A COMPARATIVE SURVEY OF CORAL REEF RESEARCH SITES*

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The complexity of coral reef environments has long attracted scientific interest, but as yet few if any research programs have compared reefs from different areas or oceans with a view to understanding the overall functioning of a reef ecosystem. Plans for such programs recently were initiated at the Smithsonian Institution, and it was found that in the undertaking of an interdisciplinary investigation of reef ecosystems, the first critical step is to choose research sites that can meet stringent scientific criteria.

The Smithsonian's comparative information on potential reef research sites in both the Caribbean and Pacific is being presented here in the hope that other investigators will find it useful in planning future reef studies. The data were originally compiled as a report on the research site selection process for the Smithsonian programs, and this has largely determined the present format. The observations are primarily qualitative in nature, presenting a broad view of comparative reef structure and composition. Their value lies in their common perspective, having been compiled by a closely integrated site selection team whose members, within a short time, visited many coral reef areas throughout the Caribbean and much of the Pacific, applying common criteria to achieve a common goal.

The site search was conducted for two programs of the Smithsonian Institution. The first, Investigations of Marine Shallow Water Ecosystems (IMSWE), was organized within the National Museum of Natural History with the support of the Smithsonian Environmental Sciences program to conduct an integrated biological and geological analysis of coral reef communities. The second was to be a much larger, multi-institutional program, the Comparative Investigations of Tropical Reef Ecosystems (CITRE), developed under the auspices of the Smithsonian Office of Environmental Sciences with a planning grant from the International Decade of Ocean Exploration Office at the National Science Foundation. The plans for the CITRE program included the development of a complete systems analysis model of the reef ecosystem based on energy and material flows through various reef components. For both programs, the scientific advantages and greater research potential of a scientifically "ideal" reef site were given first priority, with purely logistical considerations

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considered secondarily, and thus a fresh look was taken at many potential reef research areas with the context of the programs in mind. An "ideal" reef was considered to be one that is subject to little external stress, and that is characterized by as many of the scientific criteria as possible.

Since the criteria by which sites were judged have a crucial bearing on the conclusions of the site analysis, they are outlined below in some detail:

1. Ample development of all characteristic reef zones, from the "reef flat" to deep water communities in depths of 50 to 100m.

2. A steep fore-slope, to facilitate field observations by telescoping the zonation.

3. Vigorous reef growth where interactions with the surrounding water mass can be measured and with a good geological record of past development.

4. Unidirectional current flow for periods long enough to permit cross-reef metabolic studies of the type successfully used at Eniwetok (Johannes et al. 1972).

5. No overriding unique characteristics with respect to the reefs in the same area.

6. Freedom from major terrestrial, human, or natural catastrophic influences in the present or recent past.

Some practical criteria could not be ignored:

1. Sufficient accessibility to meet the needs of a large program.

2. A harbor and some accommodations and facilities, or the possibility of developing these at reasonable cost.

3. Availability of research vessel support.

4. Probability of a stable government with a favorable attitude towards the program.

5. Suitability for research needs such as multiple sampling, monitoring with shore-based instrumentation, drilling for geological samples, etc.

Since the published literature has only scattered information on many of these features, a questionnaire (Fig. 1) was developed and sent to numerous scientists with field experience in the Caribbean and the tropical Pacific. The response was generally good, particularly for the Caribbean, and provided many suggestions for potential coral reef research sites. Following preliminary evaluation of the questionnaires, survey teams were sent to the most promising reef areas to investigate their appropriateness in terms of the established criteria. The standardized reports of the survey teams, based primarily on their first hand observations, make up the body of the present paper. For the sake of brevity, no attempt has been made to cite the many earlier published reports on the areas described.

Reef descriptions were compiled from field notes and photographs. At least one, and generally two or more of the authors participated on all survey teams in order to provide a basis for valid comparative judgements. In all instances the surveys focused on the set criteria although additional details included in the reports may reflect the special interests of individual team members rather than the unusual prominence of a particular group. The conclusions in terms of site preference, were conditioned by the criteria for the proposed ecosystem programs, and would differ if other factors were to be included.

Charges for facilities or transportation, where given, are those at the time of the surveys (generally 1971) and are included only where such information is difficult to obtain to give a rough measure of practicality.

For convenience and clarity, and Caribbean and Pacific sites are treated separately. The Pacific survey was inevitably less thorough, and many other areas warrant detailed examination. The Indian Ocean and more distant Pacific areas such as Australia were excluded as being impractical for a U.S.-based program.

CARIBBEAN AREA

Until recently, Caribbean coral reefs were generally considered inferior to their Indo-Pacific counterparts, mainly because previous studies concentrated on the southern Florida and northern Bahama area (e.g. A. G. Mayor; T. W. Vaughan), which is noted for its marginal coral-reef development. Recent investigations, however, indicate that this earlier assessment of Caribbean reefs is not altogether accurate. Although reef growth in the Caribbean is accomplished by considerably fewer coral species than in the Indo-Pacific, the reef construction processes are comparable. In other words, the same variety of reef types occur in both oceans, as well as an overall similarity in zonation with depth.

Data on potential research sites were compiled for the Caribbean Sea and areas to the north. Regions of coral growth in the southwestern Atlantic, south of the barren area of heavy sedimentation off the Orinoco and Amazon rivers, were excluded from consideration owing to logistical problems and lack of scientific justification (see Laborel, 1967). Three sources of data were used: (a) the literature; (b) standard questionnaires sent to experienced workers in the Caribbean region; and (c) report from the site-survey teams. Information from the questionnaires is condensed in Table 1.

From accumulated information and the personal reports of program members, a number of sites were selected for detailed field examination, including Acklins Island (Bahamas), St. Croix (U.S. Virgin Islands), Discovery Bay (Jamaica), Glover's Reef (British Honduras) and the San Blas Islands (Panama). The data in Table 1 incorporate the conclusions of the survey team reports, which follow.

Acklins Island, Bahamas*

The reefs off the north and east coast of Acklins Island (22°30'N 74°00'W) in the eastern Caribbean were surveyed during two visits; the first on Oct. 20-24, 1970 by a two-man team, and the second from April 13-23, 1971 by an eight-man team.

Acklins Island is part of the Crooked Island District of the Bahamas, but in fact is separated from Crooked Island by "The Going Through", a tidal channel (Fig. 2). The nearest populated center is Nassau, and from there access to Acklins is by small plane or boat. An old airport at Pinefield Point will soon be replaced by the new one under construction at Pompey Bay. At present, charter airlines land on a road near this bay. Apart from this service, two weekly flights are available from Nassau to Crooked Island. The trip to Acklins is completed by taxi and ferry (small outboard).

A 27 m vessel based in Chester on northern Acklins is used primarily for shipping and ferrying from Nassau to Chester, but would be available for charter at $100/day, and it could feasibly be considered for a floating hotel or ferry for reef diving. Small boats are readily available, but outboards are not.

The population of Acklins is sparse and scattered along the western and northern coasts. Only a few settlements can be called communities. The cost of living is very high because nearly all commodities are imported. Local facilities for visitors are few and also expensive (e.g. a small cottage with barest essentials costs $11(US)/day/person, and a half-ton truck $24/day with driver). A research team would probably have to bring "bed and board" with it.

The island is composed of Pleistocene calcarenite, apparently predominantly oolitic material. Its topography is relatively flat but a series of striking "fossil dune ridges" (up to 30 m relief) parallel the present coastline. The water table is close to the surface (2-3 m) so that fresh water is readily available. The soil is very thin except in some depressions. Most of the vegetation is a heavy growth of low brush, generally about six to ten feet high, but there are a few scattered trees (coconut, mahogany, casuarina and tamarind). Mangrove swamps are well developed on the northern end of the Bight of Acklins.

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*Field survey: October 20-24, 1970, by W. H. Adey, and I. G. Macintyre. Second field survey: April 13-23, 1971, by W. H. Adey, A. Antonius, A. L. Dahl, P. M. Kier, I. G. Macintyre, M. E. Rice, and T. R. Waller.

First Visit: October 20-24, 1970

The eastern and northern areas of Acklins were investigated as well as the central lagoon area (Bight of Acklins). Heavy swells created rough weather conditions and turbidity for two days, a condition common in the area from October to April. The following sites were examined:

1. West side of Atwood Harbour, north coast of Acklins Island.

The patch reef here is no more than 15 m from shore, and it abounds with fish; a hawk's bill turtle also was observed in the area. Much of the reef surface is covered with crustose coralline algae, especially of the genera Porolithon and Neogoniolithon but large growths of Montastrea annularis, Acropora palmata, Millepora, Porites astreoides, and Porites porites were also present.

The sandy bottom of the harbor, where examined, had well-developed Thalassia beds with large heads of Neogoniolithon strictum. In the southwest where the current was strong only a thin sediment cover was present over the rock ledge and small heads of Siderastrea radians and Favia fragum occurred.

2. Patch reef directly shoreward of bank barrier reef off east coast of Acklins Island, opposite Golden Grove.

The reef here is about one and a half kilometers offshore. The abundant patch reefs in this area are surrounded by a sandy bottom and have about 6 m of relief. A very high percentage of the reef surface is covered by Porolithon, Neogoniolithon and other corallines. No large caverns were observed as described elsewhere on the Bahama Banks (Storr, 1964), but there were "overhangs" here and there. Large colonies of Acropora palmata and Millepora were observed along with abundant but small colonies of Agaricia agaricites. Additional common corals include three species of Diploria, Dichocoenia stokesii, Porites astreoides, and Montastrea annularis. A great abundance of alcyonarians was also noted.

3. Inner edge of bank barrier reef, northeast coast of Acklins Island off Pinefield Point.

Going seaward from the patch reef there is a zone of abundant Montastrea annularis and Diploria coral heads leading to the turbulent inner edge of the reef flat, where there are large overturned growths of Acropora palmata (some were live growths) and large growths of Millepora. Rock surfaces and coral debris are heavily coated with coralline algae. Fish were abundant, including a number of different types of parrot fish, some quite large, which seem to inhabit an open network of small tunnels under the coral-rock floor.

4. Off Spring Point on the west coast of Acklins Island in Acklins Bight.

For a distance of about 150 m from shore a very thin layer of sediment covers the smooth rock pavement. Rich algal growths of Halimeda, Penicillus, Batophora and Acetabularia were observed, along with two species of corals: Siderastrea radians and Flavia fragum. A few colonies of Manicina areolata were also noted.

TABLE I: Questionnaire Response - Caribbean Area

Site	Reef Structures*	Undisturbed	Accessible	Local Facilities	Political Status+
Colombia					
Islas del Rosario	-	+	0	-	-
Santa Marta	-	0	+	+	-
Curacao	+	0	+	+	+
Venezuela					
Los Roques	-	+	-	0	-
Cubagua, Coche, Margarita, Los Frayles Islas	-	+	-	-	-
Lesser Antilles					
Dominica	+	+	-	-	0
Puerto Rico					
Mona Island	0	+	0	-	+
Virgin Islands					
St. Croix	±	±	+	+	+
Hispaniola					
St. Domingo area	+	0	+	0	-
Jamaica					
Discovery Bay	+	-	+	+	0
Barrier Reef and Cays, Pedro Cays, Pedro Bank Banner Reef	+	+	+	-	0
Grand Cayman	+	+	+	0	0
Bahamas					
Acklins Island	-	+	0	0	+
Andros Island	+	+	+	0	+
Bimini	-	-	+	+	+
Bermuda	-	0	+	+	+
Mexico					
Islas de Lobos	-	+	-	-	0

Site	Reef Structures	Undisturbed	Accessible	Local Facilities	Political Status
British Honduras					
Barrier Reef	+	±	+	-	+
Turneffe Island	-	±	+	-	+
Lighthouse Reef	+	±	+	-	+
Glover's Reef	+	+	+	0	+
Colombian Islands (off Nicaragua)					
Serrana Bank	+	+	-	-	-
Roncador Bank	+	+	-	-	-
Old Providence Island	0	+	-	-	-
St. Andrews Island	-	+	-	-	-
Courtown Cays	+	+	-	-	-
Albuquerque Cays	+	+	-	-	-
Great Corn Island	±	+	-	-	-
Panama					
Holandes Cays, San Blas Islands	±	+	-	-	+

Key + = favorable or present 0 = unknown or possible - = unfavorable or impractical

± = variable

* see selection criteria above, p.
\+ basically the anticipated government attitude towards a large U.S. funded program

Questionnaires and equivalent information on Caribbean sites were supplied by the following: W. H. Adey, A. Antonius, R. W. Bauer, A. L. Dahl, R. F. Dill, J. Geister, P. W. Glynn, L. S. Land, J. C. Lang, I. G. Macintyre, J. D. Milliman, J. L. Munro, R. Pfaff, J. K. Rigby, and K. Ruetzler.

Second Visit: April 13-23, 1971

5. Atwood Harbor, North Coast of Acklins Island (see Fig. 3)

Back Reef

This area is characterized by small patch reefs scattered on a rock platform which generally has a thin sand cover. These protected patch reefs have a relatively dense coral growth consisting primarily of Acropora palmata, Montastrea annularis, Porites astreoides, Agaricia agaricites, Dichocoenia stokesii, Dichocoenia stellaris and Porites porites.

Reef Crest

Coral composition on the lee side of the reef crest is almost identical to that of the patch reefs. However, the remainder of the reef crest is dominantly composed of Acropora palmata and Montastrea annularis which form an open framework marked by the common occurrence of dead overturned coral communities.

Upper Fore-Reef Slope

The dominant characteristic of this area of the reef is a gently dipping rock pavement. The two distinct zones observed are a) barren zone 1.5-6 m and b) grooved zone 6-18 m.

Barren Zone: Predominantly a knobby rock bottom with a thin covering (2 cm) of benthic algae and fine to coarse carbonate sand. Crustose corallines generally are thriving under this algal-sediment cover. Small coral colonies scattered over the rock surface include Diploria strigosa, Siderastrea siderea, Siderastrea radians, Dichocoenia stokesii, Montastrea cavernosa, Montastrea annularis, Agaricia agaricites, Porites astreoides, Porites porites, Colphyllia natans, Isophyllia sinuosa, Meandrina meandrites. Sargassum sp., gorgonians, and Millepora sp. increase noticeably in depths less than 4 m and large patches of boring sponges are common. Scattered shallow (1 m) depressions in the rock pavement have a well-rippled coarse sand or rubble bottom. A few Diadema sp. occur under ledges in the walls of these depressions.

Grooved Zone: The most striking feature of this depth zone is the grooves which are clearly visible in aerial photographs. Off Atwood Harbour they are generally less than 30 m apart and are commonly about 60 m long. The gently dipping rock pavement transected by these grooves is encrusted with a variety of tropical-reef corals, but the colonies are generally small, well-spaced and therefore do not form an interlocking framework. Dominant corals include the following species: Diploria strigosa, Porites astreoides, Siderastrea siderea, Dichocoenia stokesii, Dichocoenia stellaris, Montastrea cavernosa, Montastrea annularis, Favia fragum, Meandrina meandrites, Diploria labyrinthiformis, Colpophyllia natans, Stephanocoenia michelinii. Gorgonians and sponges are also abundant in this depth zone.

The groove system begins in a general depth range of 5 to 10 m as an indistinct labyrinth of channels between the scattered coral growth. In our limited observations we did not find grooves originating as "spoon-shaped incisions" or "erosional pits," as reported for similar features off Andros Island (Newell et al., 1951, p. 25) and off Saipan Island (Cloud, 1959, p. 406).

These indistinct channels coalesce to form a well-defined u-shaped groove which is relatively straight and has a smooth sediment-free surface covered with a thin algal growth and corals here and there. These u-shaped grooves, which are about 10 to 15 m long, widen from 15 cm wide and 15 cm deep to 1 m wide and 1 m deep where they open out into a still deeper and wider sediment-filled groove. In some places, up to three separate u-shaped grooves were noted to be feeding into the same broad sediment-filled one.

The sediment-filled sections are generally about 50 to 60 m long with a maximum width of about 10 m. The lower sediment-filled sections tend to taper into a series of lobes at the outer limit of the grooves. The thickness of accumulated sediment in the troughs was not established; however, at the head of the sediment-filled sections the walls were 2 to 2.5 m high and gradually diminished in relief to about 1 m at the terminus. It is interesting to note that the grooves investigated were completely enclosed with no ready outlet into deeper water for the sediments.

At the head of the sediment-filled sections there is a band 5 m wide of coral rubble which grades down-slope into a well-rippled sand (wave length, 60 to 150 cm, amplitude, 12 to 15 cm). This is an extremely coarse to medium-grained skeletal calcarenite with gravel size material collecting in the ripple troughs. Texture gradation of the sediments continues down the groove so that about half-way down, the gravel is absent and there is simply a poorly sorted, extremely coarse to medium-grained skeletal calcarenite, which in turn grades into a well-sorted medium to coarse-grained skeletal calcarenite at the terminus of the groove.

Without subsurface data it is difficult to establish whether these linear features have been formed by erosion or differential accumulation of organic limestone. Newell et. al. (1951) found that grooves off Long Cay in the Bahamas cut into oolite bedrock, which clearly indicated an erosional origin.

<u>Lower Fore-Reef Slope</u>

This area starts at depths ranging from 12 to 18 m, where the slope of the sea floor increases markedly, and continues to the depth limits of our observations, approximately 40 m.

Large areas of well-developed and diverse deep-water coral communities are predominant in the upper section of this area. Sediment chutes that traverse the coral communities here and there coalesce at depths of 20 to 25 m to form an extensive sand flat. Below this sand flat the corals do not show any appreciable change in species composition but tend to construct large coral mounds covering areas of up to 220 sq. meters with approximately 3 m of relief above the surrounding sand slope.

The dominant corals of the lower fore-reef slope consist of the following species, in order of their abundance: Montastrea annularis, Agaricia agaricites, Montastrea cavernosa, Mussa angulosa, Diploria labyrinthiformis, Meandrina meandrites, Eusmilia fastigiata, Mycetophyllia lamarckiana, Colpophyllia natans, Porites astreoides, Stephanocoenia michelinii, Dichocoenia stokesii, Dichocoenia stellaris, Porites porites, Isophyllia sinuosa, and Diploria strigosa.

East Coast of Acklins Island

6. Off Pinefield Point

The area observed begins at a depth of 20 m where there is a distinct sand flat. Coral heads are sparse and widely scattered, but gorgonians and benthic algae are very common.

Below a depth of 20 m the slope of the sea floor increases and coral growths tend to be restricted to linear ridges which are separated by sand and gravel-filled grooves generally 3 m wide and 1 m deep. The coral assemblage is similar to that of the deep-water coral communities noted on the lower fore-reef slope off Atwood Harbour. Corals give way to a sand and gravel slope at depths of 35 to 40 m.

7. Misconception Rock

Misconception Rock consists of a small (100 sq. m), relatively flat rock pavement (well-sorted fine to medium calcarenite) in the reef tract that is exposed at low tide. It is approximately 1 kilometer north of Creek Point off the east coast of Acklins Island.

The rock surface is heavily pitted and etched, the characteristic erosional form of limestones in the splash zone (Newell et. al., 1951), and the outer edges are covered with a heavy algal growth. Many large gastropods (Livona pica), Diadema sp., and chitons were observed in numerous shallow depressions.

As found in other areas of the Bahamas (Newell et. al., 1951) the bank barrier reefs off eastern Acklins Island appear to be a Holocene reef veneer over pre-existing sand ridges that are exposed above sea level in places.

