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RECENT CORAL REEFS AND GEOLOGIC HISTORY OF PROVIDENCIA ISLAND (WESTERN CARIBBEAN SEA, COLOMBIA)

JORN GEISTER[1]

CONTENTS

	Página
ABSTRACT	116
1. INTRODUCTION	116
2. DESCRIPTION OF THE RECENT REEF COMPLEX	118
2.1. FORE-REEF TERRACE AND OUTER SLOPE	118
2.2. WINDWARD BARRIER REEF	118
2.2.1. THE COHERENT BARRIER REEF	119
2.2.2. THE INCOHERENT BARRIER REEF	120
2.2.3. FORE-REEF TERRACE EXTENDING TO NEAR LOW-TIDE LEVEL	120
2.3. LAGOON WITH PATCH REEFS AND FRINGING REEF	121
2.3.1. LAGOONAL TERRACES AND LAGOONAL BASINS	121
2.3.2. PATCH REEFS AND RIBBON REEFS	121
2.3.3. FRINGING REEF	125
2.4. LEEWARD SHELF AND OUTER SLOPE	125
2.4.1. SHELF AREA W OF THE ISLANDS	125
2.4.2. "LAWRANCE REEF"	125
2.4.3. THE OUTER SLOPE AT "BLUE HOLE"	125
2.5. NOTE ON THE RECENT CORAL FAUNA OF PROVIDENCIA	129
3. THE GEOLOGIC HISTORY OF THE ISLAND	129
3.1. TERTIARY VOLCANISM AND REEF SEDIMENTATION	129
3.2. PLEISTOCENE TO RECENT GEOMORPHOLOGY AND REEF FORMATION	130
3.3. POSSIBLE ORIGIN OF THE CONTEMPORARY INSULAR SHELF MORPHOLOGY	132
4. ACKNOWLEDGEMENTS	133
5. REFERENCES	133

1) Geologisches Institut Universität Bern, Switzerland

ABSTRACT

Providencia Island, composed of pre-Miocene and Miocene volcanic rocks, is surrounded by an extensive coral reef complex which, from east to west, can be subdivided morphologically and ecologically into the following subparallel units:

a) Fore-reef terrace: a bare rocky flat, from one to several kilometers broad, sloping gently from the reef to a morphological break below 30 m which marks the beginning of the outer slope.

b) Barrier reef: more than 100 m broad and totalling some 30 km in length, it rises up to near low-tide level. Coherent in the north and in the south, its middle section is a chain of coral pillars. A profuse growth of Millepora, Palythoa and abundant coralline algae covers the reef crest, where locally a true algal ridge is developed.

c) Lagoon: includes a broad and shallow lagoonal terrace adjacent to barrier reef and a deeper lagoon basin, both locally connected by steep "sand cliffs". From the lagoon floor, covered by bare sand and coral rubble, numerous patch reefs and coral heads to various heights.

d) Leeward shelf: rocky flats with scattered coral growth extend from the shore to a steep escarpment at 20 or more meters depth marking the beginning of the western outer slope. Patch reefs and sandy flats are equally abundant.

Submarine terraces, escarpments and valleys, as well as an irregular outline of many reefs reflect a complex geomorphological history of the insular shelf during Pleistocene, which is in part concealed by Holocene reef growth and sedimentation.

1. INTRODUCTION

Mentioned briefly by DARWIN 1851 in his discussion of the west Indian reefs, the extensive reef complex of Providencia (or Old Providence Island) has since received no scientific attention. Yet this reef complex is unique in the area in that it surrounds the only high-standing volcanic island situated off the Middle American shelf. Moreover its barrier reef, totalling some 32 km in length, is one of the largest in the western hemisphere.

The insular shelf and associated reef complex surrounding Providencia and its smaller sister island Sta. Catalina extende considerably to the NNE, some 15 km away from the islands (see Fig. 1). The northern part of reef and lagoon are rather distant from any source of interfering terrigenous sediments and thus resemble geomorphologically and also ecologically an incomplete atoll. The southern half, on the other hand, has characteristics more compatible with a true barrier reef and lagoon.

It is therefore not surprising that the reefs around Providencia are in many respects similar to those of the neighboring San Andrés Island (GEISTER, 1973, 1975) and to those of some nearby western Caribbean atolls (MILLIMAN 1969a, 1969b). Nevertheless, several features seem quite unique. The peculiar geomorphology of the Providencia barrier reef alone justifies a more detailed investigation.

Oceanographic and climatological data relevant to the area may be from the above publications. And interesting early account of Providencia Island and its reefs was published by Collett (1837), a member of the Royal Navy survey team unter Capt. Richard Owen that charted the insular shelf in 1835. More recent information on the geography and the people of Providencia can be found in Parsons (1956, 1964) and Wilson (1973).

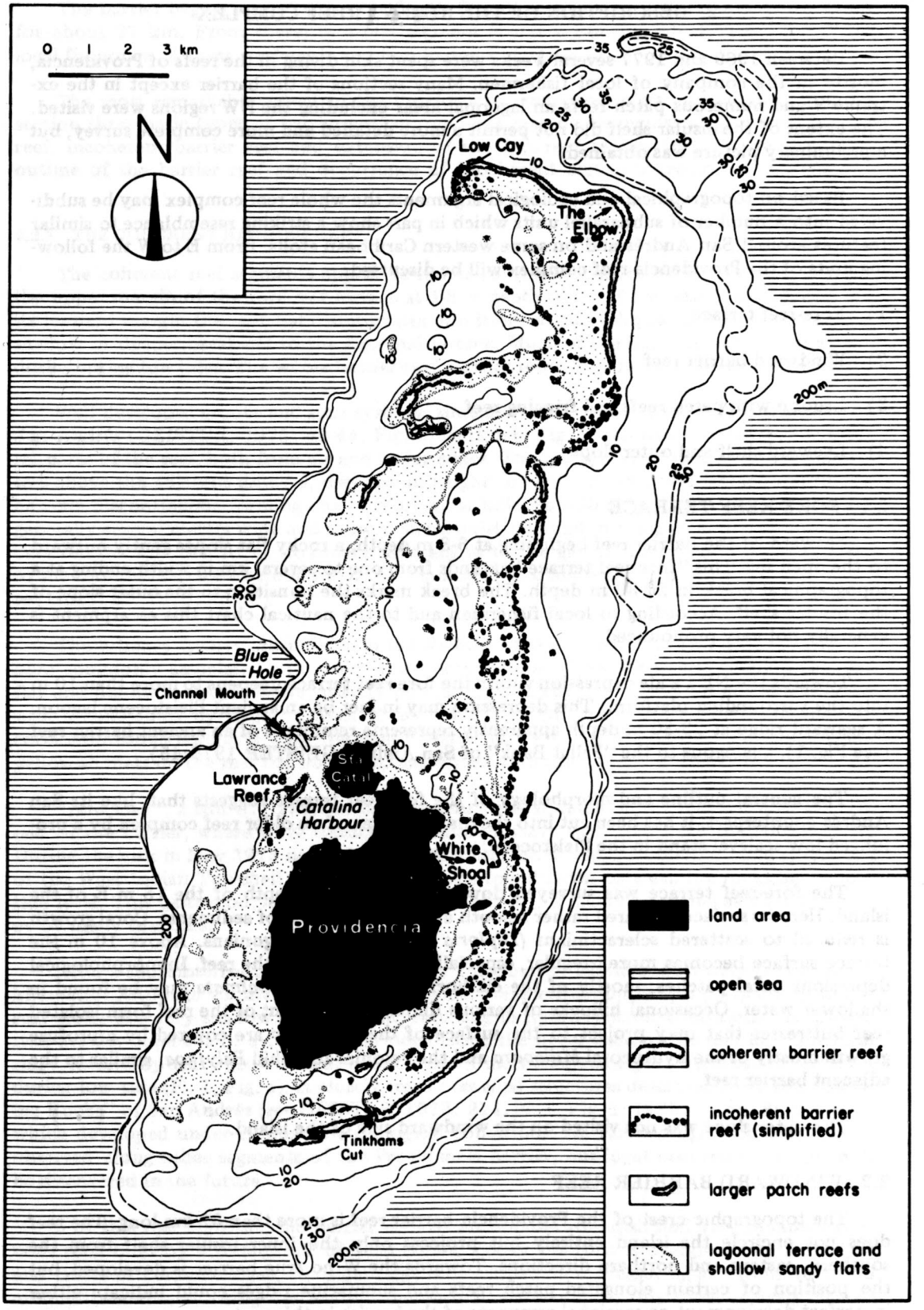


FIG. 1: Submarine topography and distribution of reefs on the insular shelf of Providence.

