BRIGHAM

YOUNG

UNIVERSITY

GEOLOGY STUDIES

Volume 13 December 1966

CONTENTS

Brigham Young University Geology Studies

Volume 13 — December 1966

Contents

A publication of the
Department of Geology
Brigham Young University
Provo, Utah 84601

Brigham Young University Geology Studies is published annually by the department. *Geology Studies* consists of graduate student and staff research in the department and occasional papers from other contributors, and is the successor to *B.Y.U. Research Studies, Geology Series,* published in separate numbers from 1954 to 1960.

Distributed February 20, 1967

Price $4.00

The Isla de Lobos and Associated Reefs, Veracruz, Mexico

J. KEITH RIGBY AND WILLIAM G. MCINTIRE

Brigham Young University; Louisiana State University

ABSTRACT.—The reef which surrounds Isla de Lobos is one of three closely associated reefs on the eastern coast of Mexico, approximately 70 miles southeast of Tampico, Tamaulipas, and is the northernmost reef with a sand cay on the western margin of the Gulf of Mexico. It rises from a detrital plain, with a depth of approximately 120 feet, to near low tide, where the reef forms a flame-shaped lagoon approximately eight thousand feet long, north-south, and three thousand five hundred feet wide.

The island is situated in a shallow lagoon which has an average depth of less than 3 feet and a reef-formed margin which is barely awash at lowest tides. Leeward and windward reefs can be differentiated topographically on fathograms and on the contour map of the reef complex and adjacent areas. Leeward development is characterized by broad, flat-bottomed, but steep-walled grooves, in contrast to more narrow V-shaped grooves in windward development. The reef toe is flanked by calcareous, reef-derived sand on all but the northeast side, where scattered data suggest a rocky floor.

Several lagoonal, reef, and surrounding deep-water habitats and communities can be differentiated and were mapped, all seem closely related to substrate character. *Thalassia* and *Halimeda* blanket much of the lagoon and have trapped a stable sand substrate. These forms, along with *Porites* spp. and *Diploria clivosa,* characterize stable sand communities. Unstable sand communities are poorly developed and only locally present, but infratidal lagoonal rocky-bottom habitats and communities are well developed, even though of limited areal extent. A rocky-shore habitat is present on hurricane-tossed boulders and man-made structures, but rocky-shore communities are only beginning to populate the area because the habitat has been only recently opened.

An algal ridge forms the crest of both windward and leeward reefs and separates the marginal reef flat, *Diploria clivosa,* and the more lagoonward, algal oncolite communities from seaward reef development. Both windward and leeward reefs are characterized by an *Acropora palmata* community in shallow water. In deeper water, from approximately 25 feet down to 50 or 55 feet, a *Diploria strigosa* community forms the windward reef and a *Montastrea annularis* community forms the leeward reef. The *Montastrea cavernosa* community forms the basal 25 to 30 feet of both windward and leeward reef development.

CONTENTS

TEXT

ILLUSTRATIONS

Text-figures

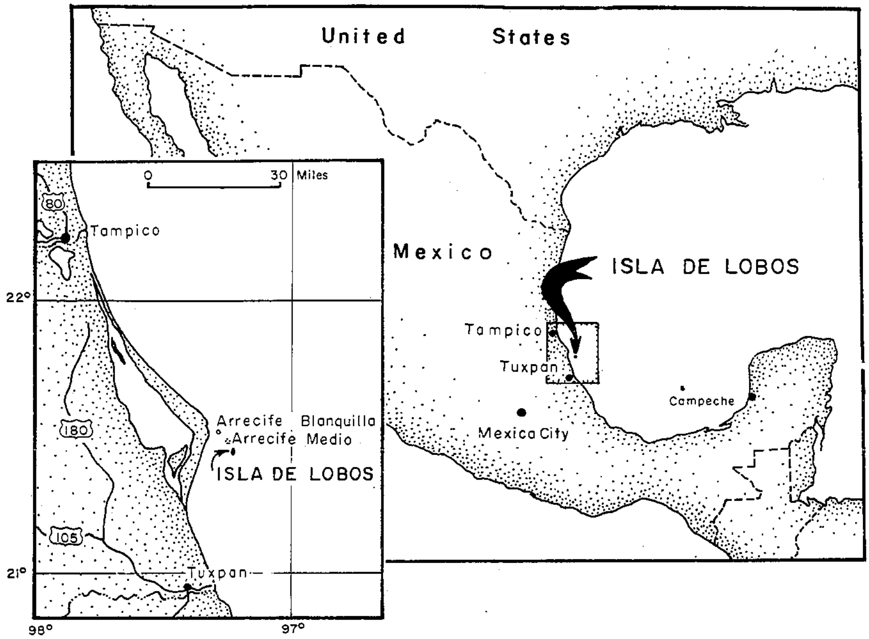
Plates

INTRODUCTION

Isla de Lobos is a small sand cay which caps one of three small, but well-defined, reefs along the eastern coast of Mexico (Text-fig. 1). These three structures rise from the broad, shallow, detrital-blanketed shelf to near low tide and are the northernmost such reefs along the western shore of the Gulf of Mexico. Other smaller coralline structures are known to the north, but usually in deeper water and of relatively limited scale. It is because of the sand cay development and well-defined reef structure that Isla de Lobos reef was selected as a base for the present study.

Location

Isla de Lobos is one of three similar reefs along a northwesterly trend, southeast of Tampico, Tamaulipas, and southeast of Caba Rojo and Tamiahua



TEXT-FIGURE 1.—Index map. The reef associated with Isla de Lobos was the major area of investigation, but reconnaissance observations were also made on the associated Blanquilla and Medio reefs.

Lagoon (Text-fig. 1). Isla de Lobos reef is the southeasternmost of the three and is located approximately 7 miles off the mainland coast, 35 miles northeast of Tuxpan, Veracrùz, and 68 miles southeast of Tampico. The island on the reef is located at approximately 21° 27' 15" North Latitude, and 97° 13' 45" West Longitude.

The island itself is a small sand cay, approximately two thousand feet long, one thousand feet wide, and with a maximum elevation of 11 or 12 feet. It is, however, a most suitable base from which to study the surrounding lagoon and reef, for from the small island most of the lagoonal and upper reef regions are readily accessible even without using small boats. Development of dock facilities by Pemex has also increased the ease of studying the surrounding deeper water regions with small boats based on the island.

Access

Isla de Lobos is currently readily accessible via Pemex barges and tugs from Tuxpan, 35 miles to the southwest. Since considerable petroleum is produced from the well platform within the lagoon, daily round trips are made between the dock on Isla de Lobos and the Barra de Tuxpan petroleum facilities east of Tuxpan. Without Pemex cooperation, the only access to the island is by small boat.

Personnel

The authors were senior scientific investigators on the study, and were ably assisted by C. Kent Chamberlain, a graduate student at Brigham Young University; Rodolfo Cruz, a graduate student at the Instituto de Geologia at University of Mexico; Rodney Adams and Norwood Rector, both on the staff of Coastal Studies Institute at Louisiana State University.

McIntire was responsible for study of the island ecology, history, sediments, etc., and Rigby was responsible for study of the reef and the lagoon. Chamberlain studied the alcyonarians of the reef complex and will publish his paper elsewhere. Adams and Rector were responsible for equipment, and logistics in general, and did most of the boat work for the party. In addition, they did sediment sampling, along with Cruz, and Rector, in particular, took many of the underwater photographs of the reef and bordering sand apron.

Marine organisms were identified by Rigby and Chamberlain, and subaerial organisms were identified by McIntire. Extensive collections were made as a joint effort of all personnel and are housed at Brigham Young University and Louisiana State University.

Mapping was a joint effort of the whole crew. McIntire, Rector, and Adams ran the fathometer traverses and carried the surveying rods in the island, reef, and lagoon surveys. Rigby and Chamberlain ran the surveying instruments, plotted the points, and contoured the maps.

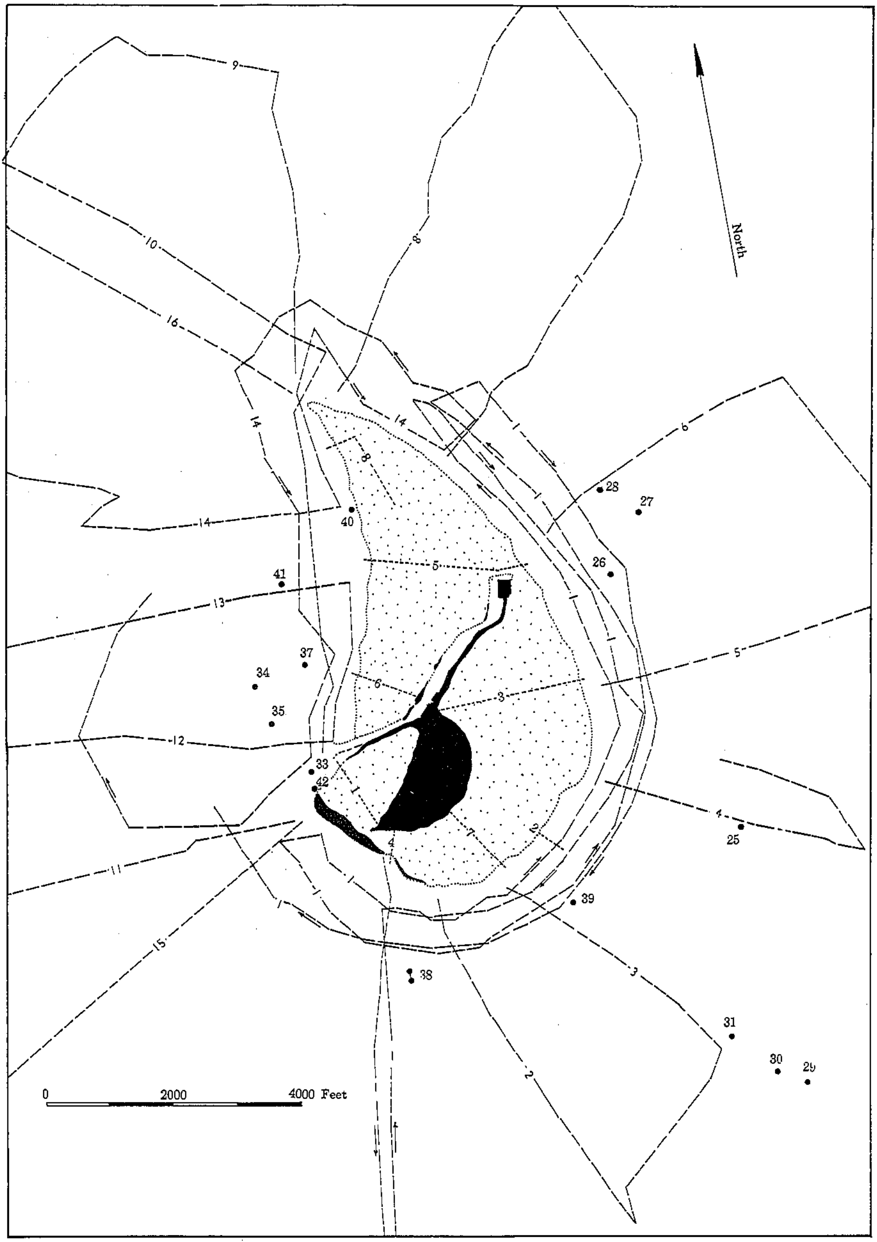
Method of Study

Outline of the island, ship channel spoil heap, and well platform were determined by plane table mapping at a scale of 500 feet per inch. Crest of the reef around the relatively shallow lagoon was walked out and mapped at the same scale from stations on the island margin, well platform, or within the lagoon. A single station was established in the interior of the lagoon northwest of the platform so that the northern tip of the reef was within instrumental limits.

Once the outline of the reef and island was established, a series of fathometer traverses were completed for topographic control within the reef and adjacent deeper water. Locations of points on the fathometer trace were established using a theodolite based in the top of the lighthouse at the southern end of the island. Direction and distances were determined trigonometrically since the elevation of the instrument was established slightly over 100 feet above sea level, and orientation to known points could be established. Thus vertical and horizontal angles would give the position of the boat at each point necessary. Two-way radio allowed communication between the boat and the lighthouse. Accuracy is greatest in the southern half of the map where angles were greatest, and least in the northern part where angles were lowest.

Fathometer traverses and control points are shown on Text-figure 2, along with shallow-water traverses, sample stations, dredge stations, and deep dive stations.

Shallow-water traverses were made using a knotted rope for distance, and paired stakes for directional control. These traverses, coupled with low altitude oblique photographs, were used in construction of the community map. Biologic samples and sediment were collected during the traverses, and tied to distance from shore.



TEXT-FIGURE 2.—Map of fathometer traverses, sample traverses and other control points on the Isla de Lobos reef complex. Fathometer traverses are shown as dashed lines and shallow water sample traverses as dotted lines. Individual sample points and deep dive localities are shown as numbered black circles.

Several traverses were made of the lower part of the reef, from near the toe upward, or from the sand apron upward. Scuba gear was used with excellent results for it allowed freedom of movement and sufficient time for study of the deeper parts of the reef and surrounding sedimentary apron.

Sediment samples from points not studied during deep dives were collected with a clam-shell sampler. These include samples taken for living foraminifera, micro-mollusks, and sediments around the flank of the reef and in the surrounding sand apron.

Notes on all underwater observations were taken on frosted plastic plates with an ordinary lead pencil, transcribed at night, and then the plates were erased ready for the next day's use.

Biologic collections were made using plastic buckets and inflated innertubes, weighted with line and lead weights, on shallow traverses. Small specimens were placed in plastic vials and larger specimens were placed in plastic bags. Deeper water collecting was done with purse-like collecting bags instead of the floating plastic buckets.

A water-soluble dye, Rodamine Red, was utilized in current velocity and direction studies. The dye mixture is slightly heavier than sea water and sinks gradually below the wave zone for determination of direction and velocity of intermediate and bottom currents. Although it diffused somewhat in its course, direction and velocity of motion were easily established.

Tidal information was not readily available for Isla de Lobos, although some information is available for Tuxpan, to the southwest, and Tampico, to the northwest. A tide gauge was established at the Pemex dock within the ship channel and a continuous hourly observation record was maintained for 48 hours. In addition, a still-water gauge was established in the lagoon at the south end of the island, but was read at somewhat irregular intervals.

The following is an approximation of crew-days spent in various types of observation or preparation, calculated on two crews per day while we were on the island.

Table 1

Crew-days Spent in Various Activities During Observation of Isla de Lobos

Plane table mapping reef and island	10 days
Theodolite-fathometer mapping	4
Shallow water traverses	6
Deep water traverses of reef	4
Deep water sediment samples	2
Current study and water chemistry	2
Helicopter flight	1
Logistics and support	6
Island sediments and water study in pits	3
Study of spoil piles	1
Review of Blanquilla and Medio Reefs	2
Office work because of weather	4
Moving and sample preparation	3

Limited analyses of various water samples were undertaken using Hach Engineer's Laboratory, Model DR-EL, a portable kit designed specifically for water analysis. Chlorinity, salinity, Ph, turbidity, hardness, and content of oxygen, iron, lead, copper, carbonates, sulfates, silica, etc., can be determined colorimetrically.

Acknowledgments

We are particularly grateful to Professor Guillermo P. Salas, Director of the Instituto de Geologia at the University of Mexico, Mexico, F. D. Much of the preliminary arrangements and attention to detail were accomplished by him and his staff.

Assistance of personnel of Petróleos Mexicanos is gratefully acknowledged. Sr. Ing. Antonio Gracia Rojas and Sr. Ing. Eduardo J. Guzmán in Mexico City arranged official permission to work on the island. Ing. Edmundo Cepeda and Ing. Rodolfo Suarez, Tampico, were especially helpful in solving logistic problems while on the island; Sr. Alvaro Lorenzo, in charge of Pemex operations at Tuxpan, and Sr. Juan Perez aided our study in many ways, and through their kindness much of the Pemex facility was made available to us. Engineer Sr. Inocencio Cadena was in charge on Isla de Lobos and supplied us with warehouse space and dock facilities, made certain that our personnel was housed, and our groceries were transported from Tuxpan. We are also grateful for the favors rendered by Capt. P. A. Carlos Mora Perez from Cerro Azul.

Appreciation is expressed to Mr. L. Lee Welch, Vincent and Welch Inc., Lake Charles, Louisiana, who allowed us to use his lodge for a base for the first four weeks of our study. His caretaker, Sr. Santos Coronado, was also very helpful and proved an excellent cook and fisherman.

Officials at the lighthouse on Isla de Lobos were also most kind. The ancient keeper of the lighthouse, Sr. Paporo Guzman, and his wife filled us in on background of the island and its recent history. Sr. Roberto Caye Beeks and his brother, Sr. Gregario Caye Beeks, both stationed at the lighthouse, were also of considerable help, particularly since both were proficient with both Spanish and English.

Mr. Norwood Rector, of Coastal Studies Institute at Louisiana State University, developed or modified considerable gear for the study. He was not only responsible for the initial development, but also made repairs in the field. He also supervised our somewhat amateurish diving and did much of the deep-water diving, collecting, and observation.

Study of the reef at Isla de Lobos was conducted through the Coastal Studies Institute, Louisiana State University and supported financially by the Geography Branch of the Office of Naval Research, contract Nonr 1575(03), NR 388 002.

TOPOGRAPHY

Isla de Lobos is a small sand cay in the interior of a broad shallow lagoon, and is the northernmost sand island associated with reef development along the western margin of the Gulf of Mexico. The reef is a flat-topped structure, but with moderately intricate marginal topography, and shows the distinctive topographic expression of both windward and leeward development.

Isla de Lobos

Isla de Lobos is built by calcareous sediment derived from the surrounding flat interior of the reef lagoon. The subaerial island is crescentic, somewhat like the main reef, and is located in the southwestern part of the lagoon (Text-figs. 2, 3). It has an arcuate eastern coast and a nearly straight western one, approximately 2100 feet long. It has a maximum width of approximately one thousand feet near the middle of the broad arcuate eastern shoreline. The island is a low feature, rising only to a maximum of 11 to 12 feet above low tide at the southern end of the island near the lighthouse. Elsewhere most of the island is only 5 or 6 feet high.