8. South of Golden Grove

The broad (12 m) platform which is a characteristic feature of the insular shelf off the east coast of Acklins Island separates the reef crest and fore-slope communities by distances of over 1.5 km.

The bottom is a smooth rock pavement which has a thin (1 cm) sediment-algal cover, consisting of a dense benthic algal layer with trapped sand- to silt-sized sediment.

Small coral mounds, having relief to less than 1 m are widely spaced on the rock pavement. Coral heads, for the most part dead, are scattered over this rock surface. Dominant live corals are Diploria strigosa, Eusmilia fastigiata, Agaricia agaricites and Dichocoenia stokesii. Rich epifaunal and infaunal assemblages occur under the live and dead coral material, including the bivalve Barbatia domingensis, the gastropod, Tegula fasciata, and the echinoids, Eucidaris tribuloides, Arbacia punctulata and Echinoneus cyclostomus.

Gorgonians are common and some are encrusted by Millepora sp.

Summary

Atwood Harbour would be an excellent location for a base station as it is a good harbour for boats, and the Bahamian government is willing to cooperate with scientists working in their territory. The northeast corner of Acklins Island, east of Atwood Harbour and North of Pinefield Point, is Crown Land and arrangements could probably be made to set this area aside as a research site. The reefs have been relatively unaffected by human activity. Fishing appears to be a minor occupation carried out in a primitive fashion on an occasional basis.

When the new airstrip is completed, accessibility to Acklins Island will be improved with regular weekly flights scheduled for the near future. Bi-weekly flights to Crooked Island are currently available from Nassau.

A number of vacated small houses on the island might be used as accommodation facilities. They might be rented at reasonable rates, but it should be recognized that amenities are lacking.

Apart from some of the small patch reefs, the reefs on the insular shelf are not well developed. The exposure of calcarenite in the reef tract off the east coast (Misconception Rock) indicates that many of the reefs may be veneers over Pleistocene sediment ridges. The shallow reef crests are commonly separated from the fore-reef slope coral communities by a very broad rock platform.

Rough seas common during the months of October through April would prevent work on the reef crest and fore-reef slope during these months.

St. Croix, U.S. Virgin Islands*

St. Croix (17°45'N, 64°40'W) is the largest of the U.S. Virgin Islands, having a surface area of 22 sq. km (45 km long and up to 11 km wide; see Fig. 4). Its population is about 35,000, and apart from

*Field survey: January 26-28, 1971, by I. G. Macintyre, assisted by H. G. Multer.

tourism, the island supports a few other industries such as bauxite refining, oil refining, and the assembly of wrist-watches.

This island is readily accessible as it is served by several major airlines. Transportation on the island is available through car rental at about $12/day or scooters at $7/day. Boats may be chartered, or rented less expensively through the Fairleigh Dickinson Laboratory. Hotel accommodations are costly, particularly during the winter season, but the marine laboratory has some rooms at reasonable rates for visiting scientists.

Terrestrial Conditions

The topography of St. Croix is "hilly" (maximum relief 355 m, Mt. Eagle). The island is composed of rocks having diverse origins and compositions, primarily Upper Cretaceous volcanic sandstones and mudstones, tuffaceous sandstones, Upper Oligocene montmorillonitic mudstones, and Lower Miocene argillaceous and sandy coral limestones. Despite the abundance of volcanic debris, no volcanoes are present on St. Croix; however, two small igneous bodies (a diorite and a gabbro) intrude the Cretaceous sedimentary rocks. Numerous small dikes are also present in the hilly ranges occurring on the eastern and northwestern sections of the island (Whetten, 1966).

St. Croix Reefs

Although St. Croix has a variety of reef types that would be excellent for scientific study, there appears to be no evidence of a reef marginal to deep oceanic waters, a serious drawback to the selection of St. Croix as a primary site.

1. Bank Barrier Reefs.

As expected, the best developed reefs occur off the eastern or windward coast, and the most striking developments are the bank barrier reefs on the landward edge of the insular shelf; these reefs parallel the northeastern and southeastern coasts for distances of over 5 km.

The bank barrier reef off Tague Bay (Fig. 2, Site 1) has about 5 m relief off the shoreward edge and is approximately 90 m wide. This reef is dominated by Acropora palmata, but an indistinct zonation was noted around the inner edge of the reef, where the base is characterized mainly by Montastrea annularis; the edge by Acropora palmata and large mounds of Porites porites (up to 2.5 m high and 4.5 m wide); and the top by Acropora palmata, Diploria sp., and Millepora sp.

The seaward edge of this reef was not investigated during this brief visit; however the transect (Fig. 6) based on information received from Dr. Multer indicates that this seaward slope drops off to a depth of 14 m and gives a graphic representation of the dominant coral distribution across the reef.

2. Algal Cup Reefs

There was not enough time to investigate the fringe reefs common around most of the promontories along the northeastern coast of St. Croix. However, the nearshore "algal cup reefs" occurring around Cottongarden Point were investigated (Fig. 5, Site 2).

These reefs, which are characterized by pronounced rims and over hangs, have a relief of about 2 m. Their upper surfaces are covered by fleshy algae including Sargassum sp. and a few flat colonies of Porites astreoides. Chips from these algal reefs, broken off with great difficulty, revealed a dense agglomeration consisting mainly of crustose coralline algae and the distinctive red encrusting foraminifera, Homotrema sp.

An unusual occurrence of Acropora prolifera in an area of high agitation was noted next to these algal reefs. Abundant algae are present on the sea floor surrounding the cup reefs, notably Penicillus sp. and Halimeda sp. (sediments are particularly rich in Halimeda-derived debris).

3. Buck Island Trail

A rapid survey of the Buck Island National Trail (Fig. 5, Site 3) indicated that this is a well-developed "palmata reef." Although separated from shore by a narrow sandy belt, it can be considered a form of fringe reef.

4. Deep Patch Reef

A deep patch reef directly east of Buck Island (Fig. 5, Site 4) consists of an area of large open frameworks, primarily Acropora palmata. This patch reef has a relief of about 8-9 m above its base, which is covered with large heads of Montastrea annularis, Diploria sp., Montastrea cavernosa, and surrounded by a great abundance of alcyonarians. Millepora was found coating some of the dead alcyonarian branches.

5. Shelf Edge North of Buck Island

This area was investigated in order to determine whether a shelf-edge reef exists at this location (Fig. 5, Site 5). The reconnaissance was carried out by a towed swimmer, and all observations were made from the surface of the water.

Although no evidence of a shelf-edge reef was found, an interesting transition in bottom characteristics was noted: at depths of about 30 m a series of sediment chutes traverse a relatively steeply dipping (about 10-20°) rock surface that is covered by alcyonarians, sponges, algae and scattered coral heads. From the surface, there appeared to be little relief between the sediment chutes and intervening rock surfaces. The sparsity of corals suggests that reef framework construction was not occurring at this depth. Although a spur and groove system appeared to be present at this location from the air survey, firsthand observations showed that the "buttress systems" described off Jamaica by Goreau (1959) are not present in this area off St. Croix.

Shoreward, the sea floor gradually grades into a rocky bottom having sand patches and scattered alcyonarians, sponges, algae and coral heads. Around depths of 15 m, large scattered colonies of Acropora palmata appear, and directly shoreward there is a zone of Millepora. Abundant colonies of Acropora palmata are present in depths of 3-6 m along with other corals such as Montastrea annularis and Diploria sp.

6. Other Reefs off St. Croix

During the R/V Eastward cruise, two other reef types were investigated in this area: inactive and submerged reefs.

The most prominent reef type off St. Croix is the inactive reef, of which Lang Bank is the best example. Inactive reefs are reefs that occur within depths of potential vigorous coral growth, but which are characterized by an absence of reef framework construction. Lang Bank, situated at the shelf edge east (windward) of St. Croix (Fig. 5) at depths of around 9-12 m, is ideally located for active barrier reef development. From limited bottom photographs, however, it is evident that an interlocking reef framework does not occur on this ridge which is covered with abundant alcyonarians and sponges and large sand patches, but only scattered coral heads. Dredge hauls from this area contained abundant alcyonarians, sponges, and small colonies of Porites porites, Porites astreoides, Diploria sp., Agaricia agaricites, Stephanocoenia michelinii, Acropora cervicornis, and Millepora sp. Coral debris heavily encrusted by coralline algae was also abundant. Meyerhoff (1926) suggested that the topography of the eastern St. Croix insular shelf is related to subaerial erosion of a Tertiary reef complex.

Submerged ridges were noted on bathymetric profiles off the southern coast of St. Croix, established at depths of about 40 m. These ridges are interpreted to be submerged reefs that were established in relation to a pre-existing lower sea level, and that occur in depths greater than are commonly associated with vigorous growth of tropical reef corals. They appear to be common features off most eastern Caribbean islands (Macintyre, 1972).

Pollution

Extensive pollution of the marine environment is occurring off the southwestern coast of St. Croix, where a garbage dump, bauxite plant and oil refinery are located (see Fig. 4). It is expected that pollution levels will rise in the near future because sewage will be piped from Christiansted (the island capital) over to this side of the island. Despite the unfortunate aspects of this circumstance, it would offer an opportunity for detailed comparison between polluted reefs off this coast and the non-polluted reefs to the east. Such studies might yield valuable information on the degrees of stress imposed on reefs by pollution, and how well they survive it.

West Indies Laboratory of Fairleigh Dickinson University

The West Indies Laboratory is located on Tague Bay, on the northeastern coast of St. Croix, and it overlooks Buck Island National Park (Fig. 5). This laboratory offers scientific facilities for researchers as well as some accommodations, when available. There are 4 small laboratories equipped with aquaria, and an outdoor aquarium area supplied by a dual saltwater system.

The Laboratory also owns two 4.9 m (16') Boston whalers and three 5.8 m (19') Rabollo boats which may be rented by visiting scientists at a minimal cost. Owing to an extensive summer program, visiting scientists are advised to plan visits for less crowded periods of the year.

An affiliate program is gradually being developed which will permit outside universities to have faculty and research space as well as teaching space privileges on the basis of a yearly charge.

Summary

Apart from the polluted reefs on the south coast of St. Croix, the coral reefs around this island have been relatively untouched by man because there is little need to exploit them for food. However, the absence of a reef marginal to deep water in the region is a drawback, as is the general lack of well-developed reef-flat zones on the shelf reefs (a distinct disadvantage in drilling operations).

On the other hand, the numerous advantages of this location make St. Croix worthy of consideration as a research site, particularly for a smaller scale program. The cooperation and available facilities of W.I.L. would make operational costs on St. Croix considerably lower than elsewhere in the Caribbean; at the same time, W.I.L. would probably facilitate detailed and sophisticated experimentation which might be difficult to undertake and complete at less well-equipped sites. Following is a brief outline of the merits of St. Croix as a study site:

1. Facilities of the West Indies Laboratory, notably;

   a. inexpensive accommodations;
   b. fish pens;
   c. outdoor and indoor aquaria supplied by all P.V.C. non-toxic dual saltwater systems and backed up by independent emergency power unit;
   d. laboratory and office space; motor boats;
   e. reference library with microfilmed periodicals and print-out service;
   f. radiocommunication with field units;
   g. monitoring service which W.I.L. intends to establish off northwestern coast.

2. The laboratory staff would be able to assist in servicing field equipment. Technicians working on Navy projects on western St. Croix might also be enlisted to aid with electronics problems.

3. Jet airport with daily flights to Washington, Miami, and New York costing less than $200 return. San Juan, P. R., is 45 minutes away by hourly scheduled flights.

4. A variety of reef types are present, including fringing, bank barrier, inactive, submerged, algal cup, polluted and non-polluted reefs.

5. Because St. Croix is an American territory there should be a minimum of red tape involved in having a section of reef tract set aside for scientific investigation; ground has already been broken with the Buck Island National Underwater Park.

6. There would be less difficulty in shipping equipment to a U.S. island, and financial advantages of a duty-free island in the purchase of equipment.

Discovery Bay, North Coast of Jamaica*

Jamaica, an independent member nation of the British Commonwealth, is a large tropical island located in the northwestern Caribbean Sea at the extreme northwest tip of the Nicaraguan Rise. It is 140 miles long and 60 miles wide and has mountain peaks in excess of 7,000 feet above sea level. Fringe reefs extend discontinuously along the north coast and are noted for their coral species diversity (Goreau and Wells, 1967).

Discovery Bay (18°30'N, 77°25'W), the site of the Discovery Bay Marine Laboratory, is located about midway along the northern Jamaica coast, and it lies adjacent to a well developed section of the fringe reef (Fig. 7). The reefs in Discovery Bay (Fig. 8) generally may be divided into the following major zones (after Kinsey, 1970; J. Lang, personal communication, 1971).

Lagoon Zone: This zone is about 400 to 500 m wide, and about 1 to 3 m deep. It has a submerged sinkhole 25 m deep, but the walls and bottom are mud covered and there are no rock exposures. Loose sand is the main constituent of the floor in the lagoon zone, and this precludes development of sessile benthic epifauna. Here and there, bare rock patches and coral heads occur with scattered gorgonians. Corals and rocks become more abundant seaweed, toward the rear zone.

Rear Zone: The inshore face of the reef crest makes up this zone, which is about 0.3 to 2 m deep. Apart from the reef flat, this is the only reef area strongly affected by tidal fluctuations and characterized by strong water movement. Bottom types range from calcareous sand, and sand and coral fragments, to bare coral-rock exposures. Living coral is

* Field survey 21 to 28 July 1971 by I. G. Macintyre, assisted by P. Dustran, E. A. Graham, L. S. Land, and J. C. Lang.

common but never covers the bottom entirely. Richest coral growth occurs in the area abutting the shoreward face of the reef flat.

Reef Flat: The reef flat comprises the area just submerged at low tide. It is subjected to strong breaking wave action as well as occasional exposure to air and rainwater. The main component is a reticulate ridge-like structure 5 to 20 m wide, composed of dead colonies of *Acropora palmata*, which separates the lagoon from the sea. The unconsolidated skeletons of *A. palmata* form a lattice-like structure. Protected areas within the reef are locations for a restricted gorgonian fauna. Channels and pools in the reef flat may reach a depth of 2 m.

Palmata Zone: This narrow zone, 5 to 10 m wide, abuts the seaward face of the reef flat and extends seaward to a depth of 4 to 6 m. The full force of wave action occurs in this zone where *Acropora palmata* is predominant. The bottom consists of coarse sand and sand-scoured coral rock littered with dead and fallen *A. palmata* colonies.

Barren Zone: A band of reduced coral diversity occurs seaward, and it can be up to 20 m wide, ranging from 5 to 8 m in depth. The most common organism, *Diadema antillarum*, which grazes on the bottom, may be responsible for the scarcity of sessile organisms. Isolated colonies of *A. palmata* occur along with small heads of *Diploria strigosa*, *Montastrea annularis*, and *Millepora complanata*.

Buttress/Mixed Zone: In the Ocho Rios area studied by Goreau (1959) as well as other areas along the northern coast, the buttress zone merges abruptly with the barren zone. Although the component species remain the same, Discovery Bay differs slightly in architecture from the other areas in that the normal buttress zone becomes flatter, with a gradual increase in coral species and coral size. This "mixed" zone is 15 to 40 m wide, and slopes from 6 to 15 m in depth. *Montastrea annularis*, one of the dominant corals in the buttress formations, occurs in Discovery Bay in the form of huge rounded masses scattered in fields of *A. cervicornis*. Diploria spp. is also common, along with *Dendrogyra cylindrus*, *Agaricia agaricites*, *Porites* spp., and *Colpophyllia natans*. This is an area of rich gorgonian diversity.

Cervicornis Zone: *A. cervicornis* becomes dominant seaward, and *M. annularis* reduced to small patches. This zone, which is 30 to 100 m wide and 20 to 25 m deep, is characterized by huge mounds of *A. cervicornis* 15 to 40 m wide with their long axis normal to the axis of the reef crest. These reefs (1 to 5 m relief) are separated by sand channels 3 to 50 m wide. Upper surfaces of these reefs are generally level, and they gradually slope to about 10 m in depth at their seaward extremity, where they drop abruptly to sand level at about 20-25 m on their seaward face. Consolidated coral rubble covered with living *A. cervicornis* is typical (Land and Goreau, 1970). Other coral species appear on the steep seaward faces and lateral reef flanks adjacent to the sand areas, including *Porites astreoides*, Mycetophyllia sp., and *Montastrea cavernosa* as well as *M. annularis*. In Discovery Bay the *A. cervicornis* reefs drop steeply at the seaward edge to a zone of sand about 40 to 60 m wide.

Upper Sill Reefs: A series of elongate but discontinuous reefs are established at 40 to 50 m depths, and rise to about 25 m depths. Platy colonies of Montastrea annularis are dominant along with a mixed coral community composed primarily of Agaricia lamarcki, Mycetophyllia sp., other species of Agaricia, Scolymia sp., fleshy algae, sponges and antipatharians.

Fore Reef Slope: The platy growths of Montastrea annularis along with Agaricia sp. and abundant sponges, gorgonians and antipatharians continue down the reef fore slope to a depth of 50 m, below which either Agaricia sp. dominate, or mixed coral growths occur consisting of Agaricia sp., Madracis sp., Montastrea cavernosa, and Mycetophyllia sp.

Lower Sill Reefs: This zone, at depths of 60 to 70 m, is characterized by either elongate ridges having less than 10 m relief or isolated rocky outcrops. Corals occurring on these features include Agaricia sp., Montastrea cavernosa, Madracis sp., and Mycetophyllia sp. Sponges and antipatharians are also abundant.

Deep Fore Reef Slope: Scleractinian corals become increasingly sparse with depth, and the dominant benthic organisms are sclerosponges and demosponges.

The Discovery Bay Laboratory

The Discovery Bay Laboratory is jointly operated by the Marine Sciences Research Center of the State University of New York, and the University of the West Indies. The Laboratory site consists of .06 sq. kilometers (15 acres) of coastal property.

Facilities have been designed primarily for coral-reef research with emphasis on on-site investigations (SCUBA facilities) rather than for training programs. Therefore, only limited space is available to visiting scientists and there are no dormitory accommodations.

The new central building consists of an air-conditioned research unit housing four small laboratories, a large "wet" laboratory, a dark room, instrument store, museum and two offices. The "wet" lab is subdivided into six semi-enclosed research bays provided with all services including seawater and central tables for aquaria and sorting and holding tanks. A separate reading and conference room is nearby. Support facilities include a machine shop, a boat and wood workshop, and a diving locker. Three boats are available a 6.7 meter (22-foot) twin outboard-motor vessel, a 4.6 meter (15-foot) work boat, and a 3.7 meter (12-foot) inflatable boat that can be carried by car to remote sites. A landrover and Volkswagen bus serve to transport equipment as well as personnel.

The laboratory is equipped with a glass-distilled water supply, dissecting and compound microscopes, histological apparatus, drying oven, pH meter, top loading and analytical balances, photographic equipment and darkroom facilities, refrigerator, freezer, centrifuge, collecting gear, etc. The diving facility contains two high-capacity air compressors, a recompression chamber with air bank, SCUBA tanks, regulators and auxiliary diving equipment.

Summary

The reefs off Discovery Bay Laboratory probably are some of the most extensively studied reefs in the world, and the data already available would be a distinct asset to a research program.

