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PRELIMINARY SURVEY OF MODERN MARINE ENVIRONMENTS OF SAN ANDRES ISLAND, COLOMBIA

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CONTENTS

ILLUSTRATIONS

I. ABSTRACT

The modern reef complex of San Andres Island, Colombia, can be divided into five major depositional environments on the basis of sediment type and biota. These are: fore-reef, reef crest, back-reef platform, lagoon, and near-shore. Dominant organisms of the reef crest are *Millepora complanata* (hydrozoan), *Palythoa mammillosa* (zoantharian), and calcareous algae. Windward, or the reef-complex environments, are characterized by abundant zoantharian corals, and leeward environments are dominated by alcyonarians.

Modern subtidal sediments from the San Andres area average 70% aragonite and 30% high Mg calcite with a maximum of 20 mole % $MgCO_3$. High concentrations of $MgCO_3$ were found only in sediments from the

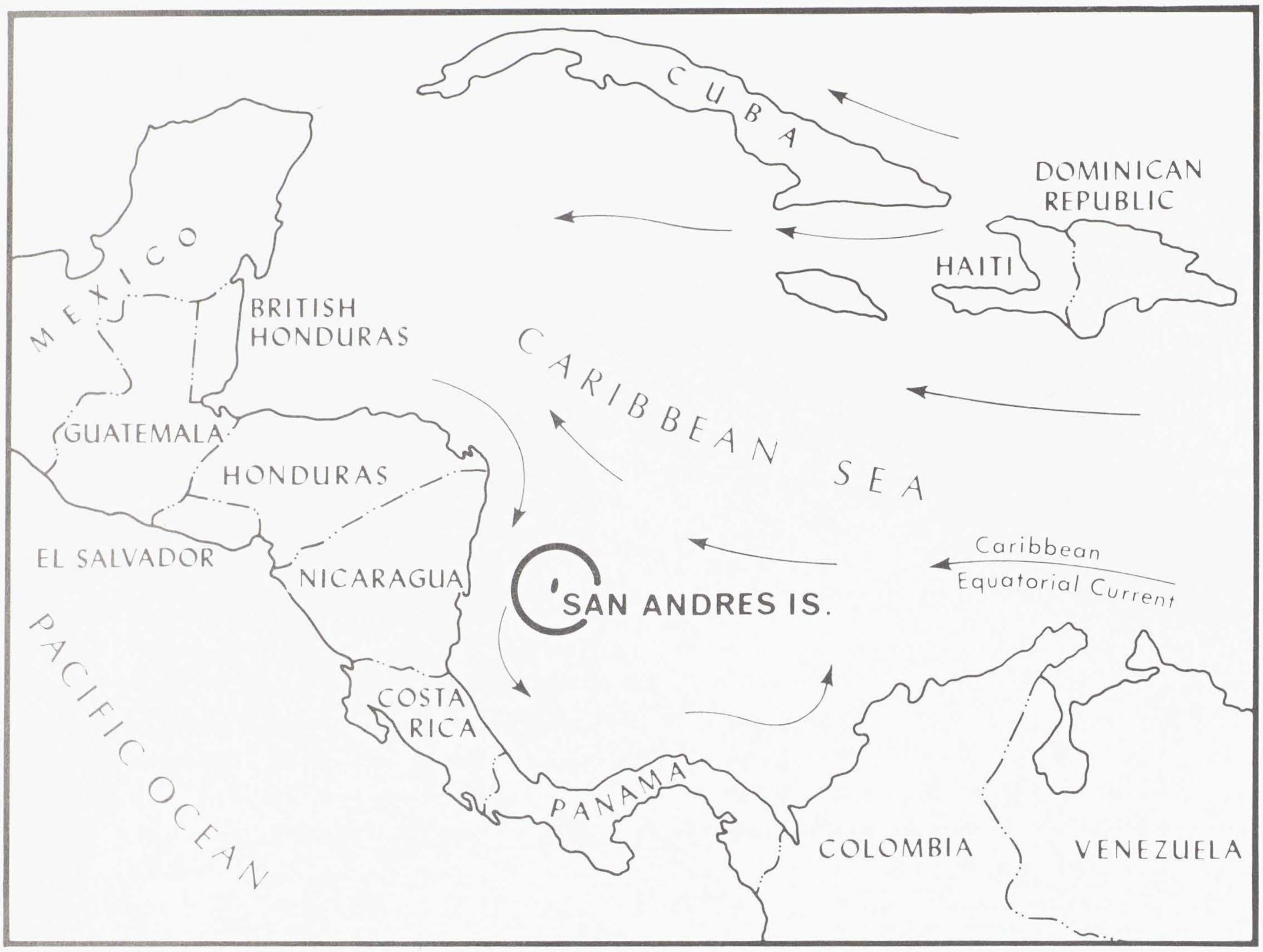

Fig. 1 – General index map of the Caribbean Sea.

reef crest and near-shore (turtle grass) environments and are attributed to coralline algae.

II. INTRODUCTION

San Andres, a Colombian possession, is a small island located approximately 200 km off the Caribbean coast of Nicaragua (Fig. 1). The island, along with several well-developed coralline banks, is situated at the eastern edge of the Nicaraguan Rise. Within a few kilometers of the island, water depths exceed 1800 m, thereby isolating the island from nearby land bodies.

San Andres is approximately 3 km wide and 13 km long and has a maximum elevation of 103 m. The island receives approximately 180 cm of rain annually and has a mean temperature of 27°C. Prevailing winds are from the east and northeast. A barrier reef exists along the east side of the island, whereas the leeward side has no evidence of barrier reef growth but does support a significant coral population.

The purpose of this investigation is to establish the characteristics useful in identifying depositional environments in the island area. These characteristics are based on sediment type and typical bottom biota.

III. LEEWARD ENVIRONMENTS

A distinct faunal zonation can be described from the leeward area (Fig. 2). For convenience, the following descriptive terminology has been applied: Shore zone (Zone 1), upper platform (Zone 2), cliff-and--cave (Zone 3) and lower platform (Zone 4).

Shore Zone

Zone 1 (Fig. 3), or the shore zone, in most places consists of a small cliff or ledge and the surf zone (Figs. 3-1, 3-2). Water depths range from 0 (spray zone) to 2 m. This environment is subjected to pounding

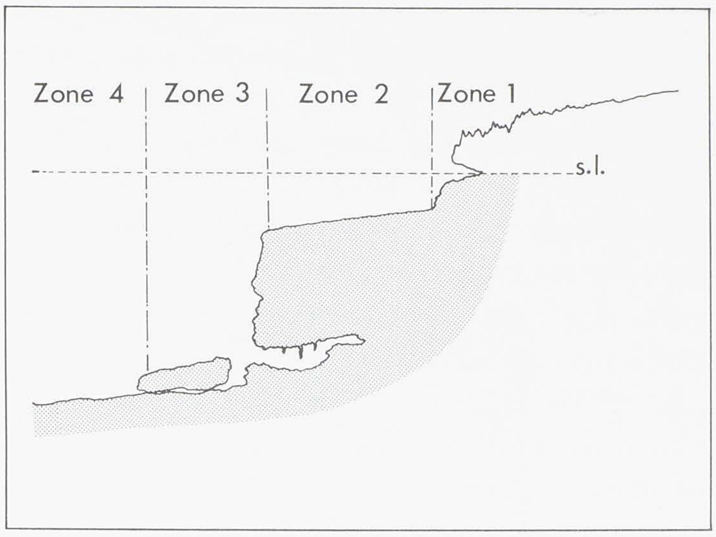

Fig. 2 – Diagrammatic zonation of the leeward side of San Andres Island.

surf or quiet water depending on the season. Zone 1 is dominated by crustose coralline algae (Fig. 3-8). These algae account for the accretion of considerable carbonate material along the shore line, where small ledges, as much as 1 m thick, have been accreted to the cliff face. In addition to algae, encrusting zoanthid anemones (Fig. 3-6) and pelecypods contribute to the accumulation and binding of carbonate material in this zone.

A distinct wave-cut notch, corresponding to present mean sea level can by observed along the leeward side of the island. In addition to wave action, destruction of the carbonate ledges occurs through the action of organisms such as polychaete worms, boring sponges, and the echinoid *Echinometra lucunter* (Fig. 3-4). Zone 1 is characterized also by other organisms including chitons (Fig. 3-7), gastropods, other echinoids (Figs. 3-3, 3-5), encrusting sponges, and small colonies of encrusting zoantharian corals.

Upper Platform

Zone 2, or upper platform (Fig. 4), is a narrow shelf ranging from 2 to 5 m in depth and from several meters to approximately one-half kilometer in width. The bottom slopes gently seaward and is characterized by a hard, limestone substrate with little or no sediment cover. The faunal assemblage in this zone is dominated by alcyonarians and large sponges. Extensive gardens of alcyonarians have developed on the firm substrate and nineteen species were identified from this environment. In addition to alcyonarians, large vase sponges are common and reach heights of almost 2 m with diameters of at least 75 cm. Upon death and decay many of the alcyonarians and sponges contribute calcareous and siliceous spicules to sediments of the surrounding area. Alcyonarian gardens provide protection for numerous mollusks *Cyphoma* and *Pteria* and echinoderms. Many large basket-starfish (*Astrophyton*) were collected from the branches of the sea whip *Pseudopterogorgia*. Zone 2 is also chacterized by small colonies of zoantharian corals.

Cliff-and-Cave Zone

Zone 3, or the cliff-and-cave zone, is characterized by a dominant zoantharian coral growth (Figs. 5 and 6). Most of the organisms are restricted to, or very near to, submarine cliffs. The cliffs form a stable substrate for coral growth, affort protection for colonies, and probably aid in the entrapment of nutrients. Tops of most major cliffs are nearly vertical with many cave openings and small ledges. Bases of cliffs are characterized by a distinct break in slope at a depth of approximately 20 m.

Colonies of zoantharian corals are common throughout Zone 3 and many are attached beneath ledges, in caves, and to the vertical faces of the cliffs. The greatest accumulation of coralline material appears to be at the base of the cliffs. Here large massive colonies (in excess of 1 m in diameter) of faviidaean corals are common.

The caves in Zone 3 support a community of rather rare organisms unique to the environment. There are unusual colonies of *Antipathes* ("Black Coral"), delicate bryozoa, *Stylaster* (colonial hydrozoan), and many types of sponges (Fig. 6). Most of the caves appear to be ancient karst features, which probably developed during Pleistocene low sea level stands. Many submarine caves were found to have fresh water mixing with sea water, indicating subterranean connections with the main island. Large fractures, the result of slumping, can also be traced through the area.

Lower Platform

Zone 4, the lower platform, is the deepest environment investigated. It is characterized by fine-grained, carbonate sediments containing 2 to 5%, by weight, non-carbonate material. Non-carbonate grains consist of hematite, magnetite, marcasite, zircon, volcanic glass, siliceous sponge spicules, and radiolarians. The faunal assemblage is dominated by burrowing organisms, such as worms and crustaceans, with scattered patches of alcyonarians. Zone 4 appears to be terminated seaward by a second set of submarine cliffs, which have been observed only on aerial photographs.

