranged from 15 to 105 feet. There was extremely good core recovery (over 80%) from both the land and water borings. There was a total of 1057 feet of water boring core and 634 feet of land boring core placed in the WERI repository. Nineteen water borings are available which were taken from the reef flat platform, reef margin and upper fore reef slope within the lower extent of the spur and groove complex (Figure 2). Thirteen land borings were taken from both vadose and phreatic zones in the Mariana Limestone (Figure 2). As a result, the efforts of this study have been directed toward the examination and analysis of these cores in terms of diagenetic sequences and pore-space evolution.

Selected sections of cores from the borings obtained by WERI were split. Based on observations of these split cores and locations of borings, representative land and water borings were selected for detailed petrographic analyses (Figure 3). Land borings were from Orote Peninsula, (LB33, LB34A and B, LB35) and Orote Island (LB 29). Water borings were selected along a transect with outer reef flat (WB 35), reef margin (WB 28 & 34) and upper reef slope (WB 27 and 28) environments represented. Water borings on the reef flat and reef margin were drilled through the modern (Holocene) reef material into Mariana limestone (Figure 4).

Fathometer traces of bottom topography were made at selected locations off Orote Point (Figure 5). Five of these traces, which characterize the seaward reef slope and lagoon floor adjacent to the study area, are presented in Figure 6. Traces 1 and 5 show the topographic relief of the natural lagoon entrance. The lagoon floor from mid channel toward the Glass Breakwater is characterized by hard substrata composed of large topographic features, which include living coral and boulder debris. Traces 2, 3 and 4 show the steepness of the seaward reef slope adjacent to the study area. Visual inspection of this study area and nearby barrier reef complex off the Glass Breakwater, shows a series of small terraces which occur at regular intervals down the reef slope: 15-22 feet, 48 to 57 feet, 100 to 110 feet and 160 to 200 feet. The 100-110 foot terrace can be seen in the fathometer traces (Figure 6). These terrace depths and a deeper terrace at 315 feet are found along the entire leeward coast of Guam. A review of Guam terraces in relation to terraces at other islands in the Pacific is presented by Emery (1962).

Core material from the selected boring was split and described. Slabs were taken from the central portion of the core at about 2 foot intervals.

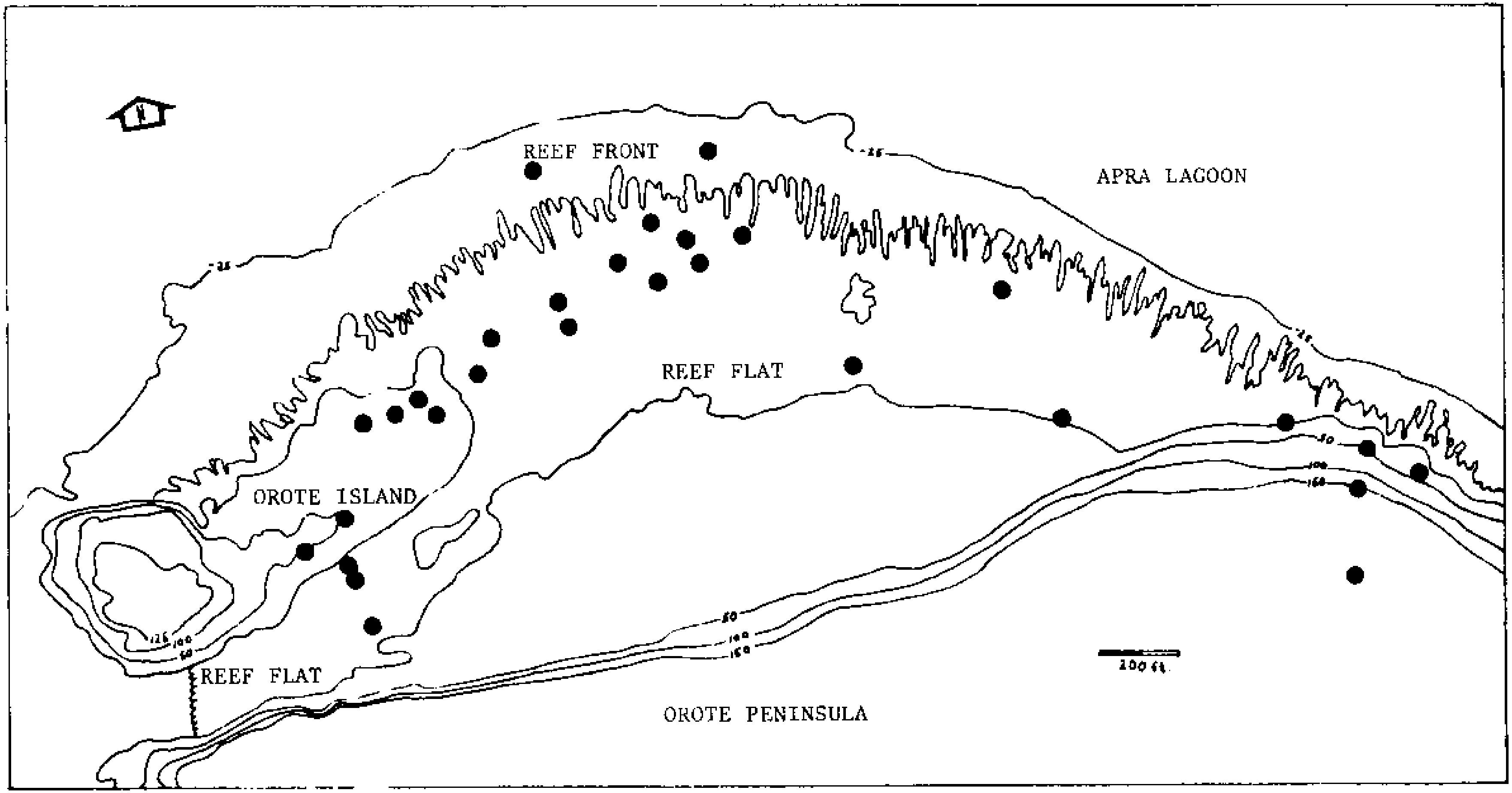

Figure 2. Location of WB and LB bore-holes at Orote Point which are in the WERI Core Depository.

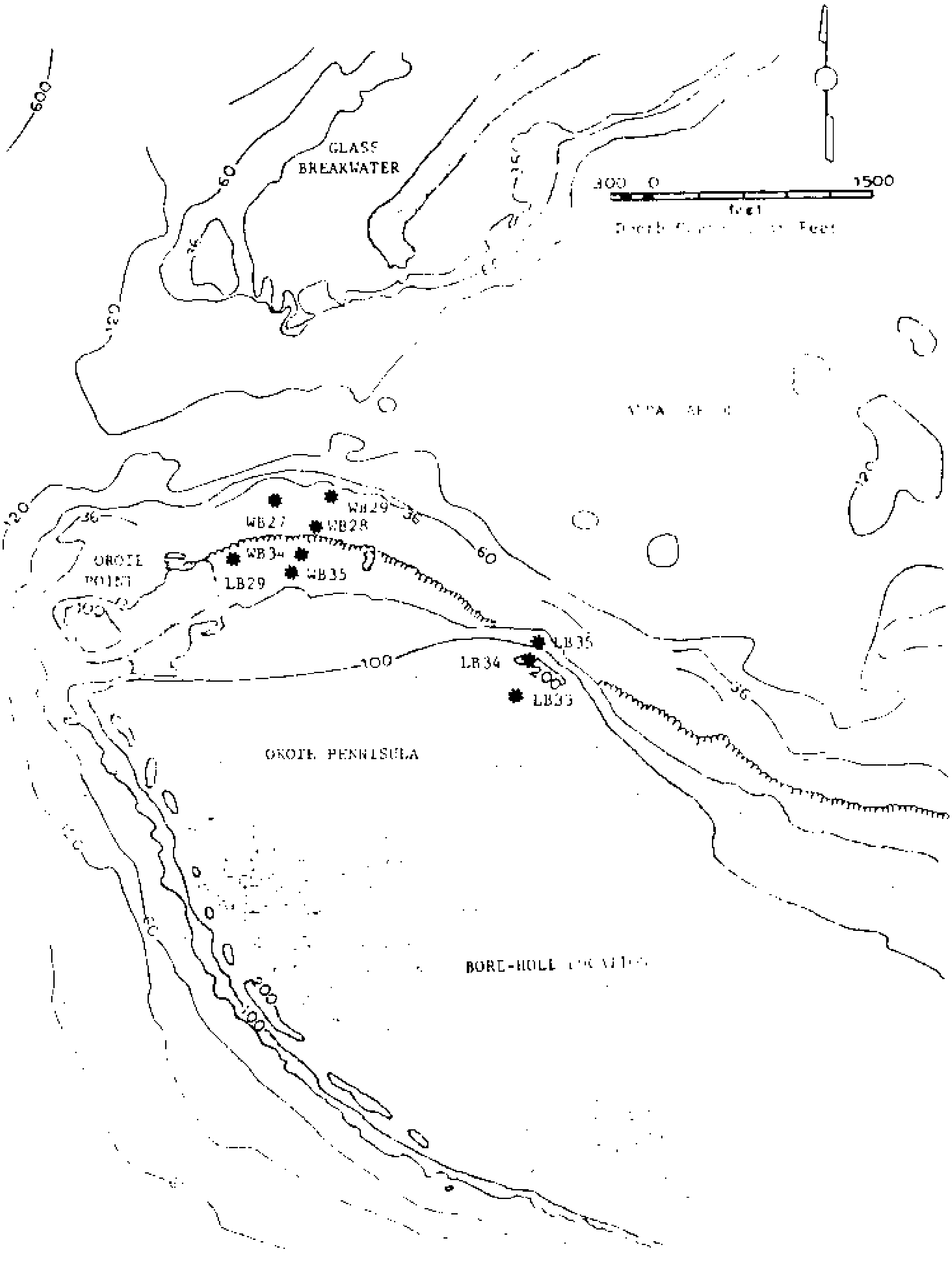

Figure 3 . Location of bore-holes used in petrographic and paleoecological examinations at Orote Point.

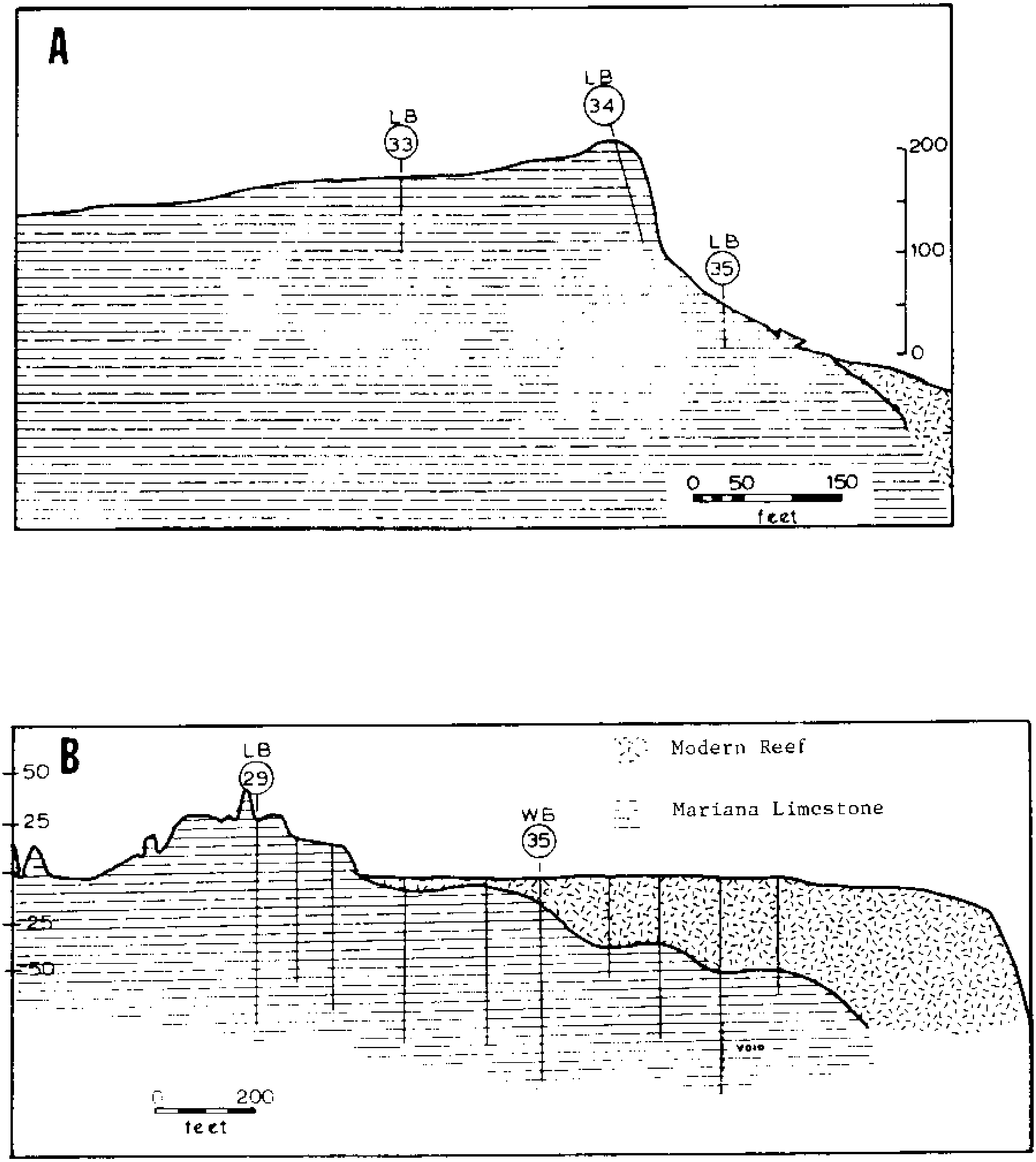

Figure 4. Cross-sections through Mariana Limestone of Orote Peninsula (A) and Modern reef with underlying Marine Limestone at Orote Point (B). Vertical lines are bore locations with depths drilled.

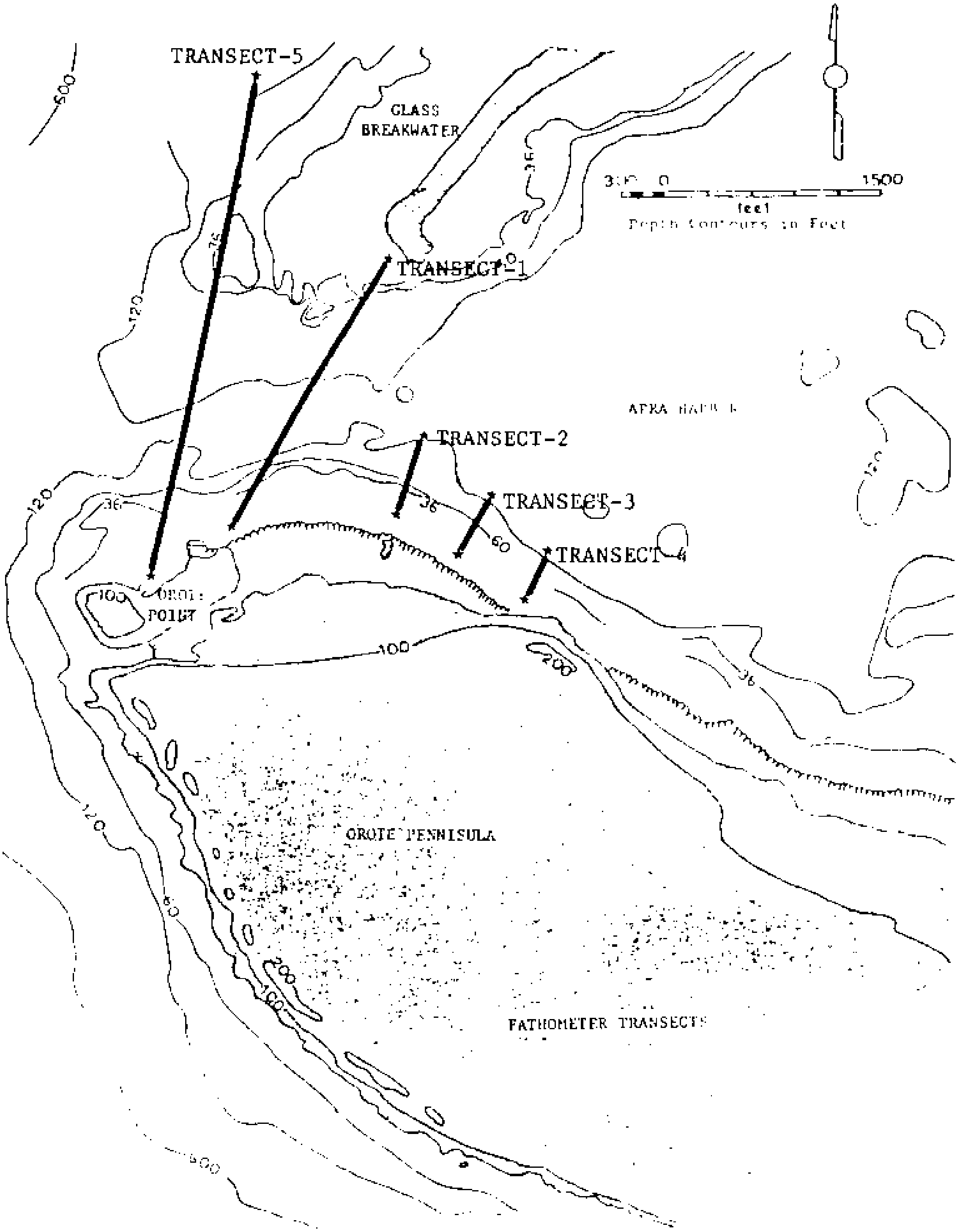

Figure 5. Fathometer transects at Orote Point.

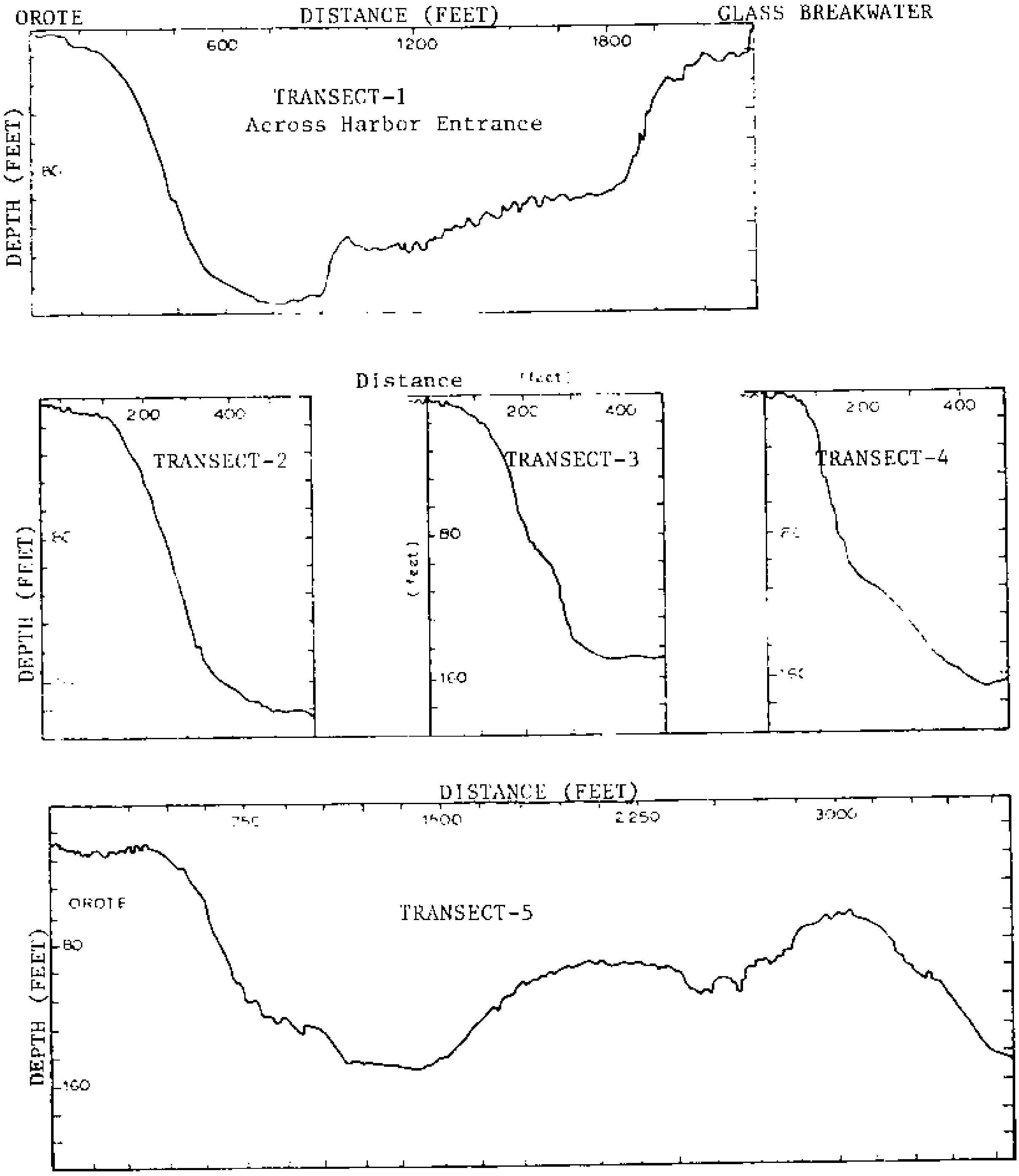

Figure 6. Fathometer traces of fringing reef slopes and lagoon floor at Orote Point. See figure 5 for locations fathometer transects.

Table 6. Cores in the WERI repository from Orote Peninsula, Guam. The cores were taken in a geotechnical survey for an ammunition Port Facility (C.E. Maquire, Inc., 1977). Cores were taken at 77 localities with depths ranging from 15 to 105 feet. Cores were taken along shore and on the Orote Peninsula Island.

	Total Depth Cored	No. Locations (ft)
Modern reef	925	29
Mariana limestone		
Vadose zone	1210	35
Phreatic zone	230	6

WB #	Water Borings at WERI Total Length (ft)	LB #	Land Borings at WERI Total Length (ft)
27	0-40	26	0-42
28	0-37.5	27	0-70
29	0-44.5	28	0-48
30	0-60	28B	37-81
31	0-105	29	0-98
32	0-75	30	0-61
33	0-76	31	0-50
34	0-60	32	5-25
35	0-100	33	0-77.5
36	0-60	34	0-98.3
37	0-52.6	35	0-35
38	15-80	36	0-50
39	0-40	37	15-44
40	3-64		634
41	0-70		
42	0-35		
43	0-15		
44	4-33.4		
45	0-30.5		
	1057		

Table 7. Major taxa with functional or morphological groups assessed in slab investigations

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1. Calcareous Algae

   a. Family Corallinaceae (red algae)

      i. crustose coralline algae: growth forms include crustose or incrusting, branching, nodules, massive knobs and laminations. Species identification in thin-section only.

      ii. articulate-segmented forms: Amphiroa, Jania, Corallina; uncommon in reef frame material, although Amphiroa sediments can be locally abundant.

   b. Family Codiaceae (green algae)

      i. Halimeda: 12 species on Guam with H. opuntia a major sediment producer in lagoon environments, species identification difficult for slabs or thin sections.

2. Foraminifera

   a. Sedentary: Families Homotrematinidae and Acervulinidae; can be used to determine reef zonation and habitat characteristics.

   b. Benthonic: >150 species, shallow water (to 60m); divided between larger (Cole, 1983) and smaller foraminifera (Todd, 1966).

   c. Planktonic: Globigerinidae; few inshore species. Orbulina is characteristic of recent lagoon floor sediments.

3. Porifera (sponge)

   a. Boring Sponges: Family Clionidae, an important bioeroder of reef framework; only as traces-bore cavities in framework material.

   b. Calcareous sponges.

4. Scerlactinians (coral)

   a. Hermitypic corals (with zoozanthellae): colonial and solitary; growth forms include tabulate, crustose, branching, large massive, knob, ramose, and foliaceous; live to maximum depth of 90m. Table 4 has genera of coral found in reefs around Guam.

Table 7 Continued.

b. Ahermitypic corals (without zoozanthellae): live at all depths to a maximum 6000m; generally at deeper depths; Family Caryophylliidae found in slope sediments at 500 to 1000 ft. off Glass Breakwater.

5. Octocorals

a. Gorgonacea (soft corals); Sinularia spp. make a carbonate buildup referred to as "spicularite", which is locally common at shallow depths.

6. Bryozoans

a. There are >18 spp. of colonial or zooarial forms, which are common to cryptofaunal community; these has been no study of bryozoans for Guam.

7. Brachiopods

a. sessile; infaunal and epifaunal; reside in deeper reef framework and are usually uncommon.

8. Gastropods

a. Vermitidae (sessile, boring): generally in calcareous algae, but common to reef framework material.

b. Benthic (free moving)

c. Pteropods: planktonic; found in lagoon and deeper slope sediments.

9. Bivalves

a. Byssate Free-swinging bivalves (e.g. Pteridae, Isognomonidae, Pectinidae); shallow inner sublittoral environments, lagoons, adapted to exposure on elevated surfaces.

b. Byssate closely attached (e.g. Modiolus); adapted to high energy environments of littoral zone, abundant on reef flats.

c. Byssate Epifaunal nesters (e.g. Area Barbatia); shallow water in crevices of coral or between branches.

d. Byssate Fissure-dwellers (e.g. Limida, Pectinidae); photonegative species found in crevices, underside of rocks, reef tunnels which are protected environments.

e. Cemented Epifaunal-Bivalves (e.g. Ostreidae, Spondylidae); shallow environments with wave action, good lighting (High energy areas).

Table 7 Continued.

   f. Free-living Epifaunal (e.g. Cardiidae, Limidae); exposed on substrata.

   g. Semi-infaunal (e.g. Atrina, Pennidae); with part of shell buried and posterior portion exposed.

   h. Infaunal (e.g. Cardiidae, Veneridae); in soft or hard substrata with tubes or fleshy siphonas.

   i. Boring (e.g. Lithophaga); excavate burrows in hard substrata.

10. Arthropods (Crustacea)

   a. growth types include crawling-soft substratum, crawling-hard substratum, burrowing, cemented, free moving, planktonic.

11. Annelida (worms)

   a. Polychaeta: errant with jaws and serpulids (burrows or tubes).

      1. Serpulidae: calcareous tubes; epibenthic, mostly encrusters.

      2. Sabellarians: form agglutinated tubes.

12. Echinoderms

   a. Echinoids (urchins): primarily spines; Spines from the pencil urchin Heterocentrotus are indicative of high energy environments. Recent urchins are important bioeroders of reef surfaces, making characteristic deep grooves.

13. Non-Skeletal grains

   a. Pelletoids (mostly fecal in origin)

   b. Ooids (Lamellae around grain)

   c. Aggregates and cryptocrystalline lumps

Table 8. Foraminiferal species occurrence by reef zones. The species above the double line are the dominant species for the zone. The species are listed in descending order of importance within each reef zone.

Reef Flat	Reef Margin	Upper Slope	Slope: 150-400M
H. rubrum	S. cylindricum	H. miniacea	C. monticularis
C. utricularis	C. utricularis	H. rubrum	C. utricularis
S. rubrum	H. rubrum	C. utricularis	H. rubrum
A. inhaerens	M. miniacea	S. cylindricum	G. vesicularis
G. vesicularis	G. vesicularis	A. inhaerens	
	C. monticularis	S. rubrum	
		G. vesicularis	
		C. monticularis	
		C. proteiformis	

Table 9. Species recruitment pattern in relation to general illumination surface types and to exposure period. The species are listed in descending order of importance for each surface type.