The Discovery Bay reefs are rich and well developed both in shallow and deep water. Since they occur very close to the coast, their location would facilitate close monitoring of various parameters. Moreover, the relatively narrow horizontal extent of the reef biotope would be advantageous in instrument monitoring, as well as in on-site investigations.

This site is readily accessible from the U.S. mainland, and accommodations are available locally at inexpensively priced guest houses (ca. $7/day single) for as many as 40 scientists.

On the other hand, there is a significant but as yet undetermined terrestrial influence on the reef ecosystem in this area. The internal sediment found in association with the present reefs is characteristically brown owing to the presence of bauxite or iron oxide that has been incorporated from terrestrial sources.

From 1964 to 1967, a ship channel was dredged and blasted into Discovery Bay to permit docking of large ocean-going vessels in this bay. The channel is about 300 to 400 m from some of the key areas of potential research. The construction of this channel as well as frequent visits of large ships into the bay provide negative influences on the reef ecosystem in this area.

The paucity of larger reef fish is notable in Discovery Bay. Although fish populations are sparse, fish traps are still used extensively, and therefore this location has limited potential for any proposed fish studies in association with the reef ecosystem. The poor development of a buttress zone in the area is an additional drawback.

The Discovery Bay Laboratory is not eqippped to handle large coral-reef study programs because of its relatively small size. Research projects might also be hampered by customs delays and the need for import licenses owing to the problem of bringing onto the island scientific equipment and material from another country.

Glover's Reef, British Honduras*

A first reconnaissance visit to British Honduras, 17-22 January 1971, included several diving stations along the barrier reef and

*Preliminary survey: January 17-22, 1971 by A. Antonius and J. N. Weber.
Field survey: June 20-27, 1971 by A. Antonius, A. L. Dahl, and K. Ruetzler.

Turneffe Island, and an air survey of the barrier reef, Turneffe Island, Lighthouse Reef and Glover's Reef. The information obtained strongly suggested that an extensive diving survey be focused on Glover's Reef, and this was conducted 20-27 June.

Description of Reefs

Glover's Reef (16°50'N, 87°50'W) is the southernmost of the three British Honduras atolls, about 75 km SE of Belize City, 45 km E of the mainland and 25 km E of the barrier reef. It is elongated in NNE-SSW direction, about 28 km long and 10 km wide. The atoll (Fig. 9) is surrounded by deep water (350-1000 m) within 1-2 km from the intertidal peripheral reef. The well developed surface-breaking atoll reef flat (mainly coral and coralline algae) is interrupted by two major openings: NE-entrance and SW-entrance (12 m deep). On its SE part, it supports a chain of six cays which are distributed over a distance of 10 km. The cays vary between 150 m and over 1 km in length and are more or less covered by coconut palms. The lagoon, in contrast to the other two British Honduras atolls, is rather deep, 8-15 m in most parts, with hundreds of patch reefs rising to the surface.

Of the six cays on Glover's Reef, only Long Cay and adjacent Little Cay are permanently inhabited. Both islands are used as a resort for diving-oriented tourists.

From the seaward margin of the peripheral reef a gradually sloping reef-front extends to the drop-off. The reef front varies in width from about 400 m (SW cays) to 1.5 km (Long Cay) and is about 500 m wide on the leeward side. The edge of the drop-off occurs at a depth of 15-25 m. A system of deep parallel grooves runs perpendicular to it. These grooves are particularly well-developed on the windward (E) side of the atoll. Sediments produced in the breaker zone are transported down the grooves permitting undisturbed coral growth in between. The leeward reefs are considerably more influenced by sediments which are driven out of the lagoon by wind generated currents.

The windward side shows a dominating, lush, growing reef-coral community including sponges and gorgonians (Fig. 10). No attempt was made to gain a complete list of species during the survey, but the general appearance of the reef and the unparalleled size of most of the coral and sponge specimens observed strongly suggest that all of the known Caribbean species can be found there. On the sketches of the reef transects only dominant species are listed.

Compared with the windward reef, the leeward side shows a slight decrease in number of scleractinian species and is slightly less populated, probably due to sedimentation (Fig. 11). The coral cover ends around 45 m and gives way to a sand slope.

The fore-reef slope is very steep at NE Cay, almost vertical at Long Cay and vertical to overhanging at SW Cay. It was explored at five different locations to a depth of 60 m. There, and as far down as one could see in the clear water (horizontal visibility at least 50 m), lush coral, sponge and algal growth continues.

The patch reefs rise to the surface from the lagoon floor, which is generally covered with sand and *Thalassia*. These reefs are mainly of *Acropora palmata* and *A. cervicornis* structure on top and *Montastrea annularis* below, with coral growth occurring to a depth of 3-4 m and occasionally 10 m. Every patch reef is a small individual reef-entity and ideal for a variety of experiments.

The winds in the vicinity of the British Honduras atolls blow steadily from the East for most of the year, being replaced between November and February by occasional Northern winds, which occur only a few times every winter and last four or five days at a time. Thus, the wind-generated western currents in the atoll area are by far predominant over the main Caribbean current, which impinges on the British Honduras atolls in a northerly or southerly direction, and regularly changes its direction several times a year.

Water temperatures at the surface vary between 25°C in winter and 31°C in the summer (open water); no significant temperature decrease was noticed during the dives (for detailed information on climatic, biologic and geologic features of Glover's Reef, see Stoddart, 1962).

Summary

British Honduras is a politically stable country, and its official language is English. Relations between the government and resident North Americans or Europeans are cordial. The British Honduras government seems to look favorably upon educational and research projects, and duty exemption for all scientific and educational equipment and materials has already been granted.

The remoteness of Glover's Reef makes it likely that it will remain undisturbed; still, there is good accessibility to Belize by air, and the atoll can be reached in any weather by boat because two-thirds of the trip takes place in a sheltered lagoon between the mainland and the barrier reef. There are no research facilities on the atoll at present, and it is not always possible to make satisfactory arrangements for an extended scientific program using tourist-oriented facilities.

Glover's Reef is well suited for direct comparison with Indo-Pacific atolls as there are no land influences, no pollution, or other human disturbances; yet the large barrier reef, and two comparable but physiographically different atolls are readily accessible. While Glover's Reef is the only one of the three atolls which was not hit by the devastating hurricane Hattie in 1961, there is a hurricane potential; a small one passed over the atoll in November 1971 without causing major damage.

In contrast to the other reefs surveyed in the Caribbean area, Glover's Reef atoll appears to offer the greatest variety of reef types and the optimum reef development in terms of population density and species diversity of reef corals and associated organisms.

San Blas Islands, Panama*

The San Blas Islands (9°39'N, 78°45'W) lie off the Caribbean coast of Panama between San Blas Point and Cape Tiburon (Fig. 12). During the Spanish conquest of Panama, the Cuna Indians were driven from the mainland to find refuge on these islands. Today, they have title to over 365 islands and a strip of land along the adjacent coast. They have jurisdiction over agreements to buy, settle or establish any forms of business on their islands.

Standard access to the San Blas Islands is by means of light plane or small boat. The islands are about 110 km east of Colon, and it takes about 8 hours from there by boat. There are scheduled flights to several San Blas localities from Panama City, and a float plane service from Colon.

One serious problem to be considered concerning travel by sea is that rough waters are common during the months of December to April, so the islands generally are not accessible by boat. Airstrips such as at Carti on the mainland (see Fig. 12) are accessible year round to light aircraft that can transport passengers to and from Panama City at a cost of $9.25 per one-way trip. Although this provides a rapid and inexpensive form of transportation to the area, and could be used by scientists when the islands are inaccessible by water, this air carrier cannot always operate on a specific schedule owing to the frequency of poor weather conditions. In addition, the short and uneven dirt airstrips preclude the use of larger aircraft so that only four or five passengers and light baggage loads can be accommodated on any one flight.

The only housing facilities presently available in the area are located on Picofeo Island, which is the only privately owned San Blas island. These facilities consist of several sheds and some machinery (including a 6-volt generator) that are part of a disused copra-processing plant. One building serves as the Picofeo Hotel which is operated by Jose Garcia, one of two Panamanian brothers who own the island and its buildings. The hotel, which is an old wooden structure, offers minimal accommodations to visitors, who are expected to bring their own food supplies at $2.50/night. Extended stays can be arranged at cheaper rates. Outsiders are generally discouraged from setting up reisdence in the other islands. However, a few tourist resorts are now being developed in the San Blas Islands, which should provide for improved access and accommodations.

A short initial visit confirmed the potential of the area, and

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*Preliminary survey: May 1-2, 1971 by A. L. Dahl and A. Childs. Field survey: August 3-7, 1971 by A. Antonius, J. C. Land, and I. G. Macintyre (assisted by C. Birkeland, D. Meyer, M. McCosker, W. K. Sacco).

located some sites for further study. Ten locations were then visited during the four-day survey. These areas are marked on maps redrawn from sections of HO chart No. 2771, San Blas Point to Concepcion Bay (Figs. 13, 17, and 22). Following are brief descriptions of the areas in the order that they were visited:

1. Off Sail Rock, Profile A-A'

Sail Rock is an exposed rock knob marking an isolated reef not far from Porvenir Island, where there is a very short airstrip (Fig. 13). The water was very turbid during the survey of the reefs in this area (less than 2 m visibility at a depth of 20 m) and there was a marked thermocline at a depth of about 3 m. The zonation across the profile is given in Fig. 14. Points worth noting in this area are the dominance of Agaricia sp. corals at the edge of the shallow platform and the lack of coral growth below about 20 m where the accumulation of fine sediments (rich in organic material) apparently prevents corals--other than the bladed Agaricia tenuifolia--from growing.

2. Picofeo Island

The Picofeo Hotel is set on piles over the water at the north end of Picofeo Island (Fig. 13). This area is characterized by typical back-reef coral communities (Fig. 15) dominated by Porites porites. As was found at Sail Rock, the outer edge of the platform is marked by a rich Agaricia sp. coral community. The reef terminates in a shallow sand flat at a depth of about 6 m.

3. Off Sardingan Point, Profile B-B'

Sardingan Point is on the mainland near San Blas Point and west of Picofeo Island (Fig. 13). The reef in this area drops off steeply to a depth of about 30 m (Fig. 16). An interesting aspect of this reef is that Agaricia sp. corals tend to dominate throughout the depth zones except in very shallow water, where Porites porites is the most abundant coral.

4. Off Salar, Profiles C-C', D-D', and E-E'

The group of islands at Salar are among the inner San Blas Islands north of Macolla Point (Fig. 12). As names for the individual islands were not available, they have been numbered from southwest to northeast (Fig. 17). The survey concentrated primarily on the area between islands 2 and 3. Several dives were completed in this area of vigorous coral growth, spectacular drop-offs, and overhangs which are described in profiles C-C' (Fig. 18), D-D' (Fig. 19), and E-E' (Fig. 20). The general zonation of the reef flat of island no. 3 is also shown in a diagramatic sketch (Fig. 21).

5. Off Ogopuquip, Profile F-F'

Three different sites were visited in the Holandes Cays (Fig. 22).

The first was at Ogopuquip on the southern side of the keys, where a profile (F-F') was prepared off the southwest point of Ogopuquip Island (Fig. 23). This area had the greatest diversity of coral species of any site visited in the San Blas Islands.

6. Holandes Cays Algal Ridge, Profile G-G'

The distinctive structure of the northern reef around the Holandes Cays is illustrated by profile G-G' (Fig. 24). This reef has a prominent algal ridge that has been described in more detail elsewhere (Glynn, in press).

7. Off Holandes Cays, Profile H-H'

Beyond the algal ridge off the east end of Holandes Cays, there is a broad rock platform similar to that observed off many of the Bahamian Islands (profile H-H', Fig. 25). The survey did not extend to the drop-off which, according to the chart, probably occurs 200 m beyond the outer end of the profile.

Summary

Some reef areas, in particular the reefs off Salar Island, meet the scientific criteria established above for a research site including: well-developed reefs, steep fore-reef slope, lack of disturbance by human activity, and a close proximity to shore. The well-developed algal ridge off the Holandes Cays offers an opportunity to make comparative studies with similar reef structures in the Pacific.

Buildings are available for conversion into research facilities. However, they are not located adjacent to well-developed reefs. Smithsonian Tropical Research Institute maintains marine laboratories and a research vessel elsewhere in Panama, and conducts research in the San Blas Island area.

Two atypical characteristics of San Blas reefs, in comparison with other Caribbean reefs, are the predominance of *Agaricia* sp. corals in all depth zones, and the presence of a well-developed algal ridge off Holandes Cays.

The inaccessibility of this area by boat for five months of the year and the limited air transport service offered present a serious logistical problem in transporting personnel and material in and out of the San Blas area. As facilities on Picofeo Island are too distant from good reef development to be useful, it would become necessary to negotiate lease arrangements with the Cuna Indians for one of the uninhabited islands.

PACIFIC AREA

In the Pacific Ocean, coral reefs are scattered over a vast geographic area. The only safe generalization about Pacific reefs is that no two reefs are identical. However, in spite of the great diversity in form and composition that characterizes these communities, a number of features demonstrate the underlying relationships within this assemblage. The coral fauna is remarkably uniform throughout the Indo-Pacific (Wells, 1969), with the highest diversity and the center of evolutionary radiation in the western tropical Pacific (Stehli and Wells, 1971). This fact frequently leads to the statement that reefs in the western Pacific are "rich" while those to the east are "impoverished." Whether this applies to all elements of the flora and fauna, however, has yet to be demonstrated. The atoll reef form is another common Pacific feature, although involving many structural variations on the basic theme. The presence of a Porolithon algal ridge is often believed to be characteristically Pacific, and is certainly common there, while it rarely occurs on Atlantic reefs.

The great number and diversity of tropical Pacific reefs has made the search for data on research sites very difficult. Information was compiled from many sources on reef structure and composition, and on logistic and practical arrangements. Most published descriptions of Pacific Islands include only terrestrial geography; specific local descriptions are rare, and only the shallow reef is mentioned. Charts from the U. S. Army Map Service and the Navy Hydrographic Office indicate with fair accuracy the presence or absence of shallow reef structure, and sometimes the nature of the offshore slope and the depth to which coral development might be expected. A few scientific papers include reef descriptions of some sort, but not for the deeper areas important to a complete reef program, and generally in localities that are otherwise unsuitable. Most of the past research on Pacific reefs was conducted either by ship-borne expeditions to otherwise inaccessible islands, or in areas that have since been disturbed by development. Also, published information tends to be too dated to be reliable for current reef conditions; much of it predates World War II.

While many questionnaires were returned by Pacific reef specialists, their information did not always meet program requirements, perhaps because of the great size and complexity of the area. Personal experience tended to be limited to a few sites and to what could be seen from above the water. Areas of field experience and interpretations of reef quality depended on the respondant's special interest (an interesting reef to a coral specialist would not necessarily be selected by a bird or sea-snake expert, for example). Also, the information was often too generalized, referring to island groups rather than to specific reefs. The areas recommended and a summary of the questionnaire responses for the Pacific area are listed in Table II.

TABLE II: Questionnaire Response - Pacific Area

Site	Reef Structures*	Undisturbed	Accessible	Local Facilities	Political Status+	Number of Recommendations
Caroline Islands						
Palau	+	±	+	+	+	6
Helen Reef	0	+	-	-	+	1
Yap	+	±	+	0	+	1
Ulithi Atoll	+	±	+	0	+	2
Woleai	+	+	0	0	+	1
Ifaluk Atoll	0	+	-	-	+	1
Truk	+	-	+	0	+	1
Ponape	+	-	+	0	+	4
Ant Atoll	0	+	+	0	+	1
Pakin Atoll	0	+	+	0	+	1
Kapingamarangi	0	+	-	-	+	2
Marshall Islands						
Majuro	+	-	+	0	+	2
Arno	+	±	+	0	+	2
Ailuk	0	+	-	-	+	1
Eniwetok	+	±	+	+	-	2
Ellice Islands						
Funafuti	+	-	-	-	+	2
Phoenix Islands						
Canton Island	0	±	0	0	+	2
Fiji Islands						
Laū	0	+	-	0	+	1
Viti Levu	+	±	+	+	+	1
Samoa Islands						
Samoa	0	±	+	0	+	3
Rose Atoll	0	+	-	-	+	1

Site	Reef Structures*	Undisturbed	Accessible	Facilities	Political Status+	Number of Recommendations
Cook Islands						
Hervey Islands (Manuae)	0	+	-	0	+	1
Line Islands						
Christmas Island	0	±	0	0	+	1
Fanning Island	0	±	0	+	+	2
Society Islands						
Tahiti	+	+	+	0	-	1
Other						
New Caledonia	+	±	+	+	-	1
Port Moresby, Papua New Guinea	+	±	+	+	+	1
Ashmore Reef, Timor Sea	0	+	-	-	+	1
Heron Island, G.B.R.	+	+	+	+	+	1
Low Isles, N. Queensland	0	+	+	0	+	1
Aldabra, Indian Ocean	-	+	-	+	+	1

Sites suggested by name only: Saipan, Marianas Islands; Nukuoro, Caroline Islands; Wotho, Marshall Islands; Onotoa Atoll, Gilbert Islands; Butaritari Atoll (Makin), Gilbert Islands; Phoenix Islands; Buka, Bougainville, Solomon Islands; Rabaul; New Britain; Bismarck Archipelago.

Key: + = favorable or present 0 = unknown or possible - = unfavorable or impractical ± = variable

* see selection criteria above, p. 38

\+ basically the anticipated government attitude to a large international but U.S. funded program

Questionnaires and equivalent information on Pacific sites were returned by the following: A. Antonius, A. L. Bloom, A. L. Dahl, M. S. Doty, F. R. Fosberg, R. Hagemeyer, H. Heatwole, R. Johannes, H. S. Ladd, E. G. Menez, H. A. Rehder, R. W. Schreiber, J. Sieburth, W. A. Starck, D. R. Stoddart, J. N. Weber, C. M. Yonge, and University of Hawaii.

It was obvious from the questionnaires and the other information available that data on the reef state and structure, and on current logistic arrangements, could only be obtained by actual site visits by scientists familiar with the basic criteria for a research site, as was done in the Caribbean. As it would have been physically impossible to visit every potential site, it was necessary to select from those on which some data were available the areas with the best prospects for a satisfactory site. One important role of the questionnaires was to help pinpoint such areas for more detailed examination. Inevitably other areas which might be ideal have been overlooked because they were not sufficiently well known, often because they are more remote. Transportation in the Pacific however is improving rapidly, and will make more such areas logistically practical.

A number of islands in the Pacific have recently been recommended for preservation as "Islands for Science" (Elliott, 1971). These were selected for their lack of human disturbance, and in many cases, have excellent coral reef development. A number of them were in fact considered at an early stage in the screening process. However, they are undisturbed precisely because they are inaccessible, and thus logistically impossible for a major research program.

Site Screening

An initial screening of possible sites in the Pacific reduced to a more manageable number the list of areas being considered although many excluded areas have characteristics that might be of great interest for more specialized programs. The following criteria were applied in the screening. Because of the need to find a reef with as few complicating external influences as possible, preference was given to atolls or barrier reef areas far from high island influences. For a large program, the need for regular air service or an immediately adjacent airstrip for possible charter service eliminated many less accessible sites. The possibility of acquiring or constructing and maintaining a facility for at least 20 people at reasonable cost was also considered important. All French territories were omitted from consideration because of uncertainties concerning long-term cooperation with government authorities. Great distance or travel time from the United States was also considered to be less desirable. The results of the screening are given below by island group, with the reasons for inclusion or exclusion from further consideration.