A ship channel and associated spoil pile have been dredged through the leeward or western lagoon to the northwest point of the island where dock facilities have been established for Pemex operations. The ship channel, approximately 22 feet deep and 75 feet wide, was dredged 1500 feet long to the tip of the island, and then an additional 2400 feet northeastward through the lagoon to a well site platform near the windward edge of the reef. A road has been constructed on top of the spoil pile on the windward edge of the ship channel. It is approximately 5 feet above low tide throughout its length. Narrow, but much higher heaps of spoil have been maintained on the leeward edge of the ship channel opposite the dock facilities and part of the well platform, presumably as protection from the strong winds of the northwesterly winter storms.

A concrete well platform, approximately 200 by 240 feet and 8 feet above low tide, was constructed in the east-central part of the lagoon, behind the windward reef a short distance. The seven producing oil wells on the platform are the base of the local Pemex operation.

The island has been shaped by prevailing winds from the southeast and shows internal structure suggesting gradual accretion to the southwest and northwest. Accretionary topography is particularly well developed in the vicinity of the Welch Lodge at the southwestern margin of the island. A bordering dune belt is also developed in this part of the island. The western shoreline presently has the appearance of an eroding coast, but one might anticipate development into an accreting shore within the next few years since the ship channel and spoil pile protect the island from additional destruction by the strong northwestern winter storms. There is some suggestion that the area between the island and the spoil piles southwest of the dock facilities is now filling with fine sediment swept in from north and south. A more nearly complete discussion of island development will be presented in a subsequent paper.

Submarine Topography

The reef around Isla de Lobos is a weakly crescentic or flame-shaped structure situated upon a gently eastward dipping platform off the main coast of Mexico. The reef rises from a gently sloping surface, approximately 120 feet deep, to a relatively uniform flat-topped lagoon, now virtually at low-tide level. At low-tide level, the reef is approximately eight thousand feet long in a northerly direction from the broad, rounded, southern margin to the sharply pointed northern tip. It has a maximum width of approximately three thousand five hundred feet, one-third distance from the south. From the area of maximum width, it thins northward by both leeward and windward reefs converging with a gently eastward-arched pattern. The southern margin is much more rounded, but with an abrupt southwestern termination (Plate 1; Plate 3, fig. 3).

Low-tide outline of the reef is a rough approximation of the shape of the main reef mass. The reef, as now delimited (Plate 1), extends to a depth of 70 or 80 feet, and at this depth is slightly over twelve thousand feet long from south to north, and is approximately six thousand feet wide normal to this, at the southern end of the island, although the outer reef boundary is somewhat irregular (Plate 2).

Main topographic features associated with the reef complex which can be differentiated are: a flat lagoon; a deeply grooved leeward reef; a more complexly grooved, but somewhat more uniform windward reef; a broad fan of calcareous sand which stretches southward from the reef and island; two broad, pointed, tongue-like sand masses which extend westward and northwestward from the southwestern and northern tips of the reef; and the rocky slope east and northeast of the reef (Text-fig. 3).

Lagoon

A shallow, weakly saucer-shaped lagoon is reef-rimmed, with the margin well defined as an algal ridge which reaches to low tide. The ridge is shown as a dashed line on Text-figures 2, 5 and 6, and Plate 1, for the exact position is difficult to map.

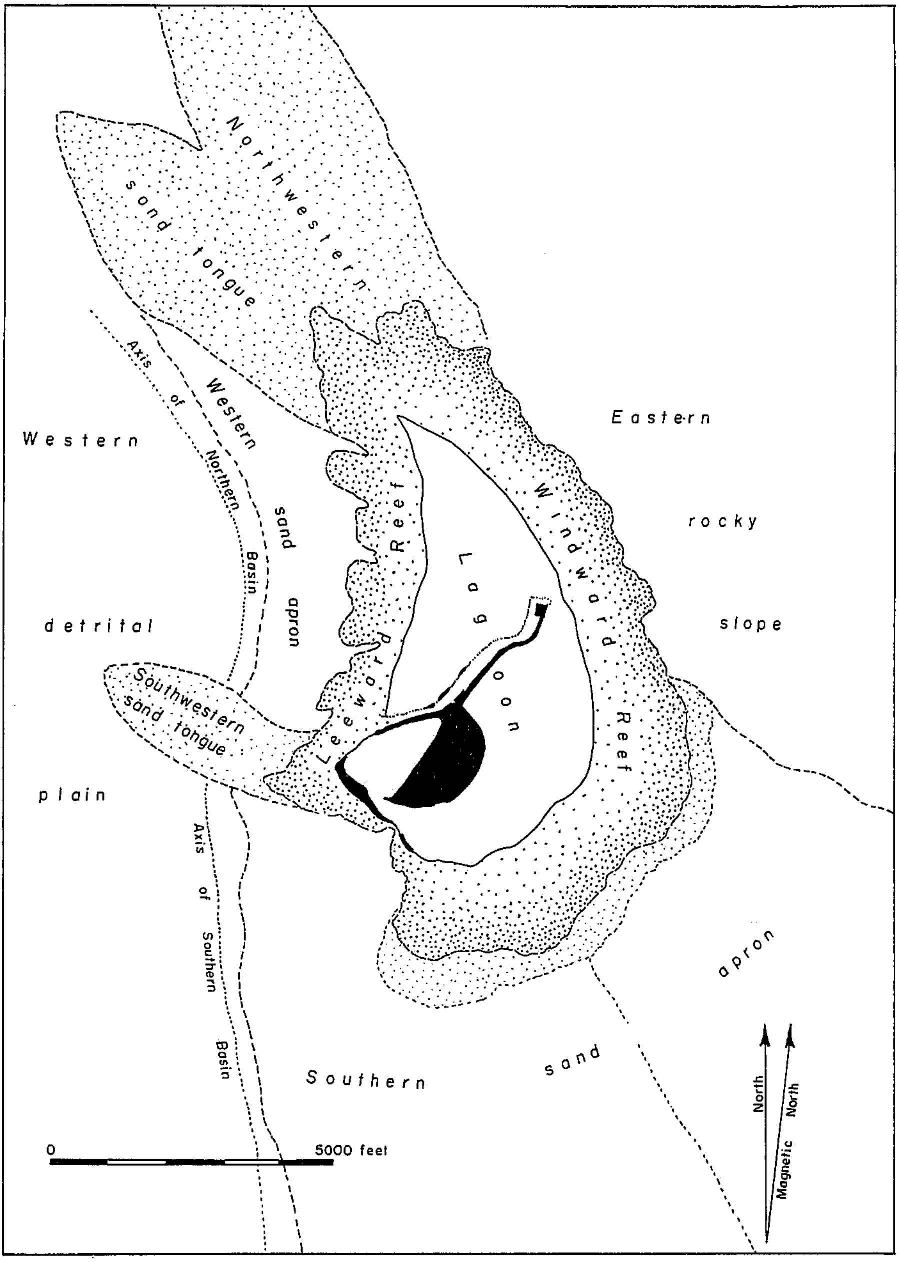
Maximum depth within the lagoon, except for the ship channel, is approximately 8 feet in the northern channel, an eroded depression in the lagoon floor at the northern end of the island (Text-fig. 3, 6). The original channel is interrupted by the ship channel and spoil heaps. Depths range up to slightly over 5 feet east of the spoil heap and up to 8 feet immediately west of the large spoil heap opposite the dock area. Elsewhere within the lagoon a more shallow channel is developed between the boulder ridge and the small spit at the southwestern tip of the island (Text-figs. 3, 6), with a maximum depth of less than 4 feet.

The vast majority of the lagoon is within two feet of low tide, and much of the area populated by the flat turtle-grass, *Thalassia*, is exposed at maximum low tide. Small irregular depressions are developed within these flats where sediments have been removed to the rock floor of the lagoon. They are rarely interconnected, but do evidence the depth of the rocky substrate upon which the plants *Thalassia* and *Halimeda* have perched a trapped sediment cover.

Only locally is there a moat or depressed area behind the marginal rim. In some regions of the southeastern margin, a weak moat is developed behind the reef flat where depths may range up to 3 or 4 feet in limited areas. A similarly weak moat is developed at the northern end of the reef, where the *Lithothamnium* ridge forms a barrier near the low-tide level, but the interior behind the ridge is depressed up to two feet. Elsewhere, as in the vicinity of the wrecked liberty ship (Plate 1), the reef flat slopes lagoonward and maximum depth of two or three feet is reached some distance away from the lagoon margin.

Leeward Reef

Topographic expression of the leeward reef is characterized by deep, steep-walled but broad grooves, separated by equally broad, flat-topped spurs (Plate 1). This pattern is developed from near the entrance into the ship



TEXT-FIGURE 3.—Main topographic regions associated with the reef complex at Isla de Lobos. The reef itself is coarsely stippled, and flanking sand regions finely stippled. Tongues from the western tips of the reef are thought to be sand swept from the reef, somewhat like the horns of a barchan dune. Calcareous sand dominates in these tongues and in the apron of sand west and south of the reef. Terrigenous sediments are most common flooring the western detrial plain.

channel, northward along the western margin of the reef to opposite the northern tip of the lagoon.

Grooves are relatively straight, from 30 to 50 feet deep below the summits of bordering spurs, and vary from 100 to as much as 400 feet wide. They are flat-bottomed and slope gently westward. All are blanketed with sand and have steeply sloping margins where sand has cascaded through the porous reef to form small scale alluvial cone-like features. Most have abrupt termination at the base of the growing reef, but continue as minor grooves and spurs up into the living coral mass. Most have bottom slopes of 10 to 15 feet per hundred feet in their initial reefward development, but flatten abruptly so that slopes of less than 10 feet per 500 feet are characteristic of their lower courses.

Six major grooves or arroyo-like depressions cut into the leeward reef (Plate 1). These are spaced six hundred to one thousand feet apart by broad, flat-topped spurs, and are from 600 to over 1400 feet long, with longest ones in the northern and southern parts of the reef.

Spurs of the leeward reef rise abruptly from a gently sloping sand apron along the western margin of the mass. Tips of spur development may extend to as deep as 75 feet, but throughout its length, the reef toe begins at approximately 70 feet deep. Spurs have a nearly vertical rise of a few feet at their termini, and then a gently convex upward surface which rises relatively evenly toward the reef crest at the lagoonal margin.

The leeward reef is widest off the northern and southern tips of the lagoon where it is as much as 1200 to 1400 feet from the reef toe to the lagoon margin. It is narrowest opposite the northern end of the island where it is only 400 feet from the toe of one of the spurs to the reef crest.

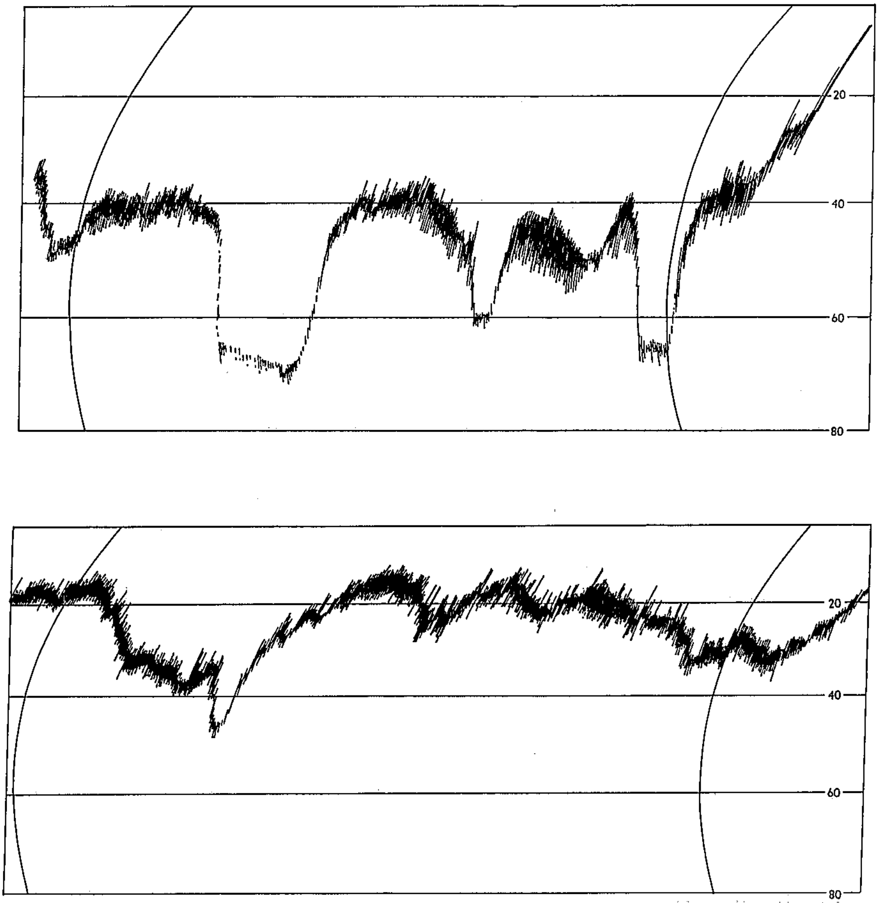
Windward Reef

The windward reef is developed along the arcuate southeastern to northeastern face of the topographic prominence (Plate 1) and is typified by numerous radiating, V-shaped grooves separated by sharp-crested spurs (Text-fig. 4). Broad, open, flat-bottomed grooves such as characterize the leeward reef are wanting. Rough channeled ground shows up from the southeast margin of the reef to opposite the well platform, but to the north of that platform for approximately 1500 feet, profiles are relatively smooth. Channeled reefs are also developed near the northern tip of the lagoon.

Narrow, but often deep, vertical-walled grooves are common in the upper surface of the reef, but show poorly on fathograms, for even in shallow water, channels a few feet wide are necessary to make an impression on the record. Where examined in the water, local relief within the middle part of the reef approaches 30 to 40 feet in some areas, but in general, there is only approximately 10 feet of local relief over most of the reef surface.

Base of the reef is well differentiated at the southeastern margin of the lagoon for it rises abruptly from the gently sloping sand apron and then slopes uniformly toward the reef crest. Toward the northeast, however, the base of the reef is poorly defined on fathograms for the distinctive sand apron cannot be differentiated and sample attempts indicate that the reef is built upon a rocky surface.

The windward reef is widest at the southeastern margin of the lagoon where it is approximately 2000 feet from the reef toe to the crest at the lagoonal



TEXT-FIGURE 4.—Fathograms of lateral traverses in the leeward and windward reefs at Isla de Lobos. A. Fathogram of the leeward reef from near the entrance of the ship channel northward to west of the well site platform. Deep flat-bottomed grooves and steep-sided, but flat-crested spurs are typical. Horizontal distance not to scale. B. Fathogram of the windward reef east and northeast of the well site platform. V-shaped grooves and sharp-crested spurs are typical. Horizontal distance not to scale.

margin (Plate 1). It is narrowest in the vicinity of the well platform where it is approximately 1200 feet wide. It is slightly wider at the northern end where it is interpreted to be 1600 to 1700 feet wide opposite the northern tip of the lagoon.

Windward reef development extends as a "horn" north of the lagoon for nearly half a mile. The extension is not a simple ridge, but appears to be two or more somewhat parallel ridges, one an extension of the present reef trend, and the other parallel to, but seaward of the first approximately 1000 feet. The latter is not as regular and appears to have several major V-shaped grooves cut into it.

Southern Sand Apron

A broad apron of coarse to medium-grained calcareous sand extends south from the reef mass (Text-fig. 3; Plate 1). It can be subdivided into two broad areas—one with a moderately steep slope developed at the toe of the reef, and the other as a long low ridge which extends south of the reef for at least one mile, the limit of our traverses.

The inner relatively steeply sloping apron buries the toe of the reef locally and seems to head in an area of relatively shallow water at the old ship channel, south of the lighthouse, where the reef is abruptly terminated. Here the sand wedge rises to within 20 feet of the surface, but gently slopes southward and southwestward at 20 to 25 feet per thousand feet (Plate 1). It has a similar slope around the southeastern margin of the reef and shows a distinctive change in slope from the steep reef and the more gently sloping outer sand bank. It is easily detectable on fathograms from directly east of the island, southwestward to opposite the boulder ridges, southwest of the island.

The outer, more gently sloping ridge of sand extends from the southern tip of the reef and marginal sand apron, southward into deeper water. It is a broad ridge with a length of approximately one mile and an east-west relief of 10 to 20 feet, rising from the nearly flat floor of the platform.

This accumulation of sand is interpreted as reef-derived calcareous sands swept into the lee of the reef by strong currents generated during winter storms from the northwest. It is also possible that the ridge is a relict feature of a buried or thinly veneered Pleistocene topography, or even an older feature, upon which the linearly arranged reefs of Isla de Lobos, Medio, and Blanquilla have developed.

Northwestern and Southwestern Sand Tongues

Two well-defined ridges or tongues of sand are evident beyond the northwestern and southwestern tips of the reef (Text-fig. 3; Plate 1). These are considered to be sand accumulations based upon isolated soundings and character of the fathograms. Both accumulations are linear ridges extending leeward from the reef mass like horns of a barchan dune and are thought to have somewhat a parallel origin. Strong bottom currents were observed to parallel the reef and are thought to be mainly responsible for shaping these features.

The southwestern ridge extends for at least two thousand feet from the toe of the reef and is at least 500 and possibly as much as 800 feet wide. It is approximately 30 feet high near the center of its development. It is slightly higher near the toe of the reef where it rises as much as 35 or 40 feet above the general base of the platform. It is interpreted as sand swept by long shore currents from the sand apron at the base of the old ship channel south of this island.

