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NEAR-SURFACE GEOLOGIC INVESTIGATIONS AT ENIWETOK ATOLL

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Air Force Weapons Laboratory

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The near-surface geology to a depth of 300 feet beneath several of the windward islands and reefs at Eniwetok Atoll was investigated during 1971 and 1972. Rotary drilling (~130 holes, 8000 lineal feet) and seismic refraction (~50,000 feet of traverse) were the primary field methods employed. Samples, classified on the basis of physical characteristics, were assigned to one of the following descriptive lithologic units: Upper Sediment, Upper Limestone, Lower Sediment, or Lower Limestone. In all sections drilled, these units were found to be sequentially ordered with depth. Correlation between geologic

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cross sections and seismic refraction profiles for two islands studied in detail indicate an internally consistent lithologic structure to the depth investigated. Based on these data, together with supportive data from other islands of the atoll, a near-surface geologic model for Eniwetok was constructed. The fundamental structural unit of the model is the Lower Limestone whose upper surface forms a bench near the present ocean ridge at a 40- to 45-foot depth and then dips gradually lagoonward. Present islands overlie and, in some cases, extend lagoonward from the bench. The overall shape of the Lower Limestone unit suggests lithification during subaerial exposure and leads to the inference that its upper surface is a solution unconformity in the sense of Schlanger (1963). Other solution unconformities in both the Lower Limestone and the overlying Lower Sediment are suspected. Detailed microscopic analyses and age determinations are required to establish positive correlation between the suspected unconformities of this paper and those delineated by previous investigations for Eniwetok and Bikini.

PREFACE

The work presented in this report was an integral portion of the Pacific Cratering Experiments, a DNA funded, AFWL directed test program to study previous nuclear test results at Eniwetok Atoll. Credit is due Robert Henny (Test Director), Anthony Pyrz (Test Conductor), Joseph Repichowski (Seismic Technician) and the rest of the AFWL Team; William Hale and his staff at the United States Geological Survey; and Phillip Helfrich and his colleagues at the University of Hawaii. Special thanks are due Harry Ladd and Joshua Tracey of the Smithsonian Institution and the United States Geological Survey, respectively, both for their continued advice throughout the program and for their critical review of this paper.

This report is a reprint, with some minor corrections, of a paper presented at the Second International Symposium on Coral Reefs, Brisbane, Australia, June 1973.

CONTENTS

Section		Page
I	INTRODUCTION	5
	1. General	5
	2. Scope of Paper	5
II	ENIWETOK GEOLOGY	6
	1. General Aspects	6
	2. Pre-PACE Investigations	6
	3. Pre-PACE Geologic Model	6
III	FIELD PROGRAM	10
	1. Drilling	10
	2. Seismic Refraction	14
	3. Other Field Methods	14
IV	RESULTS	16
	1. Sample Descriptions	16
	2. Geologic Cross Sections	19
	3. Seismic Profiles	24
V	DISCUSSION	27
VI	PROPOSED GEOLOGIC MODEL	31
VII	CONCLUSIONS	34
VIII	BIBLIOGRAPHY	35
	REFERENCES	36

ILLUSTRATIONS

Figure		Page
1	Location of Eniwetok Atoll	7
2	Map of Eniwetok Atoll Showing Location of Runit and the Aomon Group	8
3	Aerial View of Runit - Looking to the South	11
4	Aerial View of the Aomon Group - Looking to the Northwest	11
5	Runit - Drill Hole Locations	12
6	Aomon Group - Drill Hole Locations	13
7	Runit - Longitudinal Geologic Cross Section	20
8	Runit - Transverse Geologic Cross Sections	21
9	Aomon - Transverse Geologic Cross Section	22
10	Aomon Group - Longitudinal Geologic Cross Section	23
11	Aomon - Seismic Velocity Profiles	25
12	Geologic and Seismic Interpretations for Aomon Transverse Cross Section - Other Aomon Group Data Superimposed	28
13	Near Surface Geologic Model for Eniwetok Atoll	32

SECTION I
INTRODUCTION

1. GENERAL

The near surface geology to 300 ft beneath selected islands at Eniwetok Atoll was investigated during 1971 and 1972. These investigations, named PACE-1, were an integral part of the Pacific Cratering Experiments, a program to determine the influence of geology on the formation of nuclear craters at Eniwetok.

A reconnaissance of the atoll was conducted in January 1969. Field work began in July 1971 and continued intermittently until September 1972, when it was prematurely terminated with only a portion of the work finished. Recently a new program named Exploratory Program on Eniwetok (EXPOE) was initiated to complete the balance of the PACE-1 objectives.

2. SCOPE OF PAPER

This paper briefly describes the various field methods employed during PACE-1. Selected geologic cross sections based on field descriptions of the drill samples are combined with seismic refraction results to construct a near surface geologic model for Eniwetok. Many of the results presented are preliminary; final reports covering the topics discussed here and other aspects of the program will be prepared after further analysis of the data.

SECTION II
ENIWETOK GEOLOGY

1. GENERAL ASPECTS

Eniwetok Atoll is the northwestern-most atoll in the western (Ralik) chain of the Marshall Islands, central Pacific Ocean (figure 1). Its shape is broadly elliptical, 26 mi long and 19 mi wide. The atoll (figure 2) includes approximately 36 islands with an area of 2.26 square miles. Maximum elevation is less then 11 ft above mean sea level.

2. PRE-PACE INVESTIGATIONS

As a result of the US nuclear testing from the late 1940s through the 1950s, Eniwetok and Bikini Atolls are geologically and biologically, the best documented atolls in the world.

From 1950 through 1952 three deep holes with depths of 1280, 4222, and 4630 ft; 17 shallow holes with depths of 43 to 200 ft; and 4 reef holes with depths of 6 to 16 ft were drilled at Eniwetok under the auspices of the US Atomic Energy Commission and described and analyzed by the US Geological Survey (Ladd and Schlanger - 1960). The two deepest holes, which were on opposite sides of the atoll, penetrated basement rock, one returning about 15 ft of olivine basalt core.

Schlanger (1963) analyzed samples from the two deepest holes and found that, except for a 1000 ft interval from the north side of the atoll, the limestone sections were composed of shallow water (predominantly lagoonal) deposits. Leached zones were identified between 52 to 72 and 280 to 310 ft and were interpreted to be solution unconformities formed during periods of subaerial exposure. Tracey and Ladd (1974) reviewed the Quaternary stratigraphy of Eniwetok and correlated the solution unconformities with similar zones previously defined at Bikini (Emery, Tracey, and Ladd - 1954).

3. PRE-PACE GEOLOGIC MODEL

Prior to the start of the PACE Program, a geologic model was constructed for Eniwetok based upon the drilling results of the 1950s (Pratt and Cooper - 1968). Eniwetok was interpreted to be a 4600 ft thick limestone cap resting on a volcanic mound rising two miles above the ocean floor. The