Excluded from further consideration:

a. Hawaiian Islands--Reef structure and diversity inadequate. Disturbed.
b. Mariana Islands--High islands. Reefs marginal in quality. Serious disturbance by war and *Acanthaster*.
c. Guam--Reefs seriously disturbed.
d. Line Islands--Poor accessibility. Far from center of coral diversity.
e. Phoenix Islands--Inaccessible. Canton disturbed.

f. Tokelau Islands--Inaccessible.
g. Tonga--Poor accessibility.
h. Cook Islands--Poor accessibility.
i. Bismarck Archipelago, Solomon Islands, New Hebrides--High islands or inaccessible.
j. New Caledonia, French Polynesia--French administration.
K. Great Barrier Reef and other Australian reef areas--Great distance.

A further breakdown was made of those areas not excluded. Those discussed in more detail later in this paper are marked with an asterisk (*).

Caroline Islands

U. S. administration, good air service to district centers, many atolls, in center of coral diversity.

1. Palau*. Many recommendations. Greatest biological diversity in Pacific Islands. Regular air service. Some facilities. Considerable barrier reef area and one small atoll (Kayangl).
2. Helen Reef. Rich and undisturbed, but inaccessible.
3. Yap*. High island. Regular air service. Some rich reef areas.
4. Ulithi Atoll*. Airstrip and weekly Coast Guard flight, large atoll. Some disturbance during World War II.
5. Woleai Atoll*. Small, undisturbed atoll with abandoned airstrip. Excellent reefs.
6. Ifaluk Atoll. Very small atoll, inaccessible.
7. Truk. Accessible but reefs seriously disturbed.
8. Ponape*. Regular air service. High island with barrier reef. Some reef disturbance.
9. Ant Atoll*. Near Ponape, undisturbed except for recent Acanthaster damage.
10. Pakin Atoll*. Near Ponape, undisturbed.
11. Nukuoro. Inaccessible.
12. Kapingamarangi Atoll, Heavily populated, inaccessible.

Marshall Islands

U. S. administration. Many large atolls, mostly either disturbed or inaccessible.

1. Majuro*. Regular air service, disturbed.
2. Arno*. Near Majuro, undisturbed.
3. Wotho. Inaccessible.
4. Ailuk. Undisturbed but inaccessible.
5. Eniwetok. Accessible. Excellent facilities, disturbed. Clearance for foreign participants difficult to obtain.

Gilbert and Ellice Islands

Soon to have improved regular air service.

1. Funafuti. Serious World War II damage and heavily populated.

State of other reefs unknown.

Fiji Islands

Large high islands accessible. Rich reefs in outlying areas, no information on possible specific sites.

Samoa Islands

Accessible. Good fringing reef development.

1. Tutuila*. Reefs disturbed in more populated areas.
2. Manua Islands*. Undisturbed.
3. Rose Atoll. Small and totally undisturbed. Accessibility difficult.

On the basis of the initial screening, a number of areas most likely to offer suitable sites were selected, including Palau, Yap, Ulithi, Woleai, Ponape (including adjacent Ant and Pakin), Arno, and Samoa (including Rose Atoll). A survey team was therefore sent to examine these areas. Fiji and the Gilbert and Ellice Islands also have great potential, but too little information was available on which to plan a site visit, and time did not permit the more lengthy survey that would therefore be required.

U.S. Trust Territory*

Of the enormous number of reef areas scattered throughout the Marianas, Caroline and Marshall Islands, most were too inaccessible to be considered, but even the accessible areas include vast reef tracts with innumerable potential sites.

The experience and reports of the Acanthaster surveys conducted in Micronesia by the University of Guam (Tsuda, 1971) and the Acanthaster control teams operated by the U.S. Trust Territory Administration were of particular value in selecting promising areas for the survey team visits.

Transportation in Micronesia is improving. Continental Airlines--Air Micronesia now serves all the district centers (Koror, Yap, Saipan, Truk, Ponape, and Majuro) 2 to 3 times per week. In addition, Air Pacific has a charter service available for $180/hour (7-passenger airplanes), and there is a new charter service by Island Aviation, Inc., (rates around $120/hour). However, flying by other than Navy seaplanes is still restricted to those few islands with airstrips. Vessels service outlying islands at intervals of two weeks to several months.

* Field survey: August 14-September 5, 1971 by A. Antonius and A. L. Dahl [assisted by R. Randall (Palau and Yap), R. T. Tsuda (Ponape) and B. Sablan (Majuro and Arno)]

Local transportation is difficult, although small motor boats can usually be hired. The Acanthaster control teams have diving compressors and good motor boats at Palau, Truk, Ponape, and Majuro, and provided much of the logistic support for the survey team. There is an excellent marine laboratory and staff at the University of Guam, and the U.S. Trust Territory Government is highly cooperative. There is some resistance from the local populations to outside interference but in general they appeared favorably disposed towards scientific as opposed to commercial or tourist activities.

There are small hotels in the district centers, but in outlying areas it is necessary to depend on the hospitality of the local people.

Palau

Palau (7°30'N, 134°30'E) is considered to have the richest reefs of any Pacific island area. The archipelago of volcanic and high and low limestone islands contains a complex of fringing and patch reefs partly surrounded by a barrier reef (Fig. 26). A small atoll occurs immediately north of the barrier reef. After a detailed examination of charts and consultations with local specialists, a number of sites ranging throughout the archipelago were chosen for detailed examination. This was a wholly inadequate sample of the diversity of sites available, so no generalizations should be made from the few descriptions presented here.

1. Ngeregong Island

The first dive was at Ngeregong Island, on the windward (east) side of the barrier reef about 32 km south of Koror (Fig. 26). Ngeregong has an abandoned Japanese airstrip that, if restored, could simplify logistic arrangements. The outer reef slope, on the SE side of the island consists of a gentle sandy slope, with scattered coral growth, becoming even sandier with depth. The reef was poorly developed.

2. Angaur

Angaur Island lies 40 km beyond Ngeregong, at the southern end of Palau, beyond the barrier reef (Fig. 26). It has an excellent Coast Guard airfield serviced weekly from Guam. The island, formerly an important source of phosphates, lacks major reef development except on the south and west sides. The team dived on the west (leeward) side of Angaur (Fig. 26), in the center of reef development. There is a smooth rocky flat with small scattered corals extending 700 m offshore to a depth of 5 m, followed by a gentle slope 200 m wide and going down to 8 m, with larger, more abundant corals. A steeper slope, 100 m wide with lush living coral coverage, extends down to 38 m, where it is interrupted by a sand flat 30 m wide. A slope with patches of coral interspersed with sand continues down from 40 m at 1 km offshore. The water was warm and clear. The lack of diverse coral habitats, the amount of sediment, and the extended zonation interrupted by terraces were considered undesirable for a research site.

The Ngemelis Islands are 40 km SW of Koror on the western barrier reef (Fig. 26). The islands are parts of a slightly elevated coral platform, and front on the outer reef margin on the west and a sheltered channel on the southeast, as well as the lagoon to the north. The islands can be reached from Koror by boat without going outside the barrier reef. Two dives were made, first on the SE side, off a vertical drop-off going down to 240 m, and then on the sloping west side.

3. Ngemelis Islands, SE

On the sheltered SE side of Ngemelis (Fig. 28), the shallow reef flat is 300 m wide, with few corals inshore, increasing to dense coverage of the reef edge at 0.5 m depth, with soft corals predominant. Beyond the edge is a vertical slope, mostly overhanging, dropping to 260 m. Alcyonarians dominate down to 30 m, with scleractinians and gorgonians equally represented. The slope begins to project outward at 40 m, collecting calcareous sediment; corals are scarce and appear not to grow beyond 30-60 m. The water temperature decreases with depth. The drop-off is spectacular, but soft corals are dominant, and there is apparently a constant flow of sediment.

4. Ngemelis Islands, W

The west (leeward) side of the Ngemelis Islands (Fig. 29) has a broader reef flat 500 m wide with stony corals dominant at the seaward edge (0.5 m depth). There is a steep drop-off to 12 m with good coral coverage, with big buttresses dominated by Porites heads and rubble-filled chutes extending down to 20 m. A gentle slope extends down to 40 m with Pachyseris dominant, after which the slope becomes increasingly sandy and corals dwindle. Again water temperature decreased with depth. The site has high species diversity and a good drop-off, but sedimentation limits coral growth at around 50 m. At both sites the drop-offs are very near the surface, and sponges are almost completely lacking. Current patterns in the area appeared quite complex, and this, together with the inadequacies in the reef structure, would rule this area out for certain types of reef research.

Kayangl Atoll is several hours away by small boat, traveling up inside the western barrier reef, and then beyond the northern tip of Palau (Fig. 26). Kayangl would generally be accessible from Koror except in rough weather. There was some difficulty at first because of a recently instituted village policy of charging all visiting Americans $50, but the requirement was waived after the District Administrator explained the value of the research program to the islands. Three dives were made on Kayangl; in the shallow lagoon, and on the outer leeward and windward slopes.

5. Kayangl lagoon

The first dive was on the west (leeward) side of the lagoon near the entrance channel (Fig. 30). The sandy bottom, 4-6 m deep, becoming shallower toward the reef, separates the abundant patch reefs and coral heads. These are coral-covered from top to bottom, and show very great species diversity. The area is typical of shallow Pacific lagoons.

6. Kayangl leeward outer reef

The leeward outer reef of Kayangl (Fig. 30) is topped by a 50 m wide flat of calcareous algae, leading to a reef edge with lush coral growth. There is a steep drop-off to 10 m depth, still with very good coral coverage and high species diversity, followed by a gentle slope to 40 m with Pachyseris dominant. The slope flattens between 40 and 50 m, and becomes very sandy beyond 50 m. The temperature decreases markedly with depth, and the water becomes increasingly murky. The living reef ends between 50 and 60 m.

7. Kayangl windward outer reef

The east side of Kayangl is very exposed, making it impossible in most weather to anchor a small boat. The windward outer reef (no diagram) commences off the islands with a broad algal-turf-covered flat, and then drops to a platform about 1000 m wide and 7-10 m deep with little coral growth. This was not followed to the drop-off.

The lack of a developed windward coral community and the shallow lagoon prevent this from being as desirable a site as logistics and diversity might indicate.

Yap

Yap (9°30'N, 138°05'E), as a district center, is accessible (3 flights per week from Guam), and has excellent fringing reefs, especially on the northwest side, with some lagoon development inside the reef (Fig. 31). It is a high island, so that there are considerable terrestrial influences, and the reefs have experienced some Acanthaster infestation. In four dives on the west side, a superficial count of corals by R. Randall yielded over 100 species. Profiles from the dives on different parts of the reef have been combined to yield a composite section (Fig. 32).

8. Off Gorror

Two dives were made in the lagoon, on the SW side, between the reef and Yap Island. The first, off Gorror, was in a shallow sand flat area with turtle grass and occasional coral patches of high coral diversity (approximately 50 species). The water was rather murky.

9. Off Nif

The second dive, off Nif, was in one of the deep lagoon areas. The surrounding reef walls are covered with large corals down to the sandy bottom at 10 m. The reef top is exposed at low tide, with an algal turf cover and only small specimens of Favites.

10. Off Okau

The leeward outer reef off Okau begins with a rocky fore reef flat, 1500 m wide, cut by long surge channels 2 m deep and 1-2 m wide. Coral coverage increases to the reef edge at a depth of 7 m, with only a few species less than in Palau. The slope then drops steeply to 25 m with good coral growth, beyond which a more gentle slope is dominated by Pachyseris. The water changes at around 20-25 m; above it is warm and clear, below cool and turbid. Coral growth seems to end at around 40 m.

11. Mil Entrance

A final dive was made in the Mil Entrance (no diagram) on the west side between Yap and Rumung Islands. The reef flat on the north side of the channel extends down to 2 m with good coral coverage. There is a drop-off with good coral growth down to 10 m, and a gentle slope with turtle grass deeper down. A strong current of turbid water was moving out of the channel, which contained many large sharks.

Although the reef quality observed was high, the terrestrial influences, distance of the reef front from shore, and shallow limit to coral development are major disadvantages. There is also more chance of antagonistic feelings against Americans on the part of the local population in district centers.

Ulithi and Woleai

It was not possible during the short survey to arrange transportation to Ulithi or Woleai Atolls in the Yap district, but from other evidence and from conversations with chiefs from both areas, some useful information was collected.

Ulithi (10°00'N, 139°45'E) is a large atoll northeast of Yap. It has an airstrip with weekly Coast Guard flights from Guam or the possibility of charter flights ($500-$650 for 5-7 passengers, one day round-trip). There is also ship service from Yap every two weeks. There are some sunken ships in the lagoon, and other remnants of war damage, as well as an increasing ciguatera problem, but with the large size of the atoll undisturbed areas must remain. This is one of very few relatively undisturbed atolls directly accessible by plane.

Woleai (7°20'N, 143°45'E) is a small, totally undisturbed atoll presently inaccessible but with an abandoned Japanese airstrip. If the airstrip were ever repaired this could be an important site to consider, even though logistics would be somewhat more difficult. Earlier suggestions that the airstrip might be restored soon have not been confirmed. A. Antonius dived on the reefs during the 1969 Acanthaster survey, and they appeared to be well developed.

Ponape

Ponape (7°00'N, 158°00'E) is another district center, consisting of a large volcanic island and several smaller islands surrounded by a barrier reef (Fig. 33). The reefs are generally subjected to considerable terrestrial influences. There are three flights weekly from Guam to Ponape and two from Hawaii, making this the most accessible of the Caroline Islands.

Not far from Ponape, however, are two small atolls, Ant and Pakin. Ant is an atoll of moderate size only 10 miles from Ponape, while Pakin, somewhat smaller, is 30 miles away. Both can be reached by small boat from Ponape within 3 hours. One dive was made on the outer slope of each atoll, and both had excellent reef development.

12. Ant

The dive was on the leeward side just beyond the northern tip at the northernmost islet (Fig. 33). The reef crest at this point is 100 m wide, with a fore reef flat 200 m wide, extending down to the reef edge at 10 m (Fig. 34). Coral growth begins at 2 m depth, 30 m offshore, increasing to 90 percent coverage at 50 m offshore, and 100 percent at 100 m out. From the reef edge there is a steep slope down to 30 m depth with a coral cover of over 100 percent because of the overlapping table Acroporas which are dominant. The slope continues down to 50 m with interspersed sand cover increasing to 50 percent, although coral development continues much deeper. The water was warm and clear, with no change in temperature. Ant is an excellent reef, with a deep entrance, a good drop-off, and deep coral development.

13. Pakin

The dive site at Pakin was near the center of the northern reef (Fig. 33), in an exposed though not windward area. The 80 m wide reef crest merges with a sloping fore reef 50 m wide and 7 m deep at the edge (Fig. 35). The first 20 m is bare of coral cover, but coral density increases to the rugged edge, with headshaped Porites dominant. From there an almost vertical slope descends as far as could be observed, with a good coral cover of large specimens and a considerable amount of algae. Sand patches begin at 50 m, but at 60 m the coral cover is still 30 percent and continues to the limit of visibility. Again there was clear warm water with no temperature change with depth. The reef is excellent for research, with a steep drop-off and coral development to beyond normal SCUBA range. Six gray sharks were observed.

Ant has a single owner, an ardent conservationist, which might make arrangements for a long-term project difficult. Pakin has no channel into the lagoon at present, but there are government plans to open one and to build a pier in the lagoon. There would not appear to be any difficulty in locating a facility there, and logistical and construction support on Ponape seems excellent. One dive was also made on the Ponape barrier reef (see below), but it was disappointing.

14. Mant Passage

The brief dive in the Mant Passage, a northeast entrance through the windward wide of the Ponape barrier reef revealed a smooth rocky flat at 4 m depth with 20-30 percent coral coverage and low species diversity. The water was rather turbid, and one gray shark 2.5 m long was seen. The frequent heavy rainfalls in Ponape might cause technical problems for a research program, as well as affecting the reef.

Arno and Majuro

Majuro (7°05'N, 171°10'E) and adjacent Arno (7°05'N, 171°45'E), two large atolls in the southern Marshall Islands, are the only accessible atolls in the area without government entry restrictions. Majuro has two weekly flights from Hawaii, and Arno can be reached easily from Majuro. Majuro has been reported as being disturbed, while Arno is relatively untouched but dives on both atolls revealed rich reefs with an excellent configuration.

15. Kinajon (Arno)

The outer reef off Kinajon on Arno is on the sheltered south side (Fig. 36). The rocky fore reef flat 100 m wide develops good coral coverage and surge channels towards its edge at 10 m depth (Fig. 37). A steep slope with Porites heads dominant drops to 30 m where the angle of slope lessens and sand patches appear. Pachyseris then becomes dominant. At 60 m the coral cover is still 20 percent and continues as far as can be seen. The water was warm and exceptionally clear (the water surface was visible from 60 m), with no change in temperature. The reef in general seemed excellent; on the other side where the deep entrance is, it is reportedly even better developed.

16. Laura (Majuro)

On Majuro the reef was surveyed off Laura, a sheltered location on the southwest side (Fig. 36). The 60 m wide fore reef consisted of 20 m of bare surface, 20 m with a dense algal cover, and 20 m with corals, mainly Acropora, leading to the rugged reef edge at 5-8 m depth (Fig. 38). Deep surge channels cut into the reef. There is no real drop-off, but a gently rounded slope with valleys and ridges perpendicular to the shore, and also many shore-parallel steps. The coral cover decreases from 90 percent at the edge (5-8 m) to 60 percent at 12 m, to 50 percent at 20 m with increasing algal cover. The slope gets steeper with depth, becoming vertical at 40 m, where the coral cover is 20 percent. This site is accessible by road from Majuro, and has good reef features and clear water. Fishes were very abundant, but no sharks were observed.

AMERICAN SAMOA*

The Samoa Islands (14°15'S, 170°00'W) are a chain of volcanic

*Field survey: September 7-12, 1971 by A. L. Dahl and A. Antonius (assisted by S. Ritterbush).

islands with fringing coral reefs in the South Pacific. While rather far from the center of coral diversity, their ready accessibility by direct flight from Hawaii and the strong interest of the local government warranted detailed examination of the reefs. The Manua Islands are remote from the main island of Tutuila and can be reached by government or commercial boat in about 8 hours. There has also been an intermittent float plane service. Because transportation is difficult it was only possible to dive on the reefs in the vicinity of the main anchorage of each island. Since the reefs in the Manua Islands were not transected no diagrams are given.

17. Tau (Manua)

At Tau the dive was made off the northwest side (Fig. 39), a leeward but exposed area, about 300 m offshore. There is a rocky flat with huge boulders at 20-25 m depth. Few coral species are present, mainly *Porites* and *Pocillopora*, and specimens are small and scarce.

18. Olosega (Manua)

The dive off Olosega was on the sheltered leeward (west) side about 200 m offshore, at 20-25 m depth (Fig. 39). The bottom is rocky, with huge blocks, forming valleys and ridges. Coral cover is more extensive and with more species than Tau, with huge coherent colonies of table-like *Acropora* and *Porites* (*lobata?*). Many alcyonarians are also present.