2. DESCRIPTION OF THE RECENT REEF COMPLEX

Between 1969 and 1977 several weeks were spent skin diving in the reefs of Providencia, mostly in the company of local fishermen. Many sections of the barrier except in the extreme S and numerous patch reefs an lagoonal areas excluding the NW regions were visited. The extent of the insular shelf did not permit a more detailed and more complete survey, but a preliminary picture was obtained.

Based on topographical and ecological arguments the whole reef complex may be subdivided into a number of subparallel units which in part show a striking resemblance to similar features around San Andrés and on some western Caribbean atolls. From E to W the following units of the Providencia reef complex will be discussed:

1) Fore-reef terrace

2) Windward barrier reef

3) Lagoon with patch reefs and fringing reef

4) Leeward shelf and outer slope

2.1. FORE-REEF TERRACE

Seaward of the barrier reef beginning at 6-8 m depth, a rocky flat slopes gently outward to the open sea. This "fore-reef terrace" extends from one to several km in width ending at a topographical break in 20-30 m depth. The break marks the transition to the outer slope of the insular shelf. According to local fishermen and to the nautical chart this escarpment is generally not very pronounced.

Towards the NE a wide depression within the fore-reef terrace deepens to more than 10 m into the surrounding platform. This depression may in fact be an ancient Pleistocene lagoon. A seaward ridge at 23-30 m depth apparently represents remmants of an ancient barrier reef (see Fig. 1), analogous to the "Pallat Bank" of San Andrés (GEISTER 1975:45).

The general outline and morphology of the fore-reef terrace suggests that, like its San Andrés counterpart, it has been cut into the marginal area of an older reef complex by a prolonged low sealevel stand in the Pleistocene.

The fore-reef terrace was surveyed down to a maximun depth of the 15 m E of the island. Here its surface appeared rather smooth and mostly devoid of sediments. Coral growth is reduced to scattered scleractinians *(Diploria* sp. etc.) and gorgonians. Above 10 m the terrace surface becomes more irregular, especially in proximity to the reef. In morphological depresions coral patches, mostly of the elk-horn coral *Acropora palmata* may be found in shallower water. Occasional hillocks of various dimensions in front of the reef form isolated reef buttresses that may project to the surface of the sea. They are covered by a profuse growth mostly of the hydrocoral *Millepora* and the colonial zoanthid *Palythoa*, similar to the adjacent barrier reef.

The outer slope was not visited on the windward side of the island.

2.2. WINDWARD BARRIER REEF

The topographic crest of the Providencia barrier reef is more than 32 km long. The reef does not encircle the island entirely but projects only the inner insular shelf from the southern, eastern and northern directions. Towards the W no true barrier is developed, but the position of certain elongated patch reefs and submarine ridges could indicate either imperfect development or erosional remnants of the barrier in this part.

The barrier begins some 2 km off "South Point" and follows a northeasterly direction for about 27 km. From there, in a reef segment characteristically called "The Elbow" by local fishermen, it turns westwards and terminates S of "Low Cay".

The most remarkable aspect of the Providencia barrier reef is its morphology. In cross section three basic types of barrier reef morphology may be distinguished: Coherent barrier reef, incoherent barrier reef and extension of the fore-reef terrace to low tide level. The outline of the barrier reef and occurrence of incoherent segments are shown in Figure 1.

2.2.1. THE COHERENT BARRIER REEF

The coherent reef segments appear as rather continuous ridges which rise steeply from the upper margin of the fore-reef terrace at 4-8 m depth to a reef flat near low-tide level. At its leeward margin the reef flat disintegrates into irregular coral shoals, or it simply ends at a shallow or deeper break-off to the lagoonal terrace. Much of the flat may become emergent during spring low tides. The whole barrier reef reaches some 50-200 or more meters in width.

Well developed groove and spur systems, similar to those of the windward barrier reef of San Andrés (GEISTER, 1975: 40-44; Fig. 9, section 6; Fig. 10, section 8) were seen in several parts of the reef, both from air and under water. The spurs, may of which rise several meters above the adjacent grooves, decrease in height towards the fore-reef terrace and finally become discontinuous forming chains of irregular hillocks with steep flanks. The grooves are generally several meters wide and show a characteristical anastomosing pattern of bifurcation between the hillocks. At approximate right angles to the general reef trend they lead down to the fore-reef terrace where some of them continue as shallow sandy channels ("sand lines" see GEISTER 1975: 95-96).

The primary framework builder in the shallow of the barrier is the stinging coral *Millepora* commonly associated with ubiquitous incrustations of coralline algae. Behind the reef flat and before in deeper water, patchy bu luxuriant thickets of *Acropora palmata* may be seen accompanied by large colonies of the brain coral *Diploria strigosa.* Stands of the star coral *Montastrea annularis* were frequently found in the lee of the barrier. *Palythoa* forms yellowish mats on the reef flat but is also associated with the *Millepora* framework.

"Low Cay", a spit of *Acropora palmata* shingle is situated on the reef flat near the NW end of the barrier, where wave refraction results in heavy surf from both the NE and NW. During the visit in May 1973 no land plants were seen on the spit. Numerous large specimens of the West Indian Top-shell *Cittarium pica* were found living between the rocks below low tide level. This gastropod, locally known as the "whelk", is highly esteemed as a food delicacy by many islanders.

After a short interruption below "Low Cay", the barrier extends southward for one more kilometer. Although situated at the leeward side, wave refraction causes particularly strong surf along this very shallow reef segment, resulting in hydrodynamic conditions that permitted the development of a typical algal ridge along the outer edge of the reef flat. The algal ridge, formed by heavy growth of at least 30 cm of incrusting red algae (Melobesieae) emerges during low tide (Pl. 1, Fig. a). It closely resembles algal structures described from the "Blowing Rocks" of San Andrés (see GEISTER, 1973: 214. Pl. 1, Fig. 1; 1975: 55-56, Pl. 9, Fig. e) which developed under comparable ecological conditions. No further algal ridges have been observed along other segments of the Providencia barrier, but local occurrences might well be discovered in the future.

S of this reef segment, the barrier ends at an isolated roundish and very shallow cavernous rock built by a framework of dead corals. Today the rock is overgrown by soft algae and crusts of coralline algae. No algal ridge is developed here. Measuring an estimated 10-20 m in diameter and rising vertically from several meter depth, this shoal is aptly named "Table Rock" by local fishermen.

Turbulence due to crashing surf on "Table Rock", swift currents and the presence of numerous caves create an attractive environment for several species of large fish. Reef sharks *(Carcharhinus* sp.) are especially frequent here and seem more aggressive than in any other reef visited around Providencia or San Andrés. They are patrolling the foamy water and by "simulated" attacks will drive the timid diver back to his launch.

2.2.2. THE INCOHERENT BARRIER REEF

Where no continuous barrier is developed, the fore-reef terrace merges with the lagoonal terrace in its lee. The resulting transitional area of both terraces is marked by numerous irregular coral pinnacles, most of which rise from 4-8 m depth to low-tide level.

The highest pinnacles with vertical or overhanging flanks form true coral pillars, reaching several meters in diameter. Most of these have a reef flat near low-tide level. Other pinnacles remained rather low and are even more irregular in shape. The pinnacles are separated from each other by a few meters to more than 20 m. All of them show a highly cavernous structure indicative of their coralline origin.