Surfaces Exposed to Ambient Light	Shaded Surfaces of Reef Framework	Cryptic Surfaces of Reef Framework Cavities
P. squamiformis	H. rubrum	H. rubrum
A. inhaerens	M. miniacea	M. miniacea
G. vesicularis	C. utricularis	C. utricularis
	S. rubrum	C. monticularis
	G. vesicularis	S. cylindricum
		C. proteiformis

Early Successional Species [Recruitment to Newly Exposed Surfaces]	Late Successional Species [Recruitment to Colonized Surfaces]
P. squamiformis	H. rubrum
[G. fimbriate]	M. miniacea
[A. (Ladoronia) vermicularis]	C. utricularis
A. inhaerens	C. monticularis
G. vesicularis	S. cylindricum
[G. plana]	
[G. globulus]	
[G. globula]	
[S. globulus]	

These slabs were polished by wet grinding using 280 grit wet and dry sand paper which was mounted on glass plate. The smaller half-core made from the slabing procedure was the source of material for thin sections.

These half-cores were cut into 1½ by 3/4 inch blocks. Different limestone porosity types, depositional textures and fabrics were sampled from half-cores. Thin sections were made from these blocks with a standard sectioning procedure: impregnated blocks were ground flat on a cast iron lap with 400 grit grinding powder; frosted thin section glass was expoxyed to the flattened surface; sections were cut and ground on a thin section machine; and final grinding and polishing was done on glass plate with 1200 grit grinding power.

A standard petrographic microscope (20 to 400x) was used for detailed examination of thin sections for rock type, color, texture, cement and matrix materials, fossils and accessories, structures and porosity. The permeability of the limestone was inferred, based on an evaluation of the porosity. Slabs were examined under plain light with a stereo microscope (10 to 280x). Examination of slabs was done to determine depositional characteristics and components, and determination of the paleoecology. Major functional and morphological groups, as well as, important characteristics of taxonomic organisms were assessed in slab investigations (Table 7). This information was used to infer community structure and reef zonation. The occurrence of sedentary foraminifera provided information on reef zonation (Table 8) and generally exposure of recruited substratum in relation to illumination and recruitment pattern (Table 9). Mineralogical determinations were made for selected thin sections and slabs. The staining procedure as outline by Friedman (1959) was used to distinguish between calcite, Mg-calite and aragonite. Thin sections were prepared without cover glass, so that they could be lightly etched with dilute HCl acid. This etching brought component features into relief and facilitated staining and mineralogical examination.

RESULTS AND DISCUSSION

General

In this section, results from the study of the Orote Point cores are presented and their relevancy to pore-space development is discussed. The focus of this discussion is on the comparison of modern reef and associated sediments with that of earlier Mariana limestone. Particular attention is paid to ecological aspects, cement-porosity relationships, porosity classification, and diagenesis. The purpose is to describe the evolution of porosity within the older Mariana formation in terms of differences observed between the modern reef depositional environment and that of Pliestocene time. The objective is to gain an understanding of the relationship between depositional facies, present and past hydrogeologic environments, diagenesis and the water bearing properties of the Mariana limestone.

Driller and geologic, and thin section description logs are presented in the appendices. Appendix A contains the driller and geologic logs obtained by C.E. Maquire, Inc. (1979) as part of their geotechnical assessment of Orote Peninsula. Appendix B contains descriptions of thin section observations which include lithology, cementation characteristics, porosity type and floral and faunal composition.

Modern Reef and Associated Sediments

All of the WB designated cored boreholes used by this investigation were started in depositional environments associated with the present-day reef complex within the study area. Descriptions of the subsurface samples and interpretations of observed characteristics are presented below.

General Lithology

The general lithology of the cores retrieved from the WB series boreholes is best described as coral/algal boundstone and buff colored poorly sorted skeletal packstone. Massive and branching coral colonies are in growth position and encrusted with coralline algae. Typically vermetid gastropods are associated with the crustose coralline algae. The dominant sediment is skeletal packstone usually with larger-size (gravel) fragments of coral, coralline algae, fragmented shells and whole mollusk shell material. The finer grained portion of the sediment (packstone) is composed of Halimeda plates, shell, coralline algal, and coral fragments, echinoid spines and plates, and foraminifera tests. The matrix of the packstone is silt-size skeletal debris and peloidal micrite.

Fine-grained sediment in the silt-size range typically fills borings and other cavities within corals and the surrounding deposits often form a geopedal fabric. Under the microscope this internal sediment is normally a skeletal wackestone with a peloidal micrite matrix, although a finer grained packstone may be present. Very little mudstone was observed either in polished slab or thin sections.

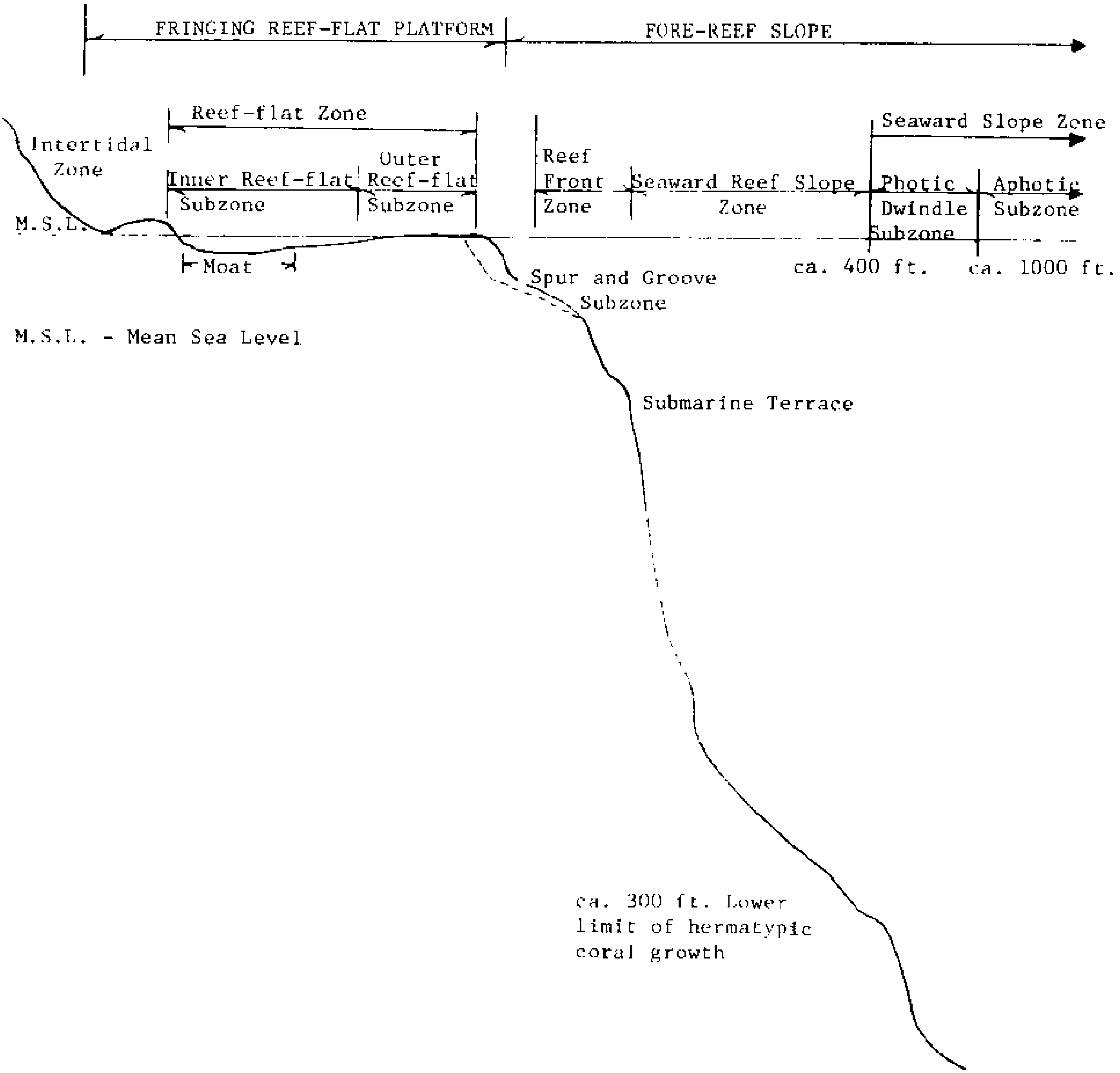

Figure 7. Zonation of fringing reef-flat platform and upper forereef slope.

The photographs of Plate 1 show the general appearance of the two main lithologic types of carbonate sediments observed within the cores of the WB series boreholes. Other sediment types are also present to a lesser degree and will be addressed in sections of more detailed discussion.

The degree of lithification within the sediments ranges from friable or loose to well indurated. Except for a few occurrences of grainstone or rudstone, the matrix contains at least some micrite. It is the micrite that forms the primary bounding agent. Where less micrite is present, e.g. grainstones, the constituent particles are cemented by fine-crystalline mosaic of probable magnesium calcite composition. Another type of cement fabric common in grainstones is radiaxial fibrous isopachous rim cement, again of probable magnesium calcite composition. Other types of cements were observed and are described in a later section.

Porosity within the core samples is primary with a number of types represented. Among these types are interparticle, intraparticle, shelter, fenestral, and growth framework. These types have been categorized by Choquette and Pray (1970) as fabric selective. In addition to these fabric selective types, much of the core material shows extensive borings by mollusk, annelid worms and algae. Pore sizes range from micropores (<4u) to megapores (up to several inches) and tend to be very irregular in distribution particularly in poorly sorted sediments. Based on visual examination of slabs and thin sections utilizing comparison charts (e.g. Flügel, 1982; p 247-257), primary porosity was estimated to be between 25% and 50%. No secondary or solutionally produced porosity was observed in the modern sediments. However, on rare occasions where older Mariana limestone fragments were incorporated into the younger material, vuggy and moldic porosity were observed in the lithic clasts.

Two processes tend to reduce the volume of pore space within the modern material, internal sediment infilling and deposition of carbonate cements. Internal sediment, usually silt-size wackestone, partially or completely fills larger interparticle voids and borings in addition to occluding much of the original intraparticle or growth-framework porosity. Various types of marine cements tend to fill voids between particles and within foraminifera tests and gastropod shells.

Ecology and Paleoecology

WB cores were drilled into the modern fringing reef (Holocene) at Orote Point (Figure 2). A modern fringing reef can be divided into a series of zones and subzone (Figure 7), which have characteristic structural features, biological components and depositional textures. Two of the studied bore holes, WB27 and WB29, were started in the seaward edge of the spur and groove subzone of the reef front zone. The spur and groove system extends from the reef margin zone to the depth of appreciable wave action which is about 25-35 feet at Orote. Some of the grooves transgress the reef margin and continue unward as either small surge channels or tunnels which trench into the outer reef flat subzone. Borehole WB28 was started in the reef margin zone at the upward extent of the spur and groove system. All the core material taken from these WB borings was modern reef framework. Two of the studied bore holes, were made in the reef flat zone.

These borings were started in modern reef framework and completed in Mariana limestone. WB34, which was drilled in the outer reef flat subzone, contacted Mariana limestone at 35 feet. WB35, which was drilled in the outer portion of the inner reef flat subzone, contacted Mariana limestone at 15 feet (Figure 4).

Based on the examination of polished slabs, the modern reef framework is subdivided into distinguishable depositional textures. These depositional textures are as follows: 1) coral/algal boundstone, in situ framework; 2) coral boundstone with layers, pockets or filled interstices of packstone to wackestone; 3) skeletal grainstone to packstone which contains large fragments of reef framework, including boundstone out of context; 4) skeletal grainstone to packstone, with no dominant skeletal component; 5) Halimeda grainstone to packstone; 6) skeletal packstone to wackestone with little or no mudstone, dominant skeletal components can occur which include benthonic foraminifera, pelecypods, Halimeda, crustose corallines and coral; 7) and floatstone to rudstone, mostly matrix supported larger grains not bound together during deposition. The general depositional textures of modern reef framework in the WB borings are presented in Table 10.

The top few feet of all WB borings is a coral/algal boundstone with in situ branching (e.g. Acorpora) and massive (e.g. Favia) corals, crustose coralline algae (primarily Porolithon) binding the coral, and fine to coarse grained internal sediment. Sediment fill within interstices is generally a packstone with uncommon fined grained wackestones and coarse grained grainstones. Cavities within the boundstone have adherent cryptofaunal communities which are characteristic of shallow reef zones (outer reef-flat to reef front). A cryptofaunal assemblage typically contains higher densities of fewer species, particularly polychaete worms (e.g. Serpulidae). Other important and sometimes dominant components include sedentary foraminifera (e.g. Sporadotrema), Porifera sponges, bryozoans, vermitid gastropods, and byssate fissure-dweller bivalves. On Guam, the adherent foraminiferan Sporadotrema cylindricum, which is usually plurivalent and produces massive "pseudo-colonies", up to 12 inches across and 2-3 inches in depth, is particularly abundant in cavities and tunnels of the reef margin zone, which have seawater circulation (Clayshulte, 1981b). Therefore the occurrence of this species in the modern reef framework can be used to infer a reef margin or upper reef front depositional zone with open cavities or tunnel systems.

The second depositional texture encountered in the WB borings (excluding WB35 which contacts Mariana limestone) is skeletal grainstone to packstone with or without large fragments of reef framework material. Grain sizes of larger particles within the finer grained matrices (silts) range from fine rounded sands to gravels. These grains are derived primarily from the reef-flat and reef margin zones and include many whole bivalve shells, cerithid gastropods and foraminiferal tests. Many of the whole bivalve shells are byssate closely attached bivalves (e.g. Modiolus) that are common in the algal matting of the outer reef-flat subzone and are characteristic of high energy environments. Additional common bivalve shells are from fissure dweller and cemented epifaunal bivalves, which are also adapted to high energy environments. The cerithid gastropods are

Table 10. Depositional textures in Modern reef borings from WB27, 28, 29, 34 and 35 cores, based on slab examinations.

BORING	DEPTH (feet)	DEPOSITIONAL TEXTURE
WB27	1-16	Coral/algal boundstone. *in situ* corals, crustose corallines (*Porolithon*) and fine sediment fill in interstices; seaward reef margin zone, in spur and groove complex; sediment fill ranges from wackestone to grainstone with grainstone more common; cavities with cryptofaunal community; few cavities with orange oxide stains.
	16-18	Skeletal grainstone/packstone with large reef framework fragments. boulder size coral with crustose corallines, out of context; fragments of branching coral, crustose coralline, codiaceae, foraminifera, mollusca.
	18-25	Coral/algal boundstone. *in situ* corals, thick layers of crustose corallines (primarily *Porolithon*) and fine internal sediment fill in interstices; cavities and pores lined with fine white chalky limestone; byssate fissure-dweller bivalves and bores in massive corals.
	25-27	Skeletal grainstone/packstone with large reef framework fragments. (like 16-18 feet).
	27-40	Coral boundstone (*in situ Pocillapora*) with fine grained wackestone to packstone sediment fill between branches; and coral/algal boundstone. with *in situ* corals, crustose corallines and sediment fill, and layers of skeletal grainstone.
WB 28	0-5	Coral/algal boundstone. *in situ* small massive and branching corals, crustose corallines (primarily *Porolithon*) and only traces of fine sediment fill; cavity with reef-flat cryptofaunal community; depositional environment is outer reef-flat to reef margin zone.
	5-10	Skeletal grainstone/packstone. rounded medium sand to gravel size particles of coral, crustose corallines, foraminifera, bivalve, gastropod, and urchin debris derived from a reef-flat environment; byssate closely attached and fissure-dweller bivalves and cemented epifaunal bivalves adapted to high energy environments.

	10-40	Coral/algal boundstone. *in situ* small massive and branching corals, thick encrustations of crustose corallines; reef-flat cryptofaunal community in cavities; cavities with orange oxide stains; infaunal and boring bivalves; few pockets of skeletal packstone to grainstone with burrow traces; few clasts of crystalline limestone, rounded Mariana with out internal structure.
WB 29	0-8	Coral/algal boundstone. with *in situ* corals (*Acropora*), crustose corallines, fine to coarse grained internal sediment fill in interstices; Layers and pockets of grainstone (coarse sands); depositional environment is reef front zone in spur and groove system; cavities with reef tunnel crypotfaunal community; reef-flat derived sediments, cavities with orange oxide stains.
	8-18	Skeletal grainstone/packstone. fine internal sediment fill; gravel fragments of coral, algal, molluscan debris; byssate closely attached bivalves from high energy environments; reef flat foraminiferan, *Baculogypsina*.
	18-44	Coral/algal boundstone. *in situ* branching, tabulate, massive corals; crustose corallines (*Porolithon*) Codiaceae algal plates, and sediment fill ranging from fine grained wackestone to grainstone with tan matrix; cryptofaunal community of dark cavity and reef tunnel complex, *Carpenteria monticularis* and *C. utricularis*; reef-flat derived sediments; Byssate epifaunal nester bivalves and cemented epifaunal bivalves.
WB34	0-2	Coral/algal boundstone *in situ* coral, crustore corallines, and pockets of paskstone to grainstone sediment fill, which is characteristic of existing outer reef-flat subzone; rounded sand size particles and only traces of finer matrix.
	2-3	Skeletal grainstone/packstone gravel to fine sand size particles derived from reef-flat environment; cryptofaunal community characteristic of reef-flat and reef tunnel community, common *Sporadotrema cylindricum* from reef tunnel complex.
	3-32	Coral/algal boundstone *in situ* corals, crustore corallines and internal sediment fill ranging from fine grained wackestone to grainstone; dark cavities of reef tunnel complex, *Carpenteria monticularis*; boring and cemented epifaunal bivalves and byssate fissure-dwellers; orange stained cavities.

	32-33	Skeletal grainstone/packstone with large reef framework fragments. gravel to fine sand size particles derived from reef-flat environment; reef tunnel sediment fill; *in situ* *Sporodotrema cylindricum* on eroded coral "wall".
	33-35	Coral/algal boundstone. *in situ* corals, crustose corallines and internal sediment fill ranging from fine grained wackestone to grainstone; boring and byssate epifaunal nester bivalves; sediments derived from reef-flat environment, with grains mostly rounded; larger reef-flat foraminifera, *Baculogypsina* and *Amphistegina*.
WB35	0-14.6	Coral/algal boundstone. pockets of skeletal grainstone/packstone; massive *Sporadotrema cylindricum* infilled with fine grained wackestone; cryptofaunal components from reef tunnel complex; depositional environment is outer reef flat subzone adjacent to reef margin zone.

common in the littoral and inner reef-flat zones. Skeletal grains with a reef margin association are primary components of cryptofaunal communities associated with larger cavities and reef tunnels.

Skeletal grainstone to packstone overlie a coral/algal boundstone that has similar faunal and floral components found in the upper boundstone deposition. This deeper boundstone, has a fine white chalky material or orange oxide stains lining small skeletal cavities, borings and vugs. Interstices within corals are generally filled with a fine grained matrix which is due, in part, to sponge borings.

There is an alternation in depositional texture in the modern reef framework between a coral/algal boundstone and a skeletal grainstone to packstone. The large framework material, particularly fragmented coral/algal boundstones, that occurs in the skeletal grainstone to packstone appears to be contemporaneous. The occurrence of fine grained wackestone is generally restricted to the interstices of tabulate and branching corals (e.g. Acropora), borings by annelida worms, arthropods, sponges and bivalves, and small irregular skeletal cavities.

The major coral genera observed in the polished slabs were Acropora, Pocillapora, Porites, Favites and Favia. Acropora appears as an important in situ framework component and sediment contributor, particularly gravel-size particles. Most of the Acropora shows extensive sponge borings which range up to 80% boring of the skeletal structure. These borings are infilled with fine grained matrix. Many of the massive corals are faviids which show less sponge borings, however, many of these massive corals have larger borings from bivalves (e.g. lithophaga), arthropods (e.g. crabs) and polychaete worms. The coral assemblage in WB core material is generally associated with the reef margin and reef front zones.

Crustose coralline algae is an important binder of the reef framework. The dominant crustose coralline algae is Porolithon onkodes. This algae is a major component of the algal ridge in the reef margin zone. Other crustose corallines which occur less frequently are Lithoporella melobesioides, Neogoniolithon cf. conicum, N. foslieli, N. pacifcum, Hydrolithon reinboldii, Mesophyllum erubescens and Lithoporella pacifica which are associated with various reef zones with different depth ranges (Table 5). The species N. pacificum, L. melobesioides and M. erubescens are found in the lower reef front and upper seaward reef slope zones. These species are found throughout WB27 and WB29 core material, with occurrences at 4 and 40 feet.

The depositonal textures, floral and faunal component and structural features observed in WB27 (40 feet) and WB29 (44 feet) are characteristic of the reef front zone in the spur and groove system. There is some in situ reef tunnel cryptofaunal assemblage development which suggest reef margin zone deposition. However, some of the crustose corallines that occur in the upper portions of these cores are generally associated with the submarine terrace systems between 25 to 130 feet. The depositonal environment for WB38 (40 feet) and WB34 (35 feet) varies between outer reef-flat subzone and reef margin. The cryptofaunal assemblage at 40 feet in WB28 is characteristic of reef margin cavities, since it includes the reef-flat globulose variety of Homotrema rubrum, Carpenteria utricularis and massive *in situ* *S. cylindrium*. The depositional environment of WB35 (15 feet) is characteristic of the outer reef-flat zone.

Reef-flat platforms and upper reef-fronts usually contain very little unconsolidated sediment. Reef-flat sediments are transported over the reef margin, deposited as intertidal beaches, or cemented into the reef framework. According to Bonem (1977), as much 50 percent of a reef frame can consist of internal sediment. Sediment deposits, which occur on reef-flats, are commonly in local depressions or leeward of large framework features and massive coral heads. Upper reef-front sediment deposits are also restricted in distribution. They are usually confined to interstices of the reef framework, tunnels, grooves, or local depressions. These shallow-water unconsolidated sediments are mostly composed of sand- and gravel-size particles with only traces of silt- and clay-sized material. Off-shore sediments become finer with depth, since the finer sands and silts are more readily transported downslope.

Sediments on Orote fringing and barrier reefs are almost exclusively bioclastic carbonates of recent origin (Clayshulte, 1982). Sediment grain sizes are dependent, in part, upon the crystalline structure, types and populations of the various component organisms. Calcareous algal components are rapidly reduced by mechanical erosion and biodegradation (worm and sponge boring) to produce very fine grains. Mollusk shells are slowly reduced to larger size classes which are controlled by organic or crystallographic contraints (Milliman, 1974). Additionally, carbonate components can orginate as sand-size particles (e.g. foraminifera). Therefore, grain-size distribution of reef sediments and degree of sediment breakdown is dependent on a number of factors which include carbonate type, biodegradation, mechanical erosion, wave energy, and both the mode and distance of particle transport.

The primary sources of the bioclasitc sediments are recently living corals, calcareous algae, foraminifera, gastropods, bivalves and other invertebrates (e.g. urchins). Calcareous algae, primarily *Amphiroa* and *Jania*, are easily broken down into medium and fine sands. Tests of the foraminiferan *Baculogypsina sphaerulata* are in the medium sand class. This foraminiferan grows in algal mats of the outer reef-flat zone near the reef margin, where its high reef production (up to 800 g $CaCo_3m^{-1} yr^{-1}$) produces large amounts of calcium carbonate sand (Clayshulte and Grimm, unpublished data). These tests are generally lighter in weight compared with other carbonate grains of similar size, and they tend to accumulate in the beach deposits.

Cement - Porosity Relationships

The abundance of porosity in modern carbonate depositional environments is dependent on a number of factors. Among these factors are 1) type and particle size of sediment constituents, 2) early development of cements, 3) occurrence of internal sediment, and 4) depositional facies. Within the Modern reef and associated carbonate sediments, porosity has been produced by depositional processes and thus is of primary origin. Pore space is created within the reef framework as voids between coral colonies and other calcareous organisms that compose the reef structure.

Pore space also occurs within the skeletal structure of coral, algae, foraminifera, bryozans, articulated bivalves, and gastropod shells. Contemporaneous with reef growth is the production, transport, an deposition of carbonate sediment. This sediment is usually derived from the mechanical and biological break down of reef-building organisms and is deposited within the reef framework as well as those environments associated with the reef system (e.g., fore reef slope, back-reef or intertidal zones, reef flat). In addition, finer-grained sediments infiltrate the pore system within organisms such as corals forming geopedal fabrics. This type of sedimentation is one of the processes that decreases the abundance of pore space (e.g. Plate 2A, B), first.

Pore space is further reduced within the modern reef environments by deposition of marine cements. Two major types of marine cements occur within the growth framework and interparticle pore space. Radiaxial fibrous or needle-like cement of probable aragonite composition occurs in the interior of gastropod shells (particularly vermetid gastropods), around mollusk shell fragments, and in numerous coral calice. Cement usually occurs where internal sediment is not present and as crystals 80-100μ long and 6-8μ wide growing more or less perpendicular to the pore wall and often occluding the original void. An example of this type of cement is shown in Plate 2. A similar needle-like cement forms in coral calice that are not oriented perpendicular to the pore wall. Here the crystal fibers either radiate as a splay into the void or oriented at an angle. In the later case, the crystal orientation is clearly an extension of the skeletal structure, often forming a herringbone fabric characteristic of some corals. The other cement type occurs within sediment and forms a fibrous to blocky cement which binds skeletal grains and peloids. Occasionally their cement will form an isopachous rim around constituent grains when less micrite matrix is present. Crystal size is usually in the micrite range (<4μ) and the cement is probably magnesium calcite although its composition may also be aragonite where the substrate is aragonite (e.g., coral fragments or mollusk shells). Where the matrix of the sediment is micrite (wackestone or packstone) the binding agent is not readily observable and may be submicron in crystal habit.

The distribution of marine cements is not uniform. Within the samples examined from the boreholes penetrating the modern reef depositional environment, there appears to be no distinct depth or areal preference for cement development. For the most part the sediments are well lithified, except for the occasional pocket, throughout the cored length. However, the occurrence of fibrous cement within growth framework is irregular in distribution.

As a result of the apparent early lithification of sediments, much of the porosity formed at the time of deposition was quickly occluded by precipitation of marine cements. Within finer-grained sediments such as skeletal wackestones and packstones, porosity was decreased from around 70% (typical of this type of sediment at the time of deposition) to as little as 25% or less after lithification. Some intraparticle and growth framework porosity was reduced first by internal sedimentation followed by or contemporaneous with fibrous aragonite cement partially or completely occluding skeletal voids (Plate 2E,F).

Although at least four distinct reef-associated depositional environments or facies were drilled (reef flat, reef margin, shallow fore reef, and lagoon), cement fabrics were nearly identical in type and distributions. Perhaps a more detailed study utilizing X-ray and microprobe techniques would reveal differences in cement chemistry and morphology between the various facies.

Using the classification of Choquette and Pray (1970), porosity is primary in origin and includes the following types: growth framework, interparticle, borings, intraparticle, fenestral, and shelter. Growth framework and fenestral are characteristic porosity types of coral/algal or coral/foraminifera boundstone. Porosity is relatively high (around 40-60%) but the degree of pore space interconnection may be limited. Interparticle and shelter porosity types are associated with sediment around and within the reef framework or skeletal debris. Shelter porosity usually exhibits larger pore sizes than interparticle porosity, however, the degree of interconnection is normally greater for the interparticle type. Porosity created by boring organisms is associated with all types of carbonate deposition and is usually very abundant. Most borings are filled or partially filled with internal sediment either derived from the organisms or infiltrates from other sources. The degree of interconnection is relatively great and some borings may extend over considerable distances.

Mariana Limestone

All of the LB designated cored boreholes were started in Mariana limestone and WB31, WB34, and WB35 encountered the Mariana at depths of 47.4, 35.0, and 15.0 feet respectively (see the geologic logs in Appendix A). Description of the subsurface samples and interpretations of observed characteristics are presented below.