19. Ofu (Manua)

The anchorage of Ofu is on the west side in a very sheltered location (Fig. 39), 200 m offshore from Alaufau, where the water is 10-20 m deep. The bottom has marked topographic relief, with small corals and red algae on top of the elevations, dense coral cover and good species diversity on the walls, and white sand in the bottoms of the troughs. The water was clear and warm. Fishes were abundant, but no sharks were observed.

Two dives were made on the fringing reefs on the north and south sides of Tutuila, the main island of American Samoa.

20. Leone Bay (Tutuila)

At Leone Bay on the windward south west side (Fig. 39), the reef was surveyed out to 350 m from the shore near Logologo Point (Fig. 40). The reef structure is irregular, somewhat resembling a spur and groove system, with a shallow reef flat, and then large reef patches in deeper water, extending down to 25 m. The coral cover is very variable, sometimes almost 100 percent, as at Ofu, but many helioporas are also present. A large flat of white completely detritus-free coarse sand occurs at 15 m depth. The water was warm and clear, with many fishes and no sharks.

21. Ogegasa Point (Tutuila)

On the north side of Tutuila, at Ogegasa Point (Fig. 39), there is a vertical basaltic rock slope from the surface to 3 m, followed by a rocky flat with small scattered corals extending 50 m offshore to a depth of 7 m (Fig. 41). From here a slope with spur and groove configurations drops to 15 m and then a very steep slope down to 30 m, ending in an extensive sand flat. This slope has the best coral coverage and richest species diversity of all the Samoan sites observed. The water was warm and slightly turbid, perhaps from a recent rainfall. Again the area was rich in fishes but lacked sharks. Apparently there are no good near-shore drop-offs around the islands of American Samoa.

It was not possible to reach Rose Atoll, as the seaplane was damaged shortly before our arrival, and time and weather precluded boat transportation. Discussions with the Office of Marine Resources which recently surveyed the atoll, indicated that the land area was inadequate for any facility, so that it could only be used for short visits.

CONCLUSIONS

The overall evaluation of the site information leads to the following conclusions for the Smithsonian-planned programs. In the Caribbean, the logistic problems and unique character of the San Blas Islands, the disturbance and political problems at Discovery Bay, and the poor reef structure of St. Croix and Acklins Island left Glover's Reef, British Honduras as the preferred site. In the Pacific no final decision was possible without further field surveys, but several areas showed good potential, including Pakin, Ulithi, and Arno. Ulithi was not visited by a survey team, and so requires further examination. A more detailed study of areas in Fiji and the Gilbert and Ellice Islands could also be productive. However, once the scientific suitability of a site was determined, it would still be necessary to negotiate with the local inhabitants for space and permission to work on their reefs.

It is important to remember that the areas reported on here were selected and described in accordance with the specific program criteria listed in the introduction, not all of which would necessarily apply to other projects. We hope that others searching for a suitable location for a coral reef research program will be able to use this information, with due caution for its limitations, in selecting a site most appropriate to their needs.

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Site name ______________________ Ocean area ____________
General location ______________________________________
Longitude ____________ Latitude ____________
Charts ____
General references ____________________________________
____

/_/ Island; /_/ Continental; /_/ Atoll; /_/ Fringing reef on /_/ volcanic or /_/ other base;
/_/ Barrier reef.

Description of site ___________________________________
____
____
____

Features:	Yes	No	Notes
Adequate comparable reef area for sampling (perhaps 1 km frontage)	/_/	/_/	____
Well developed reef flat for drilling	/_/	/_/	____
Reef development to at least 50 m depth	/_/	/_/	____
Width across reef less than 300 m	/_/	/_/	____
Reef near enough to shore to permit shore-based instrumentation	/_/	/_/	____
Reef undergoing active construction	/_/	/_/	____
Considerable species diversity	/_/	/_/	____
Reef not obviously unique	/_/	/_/	____
Major terrestrial influences absent	/_/	/_/	____
Reasonably continuous reef accumulation	/_/	/_/	____
Current and tidal flow patterns permitting cross-reef metabolic studies	/_/	/_/	____
Variety of subsidiary site types in area	/_/	/_/	____
Undisturbed by development, catastrophic storms, war, or pollution	/_/	/_/	____
Probability of remaining undisturbed	/_/	/_/	____
Weather permitting year-round work	/_/	/_/	____
Accessible, within 1 day's travel of a major airport and harbor facility	/_/	/_/	____
Anchorage and landing for work boats	/_/	/_/	____
Accommodations available	/_/	/_/	____
Research space available	/_/	/_/	____
Buildings available for conversion	/_/	/_/	____
Electricity	/_/	/_/	____
Fresh water	/_/	/_/	____
Local suppliers (food, fuel, building materials)	/_/	/_/	____
Research vessels available in general area	/_/	/_/	____

Governmental authority ________________________________
  Possible attitude toward project ____________________

Previous scientific work (include references) _________
____
____
____

Aerial Photographs (Source) ___________________________
Other notes ____
____
____
____

Information supplied by ______________________ Date ____________

A sketch map on the reverse would be helpful. Indicate scale or approximate distances if possible. (Also idealized cross sections with reef zonations)