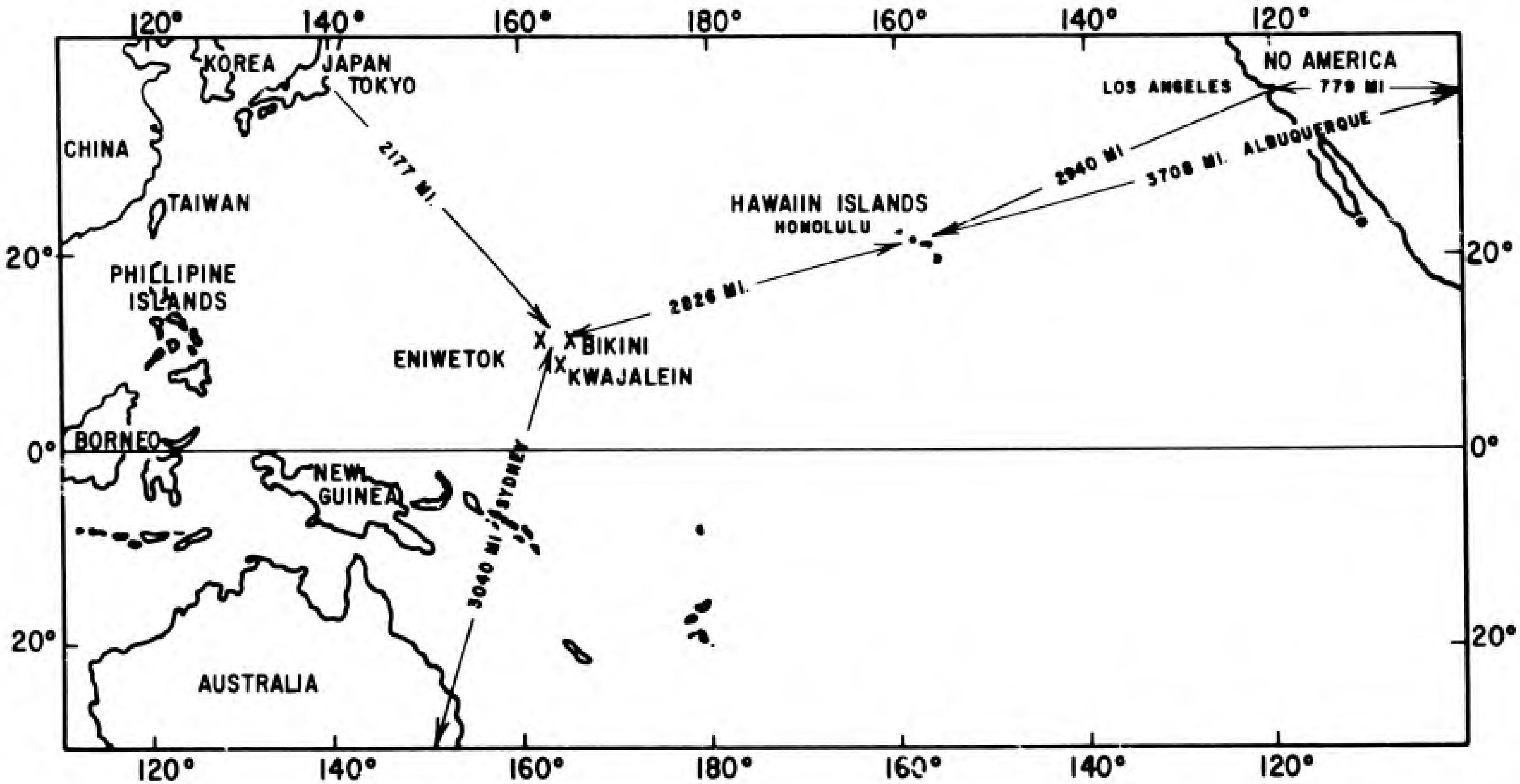

Figure 1. Location of Eniwetok Atoll

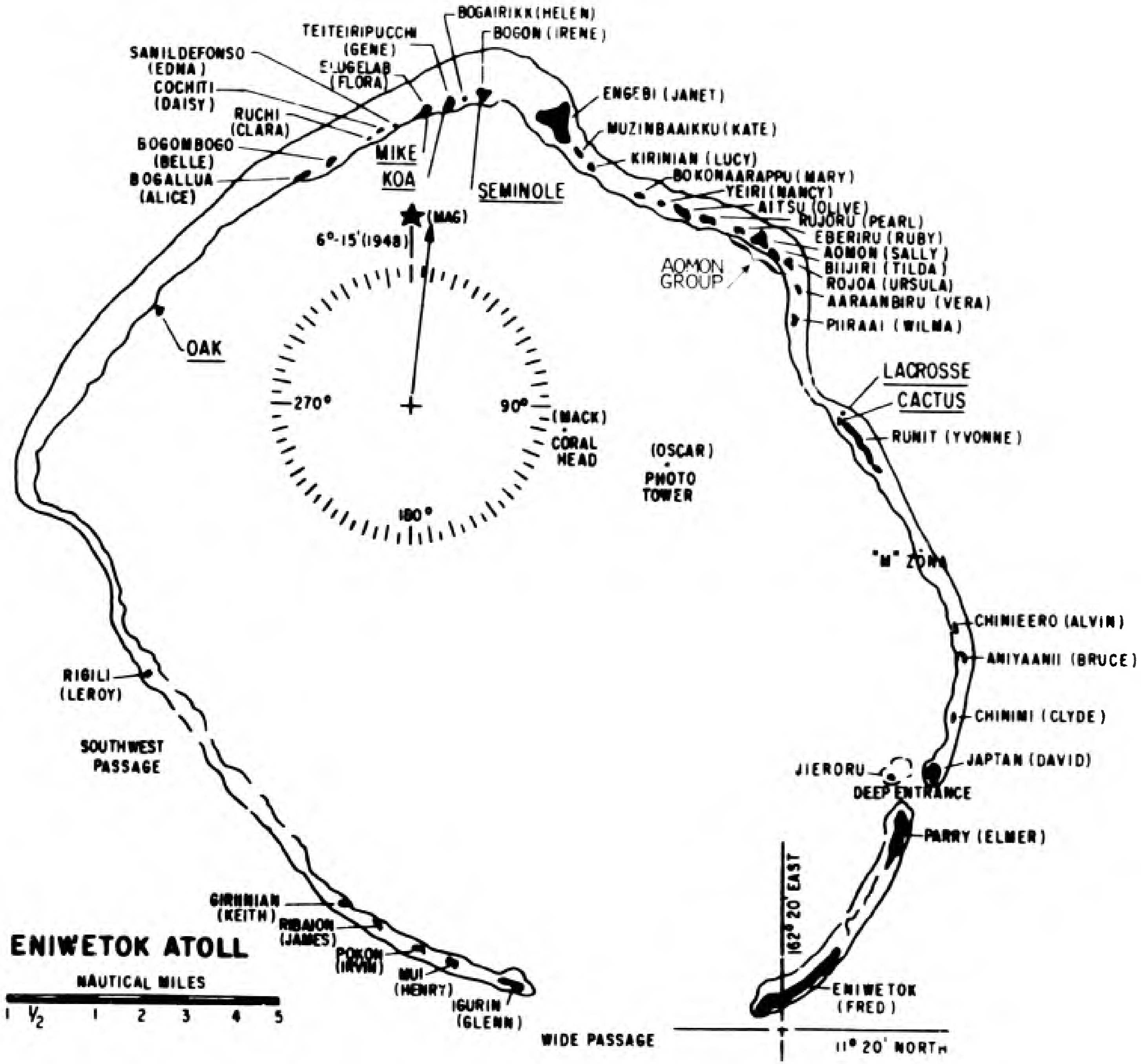

Figure 2. Map of Eniwetok Atoll Showing Location of Runit and the Aomon Group

upper several hundred feet was interpreted to be a heterogeneous mixture of unconsolidated reef detritus, coral heads, and lagoonal deposits. Except for the beach rock near the intertidal level and the reef surrounding the atoll, no consistent lithologic structure was recognized within this interval. The present work was based on this model, which has been characterized as a "bucket of sand", the bucket being the postulated wall structure of the reef and the sand being the unconsolidated sediment.

SECTION III
FIELD PROGRAM

The island of Runit (figures 3 and 5) and the islands of the Aomon group, Eberiru, Aomon, Biijiri, and Rojoa (figures 4 and 6), were selected for the detailed geological and geophysical field program consisting primarily of rotary drilling, sampling, and seismic refraction. Other field methods employed were trenching, augering, geophysical well logging, hydrologic studies, and material property testing.

1. DRILLING

Drilling was concentrated on Aomon (approximately 80 holes) and Runit (about 35 holes); other islands drilled included: Bogairikk (1), Bogon (3), Eberiru (4), Biijiri (4), and Rojoa (1). Approximately 8000 lineal feet were drilled. Drill hole designators used for PACE-1 are: PAR (Aomon), PBI (Biijiri), PRO (Rojoa), and PRU (Runit). Figures 5 and 6 are maps of Runit and the Aomon group showing the approximate location of each drill hole discussed in this report.

Two drill rigs, a Failing 1500 and a CME 55 were used for standard rotary drilling to a maximum depth of 305 ft. A salt water base bentonite mud was used for drilling in the unconsolidated and semiconsolidated materials while sea water was used for coring the consolidated materials. These standard methods together with a variety of other drilling muds and special hole treatment techniques proved insufficient to keep the holes open for later use. Accordingly, holes to be geophysically logged were cased with plastic casing.

The three types of samples collected were:

a. Cuttings

Cuttings were collected at 5 ft intervals except in zones that were cored.

b. Split Spoon

Drive samples were collected with a split spoon sampling device at 5 ft intervals in the unconsolidated material using a standard 140 lb hammer dropped over a calibrated distance to obtain penetration resistance measurements.

Figure 3. Aerial View of Runit
- Looking to the South

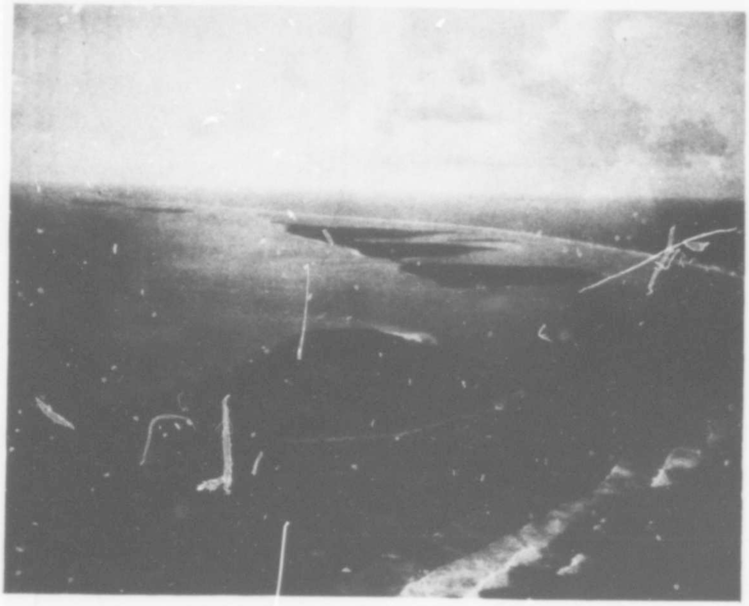

Figure 4. Aerial View of the Aomon Group
- Looking to the Northwest
(Aaraanbiru Island in foreground)