The northern tongue is actually two long linear ridges extending northwesterly from the base of the reef toward Medio Reef, a small, mainly submerged reef northwest of Isla de Lobos (Text-fig. 1). The ridges are evident for at least 4500 feet beyond the tip of the reef, approximately 7000 feet beyond the tip of the lagoon (Plate 1). The southern ridge is most clearly defined and is approximately 2500 feet wide at midlength. It rises approximately 35 feet above the general surface developed west of Isla de Lobos. The northern ridge is of similar proportions, though perhaps slightly longer.

These broad low ridges are interpreted, like the similar feature to the south, as an accumulation of sand deposited by long shore drift of currents generated by prevailing winds. Like the southern ridges, however, these too may be relict Pleistocene features, now only thinly veneered by sand.

Western Plain

The sea floor west of Isla de Lobos is an eastward sloping, sand-veneered plain, except within two or three thousand feet of the reef, where the sedimentary surface slopes gently westward (Plate 1). Junction of the two surfaces produces a long linear depression 120 feet deep, approximately one mile west of the margin of Isla de Lobos lagoon (Text-fig. 3). This depression is divided into two closed basins 20 to 30 feet deep by the southwestern sand ridge or tongue, developed west of the boulder ridge and the southwestern tip of the lagoon.

The western flank of the depression slopes approximately 50 feet per mile, and the eastern one slopes nearly five times as steeply at 50 feet per thousand feet. The eastern slope forms a broad sand apron at the base of the reef and is composed largely of reef-derived calcareous sediment, although some terrigenous clastic grains were noted in samples. On the other hand, the western slope is composed largely of land-derived clastic grains. Samples contain mainly quartz fragments with some ferromagnesium minerals, volcanic rock fragments, obsidian, and considerable calcareous debris. Some samples contained a large proportion of silt and clay-sized clastic material. Sediments accumulating in the area are considered typical of drift from either the Rio Tuxpan or Rio Panuco, but in the immediate vicinity of the reefs, calcareous sediment masks the less abundant, terrigenous, detrital material.

Eastern Rocky Slope

The area beyond the reef, east and northeast of the well platform, is mainly one of rocky exposure (Plate 1; Text-fig. 3). Several attempts to obtain samples with a clamshell sampler failed, except for recovery of small calcareous rock fragments.

Topographic expression is similar to the obviously sand-blanketed regions to the south and west of the reef, and would probably have been included with those areas were it not for the obviously rocky substrate evidenced by stuck anchors and empty samplers. It is a relatively smooth area, sloping gently seaward toward the northeast. Only locally have broad V-shaped gullies cut upslope toward the reef.

Throughout most of the area where we have sufficient control, the region slopes at the rate of 50 feet per thousand feet near the base of the reef and only 25 to 30 feet per thousand feet at a distance of one mile from the reef crest. The greatest depths recorded in the immediate vicinity are those in excess of 160 feet, the limit of our fathometer, northeast of Isla de Lobos (Plate 1).

HYDROLOGY

Circulation

Normal circulation within the lagoon and around the reef is largely the result of waves driven by the prevailing southeastern winds. Periodically strong winds from the northwest interrupt the general pattern and may locally reverse the dominant water motion.

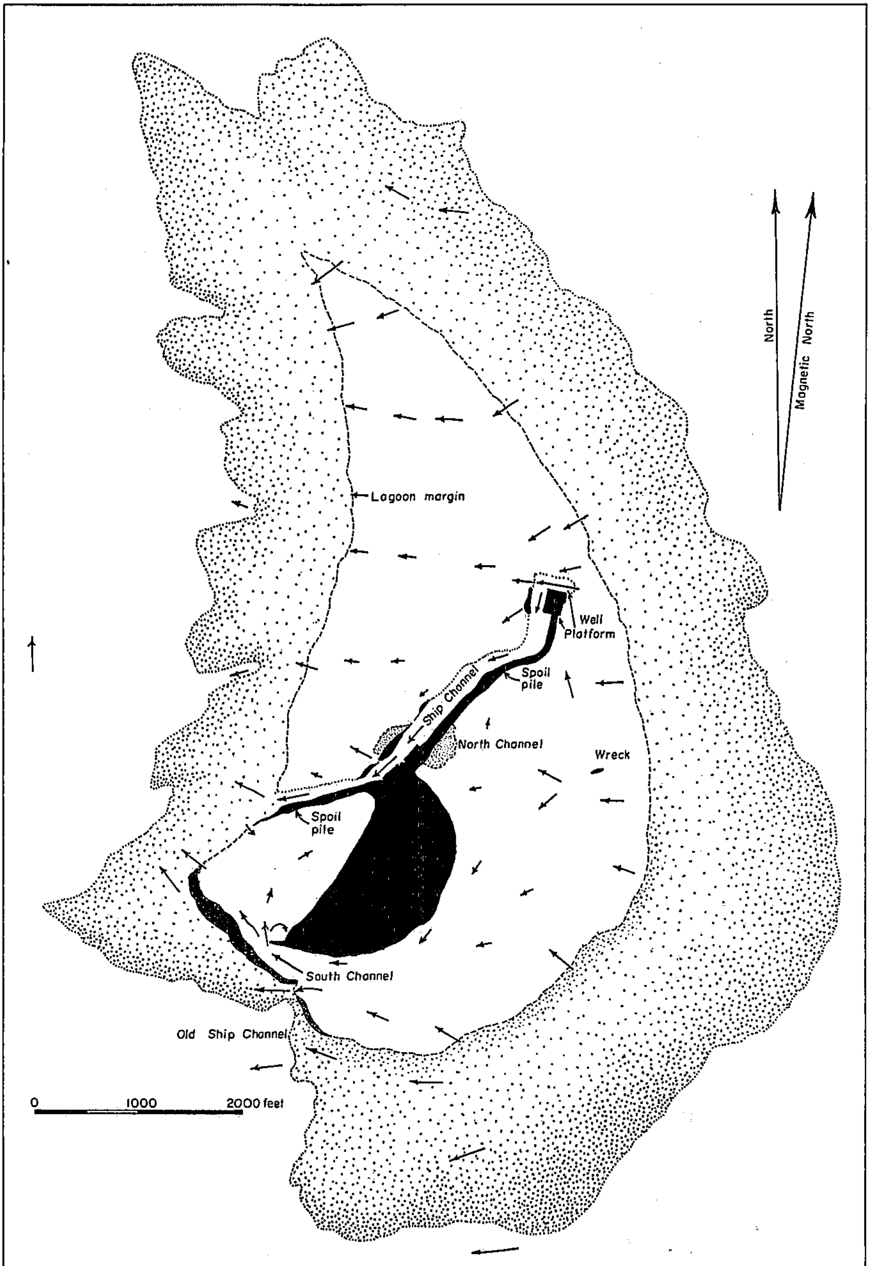
Normal circulation within the lagoon is the result of waves piling onto the eastern margin of the reef and spilling off the western side. This results in a general westward drift of water over the entire shallow surface (Text-fig. 5), but locally currents are moderately strong. Two areas with channel restrictions at the southern end of the island have relatively strong currents, although not of constant velocity or direction. One is developed between the spit at the southwestern tip of the island and the barrier of bouldery rubble on the reef crest. It is this current which constructs the spit and the loose shifting sand bar in front of it. Rubble is swept from the lagoon to the east and deposited at the southwestern tip of the island on the lee of the spit. Velocities of 2 to 3 knots were noted in the constructed channel.

The other channel occurs at a break in the boulder ridges on the reef crest, and is known as the older ship channel. Before the dredged channel was constructed into the northwestern tip of the island, this break in the reef was the main entry to the island. A more consistent current flows through this break and to the southwest. Much of the southern lagoon is drained through this gap, carrying with it considerable sediment from the *Halimeda* and *Thalassia* flats of the lagoon, onto the sand apron south of the reef. Velocities of 3 to 4 knots are not unusual in low passes through the break in the reef crest.

One of the strongest currents noted within the lagoon is developed at the northern end of the well site platform. With construction of the causeway and ship channel from the island, northeastward to the well platform, normal circulation within the northern part of the lagoon was blocked. Water which would normally have poured around the northern end of the island is now deflected as much as one thousand feet to the north where it flows past the well platform and onto the western reef (Text-fig. 5). Weak channels are now being excavated along the northeastern margin of the platform and will probably continue to develop as long as normal circulation is blocked by the spoil pile.

What is considered the normal, pre-ship channel, lagoonal circulation pattern is now developed only north of the well platform. Wind-driven waves pile water onto the lagoon flats nearly at right angles to the reef front. This water drains off the western margin where the reef crest is slightly lower. There is some southward deflection of water immediately northwest of the well site platform, but most lagoonal drainage in the northern part is directly westward across the lagoon, through the rather ill-defined *Lithothamnium* reef crest.

Interruption of the normal, pre-ship channel, current pattern is well demonstrated at the northern end of the island where a coral-populated channel was excavated in the lagoonal flats. The channel is as much as 8 feet deep, cut into flats with an average depth of less than two feet, and is approximately 200 feet wide. These depressed areas were populated with large coral heads of species most common in outer reef communities. These channels are now sites of fine-grained deposition, however, for they are abnormally deep depressions in the lagoon flats and are filled with quiet water dammed by the spoil piles. Upper surfaces of all coral heads within the channel are blanketed with fine sediment, and only the nearly vertical and overhanging margins of the heads are still alive. These abnormal lagoonal communities are now being overwhelmed by fine calcareous detritus.



TEXT-FIGURE 5.—Approximations of current directions and velocities in and adjacent to the lagoon at Isla de Lobos. The island and spoil heaps are shown in black, the boulder ridges to the southwest as white stippled on black, and the now-blocked North Channel as finely stippled. The reef is coarsely stippled. Currents generally move westward across the lagoon, except for those deflected around the island and spoil pile. North Channel was excavated by normal drainage around the island prior to dredging of the ship channel, but both parts are now filling with sediment.

Outside the lagoon, circulation around the reef is mainly from east or southeast toward the west (Text-fig. 5). Currents of 4 or 5 knots were observed at times along the southern margin of the reef and were noticeable to a depth of over 50 feet. At times, even at the base of the reef in water 65 to 75 feet deep, the current was strong and moving in a southwesterly direction. No deep diving was done at the northern end of the reef, but surficial drift is rapid and suggests a moderately strong current at depth as well.

A moderate current was noted by Rector and Adams in deep dives into the sandy and muddy area west of the reef. In 120 feet of water they noted a moderately northwesterly drift at the bottom.

Major surface drift was from the northwest for approximately one week during the middle of August. Fresh-water hyacinths and other debris from the flooding Rio Panuco moved past the island as a continuous stream. Large rafts of flotant and individual logs were also drifted southeastward, along with considerable fine sediment which produced murky water for over one week. Beaches which were normally clean were littered with fragments of root systems of many fresh-water, aqueous plants. At the same time, the prevailing winds were weak and major winds were from the northwest, presumably blowing the surface water before them. This one-week storm may be a summer equivalent to the cold northern storms of the winter, termed nortes, which reverse the normal circulation patterns.

Nortes have a pronounced effect on sedimentation and topography as well as do the prevailing winds. Perhaps one of the most noticeable effects would be the loss of the small spit at the southwestern tip of the island. It was reported to have been destroyed, after being breached, in a single storm. Much of this sand must have been washed to the south through the old ship channel onto the flanking sand apron at the base of the reef. The reversal of circulation produced by the storms probably has been the main erosion force along the northwestern shore of the island, in about the same manner as destruction of the spit. These areas of the island are adjusted to the normal circulation produced by the prevailing winds and are unstable to winds and currents from the north or northwest.

Turbidity

Water bathing the reef and lagoon of Isla de Lobos is usually sufficiently clear that objects can be recognized in up to 20 feet of water on the windward side of the reef. Leeward, and within the lagoon, fine sediment is often in suspension and increases the turbidity. Most turbid waters are those within the ship channel where fine lagoonal sediments, mixed with residual drilling mud, are constantly churned into suspension by movement of boats and barges. Distribution of turbidity may be a factor in differentiating windward and leeward reef communities, for with rare exceptions, windward water is slightly less turbid than leeward water, some of which has spilled across the sediment-laden lagoon from the windward edge. In most regions, however, water is sufficiently clear that photographs can be taken to the toe of the reef; although at depths below approximately 25 feet, it is impossible to do so without a tripod or auxiliary lighting.

Unusual turbidity resulted from flood waters of the Rio Panuco which were blown southward along the coast during an atypical period when winds from the northwest were dominant. These turbid waters reduced visibility to only a few feet and made photography of all but the shallowest features nearly impossible without some artificial light.

Clearest water resulted from a return to prevailing winds, coupled with extremely low tides. Even water within the lagoon and on the leeward edge of the reef was clearer than the normal gulf water had been during much of our period of investigation. Such clarity is probably related to reduced turbulence within the lagoon and decreased water flow through the lagoon and reefs.

Tides

Hourly observations on tide level were made during the two-day period of August 6 and 7 at the Pemex docks on Isla de Lobos; and in addition, scattered observations were made at a still-water gauge set up south of the island. Tidal range at the dock during the observed period was 1.8 feet, and this is assumed to be an average. Lower tides were observed during the latter part of August, however, when maximum low tides showed a variation of 2.7 to 2.8 feet. During average mid-cycle tides, all but the highest promontories within the lagoon remained below water. At maximum low tides, however, 15 to 20 percent of the lagoonal floor was exposed and circulation across the reef complex was nil.

There is but a single tidal cycle per day, with the cycle advancing at the rate of approximately 1 hour per day, as is typical elsewhere. Flooding tides rise rapidly and remain at crest for as long as 6 hours before the relatively slow ebbing takes place, followed by a low still stand of 2 to 3 hours.

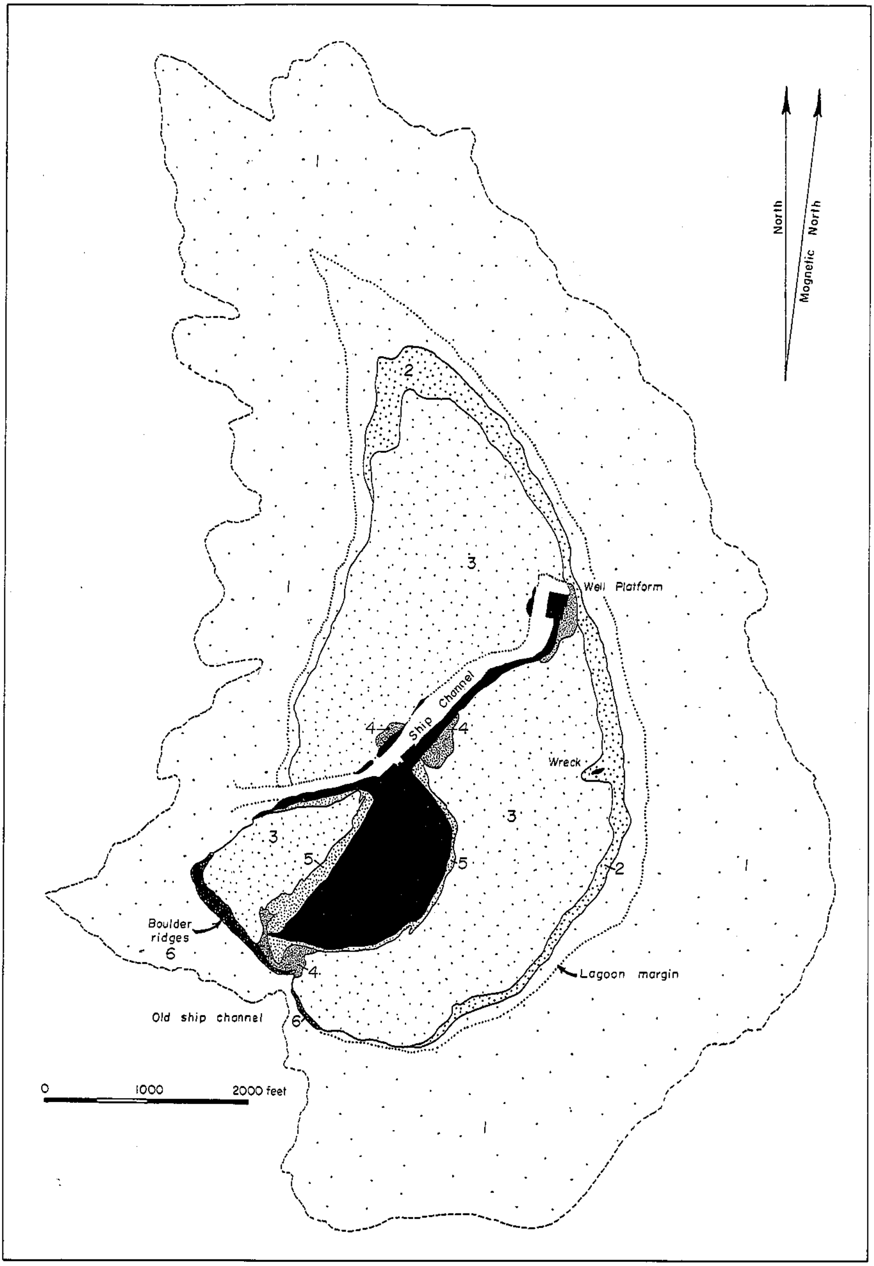
Tidal fluctuation, athough relatively small, controls the upward growth of *Thalassia*. At maximum low water these plants are killed by exposure, with the end result of patchy development within the lagoon. Similarly, vertical reef growth is limited to below the maximum low water stages.

HABITATS AND COMMUNITIES

Many earlier workers on marine ecology have recognized the marked development of associations of benthonic organisms, often with mutual exclusion or at other times with forms of broad distribution. On Isla de Lobos several distinct habitats and communities can be differentiated within the reef complex (Text-fig. 6; Plate 2). Habitat in this sense is used as the combination of biological and physical factors of the environment of either the organism or of the community. A community is considered as a distinct group of organisms living together, much as used by Newell *et al* (1959) in their study of the Andros Platform in the Bahama Islands.