Figure 1 - QUESTIONNAIRE FOR SITE SURVEY

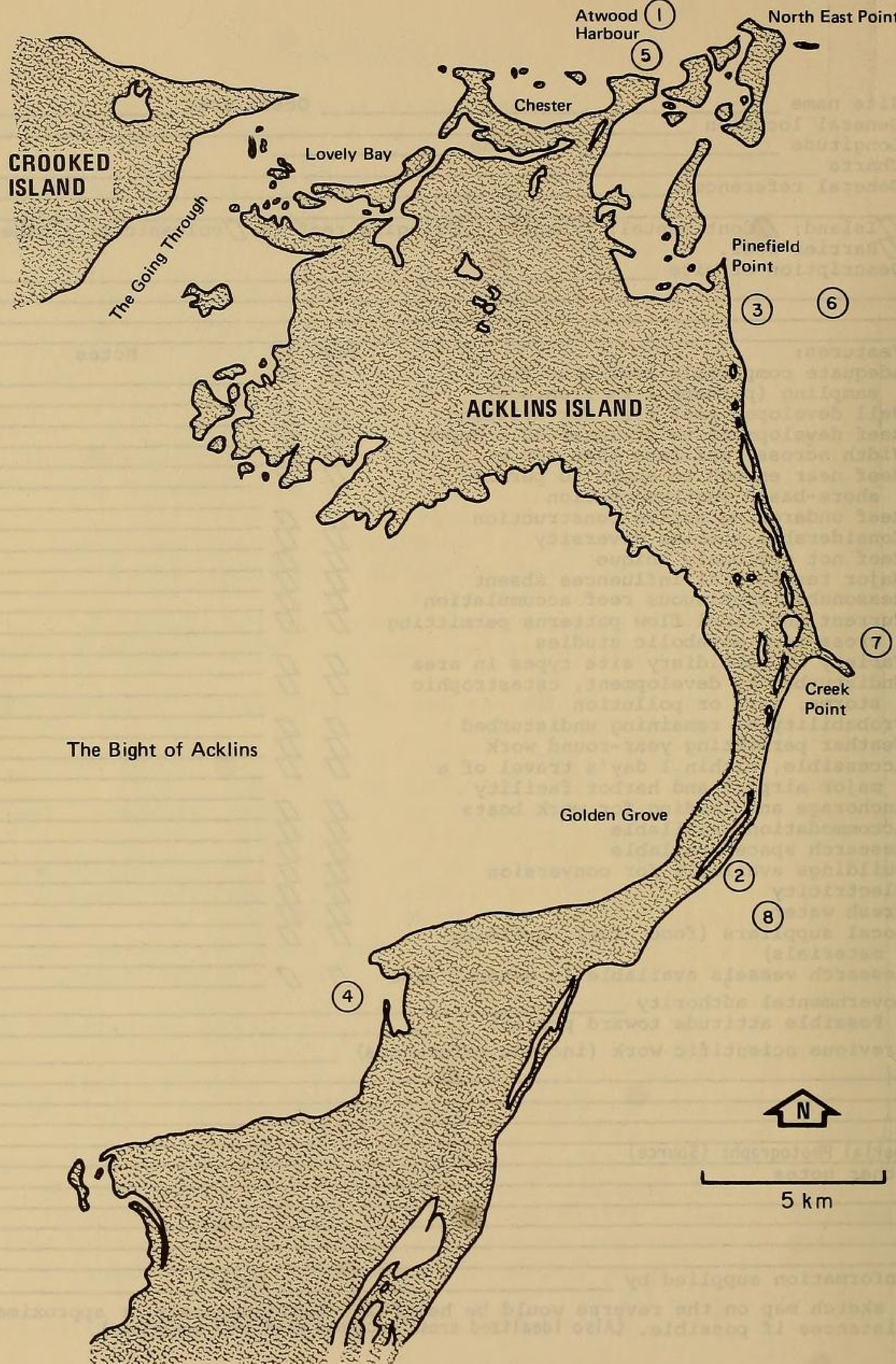


Figure 2 – ACKLINS ISLAND
22°30'N 74°00'W

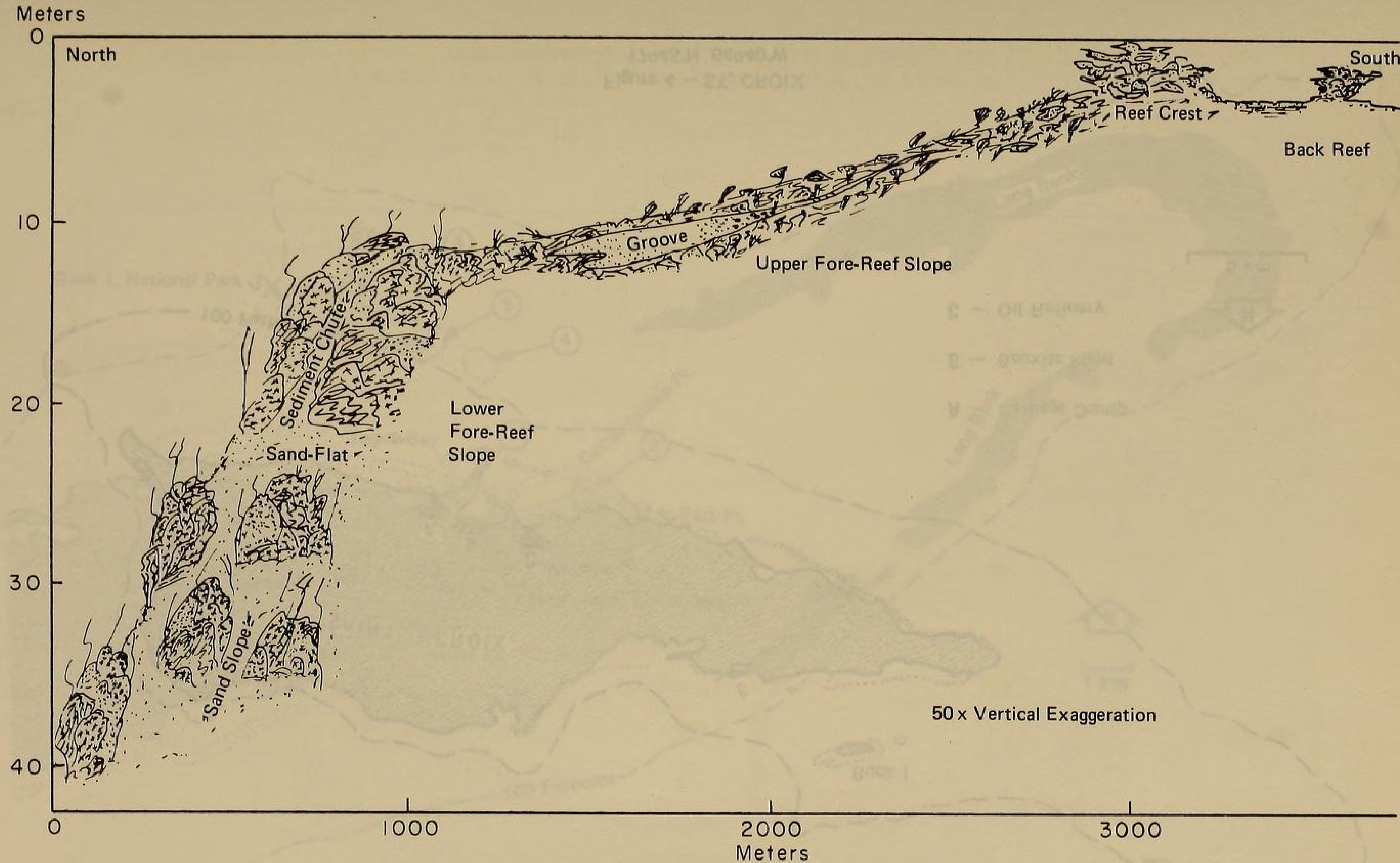


Figure 3 – SITE 5 - ATWOOD HARBOR

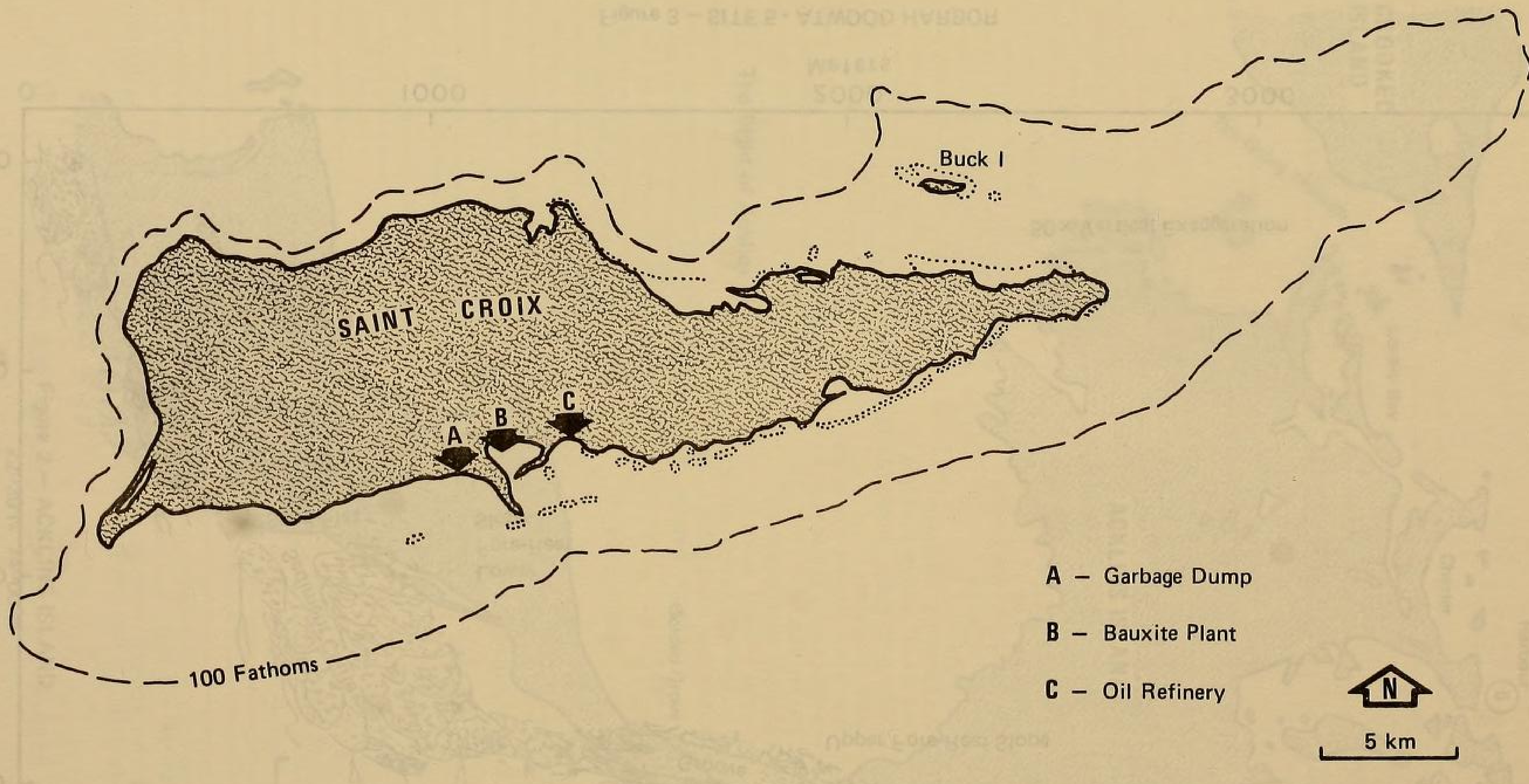


Figure 4 – ST. CROIX
17°45'N 64°40'W

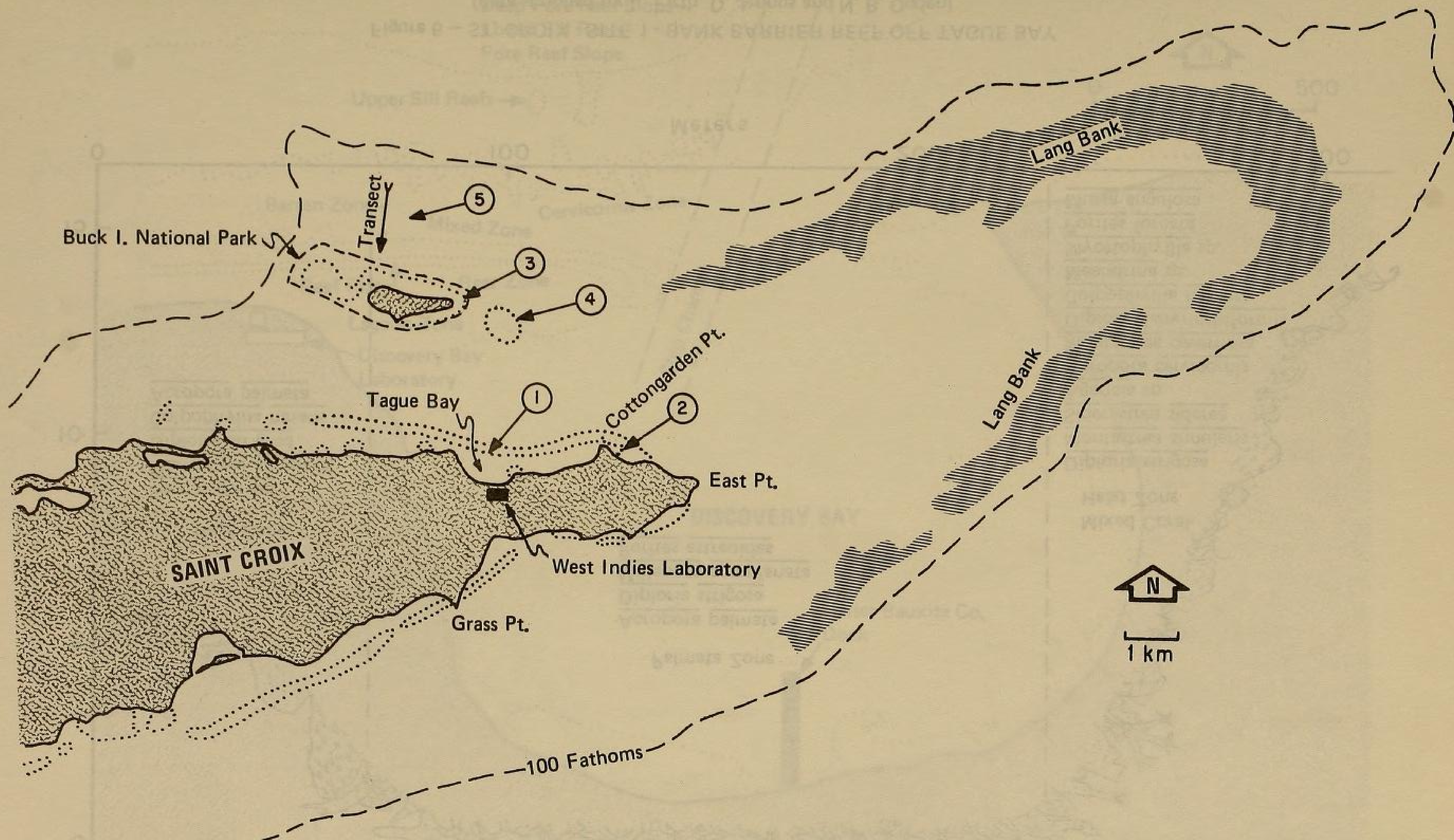


Figure 5 – EAST END OF ST. CROIX SHOWING DIVING SITES

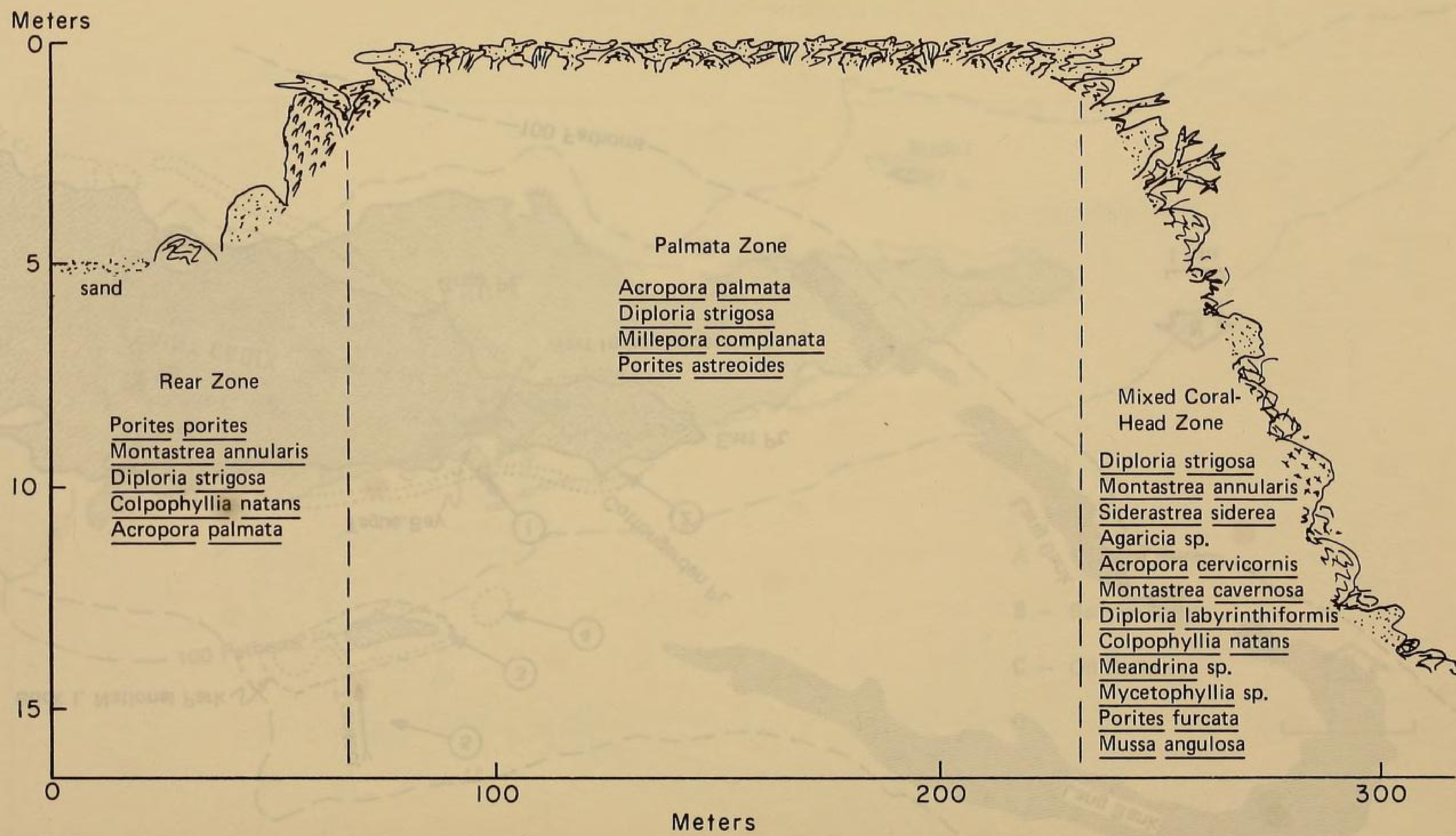


Figure 6 – ST. CROIX - SITE 1 - BANK BARRIER REEF OFF TAGUE BAY
(data supplied by L. Firth, D. Jennus and N. B. Ogden)

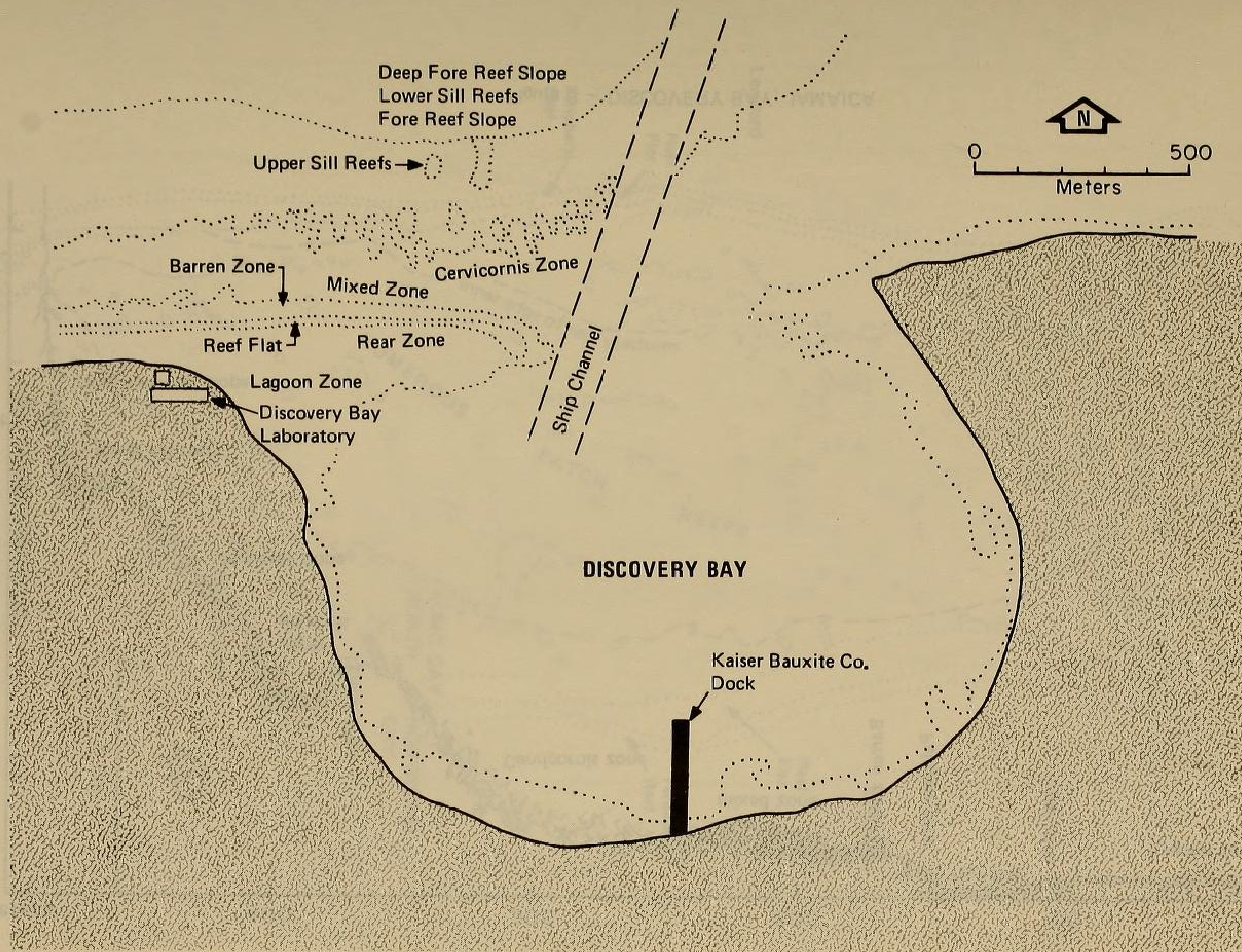


Figure 7 – DISCOVERY BAY (after Land, unpublished)
18°30'N 77°25'W

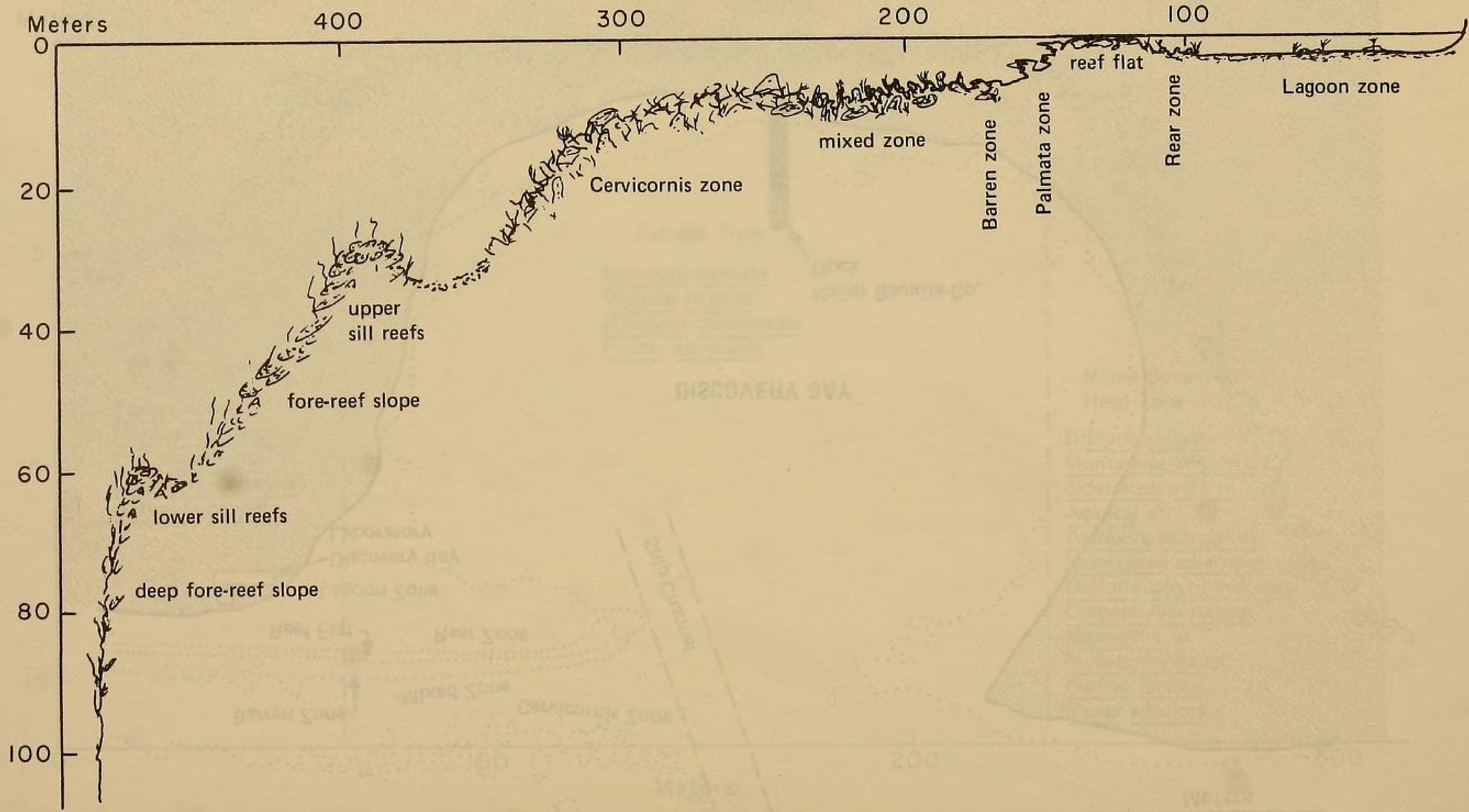


Figure 8 – DISCOVERY BAY, JAMAICA

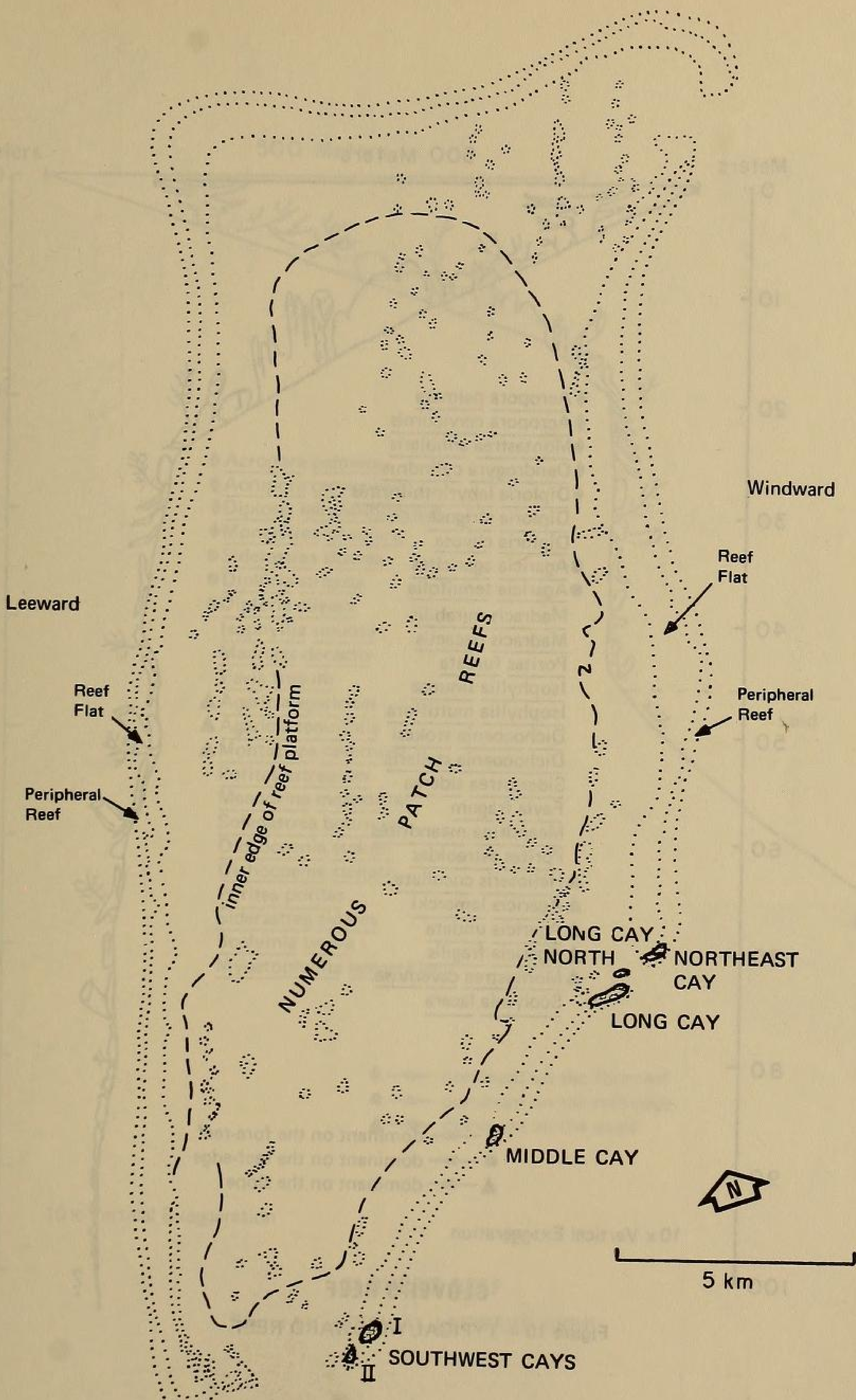
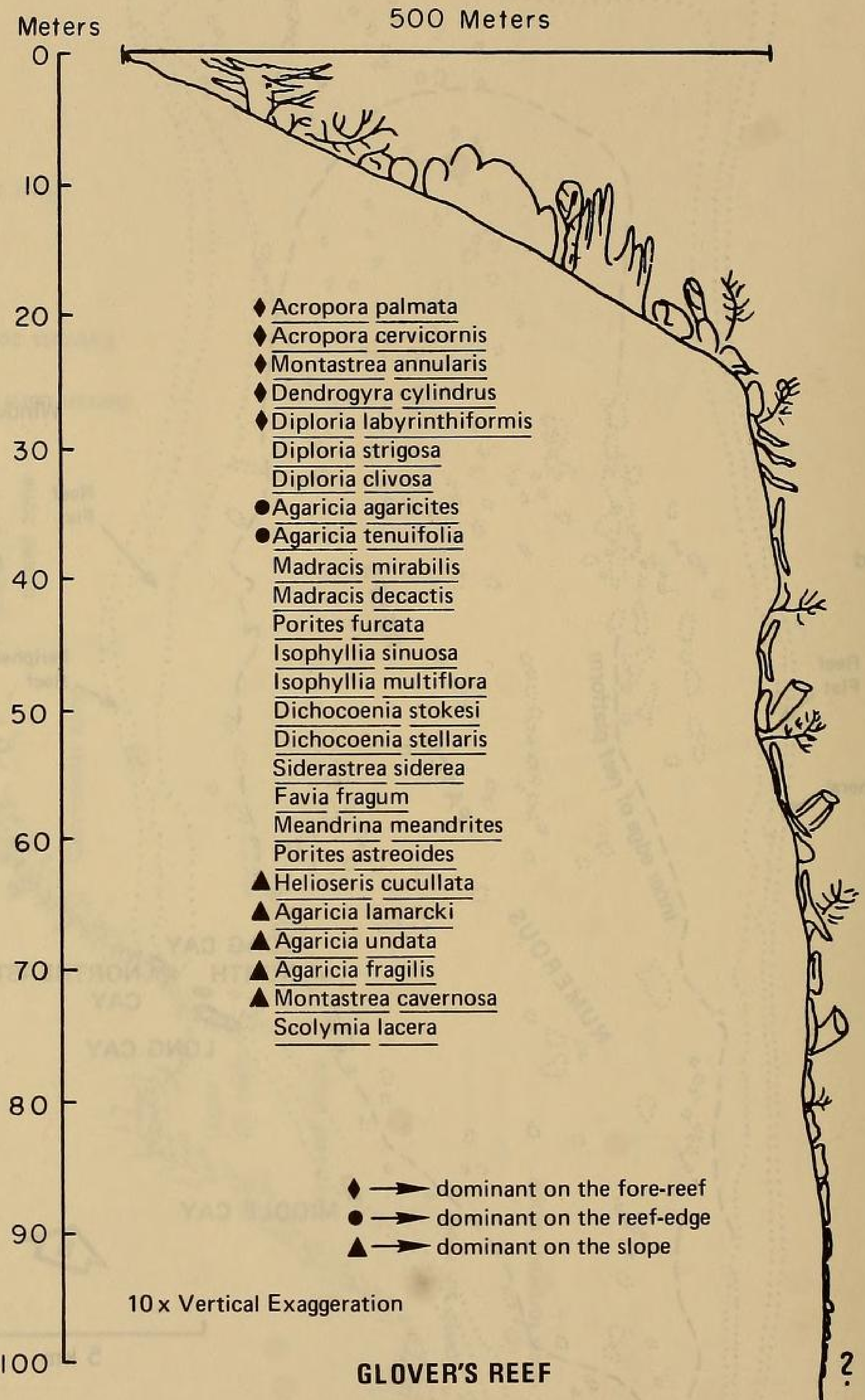
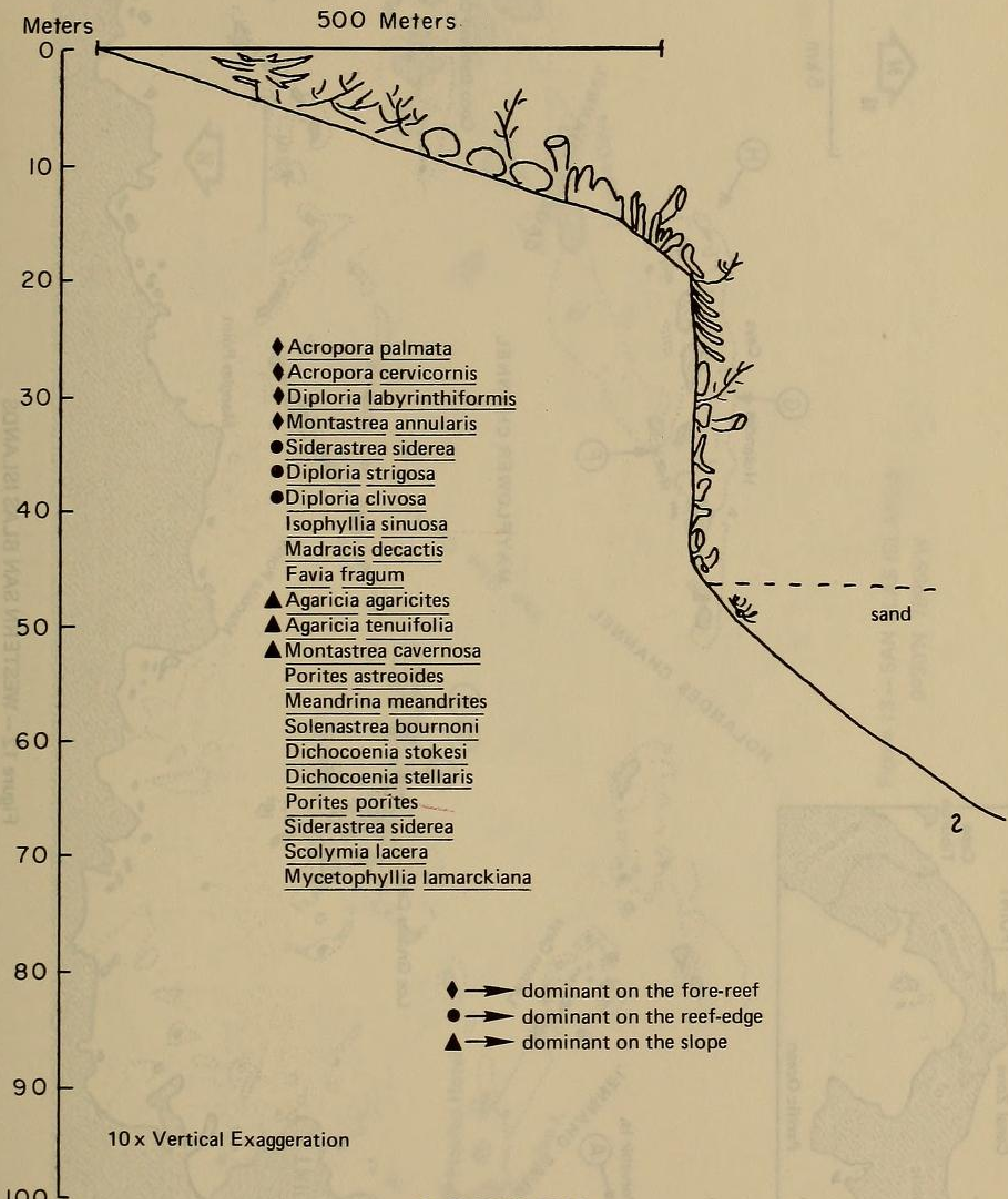