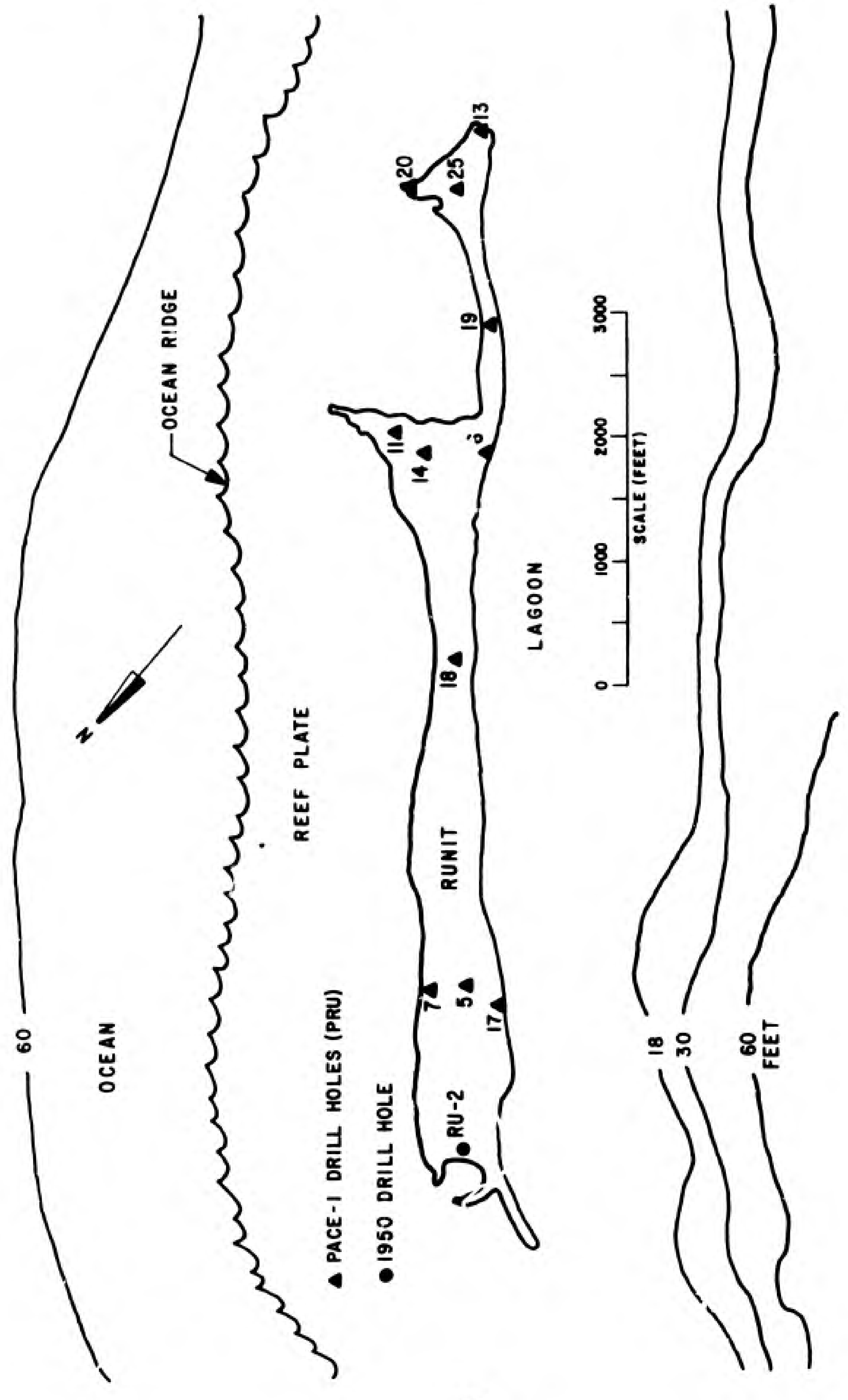

Figure 5. Runit - Drill Hole Locations

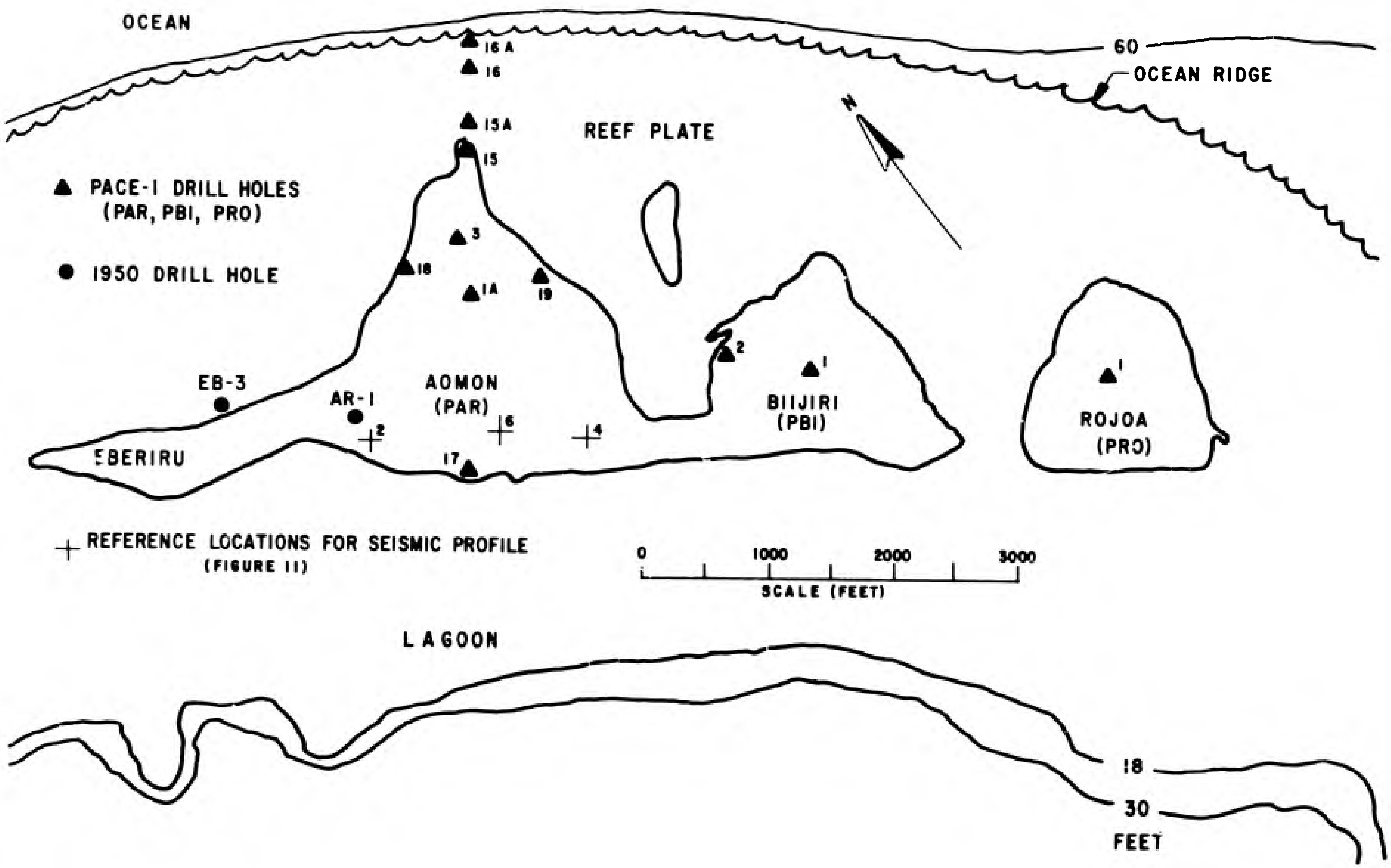

Figure 6. Aomon Group - Drill Hole Locations

c. Core

Coring was attempted whenever drive sample refusal was experienced or when drilling action indicated competent material.

2. SEISMIC REFRACTION

Seismic refraction surveys consisting of approximately 50,000 ft of variously oriented surface traverses were conducted, primarily on Aomon and Runit, but also on Sanildefonso, remnants of Elugelab and Teiteiripucchi, Bogairikk, Bogon, Eberiru, Biijiri, and Rojoa. Initial surveys were reconnaissance in nature to provide velocity profiles of the near surface lithology prior to drilling. Detailed seismic profiling was conducted at certain locations to supply further delination as required.

Refraction surveys were accomplished using a portable 12-channel seismic amplifier unit and low frequency geophones. The seismic waves were recorded on an oscillograph recorder where first-arrivals could be read to the nearest .001 second. Spread length and geophone spacing were varied depending upon depths of penetration and resolution required. Reversal shooting techniques were employed as a control on interface attitudes and apparent velocities of the different layers. The energy source consisted of approximately 1/4 lb of 400-grain primacord initiated by a seismic zero-delay firing cap all contained in a borehole below the intertidal level.

Additionally, seismic uphole and cross-hole surveys were conducted to depths of approximately 45 ft in selected boreholes to verify and correlate the near surface velocity data.

3. OTHER FIELD METHODS

a. Trenching

Trenching was conducted early in the program to establish the distribution of beach rock beneath several islands and to allow controlled sampling of the fresh water lens. In addition, the soil from ground surface to the trench bottom was sampled in .5 ft increments. More than sixty trenches were excavated on Engebi, Eberiru, Aomon, Biijiri, Rojoa, and Runit.

b. Augering

To determine the degree of homogeneity of the material, approximately two hundred 6-in diameter holes were augered to 40-ft depths on 50-ft centers along lines parallel and perpendicular to the lagoon beach of Aomon. Samples were not collected; but the degree of consolidation based upon drilling action was recorded; i.e., soft, intermediate, hard. Also, to define in greater detail the distribution of beach rock over this area, several hundred 2-in. diameter shallow holes were augered on 10-ft centers along lines perpendicular and parallel to the Aomon lagoon beach. Holes were augered either through the beach rock or to a depth of 15 ft whichever occurred first. Both upper and lower contacts of the beach rock were recorded.

c. Geophysical Well Logging

Natural gamma (lithology), gamma-gamma (bulk density), and gamma-neutron (water content) well logs were run, using a portable logger in plastic cased drill holes to augment lithologic interpretations and to provide qualitative *in situ* material property data.

d. Hydrological Studies

A number of water samples from the aforementioned trenches and from a few specially drilled holes were analyzed for water quality (chloride content and dissolved solids) and radioactivity (alpha, beta, gamma, tritium, and several isotopes). Self recording stations were established on Eberiru and Aomon to continuously record water level fluctuations. Using these data together with selected pumping tests, a preliminary water lens model for Aomon was constructed.

e. Material Property Testing

A number of split spoon samples from Aomon and Runit were tested on-site. Standard bulk descriptive properties (grain size, dry and wet density, and moisture content) were determined. Nine holes on the lagoon side of Aomon were specially drilled to depths of from 40 to 250 ft using a 6-in Dennison drive barrel. The "undisturbed" samples obtained were statically and dynamically tested. Results were used to develop an *in situ* material model for the sites drilled.