Richer coral growth is generally restricted to the upper portions of the pillars, whereas the greater part of the basis and flanks is overgrown by incrusting red algae (Melobesieae) and in part also by soft algae *(Turbinaria, Padina, Dictyota).* As in the coherent reef, *Millepora* is the principal and often only frameword builder from sealevel down to 2 or 3 m depth. *Millepora* is always accompanied by *Palythoa* and thin crusts of coralline algae. Below, thickets of *Acropora palmata* and *Diploria* sp. as well as loose patches of *Montastrea annularis* and octocorals can be found, but generally coral growth is much less vigorous here.

The sea floor between the pinnacles, at a depth of 4-8 m is covered with white rippled sand indicating the influence of swell from the open sea. This sandy flat generally merges with the sediments of the lagoonal terrace in its lee.

From the air the reddish to brownish patches of the shallow reef flats are readily distinguishable from the lower pinnacles in between thar appear dark bluish-green in color. The surrounding sandy area is light green to turquoise-green. The whole incoherent barrier reef often measures more than 100-200 m in width.

It should be noted here that in the N of the San Andrés reef complex, where a coherent barrier is lacking, a number of similar although more isolated pinnacles was observed, probably equivalents of the incoherent barrier of Providencia (GEISTER, 1975: 53-56, Fig. 3).

2.2.3. FORE-REEF TERRACE EXTENDING TO NEAR LOW-TIDE LEVEL

In the "Elbow" area the fore-reef terrace gradually shoals towards the reef flat. The line of breaking waves and foam seen from the air is not related to any morphological break but is only due to shoaling of the sea floor and the resulting effects of wave refraction. These conditions may be best observed near the "Morning Star" wreck, and they are similar in the lateral continuation of the reef. The sea floor was not surveyed to deeper water at this reef segment.

Reef growth, especially of *Millepora* is rich only around the leeward margin of the flat, from where a step or slope leads down to the lagoonal terrace. *Montastrea annularis* and gorgonians cover the lower part of this slope (Pl. 2, Fig. a). Only negligible coral growth has been observed on the rocky floor or the uppermost fore-reef terrace, where the waves break with violence. But there seems to be some growth of *Acropora palmata* in water of several meters depth judging from the amount of coral debris on "Low Cay". It is assumed that the morphology is basically erosional, forming a remnant of a Pleistocene reef covered by very limited Holocene coral and algal growth.

An analogous geomorphology is known from certain segments of the windward barrier and fringing reef at San Andrés (GEISTER, 1973:218; 1975:35. 47, 59, Fig. 9, section 5, Fig. 10, section 8).

2.3. LAGOON WITH PATCH REEFS AND FRINGING REEF

2.3.1. LAGOONAL TERRACES AND LAGOONAL BASINS

As at San Andrés, shallow (2-6 m deep) sandy terrace fringes the lee of the barrier and some larger patch reefs. This lagoonal terrace locally attains a width up to 1,2 km and terminates frequently in its lee at a steep "sand cliff"leading down to the floor of the lagoonal basins in 10 or more meters depth. The "sand cliff" apparently represents a fore-set slope of fine-grained sediments transported from the reef area to the terrace edge. Similar features were observed at San Andrés (GEISTER, 1975: 32, 38) and the atolls (MILLIMAN 1969a:8).

Two larger lagoonal basins can be distinguished N of the islands and two smaller ones to to the E and S of the main island, all of which are interconnected by shallowwater areas (Fig. 1).

The lagoon floor, covered mostly by white sand and local coral debris, is practically free of sea-grass vegetation, the principal exception being "Catalina Harbour", probably due to its wave-protected position in the lee of "Catalina Island", Patches of soft algae are common on the lagoon floor in certain areas E of the main island. Terrigenous components of the sediments due to weathering of the volcanic rocks are conspicuous near the coast of the islands. Extensive carpets of the staghorn coral *Acropora cervicornis* have been observed in certain shallow (4-7 m) lagoonal areas NE of the islands, where sufficient wave energy and currents pass through the incoherent part of the barrier reef.

2.3.2. PATCH REEFS AND RIBBON REEFS

Countless patch reefs of varying size are dotted over the floor of lagoonal terrace and basin. Only a few of them rise to near low tide level. In certain areas of the lagoonal terrace and basin. Only a few of them rise to near low tide level. In certain areas of the lagoonal terrace E of the main island anastomosing shallow ribbon reefs have ben observed, some of them more than 1 km long. At least part of them is formed predominantly by luxuriant growth of *Acropora cervicornis.*

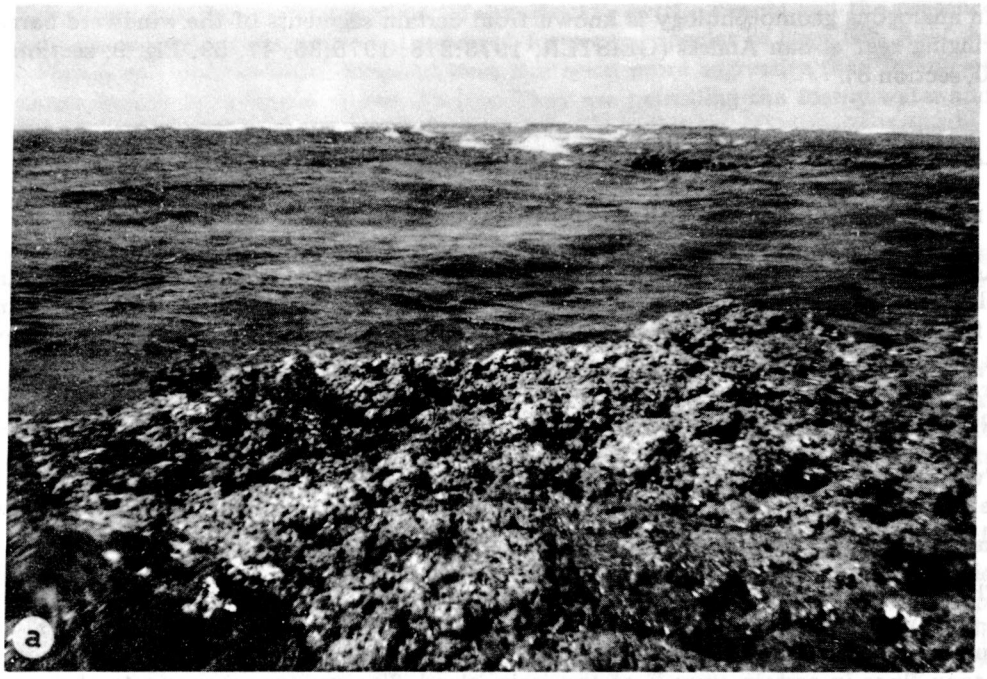
As at San Andrés (GEISTER 1975:33, 39), most patch reefs observed can be classified according to the dominant coral species of the reef crest area which reflect their degree of exposure to waves (GEISTER 1977). As a result the following ecological types of patch reefs may be distinguished in the Providencia lagoon:

1) *Palithoa-Millepora:* Shallow patch reefs near the barrier, well exposed to swell or surf.

2) *Diploria strigosa* and *Acropora palmata:* Patches in shallow agitated water, generally on the lagoonal terrace.

3) *Acropora cervicornis:* Several shallow patches in relatively protected position near island (Pl. I, Fig. b). "White Shoal", situated E of the main island, is rimmed by rich growth of *Acropora cervicornis* thickets, leaving a shallow sandy pseudolagoon in the center. From the air this patch reef appears as a tiny atoll.