General Lithology

A majority of samples from cored bore-holes which penetrate the Mariana limestone are classified as Halimeda skeletal packstone to wackestone with minor occurrences of skeletal grainstone. Skeletal constituents are benthic foraminifera tests, echinoid spines and plates, gastropod and pelecypod shells, and fragments of coral, crustose and branching calcareous algae, Halimeda plates, and encrusting foraminifera. These usually poorly sorted skeletal constituents range in size from gravel to silt and are in a peloidal micrite matrix. In hand samples and polished slabs, the appearance of the Mariana limestone in very distinctive because of general dissolution of Halimeda plates which have a knife-point slit-like mold (Plate 3).

Coral/algal or coral/foraminiferal boundstone occurs within the packstone and wackestone. Numerous corals appear to be in situ and surrounded by sediment. Coral septa are usually partially (geopedal fabric) or completely filled by skeletal wackestone. Borings are common with internal sediment.

In thin section details of the lithology are readily observable (Plate 4). Much of the original aragonite skeletal material (i.e., coral, Halimeda, mollusk shells) has been replaced by equant blocky microspar calcite (drusy spar), however, the configuration, particularly Halimeda, is preserved by a micrite envelope. Two cement types are usually present in grainstones. Isopachous rim cements bind grains and equant calcite spar tends to infill the remainder of the pore space. Calcite spar also fills pore space within skeletal material and between particles where rim cement does not occur.

A common feature seen in thin section is the product of coral replacement by sparry calcite. The original aragonite skeleton of corals has been replaced by a sparry calcite mosaic which has preserved, in detail, the skeletal structure. Calcite crystal boundaries often cut across skeletal details including earlier develoment of cement fabrics. These neomorphic fabrics (Bathurst, 1971) are indications that the rock has been subjected to the freshwater phreatic diagenetic environment. Similar features to those found in the Mariana have been extensively described in the literature (e.g. Bathurst, 1971).

Porosity types as seen in polished slabs and whole cores include enlarged fractures and solution tubes, Halimeda and other skeletal molds, and vugs. Of these porosity types, solutions tubes and fractures have the highest degree of interconnection and skeletal molds the least. Although some primary interparticle and growth framework porosity has been preserved, in thin section the dominant porosity types are moldic and vuggy. However, in general the rock is a relatively dense limestone with much of the primary porosity occluced by either marine cements or sparry calcite.

Paleoecology

Samples of the Mariana limestone from WB borings 34 and 35 and LB borings 29, 33, 34, and 35 exhibit similar depositional textures as found in the modern reef framework (Table 11). These depositional textures are as follows: 1) coral and algal (occasionally encrusting foraminiferal) boundstone, 2) coral boundstone with packstone to wackestone, 3) skeletal grainstone to packstone with large reef framework fragments, 4) skeletal grainstone to packstone (no dominant grain type), 5) Halimeda grainstone to packstone, 6) skeletal packstone to wackestone (occassionally with a dominant skeletal grain component, e.g. foraminiferal), 7) floatstone to Rudstone, 8) and travertine deposits. These textures represent deposition in different reef zones when compared to the modern reef complex. The two major reef depositional zones are lagoon and seaward reef slope zone, both shallower and deeper than a lagoonal deposition (to 300 feet).

Foraminiferal assemblages can be used to distinguish sediments deposited in lagoon and seaward slope zones. Deep water (to 1000 feet) sediments near Luminao and the entrance to Apra Harbor have been collected and examined for general content, presence of insoluble residue, and silts and clays (Emery, 1962). Recent sediments dredged from the lower seaward reef slope zone and upper seaward slope zone (400 to 1000 feet) along the Glass Breakwater have a characteristic foraminiferal assemblage. Many of

Table 11. Depositional textures of Mariana Limestone in LB borings 29,33, 34 and 35 and WB borings 34 and 35, based on slab examinations.

BORING	DEPTH (feet)	DEPOSITIONAL TEXTURE
WB34		
	35	unconformity between modern reef and Mariana Limestone
	35-40	Coral boundstone with skeletal packstone/wackestone. pockets of orange-red stained finer matrix; *Halimeda* plates; coral infilled, crystalline with little primary porosity; relict fossils and cryptofaunal communities; some moldic porosity of fossil material, poor preservation.
	40-51	Skeletal grainstone/packstone. gravel size clasts of crystalline infilled coral; pockets of orange-red and tan stained finer matrix; *Halimeda* plates, replaced with calcite, poor fossil preservation; depositional environment reef slope below wave base (60 feet); *Rotalia* larger foraminifera; few pelletoid grains (fecal?).
	51-60	Skeletal packstone/wackstone extensive red-orange staining in matrix and along fractures; *Halimeda* plates with shelter porosity; moldic fossils with common smaller foraminifera characteristic lagoon floor sediments *Bolivina*, *Quinqueloculina*, *Triloculina*; larger foraminifera *Amphistegina*, *Marginopora*, *Sorrties*, *Amphisorus*; depositional environment is reef slope or lagoon floor below deep wave base (125 ft); thin lens of fine sands showing fining upward cycles.
WB35	14.6-15	Unconformity between modern reef and Mariana Limestone.
	15-30	*Halimeda* grainstone/packstone. orange oxide stained finer matrix; few pelletoids (fecal); small moldic foraminifera, millioline shapes; pockets of modern reef grainstone/packstone; deposition on fore reef slope in seaward reef slope zone near lagoon floor.
	30-61	Skeletal grainstone/packstone. pockets of wackestone; orange oxide stained matrix; round sand sized grains and fine gravels, derived from

Table 11 Continued.

		reef-flat and reef front zones, transported down slope; pockets of modern reef grainstone/packstone and floatstone/rudstone; lagoon sediment associated smaller foraminifera; deposition on fore reef slope in seaward reef slope zone.
	61-99	Skeletal grainstone/packstone. white limestone with little orange or tan staining of matrix; rounded grains of fine sand to gravel sized particles; travertine in fractures; poor fossil perservation, only shadowy relicts; deposition on fore reef slope, zone uncertain.
LB29	0-5	Travertine and skeletal grainstone/packstone. pockets of yellow oxide stained fine matrix, wackestone; shell fragments, rounded sand sized grains, coral clasts and crustose corallines (slightly chalky).
	5-17	Coral boundstone and *Halimeda* grainstone/packstone. lagoon sediment; small moldic foraminifera, millioline types; traces of red-orange stained medium sand size grains in a fine tan matrix; aggregates; larger foraminifera, *Amphistegina* and *Rotalia*; *Acropora* coral branches with fine orange matrix in interetices and sponge bores; Sedentary foraminiferal fragments; deposition in seaward reef slope zone.
	17-21	Travertine and coral boundstone. massive coral which is crystalline and completely filled almost no primary porosity; small pockets of skeletal grainstone/packstone; small shadowy foraminifera.
	21-32	*Halimeda* grainstone/packstone. fine grained tan matrix; secondary porosity of coral, which is infilled with fine matrix; lagoon sediment, associated smaller foraminifera; deposition in seaward reef slope zone.
	32-54	Travertine and coral boundstone (as at 17-21 feet)
	54-72	Coral boundstone with packstone/wackestone (*Halimeda*). Pockets of *Halimeda* grainstone/packstone; rounded boulder and cobble sized coral fragments; travertine in fractures; small lagoon sediment associated foraminifera, moldic; planktonic foraminifera, *Globigerina*; larger foraminifera, *Sorites*; coral with primary porosity and some secondary porosity; possible *Cycloclypeus*; deposition seaward reef slope zone.

Table 11 Continued.

	72-75	Coral boundstone with packstone/wackestone. coral massive and solid, almost no porosity.
	75-97	*Halimeda* grainstone/packstone. small pockets of wackestone; travertine in fractures; large coral clasts, out of context; larger foraminifera, *Amphistegina*, *Carpenteria*, *Cycloclypeus carpenteri* which is a slope foram, *Gypsina* variety *plana*; planktonic foraminifera, *Globigerina*; fine grained matrix tan to light orange; epifaunal bivalves; moldic small foraminifera associated with seaward slope zone; *Halimeda* with secondary porosity; deposition in seaward slope zone.
	98	Travertine.
LB33	1-2	Skeletal grainstone/packstone. lagoon sediment associated smaller foraminifera; *Orbulina* planktonic foraminifera; fragments massive and infilled, *Porites*.
	2-3	Skeletal packstone/wackestone. lagoon sediment associated moldic smaller foraminifera; orange-red stained sand size grains; rounded fine sand to gravel, mostly coral; layers of *Halimeda* packstone; larger foraminifera, Rotalidae; deposition seaward reef slope zone maybe near lagoon floor.
	13-18	Skeletal grainstone/packstone with large reef framework fragments; moldic smaller foraminifera; larger foraminifera, *Sorites*, Rotalidae; coral infilled, solid.
	18-34	Skeletal grainstone/packstone. layers of *Halimeda* packstone; moldic smaller foraminifera; *Orbulina*, planktonic foraminifera; larger foraminifera, *Sorites*, *Amphistegina*, *Marginopora*, *Gypsina*; secondary porosity of *Halimeda*; possible *Miogypsinoides*.
	34-45	Coral boundstone with packstone/wackestone. Abundant moldic smaller foraminifera, foraminiferal packstone; larger foraminifera, *Heterostegina*; infaunal bivalves; coral with some primary porosity.
	45-63	Skeletal packstone/wackestone. foraminiferal packstone; larger foraminifera, *Sorites*, *Amphistegina*, *Operculina ammonoidies*, *Carpenteria proteiformis*, *Cycloclypeus carpenteri*,

Table 11 Continued.

		Heterostegina, possible *Miogypsinoides*; Sedentary foraminifera, *Homotrema*, *Sporadotrema*, *Gypsina* var. *globula*; Secondary porosity of *Halimeda*, mostly broken into small fragments; deposition on seaward reef slope zone, below lagoon depth (200 ft).
	63-67	Coral/*Gypsina* boundstone. pockets of foraminiferal packstone; *Gypsina* with small chambers and loose layers, deeper water (200-400 feet growth form); coral infilled with fine grained orange matrix; no crustose corallines.
	67-70	Skeletal grainstone/packstone and floatstone/rudstone. White fine grained matrix; rudstone gravel sized rounded coral and packstone clasts; pockets of foraminiferal packstone.
LB34	0-10	Skeletal packstone/wackestone. similar depositional texture, floral and faunal component as LB33-45 to 63 feet.
	10-15	Skeletal grainstone/packstone with large reef framework fragments. Almost a floatstone/rudstone texture like LB33-67 to 70 feet.
	15-37	Coral boundstone with packstone/wackestone. pockets and layers foraminiferal packstone; larger foraminifera, *Cycloclypeus*, *Amphistegina*, *Operculina*, possible *Miogypsinoides*, *Carpenteria*, *Gypsina*; moldic smaller foraminifera; coral fragments infilled, some secondary porosity; layered packstone with steep dip, secondary deposition of coral rubble; deposition on seaward reef slope zone.
	37-38	Travertine and floatstone/rudstone. gravel sized clasts of coral and packstone.
	38-84	Skeletal grainstone/packstone with large reef framework fragments. tannish fine grained matrix in packstone; secondary porosity of *Halimeda*; Planktonic foraminifera, *Globigerina*; larger foraminifera *Sorites*, *Cycloclypeus* - *Operculina* complex; moldic smaller foraminifera; aggregates and pellotoids; bryzoan fragments, lacy; deposition in seaward reef slope zone.
	84-87	Coral boundstone with packstone/wackestone. tan to orange fine grained matrix; larger foraminifera, *Heterostegina*.

Table 11 Continued.

	87-96	Skeletal packstone/wackestone. Halimeda and coral packstones; larger foraminifera, Heterostegina Curva, Cycloclypeus carpenteri - Operculina complex; secondary porosity of Halimeda; tannish fine grained matrix with moldic smaller foraminifera, bivalve fragments and gastropods; aggregates and pelletoids (fecal?); deposition seaward reef slope zone.
LB35	0-10	Skeletal packstone/wackestone. few gravel sized clasts of coral; moldic smaller fossils in packstone; traces of orange fine grained matrix; crustose coralline fragments; coral fragments with primary porosity.
	10-30	Skeletal grainstone/packstone. mostly compact foraminiferal packstone; moldic smaller foraminifera, Texturalia, Quinqueloculina, millioline shapes; larger foraminifera, Sorites, Amphistegina, Heterostegina, Cycloclypeus, Gypsina, secondary porosity of Halimeda; deposition in seaward reef slope zone.
	30-35	Coral boundstone with packstone/wackestone and travertine. moldic smaller foraminifera; larger foraminifera, Cycloclypeus - Operculina complex; coral branches extensively sponge bored; aggregates and pelletoids (fecal?); deposition on seaward reef slope zone.

these species have not been found in sediments collected shallower than 250 feet. Diagonostic foraminifera which are indictive of deeper slope sediments off Orote peninsula include *Cyclocypeus carpenteri*, *Operculina ammonoides*, *O. bartschi*, *Spiroclyeus* sp., *Amphistegina bicirculata*, *A. radiata*, *Heterostegina curva*, *H. depressa*, *Robulus orbicularis*, *Hauerina involuta*, *Schlumbergerina alveoliniformis*, *Quinqueloculina granulocostata*, and various species from the Genera *Bulimma*, *Pyrgo*, *Bolivia*, *Cassidulina*, *Globigerina* an *Gaudryina*.

Assuming that depositional patterns are analogous for recent sediments and those of the Mariana depositional period, then the occurrence of a *Cycloclypeus* - *Operculina* assemblage can be used to infer deposition either in the seaward reef slope zone or in a deep open lagoon environment. This would make for an upper depth range between 150 to 400 feet. It is possible that the *Cycloclypeus* - *Operculina* assemblage had a shallower depth range extension in the geological past around Guam and represents deposition in shallow lagoon or upper seaward reef slope zones. However, it is apparent that deposition is below wave base (about 60 feet). Recent and fossil *Operculina* spp. from various locations around the Indo-Pacific (from Philippines to Australia) are common in lower energy conditions where fine sands accumulate (Haynes, 1981).

The *Cyclocylpeus* - *Operculina* assemblage is generally associated with a packstone deposition, which is frequently *Halimeda* rich (Table 11). This packstone contains common smaller foraminifera which are moldic or crystalline relics. These miliolids are associated with lower energy lagoonal environments with soft bottoms or algal mats. Representative genera of smaller foraminifera common in packstone include *Triloculina*, *Quinqueloculina*, *Bolivina*, *Amphisorus*, *Orbulina*, and globigerid types.

The planktonic forminifera *Orbulina universa* is common in recent Apra lagoon sediments and rare in deeper slope sediments. Many species of Miliolidae (particuarily *Quinqueloculina* and *Trioloculina* spp.) are common in recent lagoon sediments particularily in lagoon (100-200 feet) silty sands. These sediments are *Halimeda* rich sandy "muds" with limestone blocks, boulders, cobbles and recent coral rubble (branching and foliaceous). Sponges dominant substrata surfaces and contribute a substantial quantity of spicules. There are common byssate free-swinging bivalves on exposed substrata and semi-infaunal and infaunal bivalves in sediments. *Halimeda*, primarily *H. opuntia*, plates are locally abundant on upper and middle lagoon slopes, patch reef and sparse in lagoon sediments. A few large foraminifera are common in lower slope and lagoon sediments: *Marginopora vertebralis*, *Sorites marginalis*, *Amphisorus hemprichii*, *Heterostegina depressa*, *Amphistegina lessonii*, *A. radiata*, and *Spirolina arietina*.

The occurrence and morphological characteristics of sedentary foraminifera can be used to infer depositional environments (Table 8), including depth, zone and orientation of substrata type in relation to illumination (Table 9). The most conspicuous adherent foraminifera species in the cryptic interstices of the reef-flat complex is *Homotrema rubrum*. Specimens of living *H. rubrum* occur on upper littorial reef zone substrates and on material dredged from depths to 1000 feet. Additional foraminiferal species which are equally conspicuous components of the barrier reef cyrptofaunal assemblages are M. miniacea, C. utricularis and S. cylindricum. These species were particularly common on reef slope substrata as compared with cryptic surfaces of reef-flat substrata. Specimens occur on most substratum types with relatively high densities on shaded and cryptic cavity surfaces and occasionally on exposed surfaces of reef margin substrata (Table 9).

Gypsina spp. are common on exposed and shaded surfaces of natural substrata from reef-flat and seaward reef slope environments with a few small encrustrations on dredged substrata 500-1500 feet. Continuous encrustations of Gypsina can range in size from 50μ to 0.5 m.

The less frequent species are Planogypsina squamiformis, Acervulina inhaerens, Sporadotrema rubrum and Sphaerogypsina globulus. Sporadotrema rubrum and A. inhaerens occur on exposed and shaded surfaces of substrata from reef-flats to depths of 160 feet (Tables 8 and 9). Small specimens of S. globulus (75 to 500μ diameter) are occasionally found on natural substrata.

Foraminifera colonizing barrier reef substrata are similar in species composition and density to those of fringing reef substrata. The average densities of M. miniacea and H. rubrum are similar at a given depth from 20 to 60 feet, with an increase in density and decrease in surface coverage at the deeper depths. At 100 to 200 feet there are higher densities of M. minacea than H. rubrum. External test variations and coloration of M. miniacea and H. rubrum vary consistently within two general depth zones: specimens from the reef margin to 30 feet have robust or globose tests and darker red hues, whereas specimens from 35 feet to 200 feet generally have branching tests with light red to white hues. Sporadotrema cylindricum is uncommon on all natural substrata. Carpenteria monticlaris occurs in low densities on substrata from 35 to 200 feet and higher densities on dredged material (400 to 1000 feet).

Gypsina vesicularis and the variety plana are common encrusting species on corals in the Mariana limestone. Gypsina var. plana is a growth form which is characteristically found in deeper reef zones, lagoonal environments and seaward reef slope zone. This is the primary Gypsina species seen in LB core slabs. There are uncommon occurrences of Carpenteria monticularis, C. utricularis and C. proteiformis, which are frequently associated with Gypsina and boundstone. Carpenteria proteiformis is not located in shallow environments around Guam (Clayshulte, 1981a). This species has a depth range in other parts of the Indo-Pacific between 100 to 1000 feet. This species was found in LB33 at 45-63 feet in a skeletal packstone to wackestone subfacies. This subfacies also contains a Cycloclypeus - Operculina assemblage and deeper growth forms of Homotrema and Sporadotrema (sedentary foraminifera).

There is the possible occurrence of the larger foraminiferan, Miogypsinoides in LB33 at 18 to 63 feet and LB34 at 15 to 37 feet. There were a few generally poorly preserved fossils which resembled Miogypsinoides in both thin sections and slabs. This species is an indicator for a Miocene age. If these fossils are Miogypsinoides then the limestone is older than Mariana limestone (Table 2). However, more and better fossils and thin sections of this foraminiferan will need to be obtained before any conclusions can be made.

In LB cores and Mariana limestone for WB34 and WB35, there is a periodic occurrence of boundstone. There is a conspicuous encrusting foraminiferal component (Gypsina) as a binding agent, with the common absence of crustose corallines. The corals are mostly massive types. Greth frame works have been infilled with white, tan, orange and pink fine-grained matrix. Some of the corals show extensive borings and alternations form sponges, mollusks and arthropods. Larger borings are infilled with coarse crystalline sparry calcite. These boundstones are surrounded by and growing on Halimeda packstone and skeletal grainstone to wackestone. Generally, boundstone zones in the cores do not appear to represent shallow reef framework. Based on slab examinations and preliminary field surveys, these boundstone zones represent either coral community development on a seaward reef slope or lagoonal patch reefs.

Diagenesis

The Mariana limestone within the study area has undergone significant diagenetic modifications under marine phreatic, freshwater phreatic, and freshwater vadose conditions. Within the marine environment, carbonate sediments of the Mariana are lithified by cements similar in occurrence to that previously described for the modern reef complex. Peloidal micrite is the binding agent in skeletal packstones and wackestones and isopachous rim cements occur where little to no mud matrix is present. Relic structure of other marine cements is present primarily within coral growth framework and internal chambers of gastropod shells. Within the freshwater phreatic environment, nearly all interparticle porosity is occluded by the deposition of equant spar calcite. Sediments composed of metastable marine phases (primarily aragonite) have either converted to the stable calcite phase or have been partially or completely dissolutioned. This dissolution creates distinctive moldic porosity characteristic of the Mariana limestone (particularly Halimeda plates). Additional secondary porosity develops through the enlargement of skeletal molds into vugs and development of solution tubes and cavities. Only minor diagenetic alteration occurs within the freshwater vadose environment. Some additional solution has taken place near the present-day ground surface and travertine has been deposited along fracture walls and as linings within some solution tubes and voids. The overall bulk affects of diagenesis are 1) nearly total occlusion of primary porosity, 2) development of secondary porosity by dissolution, 3) replacement (neomorphism) of metastable skeletal mineralogies.

Marine Diagenesis

Several types of submarine cements are present in samples of Mariana limestone. Among these types are micrite, peloidal micrite, isopachous rim, and needle-like or fibrous. The latter usually is present in the form of radiaxial or radial fibrous void linings. In terms of porosity occlusion, isopachous rim cements are the most important. This cement type often occurs as multigeneration rims with radiaxial to radial fibrous crystal morphology and probably has a high magnesium calcite composition. Primary interparticle porosity, in many instances, has been completely occluded by relatively thick isopachous rim cements.

A submarine origin for the rim cements is suggested by:

1. Rims occur as a first generation cement on bioclasts and lining primary voids;
2. Rims either predate or alternate with marine internal sediment;
3. Rims form well developed triple junctions or polygonal sutures (Shinn, 1975); and
4. Rim morphology appears to be identical to modern observed submarine cements.

Iospachous rim cements are best preserved in Mariana cores from LB29 and WB35. Two distinctive rims are present, each composed of multiple generations of crystal growth (Plate 4A,B). The first generation is characterized by a radiaxial morphology (Kendall and Tucker, 1973; Bathurst, 1971) consisting of elongate bladed crystals oriented perpendicular to the growth substrate. Crystal habit, where decernible, shows a width increase away from the substrate and terminations that tend to be blunt or pyramidal in shape. Similar crystal morphology is described for cements observed in the fore-reef facies of Belize (James and Ginsburg, 1981). Individual crystal widths are highly variable, but generally are between 10 and 20 microns with lengths that often exceed 100 microns. Finer-sized equant crystal growth tends to occur at the base of the first generation rim; crystal size and elongation increases toward the open pore space.

The second generation isopachous rim cement consists of a radial fibrous crystal morphology with a cloudy appearance. Thin rim cement occurs either growing on the previously described rim or directly on skeletal grains or within primary voids. The cement is composed of more elongated crystals that do not tend to widen away from the growth substrate. Individual crystal widths are generally 10 microns or less, with lengths that vary from 80 to 150 microns, dependent on the degree of grain packing. In addition, crystal terminations tend to be blunt when visible. When viewed under crossed polarized light, the diffuse fibrous pattern of the cement creates a distinctive sweeping extinction. Well developed polygonal sutures are characteristic of this generation of isopachous rim cement.

Of less pervasive distribution is a radiaxial fibrous cement of probably marine origin that occurs within the growth framework of corals and chambers of gastropods. This cement often occludes the primary open pores of skeletal material. Cement fabrics and distribution appear to be identical to observed aragonite cements described for the modern reef complex.

The most pervasive cement within wackestones and packstones is micrite or peloidal micrite. Little can be said concerning this cement because of the very fine crystalline nature, which is usually beyond the resolution capacity of the light microscope. In the Mariana samples examined, the micrite matrix of sediments has nearly the same textural appearance as that observed in its modern counterpart. Based on this observation and on the preservation of the texture, it is assumed that the cement composition was at one time high magnesium calcite.

Meteoric Diagenesis

Tectonic uplift and/or eustatic sea level oscillations are major process responsible for exposing the Mariana limestone to a freshwater diagenetic environment. The Mariana has been affected by meteoric diagenesis in three important ways. First, primary porosity has been further reduced by the precipitation of blocky and dog-tooth sparry calcite cement. Second, preferential dissolution of aragonitic skeletal material has created secondary moldic and vuggy porosity. Finally, solution by chemically aggressive phreatic and vadose groundwater has created enlarged fractures, cavities, and, interconnected solution tubes (microcavernous to cavernous porosity).

The most obvious affect of exposure to freshwater environments is the precipitation of clear calcite spar cement within primary pore space and secondary molds and vugs. Crystal morphology is characterized by blocky shape, finer size near the pore boundary or growth substrate, size increase and prismatic development into pore space. Individual crystals very in size from fine to very coarse and often completely fill the void.

Another form of spar calcite is the product of the freshwater vadose environment. Travertine, often several inches thick, lines fractures and larger cavities and is relatively abundant in a zone near the ground surface. Travertine is also found in Mariana cores taken from bore-holes (LB29, WB34, and WB35) penetrating the present-day marine phreatic environment. This leads to the conclusion that the Mariana limestone beneath the modern reef complex was, at one time, exposed to the freshwater vadose diagenetic environment.

Halimeda plates, coral debris, and mollusk shell fragments have been selectively dissolutioned by groundwater undersaturated with respect to aragonite. Except where isopachous rim cements are pervasive, the general trend is removal of the original skeletal material and partial or complete replacement by spar calcite cement (Plate 4).

The absence of significant solution removal of skeletal material in Halimeda grainstones and packstones in some cores (LB29 and WB35) may be due to the inability of fresh groundwater to effectively migrate through tightly cemented marine sediments. Isopachous rim cements may act as a protective barrier to their host bioclasts. It would seem then, that there is at least some primary depositional and early marine diagenetic control of fresh groundwater-flow patterns.

An additional diagenetic change within the Mariana limestone is the conversion of metastable mineralogies into stable forms. The most notable is the neomorphism of coral skeletal material (Plate 4E). In all instances, coral exhibits a crystal mosaic under crossed polarized light. Skeletal details and previously precipitated marine cements have been preserved. In plane light, the growth framework of the coral, including internal sediment, is very similar to that observed in the modern reef complex.

Marine cements, particularly isopachous rim and fibrous aragonite cements, have undergone similar neomorphismasn coral growth framework. Under cross-polarized light the crystal mosaic of spar calcite precipitated within void spaces often extends unbroken into the adjacent marine cement fabric. Details of crystal morphology are usually well preserved (Plate 4D). In some cases, however, the previously formed marine cements do not escape destruction. Numerous thin sections from all bore-holes showed partial or complete dissolution of rim cements (Plate 4C). In most cases the first generation cement has been affected. Often sparry calcite cement has filled the rim mold in addition to occluding the original pore space.

CONCLUSIONS

Petrologic examination of core samples from Orote Peninsula were made to determine the affects of diagenesis on water-bearing properties of modern reef and Mariana limestones. The principle limestone unit of Orote Peninsula, as surface mapped by Tracey et al. (1964), is the reef facies of the Mariana limestone. There were also a few mapped outcrops of Agana argillaceous member of the Mariana limestone and Alifan limestone. Based on the geological information and general physiography of the Peninsula, it was assumed that Orote could be used as a model of the prominant limestone plateau of northern Guam. It was believed that an understanding of the occurrence of porosity and permeability in Orote Peninsula limestone could be directly applied to northern plateau limestones, since they were composed of similar depositional units. However, paleoecological examination of core samples and preliminary field investigations have shown Orote Peninsula is probably a fore-reef facies of Mariana. This type of limestone facies was not mapped on the northern plateau (Tracey et al., 1964) and was only identified (assumed to be a similar facies) in small outcrops along the southeast coast. The petrology of this fore-reef facies was not previously examined. Occurrence of the Miocene indicator larger foraminiferan, Miogypsinoides, suggested that some of the fore-reef facies was older than Mariana. However, before any definite conclusions can be made, more petrographic examinations will be required.

Porosity evolution was evaluated within the Orote Peninsula fore-reef facies by making comparisons with modern reef depositional environments. The Modern reef at Orote Peninsula is essentially a coral/algal boundstone and poorly sorted skeletal packstone. Internal sediment is normally a skeletal wackestone with a peloidal micrite matrix, uncommon fine grained packstone and rare mudstone. Micrite is the primary bonding agent. Porosity type include interparticle, intraparticle, shelter, fenestral and growth framework with extensive borings. Pore size ranges from micropores (<4µ) to megapores. Primary porosity is estimated between 25 to 50% with no secondary or solutionally produced porosity in modern reef depositional textures.