Using the above definition, a variety of methods of differentiation of habitats is possible. They may be subdivided on the basis of salinity, depth, temperature, turbulence, light, type of substrate, or innumerable other parameters. For the present study we have found it suitable to subdivide habitats into three broad categories: lagoon, reef, and surrounding sediment apron, with subdivisions in each, based in large part upon character of the substrate.

Thorson (1957), Newell *et al* (1959), and many other workers in marine ecology have shown that marked differences exist between communities established on various substrates, although such differentiation is not always definitive. In a reconnaissance study such as ours, however, it is often the most easily documented and mapped differentiation; for in these limited observations, sedi-



TEXT-FIGURE 6.—Substrates associated with the reef at Isla de Lobos. 1. reef and rocky substrate; 2. pebble substrate composed largely of algal oncolites; 3. sand substrate composed of relatively large fragments of corals and *Halimeda* plates; 4. rocky substrates within the lagoon swept clean by normal drainage (except where the North Channel has been blocked by the construction of the ship channel); 5. unstable sand substrate and barren semi-stable sand; 6. boulder ridges.

ment character and association of organisms can be quickly observed. Habitats recognized on Isla de Lobos reef are: a rocky shore, a sandy shore, unstable sand, stable sand, and infratidal rocky bottoms within the lagoon; gravel bottoms, and rocky bottoms within the reef; and a stable and unstable sandy bottom in the surrounding deeper water.

In this sense we differentiated habitat communities, as used by Newell *et al,* (1959, p. 197-198), rather than organism communities or biocoenoses (Mobius, 1877). Organism communities are those defined on the basis of the organisms themselves, with little or no regard to physical or chemical factors of the habitat. Differentiation of biocoenoses is virtually impossible in a reconnaissance study, since mutual biologic relationships of animals and plants could not be demonstrated. Some such relationships are observable, however, and were considered although the ultimate causal relationships were not investigated.

Communities differentiated within the lagoon include: a balanid barnacle rocky-shore community; a poorly developed, unstable sand community; a group of communities characterized by *Padina, Caulerpa,* and *Penicillus* developed on a scoured, rocky, infratidal habitat; an *Arenicola* (?) community, a *Thalassia-Halimeda* community, a *Thalassia-Porites* community, a *Thalassia-Diploria strigosa* community, and a *Lithothamnium* pebble community. An unusual coral community dominated by *Montastrea annularis* is developed within a scoured channel at the north end of the island, deep within the lagoon, and is considered separately, although it has much in common with the leeward reef.

Differentiated reef communities are: a *Diploria clivosa* community as the inner pavement of the reef flat; a *Lithothamnium* ridge at the reef crest; an *Acropora palmata* community immediately in front of the crest on both leeward and windward reefs; a *Montastrea annularis* community in moderately deep water on the leeward reef; and a parallel *Diploria strigosa* community in the windward reef. A *Montastrea cavernosa* community is developed at the base of both leeward and windward reefs, and is flanked by the loose sand of the surrounding platform apron.

Sufficient observations were not made of the surrounding deeper water habitats, hence community differentiation is not attempted from our isolated dredge hauls and scattered observations on deep dives. It is apparent, however, that differing conditions are present windward and leeward, and differentiation would be impossible.

THE ROCKY SHORE

ROCKY-SHORE HABITAT

A rocky-shore habitat is only locally developed on the reef and island of Isla de Lobos, partially on man-made very recent structures, and partially on natural accumulations of coral heads on the crest of the reef, south of the island (Plate 3, figs. 3, 5). The latter area forms the oldest rocky exposures and the area where shore zonation is most well developed. Elsewhere, a rocky-shore habitat is formed by coarse debris in spoil piles along the ship channel (Plate 3, fig. 2) and by the concrete well platform and flanking protective debris.

Boulder ridges.—Two long, linear ridges of tossed coral heads were developed along the southern margin of the reef (Plate 1; Plate 3, figs. 1, 3, 5) during the 1951 hurricane, a storm which nearly destroyed the small sand island within the lagoon. Boulders and blocks of the ridge are composed of heads of *Diploria* and *Montastrea* up to 4 or 5 feet in diameter, derived from the lower part of the reef fronting on the deeper sand apron. These heads were tossed onto the crest of the *Lithothamnium* ridge into shallow water.

The larger of the two ridges is approximately 1500 feet long and up to 150 feet wide (Plate 3, fig. 3). It is relatively low so that waves break through and over most of the structure at high tide. A small sand cay is developed at the widest and highest western part, but the remainder is of bouldery rubble (Plate 3, fig. 5).

The smaller of the two is east of the old boat channel (Text-fig. 5; Plate 1) and is less continuous and much lower. It is only approximately 500 feet long as a continuous mass of blocks, but continues on eastward another 500 feet as isolated tossed heads on the crest of the reef. It is only 50 or 60 feet wide at the widest and is mainly buried at high tide. Even at low tide, however, waves commonly break over even the highest boulders.

Base of both bouldery masses is sharp on the seaward edge where blocks rest on *Lithothamnium* pavement, but on the protected lagoonward side, sand is now blanketing the lower edge (Plate 6, fig. 5).

Spoil piles and well platform.—Recent man-made structures provide another area where the rocky-shore habitat is developed. Coarse spoil, particularly where washed near the high-tide line, and debris surrounding the concrete well platform could function as a habitat where the rocky shore community might become established.

ROCKY-SHORE COMMUNITIES

The boulder ridges, spoil heaps, and the well site platform are the only places on the island where rocky-shore communities could become established. Such communities are poorly developed, probably because the habitats have only recently opened.

Within the tidal zone and supratidal zone, only small clusters of balanoid barnacles have become established. None of the distinctive intertidal or low supratidal molluscan faunas common in the Bahama Islands and elsewhere in the Carribbean area were observed. The distinctive coloration of the lower part of a rocky coast is developed, however, for boring algae have imparted the diagnostic yellow-gray color to lower parts of exposed blocks and the dark, somber gray-brown to upper parts. These color zones probably correspond to similarly colored belts developed in the Bahama Islands (Newell *et al,* 1951, p. 17-19; Newell *et al,* 1959, p. 206-208); but the distinctive fauna, except for barnacles, is not developed. One of the hopes for a continuing study of the Isla de Lobos region is that of watching a new habitat being populated.

Basal parts of the boulder ridges, below low tide, are now crusted with scabby-looking patches of pink and purple *Lithothamnium* and with brown filamentous algae. In a few favorably exposed spots small heads of purple *Siderastrea radians* have developed up to 4 inches in diameter. These corals are most common near the break in the reef at the old ship channel.

Padina and some other brown algae are common on boulders at the exposed ends of the boulder ridges where currents are strong. They are often intergrown with a mat of filamentous algae and small calcareous algal crusts, but do not extend far onto the lagoonward protected side of the ridges where currents are weak and sediments are accumulating.

Numerous small gastropods are common on many of the boulders on the back of the boulder ridge. They are often associated with small hermit crabs and appear to be grazing on the filamentous algae.

THE SANDY SHORE

SANDY-SHORE HABITAT AND COMMUNITY

Isla de Lobos is completely surrounded by a relatively narrow, steeply sloping sandy beach, but little attention was given the habitat since the only readily apparent animal inhabitants are abundant, small burrowing crabs. Characteristic plant zonation is developed, however, along the eastern and southeastern margin of the island and will be discussed in a subsequent paper dealing with island development and history.

THE LAGOON

INFRATIDAL ROCK-BOTTOM HABITATS

Exposed, eroded, rocky surfaces are well developed in the lagoon at the southern margin of the island, in the region of scour east of the sand accumulation and spit south of the Welch Lodge (Plate 1; Text-fig. 6). Similar surfaces are now developing east of the well platform in channels related to shift in water flow from the windward to leeward margin of the lagoon as a result of construction of the ship channel.

The barren area at the southern margin of the island is limited by the wedge of moving sand on the west and patches of *Thalassia* on the east (Text-fig. 6; Plate 3, fig. 1). It begins abruptly offshore at the beach step and extends southward to the crest of the reef. Loose heads of coral litter the bottom and are covered with a variety of algae. Although boundaries are somewhat irregular, barren rocky substrate covers an area approximately 200 feet across, both normal and parallel to the southern shore of the island.

INFRATIDAL ROCK-BOTTOM COMMUNITIES

Several distinct communities can be recognized within these small areas, but are undifferentiated on the map (Plate 2) because of scale. Most distinctive organisms are algae which can attach to the current-swept bottom. *Padina*, an ear-like brown alga, is common in regions of barren rocks. *Caulerpa,* a clustered grape-like green alga, and *Penicillus,* a brush-like calcareous green alga, are distinctive of other communities where thin veneers or patches of sand are available for population. These communities grade into one another as the substrate character gradually changes.

Padina sanctaecrucis, the distinctive plant of its community, is locally common where currents are most vigorous and sand has been swept away so that rocks protrude (Plate 4, fig. 6). These algae form in ear-like masses up to 3 or 4 inches high and are closely packed on most rocky surfaces. These plants make the bottom seem brownish gray when seen underwater. The *Padina* community is well developed around the base of the exposed part of the boulder ridges and on most barren rocky surfaces a few inches high, above the zone of maximum sand transport. The community is also thriving on the newly dredged blocks in the middle of the north side of the well platform, and is locally common in areas east of the platform on most of the loosened blocks and tossed coral heads. It has yet to repopulate the current-swept northeast corner or the northwestern corner or western side of the well site block, for in these areas only fine, hair-like, filamentous algae have become established.

Caulerpa cupressoides and *C. sertularioides longiseta* are common in the barren region and are the distinctive plants of their community (Plate 4, fig. 4). These algae grow in stolon-like fashion after becoming established in small sandy patches in the generally barren rocky region. Long strings of the algae now trail with the current where loosened from the substrate, or form a close network of interlacing stolons in a thin sand cover, where fixed. Bases of the colonies are commonly exposed, for the thin sand veneer is constantly in motion and only locally are their roots sufficiently dense to hold the granular substrate.

Two species, *C. cupressoides* and *C. sertularioides,* occur in sandy areas in the rocky zone. The larger, more bushy *C. cupressoides* is dominant and most widespread in the sandy zones, and the smaller, bifoliate form with two series of branchlets, *C. sertularioides,* occurs in the less deeply sand-veneered areas. Both seem able to survive in the same depth water and in waters of equal agitation. Their major limiting factor seems to be variation in depth of sand on the substrate.

Penicillus sp. is the indicator plant of an additional algal community in which the rocky substrate is only thinly veneered with sand (Plate 4, fig. 3). These brush-like forms are common around the western margin of the island, and in the more sandy regions of the rocky area south of the island. These algae have numerous, small, hair-like roots which stabilize sands and provide areas where they cannot only maintain themselves once established, but can form a favorable area for repopulation and for establishment of other organisms.

UNSTABLE SAND HABITAT

Loose drifting sand is accumulating within the lagoon only at the beach margin and at the southwestern tip of the island (Text-fig. 6; Plate 3, fig. 1). Sand-size shell debris is accumulating in a rippled and shifting bar off the southwestern tip of the island. It is expressed at the surface as a small sand spit slightly over 100 feet long and rising up to 3 or 4 feet above high tide. In the lagoon it is a blanket of shifting sand extending southward as a triangular area 200 feet across. The sand is accumulating in an area of moderate current between the spit and the eastern edge of a hurricane-tossed boulder ridge on top of the reef crest. It is burying a relatively smooth rock floor and is as much as 3 feet deep at its northwestern end near the beach. Where thickest it has developed a steep leeward slip slope, but thins gently eastward to a feather edge of rippled sand over a current-swept rocky surface. The bar is composed mainly of coarse-grained sand to granule-size particles, worn mainly from corals and algae common in the lagoon. Much of the detrital material is readily identifiable as *Halimeda* fragments, although *Porites* fragments also play an important role.

Upper surface of the sand wedge is in constant motion, for with both flooding and ebbing tides, moderately strong currents flow through the restriction. Dominant movement is from east to west and the surface is shaped with ripples ranging up to 4 or 5 inches high and up to 1 foot from crest to crest (Plate 4, fig. 2).

UNSTABLE SAND COMMUNITY

No macro-organisms were found living in or upon the sand. The mass is apparently too unstable to be populated. In addition to its shifting character, much of the bar is exposed at maximum low tides, making it a less than ideal substrate for benthonic organisms.

STABLE SAND HABITATS

Stabilized sand habitats occur throughout the lagoon on Isla de Lobos, and to some extent in the surrounding deeper water of the platform as well. Several facies can be differentiated within the lagoon, all composed largely of shell sand or fragments of the calcareous alga *Halimeda.* Relatively fine-textured sands, blanketed by a leathery algal crust, occur in quiet water immediately north and west of the island. Coarser grained sands occur through most of the remainder of the lagoon where several different communities have been differentiated. These coarser sands are largely fragments of *Halimeda* and form the substrate into which the flat-bladed grass, *Thalassia,* has rooted and in which various sponges, corals, anemones and echinoderms also grow.

STABLE SAND COMMUNITIES

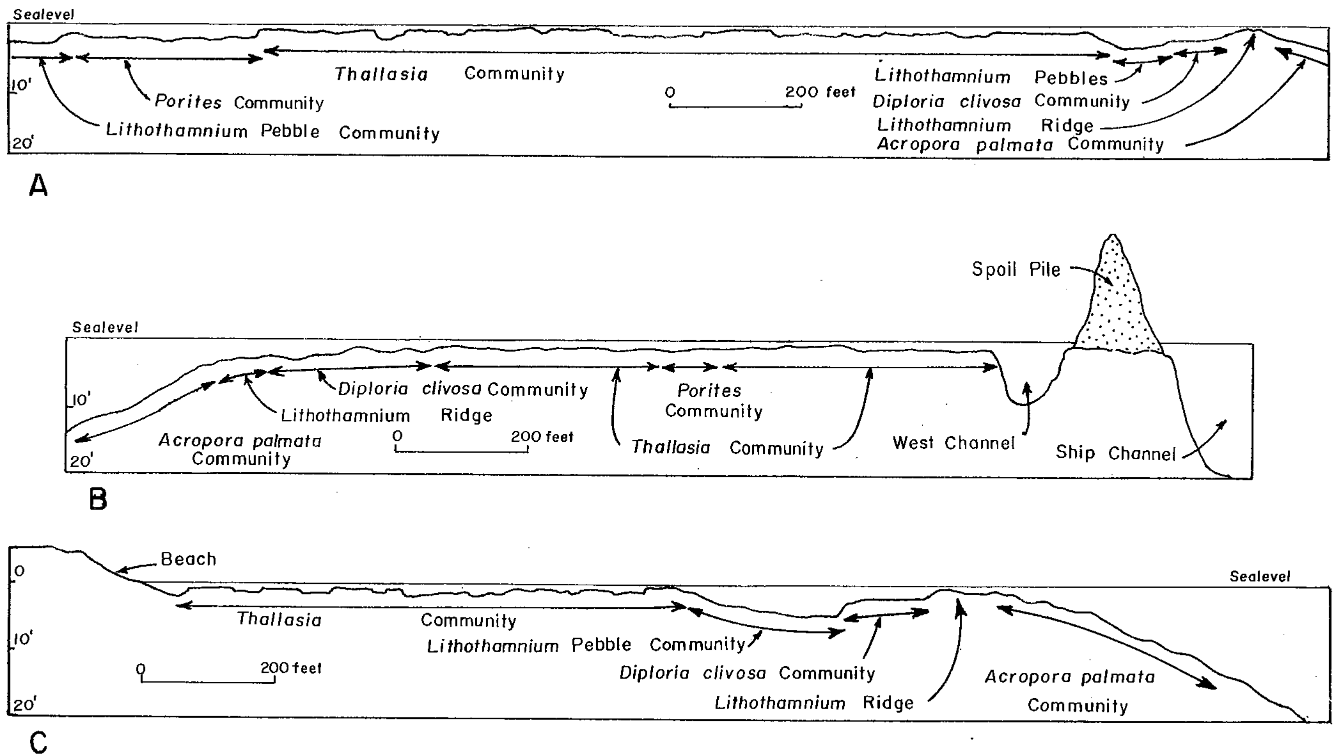
Arenicola(?) Community

Two areas of burrowed, mounded sand are present adjacent to the island (Plate 2). One of these is well defined in the leeward region, north of the small spit at the southwestern tip of the island; the other is adjacent to the northern end of the island, east of the causeway. Both are in relatively shallow and sheltered areas where coarse to medium-grained sand is now accumulating and where organic refuse collects. These are probably newly developed facies, particularly the one to the north, for prior to construction of the causeway, relatively vigorous currents swept the area. Development of the quiet environment followed causeway construction. Both northern and southern areas are floored with filamentous algae covering a stable sand flat.

The *Arenicola* (?) mounds are from 4 to 6 inches high and form low cones on the moderately smooth surface of the sand (Plate 4, fig. 1). They are most concentrated near the low-tide line, where they are spaced up to 20 mounds per square meter in the southern development. Mound spacing is progressively less dense away from the shore, until 100 feet off shore they are spaced only 1 or 2 per square meter. The area is almost sterile-looking, with only the mounds and a crust of mossy, gray-brown filamentous algae. These mounded sandy areas grade seaward into *Penicillus-Thalassia* blanketed sands. In the transition areas mounds are often 10 to 12 inches high, but are usually widely spaced.

Thalassia-Halimeda Community

The flat-bladed turtle grass, *Thalassia testudinatum,* blankets much of the interior of the shallow lagoon and occurs as scattered plants even into the *Lithothamnium* ridge around the margin. In the interior of the lagoon, however, it forms dense growths which act as efficient sediment traps and forms a distinctive facies, particularly when combined with areas where *Thalassia* and the calcareous alga *Halimeda* occur together (Plate 2). *Halimeda* occurs between the grass plants, and forms a porous substrate through which the stolon-



TEXT-FIGURE 7.—Topographic and community profiles within the lagoon. A. Profile along Traverse 5, from the windward edge, across the lagoon, to near the leeward edge, north of the well platform. B. Profile along traverse 6, from the leeward margin of the lagoon, east to the spoil pile opposite the docks. C. Profile along traverse 7, southeast from the island across the lagoon to the windward reef. Vertical exaggeration x 10.

like roots of *Thalassia* can easily penetrate. The two plants together form a porous, spongy-textured, sand-covered bottom.