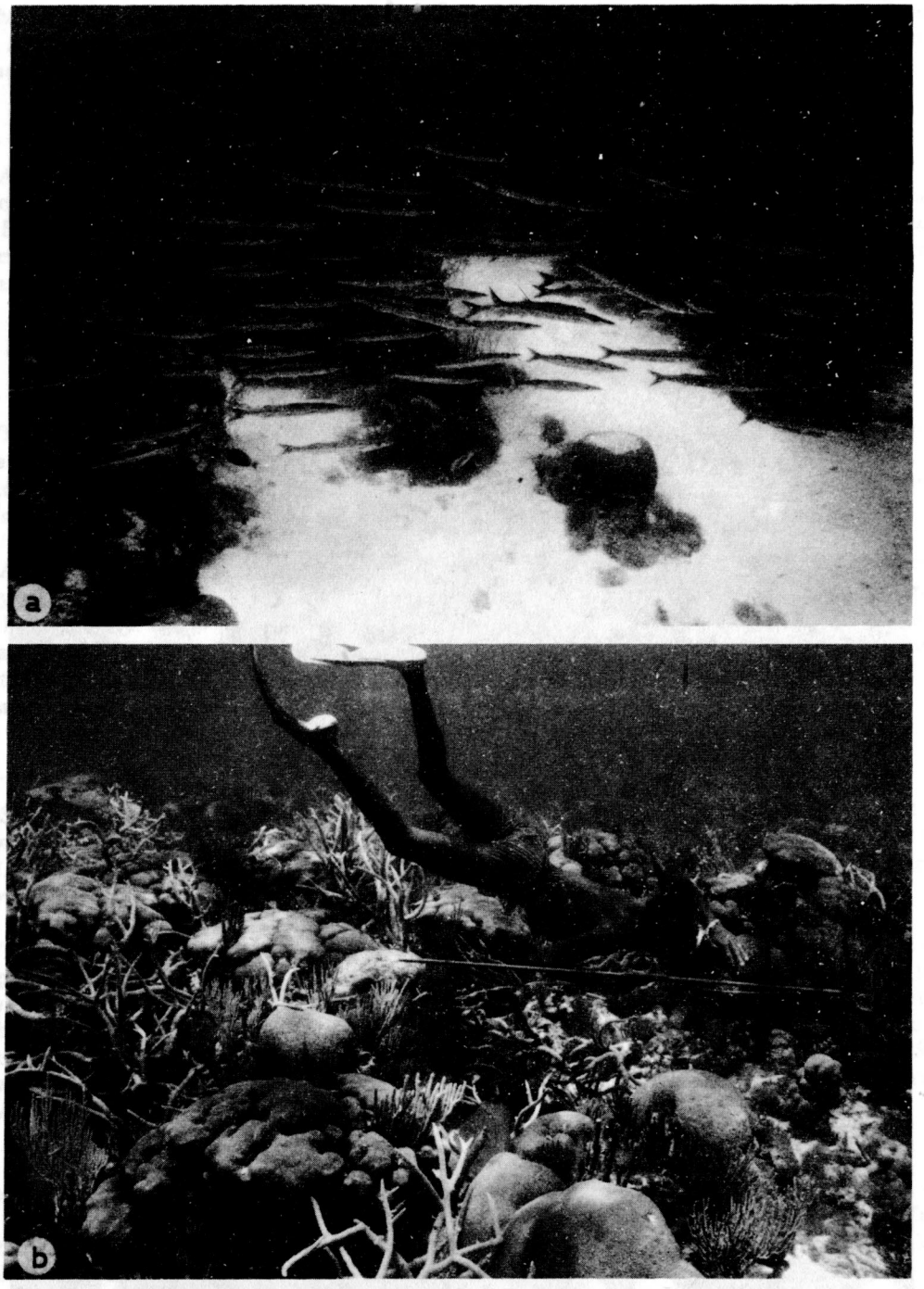
4) *Montastrea annularis:* Quiet-water patch reefs in wave-protected position or deeper water, associated frequently with certain gorgonians and several other scleractinian species (Pl. II, Figs. a, b). Occasionally mixed stands of *M. annularis* and *A. cervicornis* form well-developed patch reefs (Pl.II, Fig. b) in the shallow lagoon.



a. Algal ridge of the barrier reef S of "Low Cay" emergent during low tide and calm sea.
Foreground: Massive algal rock formed predominantly by the incrusting activities of red algae (Melobesieae).
Background: Sea breaking over algal ridges of more northerly reef segments.
Hammer for scale in center left: 32 cm.

b. Patch reef near the NE coast of Providencia in front of the electrical plant. Depth: some 2 - 4 m. Dense almost monospecific thickets of the staghorn coral *Acropora cervicornis* with a few scattered branching octocorals (center middleground and left foreground). On the slope to the lagoon big colonies of the star coral *Montastrea annularis* are recognizable in the background.

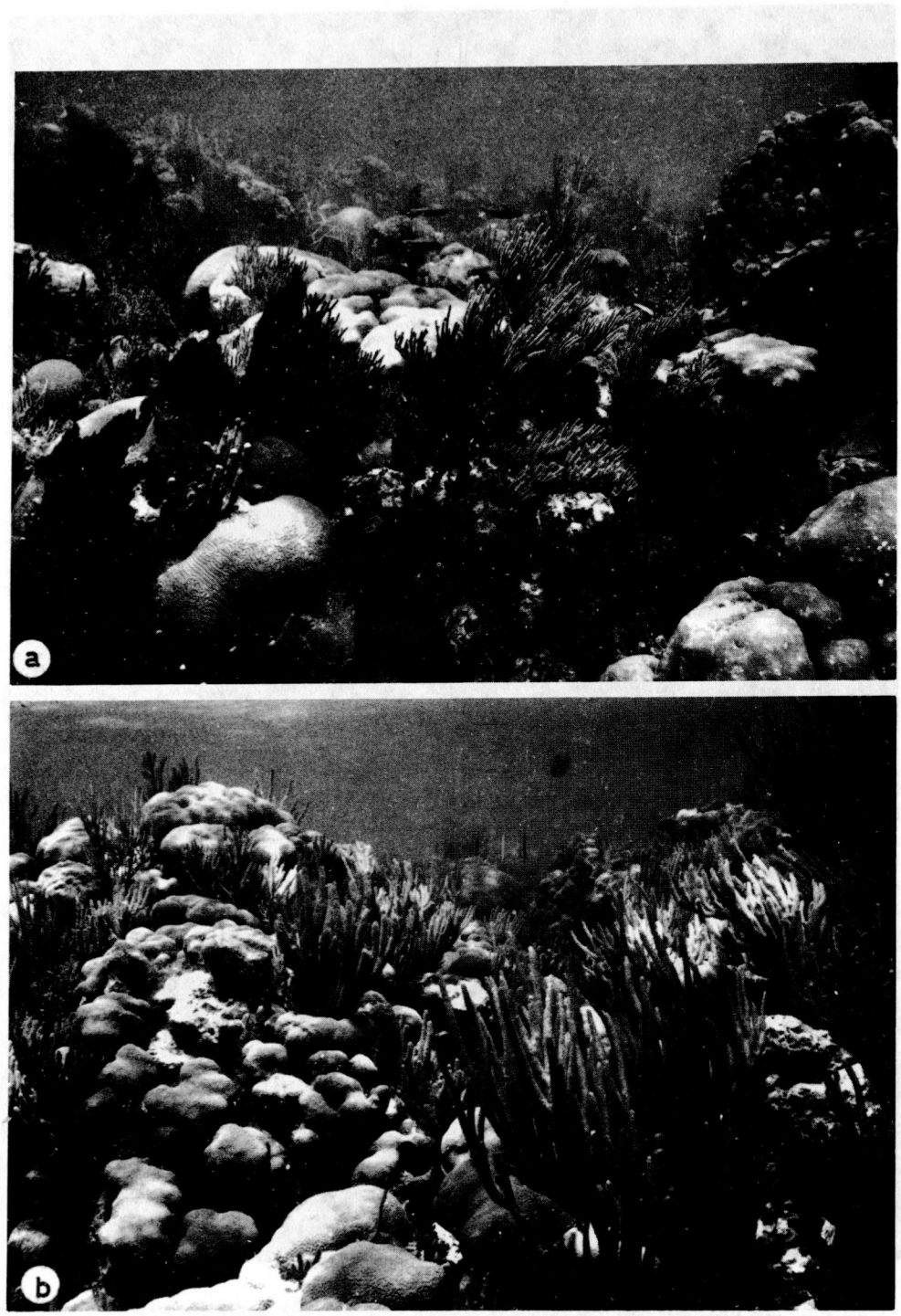
PLATE I: Algal ridge and patch ridge.



a. School of the Southern Sennet *(Sphyraena picudilla)* passing near the leeward marging of the barrier reef S of the "Elbow" area.
Foreground: Sand of the lagoonal terrace. Communities of *Montastrea annularis* and other massive sclearactinians associated with branching octocorals. Depth: 3-4 m.

b. Providencia spear-fisherman diving in patch reef formed by mixed stands of massive *Montastrea annularis* and the staghorn coral *Acropora cervicornis.* In the foreground a few colonies of the brain coral *Diplora labyrinthiformis. Depth:* some 4 m. Locality: Patch reef area SW of "The Elbow".