The Mariana limestone on Orote Peninsula has undergone diagenetic modification under marine phreatic, freshwater phreatic and freshwater vadose conditions. Marine diagenetic modifications from internal sediment fill, submarine cementation and borings have produced partial to complete occlusion of primary interparticle porosity. Marine sediments are lithified by cements similar to those found in the modern reef complex. Within the freshwater phreatic environment, nearly all interparticle porosity is occluded with some secondary porosity generation. There has also been preferential dissolution of, primarily, aragonitic clasts, which creates distinctive moldic porosity. There is only minor diagenetic alternation within the freshwater vadose environment.

At this time, the use of Orote Peninsula as a model of porosity and permeability occurrence in northern plateau limestones requires caution. Detailed petrographic examinations of Mariana limestone units of the northern plateau will need to be made in order to determine the comparability with the Orote limestone unit. However, the diagenetic processes which create and destroy porosity and permeability are similar for different limestone facies subjected to similar marine and freshwater environments. This research has provided an initial understanding of the development of diagenetic modifications of limestones ranging from modern reef to Mariana deposition.

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PLATE 1. Examples of depositional texture and composition of samples taken from the Modern reef complex. (A) Slabbed core from WB-28 at a depth of 14 feet. Massive coral encrusted with coralline algae. Internal sediment infills numerous primary pore spaces. Note the numerous borings, some exhibit geopedal fabric. Also note the algal associated vermetid gastropods. (B) Slabbed core from WB-27 at a depth of 36 feet. Coral rudstone partially encrusted with coralline algae. Note the abundance of large-sized pore spaces. Bar scales are in centimeters.


A

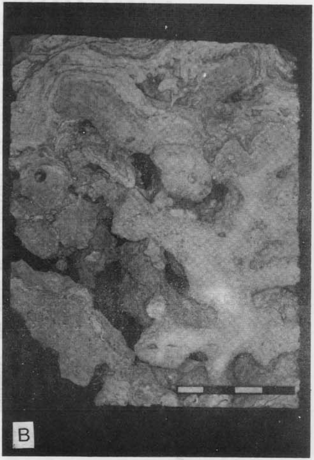
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PLATE 2. Microtextures, cement fabrics, and porosity types within the Modern reef complex. (A) Photomicrograph of a portion of thin section GWB35-2A. Silt-sized skeletal wackestone internal sediment within the growth framework of a massive coral. Some primary porosity remains, however most has been occluded by the internal sediment. Micrite is the major binding agent. Bar scale is 500 microns. (B) Photomicrograph of a portion of thin section GWB35-14. Highly bored mollusk shell in a skeletal packstone. Some borings contain internal sediment. Bar scale in 500 microns. (C) Photomicrograph of a portion of thin section GWB29-16B. Massive coral (right) encrusted with coralline algae and foraminifera. Growth framework of coral has been infilled by skeletal internal sediment. Porosity is mainly growth framework with minor interparticle porosity associated with the internal sediment. Bar scale is 500 microns. (D) Photomicrograph of a portion of thin section GWB29-22. Interparticle porosity occluded by blocky cement, composition unknown. Bioclasts are coral and algal fragments. Bar scale is 100 microns. (E) Photomicrograph of a portion of thin section GWB27-1A. Radial fibrous aragonite cement lining growth framework of massive coral. Cement appears to be an extension of the crystal structure of the coral skeleton. Bar scale is 100 microns. (F) Photomicrograph of a portion of thin section GWB29-11B. Fibrous cement (unknown composition) in interparticle pore space of a skeletal grainstone. Bar scale is 100 microns.

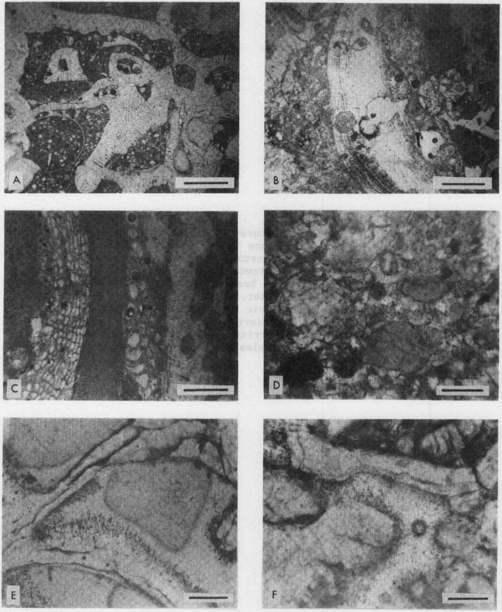
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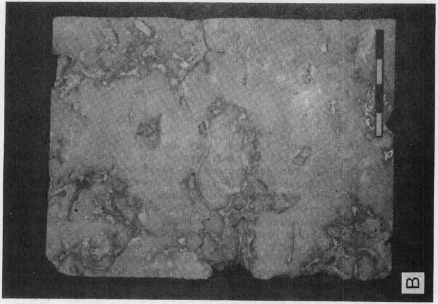
PLATE 3. Examples of diagenetic textures and porosity types of the Mariana limestone. (A) Slabbed core from WB-35 at a depth of 34 feet. Halimeda packstone to grainstone. Note the development of thick isopachous rim cements around Halimeda plates. Some primary interparticle porosity has been preserved. (B) Slabbed core from LB-35 at a depth of 17 feet. Skeletal packstone to wackestone has been exposed to meteoric diagenesis under both phreatic and vadose conditions. Secondary solution porosity evident; some pores lined with travertine and filled with sediment of non-marine origin. Bar scales are in centimeters.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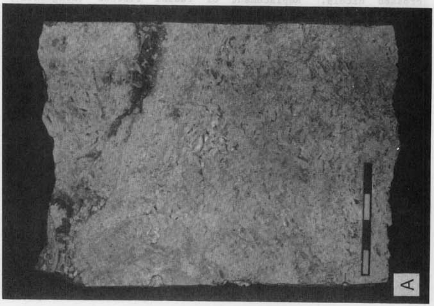
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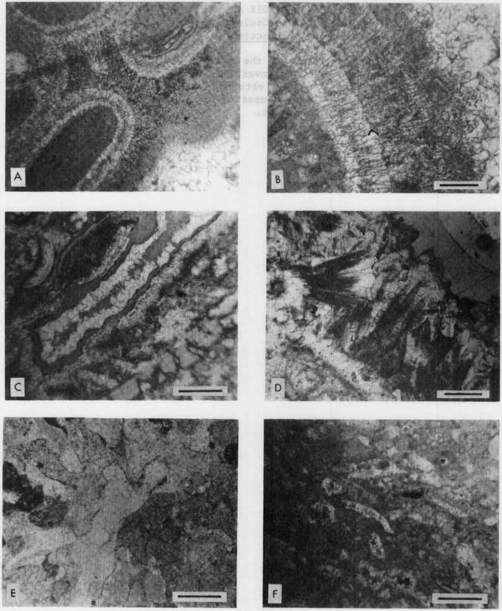
PLATE 4. Microtextures, cement fabrics, and porosity types within the Mariana limestone. (A) Photomicrograph of a portion of thin section GLB29-97. Two generations of isopachous rim cements of marine origin. Bioclasts are Halimeda plates. Large portion of interparticle pore space has been occluded by the marine cement, blocky spar calcite has filled in the remaining space (lower right). (B) closer view of rim cements. First rim is composed of radiaxial fibrous cement with bladed crystal morphology. Second rim is more radial fibrous with long needle-like crystals. May be magnesium calcite rim followed by aragonite. Bar scale is 100 microns. (C) Photomicrograph of a portion of thin section GLB29-29. Preferential dissolution of second generation rim cement in a skeletal packstone microfacies. Blocky spar calcite fills interior of pore space, empty space in pore center. Moldic porosity after marine cement. Bar scale is 500 microns. (D) Photomicrograph of a portion of thin section GLB33-34 under crossed nicols. Replacement of radial fibrous (aragonite?) cement by blocky spar calcite with relic crystal morphology. Open pore to the upper right. Bar scale is 100 microns. (E) Photomicrograph of a portion of thin section GLB35-17A under crossed nicols. Massive coral growth framework replaced by spar calcite mosaic showing original structure. Calice outlined by darker lines; former site of aragonite cement precipitation. Bar scale is 500 microns. (F) Photomicrograph of portion of thin section GLB35-35 under crossed nicols. Skeletal packstone with partially or completely occluded molds. Cement is blocky spar calcite. Bar scale is 500 microns.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APPENDIX A

Drillers and Geologic Logs

Introduction

Contained in this appendix are the driller's and geologic logs for those cored boreholes used by this investigation of the carbonate geology of Orote Point, Guam. The logs were obtained by C. E. Maguire, Inc (1979) as part of their geotechnical assessment of the Orote Point area for the construction of a Navy ammunition port.

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

CASING. 6" I.D. Flush Joint
CORE BARREL. 4" I.D. Double Tube
SOIL SAMPLER. 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

BORING FOREMAN. G. Nunnelley

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER NA HOURS

C-E MAGUIRE, INC.

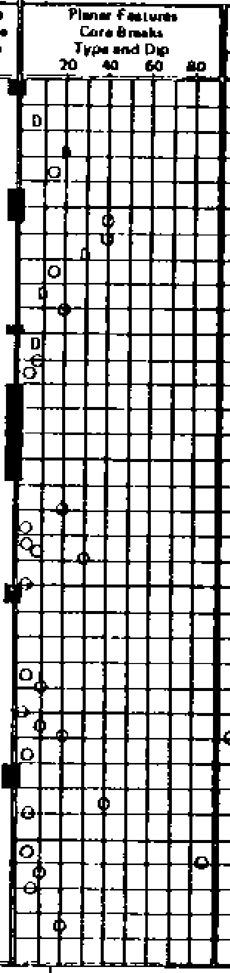
BORING LOG

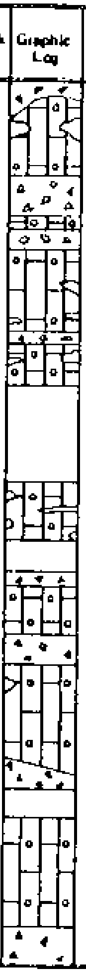
AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742-78-C-0077

BORING NO. WB-21
SHEET 1 OF 2
DATE STARTED: 12/14/78
DATE FINISHED. 12/15/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. -13.5
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW
COORDINATES. N 155,306 E 118,157

DRILLER'S LOG / GEOLOGIST'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From - To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6"-12"	12"-18"	Strata Change Depth Elev.	Surface of Core Breaks Remarks	Rock WX	Rock Descriptions
	3												Chips	L	(0.0' - 40.0') RECENT REEF DEPOSITS Physical condition: Generally porous with numerous open voids and fragments. White, buff and pink. Intact zones intermittent with detrital material. Moderately dense.
	1												Hackly		
	3												-DO-		
	3														
5	3	0-5	1	C	1	5	3.6	72	66						
	3														
	3														
	3												Hackly		
	3														
10	3	5-10	2	C	2	5	4.8	96	74				Open		
	3												Hackly		Chips and fragments 1" to 2"
	3												Open		
	2												-DO-		
	2														Void from 12.0' to 15.8'
15	2														
	2														
	2														
	3	10-18	2	C	3	8	4.3	53	82				Void		
	3														
20	3												Open		
	3														
	3														
	3	18-23	3	C	4	5	4.6	92	84						
	3														
25	3														
	3												Hackly		Hard tan coating on many surfaces from 24' to 38' rounded surfaces
	3												Open		
	3	23-28	4	C	5	5	4.6	92	86						
	3	28-29	Rockbit										Irregular		
30	3														
	3														
	1														
	1														
	2												Irregular		
35	3	29-35	4	C	6	6	4.1	68	61						3" to 4" pieces, coated.





NOTES:

SAMPLE TYPE. C = CORED S = SPOON
GROUND SURFACE TO 20.0 FT. USED 5 "CASING
FOOTAGE IN EARTH — FOOTAGE IN ROCK 40.0

CORE BREAKS SMOOTH		CORE BREAKS ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F - FILLINGS
S - SOFT
R - RUSTY
C - CLEAN

CORE BREAKS *
▮ CHIPS, LOST CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E - EXTREME
S - SEVERE
M - MODERATE
L - SLIGHT
F - FRESH

PLANAR FEATURES
C - CONTACT
F - FOLIATION
B - BEDDING
X - CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:
CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII
BORING FOREMAN: G. Nunnelley

CASING: 5" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

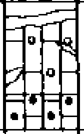
GROUND WATER OBSERVATIONS: AT __ FT. AFTER ____ HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. WB-27
SHEET 2 OF 2
DATE STARTED: 12/14/78
DATE FINISHED: 12/15/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. -13.6
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW
COORDINATES: N 156,306 E 118,167

DRILLER'S LOG													GEOLOGIST'S LOG									
Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample				RQD	Blows per 6" on Sampler		Strata Change Depth Elev	Planar Features Core Breaks Type and Dip 20 40 60 80	Surface of Core Breaks					Rock WX	Graphic Log	Rock Descriptions	Depth Below Surface
					No.	Pen. Ft.	Rec. Ft.	Rec. %		6" - 12"	12" - 18"			F	S	R	C	Remarks				
	3												■ ○					Open	L ↓			
	3												○					Hackly				
	3												○									
	3																	On void				
	3	35 - 40	5	C	7	5	3.7	73	75			40.0	◇								Change to unit 3 at 38.7 feet with cemented fragments.	
40												- 63.6									(40.0' - Terminated Hole)	40
45																						45
50																						50
55																						55
60																						60
65																						65
70																						70

NOTES:

SAMPLE TYPE C - CORED S - SPOON
GROUND SURFACE TO 20.0 FT. USED 5 "CASING
FOOTAGE IN EARTH
FOOTAGE IN ROCK 40.0

CORE BREAKS		
SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F - FILLINGS
S - SOFT
R - RUSTY
C - CLEAN

CORE BREAKS	
■	CHIPS, LOST, CORE, CAVITY
D	DRILLING BREAK
—	SLIPPERY

WEATHERING (WX)
E - EXTREME
S - SEVERE
M - MODERATE
L - SLIGHT
F - FRESH

PLANAR FEATURES
C - CONTACT
F - FOLIATION
B - BEDDING
X - CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD, POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL FILL

..RING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

BORING FOREMAN. K. Pond

CASING: 5" I.D. Flush Joint
CORE BARREL. 4" I.D. Double Tube
SOIL SAMPLER. 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER NA HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. WB 28
SHEET 1 OF 2
DATE STARTED: 12/12/78
DATE FINISHED. 12/14/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. −1.4
ENG. GEOLOGIST: W. Pitt
DATUM. MLLW
COORDINATES. N 165,132 E 110,414

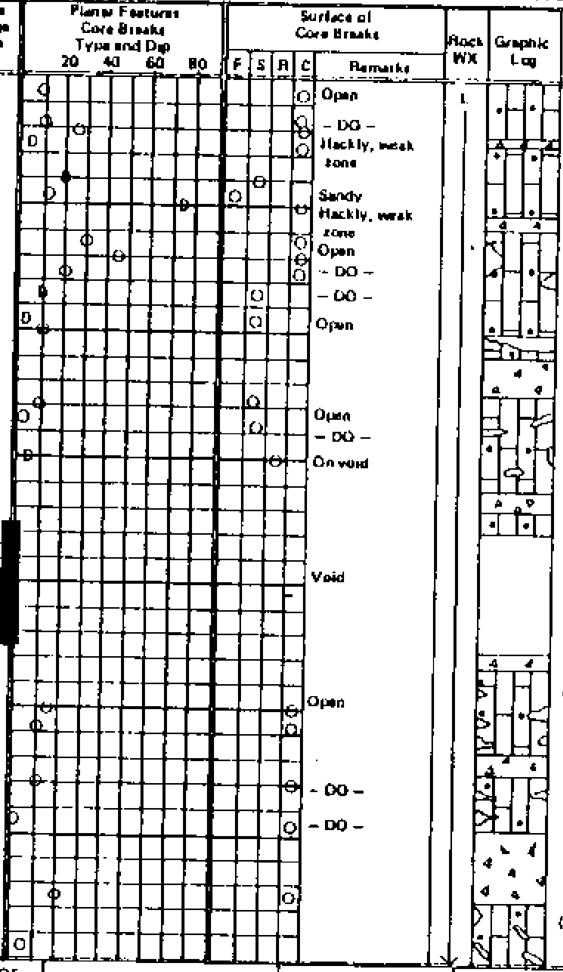
DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Run or Sample Pen. Ft.	Run or Sample Rec. Ft.	Run or Sample Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	Blows per 6" on Sampler 12" - 18"	Strata Change Depth Elev.
	10											
	10											
	5											
	5											
5	5	0 - 6	1	C	1	6	4.8	96	73			
	5											
	6											
	5											
	5											
10	5	6 - 10	1 - 2	C	2	6	4.7	95	45			
	6											
	6											
	6											
	6											
15	5	10 - 15	2	C	3	6	4.8	97	57			
	7											
	7											
	7											
	7											
20	7	16 - 20	3	C	4	6	2.6	60	40			
	10											
	10											
	10											
	10											
25	10	20 - 25	3 - 4	C	5	6	2.6	60	34			
	10											
	10											
	10											
	10											
30	10	26 - 30	4	C	6	6	4.8	97	46			
	10											
	10											
	10											
	10											
35	10	30 - 35	5	C	7	6	4.8	97	38			

NOTES:

SAMPLE TYPE C – CORED S – SPOON
GROUND SURFACE TO 30.0 FT., USED 5 "CASING
FOOTAGE IN EARTH -- FOOTAGE IN ROCK 37.5

GEOLOGIST'S LOG



Surface of Core Breaks – Remarks:

Open
– DO –
Hackly, weak zone
Sandy
Hackly, weak zone
Open
– DO –
– DO –
Open
Open
– DO –
On void
Void
Open
– DO –
– DO –

Rock Descriptions	Depth Below Surface
(0.0' - 37.5') RECENT REEF DEPOSITS Physical Condition: Generally porous with numerous open voids. Intact zones usually matrix of coral heads with detrital material in interstices. White, pink and buff. Moderately dense.	
	5
	10
	15
(16.3' - 16.9') Void with fragments	
(17.6' - 22.5') Void, no recovery	
	20
(22.6' - 37.6') Very porous with numerous large voids (unit 4) and fragments (unit 5) joints typically open and very irregular	
	25
	30
(32.5' - 35.0') Very porous	
	35

CORE BREAKS SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R – RUSTY
C – CLEAN

CORE BREAKS
▮ CHIPS, LOST CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:
CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII
BORING FOREMAN: K. Pung

CASING. 6" I.D. Flush Joint
CORE BARREL. 4" I.D. Double Tube
SOIL SAMPLER. 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER NA HOURS

C-E MAGUIRE, INC.
BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE   GUAM, MARIANA ISLANDS
PACIFIC DIVISION   NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. WB-28
SHEET 2 OF 2
DATE STARTED: 12/12/78
DATE FINISHED: 12/14/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. -1.4
ENG. GEOLOGIST: W. Pin
DATUM. MLLW
COORDINATES: N 166,132   E 110,414

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Run or Sample Pen. Ft.	Run or Sample Rec. Ft.	Run or Sample Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	Blows per 6" on Sampler 12" - 18"	Strata Change Depth Elev.
	10											
	10											37.6
	10	35 - 37.6	6	C	8	2.6	2.6	100	80			-38.9
40												
45												
50												
55												
60												
65												
70												

GEOLOGIST'S LOG

Planar Features Core Breaks Type and Dip 20 40 60 80	Surface of Core Breaks F	S	R	C	Remarks	Rock WX	Graphic Log	Rock Descriptions	Depth Below Surface
					Open	L		Fragments at top of run 8.	
◇ ○				○	Open				
								(37.6 Terminated Hole)	
									40
									45
									50
									55
									60
									65
									70

NOTES:

SAMPLE TYPE C - CORED S - SPOON
ACE TO 300 FT. USED 5 CASING

CORE BREAKS SMOOTH		CORE BREAKS ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S - SOFT
R RUSTY
C - CLEAN

CORE BREAKS,	
■	CHIPS, LOST CORE, CAVITY
○	DRILLING BREAK
—	SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M - MODERATE
L – SLIGHT
F - FRESH

PLANAR FEATURES
C – CONTACT
F - FOLIATION
B - BEDDING
X - CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

...ING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

BORING FOREMAN: M. Leusu

CASING: 5" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER NA HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. WB-29
SHEET 1 OF 2
DATE STARTED: 12/8/78
DATE FINISHED: 12/9/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. -11.9
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW
COORDINATES N 156,291 E 118,679

DRILLER'S LOG

Depth Below Surface	Casing Time Min./Ft.	Run or Sample Depth From – To	Core Box No	Type of Sample	Run or Sample				RQD	Blows per 6" on Sampler		Strata Change Depth Elev.
					No.	Pen. Ft.	Rec. Ft.	Rec. %		6" - 12"	12" - 18"	
	4											
	4											
	3											
	4											
5	4	0.0 - 4.5	1	C	1	4.5	3.6	80	62			
	4											
	4											
	4											
	4											
10	4	4.6 - 9.6	1 - 2	C	2	5	4.8	96	78			
	3											
	3											
	3											
	3											
15	4	9.6 - 14.6	2	C	3	5	4.8	85	73			
	4											
	3											
	3											
	3											
20	3	14.6 - 19.6	3	C	4	5	4.3	87	68			
	3											
	3											
	3											
	3											
25	3	19.6 - 24.5	3 - 4	C	5	5	4.6	96	26			
	3											
	3											
	3											
	4											
30	4	24.6 - 29.6	4	C	6	5	4.3	87	68			
	3											
	3											
	3											
	3											
35	3	20.6 - 34.6	5	C	7	5	2.4	48	20			

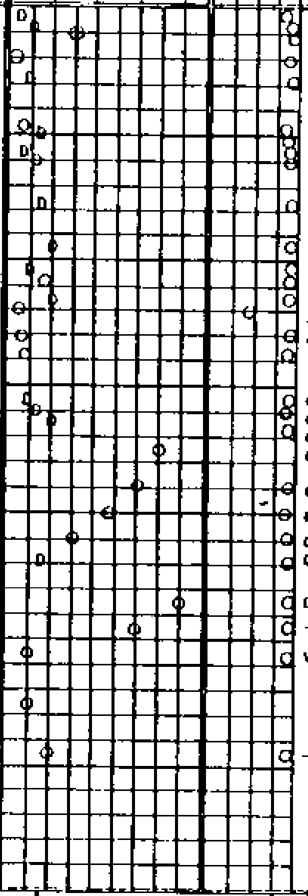
NOTES:

SAMPLE TYPE: C = CORED S = SPOON
GROUND SURFACE TO 40.0 FT. USED 5 " CASING
FOOTAGE IN EARTH – FOOTAGE IN ROCK 44.6

GEOLOGIST'S LOG

Planar Features Core Breaks Type and Dip 20 40 60 80

Surface of Core Breaks F S R C

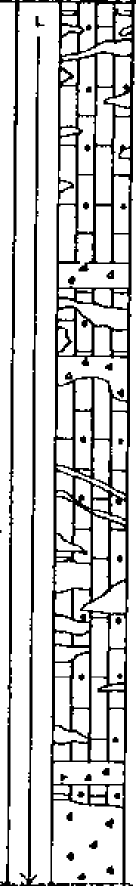


Remarks

On void
– DO –
– DO –
Open
On void
– DO –
Hackly
– DO –
On void
– DO –
– DO –
Open
Weak zone
Sandy
Open
– DO –
On void
Open
On void
Open
Open
On void
Open
On void
Open
– DO –
Void
– DO –

Rock WX

Graphic Log



Rock Descriptions

(0.0' - 44.6') RECENT REEF DEPOSITS

(0.0' - 22.0') Moderately dense coral containing many intact coral heads and algae cementation.

Physical condition: Numerous rounded voids, relatively smooth on void surfaces; most with white to buff precipitated minerals up to ½ in. thickness. Rock becomes more porous with depth.

(22.0' - 25.0') Large open voids, many cross core; generally smooth on surfaces

(26.0' - 44.6') Decrease in rock quality with large voids. Isolated 4" to 6" intact pieces. Open, weak matrix structure.

Depth Below Surface
5
10
15
20
25
30
35

CORE BREAKS		
SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R – RUSTY
C – CLEAN

CORE BREAKS	
■	CHIPS, LOST CORE, CAVITY
D	DRILLING BREAK
—	SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS-BEDDING

GRAPHIC LOG

☒	UNIT 1 HARD, DENSE ROCK
▥	UNIT 2 HARD, POROUS ROCK
▥	UNIT 3 MEDIUM HARD, DENSE ROCK
▥	UNIT 4 MEDIUM HARD POROUS ROCK
▨	UNIT 5 MEDIUM HARD, BROKEN ROCK
☐	OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

CASING: 5" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb Hammer Falling 30 in.

BORING FOREMAN: M. Louis

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER NA HOURS

C-E MAGUIRE, INC.
BORING LOG
AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. WB-29
SHEET 2 OF 2
DATE STARTED: 12/8/78
DATE FINISHED: 12/9/78
SOILS ENGINEER: J. Meynard
SURFACE ELEV. −11.9
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW
COORDINATES N 155,291 E 188,579

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Run or Sample Pen. Ft.	Run or Sample Rec. Ft.	Run or Sample Rec. %	RQD	Blows per 6" on Sampler 6"-12"	Blows per 6" on Sampler 12"-18"	Strata Change Depth Elev.
	3											
	3											
	3											
	3											
40	3	34.5 - 39.5	6	C	8	5	2.8	55	20			
	3											
	3											
	3											
	3											
45	3	39.5 - 44.5	6	C	9	5	2.3	47	38			44.6 − 56.4
50												
55												
60												
65												
70												

GEOLOGIST'S LOG

Planar Features Core Breaks Type and Dip 20 40 60 80	Surface of Core Breaks F S R C	Remarks	Rock WX	Rock Descriptions	Depth Below Surface
			L	Isolated unit 4 material with detrital fragments.	
◇	◇	Weak zone			40
				(44.5' - Terminated Hole)	45
					50
					55
					60
					65
					70

NOTES:

SAMPLE TYPE C CORED S - SPOON
SURFACE TO 40.0 FT, USED 5 "CASING

CORE BREAKS SMOOTH		CORE BREAKS ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R – RUSTY
C – CLEAN

CORE BREAKS *

▮	CHIPS, LOST CORE, CAVITY
o	DRILLING BREAK
—	SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

BORING FOREMAN: M. Lemau

CASING 6" I.D. Flush Joint
CORE BARREL 4" I.D. Double Tube
SOIL SAMPLER 1 3/8" I.D.
Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS. AT __ FT AFTER NA HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. W0-31
SHEET 1 OF 3
DATE STARTED. 11/23/78
DATE FINISHED. 12/27/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. −0.8
ENG. GEOLOGIST. W. Pitt
DATUM: MLLW

COORDINATES. N 155,020 E 118,612

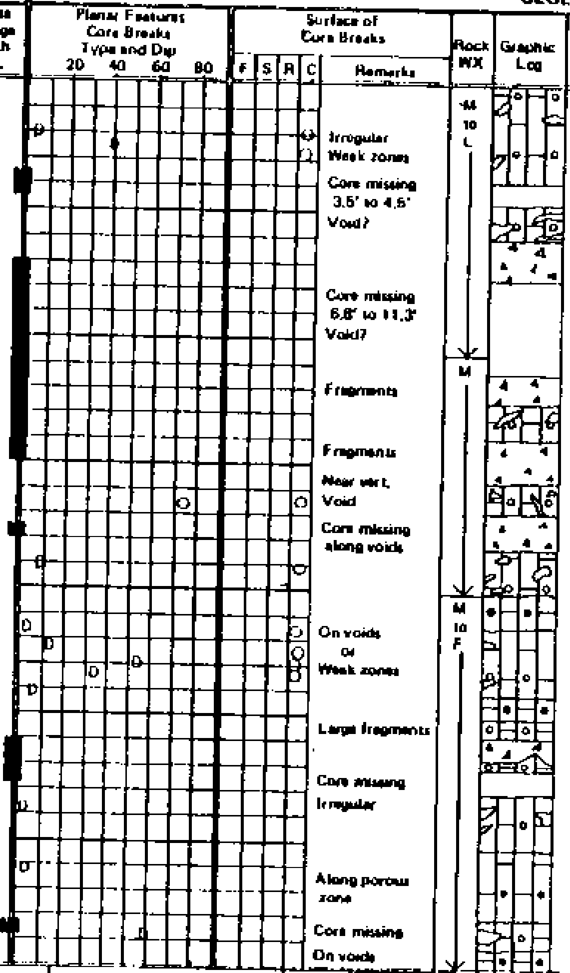
DRILLER'S LOG

Depth Below Surface	Curing Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	12" - 18"	Strata Change Depth Elev.
	4											
	4											
	3											
	3											
5	4	0 - 5	1	C	1	5	4	80	80			
	3											
	3											
	2											
	1											
10	1	5 - 10	1	C	2	5	1.7	33	8			
	1											
	1											
	2											
	2											
15	1	10 - 15	2	C	3	5	2.6	53	15			
	3											
	2											
	2											
	2											
20	2	15 - 20	2	C	4	5	4.1	83	60			
	3											
	3											
	3											
	3											
25	3	20 - 25	3	C	5	5	4.7	96	66			
	3											
	3											
	2											
	3											
30	3	25 - 30	3 - 4	C	6	5	4.2	86	66			
	3											
	3											
	3											
	3											
35	3	30 - 35	4	C	7	6	3.2	65	66			

NOTES:

SAMPLE TYPE. C - CORED S - SPOON
GROUND SURFACE TO 45.0 FT., USED 5 "CASING
FOOTAGE IN EARTH --- FOOTAGE IN ROCK 106

GEOLOGIST'S LOG



Remarks:

Irregular
Weak zones
Core missing 3.5' to 4.5' Void?
Core missing 6.8' to 11.3' Void?
Fragments
Fragments
Near vert.
Void
Core missing along voids
On voids or Weak zones
Large fragments
Core missing
Irregular
Along porous zone
Core missing
On voids

Rock Descriptions

(0.0' - 47.4') RECENT REEF DEPOSITS
Generally moderately hard, buff porous to very porous coral.
(0.0' - 6.0') Porous coral. Generally intact with occasional weaker, loosely cemented zones

(6.0' - 10.0') Porous, with many voids, several zones up to a few feet consist of fragments or lost core

Porous, many voids, fragment zones to several feet, largest pieces 8 inches.