Clumps of *Thalassia* rise above the general surface of the rocky substrate like clumps of brush which have trapped sand in western deserts (Plate 5, figs. 1, 2). In some instances, clumps of grass and *Halimeda* rise as much as two feet above surrounding areas. This is particularly true at the western edge of the *Thalassia* banks south of the island, where the margins of the grassy clumps are being eroded, and have almost vertical sides, protected by the complex root system of the grass. Some of the substrate must have been eroded, for segments of roots trail down current some inches or feet from the clumps. In most of the region, the grass flats have grown to the level of maximum low water, so that during this low-water stage (Plate 3, figs. 4, 6), the crests of many of the clumps are bare and the grass on them is killed. Once this happens the interior of the clump is then eroded until it can be stabilized by lateral growth of the grass again. This produces a patchy pattern in many areas and has been differentiated in areas where sandy bottoms dominate over grassy bottoms. This is particularly well shown in the southern end of the lagoon, south and southeast of the island.

Small mounds of grass are composed of loose sediment trapped by both *Halimeda* and *Thalassia*. *Halimeda* plates form much of the loose sediment and most apparently accumulate in place, trapped beneath the protective cover of the growing plants. The spongy mass of loose plates may reach as much as 8 inches thick, through which and into which the living *Halimeda* and the growing *Thalassia* root. Fine sediment is trapped within the cover, but makes a small fraction of the total when compared to the larger calcareous fragments of *Halimeda*.

Even in the dense grass flats, however, small, isolated, rocky-floored or sandy-floored depressions exist (Plate 5, fig. 2, 3). These are generally populated with various large anemones, sponges, small anemones, gastropoda, and octopi. These rocky areas form small open depressions in the general grassy flat, 1 to 2 feet deeper than the flat itself.

This particular community is well adapted to the shallow water environment of most of the shallow lagoon, and is particularly well developed immediately south and east of the island (Plate 3, fig. 4, 6), as well as in the interior of the lagoon east and west of the ship channel north of the island. It is the most extensive community within the lagoon and apparently represents the climax community of the lagoon.

Thallasia-Porites Community

A community of intermixed *Thalassia* and *Porites* is developed along the western margin of the lagoon, from west of the island, northward to within 2000 feet of the northern tip of the reef. West of the well platform, community development is from 500 to 600 feet wide, normal to the reef front, but to the south and north, *Porites* development is less extensive.

Toward the west, gravels of *Porites porites* pave the lagoon floor and grass is less dense. In these areas living *Porites* is most common and forms thickets up to 6 to 8 inches deep. In local areas living *Porites* covers over half the lagoon floor. At the inner limit of its development *Porites porites* forms small heads intergrown with *Halimeda* as an undergrowth to the taller *Thalassia* plants.

Other organisms common in the community include a moderate variety of sponges, some echinoids, and isolated heads of *Diploria clivosa* and *Siderastrea siderea,* both of which are usually loose.

This community grades lagoonward by loss of *Porites* into the sandy thick growths of *Thalassia* and *Halimeda;* reefward, however, *Porites* plays only a minor role, where *Diploria clivosa* becomes dominant and scattered in with *Thalassia.*

Thalassia-Diploria Community

Although isolated heads of *Diploria* occur through most of the lagoon, they become sufficiently abundant along the margin of the flats that the association is separately mapped. Corals are fairly common along the eastern margin of the lagoon for up to 500 or 600 feet behind the reef crest, and this zone of abundance is included here in the *Thalassia-Diploria* community, excluding that part of the zone where algal oncolites are the dominant substrate. The association is perhaps best developed along the western margin of the lagoon where algal pebbles are poorly developed and where a *Lithothamnium* ridge is ill defined, if present at all. In both these areas, corals consist of isolated heads of *Diploria clivosa,* in the main, but also *Siderastrea siderea, Montastrea annularis,* and *Porites branneri.* Throughout most of the area corals comprise only 20 to 25 percent of the area, and of this, *Diploria clivosa* would account for 15 to 20 percent. *Thalassia* is present, but is not as densely spaced as in the more sandy interior of the lagoon.

Lithothamnium GRAVEL HABITAT AND COMMUNITY

Oncolites of *Lithothamnium* are developed in the lee of the windward reef, at the margin of the lagoon and the *Diploria clivosa* pavement (Plate 2; Plate 5, fig. 4). The community is typically developed over a wide area at the northern tip of the reef, and at most places along the eastern margin of the lagoon, southward to just southeast of the island.

Southeast of the island, pebbles formed by encrusting *Lithothamnium* form a band approximately 150 feet wide behind the *Diploria* pavement. Lagoonward, typical sandy flats replace the pebbly base where *Thalassia* is present in dense growths.

In the vicinity of the wreck, east of the northern part of the island (Plate 2), similar pebbles form the substrate for sparse *Thalassia* for approximately 200 feet behind the coral pavement of the reef before grading into sand. In the immediate vicinity of the wreck, pebbles and small cobbles are well developed up to 2 feet deep.

Pebbles are formed by irregular crusts of algae coating mainly fragments of *Porites* (Plate 5, fig. 3) or mollusks, although in some pebbles there is no obvious foreign organic core.

In addition to the gravels of oncolites, *Thalassia* and *Halimeda* occur as scattered plants or colonies. Isolated heads of most of the reef flat corals occur throughout the pebbly zone, but most common heads are of *D. clivosa,* along with moderately abundant *Porites* in local areas. *Porites* is particularly common in the northeastern part of the lagoon.

Broadest development of the oncolitic *Lithothamnium* community is near the northern tip of the reef where pebbles blanket the interior of the lagoon over a wide area. In this region there is little grass and the pebbles are apparently constantly moved. This is also the region of best coral development within the dominantly pebble-floored facies, for here the water is slightly deeper and waves are more vigorous. Heads of *Diploria strigosa, D. clivosa, Siderastrea siderea, Porites branneri, P. porites,* and even *Acropora palmata* occur scattered throughout the pebble zone, but total probably less than 10 percent of the area. It is this region which most closely parallels the lagoonal pattern over much of Blanquilla Reef, presumably because in both areas strong waves can sweep across the flats.

THE REEF

REEF HABITATS

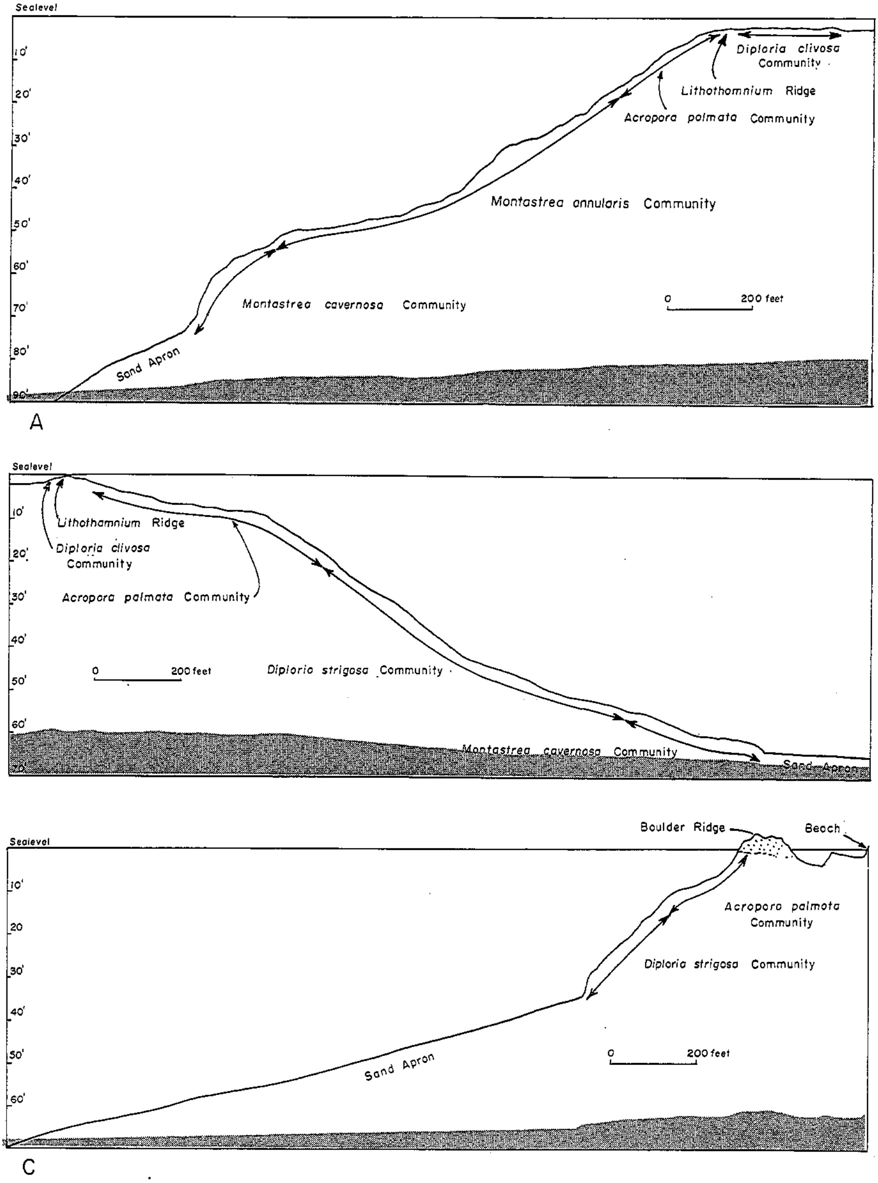
The reef habitat is developed around the margin of the lagoon at Isla de Lobos and its distribution has been discussed earlier in the section on topography. The habitat, as a major subdivision, extends from the low-tide line down to at least 75 or 80 feet, to the border of the rocky bottom with the surrounding sand apron. Within this major habitat, one can recognize many microhabitats, but three subdivisions within the reef can be easily differentiated. One of these is typical of shallow water throughout the reef and is characterized by vigorous currents and maximum light penetration, where algae have cemented the structure into a solid mass. An intermediate habitat can be separated on the basis of both reduced light and vigor of currents, in a region where pockets of sand still persist and where algal crusts form less of the rocky substrate. A lower habitat can be differentiated from those above by noting increase in sand areas within the reef and almost lack of algal crusts on the broad, open, cavernous surface. The lower habitat is characterized by markedly reduced intensity of light and current velocity. Each of these three broadly differentiable habitats is populated by a moderately distinctive community, and certainly within each, many more narrowly defined communities could be separated on a micro scale. Variations in exposure to surf, light, and sediments, to name just three parameters of the environment, produce marked variation in the micro-community within each broad zone.

REEF COMMUNITIES

Diploria clivosa Community

A broad zone of abundant *Diploria,* here considered a distinctive community, is developed at the lagoonal margin of the reef (Plate 1; Plate 3, figs. 1, 2) behind the *Lithothamnium* ridge, where it is well defined, or at the reef crest where the ridge is not developed. This pavement forms in shallow water, just below maximum low tide, and varies from 100 to over 300 feet wide around the margin of the lagoon. It is also locally developed in front of the *Lithothamnium* ridge on the leeward reef in the northern part of the reef.

The community is very well developed in the leeward reef, opposite the northern end of the island. Here the reef flat consists of an extensive development of knobby, encrusting, plate-like masses of *Diplora clivosa* (Plate 3, figs. 1, 2). The coral functions as a binder on the top of the reef and extends as isolated heads well into the lagoon and locally down into the upper part of the seaward reef. In many areas along the western margin of the lagoon *Diploria clivosa* covers as much as 70 to 80 percent of the area, in heads up to 5 or 6 feet in diameter and only a few inches high. Pockets of sand, in which



TEXT-FIGURE 8.—Topographic and community profiles of windward and leeward reefs and the flanking sand apron at Isla de Lobos. Large profiles have x 10 vertical exaggeration, but smaller black profiles are without exaggeration. A. Leeward reef profiles, opposite the well platform, near locality 41. B. Windward reef profiles southeast of the island near locality 38. C. Modified windward reef profiles south of the island, opposite the sand wedge and spit west of the old ship channel.

Halimeda, Penicillus, and *Caulerpa* grow, make up most of the remainder, although locally some heads of *Montastrea annularis, Siderastrea siderea, D. strigosa, Porites porites* and *P. furcata* (?) occur scattered in low areas in the pavement.

The *Diploria clivosa* community is also developed on the lagoonward margin of the windward reef (Plate 5, figs. 5, 6) throughout its length in water just below maximum low tides. In front of the wrecked ship the pavement is as much as 150 feet wide.

Southeast of the island the *Diploria clivosa* pavement is as much as 200 feet wide and with slightly more local relief than to the north or in the leeward reef. It is composed mainly of flat plates of *D. clivosa,* only a few inches high, which appear to encrust like frosting. Other corals are present as small heads throughout, but are most well developed in slightly sheltered areas. *Siderastrea siderea, Porites porites, Porites furcata*(?), and some *D. strigosa* are present at most localities, although most heads are at least partially overgrown around their base with *Lithothamnium.* Numerous holes in coral heads and along their margins are occupied by red and purple *Echinometra lacunter* and by the slate pencil urchin. All of these are commonly encrusted with algae or foraminifera.

The *Diploria clivosa* community is poorly developed along the southern margin of the reef and is not present at the reef crest between the boulder ridges on either margin of the old ship channel at the southern end of the island.

Lithothamnium Ridge Community

A low ridge, formed or crusted with *Lithothamnium,* is developed at the reef crest surrounding the shallow lagoon (Plate 3, fig. 2; Plate 1). It is best developed along the windward edge and leeward edge of the lagoon in the northern part of the reef. It is moderately developed along the arcuate eastern margin of the lagoon from near the wreck, southward, to the old ship channel and the ridges of rock south of the island. It is only poorly developed along the leeward edge of the lagoon, from south of the entrance to the ship channel northward to west of the well platform.

In the northern regions it rises as a distinctive barrier, as much as 3 feet above an ill-defined moat at the margin of the lagoon, and is constantly awash with strong surf and swash, except when locally exposed during maximum low tides. In this area it is 70 to 100 feet wide, with a transition into coral-encrusted regions both lagoonward and seaward. In this region it has a typical pink to light gray or purple, massive, but grossly cavernous, surface, with most openings occupied by slate pencil urchins or red and brownish purple echinoids. Locally *Diploria clivosa* forms heads as much as 3 to 5 feet in diameter, but only 1 to 4 inches high; but in general, massive algal crusts cover as much as 80 percent of the area. A few isolated heads of *Porites,* up to 4 inches in diameter, occur in protected places, along with large-bladed *Halimeda* where sufficient coarse sand has been trapped in low places.

To the southeast, in front of the wreck and southeastward (Plate 2), the ridge is less well defined, a development typical of most of the southeastern part of the lagoon margin. Here the ridge is present, but as rough, channeled and pinnacled algal surfaces, curving over old coral heads and tossed boulders. It is not the relatively smooth surface developed in northern leeward and windward structures. It is awash with strong surge and surf and appears as a sur-

FIG. 1.—Southwest tip of Isla de Lobos as seen from northwest. Lighter patchy area in foreground is *Diploria clivosa* pavement in leeward reef, and darker areas toward island are patches of *Thalassia*.

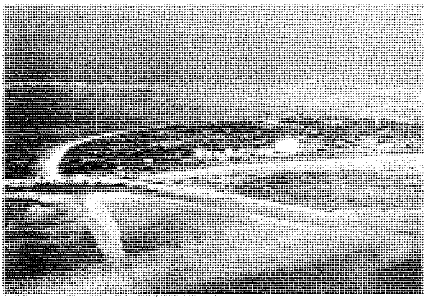


FIG. 2.—Aerial view of most of Isla de Lobos from the northwest, across the leeward lagoon. Zonation of leeward reef shows well as *Acropora* zone, algal ridge, and *Diploria clivosa* pavement.

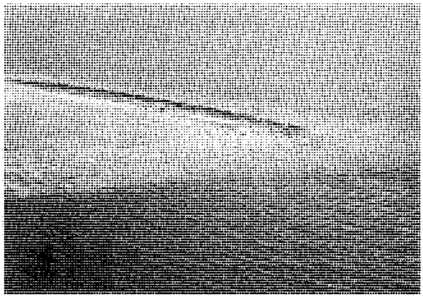


FIG. 3.—Boulder ridge at the southwest tip of the lagoon. Hurricane tossed coral heads form the ridge which is capped by a small sand cay. The ridge is approximately 1500 feet long.

FIG. 4.—Windward lagoon as seen from the lighthouse during a maximum low tide. Tops of *Thalassia* hummocks are above water.

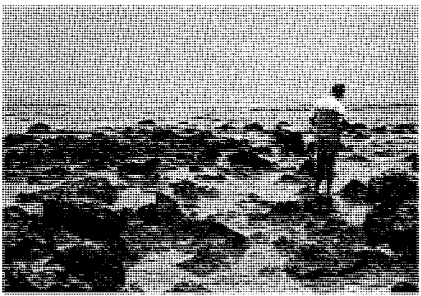


FIG. 5.—Crest of eastern end of largest boulder ridge. Heads are largely *Montastrea* and *Diploria*, now being dissolved and forming the characteristic yellow and black zones of a rocky coast.

FIG. 6.—Windward lagoon at maximum low tide with tops of *Thalassia* hummocks exposed, as seen from east side of island.

BOULDER RIDGE, THALASSIA FLATS AND AERIAL VIEWS OF ISLA DE LOBOS

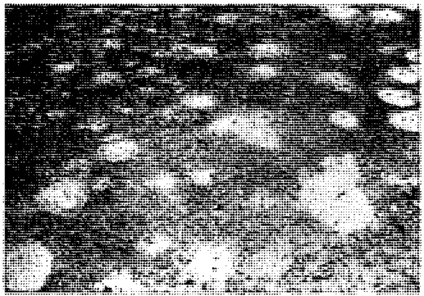


FIG. 1.—Mounds of sand tossed by burrowing worm. *Arenicola* in sheltered area north of island and east of spoil pile, in water less than 1 foot deep. Mounds are approximately 8 inches in diameter.