PLATE II: School of the southern Sennet and Providencia spear-fisherman.



a. Patch reef in the lee of the coherent barrier NNE of Sta. Catalina Islands showing calm-water fauna of massive *Montastrea annularis* among numerous octocorals (*Plexaura* sp., *Gorgonia* sp. and others). In the left foreground a colony of the brain coral *Diploria labyrinthiformis*, in the middle background a thicket of the staghorn coral *Acropora cervicornis*. Depth: *some 4 m.*

b. Similar patch reef and same area as above. The colonies of Montastrea annularis assume a branching growth habit as seen in the left foreground. Depth: some 3 m.

PLATE III: Patch reef in the lee of the coherent barrier NNE of Sta. Catalina Island.

Many coral patches in the deeper lagoon E of the island were found to be dead or almost dead and overgrown by algae. This is probably not caused by human disturbance of the environment.

2.3.3. FRINGING REEF

A shallow fringing reef lines the leeward shore of Sta. Catalina Island N and W of "Morgan's Head" (see Pl.IV). Its shallow narrow reef flat ends abruptly at a steep to vertical reef front, dropping down to a sandy lagoon floor at several meters depth. The coral fauna reflects calmwater conditions with abundant *Montastrea annularis* and certain branching gorgonians *(Plexaura* sp. etc.).

2.4. LEEWARD SHELF AND OUTER SLOPE

2.4.1. SHELF AREA WEST OF THE ISLANDS

This area is characterized by sandy and rocky flats at water depths between a few and more than 20 m with no significant growth of stony corals. Some coral patches, however, do occur and octocorals are scattered over hard susbtratum. According to air photos the condition should be similar on the leeward shelf N and SW of the islands.

A remarkable morphologic feature on the leeward shelf is "Channel Mouth", a sumarine valley leading from "Catalina Harbour" in a northwesterly direction to the shelf edge. It may well have formed as an erosional channel during a lowered Pleistocene sealevel stand, in prolongation of "Bowden Gully" which drains the NW slope of Providencia Island. "Channel Mouth" seems comparable to "Tinkhams Cut" in the windward barrier reef which would be the submarine prolongation of "Bottom House Gully".

2.4.2. "LAWRANCE REEF"

SW of "Channel Mouth" the entrance to "Catalina Harbour" is partially obstructed by "Lawrance Reef" a 700 m long coral shoal, lining the western margin of the shallow inner shelf. This reef is surrounded by a sandy flat, some 8 m deep, covered by loose sea-grass growth, except in a 10-20 m broad zone around the shoal (Pl. V, Fig. a).

The reef rises with relatively steep flanks to 4 and locally to 2 m below surface. Well developed coral growth in the shallowest part of the reef crest is dominated by *Acropora palmata* (Pl. V, Fig. b). Patches of *A. cervicornis* and *Porites porites* var. furcata are common at the higher flanks. Where the crest lies deeper and at the deeper slopes a more mixed faunal association of *Montastrea annularis, Porites clavaria, Diploria* ssp., *Siderastrea siderea, Stephanocoenia michelini, Dendrogyra cylindrus* and branching gorgonians has been observed (Pl. VI,Figs. a, b).

Apparently similar elongated shoals further to the N were seen on air photographs but were not visited. All these reefs might be remnants of a leeward barrier, partially eroded during a Pleistocene transgression and subsequently covered by younger coral growth. In fact, most of the lagoon and even part of the lagoonal basins are open to the W. This feature is in strinking similarity to the neighboring atolls (MILLIMAN 1969b: Figs. 3-6).

2.4.3. THE OUTER SLOPE AT "BLUE HOLE"

The outer slope has been visited only in the "Blue Hole" area during the 1969/1970 diving trips of the "Adventures in Marine Biology" Groups led by Sid ANDERSON Jr. around Providencia. The "Blue Hole" drop-off is and almost vertical submarine cliff, covered at least locally by rich coral growth. It is situated N of "Channel Mouth" where the 200 m curve bends far in towards E (see Fig. 1). At the location visited the drop-off descends from the marginal shelf terrace at 18 m to a narrow sandy bench at 33 m, from where a steep slope continues to greater depths. Possibly the escarpment is not always as steep and the shelf edge