(18.0' - 30.0') More massive, intact pieces to about 1'.

(30.0' - 35.0') Generally more massive with porous zone from 33.0' to 34.0'.

Depth Below Surface
5
10
15
20
25
30
35

CORE BREAKS

SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
- F – FILLINGS
- S – SOFT
- R RUSTY
- C · CLEAN

CORE BREAKS*
- ▮ CHIPS, LOST CORE, CAVITY
- D DRILLING BREAK
- — SLIPPERY

WEATHERING (WX)
- E – EXTREME
- S – SEVERE
- M · MODERATE
- L – SLIGHT
- F – FRESH

PLANAR FEATURES
- C – CONTACT
- F – FOLIATION
- B – BEDDING
- X · CROSS-BEDDING

GRAPHIC LOG
- UNIT 1 HARD, DENSE ROCK
- UNIT 2 HARD, POROUS ROCK
- UNIT 3 MEDIUM HARD DENSE ROCK
- UNIT 4 MEDIUM HARD POROUS ROCK
- UNIT 5 MEDIUM HARD, BROKEN ROCK
- OVERBURDEN SOIL FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

BORING FOREMAN: M. Lausau

CASING: 6" I.D. Flush Joint
CORE BARREL. 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT __ FT AFTER NA HOURS

C-E MAGUIRE, INC.

BORING LOG

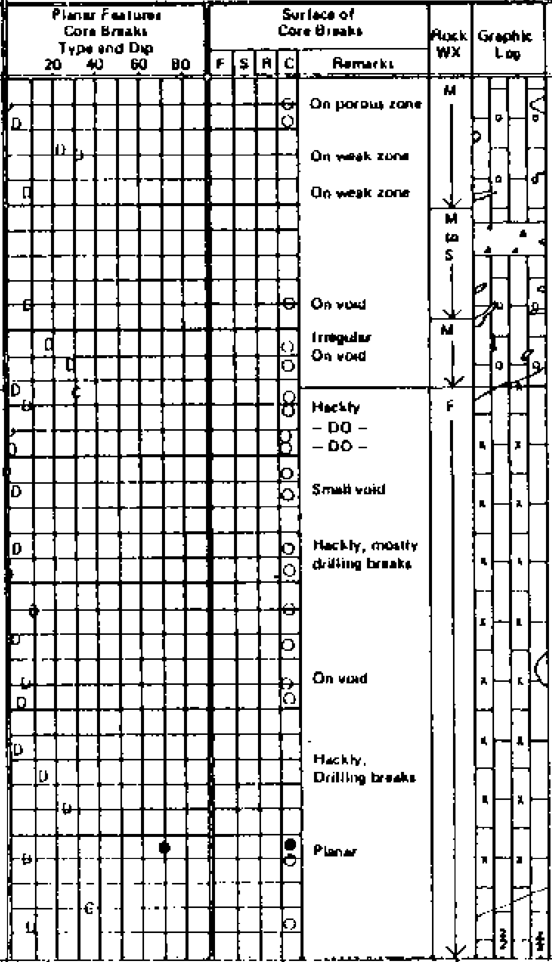
AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. WB-31
SHEET 2 OF 3
DATE STARTED: 11/23/78
DATE FINISHED. 12/27/78
SOILS ENGINEER: J. Meynerd
SURFACE ELEV. −0 8
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW
COORDINATES. N 155,020 E 118,612

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	12" - 18"	Strata Change Depth Elev.
	4											
	3											
	4											
	4											
40	4	36 - 40	6	C	7	5	6	100	80			
	4											
	4											
	3											
	4											
45	4	40 - 45	5 - 6	C	8	5	4.7	95	66			
	4											
	4											47.4
	4											− 48.2
	4											
50	4	46 - 50	6 - 7	C	9	5	6	100	80			
	4											
	4											
	5											
	6											
55	6	50 - 55	7	C	10	5	4.5	90	80			
	7											
	7											
	7											
	7											
60	7	55 - 60	8	C	11	5	5	100	100			
	7											
	7											
	7											
	7											
65	7	60 - 65	8 - 9	C	12	5	5	100	100			
	7											
	7											
	7											
	7											
70	7	65 70	9 - 10	C	13	5	4 8	96	96			

GEOLOGIST'S LOG



Remarks:
- On porous zone
- On weak zone
- On weak zone
- On void
- Irregular On void
- Hackly
- – DO –
- – DO –
- Small void
- Hackly, mostly drilling breaks
- On void
- Hackly, Drilling breaks
- Planar

Rock WX: M; M to S; M; F

Rock Descriptions

Generally porous to moderately hard coral. Drilling breaks occur at weak or loosely cemented zones and voids.

(40.8' - 42.0') Moderately fractured along voids.

(47.4' - 105') MARIANA LIMESTONE
Very hard, buff to white coralline limestone
Physical condition. Generally massive, slightly porous, intact, fresh internally. Occasional hackly drilling breaks occur across small voids or weaker zones.

NOTE. (68.0' - 70.7') Brown precipitated minerals (gouge like) enclose limestone fragments. Generally intact, fresh internally

Depth Below Surface
40
45
50
55
60
65
70

NOTES:

SAMPLE TYPE: C - CORED S - SPOON
USED 5 "CASING

CORE BREAKS		
SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F - FILLINGS
S - SOFT
R - RUSTY
C - CLEAN

CORE BREAKS
CHIPS, LOST CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E - EXTREME
S - SEVERE
M - MODERATE
L - SLIGHT
F - FRESH

PLANAR FEATURES
C - CONTACT
F - FOLIATION
B - BEDDING
X - CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD,
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 6 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

BORING FOREMAN. M. Leasau

CASING: 6" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS AT __ FT. AFTER NA HOURS

C-E MAGUIRE, INC.
BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. WB 31
SHEET 3 OF 3
DATE STARTED: 11/23/78
DATE FINISHED. 12/27/78
SOILS ENGINEER. J. Meynard
SURFACE ELEV. 0.8
ENG. GEOLOGIST W. Pitt
DATUM: MLLW
COORDINATES. N 166,020 E 118,612

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	12" - 18"	Strata Change Depth Elev.
	2											
	0											
	0											
	0											
	3	70 - 75	10	C	14	5	68	13	8			
75												
80												
85												
90												
95												
100	0											
	0											
	6											
	7											
	7											
105	7	99 - 105	10	C	16	6	4	68	62			106 106.8

NOTES:

SAMPLE TYPE. C = CORED S - SPOON
GROUND SURFACE TO 45.0 FT. USED 6 "CASING
FOOTAGE IN EARTH
FOOTAGE IN ROCK 105

GEOLOGIST'S LOG

Planar Features Core Breaks Type and Dip 20 40 60 80	Surface of Core Breaks F S R C	Remarks	Rock WX	Graphic Log	Rock Descriptions	Depth Below Surface
		80° Void surface	F		(70.7' - 99.0') Void, no recovery NOTE: Drill rods dropped in borehole 28.3 feet Drilling resumed at 99.0 feet	
						75
						80
		Void 70.7' - 99.0'		Void	Void, no recovery	
						85
						90
						95
D	O O		F		(99.0' - 106.0') Brown precipitated gouge like material encloses limestone fragments. Intact, generally fresh, massive.	100
D	O	Irregular On void				
D	O				(106.0' - Terminated Hole)	105

CORE BREAKS SMOOTH		CORE BREAKS ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R – RUSTY
C – CLEAN

CORE BREAKS
▮ CHIPS, LOST CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

BORING FOREMAN. G. Morris

CASING. 6" I.D. Flush Joint
CORE BARREL 4" I.D. Double Tube
SOIL SAMPLER. 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT __ FT. AFTER N/A HOURS

C-E MAGUIRE, INC.

BORING LOG

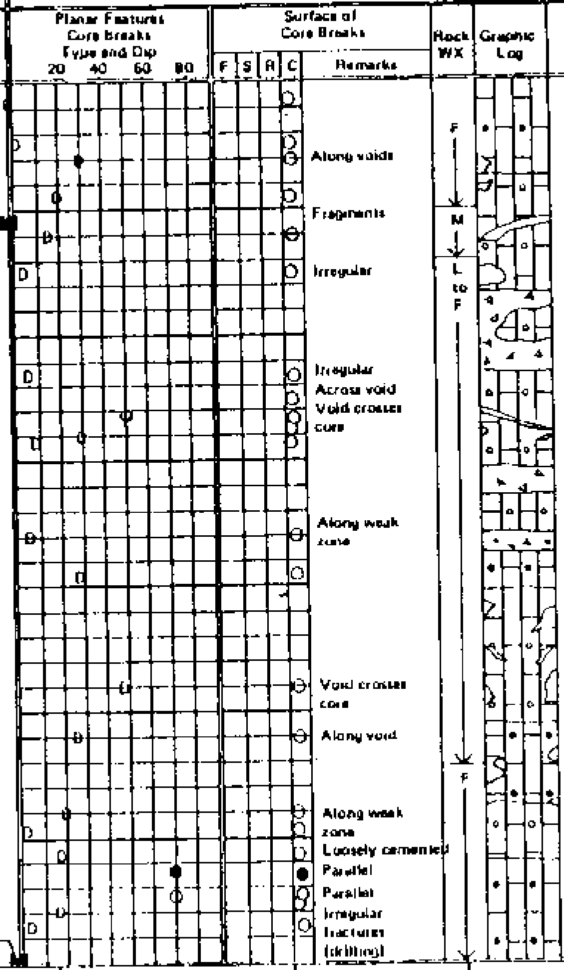
AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. WB-34
SHEET 1 OF 2
DATE STARTED: 11/26/78
DATE FINISHED: 11/26/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. − 0 7
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW
COORDINATES. N 155,046 E 118,317

DRILLER'S LOG

Depth Below Surface	Coring Time Min /Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	12" - 18"	Strata Change Depth Elev.
	7											
	7											
	7											
	7											
5	7	0 - 5	1	C	1	5	5	100	89			
	7											
	7											
	7											
	7											
10	7	5 - 10	1-2	C	2	5	4	80	40			
	7											
	7											
	7											
	7											
15	7	10 - 16	2-3	C	3	5	5	100	73			
	6											
	6											
	7											
	7											
20	7	15 - 20	3	C	4	5	4.5	90	72			
	8											
	8											
	9											
	7											
25	7	20 - 25	4	C	5	5	4.4	88	63			
	7											
	7											
	7											
	6											
30	7	26 - 30	4-5	C	6	5	3.6	72	48			
	9											
	9											
	9											
	9											35.0
	9	30 - 35	5	C	7	5	5	100	98			−36.7

GEOLOGIST'S LOG



Remarks:
Along voids
Fragments
Irregular
Irregular
Across void
Void crosses core
Along weak zone
Void crosses core
Along void
Along weak zone
Loosely cemented
Parallel
Parallel
Irregular fractures (drilling)

Rock Descriptions	Depth Below Surface
(0.0' - 35.0') RECENT REEF DEPOSITS Generally moderately dense to porous coral. Physical condition. Primarily detrital to loosely cemented, voids are numerous.	
	5
Porous to weakly cemented, several large voids, numerous breaks along voids or weak zones.	
	10
	15
	20
More massive than above, with several voids. Numerous drilling breaks along voids.	
	25
Massive, with only occasional small void or loosely cemented zone	
	30
	35

NOTES:

SAMPLE TYPE C - CORED S - SPOON
GROUND SURFACE TO 30.0 FT. USED 5 " CASING
FOOTAGE IN EARTH
FOOTAGE IN ROCK 60.0

CORE BREAKS

SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS

F - FILLINGS
S - SOFT
R - RUSTY
C - CLEAN

CORE BREAKS,

▙	CHIPS, LOST CORE, CAVITY
D	DRILLING BREAK
—	SLIPPERY

WEATHERING (WX)

E - EXTREME
S - SEVERE
M - MODERATE
L - SLIGHT
F - FRESH

PLANAR FEATURES

C - CONTACT
F - FOLIATION
B - BEDDING
X - CROSS BEDDING

GRAPHIC LOG

[X]	UNIT 1 HARD, DENSE ROCK
[£]	UNIT 2 HARD, POROUS ROCK
[•]	UNIT 3 MEDIUM HARD DENSE ROCK
[o]	UNIT 4 MEDIUM HARD POROUS ROCK
[△]	UNIT 5 MEDIUM HARD BROKEN ROCK
☐	OVERBURDEN SOIL, FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

BORING FOREMAN. G. Morris

CASING. 6" I.D. Flush Joint
CORE BARREL. 4" I.D. Double Tube
SOIL SAMPLER. 1 3/8" I.D.
Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT __ FT. AFTER N/A HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

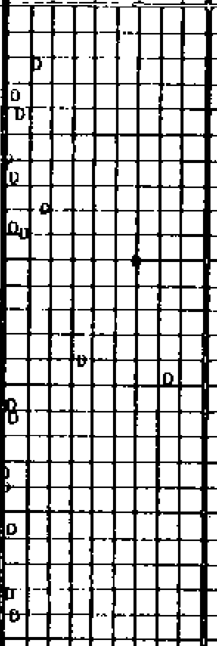
BORING NO. WB-34
SHEET 2 OF 2
DATE STARTED: 11/26/78
DATE FINISHED: 11/28/78
SOILS ENGINEER: J. Meynard
SURFACE ELEV. -0.7
ENG. GEOLOGIST. W. Pitt
DATUM: MLLW
COORDINATES. N 166,046 E 118,317

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From - To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	12" - 18"	Strata Change Depth Elev.
	7											
	7											
	7											
	7											
40	7	35 - 40	6	C	8	5	4.9	98	98			
	7											
	7											
	7											
	7											
45	7	40 - 45	6-7	C	9	5	5	100	100			
	7											
	7											
	7											
	6											
50	6	45 - 50	7-8	C	10	5	4.8	96	96			
	8											
	8											
	8											
	8											
55	8	50 - 55	8	C	11	5	5	100	100			
	8											
	8											
	8											
	8											
60	8	65 - 60	8 9	C	12	5	5	100	100			60.0 - 60.7
65												
70												

GEOLOGIST'S LOG

Planar Features Core Breaks Type and Dip



Surface of Core Breaks: Remarks
Hackly
- DO -
- DO -
- DO -
Across void
Across void
Irregular, hackly
Irregular along voids
- DO -
Across void
- DO -
Hackly
Hackly
- DO -

Rock WX / Graphic Log

Rock Descriptions	Depth Below Surface
(35.0' - 60.0') MARIANA LIMESTONE Buff to white, hard recrystallized coralline limestone. Physical condition: Generally fresh, massive with a few open voids. Voids have travertine on surfaces.	
	40
Numerous small voids and fissures are partially to totally infilled with precipitated minerals (travertine) and/or red cemented "soil" like material.	45
Rock is massive, fresh internally.	50
	55
(60.0' - Terminated Hole)	60
	65
	70

NOTES.

SAMPLE TYPE. C - CORED S - SPOON
GROUND SURFACE TO 30.0 FT. USED 6 "CASING.
FOOTAGE IN EARTH - FOOTAGE IN ROCK 60.0

CORE BREAKS SMOOTH		CORE BREAKS ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F FILLINGS
S SOFT
R - RUSTY
C CLEAN

CORE BREAKS
▨ CHIPS, LOST
CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E - EXTREME
S SEVERE
M MODERATE
L - SLIGHT
F - FRESH

PLANAR FEATURES
C - CONTACT
F FOLIATION
B BEDDING
X - CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

CASING: 6" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

BORING FOREMAN: I. M. Lamas

GROUND WATER OBSERVATIONS. AT ___ FT. AFTER N/A HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. WB-35
SHEET 1 OF 3
DATE STARTED: 11/8/78
DATE FINISHED: 11/12/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. - 1.1
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW

COORDINATES N 154,818 E 118,175

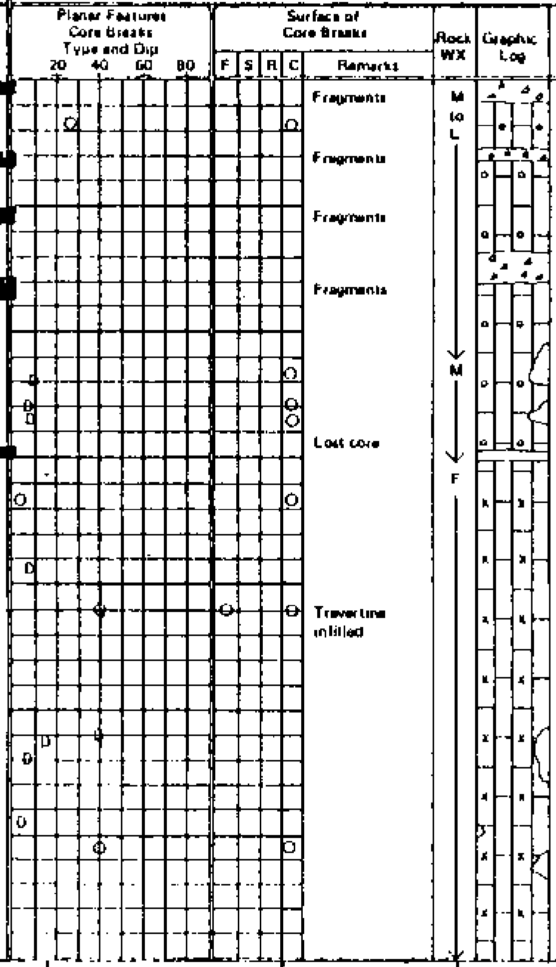
DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	12" - 18"	Strata Change Depth Elev.
	–											
	–											
	–											
	–											
5	5	0 - 6	1	C	1	6	4.5	90	43			
	1.5											
	2											
	1											
	1.5											
10	2	6 - 10	1-2	C	2	6	4	80	23			
	1.5											
	2.5											
	2.5											
	2.5											
15	2	10 - 14.5	2	C	3	4.4	3.8	78	70			
	3											
	4											
	4											
	4											
20	4	15 - 20	3	C	4	6	4.7	95	95			
	4											
	4											
	7	20 - 22.5	3	C	5	2.6	2.4	96	96			
	4											
25	4	22.5 - 25	4	C	6	2.5	2.5	100	86			
	4											
	4											
	4											
	4											
30	4	25 - 29.3	4	C	7	4.3	4.3	100	100			
	4	29.3 - 30	5	C	8	0.7	0.7	100	100			
	4											
	4											
	4											
35	4	30 - 35	5	C	9	5	5.	100	83			

NOTES.

SAMPLE TYPE C - CORED S - SPOON
GROUND SURFACE TO 16.0 FT. USED 5 " CASING
[illegible] FOOTAGE IN ROCK 100.0

GEOLOGIST'S LOG



Rock Descriptions	Depth Below Surface
(0.0' - 16.0') RECENT REEF DEPOSITS Moderately hard buff to white, porous to slightly porous coral. Poorly to well cemented. Local zones up to 1 foot consist of fragments.	
	5
(10.0' - 14.5') Coral porous with occasional open voids.	10
(15.0' - 100.0') MARIANA LIMESTONE Very hard buff to light pink, slightly porous, recrystallized coralline limestone. Physical condition: Generally massive, intact with minor drilling breaks and occasional open voids.	15
	20
Small voids at 29.6' and 30.6 feet.	25
	30
	35

CORE BREAKS SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	▢
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F - FILLINGS
S - SOFT
R - RUSTY
C - CLEAN

CORE BREAKS
▮ CHIPS, LOST CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E EXTREME
S - SEVERE
M MODERATE
L - SLIGHT
F - FRESH

PLANAR FEATURES
C - CONTACT
F - FOLIATION
B - BEDDING
X CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

CASING: 5" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

BORING FOREMAN: M. Lasua

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER N/A HOURS

C-E MAGUIRE, INC.

BORING LOG

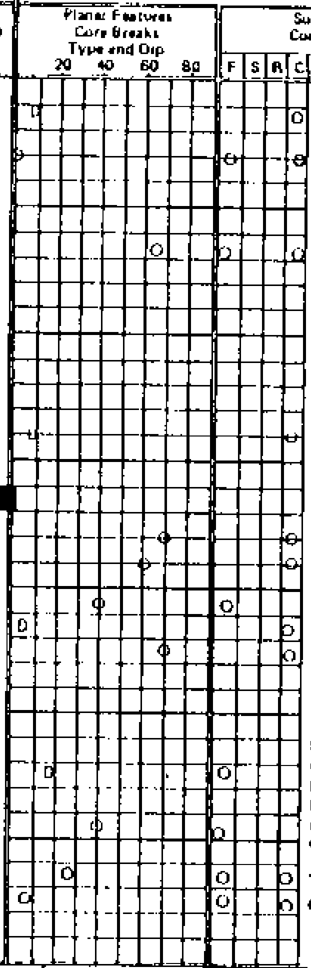
AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. WB-35
SHEET 2 OF 3
DATE STARTED: 11/8/78
DATE FINISHED: 11/12/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. – 1.1
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW
COORDINATES: N 164,918 E 118,176

DRILLER'S LOG

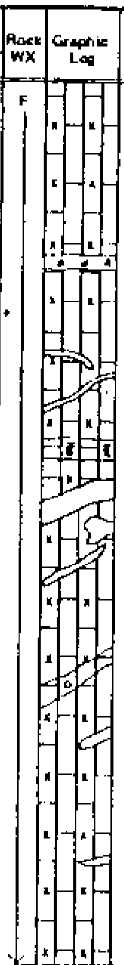
Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Run or Sample Pen. Ft.	Run or Sample Rec. Ft.	Run or Sample Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	Blows per 6" on Sampler 12" - 18"	Strata Change Depth Elev
	4											
	4											
	4.5											
	5											
40	4	35 - 40	6	C	10	5	5	100	100			
	4											
	4											
	3.5											
	4											
45	4	40 - 45	6-7	C	11	5	5	100	92			
	4											
	4											
	4											
	4											
50	4	45 - 50	7-8	C	12	5	5	100	95			
	4											
	3											
	3											
	4											
55	4	50 - 55	8	C	13	5	4	80	48			
	4											
	4											
	2.5											
	3											
60	3	55 - 60	0	C	14	5	5	100	86			
65		60 - 65	9 - 10	C	16	5	5	100	92			
70		65 - 70	10-11	C	16	5	5	100	100			

GEOLOGIST'S LOG



Remarks:

- Travertine on surface
- Travertine on surface
- Core lost
- Soft powdery wx effects
- Soft, powdery wx effects
- Partially healed by travertine, soft, "soil" on surface
- Travertine On surface



Rock Descriptions

Rock Descriptions	Depth Below Surface
Very hard, slightly porous to nonporous limestone, as above.	
	40
Beginning at 41.6 ft., rock is slightly more porous and contains several travertine infilled voids.	
	45
(49.1' - 50') Porous with 3 in., loosely cemented zone (Detrital)	
	50
	55
(58.3') 2 in. zone consisting of loosely cemented coral fragments (detrital) crosses core.	
	60
	65
	70

NOTES:

SAMPLE TYPE C - CORED S - SPOON
GROUND SURFACE TO 65.0 FT. USED 5 "CASING
FOOTAGE IN EARTH
FOOTAGE IN ROCK 100.0

CORE BREAKS SMOOTH		CORE BREAKS ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S - SOFT
R - RUSTY
C – CLEAN

CORE BREAKS *
█ CHIPS, LOST CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E EXTREME
S - SEVERE
M - MODERATE
L – SLIGHT
F - FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD BROKEN ROCK
OVERBURDEN, SOIL FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

CASING 5" I.D. Flush Joint
CORE BARREL 4" I.D. Double Tube
SOIL SAMPLER 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

BORING FOREMAN: M. Lauso

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER N/A HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742-78-C-0077

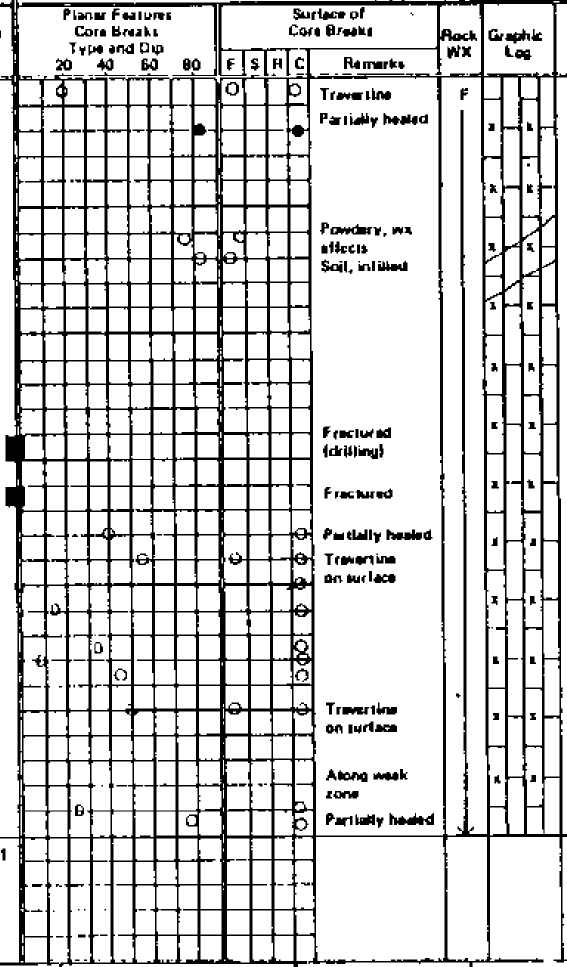
BORING NO. WB-35
SHEET 3 OF 3
DATE STARTED: 11/8/78
DATE FINISHED: 11/12/78
SOILS ENGINEER: J. Meynard
SURFACE ELEV. −1.1
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW

COORDINATES. N 164,918 E 118,175

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6"-12"	12"-18"	Strata Change Depth Elev.
75		70-76	11	C	17	5	4.8	96	76			
80		76-80	12	C	18	5	5	100	66			
	6	80-81.8	12	C	19	1.4	1.4	100	100			
	6											
	6											
	6											
85	6	81.8-85	13	C	20	3.2	3.2	100	100			
	6											
	6											
	6											
	6	85-89	13	C	21	4	4	100	100			
90	6	89-90	14	C	22	1	1	100	100			
	6											
	6											
	6											
	6											
95	6	90-95	14	C	23	5	4.7	96	90			
	6											
	6											
	6											
	6											
100	6	95-100	15	C	24	5	4.8	96	88			100.0
												−101.1
105												

GEOLOGIST'S LOG



Remarks	Rock Descriptions	Depth Below Surface
Travertine Partially healed	(71' - 74.6') Irregular, travertine healed joint, near vertical.	
		75
Powdery, wx effects Soil, infilled	(76.5' - 78') Several subparallel joints, partially healed by travertine some contain "soil" like material on joint surfaces up to 2 in. thick.	
		80
Fractured (drilling)		85
Fractured		
Partially healed Travertine on surface		90
Travertine on surface		95
Along weak zone Partially healed		100
	(100.0' - Terminated Hole)	
		105

NOTES:

SAMPLE TYPE. C - CORED S - SPOON
GROUND SURFACE TO 65.0 FT. USED 5 " CASING
FOOTAGE IN EARTH
FOOTAGE IN ROCK 100.0

CORE BREAKS SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R – RUSTY
C – CLEAN

CORE BREAKS	
■	CHIPS, LOST CORE, CAVITY
D	DRILLING BREAK
—	SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, FIBROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN SOIL, FILL

BORING CONTRACTOR.