IV. WINDWARD ENVIRONMENTS

The windward (east and northeast) side of San Andres is characterized by the development of a reef complex with the following five distinct ecologic zones (Fig. 7): 1) Shore (the beach and near-shore area), 2) back-reef lagoon (with barren sand and patch reefs), 3) back-reef platform (with sand and coralline rubble), 4) reef crest, 5) fore-reef. This zonation agrees favorably with zones described by Geister (1973).

Shore Zone

The shore zone can be divided into two basic environments: 1) the beach/surf zone, and 2) the near-shore area. Sediments of the beach are medium to coarse-grained and composed almost entirely of carbonate shell fragments. Non-carbonate residue of beach material is usually less than 1%, by weight, and consists of siliceous sponge spicules and organic contamination. In several areas, such as Johnny Cay (Fig. 8-1) and parts of the beach south of the town of San Luis (Fig. 8-2), beach sands have been cemented to form beachrock (Fig. 8-3). These beachrock deposits are typically 1 m thick and 5 to 8 m wide, dip seaward at 3° to 5°, and consist predominantly of coarse-grained carbonate sand (95%). Coral fragments, foraminifers, echinoid, pelecypod, and gastropod fragments, and unidentifiable grains are the most common grain types (Fig. 8-4). In addition to sand particles, large fragments of the gastropod *Strombus gigas* are abundant. Cementation is accomplished by precipitation of aragonite around individual grains, as can be observed in thin sections from most beachrock samples (Figs. 8-4, 8-5). Similar beachrock formation has been described by Ginsburg (1953), Friedman (1968), and Gavish and Friedman (1969). Stratification in many of the samples (Fig. 8-3) is caused by differential cementation. The first few centimeters of the beachrock, although well cemented by aragonite, are very porous. Beachrock areas are characterized by numerous living organisms that do not inhabit areas of uncemented beach sands. Apparently the firm substrate yields more protection. The dominant organisms are gastropods (*Nerita* spp., *Cittarium pica,* and *Purpura patula*), the echinoid *Echinometra lucunter,* and polychaete worms.

Unconsolidated sediment samples, collected near beachrock deposits, show the same general textural parameters as rock counterparts. Sieve analyses of the sands

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Fig. 3 – Physiography and typical biota of shore zone (Zone 1).

1. Small submarine cliff at the present shore line. Note abundant echinoids of the genus *Diadema* (photo courtesy of Dr. Frank Barnwell).
2. Wave-cut notch at present sea level, on the leeward side of San Andres Island.
3. *Eucidaris tribuloides.*
4. *Echinometra lucunter.*
5. *Diadema antillarum.*
6. *Palythoa* sp.
7. *Ischnochiton* sp.
8. Algal encrustation on a broken bottle.

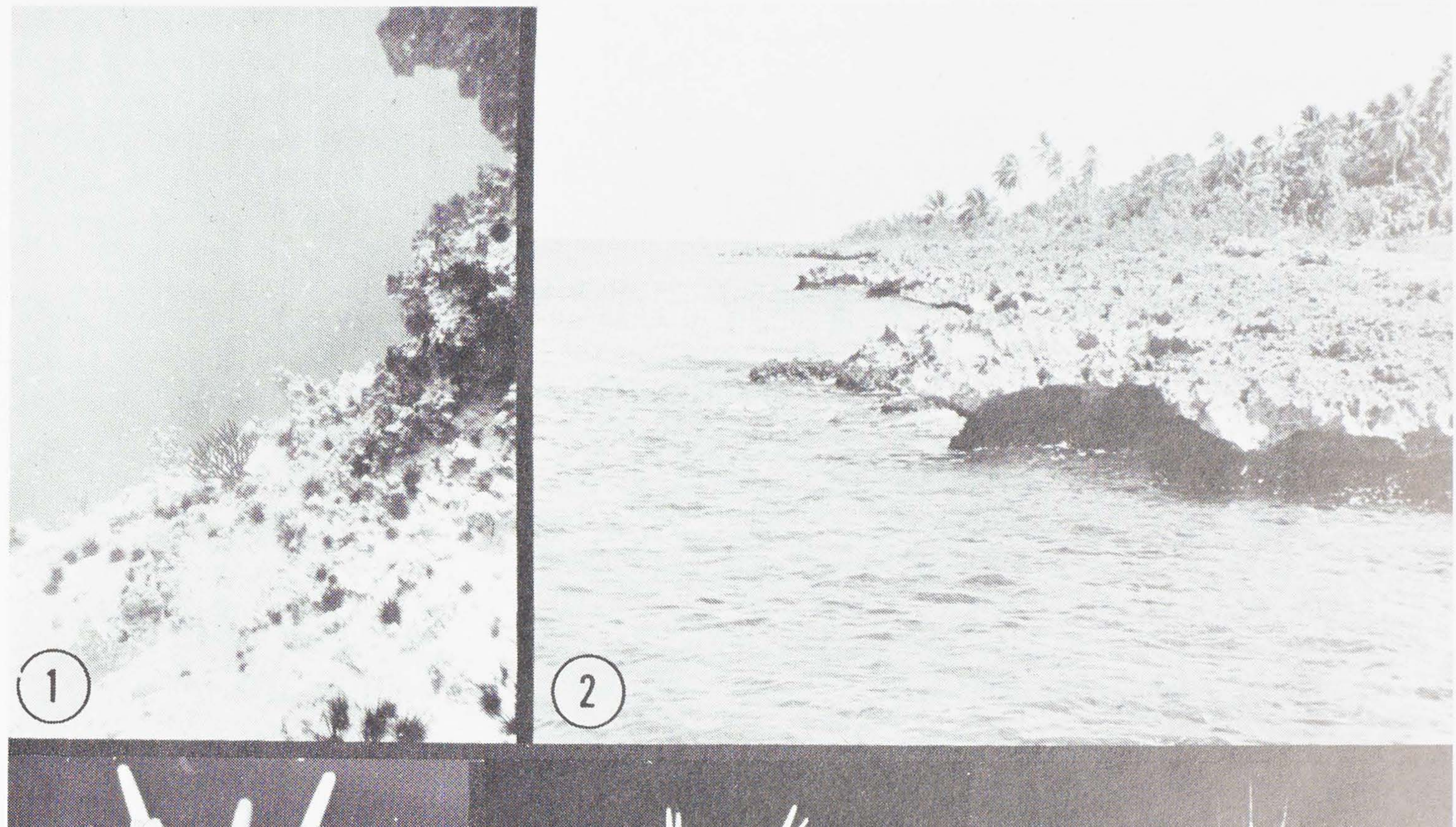


FIGURE 3

Fig. 4 – Typical bottom community of the upper platform (Zone 2).

indicate 90% of the sand material is coarse-grained (greater than 0.50 mm in diameter). Typically, the beach/surf zone is sparsely inhabited and can be characterized by fragments of large gastropod and pelecypod shells, coral debris, and limestone pebbles eroded from the island.

The second environment of the shore zone is the near-shore, or turtle grass area, which is immediately seaward of the surf zone. In this zone, water depth is less than 4 m. The bottom community and sediment in this area are diverse (Fig. 9-1). Most of the bottom material is covered by *Thalassia testudinum* (turtle grass) (Fig. 9-2) and coralline algae (Fig. 9-3), which act as effective sediment binders. In addition, the green algae *Halimeda, Udotea, Penicillus* and *Rhipocephalus* are also important sediment contributors and binders. This relationship has been reported by several investigators (Ginsburg, 1956; Scoffin, 1970; and Till, 1970). In addition to algae, the turtle grass area also has a large population of small zoantharian corals. Corals of particular importance as zone indicators are: *Diploria*

Fig. 5 – Typical biota of cliff-and-cave zone (Zone 3).

1 and 4. *Mussa angulosa.*

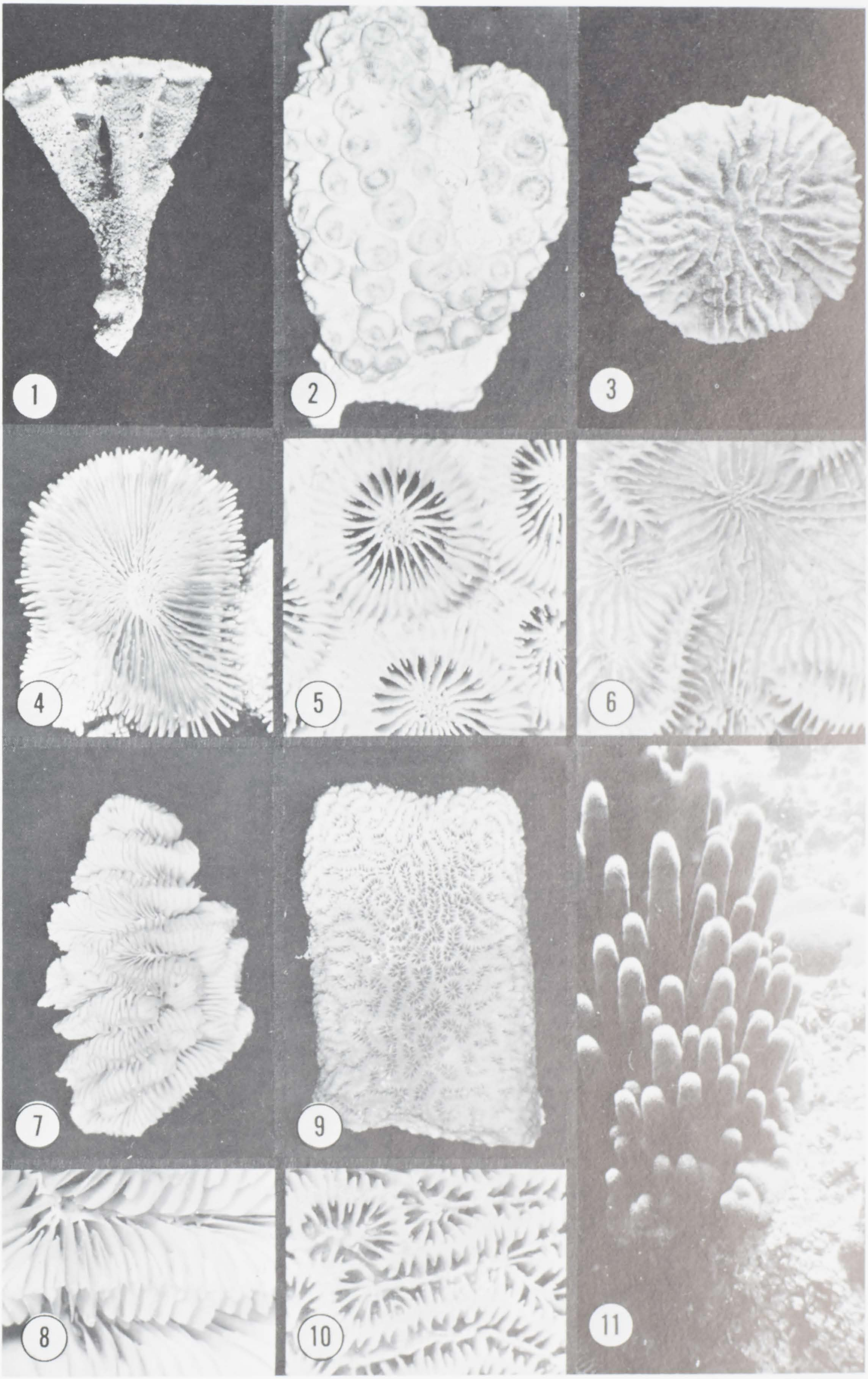
2 and 5. *Montastrea cavernosa.*

3 and 6. *Isophyllia sinuosa.*

7 and 8. *Meandrina meandrites.*

9 and 10. *Dendrogyra cylindrus.*

11. Large colony of *D. cylindrus* approximately 1 m in height (photo courtesy of Dr. Frank Barnwell).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clivosa, Manicina areolata (Fig. 9-6), *Porites porites* (Fig. 9-4), *Porites asteroides* (Fig. 9-7), and *Siderastrea radians.* Another zone indicator in the turtle grass area is the echinoid *Lytechinus varigatus* (Fig. 9-5), which is seldom found living outside the turtle grass area or at depths greater than 4 m below sea level.