SECTION IV
RESULTS

1. SAMPLE DESCRIPTIONS

Cuttings, split spoon samples, and cores were logged and described in the field. Sample descriptions were based primarily on physical characteristics (degree and consistency of consolidation) although textural characteristics, cementation and solution features, and dominant faunal elements were also recorded. Using these field descriptions, and considering their stratigraphic position, samples were classified into one of four descriptive lithologic units: a) Upper Sediment, b) Upper Limestone, c) Lower Sediment, or d) Lower Limestone. These units are similar to those used by Emery, Tracey, and Ladd (1954), Ladd and Schlanger (1960), and Schlanger (1963). Where present, each of the units occurs with depth in the order listed. A brief discussion of each of the four units follows.

a. Upper Sediment

The Upper Sediment is a heterogeneous mixture of unconsolidated sand and gravel size detritus derived from the ocean reef and to a lesser extent the lagoon. Major faunal elements include foram tests and fragments of coral and algae. This unit constitutes the present island masses above intertidal level and except where it overlies the reef plate is gradational to the underlying Lower Sediment unit below the intertidal level. The differentiation between the Upper and Lower Sediment was based on the significant differences in engineering properties of the material above and below water level.

b. Upper Limestone

The Upper Limestone is a composite unit up to 15 ft thick that extends lagoonward from the ocean ridge at the intertidal level. The Upper Limestone contains three distinct facies: 1) beach rock, 2) boulder conglomerate, and 3) reef plate. While these facies are probably present in the Lower Limestone they are not delineated. Although there are gradations within facies the facies are not gradational from one to another and where examined in the field are found to overlap unconformably. While surface outcrops are readily identifiable, since the lateral distribution can be readily examined, identification solely on the basis of drill samples is difficult. For this reason the

Upper Limestone is undifferentiated in most sections.

(1) Beach Rock

The beach rock facies consists of a moderately well cemented calcarenite composed of reef detritus usually dominated by forams. The rock has a fresh appearance and lacks secondary solution and cementation features, while the components exhibit typical beach characteristics of abrasion and sun bleached coloration. Beach rock, forming along most lagoon beaches and along some inter-island and ocean beaches, generally exhibits a shingle-like pattern following the strike and dip of the associated beach.

Within present island boundaries beach rock is found at or near the intertidal level. Two patterns of distribution are apparent. On the lagoon half of Aomon, drilling, augering, and trenching data show the beach rock to be distributed in a shingle-like pattern with strike and dip similar to beach rock found on the present lagoon beach. In the interior of Runit, drilling and trenching data suggest that the beach rock is flat lying. This flat lying beach rock is both thicker and more competent than the shingle variety. Several of the thicker sections apparently overlay, and may be confused with, the reef plate.

(2) Boulder Conglomerate

The boulder conglomerate facies is a flat lying competent unit, one to four feet thick, distributed in a series of groins extending oceanward from the present island masses. The unit overlies the reef plate and underlies portions of the present islands including beach rock where present. The conglomerate is composed of closely packed, well rounded reef material, chiefly corals and calcareous algae, an inch to a foot in size with sand size reef material filling the intersticies.

(3) Reef Plate

The reef plate facies is a competent surface rock extending from the ocean ridge lagoonward and exhibiting both erosional (wave planatation and solution depressions) and depositional (primarily coralline algal growth at the ocean ridge) surface features. Near the ocean ridge the plate is at least 13 ft thick and consists primarily of corals in growth position with reef detritus filling the intersticies. Lagoonward the plate thins to a few feet beneath present island boundaries and consists of fewer corals in growth position with a corresponding increase in detritus. The entire unit is well cemented and demonstrates an overall fresh appearance.

The reef plate overlies the Lower Sediment unit except near the ocean ridge where there appears to be an intermediate limestone separating it from the Lower Limestone. Present islands overlie the reef plate to varying degrees. For example beneath Aomon, 1000 ft from the reef plate/island boundary, traces of the reef plate at intertidal level (uncemented Heliopora in growth position), overlain by a weakly cemented beach rock, were identified by Tracey and Ladd (1973).

c. Lower Sediment

The Lower Sediment is an unconsolidated to semiconsolidated unit extending downward from the intertidal level to the Lower Limestone on which it lies. Oceanward the Lower Sediment extends for some distance beneath the reef plate while lagoonward it extends outward probably covering the lagoon floor.

Compositionally the Lower Sediment is very similar to the Upper Sediment except that it contains larger coral fragments, some of which may represent coral heads in growth position. Seismic results supported by drilling indicates that the Lower Sediment consists of two subunits: an overlying layer of unconsolidated sand and gravel followed by an interbedded limestone and unconsolidated to semiconsolidated sand and gravel layer. The boundary between these subunits is gradational, dipping from 45 ft beneath the reef plate/island boundary to 80 ft beneath the lagoon/island boundary of Aomon. The lower subunit has not been recognized on Runit.

d. Lower Limestone

The Lower Limestone, the lowest unit recognized in this study, is a heterogeneous competent limestone that extends at depth from near the ocean ridge to at least the lagoon/island boundary and, while not sampled in this study, probably continues out under the lagoon floor. Beneath Runit island and beneath the Aomon reef plate the unit is characteristically flat lying at a depth of approximately 45 ft. Beneath Aomon island the unit dips lagoonward from 45 to 220 ft with minimum thicknesses of 110 and 85 ft at the respective locations.

While no attempt was made to differentiate, the Lower Limestone appears to contain elements similar to the Upper Limestone and the Lower Sediment. Visually the Lower Limestone differs from the Upper Limestone by its bleached, chalky-white appearance and its extensive solution features.

2. GEOLOGIC CROSS SECTIONS

Figures 7 through 10 are longitudinal and transverse geologic cross sections for Runit and the Aomon group of islands. See figures 5 and 6 for drill hole locations. Preliminary interpretations are based upon the megascopic descriptions and classification scheme previously discussed. Coring was attempted only in the Upper and Lower Limestone units from which returns averaged 60 to 80 percent. Individual holes have not been corrected for elevation (maximum of 10 ft between island and reef plate); but the top of the Upper Limestone can be used as an approximate intertidal reference horizon.

a. Runit

Runit sections are all lithologically similar. Each contains an average of 45 ft of unconsolidated sand and gravel (Upper and Lower Sediment), separated by a 3 to 5 ft unit of Upper Limestone at the intertidal level. The contact of the Lower Limestone at 45 ft is sharp (within a few feet) and the unit is uniformly competent over the depths penetrated (45 ft average, 105 ft maximum). No other units were recognized below the Lower Limestone. Figure 7 is a cross section along the approximate longitudinal center-line of Runit. Three ocean to lagoon cross sections are shown in figure 8.

b. Aomon Group

Sections from islands of the Aomon group are lithologically similar to those observed at Runit, except that the Lower Limestone slopes from the 45 ft bench near the reef plate/island boundary to 220 ft at the lagoon/island boundary. In addition, the sharpness of the contact below the bench decreases. As in the case of Runit no other units were recognized below the Lower Limestone.

Figure 9 is a geologic cross section from near the ocean margin to the lagoon/island border showing the lagoonward dipping Lower Limestone. In PAR-17 the two zones (80 to 115 and 180 to 190 ft) consisting of interbeds of limestone and unconsolidated sand and gravel are not considered to be part of the Lower Limestone. The Lower Limestone boundary in PAR-3 is questionable because of small core return and may represent thin interbeds similar to that