Figure 9 – GLOVER'S REEF (modified after Stoddart, 1962)
16°50'N 87°50'W



GLOVER'S REEF

Figure 10 – TYPICAL WINDWARD REEF



GLOVER'S REEF

Figure 11 – TYPICAL LEEWARD REEF

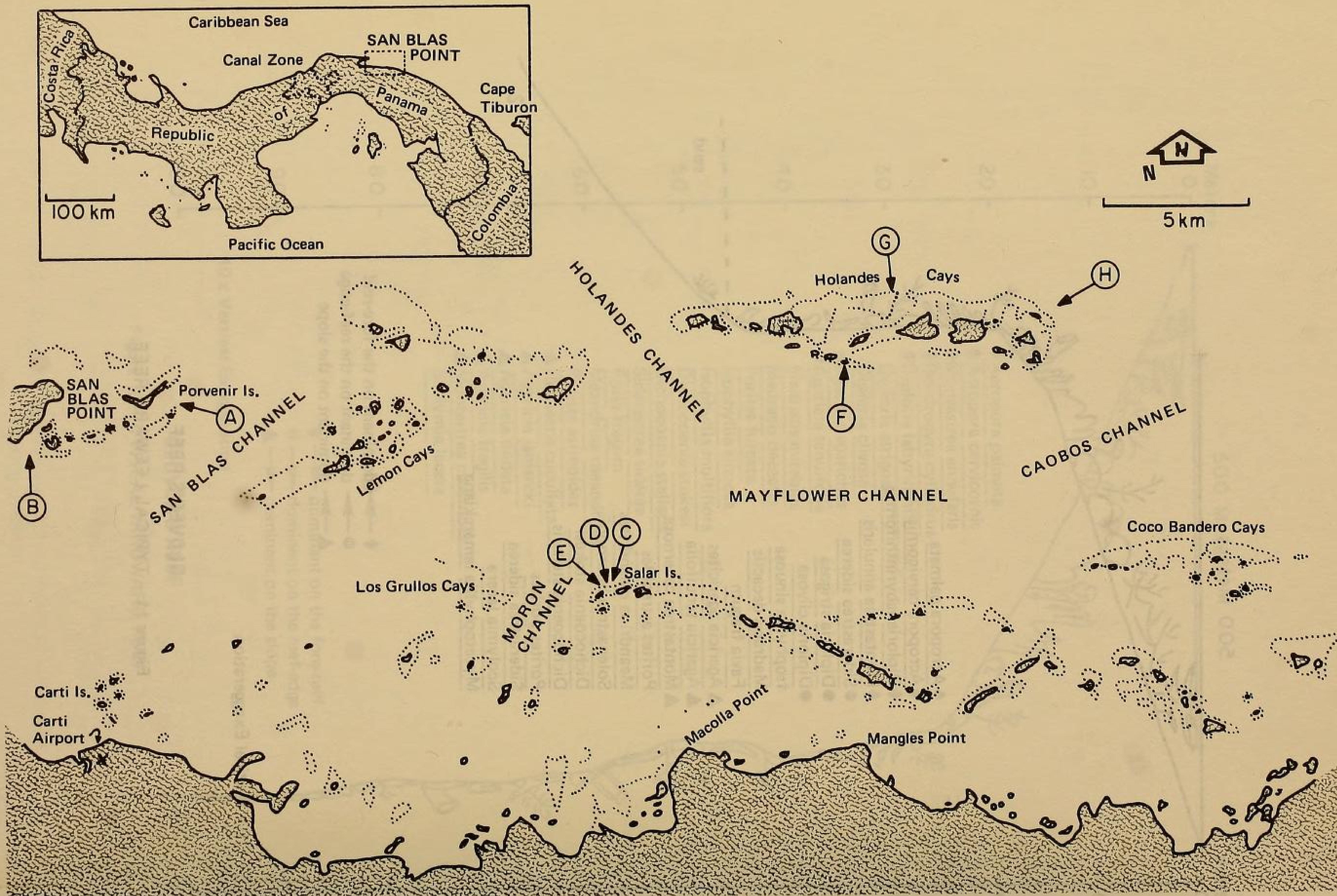


Figure 12 – WESTERN SAN BLAS ISLANDS
9°30'N 78°45'W

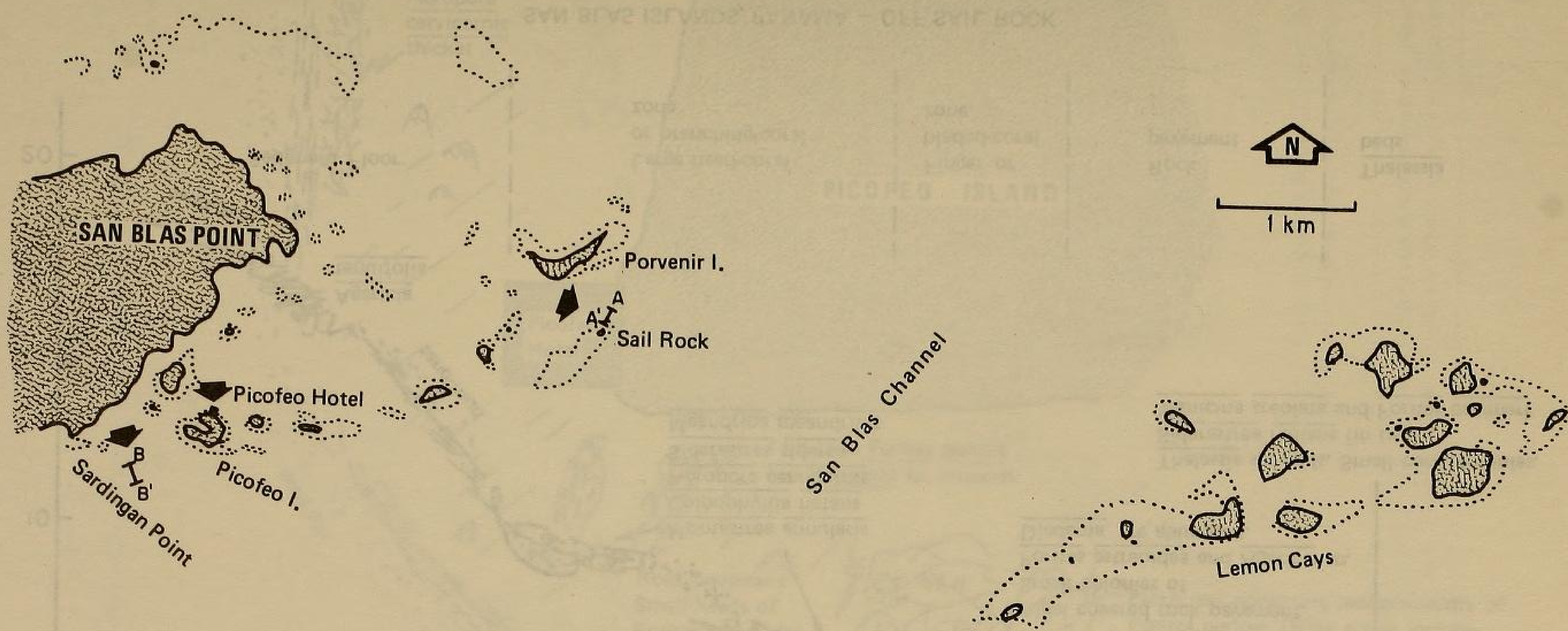
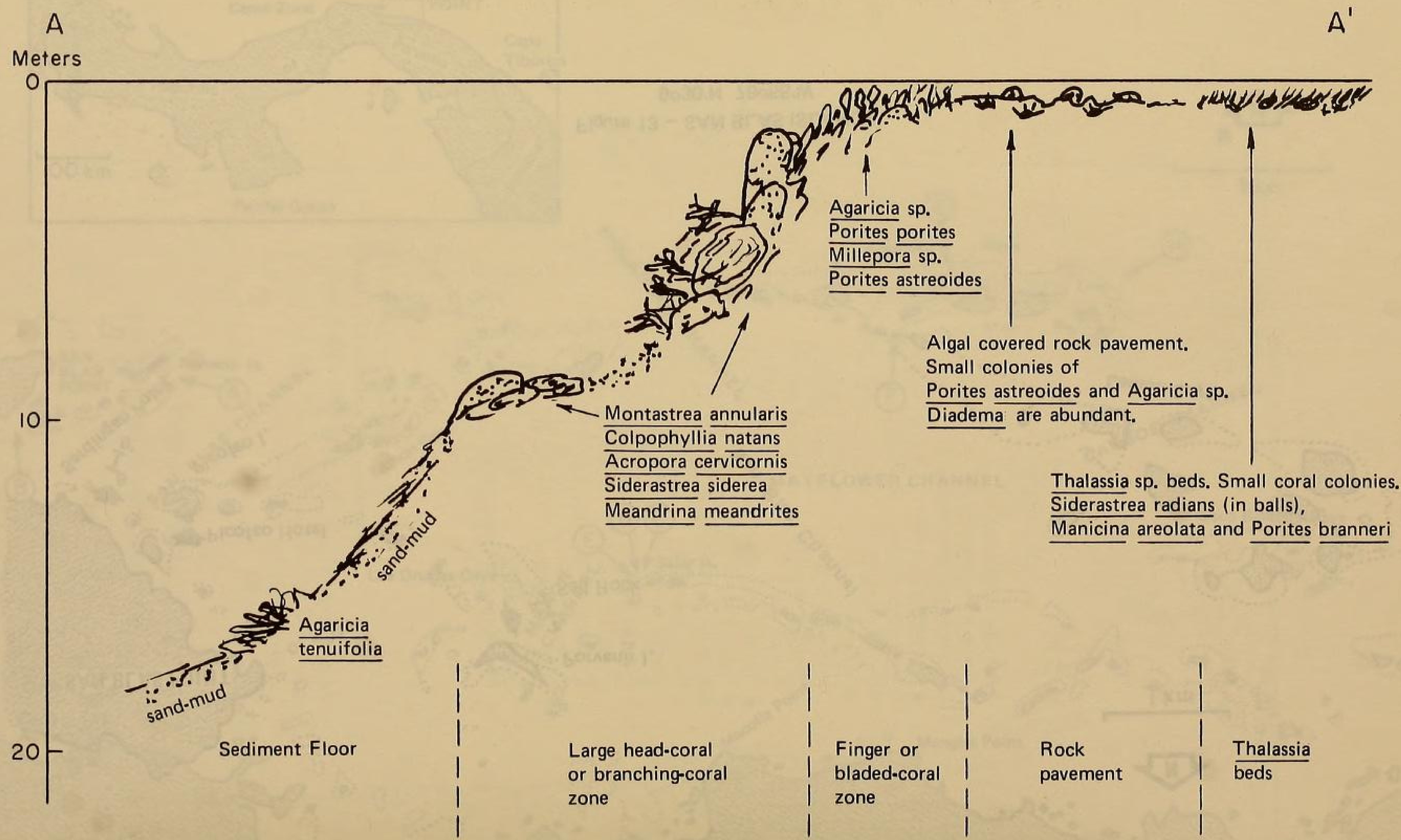


Figure 13 – SAN BLAS ISLANDS
9°30'N 78°55'W



SAN BLAS ISLANDS, PANAMA – OFF SAIL ROCK

Figure 14 – PROFILE A – A'