In addition to grassy bottoms in the shore zone, there are areas that are covered with coralline rubble. The bottom material appears to be derived from dead reefs of probable Pleistocene age and is particularly evident along the northeastern shore line of the island.

Back-Reef Lagoon

The back-reef lagoon (Fig. 10-1) is a complex area made up of two principal environments, barren sand bottom and patch reef. The periphery of the lagoonal area is characterized by a distinct break in slope at a depth of approximately 5 m where the bottom becomes flat and featureless. The lagoonal area is almost completely enclosed by shallow platforms, where there is little sediment cover and eroded limestone with fossil corals is commonly exposed. Water depths at the lagoonal periphery correspond to depths at the tops of submarine cliffs on the leeward side of the island (approximately 5 m). Based on the apparent terracing, it is probable that the bathymetry of the lagoon was modified during a Pleistocene low sea level stand. The bottom of the lagoon is flat and the biota is characterized by small, scattered patches of *Halimeda,* foraminifers, the gastropod *Strombus gigas,* scaphopods, burrowing worms and crustaceans, the pelecypod *Pinna* sp., and irregular echinoids. Coral growth is seemingly absent.

Lagoonal sediment is poorly sorted, with an abundance of fine material. Almost 60% of the sand is less than 0.149 mm in diameter. Orbitoid foraminifers constitute up to 35% of lagoonal sand grains. Non-carbonate residues consist of radiolarian remains and sponge spicules. Based on X-ray analysis, the samples are approximately 70% aragonite and 30% high-magnesian calcite, with 16 mole % $MgCO_3$ in the calcite fraction.

Scattered throughout the lagoon are small patch reefs (Fig. 10-2), most of which are round to oval in plan view, dome-shaped, and 10 to 30 m in diameter. Water depth over the top of the patch reefs ranges from less than 1 m to nearly 10 m.

Typically, the patch reef community is dominated by one of the three following organisms: alcyonarians, *Montastrea annularis* (Fig. 10-6), or *Acropora palmata* (Fig. 10-5). *Montastrea annularis* appears to dominate the deeper patch reefs (deeper than 7 to 10 m) (Fig. 10-4), whereas *A. palmata* prefers shallower environments (Fig. 10-3). Alcyonarians are present in both settings, but apparently prefer intermediate depths of 3 to 7 m. Other organisms occurring in the patch reef environment include: encrusting algae, *Millepora* sp., numerous small zoantharian corals, gastropods, sponges, and crustaceans.

Back-Reef Platform

Back-reef platforms, surrounding the lagoonal area, represent Pleistocene terraces.

Fig. 6 – Typical biota of cliff-and-cave zone (Zone 3) (continued).

1 and 4. *Colpophyllia* sp.

2 and 5. *Diploria strigosa.*

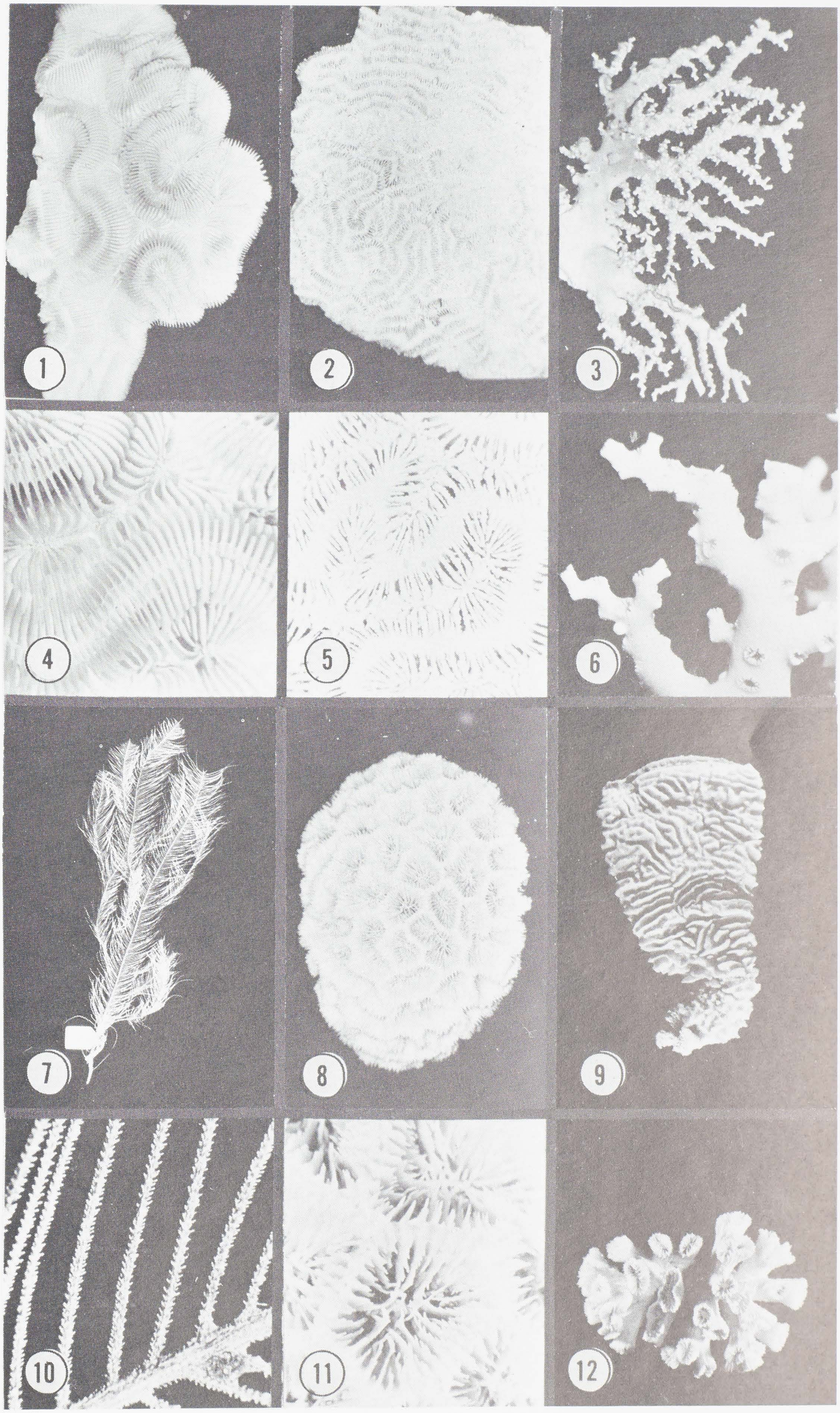
3 and 6. *Stylaster* sp. (cave fauna).

7 and 10. *Antipathes* sp. (cave fauna).

8 and 11. *Isophyllastrea rigida.*

9. Porifera (cave fauna).

12. *Eusmilia fastigiata.*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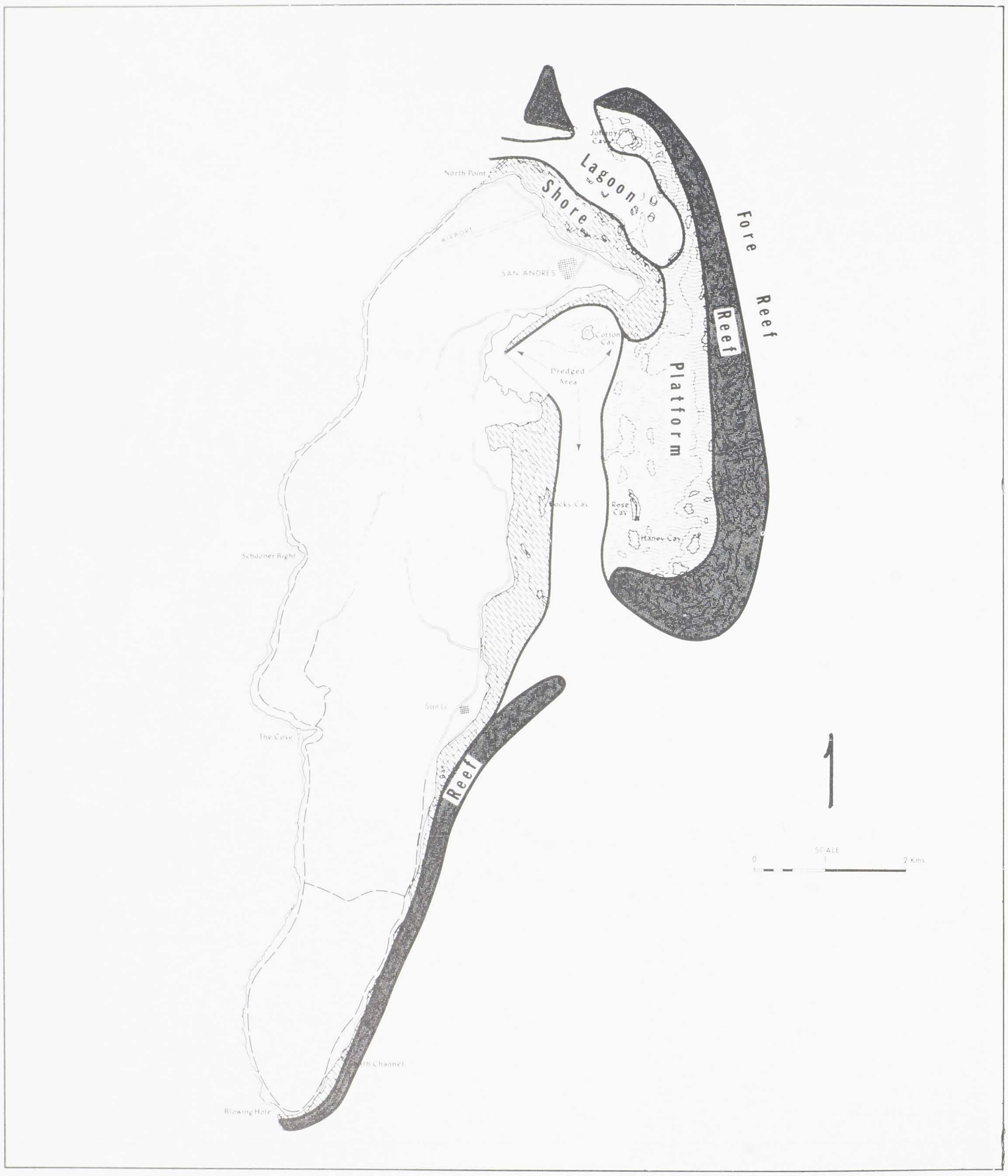

Fig. 7 – Depositional environments of the windward side of San Andres Island.