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

BORING FOREMAN Nunnelley

CASING 5" I D Flush Joint
CORE BARREL 4" I D. Double Tube
SOIL SAMPLER 1 3/8" I D.
Standard Split Barrel, Driven with 140 lb Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER * HOURS

C E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND

CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. 18 - 29
SHEET 1 OF 3
DATE STARTED: 11/25/78
DATE FINISHED: 12/2/78
SOILS ENGINEER: J. Maynerd
SURFACE ELEV. 24.1
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW

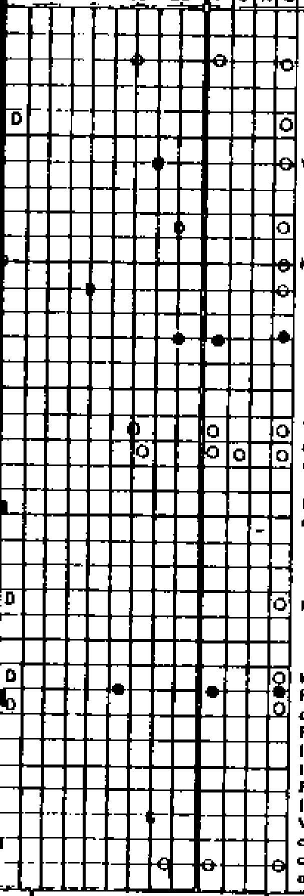
COORDINATES: N 164,761 E 117,632

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Run or Sample Pen. Ft.	Run or Sample Rec. Ft.	Run or Sample Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	Blows per 6" on Sampler 12" - 18"	Strata Change Depth Elev.
	4	0.0 - 5.0	1	C	1	5	5	100	50			
	4											
	4											
	4											
5	4											
	4	5.0 7.5	1 - 2	C	2	2.5	2.2	83	83			
	4											
	3	7.5 - 12.5	2	C	3	5	4.9	98	98			
	3											
10	3											
	3											
	3	12.5 - 17.5	3	C	4	5	5	100	83			
	3											
	3											
15	3											
	3											
	3	17.5 - 22.5	4	C	5	5	4.4	88	36/50			
	2											
	2											
20	3											
	4											
	4	22.5 - 27.5	4 - 5	C	6	5	5	100	51/85			
	4											
	4											
25	4											
	4											
	4	27.5 - 32.5	5	C	7	5	3.8	76	76			
	3											
	3											
30	3											
	3											
	3	32.5 - 37.5	6	C	8	5	4.7	95	50			
	3											
	3											
35	2											

GEOLOGIST'S LOG

Planar Features Core Breaks Type and Dip 20 40 60 80 | Surface of Core Breaks F S R C | Remarks | Rock WX | Graphic Log | Rock Descriptions | Depth Below Surface



Red clay on surface

Void, partially healed

Along partially healed joint

Hackly

Along small void

Void crosses core, travertine on surface

Broken, some core lost

Hackly

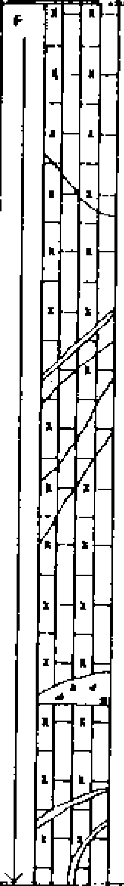
Hackly

Planar, travertine on surface

Fragments (drilling)

Irregular Fragments (drilling)

Void crosses core, travertine crystal growth on surface



(0.0' - 98.0') MARIANA LIMESTONE

(0.0' - 1.5') Numerous voids, soil on void surfaces.

(1.5' - 7.5') Travertine partially to completely infilled voids. Layering develops near vertically, parallel to void surfaces.

(7.5' - 13.8') Massive, intact recrystallized coralline limestone.

(13.8' - 16.8') Partially infilled void crosses core at 80° to core axis. Travertine and red clay on void surfaces.

(18.0' - 21.5') Travertine infilled void (2 to 3 in. thick) crosses core nearly vertically.

(21.5' - 32.0') Predominantly massive intact limestone.

(32.0' - 41.8') Vertical travertine development in cavity - occasional vertical open voids within mineralization.

Depth Below Surface: 5, 10, 15, 20, 25, 30, 35

NOTES:

*No groundwater was observed.

SAMPLE TYPE C - CORED S - SPOON
GROUND SURFACE TO 60.0 FT. USED 5 " CASING
FOOTAGE IN EARTH
FOOTAGE IN ROCK 98.0

CORE BREAKS

SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS

F - FILLINGS
S - SOFT
R - RUSTY
C - CLEAN

CORE BREAKS

▮	CHIPS, LOST CORE, CAVITY
D	DRILLING BREAK
—	SLIPPERY

WEATHERING (WX)

E - EXTREME
S - SEVERE
M - MODERATE
L - SLIGHT
F - FRESH

PLANAR FEATURES

C - CONTACT
F - FOLIATION
B - BEDDING
X - CROSS-BEDDING

GRAPHIC LOG

UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

BORING FOREMAN. Nunnelley

CASING. 6" I.D. Flush Joint
CORE BARREL 4" I.D. Double Tube
SOIL SAMPLER 1 3/8" I.D.
Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER ___ HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. LB - 29
SHEET 2 OF 3
DATE STARTED: 11/26/78
DATE FINISHED: 12/2/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. 24.1
ENG. GEOLOGIST: W. Pili
DATUM: MLLW
COORDINATES. N 154,761 E 117632

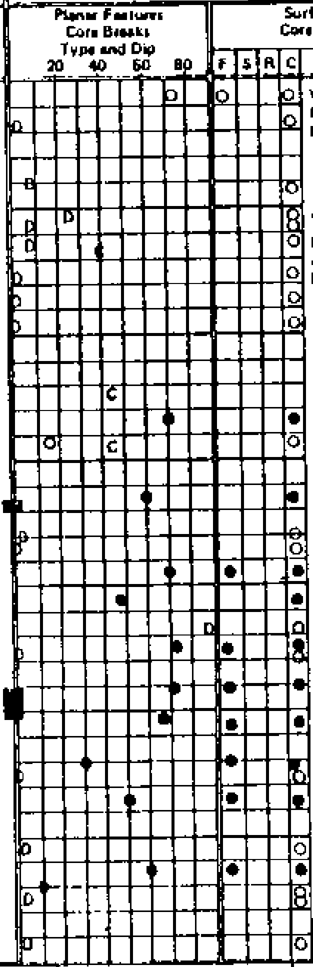
DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6"-12"	12"-18"	Strata Change Depth Elev.
	2											
	3											
	3	37.6 - 42.0	8 - 9	C	9	4.5	5	110	55/102			
	3											
	3											
40	3											
	3	42.0 - 47.0	9 - 10	C	10	5	4.6	92	92			
	3											
	3											
	3											
45	3											
	3	47.0 - 52.0	10	C	11	5	4.7	93	93			
	3											
	3											
	3											
50	3											
	3	52.0 - 57.0	11	C	12	5	5	100	44/73			
	3											
	3											
	3											
55	3											
	3	57.0 - 60.0	11 - 12	C	13	3	2.3	77	77			
	4											
	4											
	4											
60	–	60.0 - 63.0	12	C	14	3	2.6	86	86			
	–											
	–	63.0 - 68.0	12 - 13	C	15	5	4.9	98	98			
	7											
	7											
65	7											
	7											
	7	68.0 - 73.0	13	C	16	5	5	100	100			
	6											
70	6											

NOTES:

SAMPLE TYPE C - CORED S - SPOON
GROUND SURFACE TO 60.0 FT. USED 5" CASING
FOOTAGE IN EARTH - FOOTAGE IN ROCK 98.0

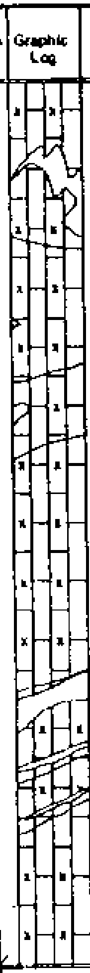
GEOLOGIST'S LOG



Remarks:

Void, cont. from page 1
Hackly
Along void
Irregular
Approx. 40°
Hackly
Irregular, 45°
Along void
Irregular
Fractured (drilling)
Hackly
– DO –
Void crosses core
traverline on surface
Along void
Partially healed void crosses core
Travertine void 13"
Travertine on surface
Open, travertine on surfaces
Hackly
Open - 1 in. travertine on bottom
Along voids
Travertine along surfaces
Hackly
Hackly

Rock WX: F



Rock Descriptions

(37.8' - 38.5') Irregular void in travertine, "stalactite" development

(41.3') Open void in travertine.
(41.8' - 47.5') Massive, slightly porous limestone, generally fresh internally, intact.

(47.5' - 49.3') Travertine infilled cavity, near vertical layering. Upper and lower cavity surfaces at 45° to 50° from core axis.

(59.0' - 65.0') Several travertine infilled joints and voids, generally completely infilled, voids cross core at angles generally greater than 60°.

Depth Below Surface: 40, 45, 50, 55, 60, 65, 70

CORE BREAKS SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R – RUSTY
C – CLEAN

CORE BREAKS
█ CHIPS, LOST CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E - EXTREME
S - SEVERE
M - MODERATE
L - SLIGHT
F - FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B - BEDDING
X – CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:
CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII
BORING FOREMAN. Nunnelley

CASING: 6" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER ___ HOURS

C-E MAGUIRE, INC.
BORING LOG
AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

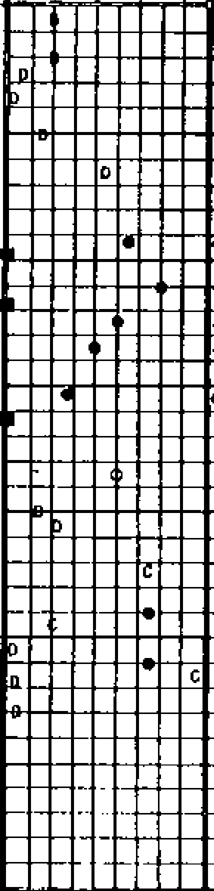
BORING NO. LB - 29
SHEET 3 OF 3
DATE STARTED: 11/26/78
DATE FINISHED: 12/2/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. 24.1
ENG. GEOLOGIST: W. Pitt
DATUM. MLLW
COORDINATES. N 164,781 E 117,632

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	12" - 18"	Strata Change Depth Elev.
	6											
	6											
	6	73.0 - 77.3	13	C	17	4.3	4.3	100	100			
	6											
	8											
75	8											
	6	77.3 - 82.0	14	C	18	4.7	4.7	100	34/80			
	6											
	8											
	6											
80	5											
	6	82.0 - 87.0	14 - 15	C	19	5	5	100	48/80			
	5											
	6											
85	5											
	6											
	5	87.0 - 92.0	15 - 16	C	20	5	4.6	92	83			
	5											
	5											
90	5											
	5											
	5	92.0 - 96.0	16	C	21	4	3.3	80	80			
	6											
	6											
95	6											
	6											
	6	96.0 - 98.0	17	C	22	2	1.7	83	83			
	6											98.0
												-73.9
100												
105												

GEOLOGIST'S LOG

Planar Features Core Breaks Type and Dip



Surface of Core Breaks: F S R C — Remarks

Remarks
Along weak zone "punky"
Along weak zone
Along void
Along void
Along weak zone, punky
2-65° joints cross, one partially healed travertine on surfaces
– DO –
– DO – Fractured (drilling)
Across joint
Across joint
Partially healed Irregular

Rock WX: F

Graphic Log

Rock Descriptions

Generally massive, intact, unit 1.

(85.0' - 87.0') 2 partially infilled voids have stalactite development.

2 partially healed voids (joints) cross core at 80°.

(92.0' - 94.7') Completely infilled void - travertine.

(96.0' - 98.0') Travertine infilled void - upper surface at approx. 85° to core axis.

(98.0' - Terminated Hole)

Depth Below Surface: 75, 80, 85, 90, 95, 100, 105

NOTES:

SAMPLE TYPE C - CORED S - SPOON
GROUND SURFACE TO 60 FT. USED 6 "CASING
FOOTAGE IN EARTH - FOOTAGE IN ROCK 98.0

CORE BREAKS SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	▢
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R – RUSTY
C – CLEAN

CORE BREAKS *
■ CHIPS, LOST CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

CASING. 6" I.D. Flush Joint
CORE BARREL. 4" I.D. Double Tube
SOIL SAMPLER 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

BORING FOREMAN. G. Morris

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER * HOURS

C.E MAGUIRE, INC.

BORING LOG

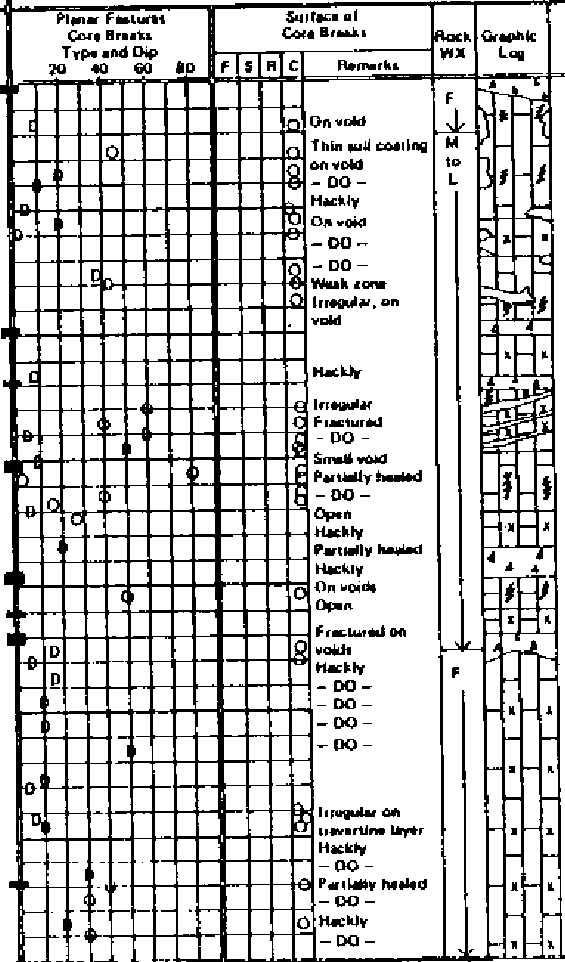
AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. LB - 33
SHEET 1 OF 3
DATE STARTED: 12/8/78
DATE FINISHED: 12/11/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. 174.0
ENG. GEOLOGIST: W. Pitt
DATUM. MLLW
COORDINATES: N 154,016 E 110,993

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Run or Sample Pen. Ft.	Run or Sample Rec. Ft.	Run or Sample Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	Blows per 6" on Sampler 12" - 18"	Strata Change Depth Elev.
	6	0.0 - 5.0	1	C	1	5	5	100	80			
	6											
	0											
	6											
	6											
5	5	5.0 - 10.0	1 - 2	C	2	5	4.8	96	62			
	6											
	5											
	6											
	5											
10	5	10.0 - 15.0	2 - 3	C	3	5	4.8	97	82			
	6											
	5											
	5											
	6											
15	5	15.0 - 20.0	3	C	4	5	5	100	61			
	6											
	5											
	6											
	6											
20	5	20.0 - 25.0	3 - 4	C	5	5	5	100	76			
	5											
	5											
	5											
	5											
25	6	25.0 - 30.0	4 - 5	C	6	5	4.9	98	88			
	6											
	5											
	6											
	6											
30	5	30.0 - 35.0	5 - 6	C	7	5	5	100	95			
	6											
	5											
	6											
35	6											

GEOLOGIST'S LOG



Remarks

- On void
- Thin soil coating on void
- – DO –
- Hackly
- On void
- – DO –
- – DO –
- Weak zone
- Irregular, on void
- Hackly
- Irregular
- Fractured
- – DO –
- Small void
- Partially healed
- – DO –
- Open
- Hackly
- Partially healed
- Hackly
- On voids
- Open
- Fractured on voids
- Hackly
- – DO –
- – DO –
- – DO –
- – DO –
- Irregular on travertine layer
- Hackly
- – DO –
- Partially healed
- – DO –
- Hackly
- – DO –

Rock Descriptions

(0.0' - 77.5') MARIANA LIMESTONE
(0.0' - 1.0') Hard, white recrystallized, coralline limestone.
(1.0' - 2.6') Dense cemented matrix consisting of red, soil like material encloses angular white limestone fragments with voids and solution features. Roots in voids near surface. Most voids crystal lined, occasional thin silty coating
(2.6' - 22.5') Dense to porous limestone. Several zones consist of weak and porous to fragments.

Below 22.5' core generally more intact, fewer fragments. Small voids present. Occasional open solution features.

Depth Below Surface: 5, 10, 15, 20, 25, 30, 35

NOTES:

*No groundwater was observed.

SAMPLE TYPE: C = CORED S = SPOON
GROUND SURFACE TO 20.0 FT. USED 5 "CASING
FOOTAGE IN EARTH — FOOTAGE IN ROCK 77.5

CORE BREAKS SMOOTH		CORE BREAKS ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F - FILLINGS
S - SOFT
R - RUSTY
C - CLEAN

CORE BREAKS

▮	CHIPS, LOST CORE, CAVITY
D	DRILLING BREAK
—	SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 6 MEDIUM HARD, BROKEN ROCK
OVERBURDEN SOIL, FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

BORING FOREMAN: G. Morris

CASING: 6" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER ___ HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES

U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND

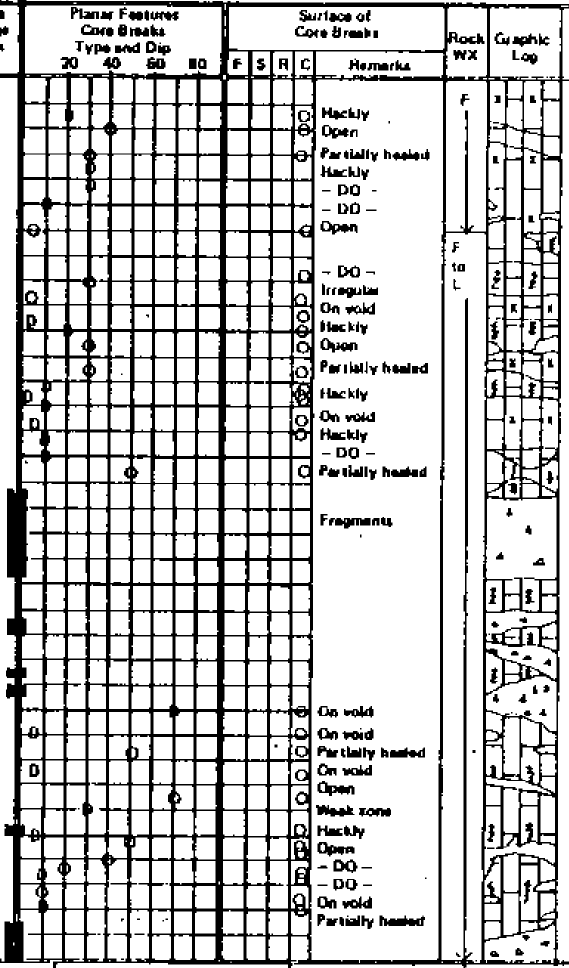
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. LB - 33
SHEET 2 OF 3
DATE STARTED: 12/8/78
DATE FINISHED: 12/11/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. 174.0
ENG. GEOLOGIST: W. Fitt
DATUM. MLLW
COORDINATES: N 164,016 E 119,903

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6"-12"	12"-18"	Strata Change Depth Elev.
	6	35.0 - 40.0	8	C	8	5	5	100	78			
	5											
	6											
	5											
	5											
40	6	40.0 - 45.0	8 - 7	C	9	5	5	100	80			
	6											
	6											
	6											
	6											
45	5	45.0 - 50.0	7 - 8	C	10	5	5	100	82			
	6											
	6											
	6											
	6											
50	6	50.0 - 55.0	8 - 8	C	11	5	4.8	96	46			
	6											
	6											
	5											
	5											
55	6	55.0 - 60.0	8	C	12	5	5	100	20			
	5											
	5											
	5											
	5											
60	10	60.0 - 65.0	10	C	13	5	5	100	95			
	10											
	10											
	10											
	10											
65	10	65.0 - 70.0	10 - 11	C	14	5	5	100	63			
	10											
	10											
	10											
70	10											

GEOLOGIST'S LOG



Surface of Core Breaks – Remarks:
Hackly
Open
Partially healed
Hackly
– DO –
– DO –
Open
– DO –
Irregular
On void
Hackly
Open
Partially healed
Hackly
On void
Hackly
– DO –
Partially healed
Fragments
On void
On void
Partially healed
On void
Open
Weak zone
Hackly
Open
– DO –
– DO –
On void
Partially healed

Rock WX: F (35.0 – 41.0); F to L (41.0 – 70.0)

Rock Descriptions:

Coral structures apparent at 41.0'.

(42.0' - 44.0') Porous.

Isolated zones of unit 1.

1" to 3" fragments. Breakage partially due to excessive drilling pressure.

Depth Below Surface: 40, 45, 50, 55, 60, 65, 70

NOTES:

SAMPLE TYPE: C - CORED S - SPOON
GROUND SURFACE TO 20.0 FT. USED 6 "CASING
FOOTAGE IN EARTH –
FOOTAGE IN ROCK 77.6

CORE BREAKS SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R – RUSTY
C – CLEAN

CORE BREAKS*

■	CHIPS, LOST CORE, CAVITY
D	DRILLING BREAK
—	SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:
CONTINENTAL DRILLING HAWAII, INC.
HONOLULU, HAWAII
BORING FOREMAN: G. Morris

CASING: 6" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT __ FT. AFTER __ HOURS

C-E MAGUIRE, INC.
BORING LOG

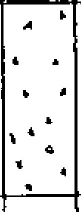
AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. LB - 33
SHEET 3 OF 3
DATE STARTED: 12/8/78
DATE FINISHED: 12/11/78
SOILS ENGINEER: J. Meynard
SURFACE ELEV. 174.0
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW
COORDINATES: N 164,016 E 119,993

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From - To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6"-12"	12"-18"	Strata Change Depth Elev.
	10	70.0 - 77.5	11	C	15	6.6	3.5	64	0			
	10											
	10											
	10											
75	10											
	0											
	1											77.5 96.6
80												
85												
90												
95												
100												
105												

GEOLOGIST'S LOG

Planar Features Core Breaks Type and Dip 20 40 60 80	Surface of Core Breaks F S R C	Remarks	Rock WX	Graphic Log	Rock Descriptions	Depth Below Surface
			F ↓		Fragments of white limestone, 1" to 3".	75
					(77.5' - Terminated Hole)	80
						85
						90
						95
						100
						105

NOTES:

SAMPLE TYPE: C - CORED S - SPOON
GROUND SURFACE TO 20.0 FT. USED 5 " CASING
FOOTAGE IN EARTH - FOOTAGE IN ROCK 7.5

CORE BREAKS SMOOTH		CORE BREAKS ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F - FILLINGS
S - SOFT
R - RUSTY
C - CLEAN

CORE BREAKS
■ CHIPS, LOST CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E - EXTREME
S - SEVERE
M - MODERATE
L - SLIGHT
F - FRESH

PLANAR FEATURES
C - CONTACT
F - FOLIATION
B - BEDDING
X - CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

BORING FOREMAN: O. Adams

CASING 6" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER. 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER * HOURS

C-E MAGUIRE, INC.

BORING LOG

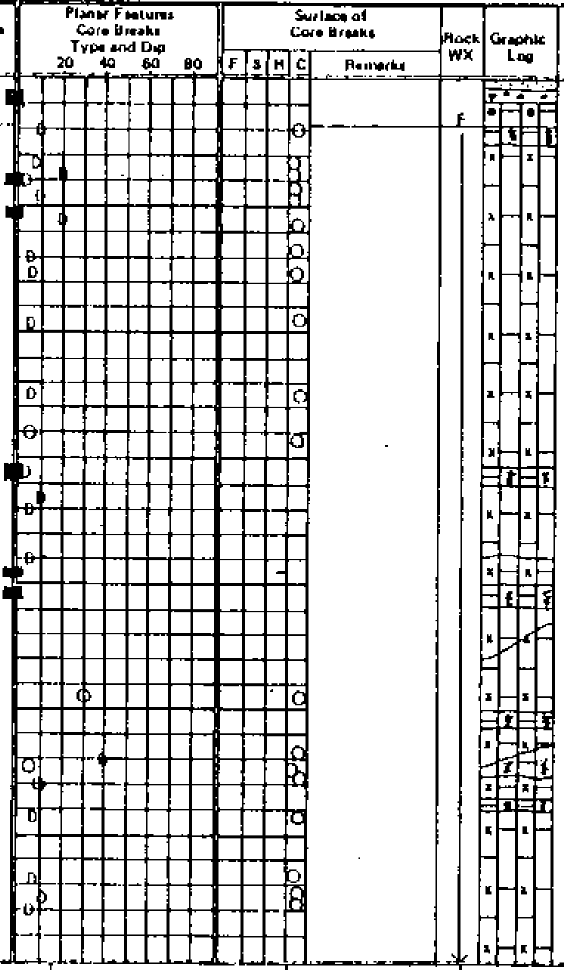
AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. LB-34
SHEET 1 OF 3
DATE STARTED: 10/28/78
DATE FINISHED: 11/1/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. 206.4
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW
COORDINATES. N 164,226 E 120,029

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From - To	Core Box No.	Type of Sample	Run or Sample No.	Pen.	Rec	Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	12" - 18"	Strata Change Depth Elev.
	5											
	4											1.8
	4											204.6
	4											
5	4	0 - 6	1	C	R-1	6	4.8	92	80			
	3											
	3											
	3											
	3											
10	2	5 - 10	2	C	R-2	5	4.7	93	93			
	3											
	4											
	4											
	4	10 - 14	2	C	3	4	4	100	100			
15	10											
	9											
	5											
	5											
	3	14 - 19	3	C	4	6	4.8	92	92			
20	5											
	5											
	2											
	2											
	3	19 - 24	3	C	5	5	5	100	44			
25	7											
	4											
	4 4											
	4	24 - 26.6	4	C	6	2.6	2.2	80	40			
	3											
30	3											
	4											
	2	26.6 - 31.6	4	C	7	5	5	100	100			
	2											
	1											
35	2											

GEOLOGIST'S LOG



Rock Descriptions

Rock Descriptions	Depth Below Surface
CONCRETE, FILL (0.36' CONCRETE, 1.45' SOIL FILL)	
(1.8' - 86.5') MARIANA LIMESTONE Hard, white to pink recrystallized coralline limestone. Physical condition: Predominantly massive, slightly porous, intact. Drills well, fresh internally. Occasional zone consisting of partially infilled voids, and solution features, otherwise intact with only minor drilling breaks.	5
	10
	15
(19.0' - 21.0') Partially infilled solution voids, broken, 1" to 4" pieces, small roots and reddish soil in voids.	20
Partially infilled void, travertine.	25
Solution cavity, crystal growth on surface.	
	30
	35

NOTES:

*No groundwater was observed.