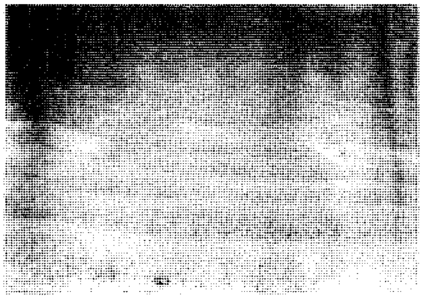


FIG. 2.—Rippled crest of sand wedge at southwestern margin of island. Water is murky and approximately 2 feet deep. Ripples are up to 4 inches high and 8 to 10 inches from crest to crest.

FIG. 3.—*Penicillus* grove on rocky substrate in channel south of island. Water is approximately 2 feet deep, and individual plants 2 to 3 inches high.

FIG. 4.—*Caulerpa cupressoides* on rocky substrate in channel at south of island, in water approximately 2 feet deep. Some *Padina* is attached to exposed rocky surface. *Caulerpa* is approximately 2 inches high.

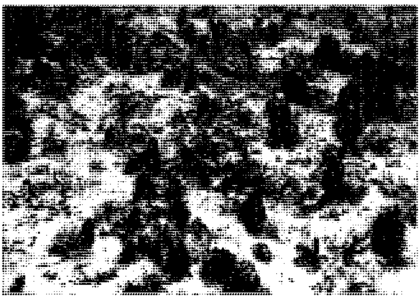


FIG. 5.—*Penicillus* and filamentous red and red-brown algae on rocky substrate in channel where thin sand veneers the rocks. Water is approximately 2 feet deep. *Penicillus* is approximately 3 inches high.

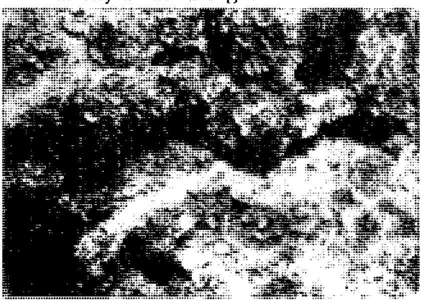


FIG. 6.—*Padina* and filamentous algae attached to tossed blocks on the submerged part of the boulder ridges, west of the old ship channel, south of the island. Largest masses of *Padina* are 3 to 4 inches across.

UNDERWATER PHOTOGRAPHS OF LAGOONAL ENVIRONMENTS ON ISLA DE LOBOS

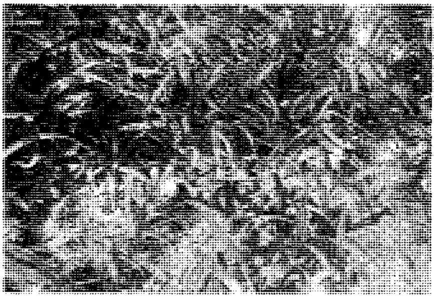


FIG. 1.—Flat-bladed *Thalassia* growing in an undergrowth of *Halimeda opuntia.* The large colony of *Haliclona* is typical of development in the blocked channel. Individual grass blades approximately 1 foot long.

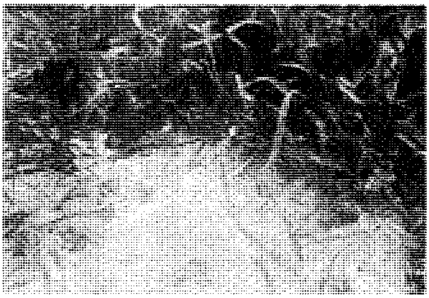


FIG. 2.—Border ot rocky, anemones-covered sandy flats and hummocks of the marine grass *Thalassia,* in approximately 3 feet of water. Traverse 5, 250 feet northeast of the island.

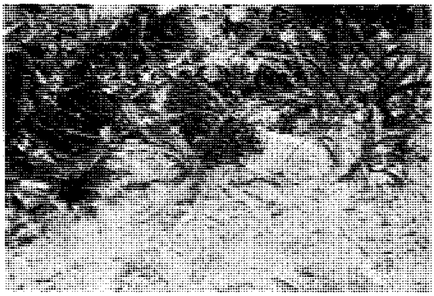


FIG. 3.—*Thalassia* in sparse growth in pebble substrate of fragments of *Porites porites.* Darker clumps are colonies of *Halimeda opuntia.* Individual grass blades approximately 1 foot long. Traverse 5, 300 feet.

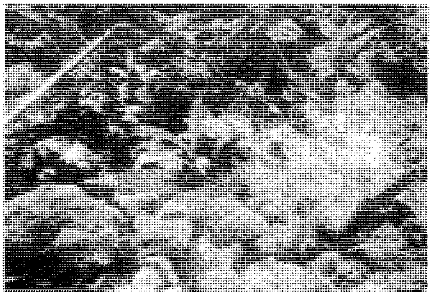


FIG. 4.—Nodular pebbles of encrusting *Lithothamnium* in immediate lee of windward reef, Traverse 7, 1060 feet southeast of the island in 2 feet of water. Rod is one-quarter inch in diameter.

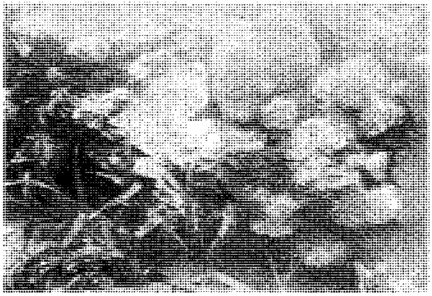


FIG. 5.—Complex head of *Diploria clivosa* at margin of pavement with *Thalassia* area. *Thalassia* blades approximately 1 foot long. Isolated reef head in channel north of the island in 4 feet of water.

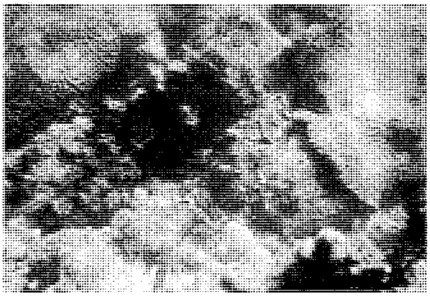


FIG. 6.—Surface of *Diploria clivosa* pavement in 1 foot of water. Corals, the algae *Halimeda,* and crusts of *Lithothamnium* form the surface. Base of photograph is approximately 2 feet. Traverse 7, 1200 feet.

UNDERWATER PHOTOGRAPHS OF LAGOONAL AND MARGINAL ENVIRONMENTS ON ISLA DE LOBOS

FIG. 1.—Small colonies of *Acropora palmata*, *Montastrea cavernosa* and *Diploria clivosa* on algal-coated bedrock near reef crest, south of island west of old ship channel. Base of photograph approximately 2 feet across.

FIG. 2.—Small *Acropora palmata* head and smaller heads of *Diploria* on crest of algal ridge on west side of old ship channel. Water is approximately 5 feet deep. Base of colony approximately 6 inches across.

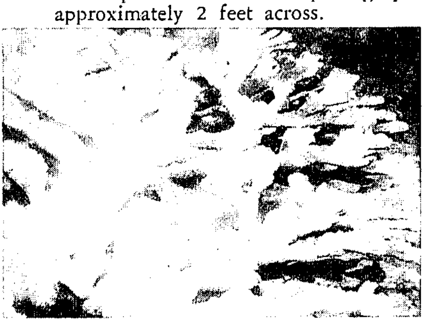


FIG. 3.—Large *Acropora palmata* colony nearly 8 feet in diameter in leeward reef, southwest of tip of island. Water 6 feet deep.

FIG. 4.—Tips of large colony of *Acropora palmata*(?) with small irregular nodes or conical mounds on upper surface, in 4 feet of water west of old ship channel. Base of photograph approximately 3 feet.

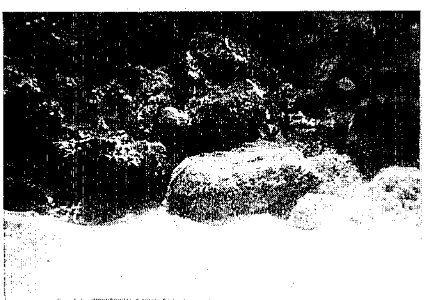


FIG. 5.—Protected northeast side of western boulder ridge southwest of the island. Skeletal sand partially buries tossed blocks composed of *Montastrea* and *Diploria* heads up to 2 feet in diameter in 3 feet of water.

FIG. 6.—*Montastrea annularis* head with large colonies of the brownish chimney sponge, *Haliclona longleyi* in channel north of island. Base of photograph approximately 4 feet across.

UNDERWATER PHOTOGRAPHS OF UPPER REEF ENVIRONMENTS ON ISLA DE LOBOS

FIG. 1.—*Acropora palmata* community at west edge of old ship channel south of the island, in water approximately 10 feet deep. *Acropora* forms the crest of the reef and *Diploria* the base. *Acropora* approximately 6 feet high.

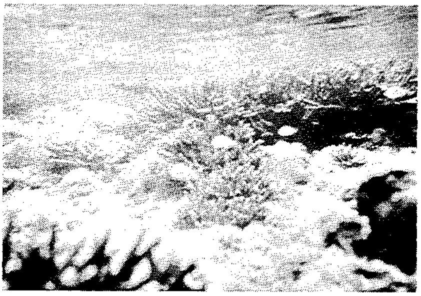


FIG. 2.—Upper *Acropora palmata* community near the north end of the lagoon, in the leeward reef. *Acropora cervicornis* and *A. palmata* form the upper part of the reef over *Lithothamnium*-crusted *Montastrea.*

FIG. 3.—*Montastrea annularis* in typical development in leeward reef in 10 to 15 feet of water, west of the north end of the island. Base of photograph approximately 2 feet across.

FIG. 4.—Lower *Acropora palmata* community with 1-foot head of that species capping algal-crusted *Diploria* head. *Diploria strigosa* and *Montastrea annularis* forms most of the base of the reef.

FIG. 5.—Large colony of *Pseudopterogorgia acerosa* attached to dead coral, now largely covered with *Lithothamnium.* Reef slope in front of lighthouse, south of the island, approximately 15 feet water. Colony 3 to 4 feet high.

FIG. 6.—*Plexaura homanalla* on algal-crusted coral with head of *Diploria* the only living stony coral. *Diploria* head approximately 1 foot in diameter, in water 10 to 15 feet deep on reef slope south of lighthouse.

UNDERWATER PHOTOGRAPHS OF REEF ENVIRONMENTS ON ISLA DE LOBOS

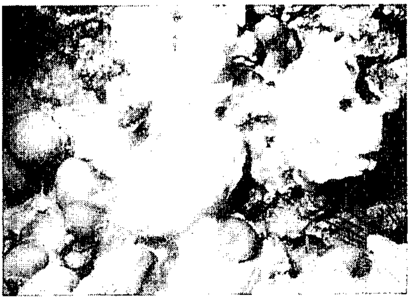


FIG. 1.—*Millepora* sp. and *Montastrea annularis* in the lower *D. strigosa* community at southeastern corner of the reef in approximately 40 feet of water. Individual *Montastrea* heads are 4 to 6 inches in diameter.

FIG. 2.—*Millepora* sp. and *Montastrea cavernosa* in the lower part of the *M. cavernosa* community southeast of the island in water approximately 60 feet deep, at the toe of the reef. Locality 38.

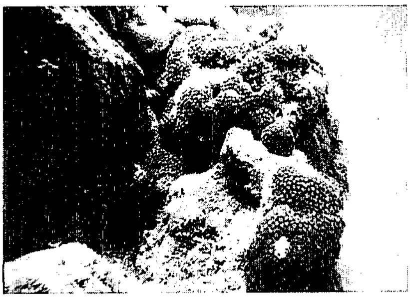


FIG. 3.—*Montastrea cavernosa,* both alive and dead, at the toe of the reef and the margin of the sand flat south of the lighthouse, east of the old ship channel, in water approximately 25 feet deep.

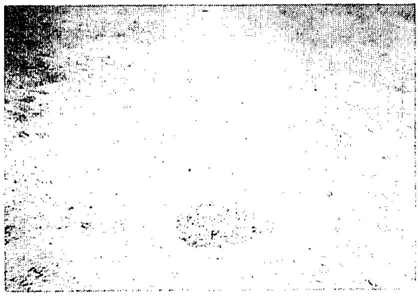


FIG. 4.—Burrowed sand of southern sand apron in old ship channel area, south of the island, in water approximately 20 feet deep. Coarse texture of the sand and reworked surface is typical.

FIG. 5.—*Montastrea cavernosa* sheet with arms of *Comatula*(?) at left and *Callyspongia vaginalis* upright in center. Southeast base of reef Locality 38, approximately 60 feet of water.

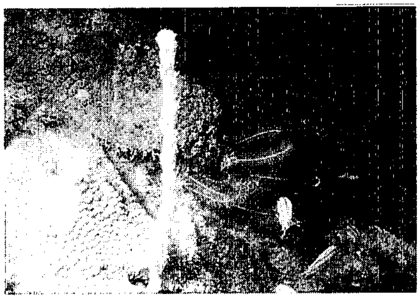


FIG. 6.—*Montastrea cavernosa* sheet with *Comatula*(?) and *Callyspongia* as in Fig. 5. Same locality as Fig. 5.

UNDERWATER PHOTOGRAPHS OF LOWER REEF AND SAND FLAT ENVIRONMENTS ON ISLA DE LOBOS face being etched and at the same time partially covered with algal crusts. Corals are more common here than in northern developments, perhaps amounting to 40 or 50 percent of the area, and various echinoids are well distributed and common. Most common corals are *Diploria clivosa, D. strigosa, Siderastrea siderea,* and rare massive *Porites branneri.* Locally *Millepora* occurs in somewhat sheltered areas. Many soft-body forms are present in the reef crest as well. Large anemones and brown sea-squirts are perhaps the most common and typical, and both occur on the most exposed and on only slightly protected surfaces. A few colonies of alcyonarians occur locally, but they are squat, low forms.

The leeward reef crest has an even less well-defined algal ridge from the west of the well site, southward to near the southwestern tip of the lagoon (Plate 3, figs. 2, 3). Instead of a pronounced ridge, the western side of the lagoon merely slopes gently seaward, and in this transition from the nearly flat surface of the lagoon to the steep seaward slope of the reef front, *Lithothamnium* is an important binder and encrusting organism. Locally it forms as much as 60 to 70 percent of the area, but elsewhere within the same zone it is far less extensive and most of the surface is covered with living corals. Perhaps the central part of this zone, west of the northern part of the island and northward for approximately 1500 feet, should not even be included in the *Lithothamnium* ridge, even though the organism is locally dominant, for the ridge-like structure is not developed at the reef crest.

At the northern tip of the island the *Lithothamnium* crest is as much as 300 to 400 feet across, and is a flat-topped, massive, moderately smooth structure. Echinoids are common to abundant throughout the northern algal flat, but corals are rare. Those present, usually *Diploria clivosa* or *Siderastrea siderea,* form small low heads or crusts, and never compose more than 10 or 15 percent of the area.

Acropora palmata Community

The upper part of both the windward and leeward reefs is formed of a community distinguished by development of *Acropora palmata,* superimposed upon a base of massive or hemispherical corals (Plate 6, fig. 1-4). It is most well developed in water of 15 feet or less, immediately in front of the algal ridge or crest (Plate 2).

Leeward development is traceable from south of the ship channel northward to the tip of the lagoon and reef. The inner limit of the community is distinguished by a few corals and considerable *Lithothamnium* crust, but in addition to this by broad, though low, colonies of *Acropora palmata.* Individual fronds or branches of the colony are aligned normal to the reef trend, and often have small conical tufts, somewhat reminiscent of the tips of *A. cervicornis,* at the tips of the branches (Plate 6, fig. 4). In shallow water, *Diploria clivosa* forms sheets around the bases of *Acropora* colonies and is associated in deeper water with low cauliflower-like or hemispherical masses of *Diploria strigosa* and *Montastrea annularis,* the latter two common in the slightly deeper water in grooves or down slope from the crest.

West of the well platform the shallower part of the *Acropora palmata* community is characterized by a dominance of *Diploria clivosa,* with minor development of *D. strigosa* and *Montastrea cavernosa* forming a pavement and undergrowth of heads, capped by heads of *Acropora palmata. Acropora* colonies are nearly circular gentle cones rather than distinctly aligned branches, and some of the *Acropora* is dead, particularly at the tips of the branches. In addition to these dominant corals, *Siderastrea siderea, Porites branneri,* and broad knobby heads of *Millepora* are present as accessory organisms, along with crusts of *Lithothamnium,* red and purplish echinoids, boring sponges, slate-pencil urchins, bright red and purple tunicates, brown anemones, and colonies of the algae *Halimeda, Caulerpa,* and *Penicillus.*

The outer deeper part of *Acropora* community development is distinguished by greater relief and with larger, higher heads of most of the corals. *Diploria clivosa* gives way to *Montastrea annularis* as the dominant coral at the base to the reef, but is still present with others as a minor form, accessory to the main reef mass. Colonies of *Acropora palmata* grow as moderately large, but high, tree-like forms whose upper crest gradually lowers as the community is traced seaward, until in water approximately 20 feet deep, most *Acropora* growth stops. The outer limit of the community was mapped at that transition.

Relief is much greater in the outer zone, for grooves separating the coral heads are deeper and are often choked with rolled logs of *Acropora,* fragments of *Montastrea* and other coral heads which litter the gullies like a log jam.