Fig. 8 – Modern beachrock deposits, San Andres Island.

1. Aerial photograph of Johnny Cay. Note crescent shape deposits of beachrock on the windward side. Arrow indicates direction of prevailing winds.
2. Beachrock deposit along the beach, south of San Luis.
3. Polished block of beachrock material (sample 29-F/R-61). Note stratification and primary porosity. Arrow indicates up direction.
4. Photomicrograph of sample 29-F/R-61. Arrow indicates location of photomicrograph 5.
5. Aragonite cement of sample 29-F/R-61.

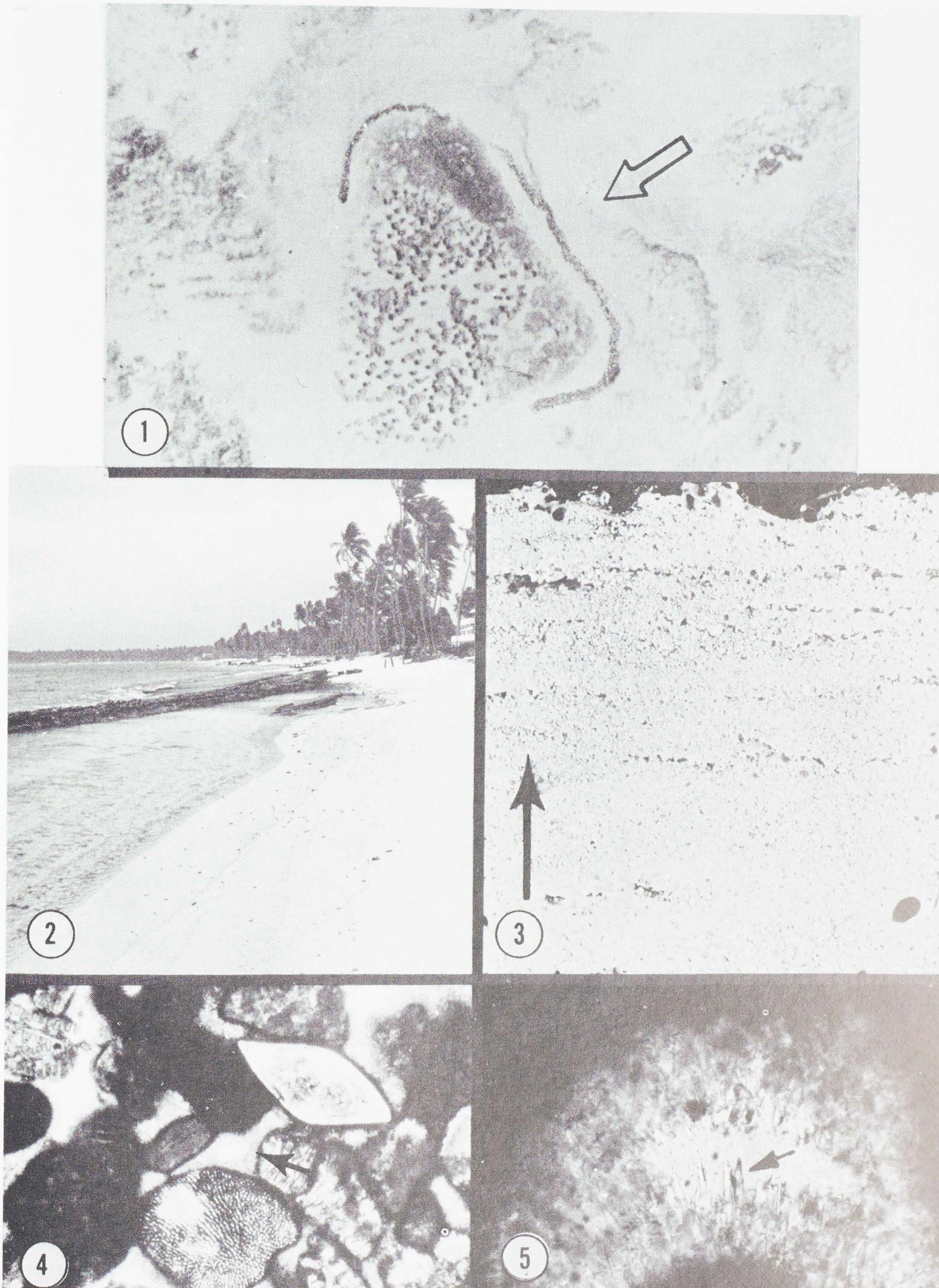

FIGURE 8

Sediment cover is typically 3 to 5 cm thick and in a few places exceeds 25 cm. The limestone platforms, cut by wave action, are typically flat and featureless with a water depth of approximately 2 m. Leeward sides of platforms are commonly marked by a distinct slope break at the edge of the back-reef lagoon. The windward side also is characterized by a slope change and the development of a barrier reef.

Three distinct environments are found within the platform area: barren sand, rubble deposits, and small patch reefs.

Platform areas are typically covered by a thin veneer of relatively barren, rippled carbonate sand (Fig. 11-1). Bottom communities are restricted to gastropods (*Strombus gigas, Vasum muricatum*, and *Oliva* sp.), the irregular echinoid *Clypeaster subdepressus* (Fig. 11-4), and burrowing crustaceans.

Sediment from the platform area is poorly sorted, with approximately 85% of the sample being coarser than 0.25 mm. Dominant constituent grains are foraminifers (27%), algae (20%), and coral fragments (15%).

Rubble deposits (Figs. 11-2, 11-3), on the back-reef platform, are very significant as environmental indicators in the San Andres area. Many rubble deposits have been reported as fore-reef accumulations associated with reefs (Ginsburg, 1964). However, Kornicker and Boyd (1962) reported rubble deposits from the back-reef lagoon area of the Alacran reef in Mexico. Apparently location of the rubble zone is a function of both reef configuration and wave direction. The rubble consists of large fragments of eroded coral debris (Fig. 11-3). Specimens average 10 cm in length and 3 to 5 cm in width. Fragments of *Acropora cervicornis, A. palmata, Porites porites,* and *Millepora* sp. have been identified. Of these organisms, *A. palmata* and *P. porites* are the dominant constituents. Fauna of rubble deposits is commonly restricted to crustaceans, polychaete worms, and mollusks. Living coral is absent. Most of the rubble material is coated by encrusting red algae, which serves as a cementing agent in many locations. Only 4% of the material from the rubble zone is less than 0.25 mm in diameter. The remaining 96% consists of coarse-grained sand with 35% of grains having diameters greater than 2.0 mm. The crustose coralline algae comprise almost 15% of the constituent grains and *Halimeda* contributes approximately 20%. Non-carbonate residue samples consist primarily of sponge spicules and radiolarian remains.

Scattered throughout the back-reef platform zone are small, isolated patch reefs (Fig. 12-1). These reefs are commonly less than 20 m in diameter and no more than 2 m high (Figs. 12-2, 12-3). Three organisms (Figs. 12-4, 12-5, 12-6) dominate the patch reefs and represent the principal frame builders in this zone: *Acropora palmata, Porites porites,* and *Diploria strigosa*. Numerous minor zoantharian corals exist here also, but are unimportant as frame builders. In addition to corals, the following organisms can be found within the patch reef frame: *Diadema antillarum* and *Eucidaris tribuloides* (echinoids), sea anemones, gastropods (*Astraea* sp. and *Conus* sp.), *Millepora* sp., crustaceans, and sponges.

Fig. 9 — Typical biota of the near shore (turtle grass) zone.

1. General configuration of the bottom in turtle grass areas. A Trigger Fish is in the foreground (photo courtesy of Dr. Frank Barnwell).
2. Close-up of bottom material (courtesy of Union Oil Company of California).
3. Coralline algae.
4. *Porites porites*
5. *Lytechinus varigatus.*
6. *Manicina areolata.*
7. *Porites astreoides.*