SAMPLE TYPE C = CORED S = SPOON
GROUND SURFACE TO 26.0 FT. USED 5 "CASING
FOOTAGE IN EARTH 1.8 FOOTAGE IN ROCK 84.7

CORE BREAKS SMOOTH		CORE BREAKS ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F - FILLINGS
S - SOFT
R - RUSTY
C - CLEAN

CORE BREAKS
▮ CHIPS, LOST CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

CASING 6" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

BORING FOREMAN. Q. Adams

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER * HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND

CONTRACT NO. N62742 - 78 - C - 0077

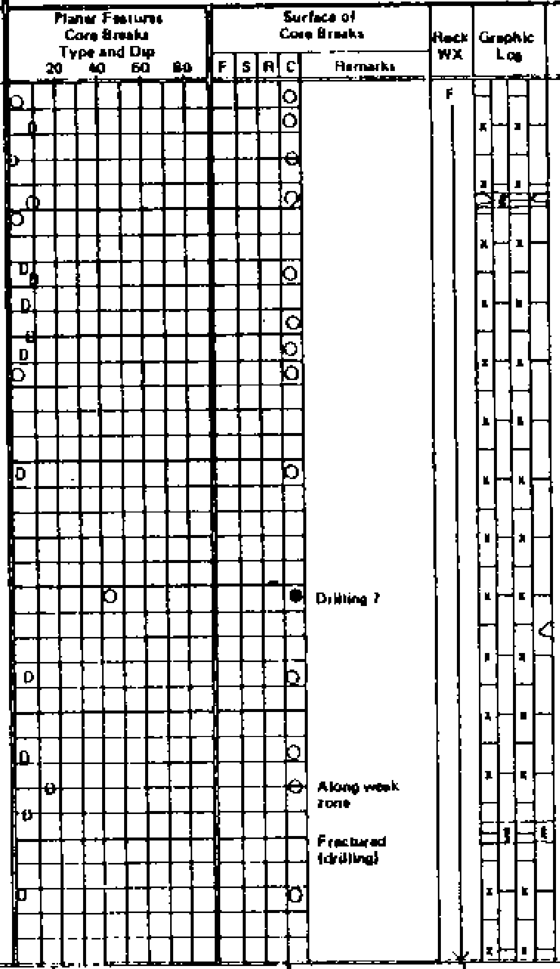
BORING NO. LB-34
SHEET 2 OF 3
DATE STARTED: 10/26/78
DATE FINISHED 11/1/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. 206.4
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW

COORDINATES. N 164,226 E 120,029

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Run or Sample Pen. Ft.	Run or Sample Rec. Ft.	Run or Sample Rec. %	RQD	Blows per 6" on Sampler 6"-12"	Blows per 6" on Sampler 12"-18"	Strata Change Depth Elev.
	2	31.6 - 35.6	6	C	8	4	4	100	94			
	2											
	3											
	2											
	2											
40	2	35.6 - 40.6	6	C	9	5	4.7	98	91			
	2											
	2											
	2											
	2											
45	2	40.6 - 45.6	7	C	10	5	5	100	100			
	3											
	3											
	2											
	3											
50	2	45.6 - 50.6	8	C	11	5	4.9	98	98			
	2											
	2											
	3											
	4											
55	2	50.6 - 55.5	8-9	C	12	5	4.9	98	96			
	3											
	2											
	2											
	2											
60	2	55.6 - 60.6	9-10	C	13	5	5	100	100			
	3											
	2											
	2											
	2											
65	2	60.6 - 65.6	10-11	C	14	5	5	100	98			
	3											
	2											
	2											
70	2											

GEOLOGIST'S LOG



Remarks:

Drilling ?

Along weak zone

Fractured (drilling)

Rock Descriptions	Depth Below Surface
White to buff, recrystallized.	
	40
	45
Very hard, buff to white recrystallized Mariana Limestone. Generally slightly porous to massive, intact, with occasional drilling break.	
	50
	55
	60
	65
Fractured zone (7 in.) probably due to drilling.	
	70

NOTES:

*No groundwater was observed

SAMPLE TYPE C - CORED S - SPOON
GROUND SURFACE TO 26.0 FT. USED 5 "CASING
FOOTAGE IN EARTH 1.8
FOOTAGE IN ROCK 84.7

CORE BREAKS SMOOTH		CORE BREAKS ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R RUSTY
C – CLEAN

CORE BREAKS
▮ CHIPS, LOST CORE, CAVITY
0 DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN SOIL, FILL

BORING CONTRACTOR:
CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII
BORING FOREMAN: O. Adams

CASING: 5" I.D. Flush Joint
CORE BARREL: 4" I.D. Double Tube
SOIL SAMPLER: 1 3/8" I.D. Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER * HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND

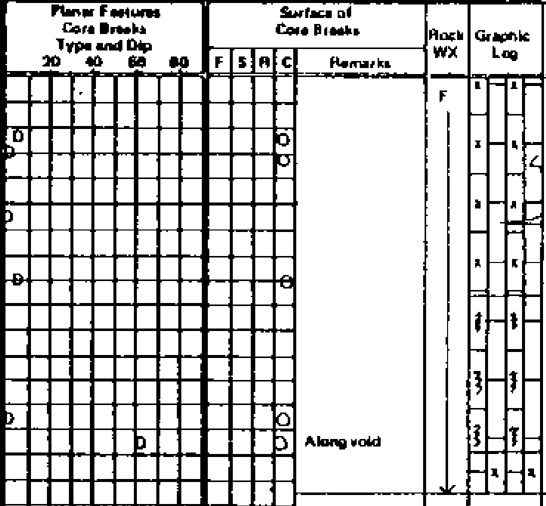
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. LB-34
SHEET 3 OF 3
DATE STARTED: 10/28/78
DATE FINISHED: 11/1/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. 206.4
ENG. GEOLOGIST: W. Pill
DATUM: MLLW
COORDINATES. N 164,226 E 120,029

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	12" - 18"	Strata Change Depth Elev.
	2	65.5 - 70.5	11	C	15	5	4.7	93	93			
	2											
	1											
	2											
	1											
75	2	70.5 - 75.5	12	C	16	5	5	100	100			
	2	75.5 - 76.5	12	C	17	12	12	100	93			
	2											
	2											
	2											
80	1											
	1	76.5 - 81.5	13	C	18	5	4.8	96	96			
	1											
	1											
	1											
85	1											
		81.5 - 86.5	14	C	19	5	5	100	100			86.5 119.9
90												
95												
100												
105												

GEOLOGIST'S LOG



Rock Descriptions

Very hard, white to buff recrystallized coralline limestone.

(78.8' - 84.6') Slightly porous, with occasional void

(86.5' - Terminated Hole)

Depth Below Surface: 75, 80, 85, 90, 95, 100, 105

NOTES:

*No groundwater was observed.

SAMPLE TYPE: C - CORED S - SPOON
GROUND SURFACE TO 26.0 FT. USED 5 "CASING
FOOTAGE IN EARTH 1.8 FOOTAGE IN ROCK 84.7

CORE BREAKS

SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R – RUSTY
C – CLEAN

CORE BREAKS *

■	CHIPS, LOST CORE, CAVITY
□	DRILLING BREAK
—	SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:

CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII

CASING. 6" I.D. Flush Joint
CORE BARREL. 4" I.D. Double Tube
SOIL SAMPLER 1 3/8" I.D.
Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

BORING FOREMAN: M. Lessau

GROUND WATER OBSERVATIONS: AT – FT. AFTER * HOURS

CE MAGUIRE, INC./R. M. TOWILL CORPORATION

A JOINT VENTURE

BORING LOG

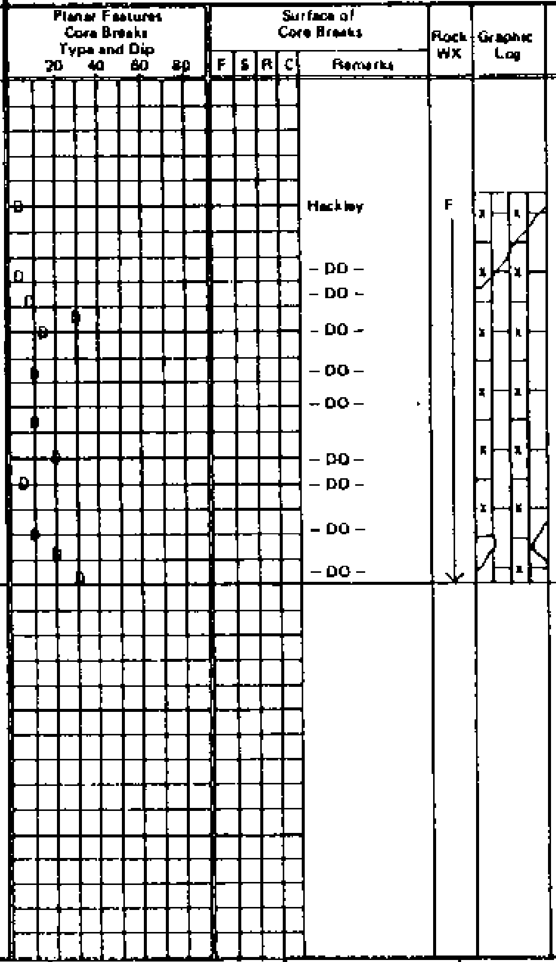
AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLAND
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND
CONTRACT NO. N62742 - 78 - C - 0077

BORING NO. LB - 34A
SHEET 1 OF 1
DATE STARTED: 12/13/78
DATE FINISHED: 12/16/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. 206.4
ENG. GEOLOGIST: J. Maynard
DATUM: MLLW
COORDINATES: N 164,226 E 120,029

DRILLER'S LOG

Depth Below Surface	Coring Time Min /Ft	Run or Sample Depth From - To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	12" - 18"	Strata Change Depth Elev.
80												
85	6		1	C	R1	5	5	100	100			
	6											
	6											
	6											
90	6											
	6											
	6											
	6											
	6											
95	6											
	6											
	6											
	6											
	6											
	6											100.0 106.4
100												
105												
110												
115												

GEOLOGIST'S LOG



Remarks	Depth Below Surface
Hackley	85
– DO –	
– DO –	
– DO –	90
– DO –	
– DO –	
– DO –	95
– DO –	
– DO –	
– DO –	100

Rock Descriptions	Depth Below Surface
Redrilled hole 0.0' to 85.0'.	80
(85.0' - 100.0') MARIANA LIMESTONE White to buff, recrystallized coralline limestone. Predominantly massive slightly porous, intact with only occasional drilling breaks	85
	90
	95
(100.0' - Terminated Hole)	100
	105
	110
	115

NOTES:

*No groundwater was observed

SAMPLE TYPE: C - CORED S - SPOON
GROUND SURFACE TO 85.0 FT. USED 5 "CASING
FOOTAGE IN EARTH – FOOTAGE IN ROCK 15.0

CORE BREAKS SMOOTH		CORE BREAKS ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R – RUSTY
C – CLEAN

CORE BREAKS*
■ CHIPS, LOST CORE, CAVITY
D DRILLING BREAK
— SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS-BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 5 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

BORING CONTRACTOR:
CONTINENTAL
DRILLING
HAWAII, INC.
HONOLULU, HAWAII
BORING FOREMAN. Morra

CASING 6" I.D. Flush Joint
CORE BARREL 4" I.D. Double Tube
SOIL SAMPLER 1 3/8" I.D.
Standard Split Barrel, Driven with 140 lb. Hammer Falling 30 in.

GROUND WATER OBSERVATIONS: AT ___ FT. AFTER * ___ HOURS

C-E MAGUIRE, INC.

BORING LOG

AMMUNITION PORT FACILITIES
U.S. NAVAL MAGAZINE GUAM, MARIANA ISLANDS
PACIFIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND

CONTRACT NO. N62742 - 78 - C - 0077

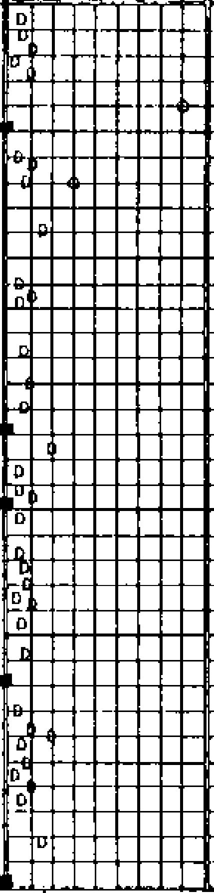
BORING NO. LB - 35
SHEET 1 OF 1
DATE STARTED: 12/6/78
DATE FINISHED: 12/8/78
SOILS ENGINEER: J. Maynard
SURFACE ELEV. 41.0
ENG. GEOLOGIST: W. Pitt
DATUM: MLLW
COORDINATES: N 164,321 E 120,071

DRILLER'S LOG

Depth Below Surface	Coring Time Min./Ft.	Run or Sample Depth From – To	Core Box No.	Type of Sample	Run or Sample No.	Pen. Ft.	Rec. Ft.	Rec. %	RQD	Blows per 6" on Sampler 6" - 12"	12" - 18"	Strata Change Depth Elev.
	8	0.0 - 5.0	1	C	1	5	5	100	83			
	8											
	8											
	8											
5	8											
	7	5.0 - 7.0	1	C	2	2	2	100	100			
	7											
	7	7.0 - 12.0	2	C	3	6	6	100	90			
	7											
10	7											
	7											
	7	12.0 - 17.0	2 - 3	C	4	6	5	100	88			
	7											
	7											
16	7											
	7											
	7	17.0 - 22.0	3 - 4	C	5	6	6	100	100			
	7											
	7											
20	7											
	7											
	7	22.0 - 27.0	4	C	6	5	4.8	97	82			
	7											
	7											
25	7											
	7											
	7	27.0 - 32.0	5	C	7	5	5	100	100			
	7											
	7											
30	7											
	7											
	7	32.0 - 35.0	6	C	8	3	3	100	100			
	7											
	7											
35	7										35.0 6.0	

GEOLOGIST'S LOG

Planar Features Core Breaks Type and Dip



Surface of Core Breaks (F S R C) – Remarks:

- Irregular
- – DO –
- Hackly
- – DO –
- – DO –
- – DO –
- Along void
- Hackly
- – DO –
- – DO –
- – DO –
- – DO –
- Void
- Irregular
- Void
- Irregular
- Hackly
- – DO –
- – DO –
- On void
- Hackly
- – DO –
- – DO –
- – DO –
- On void
- – DO –
- Hackly
- – DO –
- Hackly
- – DO –
- – DO –
- – DO –
- – DO –

Rock WX: F to L (0.0 – 18.0); F (18.0 – 35.0)

Graphic Log

Rock Descriptions

(0.0' - 35.0') MARIANA LIMESTONE
White, Hard, porous, recrystallized coralline limestone. Interconnected solution features and voids numerous. Several voids have thin (¼") travertine on void surfaces. Red-brown staining or thin silty coating on most void surfaces. Most breaks are drilling breaks on weak zones and voids. Roots.

Core denser, generally fewer voids. Red-brown staining generally absent.

(35.0' - Terminated Hole)

Depth Below Surface: 5, 10, 16, 20, 25, 30, 35

NOTES.

*No groundwater was observed.

SAMPLE TYPE C = CORED S = SPOON
GROUND SURFACE TO 5.0 FT., USED 5 "CASING
FOOTAGE IN EARTH
FOOTAGE IN ROCK 35.0

CORE BREAKS SMOOTH		ROUGH
●	JOINT	○
■	BEDDING	□
▲	FOLIATION	△
◆	CONTACT	◇

SURFACE OF CORE BREAKS
F – FILLINGS
S – SOFT
R – RUSTY
C – CLEAN

CORE BREAKS*

▮	CHIPS, LOST CORE, CAVITY
D	DRILLING BREAK
—	SLIPPERY

WEATHERING (WX)
E – EXTREME
S – SEVERE
M – MODERATE
L – SLIGHT
F – FRESH

PLANAR FEATURES
C – CONTACT
F – FOLIATION
B – BEDDING
X – CROSS BEDDING

GRAPHIC LOG
UNIT 1 HARD, DENSE ROCK
UNIT 2 HARD, POROUS ROCK
UNIT 3 MEDIUM HARD, DENSE ROCK
UNIT 4 MEDIUM HARD POROUS ROCK
UNIT 6 MEDIUM HARD, BROKEN ROCK
OVERBURDEN, SOIL, FILL

APPENDIX B
THIN SECTION DESCRIPTIONS
Introduction

The following is a description of thin section observations used in this investigation. Thin sections were cut from various cores at selected depths in order to examine in detail lithology, cementation characteristics, porosity type and floral and faunal composition. A number of sections were stained using methods of Friedman (1959) to determine the gross mineralogy.

The numbering system used to identify the various thin sections is composed of a prefix of letters followed by a number set. For example, an identifying number of GWB27-10 or GLB33-11A has the following measuring: G indicates that the thin section is from samples collected on Guam; WB or LB indicates the series of borings which are water boring and land boring, respectively; the number indicates the borehole number; finally, the number following the dash is the sample depth. Where more than one thin section was cut for a selected depth, a letter may follow the depth number.

Thin section descriptions are arranged by series, beginning with the water borings. Each borehole is then described by depth starting at the top of the core. For additional details of the geologic log of the boreholes, refer to Appendix A.

Thin Section Descriptions

Borehole = WB-27

Depth (ft)	Description
1.0	Section numbers: GWB27-1A; GWB27-1B Massive coral with minor skeletal packstone. Coral is probably *Favia* and is the dominant constituent. Coral partially encrusted with coralline algae with inbedded vermetid gastropods. Internal sediment partially or completely fills numerous coral septa and other voids. Internal sediment is a silt-sized peloidal skeletal wackestone to packstone. Geopetal fabric is common within partially filled pore space; abrupt contact between pore wall and sediment. Radial fibrous (needle-like) cement lining numerous septa. Cement is probably aragonite in composition and is continuous with substrate of pore wall. No obvious cement types were observed within the sediment except where the micrite matrix was less abundant and larger pores exist between constituent grains. Here a fibrous and mosaic cement binds the sediment. Mineralogy of the cement is not known but is probably aragonite. Porosity is interparticle, intraparticle, and growth framework, all of primary origin.
6.0	Section number: GWB27-6 Massive coral with internal sediment and minor encrusting coralling algae. Internal sediment is silt-size skeletal packstone; skeletal grains are dominatly coral fragments. Similar characteristics as above sections; needle-like cement lining numerous septa, little cement observed in internal sediment, and porosity is primary in origin. Porosity includes boring type.
9.0	Section numbers: GWB27-9A; GWB27-9B Coral/algal boundstone. Coralline algae has included vermetid gastropods. Internal sediment fills pore space and numerous septa in same manner as above sections. Cement occurs in some coral septa as radial fibrous crystals oriented more or less perpendicular to pore wall. A few pores are occluded by cement fibers; crystal length is 80-100 um and width ranges 6-8 um. Cement is probably aragonite in compositions. Primary porosity similar to above observed types with the inclusion of fenestral porosity associated with the coralline algae encrustations.
18.0	Section numbers: GWB27-18A; GWB27-18B; GWD27-18C; and GWB27-18D Coral/algal boundstone. Coralline algae encrusting massive coral with wackestone to packstone internal sediment. Internal sediment is silt-to very fine sand-sized skeletal packstone to grainstone with a peloidal micrite matrix were mud is present. Minor occurrences of associated sediments composed of larger fragments of branching-type red algae, echinoid spines, *Halimeda* plates, coral, and mollusk shells set in a finer-grained matrix similar to that of the internal sediment. Coral and other skeletal material has been bored; borings are partially or completely filled with sediment; geopedal fabric is common. Cement and porosity characteristics same as above sections.

26.0 Section number: GWB27-26

Skeletal wackestone and encrusting coralline algae. Sediment is probably a void filling and lacks larger skeletal fragments. Similar textural characteristics, cement fabrics, and porosity types or above section. An exception is the occurrence of a spherulitic-like pore occluding cement fabric within a portion of the sediment. Predominant cement type where less peloidal micrite is present. Bladed crystals radiate out from the center of the pore space. Sperulites average about 40 um in diameter; relatively uniform in size. Mineralogy is not known.

29.0 Section number: GWB27-29

Branching coral with skeletal wackestone. Coral septa partially or completely filled with internal sediment. Internal sediment and associated sediment are the same in character; silt-sized peloidal skeletal wackestone. Numerous spherulites occur in the wackestone and are distinctly circular in cross section; same characteristics as described above. Where pore space occurred between skeletal grains micrite peloids, a fibrous or needle-like cements formed the binding agent. Crystal length was only a few microns; difficult to distinguish between individual crystals. Some appeared to be radial in character; perpendicular to substrate. Mineralogy of this cement is not known.

33.0 Section numbers: GWB27-33A; GWB27-33B

Skeletal wackestone and encrusting coralline algae. Sediment constituents are fragments of mollusk shells, encrusting foraminifera, echinoid spines, coral, coralline alga, and *Halimeda* plates in a silt-size skeletal wackestone to packstone matrix. Matrix also contains numerous spherulites. Cement types similar to above. Primary porosity preserved or interparticle, intraparticle, and fenestral (in coralline algal structure).

40.0 Section number: GWB27-40

Coral/algal boundstone. Coralline algae encrusting massive coral. Minor occurrence of silt-sized peloidal skeletal wackestone internal sediment. Sediment contains spherulites. Similar features as observed in sections at a depth of 9 feet. Minor occurrences of radial fibrous aragonitic cement in coral septa.

Borehole: WB-29

Depth (ft)	Description
Surface	Section numbers: GWB29-TOP; GWB29-TOP-B Coral/algal boundstone with internal and associated sediment. Massive coral encrusted by coralline algae; vermitid gastropods associated with coralline algae. Internal sediment partially or completely fills a number of coral septa, borings, and other pore spaces; geopedal fabric common. Sediment is a silt-sized peloidal skeletal wackestone. Associated sediment is coarse grained (sand-size) skeletal packstone; grains composed of mollusk shell and coralline algal fragments with minor amounts of other skeletal fragments. Visible cement fabric is within coral septa. Cement is a fibrous or needle-like crystal (probably aragonitic) 80-100 um long and 6-8 um wide; numerous septa have been occluded by the cement. Also occurs in the interior of vermitid gastropod shells. Crystal orientation is more or less perpendicular to pore wall. Primary porosity preserved or interparticle, intraparticle, growth framework, and fenestral (in coralline algae).
4.0	Section numbers: GWB29-4A; GWB29-4B; GWB29-4C Coral/algal boundstone with internal sediment. Same characteristics as those described above. Some iron oxide stains are associated with the coralline algae along contacts with either coral on sediment and along growth lines within the algal structure. Numerous borings in algae, coral, and sediments.
5.0	Section number: GWB29-5 Coral-algal boundstone with internal and associated sediment. Silt-sized peloidal skeletal wackestone to sand-sized skeletal packstone with same characteristics as those described above. In some places the sediment is more loosely packed than elsewhere and has better developed interparticle porosity.
10.0	Section numbers: GWB29-10; GWB29-10A Coral/algal boundstone with internal sediment. Same characteristics as above sections; somewhat more iron-oxide staining and the internal sediment filling smaller coral septa is a peloidal mudstone with only occasional skeletal fragments (rare, Halimeda).
11.0	Section numbers: GWB29-11A; GWB29-11B. Skeletal grainstone with internal sediment. Grainstone composed of loosely packed fragments of coral, coralline algae, foraminifera and mollusk shells. Silt-sized skeletal wackestone partially fills larger pore spaces between grains and where shelter porosity has formed. Fibrous as needle-like (probably aragonite) cement fringes partially surround a few mollusk shells and fragments; similar fibrous cement is binding aragonitic coral fragments. Within finer grained (silt-size and less), the cement type if difficult to observe but may be a mosaic at the micrite size. Primary porosity preserved as interparticle (dominant

type), growth framework, and minor borings. In general porosity is relatively high, estimated at about 30-40%.

16.0 Section numbers: GWB 29-16A; GWB29-16B

Coral/algal boundstone with internal sediment. Massive coral encrusted with coralline algae. silt-size peloidal skeletal wackestone infills coral septa, borings, and other pore space often occluding the void or forming geopedal fabric. similar characteristics as boundstone described above including iron oxide staining associated with coralline algae; with notable exception of little cement occurrence within coral septa.

22.0 Section numbers: GWB29-22; GWB29-22A

Coral/algal boundstone and skeletal packstone. Coralline algae encrusted massive coral; may be fragments (i.e. not in growth position) set in a matrix of silt-sized peloidal skeletal packstone with minor silt-sized grainstone. Radial fibrous aragonitic cement in coral septa is more abundant than in previous (GWB29-16) section; length of fibrous crystals is 60-80 um and the width is 8-10 um; crystals terminate with a point, Blockly microcrystalline (<4um) cement (probably Mg-calcite composition) present within the peloidal micrite matrix of the sediment and within the utricles of a _Halimeda_ plate. Primary porosity preserved as interparticle, borings, and growth framework.

30.0 Section numbers: GWB29-30A; GWB29-30B

Coral/algal-foraminifera boundstone and sediment. Massive coral encrusted with alternating layers of coralline algae and the foraminifera _Gypsina vesicularis_ overlain by silt-sized peloidal skeletal wackestone to silt-sized peloidal skeletal packstone. Some sediment partially or completely infills coral septa and borings; geopetal fabric common. Blocky microcrystalline (>4um) visible within sediment portion containing lens peloidal micrite; uneven cement distribution given a mottled appearance to the sediment texture. Primary porosity preserved as fenestral (dominant), borings, growth framework and interparticle. Porosity is relatively low within the wackestone, except for borings.

34.0 Section numbers: GWB29-34

Massive coral with minor occurrence of encrusting coralline algae and _Gypsina_, internal sediment, and vermetid gastropod. Internal sediment is a silt-sized skeletal wackestone. Nearly all coral septa are empty of both sediment and cement. Primary porosity is preserved as growth framework with minor borings.

38.0 Section numbers: GWB29-38A; GWB29-38B

Halimeda plates in a matrix of packstone to wackestone. _Halimeda_ plates (abundant) and mollusk shell fragments occur in a silt-sized skeletal wackestone to packstone; minor occurrence of a silt-sized skeletal grainstone cemented by a blocky microcrystalline (incomplete) rind. Other skeletal material includes coral fragments, coralline algae fragments, and minor occurrence of a high spiraled gastropod. Blocky microcrystalline (>4um) cement occludes most of the pore space of the Halimeda utricle.

44.0 Section numbers: GWB29-44A; GWB29-44B
Coral/algal - foraminifera boundstone. Similar characteristics as described for the 30-feet depth. Radial fibrous cement occur in vermetid gastropod shells (interior). Minor occurrence of Halimeda.