Acropora is a relatively minor, but distinctive, part of the outer part of the zone. It forms less than 20 percent of the area. Most of the reef, perhaps locally as much as 60 percent of the area, is composed of large heads of *Montastrea annularis,* with *Diploria strigosa* and *Siderastrea siderea* each forming as much as 10 percent of the area. *Porites, Meandrina, Mussa,* and *Agaricia* are all present within the community, but form a minor volume, as does *Montastrea cavernosa,* the species that forms much of the reef toe in both windward and leeward reefs. *Millepora* is present as a bladed form in the lower part of the zone, while the genus takes on a knobby massive form in the shallower part of the inner community development.

Observations on the windward *Acropora* community are more limited because of the constant surf over this part of the reef. However, the upper or inner part of the community was studied in three localities, and the lower or outer part in two areas. In most respects, the windward reef fauna is similar to that of the leeward reef within the *Acropora* community, with the exception that *Montastrea* plays a minor roll in windward reefs and its place is taken by massive heads of *Diploria strigosa,* 4 to 6 feet in diameter. The latter species composes 50 to 60 percent of the area in both inner and outer parts of the community development. Two forms of *Acropora palmata* are recognizable, as in lee reefs—one form with conical mounds and an almost *A. cervicornis* upper surface and distal margin to the branches, and the other form with a smooth upper surface and with blunt ends to the fronds (Plate 6, fig. 3). The former occurs high on the reef front and characterizes the inner zone, and the other in water slightly deeper, down to the outer limit of the community. Colonies up to 8 feet in diameter and equally as high occur in water approximately 25 feet deep. In both forms branches are strongly aligned normal to the reef front. Crusts of *Lithothamnium* are significantly deeper in windward community development, where they are common in water up to 30 feet deep.

Montastrea annularis Community

The *Montastrea annularis* community is developed in the leeward reef in depths of from approximately 20 feet down to approximately 50 to 55 feet. It grades lagoonward into the *Acropora palmata* community by appearance of that coral, and downward into the *Montastrea cavernosa* community where that form becomes the dominant coral in the fabric. It has been mapped from the old ship channel at the southern end of the island, around the southwestern tip of the lagoon, then northward to the tip of the reef and lagoon (Plate 1). Throughout its development it is characterized by dominance of *Montastrea annularis,* with other hemispherical or massive corals present but quantitatively less important.

In the southern development, *Montastrea annularis* composes as much as 40 to 50 percent of the area, with *Diploria strigosa, D. labyrinthiformis,* and *Montastrea cavernosa* less common. In water 20 to 30 feet deep, gigantic isolated coral heads up to 15 feet in diameter and up to 20 feet high form buttresses between somewhat irregular grooves. *Montastrea annularis* forms yellowish green, cauliflower-type colonies and *Diploria* spp. forms massive hemispherical heads that are characteristically tan or yellow gray-brown with color most intense in depressed parts of the skeletons. *Montastrea cavernosa* is present as sheet-like and massive hemispherical colonies which appear medium gray-brown from above.

West of the island, opposite the high spoil piles, *Montastrea annularis* forms massive colonies that compose up to 75 percent of the reef (Plate 7, figs. 3, 4). The remainder of the reef is mainly *Montastrea cavernosa* and *Diploria labyrinthiformis* (?), both of which form sheets in addition to the normal hemispherical heads. Sheets are most commonly developed along the sides of well-defined, deep grooves and broad channels. Here the whole zone is alive, with little algal encrustation. *Lithothamnium* is present, but in minor amounts and is not a distinctive binder like it is higher in the reef. One gets the impression that below approximately 30 feet, the fabric of the reef is much more open. This, of course, reaches its maximum development near the toe of the reef in the *Montastrea cavernosa* community where an open cavernous fabric is typical. This is probably related to reduction in binding done by *Lithothamnium,* so that lower zones are more porous.

Diploria strigosa Community

The *Diploria strigosa* community is developed along the windward margin of the reef, and is gradational below the *Acropora palmata* and above the *Montastrea cavernosa* communities. It is mappable from east of the old ship channel, south of the island, eastward and northward to the northern tip of the reef and lagoon (Plate 2). It is one of the broadest developed communities within the reef and is approximately the equivalent of the *Montastrea* community developed within the leeward reef.

Only the upper part of this zone has been studied because of the vigorous surf on the windward side of the lagoon, but the community is distinctive. It is separable from the shallower *Acropora* zone because that distinctive genus is wanting in all water deeper than approximately 25 feet, and separable from the lower *Montastrea cavernosa* community because that form is dominant only in depths greater than approximately 55 to 60 feet.

Massive hemispherical or sheet-like development of *Diploria strigosa, D. clivosa, D. labyrinthiformis*(?), *Siderastrea siderea*(?) and *Montastrea annularis* is typical of the zone. *D. strigosa* comprises as much as 50 percent of the area, with *D. clivosa* and *M. annularis* each covering perhaps as much as 15 percent. *Siderastrea* sp. and *M. cavernosa* are relatively rare within the zone, as are heads of *Millepora.*

Deep, narrow channels are developed throughout the zone and most are floored with coarse coral debris. The channels apparently broaden and become sand floored in the lower part of the zone in approximately 40 feet of water.

Montastrea cavernosa Community

The *Montastrea cavernosa* community is well developed at the toe of both windward and leeward reefs of Isla de Lobos. It is the lowermost community studied, although there may be deeper coral development in the rocky area northeast of the Isla de Lobos reef. The community is developed in water from approximately 55 or 60 feet down to the base of the reef at depths of 75 to 80 feet deep at the margin of the surrounding sand apron.

This community was studied in three separate localities (Text-fig. 2)—one locality along the margin of one of the large flat-bottomed grooves typical of the leeward reef west of the well platform, and at two localities east of the old ship channel and southeast of the island, at the southeastern tip of the windward reef.

Windward development of the community was studied in 65 and 75 feet of water at the toe of the reef at the margin of the flanking sand apron. In both areas where dives were made, most of the living corals are *Montastrea cavernosa,* which forms broad, brownish gray sheets and low, hemispherical heads which cover approximately 50 percent of the area (Plate 8, figs. 2, 3, 5 and 6). In many areas it appears as a thin sheet which spreads, frosting-like, over older rocks and dead heads. *Diploria labyrinthiformis* accounts for approximately 10 percent of the area. Other corals are minor and cover, as a total, less than 5 percent of the area. Included are a siderastrid form, *Agaricia fragilis, Mussa angulosa,* and *Madracis* sp. The latter forms knobby masses on the shadowy underside of heads and sheets, but the other species form isolated heads or colonies.

Heads of corals rise from a few inches to as much as 8 feet directly from the sand apron. The entire reef toe is exceedingly cavernous and appears like hollow, hemispherical heads balanced on isolated tips. It gives the impression of being at least half voids between and under heads. In many areas there are openings large enough to crawl or look into for 30 or 40 feet under arched heads and crusts, now gently suspended on arched fingers. One can easily see how great heads could be readily torn loose from the cavernous structure and tossed high on the reef. This is the part of the reef which could be sufficiently porous, even after being filled with calcareous sand, to be a significant reservoir for petroleum, particularly when sealed with the nearly impervious upper part of the reef which various authors have described.

The alcyonarians *Eunicea* (*Euniceopsis*) *clavigera* and *E.* (*Euniceopsis*) *calyculata coronata* are relatively common attached to dead areas on the reef or to only slightly buried dead blocks out a short distance into the surrounding sand flats. They are probably at their greatest development within this zone of the reef.

Bright orange crinoids, *Comatula*(?) sp., are distinctive organisms present only within this community (Plate 7, fig. 6). They are common in most crevices or under most shadowy edges, extending only the grasping, bright orange, feathery pinnate arms for food, some reaching 8 inches above the rocks. In some areas there are 6 to 8 individuals per square meter, and more would probably have been present had more suitable, dark, protective crevices developed. In most areas, however, 2 or 3 per square meter is typical.

Two species of *Caulerpa,* a broad-bladed lobate form and a small green-graped species, and some brown flat-leaved algae are common in the lower part of the zone, particularly where sand has blanketed rocks a fraction of an inch thick. *Caulerpa* is most common in the slightly sandy areas.

Leeward observations were made at the toe of the reef in water 75 feet deep, west of the well platform, directly out from the large marooned tree stuck on the reef crest. The reef here rises almost vertically for the first few feet, and then assumes the normal gently rising pattern toward the lagoon.

The most dominant coral in this lower reef community is *Montastrea cavernosa.* It is the only living coral in the lower 5 or 10 feet of the reef where we saw it, and is the dominant form in the lower 20 to 25 feet of the reef as a whole. It forms sheets and hemispherical heads, as in the windward reef. In addition to *Montastrea, Madracis* is common and forms lumpy areas several feet across, appearing like massive *Porites* thickets. *Mussa angulosa, Agaricia fragilis, Porites branneri*(?), and *Siderastrea*(?) sp. are all important, though not dominant, corals a few feet above the sand-reef interface. The latter species all increase upwards, so that at the base of the shallower *Montastrea annularis* zone, they are even more common, although still not dominant in the reef fabric.

Crinoids are relatively rare, and alcyonarians were not seen in leeward reef development. *Oculina* was collected only from here, and some cheilostomous bryozoans are also common with *Madracis* in shadowy areas. *Oculina* is growing in shadows, expanding the colony downward.

Sponges are essentially the same as in windward development, but are less robust and more widely spaced.

The general fabric of the reef is nearly as porous or cavernous as in windward development, but here deeper openings are mainly filled with fine calcareous debris. Coral heads are not as large, although individual heads seem to be doing well. More dead-looking, algal-crusted, coral material is present here than windward, and many of the gullies that feed into the large flat-bottomed grooves are filled with sand and gravel. Fine sand and silt are burying the base of the reef toe, obviously lapping around the coral heads and up onto the reef, like small alluvial fans. The latter areas slope relatively steeply away from the reef to meet the flat bottom of the gully or groove a few feet away. Most of the calcareous sediment has apparently been passed down through the reef structure rather than over it. The upper parts of the coral heads are relatively clear of debris while the lower areas are obviously flanked by sediment only recently in transport, so lightly consolidated that minor turbidity currents are generated by slight digging into the unstable slope.

Both windward and leeward reefs in the vicinity of Isla de Lobos are apparently composed of a lower open and cavernous structure, which may or may not be filled with calcareous sediments washed into the structure from above, and an upper more firmly cemented zone. It is within the upper zone that most workers have studied in the past, and hence the concept has developed that all reefs are solidly knit structures. In the Lobos reefs, however, only the upper half appears to be firmly cemented with binding organisms such as algae. In the lower half of the structure most binding is done by lateral growth of coral heads, and this only sufficient for support during normal growth. During periods of intense, deep storms large heads are obviously ripped loose and tossed about.

North Channel Community

A moderately deep channel was developed in the otherwise shallow lagoon north of the island prior to construction of the ship channel and causeway. It is shown as a distinct facies or community on the map (Plate 2) because it is a reef-front assemblage, isolated within the shallow grass-covered lagoon.

The channel extends approximately 175 feet east of the causeway and is perhaps twice that wide parallel to the spoil heap. On the three sides away from the causeway the channel shallows and is floored with dead coral heads and *Lithothamnium*-coated pavement to the margin where shallow *Thalassia* banks limit the coral growth. Since construction of the causeway and diversion of lagoon waters northward around the well platform, the channel has been filling with soft, fine-grained sediment and the earlier established coral community is now being reduced.

The channel is presently cut into two segments by the spoil heap and ship channel—one west of the high protective mound opposite the docks, and the other east of the causeway and north of the island. In both, large flat-topped heads of corals have developed up to low-tide level, and are now growing horizontally. *Montastrea, Diploria, Meandrina, Porites,* and *Siderastrea* are present in both segments and form heads up to 6 feet high and as much as 8 or 10 feet in diameter. The upper surface of most heads is now crusted with *Lithothamnium* or blanketed with fine sediment in which *Halimeda* is growing. Vertical or overhanging sides of the heads are still alive, and isolated masses seem to be doing well in spite of the highly turbid, quiet water. Some hemispherical heads and remnants of older algal-crusted heads are developed in the eastern segment.

Montastrea annularis is the dominant form in the deeper water, and forms the most conspicuous heads and flat-topped tables. *Diploria clivosa, Meandrina meandrina,* and *Porites wanneri* are all present in varying proportions and are more common than *Montastrea* along the northern part of the eastern segment.

Most *Porites* heads are on the rocky floor of the channel, but some have peculiarly perched on top of the flattened heads, as though they have been able to survive in an area where other corals have been killed. They are noticeably out of place.

Red and black urchins occur in the crests and along the flanks of the coral heads. *Diadema* occurs more rarely. In addition to urchins, many large clumps of the sponge *Haliclona longleyi* are growing on the corals. Heaps of shell debris occur below some coral heads at entrances to openings now occupied by octopi.

The floor of the depression is blanketed by a thick mat of *Thalassia* with clumps of *Halimeda* spaced here and there in the grass. Both grass and the rocky base are now veneered with fine silty sediments, much of which is highly organic immediately beneath the oxygenated surface. There is considerable dead *Thalassia* blanketing the sides of the spoil heap and in the deeper areas of the channel. Construction of the causeway has obviously interrupted the normal sedimentary and faunal pattern of the area.

Dead and Channeled Area of Reef

The area west of the island, but south of the newly dredged ship channel, in the vicinity of the boulder ramparts south and southwest of the island, shows marked reduction in reef development, at least in the upper part of the area where coral growth might be expected.

Coral growth is restricted south of the boulder ramparts, particularly west of the deep break in the reef marking the old ship channel. *Lithothamnium,* a pink and light purple encrusting form, has blanketed all the upper part of the reef mass, and has welded the top of the reef into a solid structure which is now being bored by various organisms. Worms are common and various species of echinoids, particularly brownish red and reddish purple *Echinometra lacunter* are common. In some areas they occur 20 to 25 per square meter in both exposed and sheltered slopes of the algal pavement.

Millepora is present, but in limited development. It forms tan, low and encrusting masses, with finger-like vertical tips as much as an inch long, often light gray-brown at the terminus. It is functioning as a binder, somewhat like the algal pavement, but occupies less than 5 or 10 percent of the area.

Acropora palmata occurs as isolated, often stunted heads in the *Lithothamnium* area, locally growing in up to 8 or 10 feet of water. These are isolated heads 5 or 6 feet high and of approximately the same diameter, and are spaced tens of feet apart in front of the boulder ridge. Irregular growth of this species characterizes a part of the reef which seems to have suffered by restriction of circulation related to the boulder ridge. The massive hemispherical heads of *Diploria strigosa, D. clivosa, Montastrea annularis,* and *Montastrea cavernosa* which form the lower parts of the reef are affected only in their upper growth. They are here dead and crusted by pink massive algae, even though elsewhere, away from the boulder area, they grow to near the low-tide level in some profusion.

West of the large boulder area, at the southwestern tip of the reef, the upper part of the reef is similarly mainly a dead coral region, now being crusted with calcareous algae. Remnants of the *Diploria clivosa* pavement are evident among the boulders, for *D. clivosa* and *Montastrea annularis* form small heads, generally on the western sides of bouldery masses, for a few feet away from the base of the boulder ridge. To the north, however, even these more hardy species are dead and algal crusted, or are now mainly buried by sand. The echinoids, *Echinometra lacunter,* both red and black forms, and *Diadema* are common in the cavernous upper surface of this region north of the western part of the boulder beach.

Northwest of the boulder area, from a depth of approximately 3 feet outward to at least 15 feet, the upper surface of the largely dead reef is only a veneer of *Lithothamnium* now being bored by echinoids. Boring sponges, mainly a brick-red, coarse-textured *Cliona,* are common in overhanging areas along the upper dead part of the reef. Red, purple, and brown tunicates are also common in protected places.

Most of the corals which are present develop relatively small heads, usually less than 1 foot in diameter. Most prominent species, in water less than 10 feet deep, are: *Diploria clivosa,* which forms flat knobby heads up to 1.5 feet in diameter, *Meandrina* sp., *Porites porites, Siderastrea siderea, D. strigosa,* and *Acropora palmata.* Combined area covered by corals is less than 5 percent of the surface. All hemispherical forms appear to be a repopulation, for they are growing discordantly over algal crusts which in turn have developed on top of the main dead coral mass. Some *Acropora palmata* colonies seem to represent repopulation as well, for the species forms very small, low palmate colonies.

The near "desert" conditions of the reef flat and immediate seaward part of the reef was possibly produced by restriction of circulation by the boulder rampart to the southeast, for it cut off most wave action generated by prevailing winds. The reef crest is now bathed mainly by sediment-laden lagoonal water that streams past the south end of the island between the spit and the boulder ridge. It is probably nutrient poor and has reduced oxygen content as well. Killing of the upper part of the reef is probably not related to dredging to the north, for repopulation seems older than that activity, judging from the limited effect on corals closer to the ship channel.

Toward the north, beyond the area shadowed by the boulder ridge, corals are less seriously affected, so that from 500 to 600 feet north of the western end of the boulder ridge, more normal, leeward reef coral development can be seen. In this region *Diploria clivosa* covers as much as 70 to 80 percent of the surface near the reef crest, with only minor areas of *Lithothamnium* crusts. Coral heads are large and rise as much as 2 or 3 feet above pockets of sand where *Porites porites, Siderastrea siderea, Halimeda,* and *Penicillus* seem to be doing well.

Most serious retardation of the reef in this northern area is seen on the seaward slope, in water 10 to 15 feet deep, where as much as 90 percent of the area is now crusted by *Lithothamnium.* Corals are only minor in the present community fabric, even though the dead rocky base consists of large heads of *Diploria* and *Montastrea.* In this area *Acropora palmata, Diplora clivosa,* and *D. strigosa* are the only surviving corals. Leeward tips of *Acropora* fronds are dead, but windward tips are still alive in many colonies, particularly where the colonies are aligned in a northwest-southeast direction, normal to the reef edge.

Buttresses and grooves are well developed in the reef mass, even in the dead area. *Diploria clivosa* forms the base and sides of buttresses now occasionally capped with clumps of *Acropora. Montastrea* and *Porites* are present, but as accessory to the major fabric. The channels are deep, straight-walled grooves. Many have abrupt beginnings and terminations 10 to 15 feet high, but others taper near the reef crest much like subaerial streams.