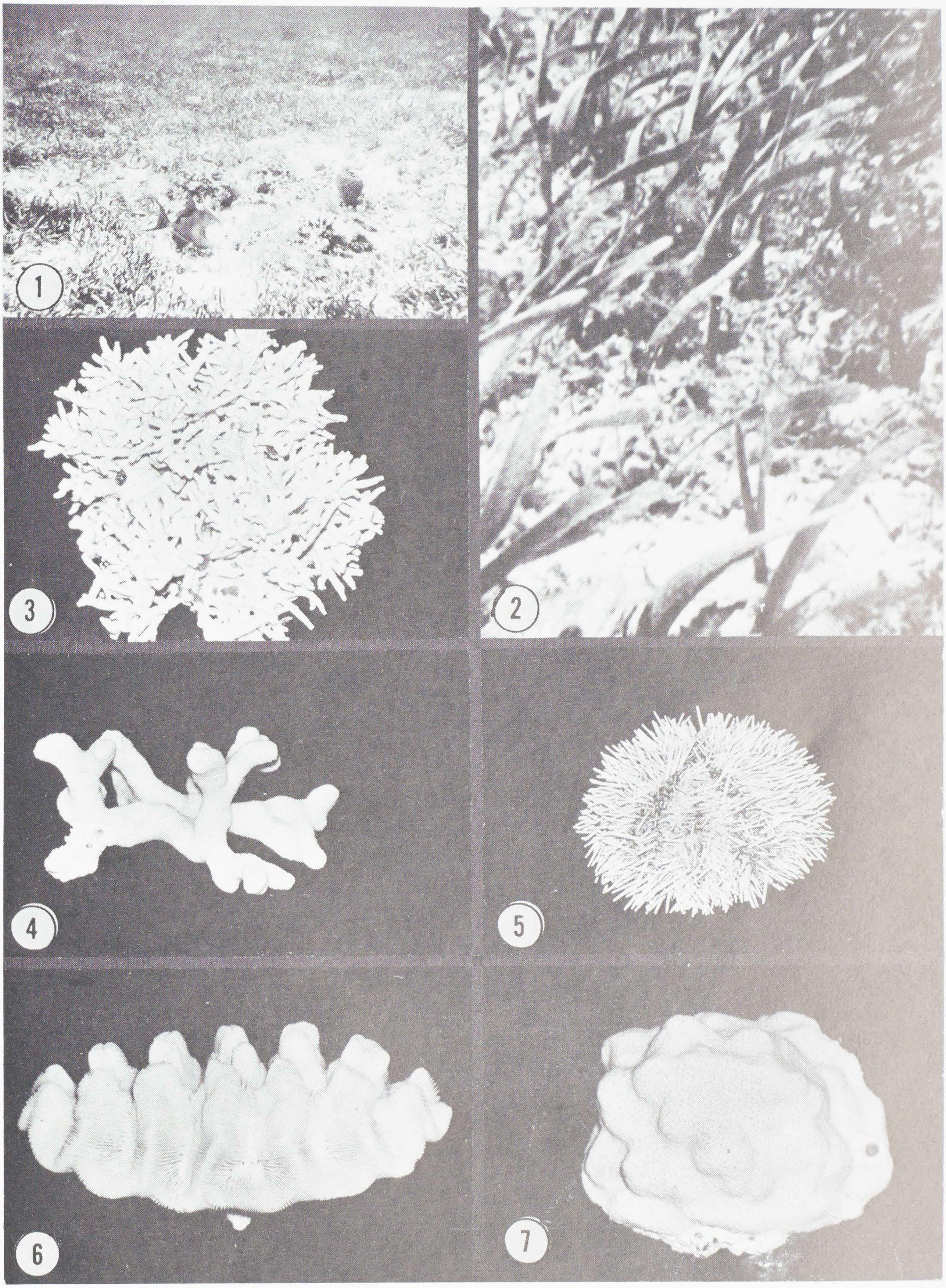

FIGURE 9

Reef Crest

The main reef crest lies along the windward margin of the platform zone. The barrier reef in the San Andres area (Fig. 7) has been subdivided into a northern reef and a southern reef. The reef tract is approximately 15 km long and aligned in a north-south direction. The northern reef is approximately 3 km from shore, whereas the southern reef is less than 300 m from shore. Water depth across the top of the reef is normally less than 30 cm and corals are commonly exposed during spring tides. The immediate back-reef water depth is less than 2 m, whereas the immediate fore-reef water depth ranges from 5 to 10 m.

Two distinct morphological differences exist within the reef crest. The north end of the northern reef is characterized by a gentle slope on the seaward side. The sea bottom is lithified coralline material approximately 5 m thick, in which subsurface passageways are developed. Extensive coral growth has formed a canopy (false bottom), sloping 10° to 15° seaward, throughout this area. The false bottom supports only a sparse community of corals and algae. At the crest of the main reef is a well-developed community of *Millepora complanata* (Figs. 14-2, 14-4), *Palythoa mammillosa* (Fig. 14-3), and encrusting algae. The northern section of the reef tract probably represents the oldest part of the modern reef crest, and growth is apparently now suppressed.

The southern section of the northern reef and the southern reef are, at present, growing rapidly. Large pinnacles of *Millepora* and lime secreting algae form the frame of the reef crest (Fig. 14-1). Openings in the frame are filled by numerous zoantharian corals, gastropods, and alcyonarians. Isolated patches of *Acropora palmata* and *Montastrea annularis* are also present, but they represent seaward patches of coral rather than part of the main reef crest.

The pinnacles of *Millepora* are as much as 10 m high and 3 m in diameter, rising to within a few centimeters of sea level. They are separated by narrow, vertical-walled channels that are less than 1 m wide (Fig. 14-5). These channels form an intricate maze within the reef crest and probably correspond to the caves (passageways) of the northern section of the reef. The channels are characterized by strong, surging currents, which are related to wave action. Rippled sand is common, and most ripples have an amplitude of 10 cm, a wavelength of 45 cm, and are formed perpendicular to the surge direction. Bottoms of channels are commonly filled with well-sorted, coarse-grained carbonate sand. There are no fine materials and 99% of the grains are greater than 0.50 mm in diameter. Dominant constituent grains are coralline fragments (25%), and almost 45% of the grains are unidentifiable. No non-carbonate residue was recovered.

Coralline growth is restricted to the upper portion of the channel walls. The lower 1 m is marked by clean, eroded, coralline limestone. The channels have no apparent orientation. They form meander-like passageways through the reef tract, and open into small "courtyard-like" areas. The "courtyards" are approximately 6 m deep. The bottoms are flat and veneered with sand. They are commonly enclosed by vertical walls of *Millepora* and algae.

Fig. 10 – Back-reef lagoon zone, San Andres Island.

1. Aerial photograph of the northern San Andres area. Arrow indicates patch reef.
2. Aerial photograph of individual patch reefs.
3. Underwater photograph at edge of a patch reef built by *Acropora palmata.*
4. Underwater photograph of patch reef built by *Montastrea annularis.*
5. Individual specimen of *Acropora palmata.*
6. Individual specimen of *Montastrea annularis.*

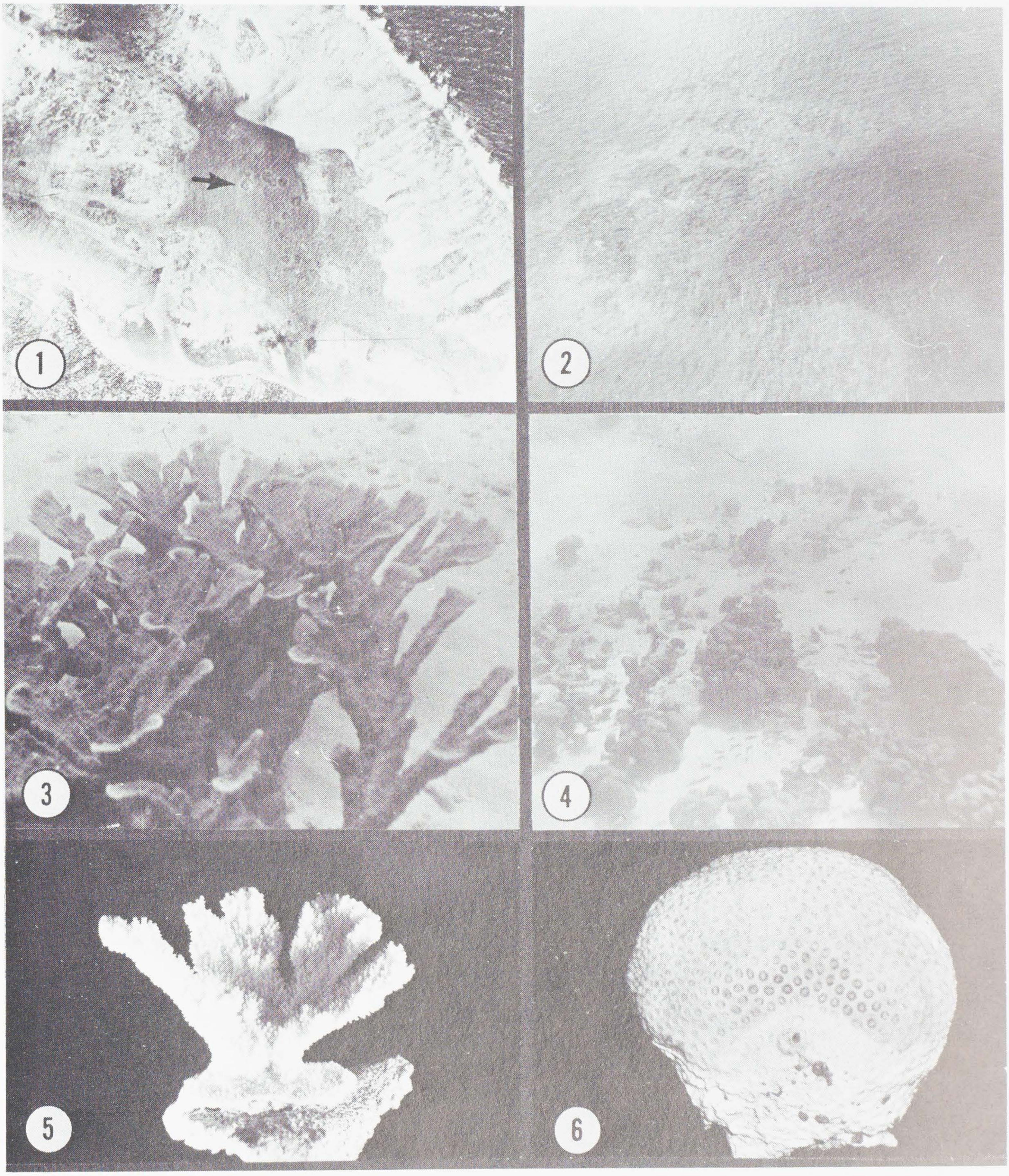

FIGURE 10

The primary frame builder of the San Andres reef crest is *Millepora complanata* (Figs. 14-2, 14-4). However, the reef tract is characterized by numerous zoantharian corals and alcyonarians; 25 species of coral have been identified from this zone. Almost all of the species of coral found on the windward side of the island can be found within the reef crest.

Fore-Reef

The fore-reef zone in the San Andres area is characterized by a hard, coralline limestone bottom, covered by numerous small zoantharian corals and alcyonarians. This zone extends seaward of the reef crest locally for a distance of approximately 5 km and probably represents an eroded terrace of Pleistocene age. The bottom slopes seaward at 2° to 5°, and is somewhat irregular, being modified by long, linear channels, which can be traced seaward from the reef zone. The channels are generally less than 1 m wide at the bottom, with sides that slope at 30° to 40°. The water depth in channels is 10 to 15 m and becomes progressively deeper in the seaward direction. Channels can be observed both from the air and underwater and are probably spur and groove structures similar in design to those described by Shinn (1963) in Florida. The main water currents through this zone at the time of sampling were parallel to the reef crest. None corresponded to the direction of the channels.

Carbonate sediment from the bottoms of the channels is characteristically coarse-grained with 90% of the grains having a diameter greater than 0.50 mm. No non-carbonate residue was recovered from the sample. Fragments of coral (10%), echinoids (10%), and *Halimeda* (12%) are the principal constituent grains. Forty per cent of the grains were unidentifiable.

Due to lack of adequate equipment and heavy seas, no observations were made in the fore-reef zone farther than 3 to 4 km seaward of the main reef crest.

V. CARBONATE MINERALOGY

Marine sediments from the San Andres Island area were analyzed by X-ray diffraction methods and relative percentages of aragonite, high-magnesian calcite, and low-magnesian calcite were determined by methods evaluated by Royse, Wadell and Petersen (1971). Sediment sample sites for the windward side of the island are shown in Figure 13. The sediments were found to have an average composition of 70% aragonite, 30% high magnesian calcite, and 0% low-magnesian calcite. However, beach sands were found to contain as much as 32% low-magnesian calcite, with an average of 10% low-magnesian calcite, 22% high magnesian calcite, and 68% aragonite. Figure 15 depicts the compositional distribution of these sediments. The samples indicated in Figure 15 may be separated into four classes: 1) Subtidal sediments, 2) beach or near-shore sands, 3) beachrock, 4) limestone deposits of late Pleistocene age. Generally, samples consist of the top few inches of lagoonal or near-reef sediments. Beach and near-shore sands are subaerially exposed or contaminated by detrital, low-magnesian calcite derived from older limestones. Beachrock and deposits of late Pleistocene age are in some phase of early diagenesis and are lithi-

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Fig. 11 – Back-reef rubble zone of the modern reef, San Andres Island.