Borehole: WB-34

Depth (ft)	Description
1.0	Section number: GWB34.1

Skeletal packstone to wackestone with larger-sized skeletal fragments (Floatstone). Larger skeletal fragments of coral, coralline algae, mollusk shells, foraminifera, echinoid spines, and Halimeda plates. Septa of coral fragments are partially or completely infilled with silt-size skeletal wackestone; geopedal fabric common. Sediment filled septa and borings show two distinct generations of internal sediment of similar characteristics but later sediment is slightly lighter in color. No visible cement occurrence within sediment or skeletal framework. Primary porosity preserved as growth framework, borings, shelter, and interparticle.

2.0 Section numbers: GWB34-2; GWB34-2A.

Coral/algal-foraminifera boundstone with associated sediment. Massive coral encrusted with alternating discontinuous layers of coralline algae and the foraminifera Gypsina vesicularis. Associated sediment composed of fine to medium sand sized fragments of coral, mollusk shell, encrusting and branching coralline algae, and encrusting foraminifera. Minor occurrences of whole foraminifera tests, and gastropod (some vermetid) shells. Larger fragments occur in a matrix of silt-sized skeletal packstone to minor wackestone. Internal silt-sized skeletal wackestone infills numerous voids; geopedal fabric common. Little cement development observed expect for the occurrence of radial fibrous rim within vermetid gastropod shells fenestral pores in algal and occasional boring; fibrous cement is proably aragonite. Primary porosity preserved as growth framework, ferrestral, shelter, interparticle, and borings.

3.0 Section number: GWB34-3.

Coral/algal-foraminifera boundstone. Some characteristics as at the 2-foot depth. Minor occurrence of Halimeda; plate appeared to be partially dissolutioned, other skeletal constituents appear to be unchanged.

11.0 Section numbers: GWB34-11; GWB34-11A.

Coral-algal boundstone with internal silt-sized skeletal wackestone. Numerous smaller sized coral septa occluded by radial fibrous aragonite cement; needle-like crystals are usually inclined from the pore wall forming a herringbone pattern in long narrow pores. Greater abundance of cement fabric than at shallower depths. Radial fibrous cement occurs within vermetid gastropod shells; no cement present where shell is filled with internal sediment. Primary porosity preserved as growth framework fenestral, borings, shelter, and interparticle.

15.0 Section number: GWB34-11.

Coral/algal-foraminifera boundstone with internal sediment. Massive coral encrusted mainly with coralline algae with lesser occurrence of encrusting foraminifera (much less than at shallower depths). Internal silt-sized peloidal skeletal wackestone partially or completely infills numerous coral septa. borings, and other voids. Vermetid gastropods associated with coralline algae. Cement and porosity characteristics similar to that at 11.0 feet; visibly more abundant radial fibrous cement within coral septa; very distinct herringbone patterns.

23.0 Section number: GWB34-23.

Coral fragment and wackestone to packstone. Larger sized fragments of coral, coralline algae, and mollusk shells in a fine sand to silt-sized skeletal wackestone to grainstone matrix, larger gastropod shell is fractured with slight displacement of fragments; some minor compaction, although sediment in general has very open pore system. Cement in coral septa is less abundant than at 15 feet, but shows same characteristics. Blocky to elongated microcrystalline (<4μm) clear cement binds grains where mud is not present; tends to occlude the original interparticle pore space. Primary porosity preserved as interparticle, growth framework, and shelter.

24.0 Section number: GWB34-24.

Coral with mudstone to wackestone internal sediment. Most coral septa are open; occasional cement developed in speta. Growth framework porosity.

26.0 Section number: GWB34-25

Packstone. Coarse sand to silt-sized skeletal packstone with gradations to grainstone. Blocky microcrystalline cement binds grains. Similar composition as at 23 feet. Primary porosity preserved as interparticle, shelter, and growth framework.

32.0 Section number: GWB34-32.

Coral/algal boundstone with internal sediment. Similar characteristics as those described for the section at 11 feet; greater abundance of fibrous cement, however. Some iron-oxide stain along contact of coralline algae and associated sediment.

33.0 Section numbers: GWB34-33.5A; GWB34-33.5B.

Coral/algal boundstone. Some characteristics as at depth 33.0 feet.

35.0 Section numbers GWB34-35A.

Coral/algal boundstone with associated sediment. Some characteristics as the above two thin sections with the notable exception of the occurrence of a well developed isopachous radiaxial rim cement. Rim cement lines numerous coral septa and other pore space and coats larger grains within the sediments. First occurrence of this type of cement. There is an apparent lack of the fibrous, needle-like cement within coral septa. Rim cement is probably Mg-calcite in composition. Sample for this thin section is at the contact between the modern reef and the underlying Mariana limestone.

Section number: GWB34-35B.

Mariana limestone: Halimeda packstone. Sediment composed of larger sized (coarse sand size) Halimeda paltes, whole gastropod shells, fragments of coral and coralline algae, and echinoid plates in a matrix of fine sand and silt-sized skeletal packstone. Halimeda plates and shell material have been removed with the mold partially or completed occluded by blocky moasic calcite spar; crystal size increases away from mold wall. Outline of Halimeda plate preserved by a micrite envelope. Coral septa and numerous other pore types are lined by a blocky calcite spar rim cement often with dog-tooth terminations oriented into pore space. Coral fragments have been replaced by mosaic sparry calcite with preservation of original features. Minor iron oxide stains with partially or completely occluded pores. Porosity is mostly secondary moldic and vuggy types; minor primary growth framework associated with coral fragments.

37.0 Section number: GWB34-37.

Mariana limestone: Skeletal mudstone. Occasional mollusk shell fragment and foraminifera test in a mudstone matrix. Calcite masaic appears to have replaced some of the micrite matrix, particularly around pore spaces. Porosity is secondary vuggy type with many pores lined with a replaced fibrous isopachous rim cement (original composition probably was Mg-calcite). A few pores exhibit a selective solutional removal of a portion of the rim cement.

51.0 Section number: GWB34-51A; GWB34-51B.

Mariana limestone: travertine and peloidal mudstone. Travertine overlain by laminated peloidal mudstone with occasional skeletal fragments. Iron oxide stains along contact lines within travertine, between travertine and mudstone, and selected skeletal fragments. Mudstone appears to be derived from the modern reef depositional environment forming a void filling. Micrite peloids are cemented by blocky microcrystalline rim cement of probable mg-calcite composition. Some primary interparticle pore space between peloids and minor skelter porosity.

55.0 Section number: GWB34-55.

Mariana limestone: Skeletal packstone. Sand sized fragments of coralline algae, mollusk shell, Halimeda plates, and echinoid spines with whole larger foraminifera tests in a matrix of fine sand to silt-sized skeletal packstone. Most skeletal material has been replaced by a blocky microspar calcite cement (drusy clacite spar) and are outline by a micrite envelope. Mg-calcite skeletal fragments appear unchanged. Pores not occluded are lined with either calcite spar or a thick isopachous radiaxial rim cement (approximately 0.2 mm thick). Porosity is secondary moldic and vuggy types and is relatively low because of sparry calcite cement occluding molds.

Borehole: WB-35

Depth (ft)	Description
2.0	Section numbers: GWB35-2A; GWB35-2B. Coral/algal - foraminifera boundstone with internal and associated sediment. Marine coral encrusted with coralline algae and minor occurrence of *Gypsina vesicularis* in discontinuous layers. Associated sediments composed of fine sand sized fragments of mollusk shell, coral, and coralline algae in a silt-sized peloidal skeletal wackestone to packstone matrix. Occasional large-size whole mollusk shells and vermetid gastropods associated with the encrusting coralline algae. Internal sediment is a silt-sized peloidal skeletal wackestone. Radial fibrous to blocky microcrystalline cement occur in a few pores associated with the coralline algae; radial fibrous cement occur in a few vermetid gastropod shells similar to that described for other sections of samples collected for the modern environment of deposition. Only these cement types are readily apparent. Primary porosity preserved as growth framework, interparticle, fenestral, and borings.
3.0	Section number: GWB35-3. Massive coral with internal sediment. Small amount of silt-sized skeletal wackestone to mudstone infilling coral septa; geopedal fabric is common. Minor occurrence of a needle-like fibrous aragonite cement lining septa walls. Both coral and cement positively identified by staining. Growth framework porosity.
9.0	Section numbers: GWB35-9; GWB35-9A; GWB35-9B; GWB35-9C; GWB35-9D. Skeletal packstone. Large fragments of coral and molluska shells in a matrix of sand to silt-sized skeletal packstone to wackestone (later infills as internal sediment). Skeletal constituents are whole gastropod shells, and mollusk shell debris, echinoid spines, encrusting foraminifera, and coralline algae, and coral fragments. Mollusk shells are extensively bored and filled with internal sediment. A number of larger mollusk shell fragments have been extensively bored by algae on the exterior surface. Two types of cements are present: one occur as needle-like fibers within gastropod shells, often occluding the interior cavity space, the other is a prosimatic or blocky microcrystalline cement binding skeletal grains, often forms a rim coating on grains or peloids. Primary porosity preserved as interparticle, growth framework, intraparticle, borings, shelter, and fenestral (in coralline algae).
12.0	Section numbers: GWB35-12. Coral/algal boundstone with internal and associate sediment. Similar characteristics as at 2.0 - foot depth with the exception of encrusting foraminifera. Needle-like fiber cement occurs in coral septa; forms herringbone pattern and is an extension (optically continuous) of the crystal growth pattern of the original coral structure (composition: aragonite). Primary porosity preserved as growth framework and interparticle.

14.0 Section numbers: GWB35-14; GWB35-14A; GWB35-14B.
Skeletal packstone. Same features and characteristics as those described for the 9.0 - foot depth. Mollusk shells are extensively bored with boring partially or completely filled with internal sediment.

15.0 Section numbers: GWB35-15A; GWB35-15B.
Mariana limestone: Halimeda packstone. Halimeda plates, mollusk shell and coralline algae fragments, foraminifera tests, and echinoid spines (other skeletal constituents are probably replaced coral fragments) in a micrite matrix. Fragment size range from sand to silt and poorly sorted. Similar characteristics as those described for section GWB34-3513 (depth: 35 feet) with notable exception that some of the Halimeda plates have not been totally replaced by blocky mosaic calcite cement and the occurrence of multi-generation isopachous rim cement lining probably primary pores. It appears that there are at least three generations and possibly as many as five. Where three distinct rims are visible, the first two appear to be radial fibrous followed by blocky spar calcite (the last rim in all cores). The fibrous rim cement contains inclusions and dust lines. Rim thickness for the first rim in about 0.4 mm and the next two are about 0.3 mm, although they vary from pore to pore. In places the calcite cement occludes the pore space and forms dusty fabric. Occasional pores show selective dissolution of the thicker rim cement, leaving a void between the pore wall and the second rim. Porosity is secondary and includes mold and vuggy types in addition to interparticle (void space rim cements of probable marine origin line interparticle or intraparticle pores).

17.0 Section numbers: GWB35-17; GWB35-17A; GWB35-17B.
Mariana limestone: skeletal packstone. Similar lithology as that described for the previous sections except there is a lack of Halimeda plates and only are generations of isbpachous rim cement. Rim cement exhibit a relic fibrous texture; replaced by mosaic calcite.

20.0 Section numbers: GWB35-20; GWB35-20A; GWB35-20B.
Mariana limestone: Skeletal packstone to wackestone. Same general lithology as at a depth of 15.0 feet; multi-generations rim cement. Notable exception is the lack of Halimeda plates.

30.0 Section numbers: GWB35-30A; GWB35-30B; GWB35-30C.
Mariana limestone: skeletal packstone. Similar lithology as at 17.0 feet except with occasional occurrence of Halimeda and multi-generation isopachous rim cements similar to that previously described (including the selective dissolution). Remenant rim cements exhibit a haze extinction that roughly outlines radial fibrous crystal growth with lengths equal to the rim thickness.

34.0 Section numbers: GWB35-34; GWB35-34A; GWB35-34B.

Mariana limestone: Halimeda packstone to wackestone, skeletal grainstone. Sections 34 and 34A show similar lithology as that at 15.0 to 20.0 feet. Dominant skeletal material is Halimeda with coralline algal fragments, foraminifera tests, and other skeletal constituents as described above. Halimeda plates show internal details and a micrite envelope outlining the plate boundary. Utricules are infilled with microspar calcite cement. Where less mudstone (micrite) matrix a multi-generations isopachous rim cement has formed around skeletal grains. Drusy spar calcite cement partially filled or occludes numerous pores and replaces previously removed rim cement and Halimeda plates. Same selective rim-oxide staining of echinoid spine fragments and along some contact lines. Secondary porosity is moldic and vuggy with primary porosity occluded by calcite cement. Section 34D is a skeletal grainstone with well developed thick isopachous radial fibrous rims cement. Skeletal grains are composed of coral, coralline algae, and mollusk shell fragments as the abundant constituents. Coral and shell material appear to be fresh and yield a positive stain test for aragonite. Rim cement is one generation, relatively thick (0.23 mm average, but depends on grain size), and abundance; well developed triple junctions. Primary porosity preserve as interparticle and relatively high at an estimate of 20%.

40.0 Sections numbers: GWB35-40; GWB35-40B; GWB35-40C.

Mariana limestone: skeletal packstone. Nearly all skeletal material except fragments of coralline algae have been removed by dissolutions and same have been partially a completely replaced by microspar calcite cement. Where coral is present, it has been preserved by replacement by a calcite mosaic. The relic structure of the coral including a fine-crystalline needle-like fibrous cement occurring in coral septa, is readily observable. Secondary moldic porosity is dominant type and relatively high in abundance, estimate of 30%.

42.0 Section numbers: GWB35-42A; GWB35-42B; GWB35-42C; GWB35-42D.

Crevice fill: skeletal packstone with internal sediment. Sediment has a fresh appearance (positive stain for aragonite) with preservation of primary porosity types; probably is a crevice fill within the Mariana limestone and derived from the modern depositional environment. Same lithology as that described for similar sediments at depths less than 15.0 feet. Occurrence of a thick isopachous radial fibrous rim cement similar to that described in sections at 30 ft. In scattered places (very few) there are occurrences of what appears to to a replacement of small portions of the micrite matrix by microcrystalline calcite which appears as mosaic pattern with relic structures. This modern sediment is separated from the older Mariana limestone by a layer of travertine (GWB35-42D shows contact).

48.0 Section numbers: GWB35-48; GWB35-48A.

Crevice fill: skeletal grainstone to packstone with internal sediment. Skeletal constituents fragments of coralline algae, mollusk shells (some whole), coral, echinoid spines, and foraminifera. Internal sediment is fine sand to silt-size skeletal packstone to wackestone. Occurrence of thick (0.24 mm) isopachous radial fibrous rim cement as described for sections at 30.0 feet; multi-generation cement. Porosity type is primary interparticle and intraparticle.

58.0 Section numbers: GWB35-58A; GWB35-58B; GWB35-58C.

Crevice fill: skeletal grainstone with isopachous rim cement. Some lithology as grainstone description for previous section (at 48.0 feet); rim cement is about 0.10 mm average thickness, somewhat less than at 48.0 feet. Porosity type is interparticle with minor intraparticle. Positive stain for aragonite on coral and mollusk shell fragments.

63.0 Section number: GWB35-63.

Crevice fill: skeletal grainstone. fine sand to silt-size grains cemented by an isopachous radial fibrous rim cement. Some lithology as at 58.0 feet. Estimate of porosity is about 10%.

69.0 Section numbers: GWB35-69; GWB35-69B.

Mariana limestone: coral/algal-foraminifera boundstone with internal sediment. Lithology in this section has the same general appearance as its modern day counterpart (as described for depths less than 15.0 feet). The main difference is the apparent replacement of aragonitic skeletal material by mosaic calcite spar with the preservation of the original structure and the partial or complete infilling of primary interparticle and intraparticle (including growth framework) by microspar calcite cement. Porosity is moldic to mostly vuggy types; estimate is less than 5%.

82.0 Section number: GWB35-82.

Mariana limestone: skeletal packstone to wackestone. Similar lithology as that described for section at 15.0 feet. Occurrence of Halimeda plates and multi-generation isopachous rim cements.

99.0 Section number: GWB35-99.

Mariana limestone: Skeletal packstone to wackestone. Some lithology as that described for the 82-foot depth.

Borehole: LB-33

Depth (ft)	Description
1.0	Section number: GLB33-1. Mariana limestone: skeletal packstone to wackestone. Skeletal constituents are sand to silt-sized fragments of coralline algae, mollusk shells, and other types; foraminifera tests also present. Aragonitic skeletal fragments appear to have been replaced by microspar (drusy) calcite cement. Iron oxide stains grains in a portion of the section; grains are cemented by sparry calcite. Secondary porosity types are moldic to mostly vuggy; relatively low in abundance.
5.0	Section number: GLB33-5. Mariana limestone: skeletal packstone to wackestone. Sand-to silt-sized skeletal fragments of coralline algae, mollusk shells, and encrusting foraminifera and occasional whole gastropods and _Halimeda_ plates in a peloidal micrite matrix. Sparry calcite cements occur within micrite and binds skeletal grains where no micrite is present. Some pore space is partially as completely occluded by spar calcite cement; dog-tooth spar occurs in open voids. Many skeletal grains are outlined by a micrite envelope. Porosity is moldic to mostly vuggy types.
6.0	Section numbers: GLB33-6. Skeletal packstone. Skeletal constituents are encrusting foraminifera and tests, coralline algae, _Halimeda_ plates and other undistinguishable skeletal fragments (probably mollusk shell or coral). Similar lithology to that described for 5-foot depth. Much of the skeletal fragments have been replaced by spar calcite cement; spar calcite also binds grains and occurs within the micrite matrix. Porosity is moldic to vuggy.
12.5	Section number: GLB33-12.5. Mariana limestone: Coral fragment with associated sediment. Neomorphic coral fragment in sand to silt-size skeletal packstone. Skeletal constituents are coral, algal and foraminiferal fragments and other non-distinguishable debris. Coral appears to have been replaced by fine-crystalline mosaic calcite preserving some of the original structure. Some coral septa probably filled with internal wackestone. Open pores in coral appear to be either original septa or exhumed fabric, dog-tooth spar calcite line many pores. Spar crystals are perpendicular or at a slight angle to the septa wall (similar to the orientation of aragonite fibrous cement in the modern corals described above). Porosity is moldic to vuggy.

20.0 Section number: GLB33-20.

Mariana limestone: Mudstone overlying Halimeda packstone. Mudstone appears to have been partially recrystallized to microspar calcite. Halimeda plates in skeletal packstone have been mostly replaced by drusy calcite spar. Spar calcite is also abundant within the peloidal micrite matrix of the packstone. Porosity in moldic to mostly vuggy in packstone and vuggy in mudstone.

29.5 Section number: GLB33-29.5.

Mariana limestone: Halimeda packstone. Skeletal constituents are Halimeda plates, echinoid spines, gastropod shells, and fragments of coralline algae and proable mollusk shell and coral debris. Packstone matrix is peloidal micrite. Most skeletal constituents are outlined by a micrite envelope. Drusy calcite spar has replaced much of the skeletal material and partially or completely occludes voids. Microspar many place some of the matrix. Large part of section is a fine to coarse-crystalline travertine void filling with iron-oxide stains along layer contacts and at sediment-travertine contact. Porosity is moldic to vuggy within the packstone.

34.0 Section number: GLB33-34.

Mariana limestone: Coral/foraminifera boundstone. Much of the structure is difficult to distinguish because of the general replacement by fine-crystalline mosaic calcite. Coral septa are outlined and some are filled with skeletal peloidal wackestone. Most aragonitic skeletal material has been replaced by mosaic calcite; other material outlined by micrite envelope. Lithology is similar to that described for packstone at 29.5 feet. One part of section shows prismatic spar calcite filling void; fibrous shadow (opague) within calcite crystals, may be relic fibrous cement. Porosity is moldic to vuggy.

42.5 Section number: GLB33-42.5.

Mariana limestone: skeletal packstone. Lithology is the same as that at 5.0 and 6.0 feet. Dog-tooth calcite spar lines pores and coats some larger grains. Porosity is moldic with some vuggy types with a relatively low abundance.

47.5 Section number: GLB33-47.5.

Mariana limestone: skeletal wackestone. Silt-sized with occasional larger skeletal clast in a micrite matrix. Similar lithology and composition as that at 5.0 and 6.0 feet except much less Halimeda is present. Porosity is mainly vuggy.

55.0 Section number: GLB33-55.

Mariana limestone: skeletal packstone. Some lithology and composition as at 5.0 feet but little occurrence of Halimeda. Microspar calcite replacement of most skeletal fragments; micrite envelope outlines, and dog-tooth spar lining voids. Porosity is moldic and vuggy.

62.0 Section number: GLB33.62.

Mariana limestone: Coral/foraminifera boundstone. Some lithology and composition as that at 34.0 feet.

65.5 Section number: GLB33-65.5.

Mariana limestone: skeletal packstone to wackestone. Bedding is present in sediment. Sand to silt-sized skeletal packstone with skeletal wackestone layers. Skeletal constituents are mollusk shells (some whole gastropods), echinoid spines, Halimeda plates, coralline algal fragments, foraminifera debris, and other undistinguishable skeletal material. Aragonitic skeletal material has been replaced by drusy calcite spar. Spar also lines voids. Similar lithology as that described above for packstones and wackestones of the Mariana limestone. Porosity is moldic to vuggy types.

Borehole: LB-34 & 34A

Depth (ft) Description

5.0 Section number: GLB34-5.

Mariana limestone: skeletal grainstone to packstone. Skeletal constituents are foraminifera tests and fragments of encrusting types, coral fragments, coralline algal fragments, echinoid spines, some *Halimeda* plates, wackestone peloids, and non-distinguishable skeletal material. Aragonitic skeletal material replaced by drusy spar calcite. Spar calcite binds grains and dog-tooth spar lines voids. Micrite envelopes around most skeletal grains. Porosity is moldic to vuggy with all interparticle porosity occluded by spar calcite cement; some iron-oxide staining along pore walls.

9.0 Section number: GLB34-9.

Mariana limestone: skeletal packstone to wackestone. Same lithology as that at 5.0 feet.

16.5 Section number: GLB34-16.5.

Mariana limestone: *Halimeda* packstone overlain by skeletal grainstone. Skeletal constituents are *Halimeda* plates, foraminifera tests, fragments of encrusting foraminifera, coralline algae, and mollusk shells, and an occasional whole spiraled gastropod shell. Some *Halimeda* plates show internal details; most have been replaced by drusy spar calcite. Spar calcite also binds and coats skeletal grains. Relatively thick micrite envelope outlines skeletal grains. Some interparticle porosity remains; most is moldic to vuggy types.

29.0 Section number: GLB34-29.

Mariana limestone: neomorphic coral fragment. Coral has silt-sized skeletal wackestone internal sediment and some encrusting foraminifera. Coral has been replaced by microspar calcite mosaic with preservation of original structure. Porosity is vuggy with minor occurrence of (secondary on exhumed) growth framework.

42.0 Section number: GLB34-42.

Mariana limestone: neomorphic coral fragment. Some lithology as that at 29.0 feet; both coral fragments occur within a skeletal packstone with a lithology similar to that at 16.5 feet.

56.0 Section number: GLB34-56; GLB34-56.6.

Mariana limestone: skeletal packstone to grainstone. Similar skeletal constituents and lithology as above. Somewhat less calcite spar lining of voids; greater abundance of vuggy porosity.

60.5 Section number: GLB34-60.5.

Mariana limestone: neomorphic coral fragment. Some lithology or at 29.0 feet.

62.5 Section number GLB34-62.5.

Mariana limestone: Halimeda - foraminifera skeletal packstone to grainstone. Some lithology as that at 16.5 feet. Porosity is moldic and vuggy types and abundant.

77.0 Section number: GLB34-77.

Mariana limestone: Halimeda and foraminifera packstone. Similar lithology as at 62.5 feet except there appears to be more than one generation of a rim cement within some of the voids; first rim is mostly a micrite and is isopachous, followed by a rim of spar calcite. Occasional pore shown preferential dissolution of first rim. Porosity characteristic similar to other packstone description.

82.0 Section number: GLB34A-77.

Mariana limestone: neomorphic coral fragment and skeletal packstone to wackestone. Skeletal constituents are coral, encrusting foraminifera, wackestone to micrite peloids, and non-distinguishable skeletal material. Similar lithology as above packstones. Some voids are lined with three generations of isopachous rim cements; details of the crystal habit of rim cements not visible; cements have the appearance of micrite. Little to no calcite spar lining larger voids. Porosity is moldic to mostly vuggy types.

84.0 Section number: GLB34A-82.

Mariana limestone: skeletal packstone. Similar lithology as at 82.0. Two generations rim cement; first in isopachous with same characteristics as above; second, when present is calcite spar. Porosity is moldic to vuggy types.

98.3 Section number: GLB34A-98.3.

Mariana limestone: coral-foraminifera skeletal packstone to wackestone. Same lithology and porosity characteristics as that described for 16.5 foot depth except lesser abundance of Halimeda and greater abundance of foraminiferal material.

Borehole: LB-35.

Depth (ft) Description

2.0 Section number: GLB35-2.

Mariana limestone: coral/foraminifera boundstone and associated sediment. Massive coral encrusted with the foraminiferan Gypsina (no coralline algae in association). Sediment is a void filling (geopedal fabric); silt-size skeletal wackestone to packstone. some bedding characteristics are present. Neomorphic coral with well preserved original structure. Some pores showing internal sediment, following by a spar calcite cement, followed by a second generation of sediment. Multi-generation rim cement also present; at least two generations. Porosity is moldic and vuggy with some primary preserved as shelters, growth framework, fenestral; and minor interparticle.

5.0 Section numbers: GLB35-5; GLB35-5A; GLB35-5B.

Mariana limestone: Coral/foraminiferal-algal boundstone. Some lithology and composition as above except coralline algae also encrusts coral. Same porosity characteristics.

10.0 Section numbers: GLB35-10; GLB35-10A.

Mariana limestone: Skeletal packstone to wackestone. Skeletal constituents are non-distinguishable fragments, mostly replaced by microspar calcite. Spar also occurs with micrite matrix. Larger-sized skeletal fragments are encrusting foraminifera and coralline algae. Porosity is moldic to mostly vuggy types.

17.0 Section number: GLB35-17.

Mariana limestone: neomorphic coral with skeletal wackestone to mudstone internal sediment. Some preferential iron-oxide stains within internal sediment and along what appear to be mudstone filled fractures in the coral. Porosity is vuggy type.

22.0 Section number:; GLB35-22.

Mariana limestone:; coral/foraminifera-algal boundstone with internal and associated sediment. Massive coral (neomorphic) is encrusted with the foraminiferan Gypsina and to a minor extent coralline algae. Internal sediment in coral septa; silt-sized skeletal wackestone. Associated sediment is a sand-sized and smaller poorly sorted skeletal packstone. Skeletal constituents are broken foram tests, fragments of encrusting foraminifera, coralline algal fragments, minor Halimeda, and non-distinguishable skeletal fragments. Most open voids are lined with sparry calcite rims. Porosity is mainly moldic however, some primary growth framework porosity associated with the coral (open septa).

26.0 Section numbers: GLB35-26A; GLB35-26B.

Mariana limestone: skeletal packstone to wackestone. Skeletal constituents are fragments of encrusting coralline algae and foraminifera, echinoid plates, and non-distinguishable skeletal debris. Constituents are in a microspar to micrite matrix. Porosity is vuggy type with a lesser occurrence of spar calcite linings.

30.0 Section numbers: GLB35-30; GLB35-30A.

Mariana limestone: skeletal packstone. Skeletal constituents are echinoid spines, foram tests, and fragments of coralline algae (branching and encrusting), encrusting foraminifera, coral, and mollusk shells. Well developed micrite envelope around most skeletal fragments. Drusy spar calcite replaces much of the skeletal debris. Porosity is moldic to vuggy; little development of spar rim cement.

36.0 Section number: GLB35-36.

Mariana limestone: coral/foraminifera-algal boundstone with skeletal wackestone internal sediment and skeletal packstone to wackestone associated sediment. Some lithology and porosity characteristics as that described for sections at 2.0 and 5.0 feet.