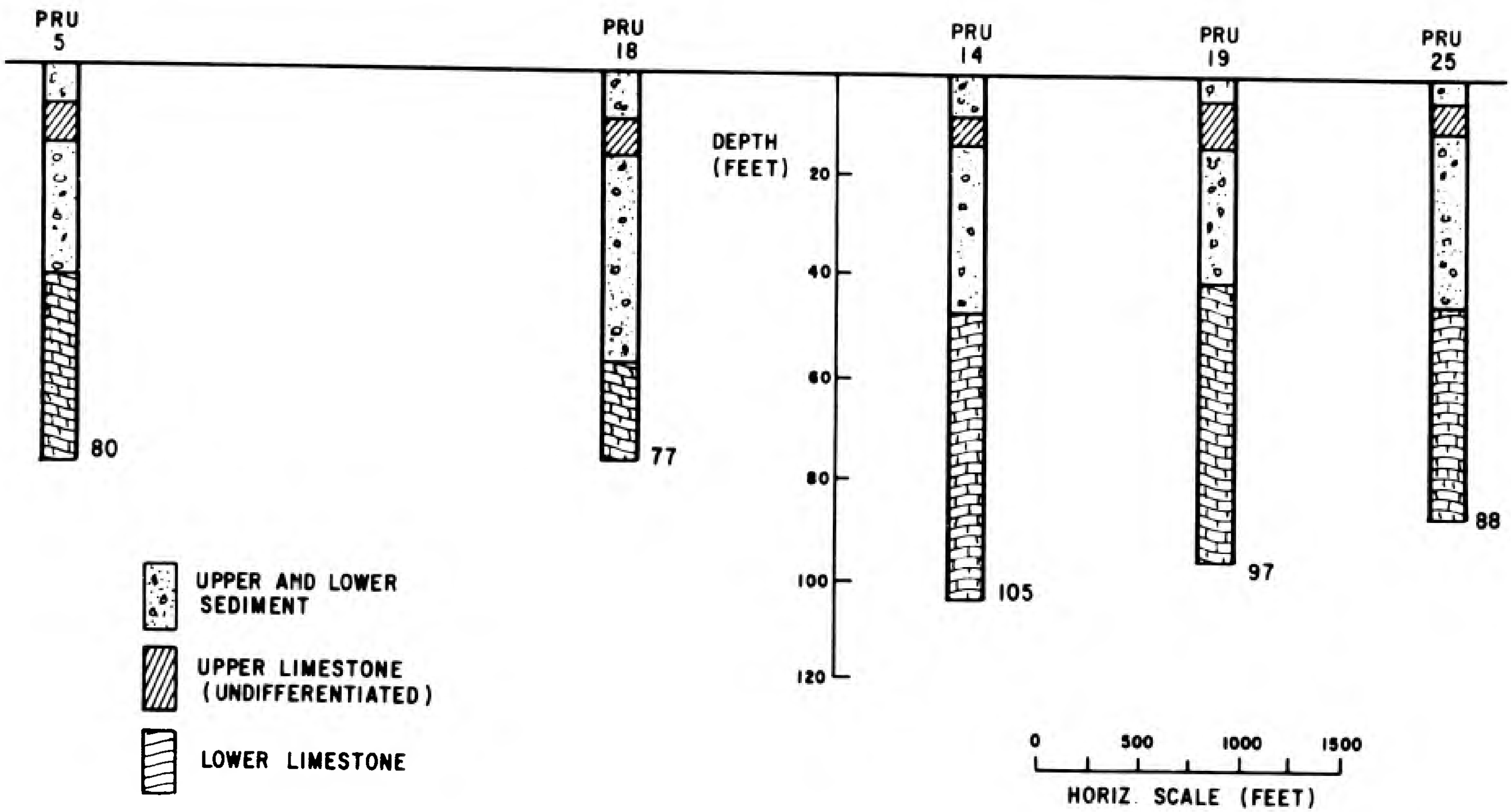

Figure 7. Runit - Longitudinal Geologic Cross Section

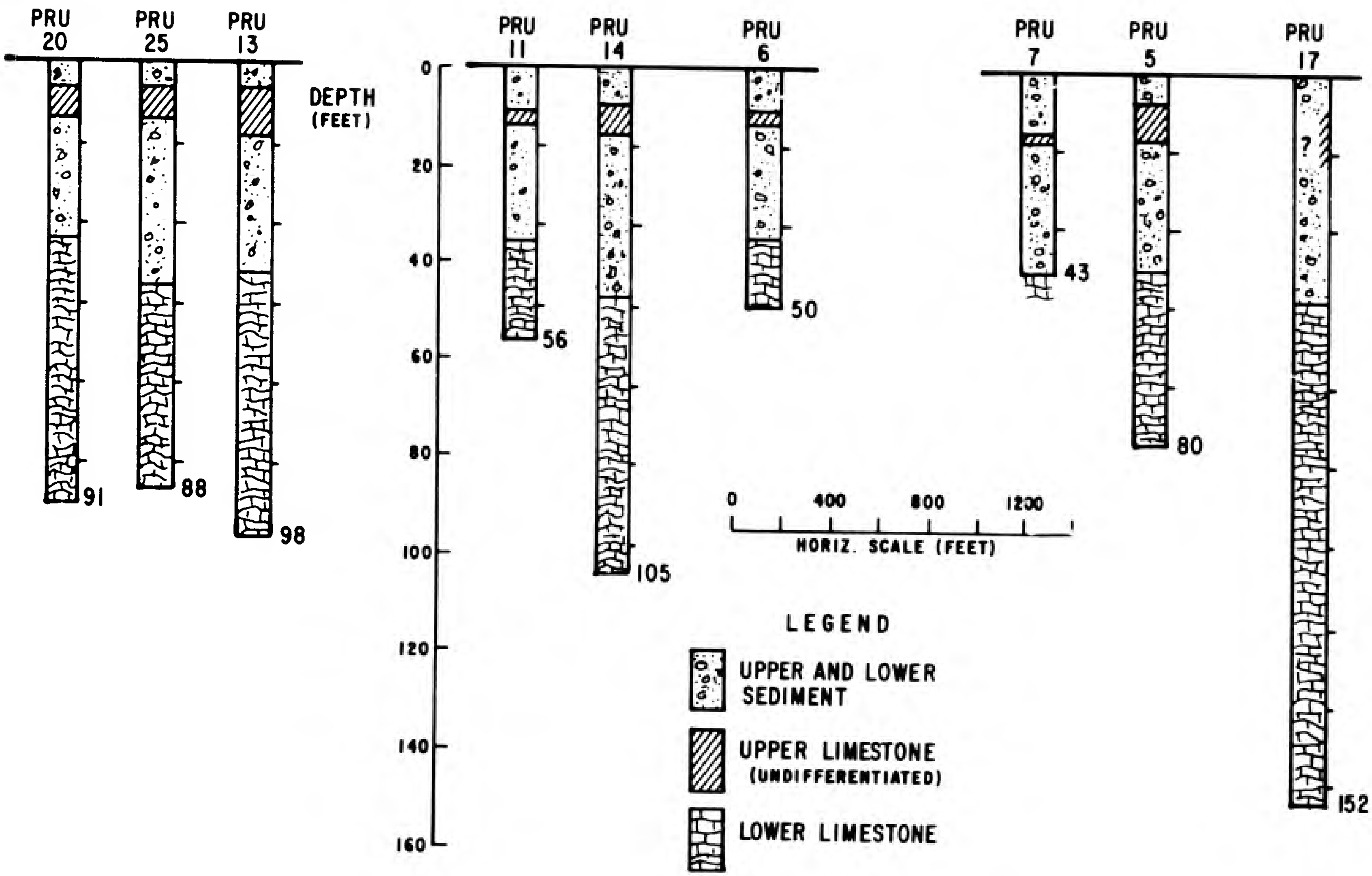

Figure 8. Runit - Transverse Geologic Cross Sections

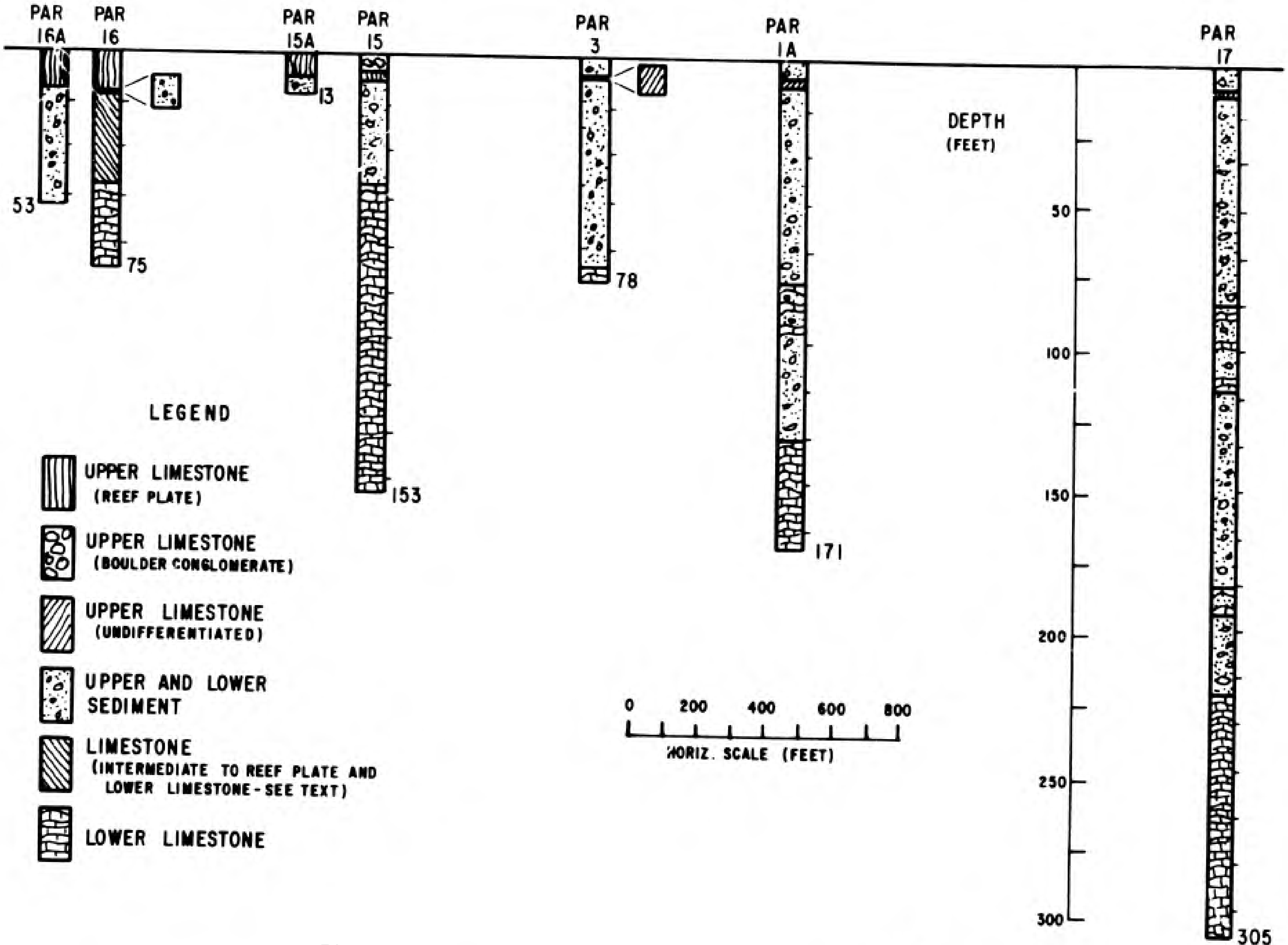

Figure 9. Aomon - Transverse Geologic Cross Section

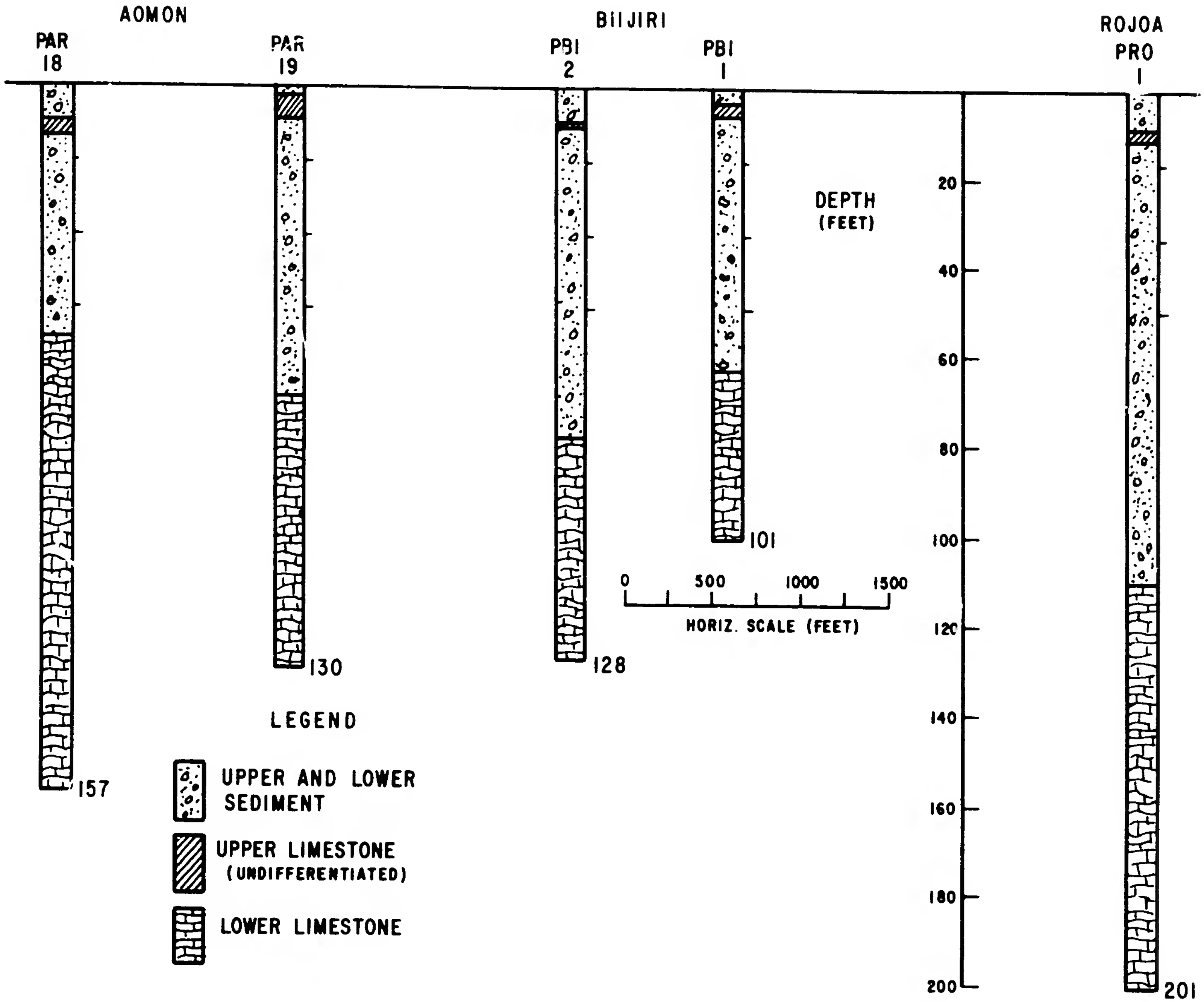

Figure 10. Aomon Group - Longitudinal Geologic Cross Section

described from PAR-17. Seismic results tend to support the interbed interpretations for both PAR-3 and 17.

Between the ocean ridge and island boundary the Upper Limestone (reef plate) forms the surface and becomes thinner and more detrital towards the island. PAR-15, near the island boundary penetrates a boulder conglomerate overlying the reef plate.

PAR-16 returned almost continuous limestone core over the 75 ft drilled. A break occurs at 13 ft where approximately a foot of unconsolidated sand and gravel (Upper Sediment?) was recovered. This break is interpreted as the bottom of the reef plate and agrees with PAR-16A. The limestone below is visually indistinguishable from the reef plate and does not become visually similar to the Lower Limestone until a depth between 40 and 50 ft. The top of the Lower Limestone is, therefore, tentatively placed at 45 ft. This intermediate limestone is differentiated, on the basis of visual characteristics, from the Lower Limestone, and, on the basis of the one-half meter break, from the reef plate.

The absence of limestone below 13 ft in PAR-16A is difficult to explain in view of PAR-16. The hole may have penetrated a sand and gravel filled cavity, or the hole location may be oceanward of the former ocean ridge present at the time the 45 ft bench of the Lower Limestone was formed.

Figure 10 is a geologic cross section across islands of the Aomon group roughly equidistant from the ocean ridge. The data suggests that the depth to the Lower Limestone may be related to the distance from the present ocean ridge.

3. SEISMIC PROFILES

Figure 11 presents two seismic velocity profiles for Aomon. The profiles are based on an independent interpretation of refraction data without prior knowledge of the drilling results. The quality of data obtained in the refraction surveys ranged from excellent to good and the results are therefore considered to be reliable. Reversal shooting techniques and close spacing between both geophones and shot points indicate that changes in lateral velocity within the material are small. Because of the usual uncertainties inherent in refraction surveys, an error of up to ± 10 percent is estimated for all depths shown.