1. Aerial photograph showing the well developed back-reef rubble (R) and sand (S) deposits.

2 and 3. Typical coralline rubble.

4. *Clypeaster subdepressus,* a common echinoid on the sand bottom.
5. *Diadema antillarum,* communities of this echinoid are common on both sand and rubble bottoms.
6. A common echinoid on the sand bottom.

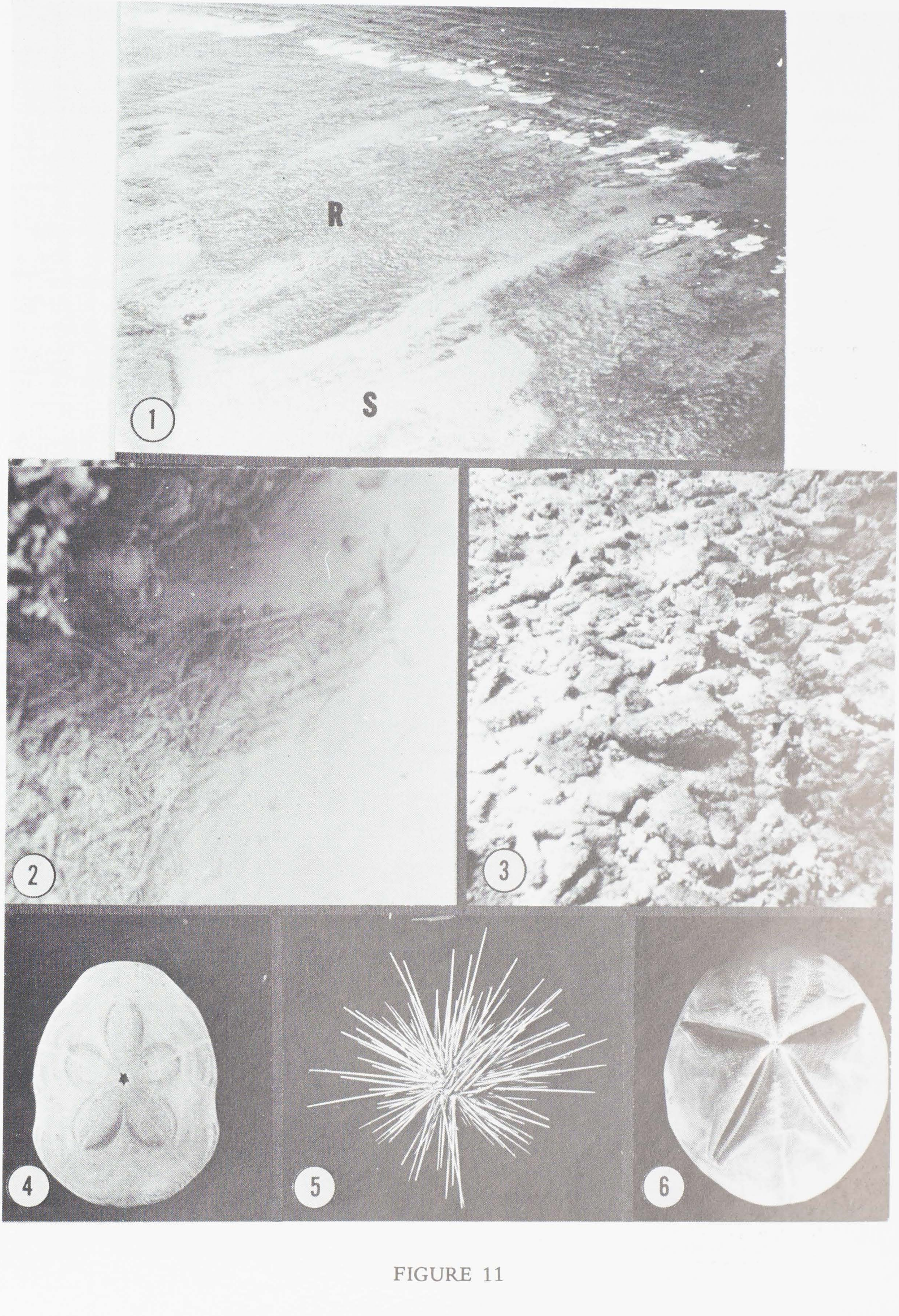

FIGURE 11

fied. As might be expected, the tendency for conversion to low-magnesian calcite is related to age and probable subaerial diagenesis. It should be noted that low-magnesian calcite was found only in the near-shore areas where there is a good possibility of subaerial exposure.

No dolomite was found in any of the sediment samples collected in the San Andres area. However, high-magnesian calcite may contain up to 20 mole % $MgCO_3$ in many areas. Figure 16 depicts the distribution of $MgCO_3$ based on mole % in high-magnesian calcite. It is interesting to note that two anomalous areas exist within the reef complex: the turtle grass zone and the main reef crest. These high concentrations of $MgCO_3$ can probably be explained by the presence of coralline algae and the echinoids *Lytechinus* and *Diadema*. High magnesium concentration is found in the skeletal parts of both forms (up to 43.5 mole % $MgCO_3$). Even though this high per cent is localized, its presence indicates an ability to concentrate magnesium (Schroeder, *et al.*, 1969). According to Schmalz (1965), the red alga *Goniolithon* may contain up to 18 mole % $MgCO_3$ (by X-ray analysis).

VI. SUMMARY AND CONCLUSIONS

The characteristics of the modern environments of San Andres can be summarized best by a comparison of biota, sediment, and bottom physiography. With the data presented, it is then possible to determine particular zone parameters.

The leeward side of the island can be characterized by: 1) well-developed cliffs, caves, and wave-cut notches; 2) encrusting red algal accumulations in the surf zone; 3) accumulation of massive corals at bases of large submarine cliffs; 4) extensive alcyonarian gardens. The leeward side of the island consists of a series of cliffs and terraces eroded by waves during fluctuation of sea levels during Pleistocene time. The modern sediments form a thin veneer, superimposed on old erosional surfaces.

The environments of the windward side of the island can be distinguished on the basis of sediment composition. By comparing samples from traverses noted in Figure 13, it is possible to show relative changes in percentages of constituent grains (Fig. 17). By comparisons of this type, several interesting changes can be observed in the contents of the samples:

1. Large percentages of foraminifers are present in back-reef ecologic zones, and foraminifers decrease in abundance as one approaches and passes the main reef crest.
2. The abundance of coralline algae gradually increases toward the reef crest.
3. As might be expected, coral fragments increase in abundance toward the reef crest, as do echinoid fragments and gastropod remains.
4. The percentage of pelecypod fragments is higher toward the shore and decreases toward the reef crest.
5. Alcyonarian spicules generally decrease toward the reef crest but they are abundant on the leeward side of patch reefs.

Although *Millepora complanata* is the primary frame builder of the reef crest in the San Andres area, it should be pointed out that this relationship is not common. When comparisons are made with other modern reef areas, *Millepora* is typically found to be

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Fig. 12 – Patch reefs of the back-reef platform zone.

1. Oblique aerial photograph of the immediate back-reef platform with small patch reefs. The island is Johnny Cay.
2. Underwater photograph of a patch reef constructed by *Diploria strigosa* and *Acropora palmata* (photo courtesy of Union Oil Company of California).
3. Underwater photograph of *Porites* patch reef.
4. *Acropora palmata.*
5. *Diploria strigosa.*
6. *Porites porites.*