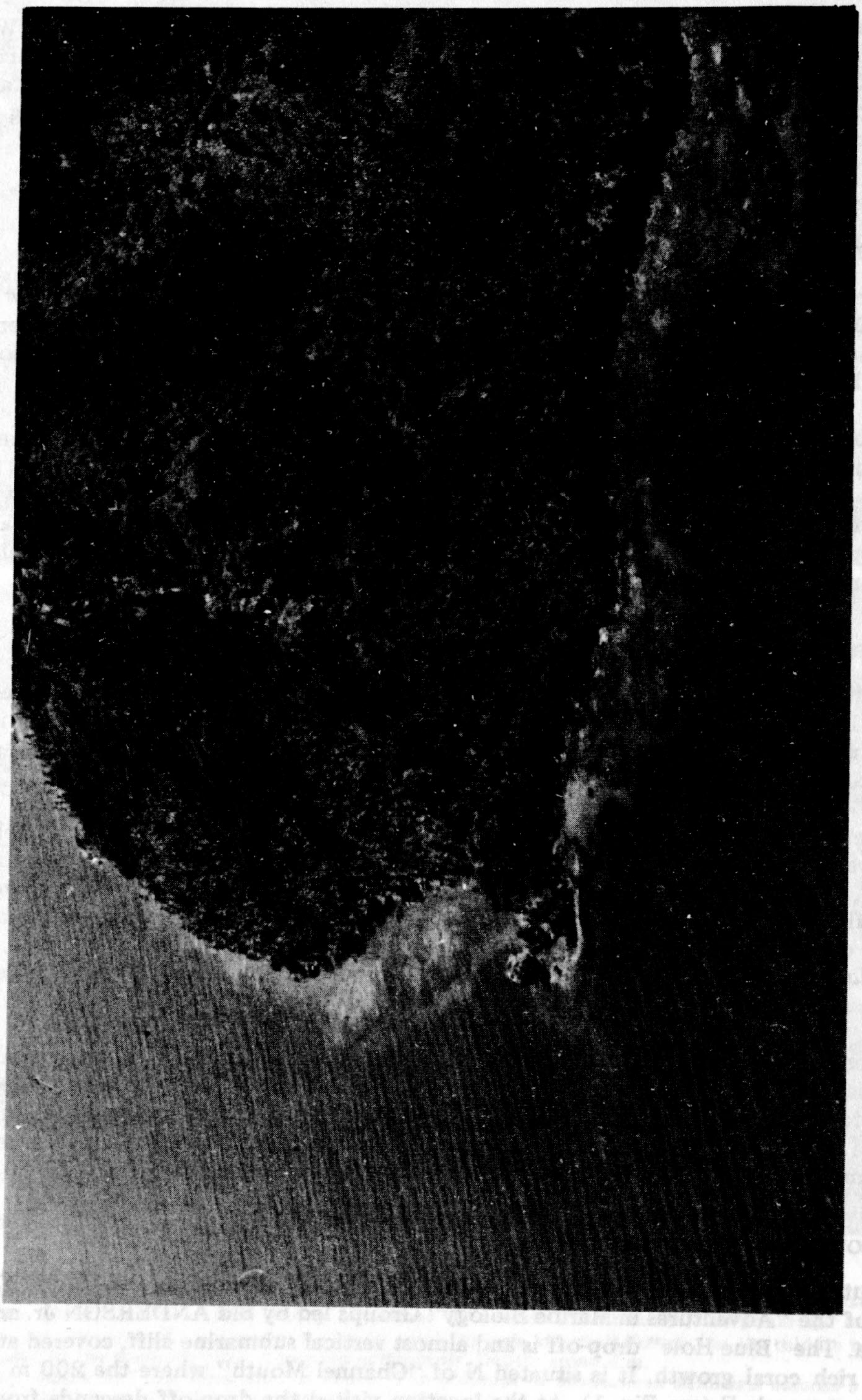
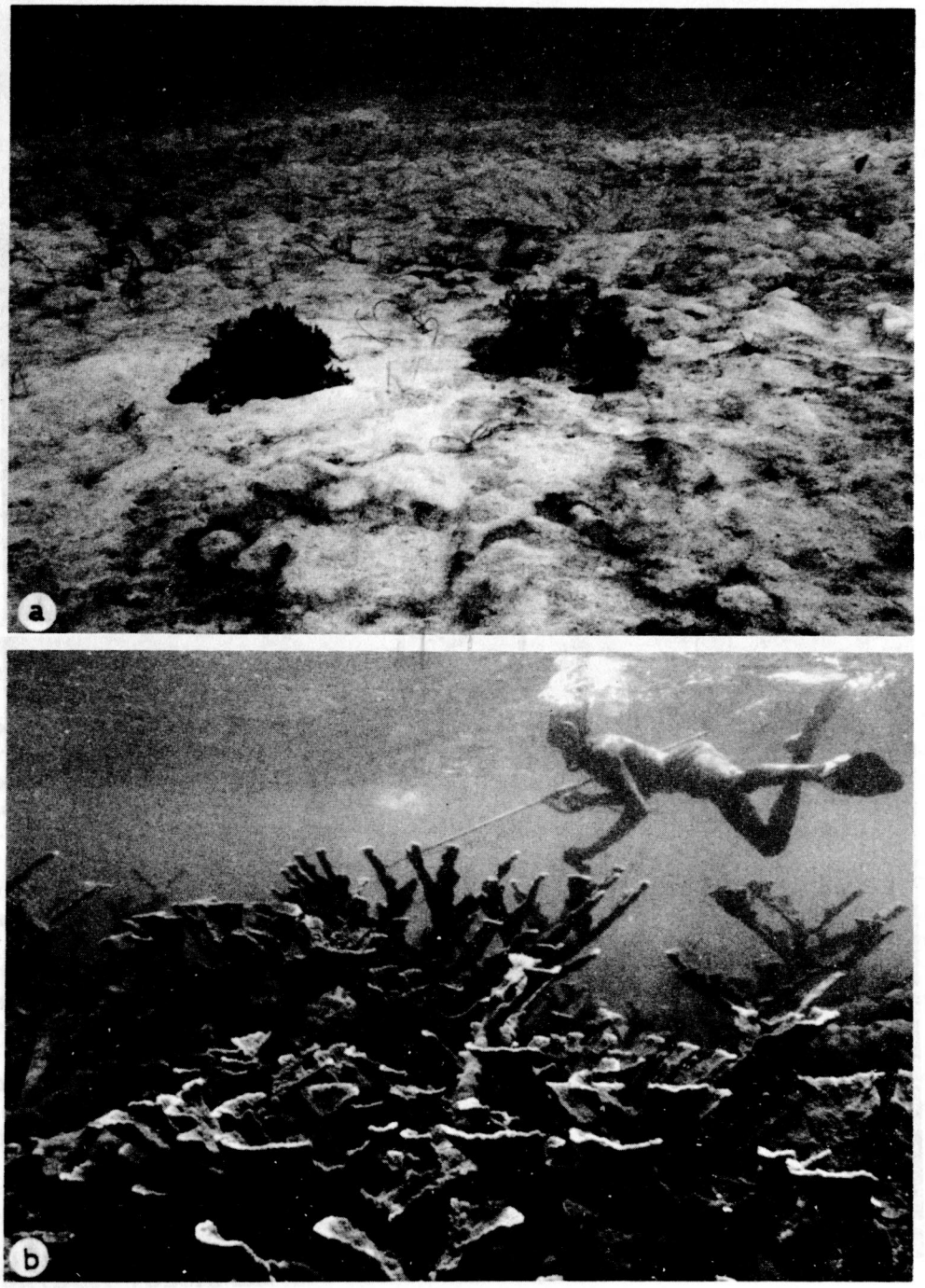
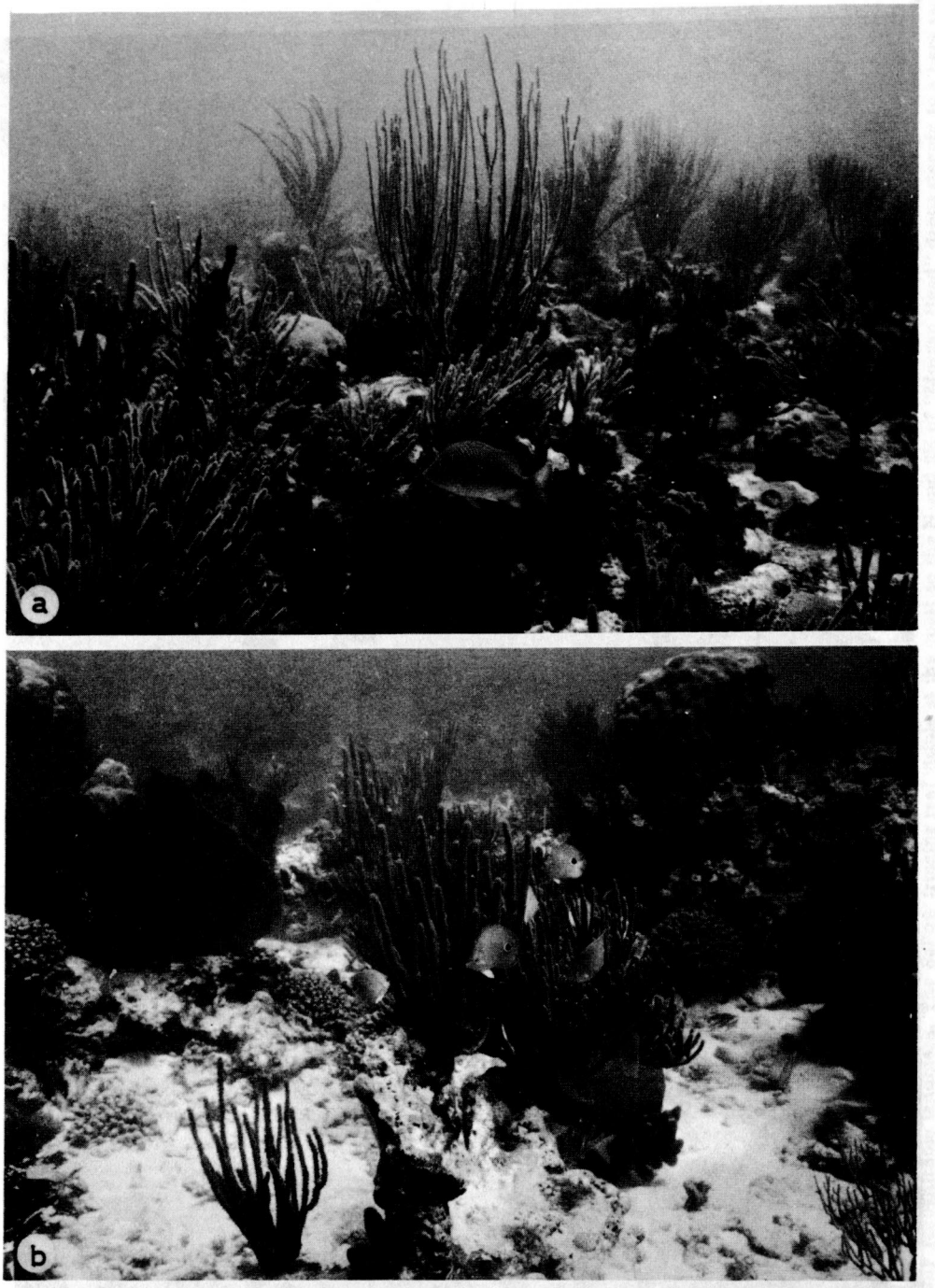


PLATE IV: Southwest coast of Santa Catalina Island as viewed from the air. The conspicuous roundish rock at the coast line in the left middleground is "Morgan Head", an easily recognizable landmark. The Sallow fringing reef visible at the coast to the N and SE of "Morgan Head" drops steeply to a bare sandy bottom at a depth of several meters, as indicated by the light colors. A few meters distant from the reef the sea floor is covered by sparse growth of sea-grass and algae and therefore appears darker. (Photo: courtesy Sid ANDERSON, Jr.).



a. Sandy flat near SW margin of "Lawrance Reef" at some 8 m depth. Poor growth of algae and sea grass on sandy sea floor. In the center two Queen conchs *(Strombus gigas)* overgrown by algae.
b. Shallow crest of "Lawrance Reef" covered by thickets of the elk-horn coral *Acropora palmata. Depth:* ca. 2-3 m.