Immediately southeast of the boulder ridge, west of the old ship channel, deep grooves and channels are developed in front of the ridge crest. Many are 3 to 5 feet wide and up to 20 feet deep. They deepen seaward between vertical walls of living *Diploria strigosa* and dead *Diploria* and *Montastrea,* now *Lithothamnium* coated. Troughs of these channels are commonly sand-covered, often rippled, for this is an area of active sediment transport.

Gullies west and northwest of the western edge of the boulder bed are oriented roughly normal to the reef edge, but with an irregular, almost anastomosing pattern on all but the highest part of the *Lithothamnium* ridge. These depressions may be linear, irregularly circular, or irregularly arborescent around some of the now planed coral heads. The gullies are commonly floored with smooth algal crusts, but in addition, often have coarse blocks or cobbles of corals in depressions. There is little sand in the area and practically none in the gully troughs. As individual troughs are traced westward from the reef margin into deeper water the gullies form a more regularly oriented and spaced system. It is about at this depth that the coral growth becomes more normal as well.

SURROUNDING DEEP-WATER HABITATS AND COMMUNITIES

The reefs of Isla de Lobos, Medio, and Blanquilla rise from a sand-veneered platform along the eastern coast, and within this relatively deep-water environment, many habitats and communities could probably be differentiated. Our sampling is not sufficiently dense to allow more than broad generalizations, such as those presented in the section on topography. Additional work is planned on this aspect of the reef complex in coming years.

GEOLOGIC HISTORY

LATE LAGOONAL HISTORY

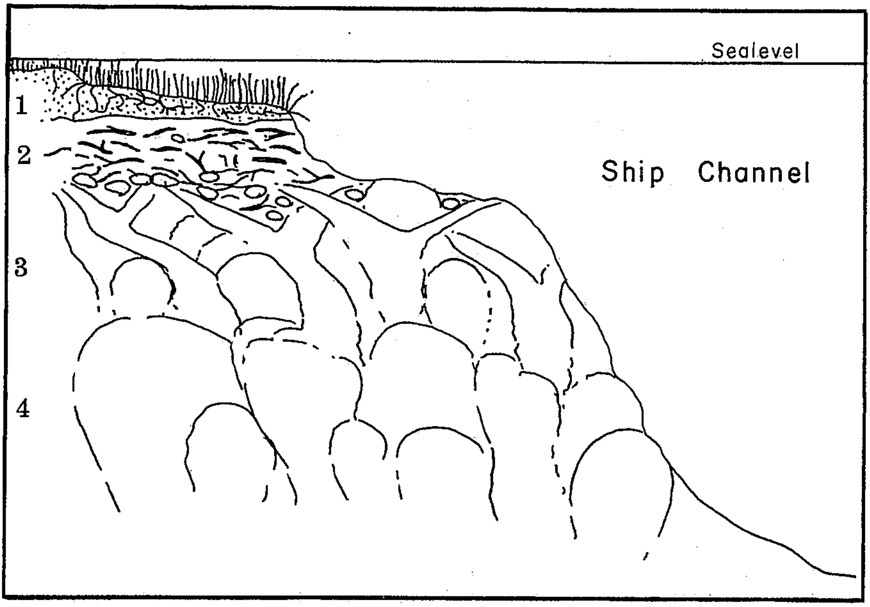
The spoil piles and margin of the dredged ship channel give an unusual opportunity to study the upper part of the reef flat across most of the lagoon. Much of the spoil appears to have been moved little after the initial dredging, hence any zonation in the spoil might be similar to that within the bedrock of the island and give some clues to the development of the lagoon flats.

Large fragments of *Diploria* and *Montastrea,* two corals common in the leeward reef, dominate the dredged fauna in the vicinity of the flare, at the southwestern end of the spoil pile near the entrance to the ship channel. *Montastrea annularis, Diploria clivosa,* and *D. strigosa,* with minor amounts of *Porites wanneri*(?), form the coarse material exposed on the washed channelward face of the spoil pile from near the flare to within 300 feet of the Pemex docks, approximately 550 feet to the northeast.

Acropora palmata logs are first apparent in the spoil approximately 300 feet southwest of the dock facilities and become more common in the spoil toward the docks. *Acropora* is a major element of the dredgings throughout the remainder of the spoil pile, until near the well platform where coarse debris is not evident and much of the pile may have been transported.

Throughout much of the spoil pile, northeast of the island and dock area, there is a lower zone approximately 2 feet thick in which *Diploria clivosa* and *Montastrea annularis* are the dominant coral species present, but above this lower zone, *Acropora palmata* fragments dominate. This is particularly well shown near the bend in the spoil heap, 1200 feet north of the island, on the channel side of the roadway. This relationship suggests that *Diploria* and *Montastrea* occur above *Acropora* in bedrock of the island.

The largest dredged fragments visible north of the docks are of *Acropora palmata* and range up to 4 or 5 feet in diameter, and up to 7 feet long. Most fragments of this and other species are smaller, usually only half this size. All fragments of *Acropora* are coated with *Lithothamnium* crusts, so that in some specimens an algal crust as much as 3 inches thick had developed. In addition to being enlarged by calcareous algal crusts, some *Acropora* masses are overgrown with *Agaricia fragilis* fronds, then covered with algae. There is nothing



TEXT-FIGURE 9.—Diagramatic cross section of the margin of the ship channel showing possible zonation. 1. *Halimeda* sand in which *Thalassia* acts as a sediment trap; 2. *Porites porites* gravels associated with algal oncolites; 3. *Acropora palmata* and associated hemispherical corals; 4. *Montastrea* and *Diploria*. Vertical zonation is based upon an inferred relationship interpreted from sequences in spoil from the ship channel and observations of the upper part in the cut edge of the channel. Not to scale.

evident within the spoil heap suggestive of a community older than an *Acropora* one in the gross pattern of reef development.

Fine sediment and rubble, mainly *Porites* fragments and mollusk shells mixed with drilling mud, have been cleaned from the dredged channel and heaped in a pile approximately 6 feet high on top of a graded surface southwest of the docks. This accumulation is unquestionably not related to original dredging but represents fine pebble and cobble-sized material swept into the channel later. The association is typical of *Thalassia* grass flats developed at present to the northwest, suggesting that the debris was washed in during severe winter storms that sweep in from the northwest, driving waves in over the lagoonal flats into the ship channel from the normally leeward side of the lagoon.

It is unfortunate that walls of the ship channel are now thickly veneered with sediment derived from the lagoon, mixed with drilling mud. One can then only infer a stratigraphic relationship based upon an inverted sequence in the spoil and upon limited observations of the upper part of the breached grass flats at the margin of the channel.

Using this type of evidence, one can observe that the present-day *Thalassia* flats are developed upon a surface of *Porites* fragments in walls of the channel near the well site. In several cuts, north and west of the platform, a gravel layer up to one-foot thick of *Porites* fragments is developed below the *Thalassia* cover and obviously antedates the grass in an ecologic succession (Text-fig. 9).

One can infer from the spoil heaps that the *Porites* gravels are built upon a sequence of *Diploria clivosa* and *Montastrea annularis* (Text-fig. 9), which in turn is built upon a sequence in which *Acropora palmata* is the dominant species. Thickness of these latter sequences cannot be determined with the information at hand. Judging from abundance at any point, however, the *Diploria* association seems to be thickest toward the leeward edge of the lagoon, and probably thins to only a few feet in the interior of the lagoon.

BLANQUILLA REEF

Blanquilla Reef is the northwesternmost of the three associated reefs southwest of Cabo Rojo and Tamiahua Lagoon (Text-fig. 1), and is the intermediate one in size. It is an elliptical reef, approximately 3000 feet long in a northwest-southwest direction, and approximately half that wide. It is a flat-topped reef, with a shallow lagoon completely rimmed by active growing reef communities. Unlike Isla de Lobos reef, there is no island above high tide, but two small areas of coarse, rounded gravels are developed in the lagoon. One is a compound spit-like accumulation in the south central part of the lagoon, in approximately the position of Isla de Lobos within the reef flat there, and the other in a more central position and much lower. The central gravel bank is not exposed at low tide, but the larger south-central one is approximately 2 feet higher and is exposed during extreme low water.

LEEWARD REEF

Reef development is similar to that at Isla de Lobos. The leeward reef has an outer *Montastrea*-dominated community that extends down to at least 20 feet, the lower limit of our observation. A community dominated by *Acropora palmata* is developed in front of the reef crest in shallower water, where large smooth margined, circular colonies, up to 6 feet tall, grow to near the low-tide limit. At the outer margin of the *Acropora* community, the surface is approximately 80 percent live coral, either *Acropora palmata* or *Montastrea* with minor areas of *Diploria clivosa*. Such development continues to near the *Lithothamnium* crest where most coral growth stops abruptly and all but approximately 20 percent of the area is crusted with algae. As one approaches the algal-crusted area from the lee side, *Acropora palmata* colonies are much shorter and commonly dead, particularly at the tips of fronds. A few small colonies of *Acropora cervicornis* are present in the upper shallows in front of the algal ridge, but are not present on the ridge or in deeper water. Hemispherical corals, like *Diploria strigosa*, become low, plate-like crusts and many have dead interiors so that they form small micro-atolls, and finally disappear from the community. *Diploria clivosa* forms irregular sheets interspersed with major areas of algal crusts in water from one foot to only a few inches deep at low tide. As the ridge is approached, corals become rare and the entire surface is covered with pink crusts of *Lithothamnium*.

There are some weak, irregular, radial grooves on the seaward crest at the base of the algal ridge, but most grooves are larger and more definitely defined in slightly deeper water. Straight-walled, narrow, cavernous openings up to 30 feet deep occur as seaward extensions of the grooves in the ridge and the meandering, ditch-like grooves in the *Acropora palmata* zone. In some instances the grooves have been bridged with corals to produce an intricate, very narrow depression, inches across but feet deep, or an open, cavernous reef mass. Where the grooves are wide they are floored with coarse coral debris. Sand is rare, even in the interior of the lagoon, and must be swept off the reef into deeper water or hidden within the open porous reef at depth.

The *Lithothamnium* ridge is a strong, well-defined feature along the west side, up to 200 yards across, broken only at the southwestern part where it becomes irregular and weak, somewhat like the leeward ridge on Lobos. Here coral heads lap far onto the flat-topped reef, and shallow grooves cut into the margin of the lagoon. Isolated heads of *Diploria clivosa* occur in low spots, along with many reddish brown and purple echinoids, and are the main organisms of the flat other than the algal crust. Even in areas of maximum coral development, however, they cover less than 15 percent of the area. Many isolated, tossed, dark gray-brown heads of corals have accumulated on the crest of the reef, particularly at the northern and western margin of the flats. Most are lodged on the bordering algal ridge.

LAGOON

Algal crusts grade lagoonward from the massive, sheet-like surface of the reef crest into rounded knobby pebbles immediately behind the reef. This pebbly development covers two-thirds of the flat lagoon bottom around the outer margin. Pebbles are formed of algal crusts over *Porites porites* fragments, snail and pelecypod shells, and some are compound oncolites of algal masses.

Pebbly algal oncolites grade into intermixed, arborescent, algal structures and pebbly masses in the inner third of the lagoon. Locally arborescent masses cover as much as 20 percent of the area, and are intermixed with oncolites, a few coral heads, and patches or thickets of a weed-like tan algae. The association is developed within the lagoon interior, particularly away from the pebble bars, where the water is up to three feet deep even at very low tides.

Isolated heads of corals are developed within this pebbly facies, but never cover more than 10 or 15 percent of the immediate area. *Siderastrea radians* and *Porites porites* dominate as heads only a few inches high or in diameter. They form fragments around which many of the algal pebbles grow, and are most abundant 300 to 400 feet in from the leeward edge, where the water deepens to as much as 3 feet at low tide. Corals are also moderately common east of the medial gravel bar, where heads up to two feet were noted. Most heads in the eastern part of the lagoon are *Diploria clivosa*, but a few heads of *D. strigosa*, *Meandrina*, and a massive *Porites* also occur.

Diadema and other echinoids are common across the lagoon flat, associated with nearly every head or irregular *Lithothamnium* crusted root of a head. A few, large, white echinoids, noted only in the *Thalassia* flats on Lobos, also occur in some of the quieter water. The light-gray forms are rare, however, particularly when compared with the black, long spined *Diadema*, or the reddish brown and purple-black *Echinometra lacunter*, forms which occur not only within the lagoon, but throughout the algal ridge and seaward slopes of the reef as well.

Pebbles are the sediment of the lagoon. The lagoon is swept free of fine sediments, except in the immediate lee of some of the broader coral heads and of some of the gravel accumulations, where bioclastic sand is accumulating. In several of these protected areas, sandy patches are forming up to 2 feet across and in some of these, a light tan, knobby holothurian is very common. In one area of maximum development 70 holothurians were counted per one meter square, but most sandy areas are more thinly populated. These echinoderms were grazing upon fragments of a tan weed-like algae, fragments of which form most of the sand in the area. Holothurians were not seen outside the small sandy patches.

Small gravel bars in the interior are composed of rolled algal pebbles, now rounded and with packing sufficiently loose that walking across the bars is difficult. They form with a moderately steep western or leeward margin and a more gentle eastern margin, presumably because of shaping by waves, driven across the windward reef flat by prevailing winds. These interior bars are estimated to be from 50 to 200 feet wide and as much as 400 to 500 feet long. They separate shallow water of the western part of the lagoon from slightly deeper water of the eastern flats.

WINDWARD REEF

The windward *Lithothamnium*-coated reef flat is as broad as the leeward one. It has a distinct inner margin two to three feet high, shaped like the lee of a dune, although it is now solidly bound by encrusting algae. The flat was constructed of tossed pebbles, welded together to form a wave-swept platform now buried by only a few inches of water. It is within a slightly deeper moat behind the algal flat that most of the observed sand is accumulating.

The windward reef was not observed in any detail because of rough surf, but it appeared, in hurried traverses, to be formed in the upper part mainly of *Diploria strigosa* and *Acropora palmata,* like the windward reef of Isla de Lobos. Lower zones were not observed.

Thalassia and its associated fauna are not present on the Blanquilla Reef, presumably because a suitable substrate is lacking. Development of a *Thalassia* cover seems the next step, however, if sufficient sand can accumulate.

At the time of our brief visit, Pemex had placed a dredge near the southern margin of the gravel bars in the interior of the lagoon, presumably in preparation for dredging a ship channel to serve a planned well site.

MEDIO REEF

Medio, or Middle, Reef is the central reef of the three closely associated with Isla de Lobos. It is also the smallest of the three. Medio Reef is approximately 2 miles northwest of Isla de Lobos reef, and 2 miles southeast of Blanquilla Reef. Like Blanquilla it lacks a cay, although now Petróleos Mexicanos has constructed a large concrete well platform on the structure. Little time was spent on Medios, and no time in the water investigating reef and lagoonal development. However, from limited observations one can recognize a well-defined *Lithothamnium* ridge and windward and leeward reef development around a shallow lagoon. The lagoon is now breached with a ship channel dug to serve the well platform. The channel extends nearly through the lagoon from the leeward side to within a few tens of feet of the reef crest on the windward side. The channel cuts the larger part of the reef structure on the east from the smaller pointed part of the reef on the west, the side where the well site is situated.

The reef at Medio has much more in common with that at Blanquilla than with the larger one on Isla de Lobos, for on both these smaller reefs strong waves surge completely across the lagoon. On neither is there a sandy lagoon capped by *Thalassia,* but on both, isolated coral heads grow attached to a rocky substrate in water a few feet deep. *Acropora* and *Montastrea* colonies are recognizable throughout the lagoon and in bordering reef tracts near low tide. Little else was differentiated from the very superficial look at the reef.

REFERENCES CITED

Klovan, J. E., 1964, Facies analysis of Redwater reef complex, Alberta; Bull. Canad. Petrol. Geol., v. 12, p. 1-100, pls. 1-9, 20 text-figs.

Kornicker, L. S., and Boyd, D. W., 1962, Shallow-water geology and environments of Alacran reef complex, Campeche Bank, Mexico; Bull. Amer. Assoc. Petrol. Geol., v. 46, p. 640-673, 34 text-figs.

Mobius, Karl, 1877, Die Auster und die Austervirtschaft; Berlin (Translation, 1880, The oyster and oyster culture; Rept. U.S. Fish. Commission, 1880, p. 683-751).

Murray, J. W., 1966, An oil producing reef-fringed carbonate bank in the Upper Devonian Swan Hills Member, Judy Creek, Alberta; Bull. Canad. Petrol. Geol., v. 14, p. 1-103, 23 pls., 12 text-figs.

Newell, N. D., Imbrie, John, Purdy, E. G., and Thurber, D. L., 1959, Organism communities and bottom facies, Great Bahama Bank; Bull. Amer. Mus. Nat. Hist., v. 117, art. 4, p. 177-228, pls. 58-69, text-figs. 1-17.

———, Rigby, J. K., Whiteman, A. J., and Bradley, J. S., 1951, Shoal-water geology and environments, eastern Andros Island, Bahamas; Bull. Amer. Mus. Nat. Hist., v. 97, art. 1, p. 1-29, pls. 1-8.

Thorson, Gunnar, 1957, Bottom communities; *in* Treatise on marine ecology and paleoecology; Volume 1, Ecology; Mem. Geol. Soc. Amer. 67, p. 461-534, 20 text-figs.

Wells, J. W., 1957, Coral reefs, *in* Treatise on marine ecology and paleoecology, Volume 1, Ecology; Mem. Geol. Soc. Amer. 67, p. 609-632, 9 pls., 2 text-figs.

Yonge, C. M., 1940, The biology of reef-building corals, *in* The Great Barrier expedition 1928-1929, Scientific Reports; London, British Mus. Nat. Hist., v. 1, no. 14, p. 353-391.

Manuscript received November 15, 1966