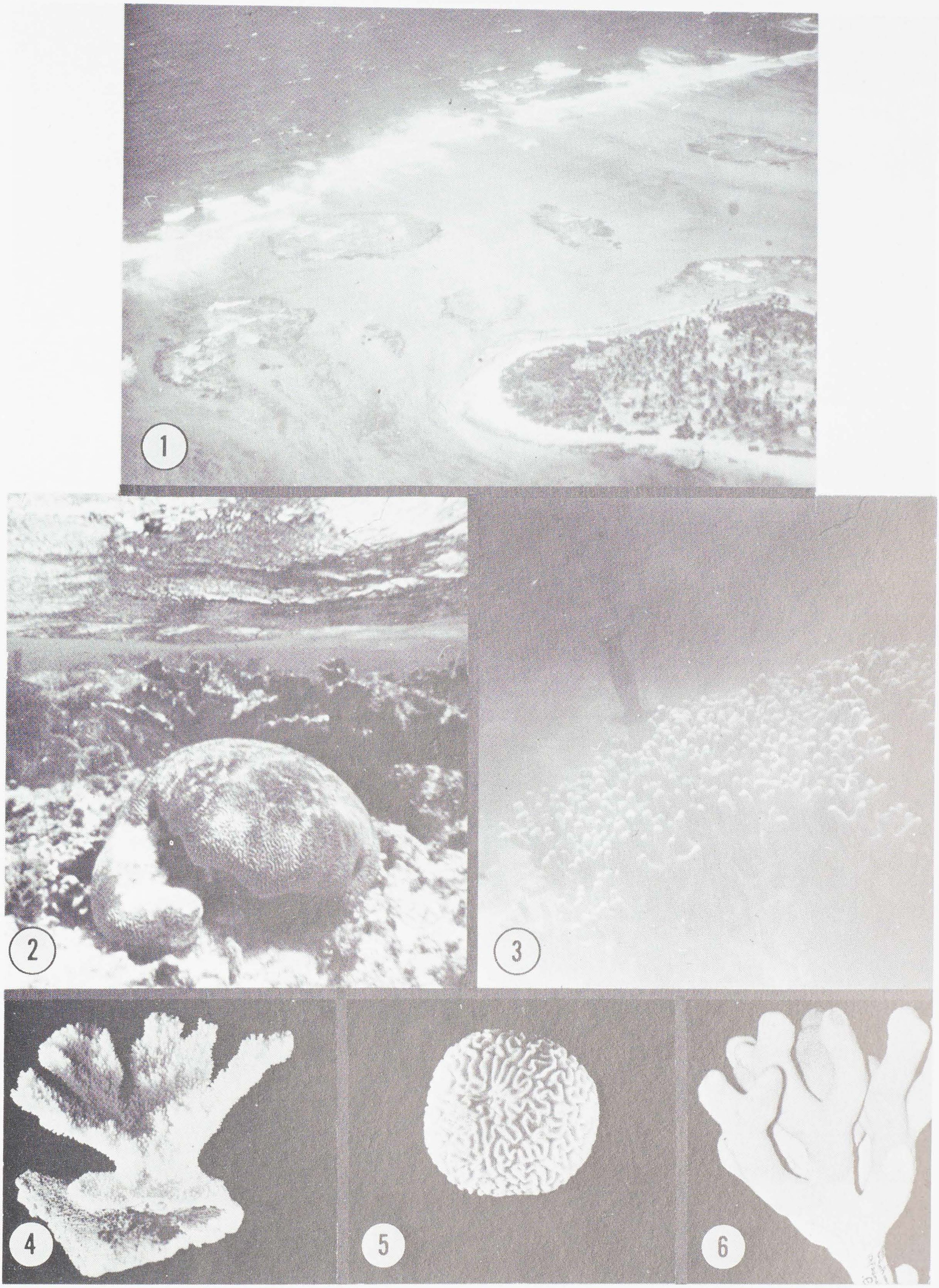


FIGURE 12

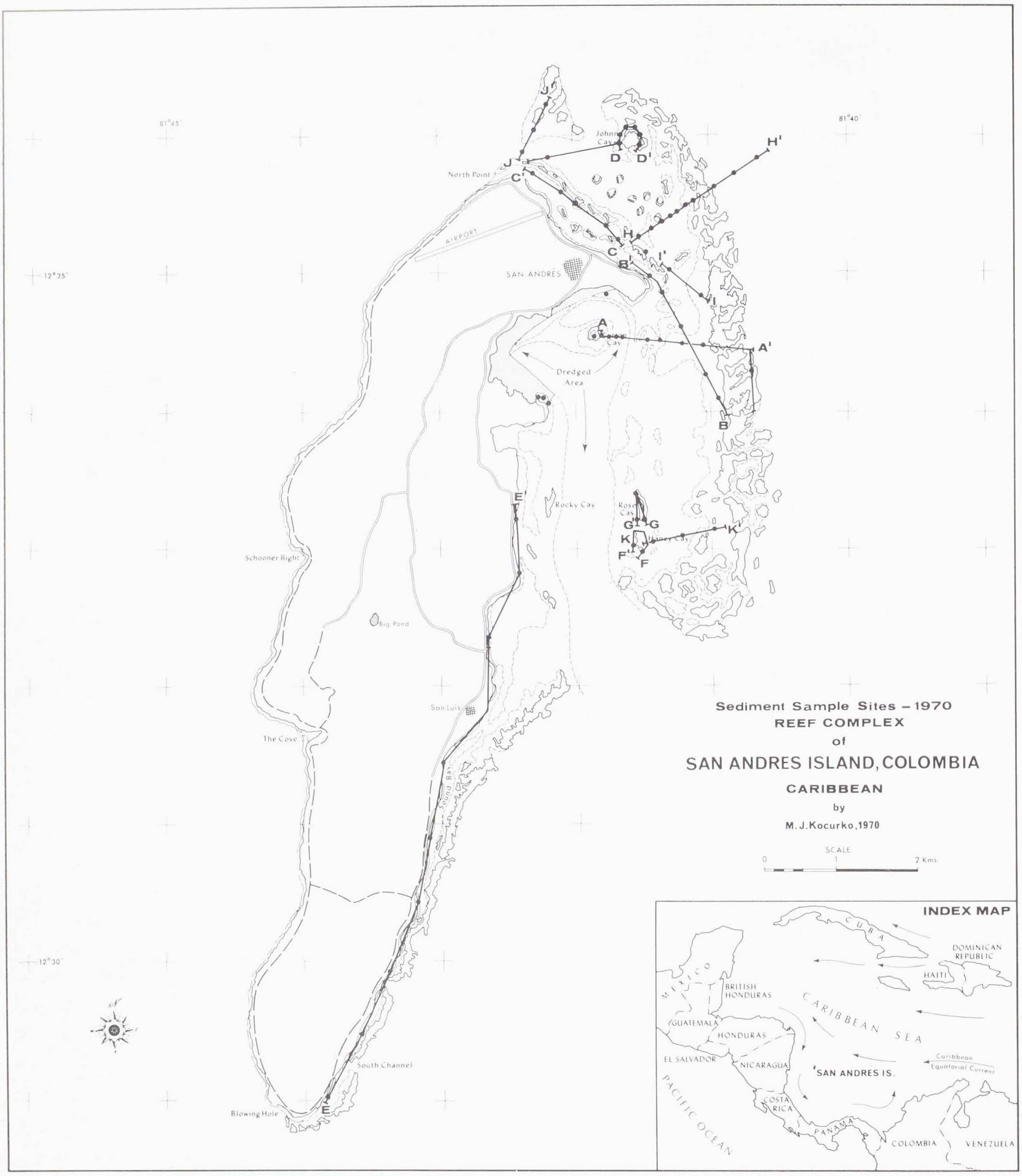
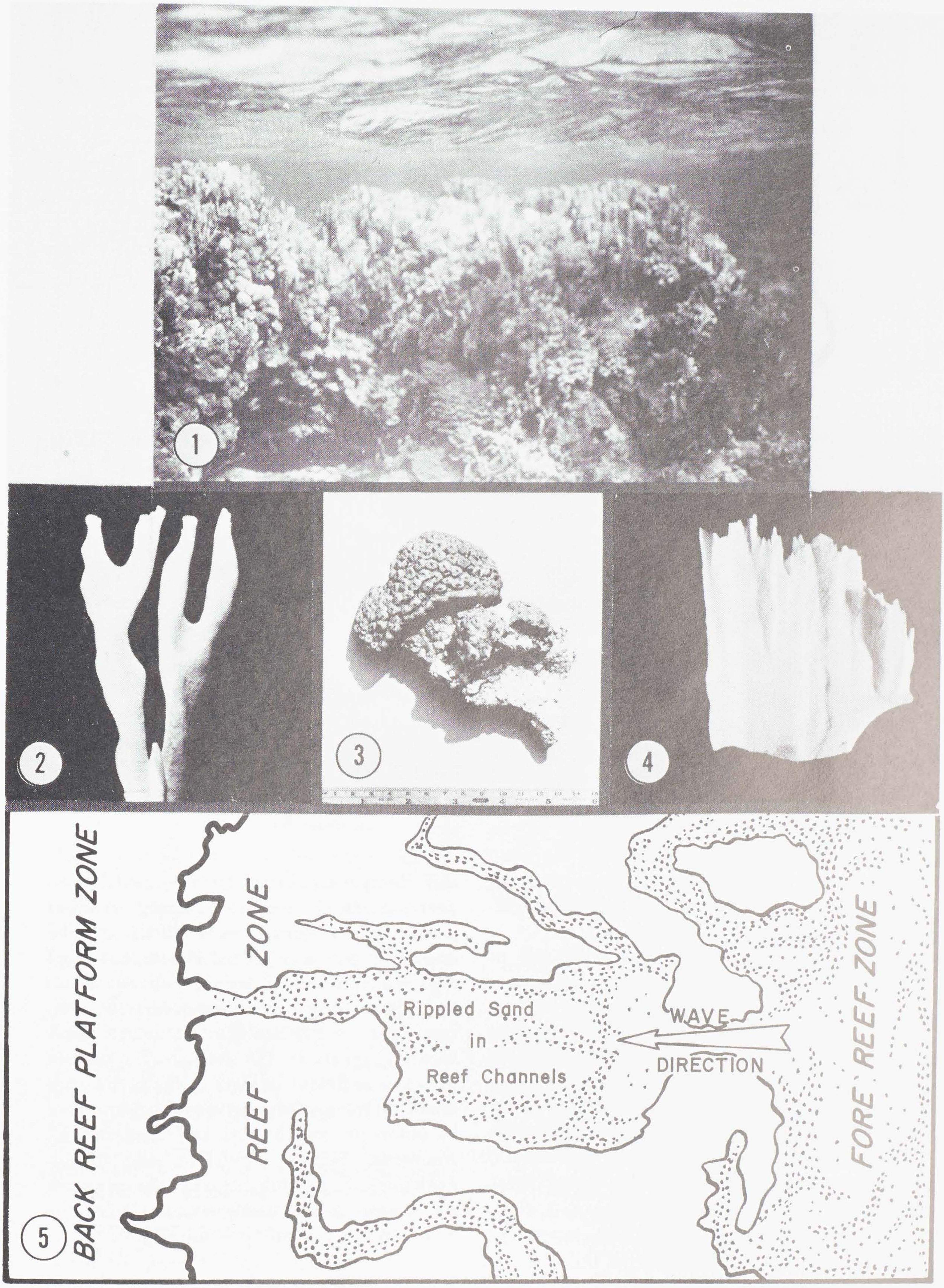


Fig. 13 – Sediment sample sites from the windward side of San Andres Island.

Fig. 14 – Main reef crest, San Andres Island.

1. Underwater photograph of the main reef crest (cross-sectional view). The fore-reef zone is to the right.
2 and 4. *Millepora complanata.*
3. *Palythoa mammillosa.*
5. A diagrammatic map of reef channels.


1
2
3
4
5
BACK REEF PLATFORM ZONE
REEF ZONE
Rippled Sand in Reef Channels
WAVE DIRECTION
FORE REEF ZONE

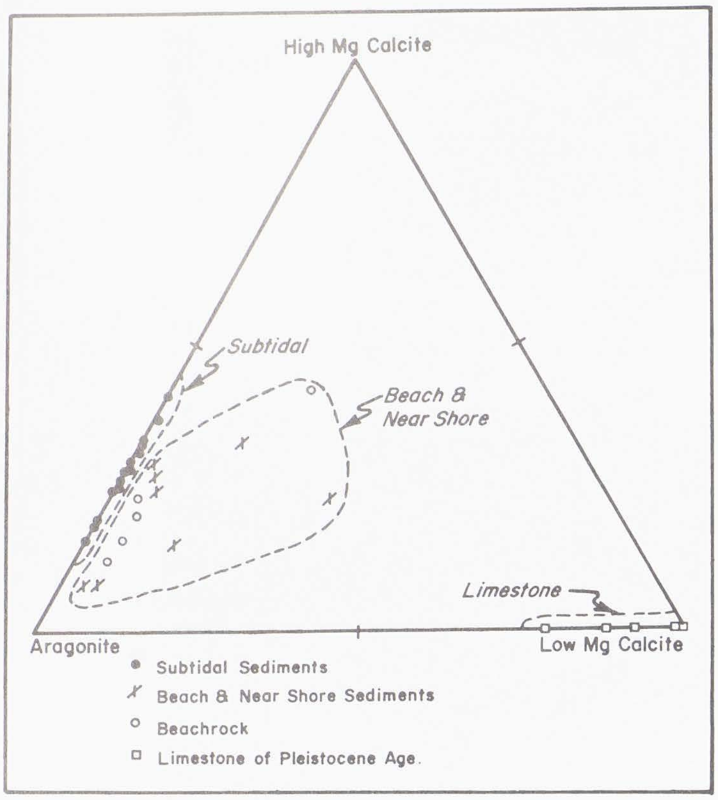


Fig. 15 – Mineralogy distribution of sediment and limestone samples from San Andres Island.