PLATE V: Sandy flat and shallow crest of "Lawrence Reef".



a. Deeper water protected reef crest community near northeaster end of "Lawrance Reef" showing growth of massive *Montastrea annularis* and *Porites astreoides* as well as numerous Sea whips (*Plexaura* sp. and others). Deep: some 5 m.

b. Association of scattered octocorals *(Plexaura* sp., *Gorgonia* sp. and others) and scleractinians *(Porites porites* var. *furcata, Porites astreoides, Montastrea annularis, Diploria strigosa)* on reef crest of "Lawrance Reef". In many reef crest areas similar loose coral associations are common. In the center a school of the Foureye Butterflyfish *(Chaetodon capistratus).* Depth: some 3 m.

PLATE VI: Deeper water protected reef crest community and association of scattered octo-octocorals and scleractinians of "Laurence Reef".

not as shallow along the whole drop-off.

The coral association along the shelf rim near "Blue Hole" is characterized by *Montastrea annularis, Porites astreoides, P. clavaria, Siderastrea siderea* and a few colonies of the pillar coral *Dendrogyra cylindrus*. The occurrence of sea-fans and other octocorals is wide-spread. Along the deeper escarpment above the sandy bench *Eusmilia fastigiata, Colpophyllia natans,* mussids (including *Scolymia lacera* and *S. cubensis)* and *Meandrina meandrites* become very conspicuous. Large plate-like agaricids such as *Agaricia undata* are locally dominant. Various octocorals were found distributed all over the drop-off.

Narrow steps or benches that line the outer slope of the insular shelf at depths between 35 and 46 m are also known from San Andrés Island where they are also sand covered (GEISTER 1975: 128, Fig. 7, Fig. 10, section 8).

2.5. NOTE ON THE RECENT CORAL FAUNA OF PROVIDENCIA

Although no systematic colection of corals was attempted at Providencia as was done around San Andrés GESITER 1975, Tab. 10), it appears that basic faunal composition is about the same around both islands. In addition, two species not found at San Andrés occur at providencia: *Scolymia cubensis* (recovered from "Blue Hole" at 25m depth) and *Tubastrea tenuilamellosa* (from a cave in a coral pillar of the broken barrier reef at 0,75 m depth). On the other hand *Solenastrea hyades,* a species of which only one specimen was recovered near "Bocatora Hole"/San Andrés in 1977, has not so far been seen around Providencia.

All the basic benthic associations formely defined as breaker zones or wave zones (GEISTER 1977) were also encountered around Providencia; however, their relative surface covering may differ considerably from San Andrés.

For example, the staghorn coral, *Acropora cervicornis,* locally known as "gourd borer" or "devil's bone", covers extensive areas on the lagoon floor at Providencia. It is also the dominant constituent of many patch reefs. At San Andrés such *cervicornis* thickets are rather rare and occasionally smashed by storm waves.

In contrast, no extensive reefs of *Porites porites* were observed at Providencia, whereas they form a characteristic constituent of the southern part of the San Andrés lagoon. It appears that the incoherent barrier at Providencia permits the diffusion of sufficient wave energy into the deeper lagoon and thus favors the development of a *cervicornis* zone. In contrast, only feeble wave exposure is present in the southern San Andrés lagoon where a very shallow barrier reef flat prevents excessive agitación even of surface waters. These conditions of very low wave exposure favor the development of a *porites* wave zone.

The remaining basic coral communities or "wave zones" (GEISTER, 1977) such as algal ridge, *Millepora-Palythoa* zone, *strigosa-palmata* zone and *annularis* zone are represented around both islands in about the same proportions.

3. THE GEOLOGIC HISTORY OF THE ISLAND

3.1. TERTIARY VOLCANISM AND REEF SEDIMENTATION

Although several articles have appeared on the geology of the islands (SARMIENTO-ALARCON & SANDOVAL, 1953; MITCHELL, 1955; HUBACH, 1956; PAGNACCO & RADELLI, 1962) the complex volcanic history of Providencia has never been studied in detail.

On the basis of my own field observations conducted in 1969-70 and 1973, the volcanic eventos can be grouped into an older and a younger period of activity. An older complex of

volcanic rocks appears to be of pre-Miocene age (see below). Some of its effusives show a fluidal texture and may be submarine. Although they have a vitreous aspect similar to obsidian, a microgranular structure due to microliths of feldspar may be recognized under the microscope. Subsequent eruptions yielded a considerable mass of andesitic to basaltic lavas and conglomerates that partly overly the older rocks. They are mainly responsible for the present outline and rugged topography of the island whose highest peaks rise up to 400 m above the surrounding sea.

Five principal flows of these subaerial lavas, that radiate from a crater area in the central part of the island, can be recognized today. In outcrops near "South Point" these lavas and associated tuffs interfinger with near-shore and lagoonal sediments containing macrofossils of Miocene - most likely early Miocene - age. The fossils comprise such diverse groups as reef corals *(Stylophora, Pocillopora, Pironastrea, Coscinaraea,* poritids, *Montastrea, Favia, Trachyphyllia),* mollusks *(Ostrea,* cardiid, pectinid, gastropod), echinoids *(Clypeaster, Encope)* and balanids (manuscript in preparation). These sediments provide an indirect indication that a reef complex with lagoon and possibly with barrier reef existed already in Tertiary time.

No evidence for considerably younger eruptions or other volcanic activities can be found on land. Mitchell (1955:77) reported the presence of hot springs and sulphurous deposits, which would indicate an extension of volcanic activity to Holocene time, but no such phenomena were observed during field studies conducted from 1969-73. The volcanism is, therefore, most probably only of pre-Miocene and Miocene age. Since the Miocene the island has aparently been subjected only to erosion.

3.2. PLEISTOCENE TO RECENT GEOMORPHOLOGY AND REEF FORMATION

Several limestone terraces were formed both on the island and on the insular shelf during Pleistocene sea level oscillations. In contrast, no erosional terrace in the volcanics is evident, a fact understandable in view of the considerable resistance of these lavas to marine erosion.