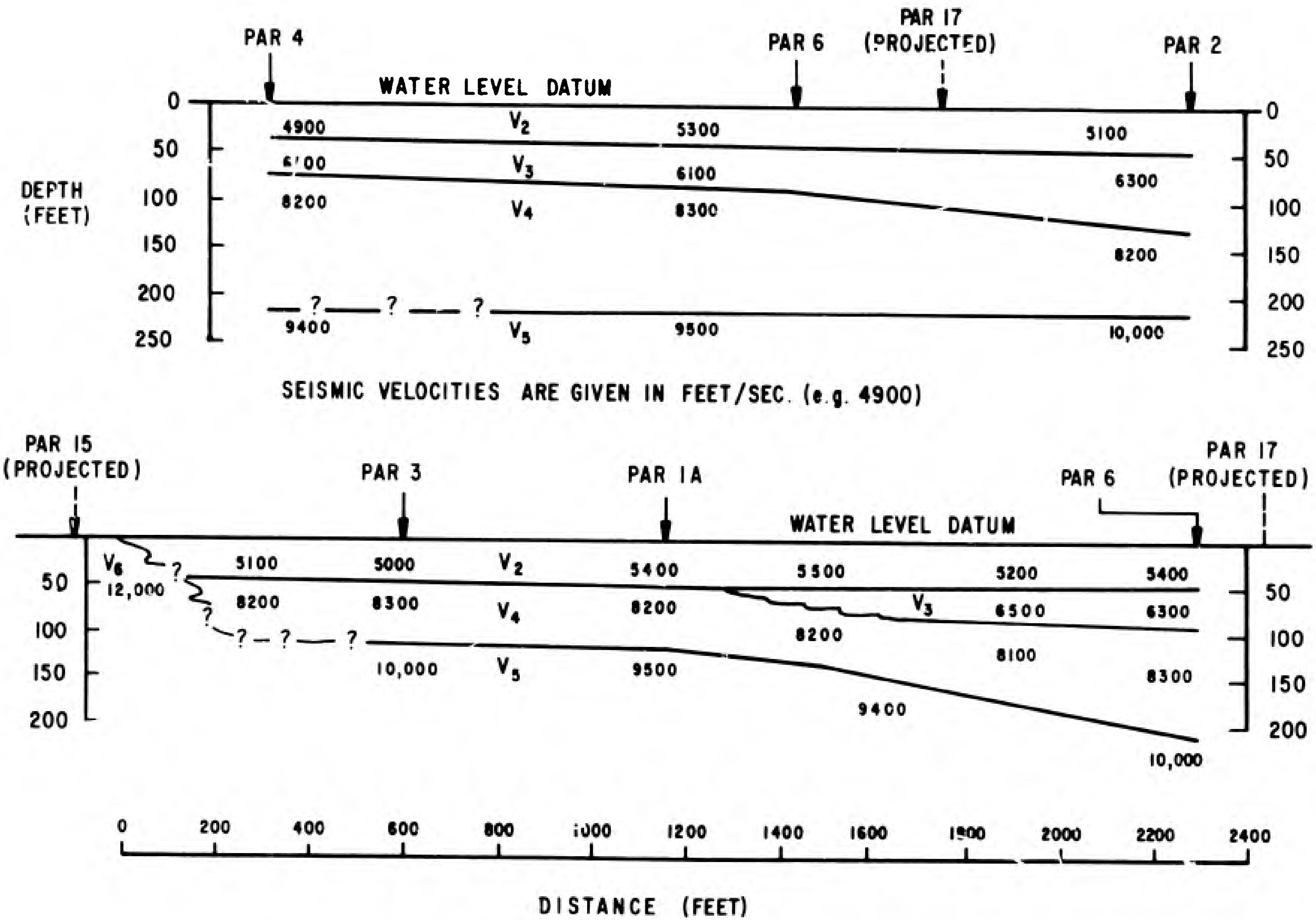

Figure 11. Aomon - Seismic Velocity Profiles

The top seismic profile is parallel to the lagoon margin of Aomon through stations 4, 6, and 2 (figure 6). Interpretation indicates that four distinct refracting interfaces occur within the 460 ft penetrated by the survey. Datum on the profile is approximately the intertidal level. The weathered soil layer (V_0)(0 to 10 ft) and the beach rock (V_1) (0 to 3 ft) are not shown. The weathered soil layer is composed of moist aerated sand and gravel having a velocity ranging between 1100 and 2000 ft/sec. Beach rock, where encountered, has a velocity ranging between 7500 and 9200 ft/sec. Refracting interfaces encountered below the intertidal level form boundaries between materials exhibiting seismic velocities of (V_2) (4900 to 5300 ft/sec), (V_3) (6100 to 6300 ft/sec), (V_4) (8200 to 8300 ft/sec), and (V_5) (9400 to 10,000 ft/sec).

Layers (V_2) and (V_3) probably represent a heterogeneous mixture of unconsolidated sand and gravel. The small and gradational velocity contrast between (V_2) and (V_3) suggests an increase in compaction caused by overburden weight. At the (V_3 - V_4) boundary an abrupt and distinct velocity change occurs. The velocity values associated with (V_4) indicate that the material is either a soft rock or an interbedded sequence of soft to hard rock and unconsolidated to consolidated sand and gravel. The travel time curves do not support an interpretation of a rock layer being present at this depth with an underlying sequence of unconsolidated sand and gravel. At a depth of about 210 ft the (V_5) layer is encountered and it extends to an unknown depth below 460 ft. The high velocity range exhibited by this layer indicates a competent rock.

The bottom seismic profile of figure 11 is from the ocean to lagoon along the drilling line PAR-15 to PAR-17. In addition to velocity layers (V_2 to V_5), which are similar to identically numbered layers in the top profile, a velocity layer (V_6) which extends in from the ocean is encountered. The exact delineation between (V_5) and (V_6) is in question. The precise interface attitudes could not be determined with confidence from the available data. However, the abrupt velocity discordance indicates that the (V_6) material lies near or at the ground surface, has a velocity of 12,000 ft/sec, and is probably different from the adjacent and deeper (V_5) layer.

With the exception of the (V_6) material both profiles exhibit the same stratigraphic sequence over the depth of penetration. The geologic structure depicted is one of lagoonward dipping beds, with competency increasing with depth.

SECTION V
DISCUSSION

Figure 12 presents geologic data from the Aomon transverse cross section (figure 9). Also included are geologic data from other sections of the Aomon group (figures 6 and 10) including the two pertinent 1950 holes EB-3 and AR-1 (Ladd and Schlanger - 1960). Each section is plotted as a function of its distance from the present ocean ridge with elevation corrected to the general island topography. Each section is represented by a vertical line beginning at either the bottom of the reef plate or the top of the Lower Limestone. Total depth is indicated by the extension of the vertical line to that depth.

Based on only the transverse cross section data, a geologic interpretation is drawn; where questionable it is dashed. The bottom of the reef plate is well defined in PAR-15, 15A, 16, and 16A. The top of the Lower Limestone is well defined in PAR-15, 1A, and 17, but questionable in PAR-3 and 16. Zones of interbedded limestone and sediment are defined in PAR-1A and 17, and as an alternative interpretation for PAR-3. Interpretation of PAR-16 and 16A below the reef plate, without detailed microscopic study, is tentative for reasons previously discussed. Hole PAR-17 was terminated at 305 ft, because the drillers could not maintain circulation, suggesting the presence at that depth of solution cavities which might correlate with Schlanger's (1963) "295 ft unconformity" observed in holes at Eniwetok.

The bottom seismic velocity profile from figure 11 is superimposed on figure 12. Except for the portion of the profile oceanward from PAR-3, where the seismic results are difficult to interpret, there is good agreement between the geologic and seismic interpretations both with respect to the lithologic units observed and to the inferred geologic structure. The (V_4 - V_5) seismic boundary correlates with the top of the Lower Limestone in PAR-1A and 17. At PAR-3 the seismic results support the interpretation that the limestone at 75 ft probably represents a zone of interbedded limestone and sediment rather than the Lower Limestone.

The (V_2 - V_4 and V_3 - V_4) seismic boundaries do not correlate as well with the zone of interbedded limestone and sediment sampled in the drilling. This might be because the boundaries are gradational or because of poor core re-

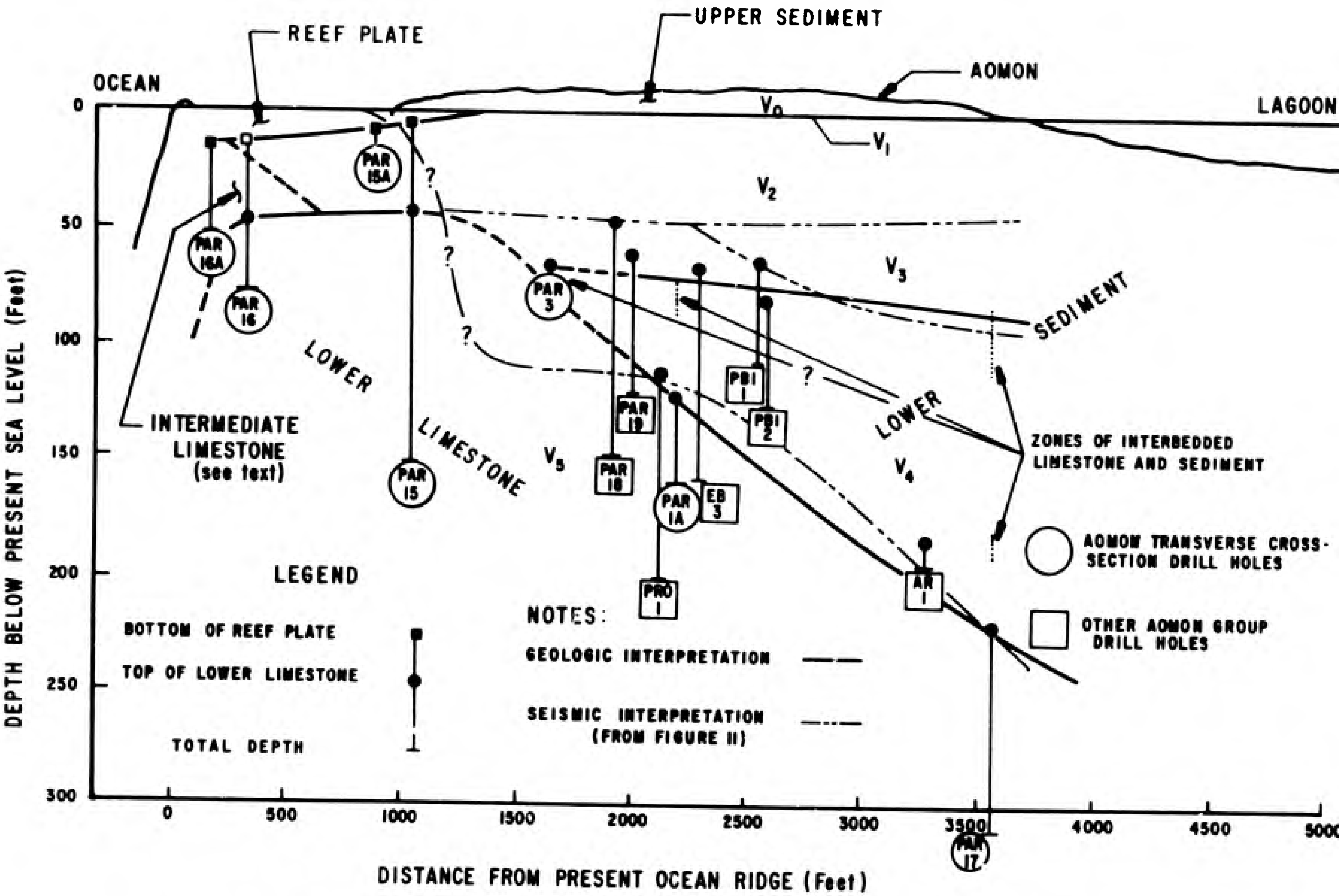

Figure 12. Geologic and Seismic Interpretations for Aomon Transverse Cross Section - Other Aomon Group Data Superimposed

covery. In any case the correlation appears sufficient to suggest that the Lower Sediment consists of a t least two subunits, unconsolidated sediment above the boundaries and interbedded limestone and sediment below. Constraints imposed by both the seismic and drilling data would be best satisfied if the interbedded limestone layers were discontinuous.

The (V_2 - V_3) seismic boundary is interpreted as a change in bulk density of the unconsolidated sediment which would be difficult to interpret in samples or in drilling action. Cursory inspection of the standard penetration data, however, indicates an increase in penetration resistance with depth that may be correlatable.