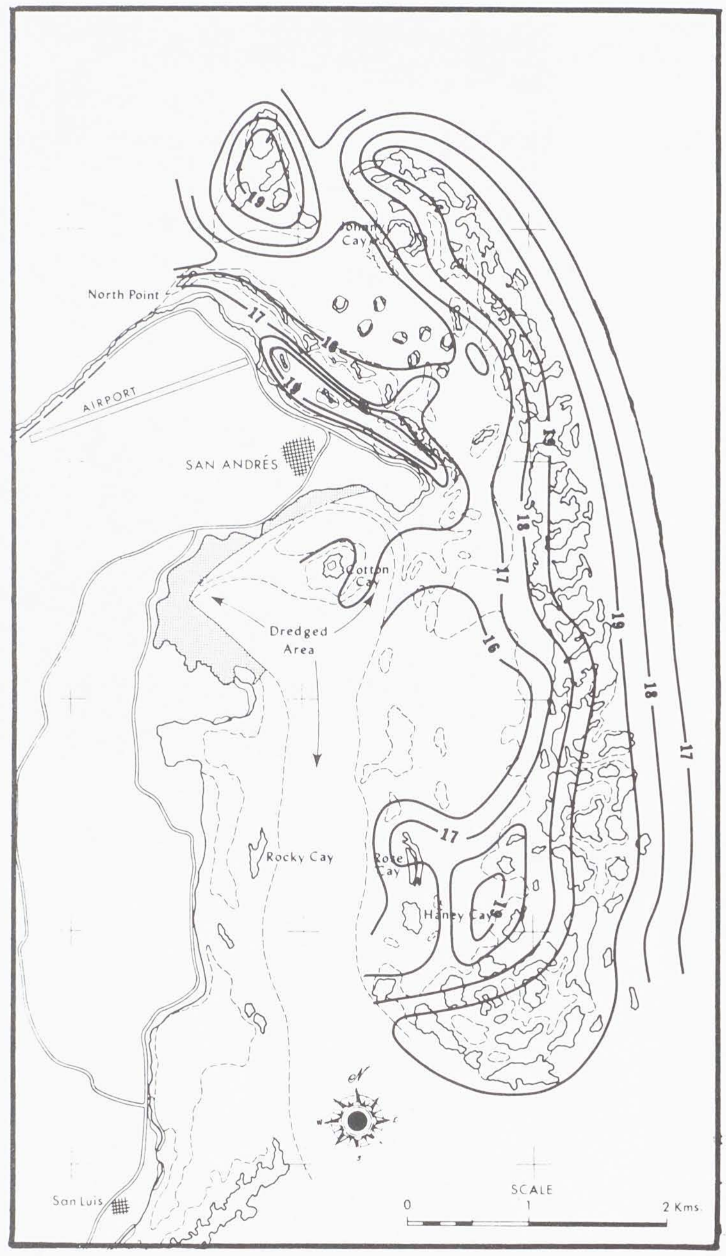


Fig. 16 – Distribution of magnesium carbonate in the San Andres area (values in mole %).

a frame builder of secondary importance. For example, Ginsburg (1953) reported *Acropora palmata* to be the major frame builder of the Florida reefs. He did, however, note that *Millepora* occupies a major fore-reef zone. Reefs along the coast of British Honduras are often built primarily by *Montastrea annularis*. Kornicker and Boyd (1962) reported *Millepora* and *Acropora palmata* as primary frame builders of the Alacran reef in Mexico. Although the same types of organisms are present in most reefs, their ecologic positions may be slightly different from area to area.

Modern reefs, along the eastern side of San Andres Island, have formed on a terrace of Pleistocene age. The dominant reef organisms are *Millepora complanata* and *Palythoa mammillosa*. Based on bottom sediment type and faunal distributions, the modern reef complex on the windward side of the island has been divided into five major ecologic zones: 1) near-shore area, 2) back-reef lagoon, 3) back-reef platform, 4) reef crest, 5) fore-reef.

Within the main reef area a distinct faunal zonation can be observed. In the fore-reef area *Montastrea annularis* is predominant and *Acropora palmata* is of secondary importance. In the reef zone, *Millepora complanta* and *Palythoa mammillosa* are the dominant forms. The immediate back-reef area is characterized by *Acropora palmata* and *Diploria strigosa*. Lime-secreting coralline algae are particularly important as cementing agents in the main reef zone and effective sediment binders in the turtle grass areas. Other algal forms are also important as sediment contributors and binders *(i.e., Halimeda, Udotea, Penicillus,* and *Rhipocephalus).* It is probable that the presence of crustose coralline algae account for the high $MgCO_3$ content (up to 20 mole %) of sediment samples from the reef and shore zone areas.

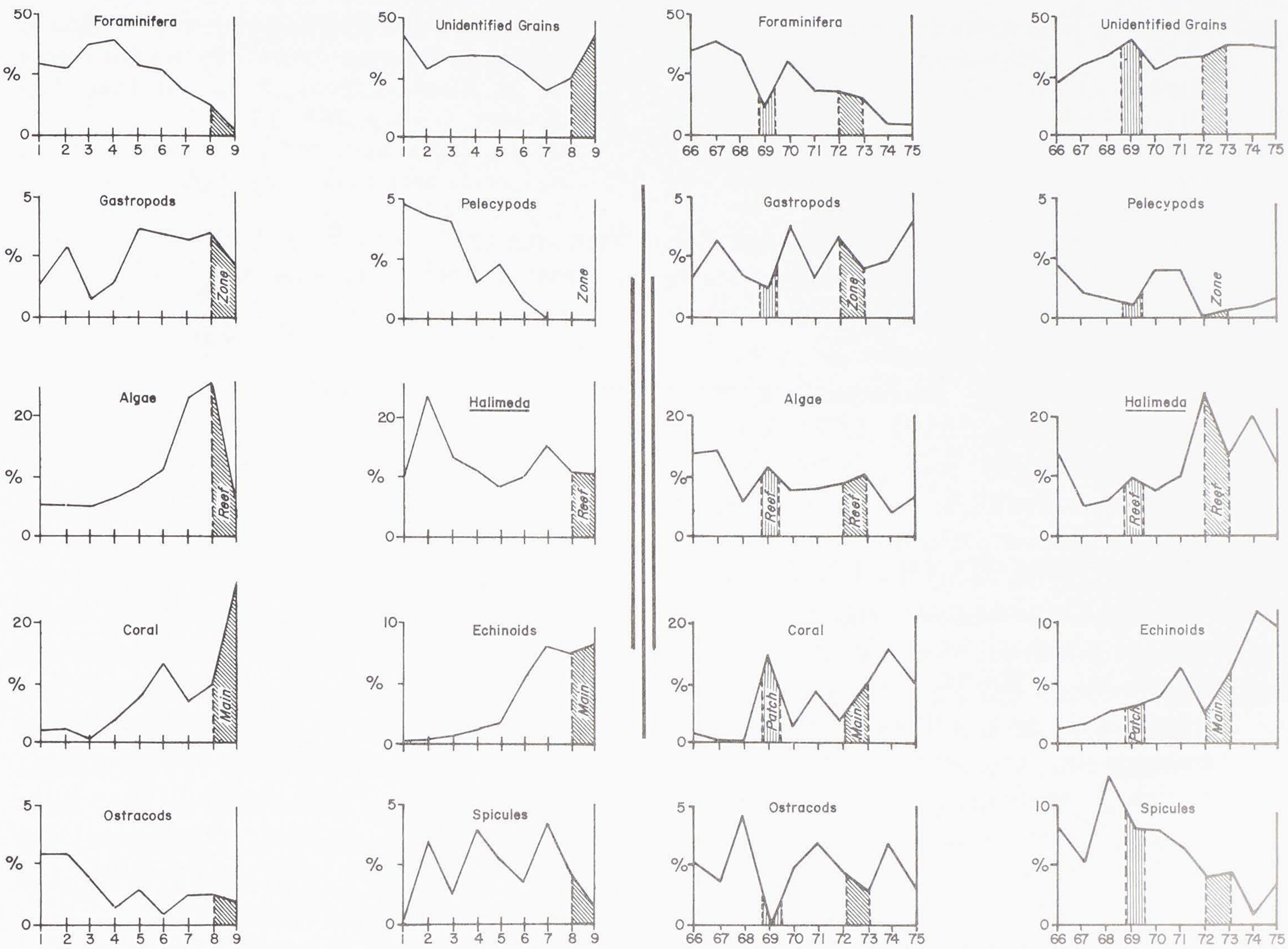


Fig. 17 – Relative changes in constituent grain percentages of samples from shore to fore reef. Samples 1 to 9 represent traverse "A", samples 66 to 75 represent traverse "H" (Fig. 13).

VII. ACKNOWLEDGMENTS

I am indebted to Union Oil Company Foundation for financial support of this project. Appreciation is also extended to John P. Brand for assistance in the field and Alonzo D. Jacka for assistance in the preparation of this manuscript. This project was part of a doctoral dissertation prepared at Texas Tech University in 1972.

VIII. LITERATURE CITED

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REVIEWS

CONTRIBUTIONS TO THE HISTORY OF GEOLOGY, edited by George W. White, a series of classical works in geology, reprinted in facsimile with introductory biographical and bibliographical commentaries by the editor and other distinguished students of the history of geology. These volumes are handsomely and skillfully reproduced and were carefully selected to make essential but almost unobtainable titles available to students and historians at relatively modest cost. Published by Hafner Press, a division of Macmillan Publishing Company, Inc., New York.

9. THE WERNERIAN THEORY OF THE NEPTUNIAN ORIGIN OF ROCKS, a facsimile reprint of *Elements of Geognosy, 1808,* by Robert Jameson; with an introduction by Jessie M. Sweet and a foreword by George W. White. New York, 1976, xxiv + xvi + 387 pp., $25.00

Robert Jameson, Regius Professor of Natural History at the University of Edinburgh (1804-1854), student of Abraham Gottlob Werner and diehard Neptunist, founder and permanent president of the Wernerian Natural History Society, and the foremost English language spokesman for Wernerian philosophy, published in 1808 the third volume of his *System of Mineralogy.* This third volume, titled *Elements of Geognosy,* presents Werner's system of rock classification and Werner's Neptunist theory of the origin of rocks to the English reader in its fullest and most complete form. This work serves as both an explanation and a defense of Werner's rock classification and his geognosy. The text is a faithful translation of Werner, augmented and expanded by Jameson from his own experience. Jameson also included long quotations from Huttonian theory and Playfair's *Illustrations,* refuting point by point the Plutonist views; and, in another section, contrasted the Huttonian Plutonist philosophy with the Wernerian Neptunist philosophy.

The influence of Jameson's explication of Wernerian ideas was enormous. It was through this volume that Werner's concepts and his classification of rocks reached English-speaking scientists throughout the world and, for the next several decades, the quite numerous references to Wernerian philosophy and classification in British and American works can be traced to the Jameson text.

In the introduction to this reprint edition, Miss Jessie M. Sweet, the principal authority on the life of Robert Jameson and his work, provides a lucid and thorough review of Jameson's life, his education, his students and associates, and his scientific work. Her contribution is well-documented and most useful.

In addition to making the Jameson work generally available to students and research scholars in the history of science, this volume will be of great assistance to understanding the relationship between Werner and one of his most devoted students and the key role that Jameson held in the controversy between the Neptunist and Plutonist schools.

—H.C.S.