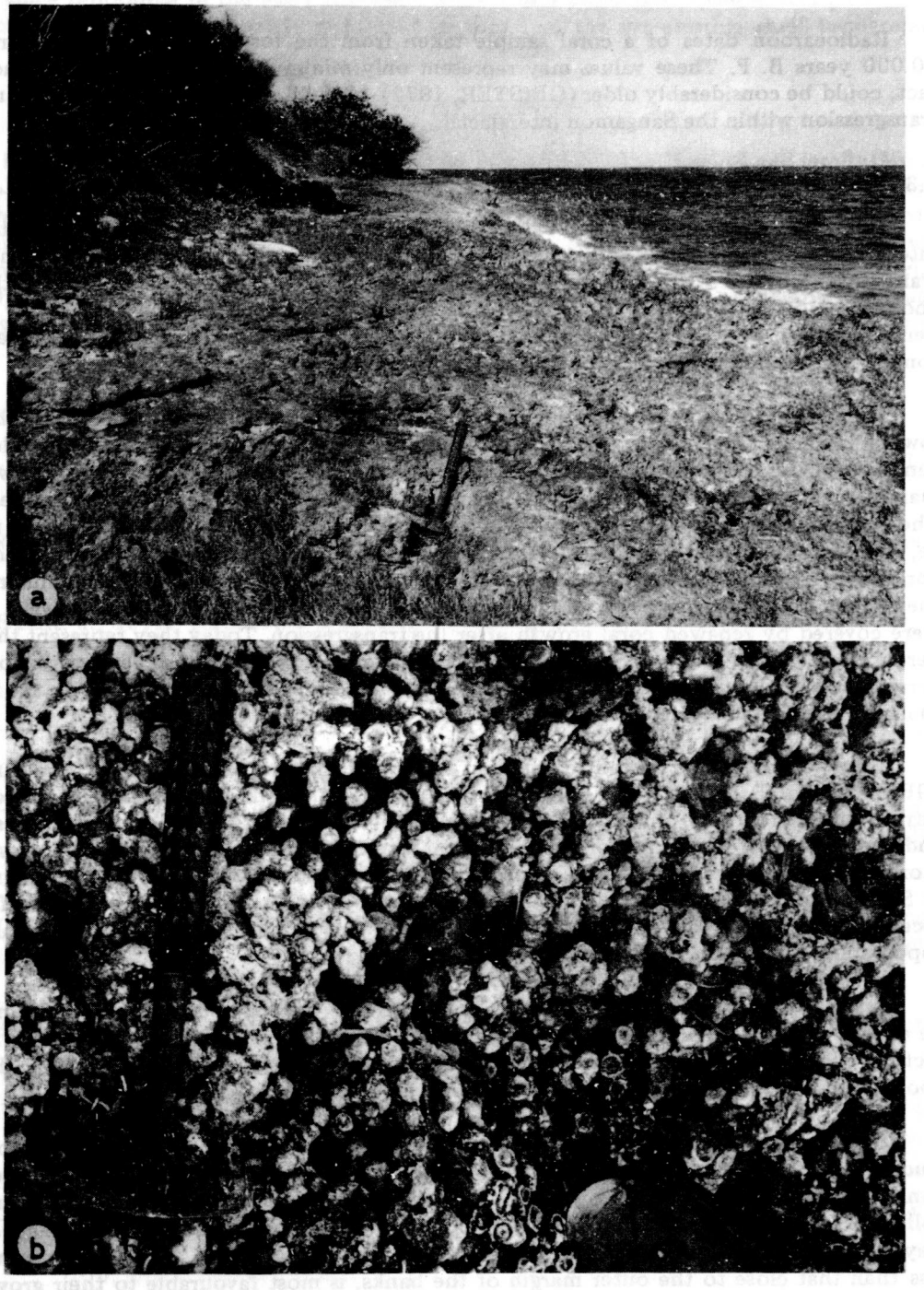
Near "South Point", at an elevation of 50-60 m above the present sealevel, a narrow relict terrace has been preserved. It is cut in Miocene limestone and apparently marcks a relatively high sea level stand sometime during the Pleistocene.

Close to this spot the Recent coastal cliff is cut into a raised Pleistocene fringing reef whose reef flat formes a terrace up to some 2 m above present sealevel (Pl. 7, Figs. a, b). The reef framework of almost monospecific stands of the finger coral *Porites porites* var. furcata indicates a protected environment, subject only to feeble exposure to waves during its formation (GEISTER, 1977:25). Among the prevalent *Porites porites* var. furcata colonies a few specimens of the following coral species have been collected:

Acropora palmata
A. cervicornis
Porites astreoides
Siderastrea siderea
S. radians
Diploria clivosa
Diploria labyrinthiformis
Montastrea annularis
Isophyllastrea rigida

Among the corals and in the lithified lagoonal sand adjacent to the reef a number of mollusk shells was found, most abundant being the gastropod *Cittarium pica.* This species is commonly found today in Providencia living on Recent cliffs below low-tide level.

Any shallow fringing reef along the eastern margin of "South Point", if unprotected, would be exposed to heavy swell, normally approaching from an easterly direction. Therefore, it can be assumed that the quietwater fauna of the fossil fringing reef is indirect evidence of a protecting barrier during that time. The postition of the elevated fringing reef shows that a corresponding barrier must have protruded some 2 or 3 m above the crest of today's barrier reef. As was shown above, these considerations supplement quite well several features



a. Raised Pleistocene fringing reef near "South Point", Providencia forming a narrow coastal terrace. Hammer for scale: 32 cm.
b. Reef flat of above Pleistocene fringing reef consisting of almost monospecific stands of the finger coral *Porites porites* var. *furcata.* Hammer for scale: 32 cm. View from above.

PLATE VII: Raised Pleistocene fringing reef and reef flat of above, near "South Point", Providencia.

of the insular sheld where erosional morphology is a consistent feature in many segments of the Recent barrier reef.

Radiocarbon dates of a coral sample taken from the fossil reef yielded ages around 30.000 years B. P. These values may represent only minimum age and the reef terrace, in fact, could be considerably older (GEISTER, 1972). More likely this reef dates from a major transgression within the Sangamon interglacial.

3.3. POSSIBLE ORIGIN OF THE CONTEMPORARY INSULAR SHELF MORPHOLOGY

The most remarkable aspects of the Providencia barrier reef are its partial fragmentation into a chain of coral pillars and knolls along the windward side and its wide gap on the leeward shelf. Moreover, the windward barrier is paralleled by a chain of patch reefs on the lagoonal terrace, which locally develop into high coral pillars, thus forming a secondary incoherent barrier. This tract of patch reefs alone separates the lagoon from the open sea for some 7 km, where the barrier proper is lacking (see Fig. 1).

The peculiar outline and topography of the barrier reef here described suggests the folowing geomorphological history: During a prolonged lowered sea-level stand of the Pleistocene the planation of the fore-reef terrace proceeded locally completely across the whole marginal reef area of a hypothetical Pleistocene reef complex to the old lagoonal basin behind. The resulting comparatively deep and flat topographical crest adjacent to the lagoonal terrace, some 5-10 m below today's sealevel, was colonized subsequently at the windward side by coral patches which developed into pinnacles during slowly rising sealevel. The remmnants of the old barrier reef adjacent to the lagoon basins on both the windward and leeward sides were covered by renewed coral growth after the transgression. Today they represent the coherent segments of the barrier reef. The absence of coral pillars in the leeward gap of the barrier may be due to an unsuitable substrate of loose sediments accumulating on the inner shelf of this wave protected area.

Based on evidence obtained during studies of similar phenomena at San Andrés (GEISTER, 1975:129-132, 161, Fig. 28), it is assumed that the formation of the fore-reef terrace (or 20 m terrace) of Providencia is considerably older than the Holocene transgression, and most likely of Sangamon or pre-Sangamon age. Renewed reef growth on the erosional morphology may have already begun durin a late Pleistocene submergence, as was recognized at San Andrés. After the late Wisconsin emergence and Holocene reflooding of the shelf, Holocene coral growth would only have modified the antecedent erosional / constructional reef topography.

This hypothesis needs further confirmation by core drilling and radiometric dating, to be carried out at several locations on the Providencia insular shelf. At the moment no satisfactory explanation can be given for the development of the patch reef chain along the lagoonal terrace substituting for the main barrier over several kilometers.

It is merely of historical interest today that Darwin (1851:196-198), bases mainly on his studies of nautical charts, explained the formation of the fore-reef terraces ("submerged banks") at Providencia and nearby atolls by accumulation of sediments, i. e. fine drift matter collected in the lee of prevailing sea-currents. However, the position of the reef tracts some way within the line of deep water he could not explain, "without it be, that a depth somewat less than that close to the outer margin of the banks, is most favourable to their growth".

From the evidence above we may make the preliminary conclusion that the existence of an insular shelf can be traced back at least to Miocene time. The contemporary shelf morphology is the product of a complex history of sealevel oscillations accompanied by terracing at different levels, renewed reef growth and erosion. Of this history, at present, only a few evolutionary stages may be recognized. Volcanic activity did not contribute to the geomorphologic evolution of the shelf in post-Miocene. The shelf was last exposed to subaerial weathe-

ring during the sealevel lowering that accompanied the late Wisconsin glaciation. It appears that since reflooding in the early Holocene some 5.000 years ago, renewed reef growth and sedimentation have only partly concealed or modified the pre-existing shelf topography.

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