When the data from the remaining sections of the Aomon group are plotted with respect to the present ocean ridge, as shown in figure 12, the "Lower Limestone picks" all correlate with either the Lower Limestone or the interbedded limestone and sediment subunit of the Lower Sediment. While we believe that these data are consistent and support the geologic and seismic interpretation presented for the Aomon transverse cross section, it is difficult to explain the apparent differences between individual sections within the Lower Sediment subunit; i.e., interbedded limestone and sediment (PAR-3, 1A, 17), continuous limestone (PAR-18, 19; PBi-1, 2; and EB-3), and lack of limestone or interbeds (PRO-1 and AR-1). Only with detailed microscopic study together with pertinent age determinations at suspected unconformities can this problem be properly addressed.

Although not presented in this paper the seismic interpretations for Runit agree with the geologic cross sections of figures 7 and 8 and the 1950 data from RU-2 (Ladd and Schlanger - 1960). The seismic boundary between the Lower Sediment and Lower Limestone is abrupt and distinct. No other velocity layers are observed within the Lower Sediment, supporting the geologic interpretation that the Lower Sediment consists solely of unconsolidated sand and gravel. The lithologic structure (Lower Limestone bench) beneath Runit appears similar to that observed beneath the Aomon reef plate. While the elevation of the Runit bench is the same as that of Aomon it extends at least 1000 ft farther from the ocean ridge.

In summary, seismic results correlate well with the drilling data when boundaries are sharp and clearly defined, e.g., the Lower Sediment/Lower Limestone boundaries beneath Aomon and Runit. When boundaries are not well defined by the drilling data, due probably to interbedded or gradational characteristics of the media, seismic results provide an interpretation that is both reasonable and consistent with the drilling data, e.g., the boundary between subunits of the Lower Sediment beneath Aomon. Using the combined geologic-seismic interpretive approach, it is observed that both Runit and the islands of the Aomon group demonstrate an internally consistent lithologic structure, uniformly horizontal beneath Runit and lagoonward dipping beneath the Aomon group. This is in contrast to the previously postulated "bucket of sand" model for Eniwetok.

SECTION VI
PROPOSED GEOLOGIC MODEL

Figure 13 presents a generalized cross section for our near surface geologic model of Eniwetok. The model is constructed primarily from a combined geologic and seismic interpretation of the Aomon transverse profile modified by the remaining data from the Aomon group (figure 12). While the supportive evidence for this model is based on an engineering evaluation of a relatively complex geologic situation, we believe that it presents the principal lithologic and structural features of the upper 300 ft. The stratigraphic details of the model and its geologic history can only be determined after further study.

The major feature of the model is the Lower Limestone unit. We hypothesize that this basic structural unit is valid for the atoll in general. That is, if the Lower Limestone is a diagenetically cemented body formed during subaerial exposure, as suggested by its geometry, then the configuration of the Lower Limestone is a reflection of the atoll topography at the time of emergence. The 45 ft Lower Limestone bench, observed beneath both Aomon and Runit, is then a consequence of a sea level stand and should generally prevail around the atoll. The lagoonward dipping portion of the structure may vary locally due to a combination of factors including deposition, lithification, and erosion.

The 45 ft depth of the Lower Limestone bench is an invariant feature of the model and reflects the present atoll configuration. The width of the Lower Limestone bench is shown by present data to be at least 600 to 1000 ft wide beneath Aomon and Runit and could be expected to vary considerably as is evidenced by the distribution of the present reef plate. The horizontal position of the bench relative to overlying islands and reef may also vary depending on the amount of lateral migration of the reef during growth upward from the bench. This may explain why the data from the Aomon group are internally consistent when normalized by the distance to the present ocean ridge; but are not consistent with the Runit data, when normalized in the same manner.

The geometry of the Lower Sediment unit is a consequence of the geometry of the Lower Limestone unit and the amount of detritus produced and transported from the ocean reef as it built upward. The upper boundary of the interbedded

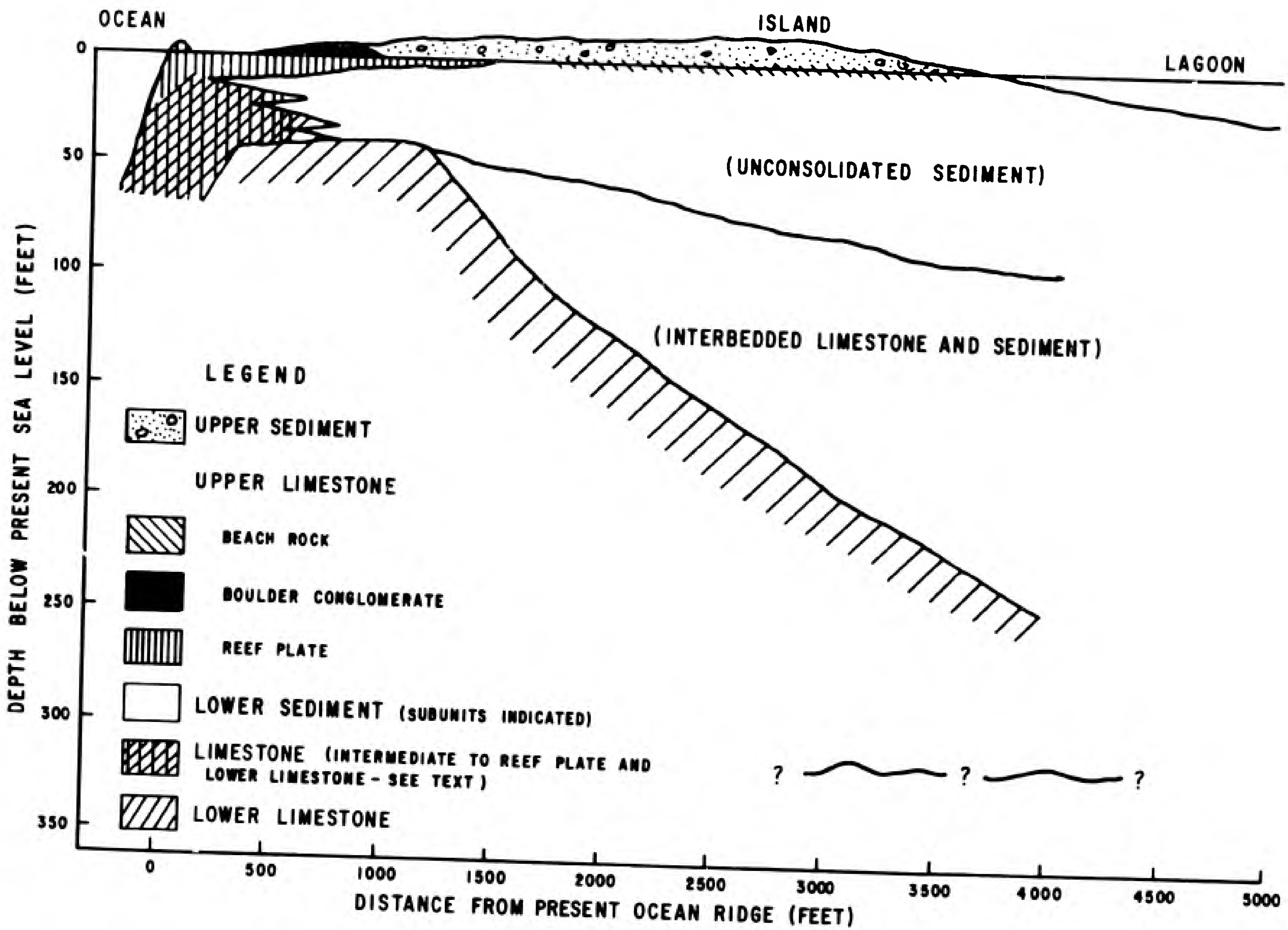

Figure 13. Near Surface Geologic Model for Eniwetok Atoll

limestone and sediment subunit of the Lower Sediment may represent another diagenetic surface due to later subaerial exposure. Other diagenetic surfaces may also be present within this subunit. Each of these new surfaces would control the geometry of the overlying sediment. The islands, in turn, are a consequence of the Lower Sediment unit modified by present atoll surface processes (wind, wave currents, storms, vegetation, etc.). The greater the amount of detritus available from the ocean reef the farther lagoonward an island extends. In this sense, Runit appears to lie entirely over the Lower Limestone bench while the Aomon group has "spilled" over the bench and extended into the basin. The present shape of an island may, thus, reflect in part the subsurface structure and the relative location of the Lower Limestone bench.

SECTION VII
CONCLUSIONS

Based upon the limitations of the field program, the sample classification scheme adopted, and the combined geologic-seismic interpretive approach the following conclusions are offered:

1. The near surface geology (0-300 ft) of Eniwetok consists of a sequential set of structurally ordered lithologic units which is generalized in the proposed model depicted in figure 13.

2. The fundamental structural unit is a competent limestone (Lower Limestone of the model) whose overall shape suggests lithification during subaerial exposure.

3. At least two surfaces representing solution unconformities (in the sense of Schlanger - 1963) occur within the first 300 ft. The main such surface is represented by the top of the Lower Limestone unit, the second by the boundary separating the two subunits of the Lower Sediment, while a third was possibly detected in one hole (PAR-17) at a depth of 305 ft. Others may be present within the Lower Limestone and Lower Sediment units.

4. It is tempting to try to correlate these solution unconformities both between Runit and the Aomon group and these in turn with previously delineated solution unconformities from Eniwetok and Bikini. Such correlations are premature at this time and must follow a detailed stratigraphic and petrographic study of the samples together with a critical set of age determinations at suspected unconformities.

SECTION VIII

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