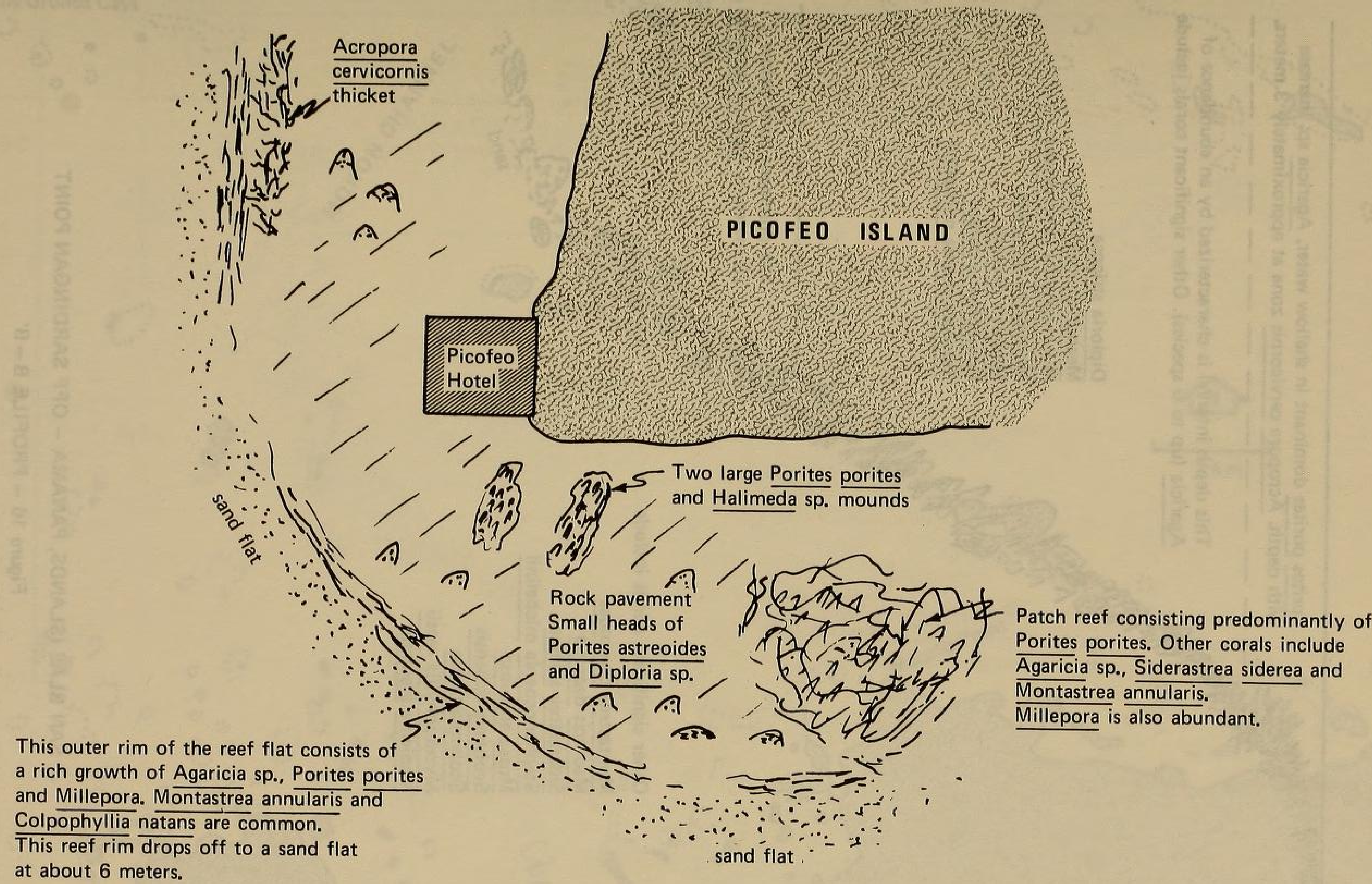
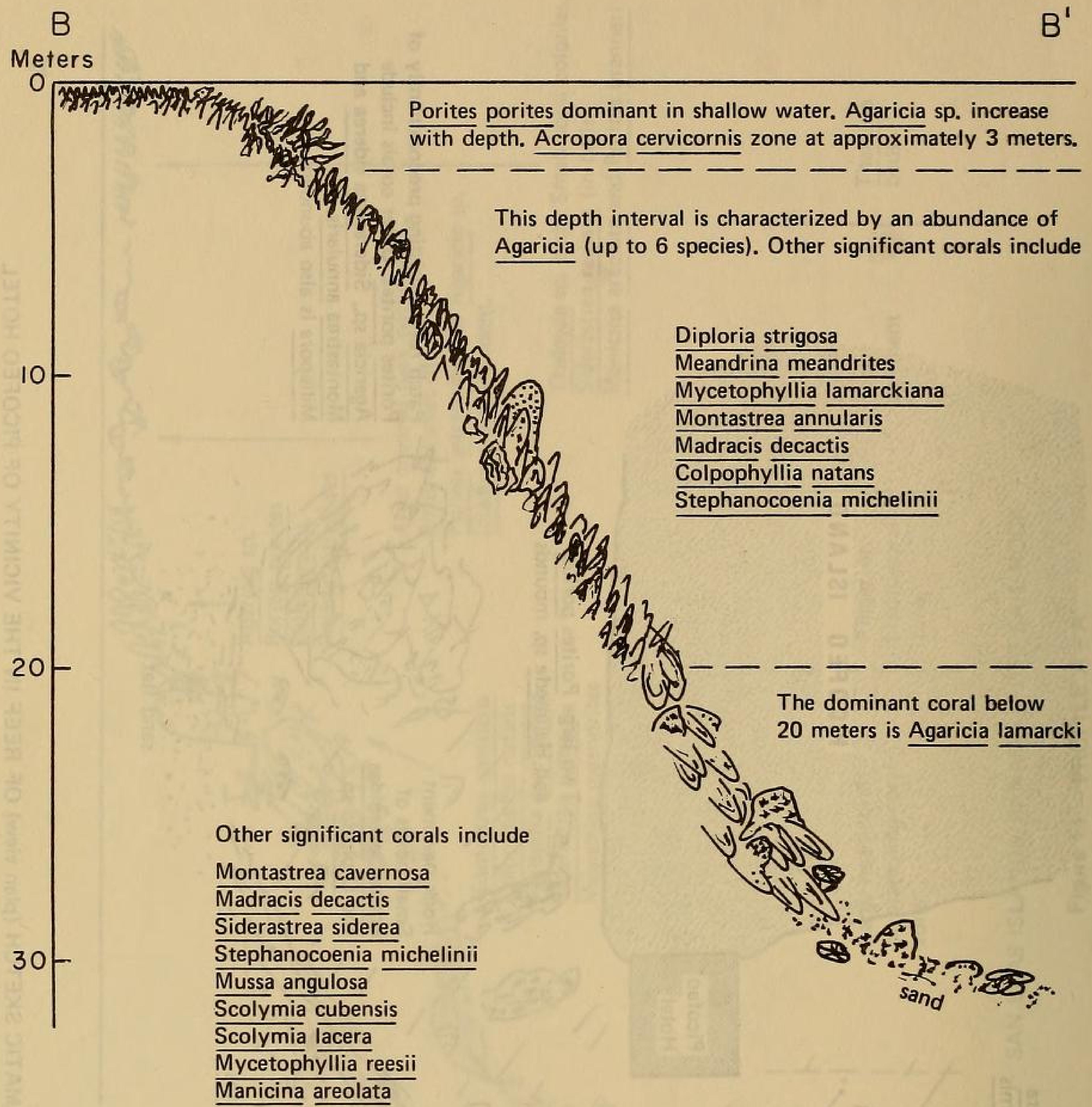


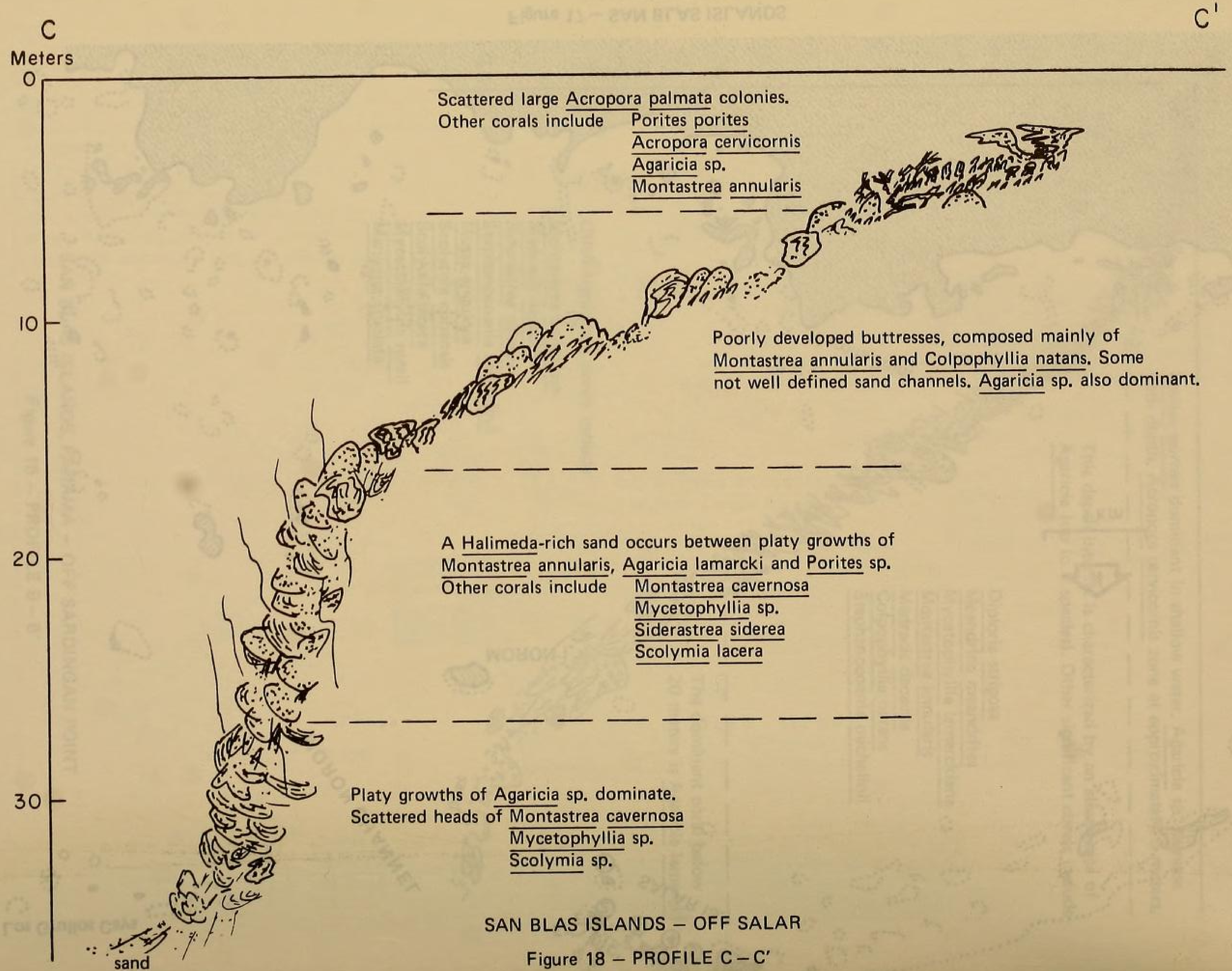
Figure 15 – DIAGRAMATIC SKETCH (plan view) OF REEF IN THE VICINITY OF PICOFEO HOTEL



SAN BLAS ISLANDS, PANAMA – OFF SARDINGAN POINT

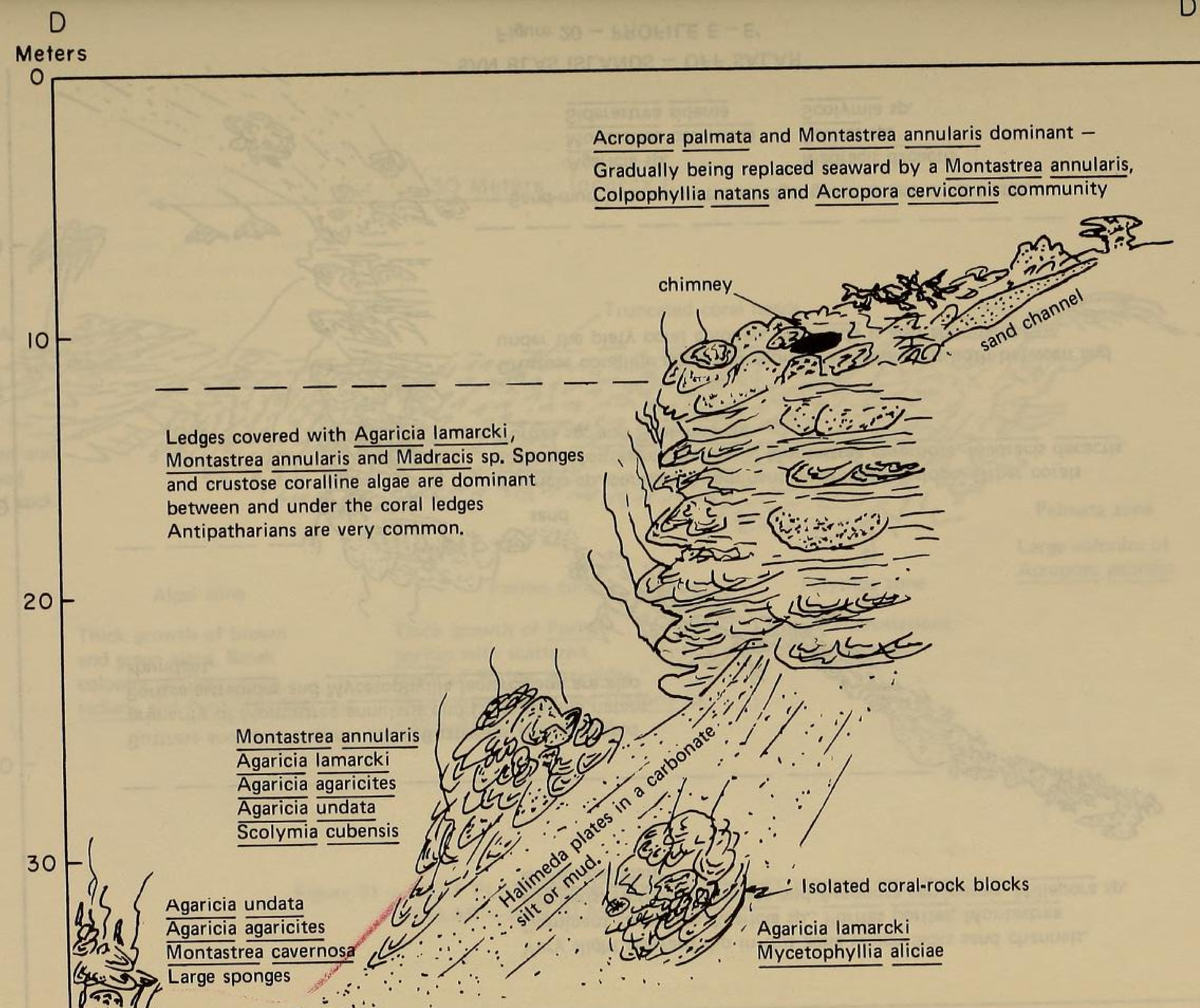
Figure 16 – PROFILE B – B'

Figure 17 – SAN BLAS ISLANDS
9°30'N 78°48'W



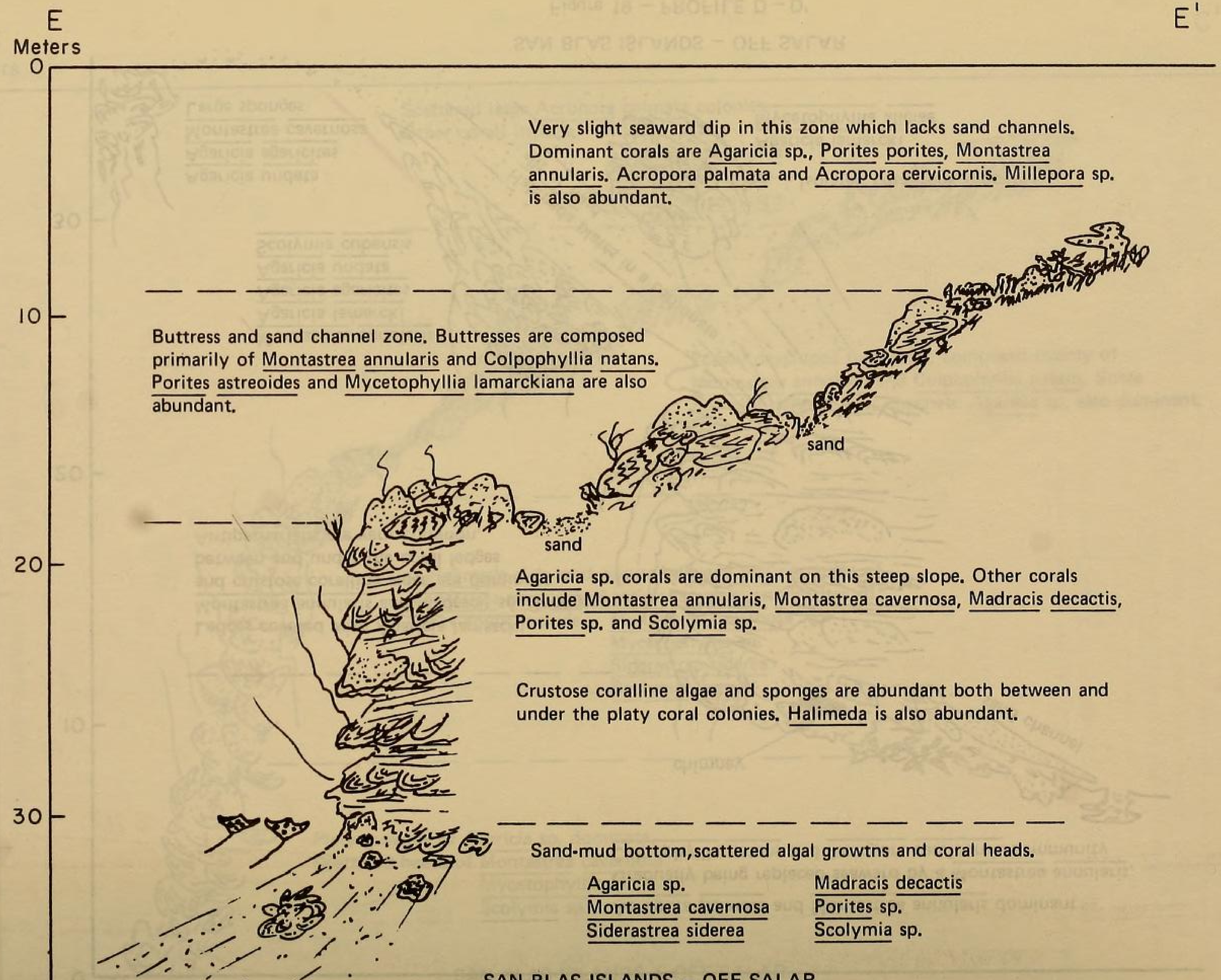
SAN BLAS ISLANDS – OFF SALAR

Figure 18 – PROFILE C–C'



SAN BLAS ISLANDS – OFF SALAR

Figure 19 – PROFILE D – D'



SAN BLAS ISLANDS – OFF SALAR

Figure 20 – PROFILE E – E'

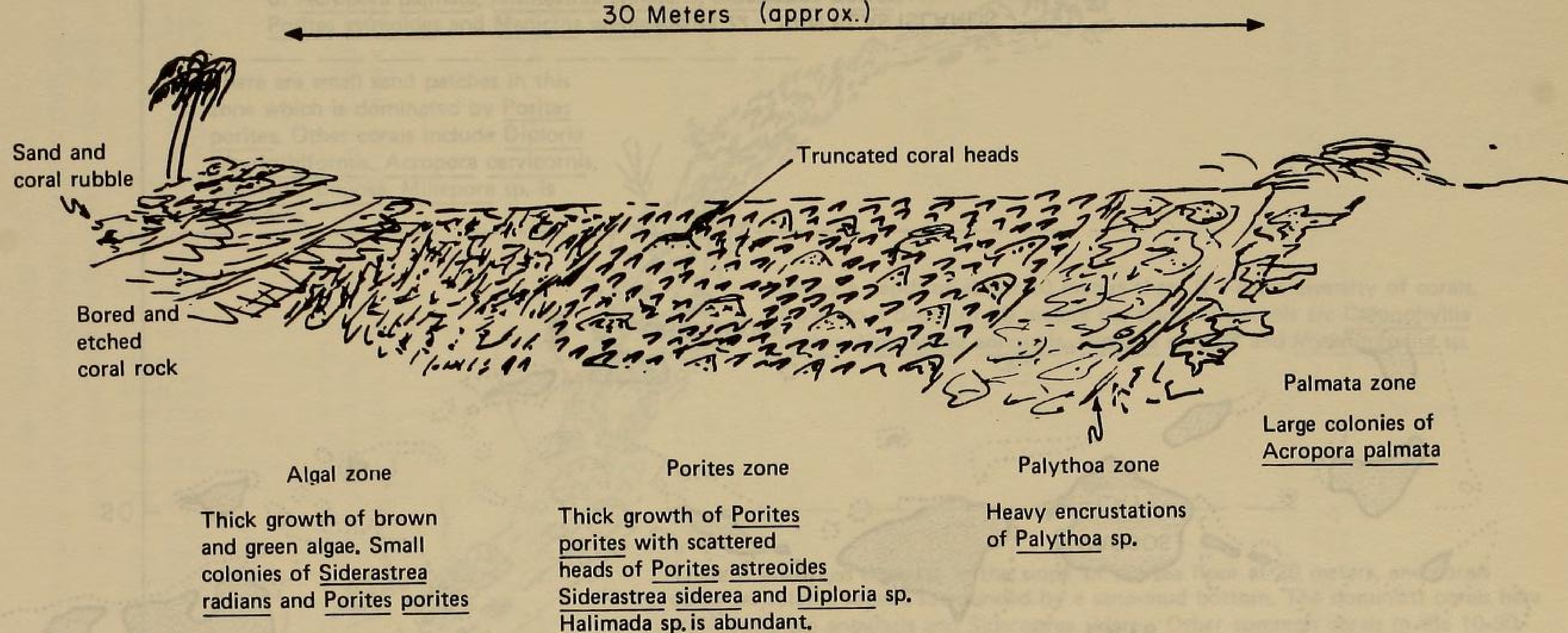


Figure 21 – REEF FLAT OFF NORTHWEST COAST ISLAND NO. 3
SALAR – SAN BLAS ISLANDS

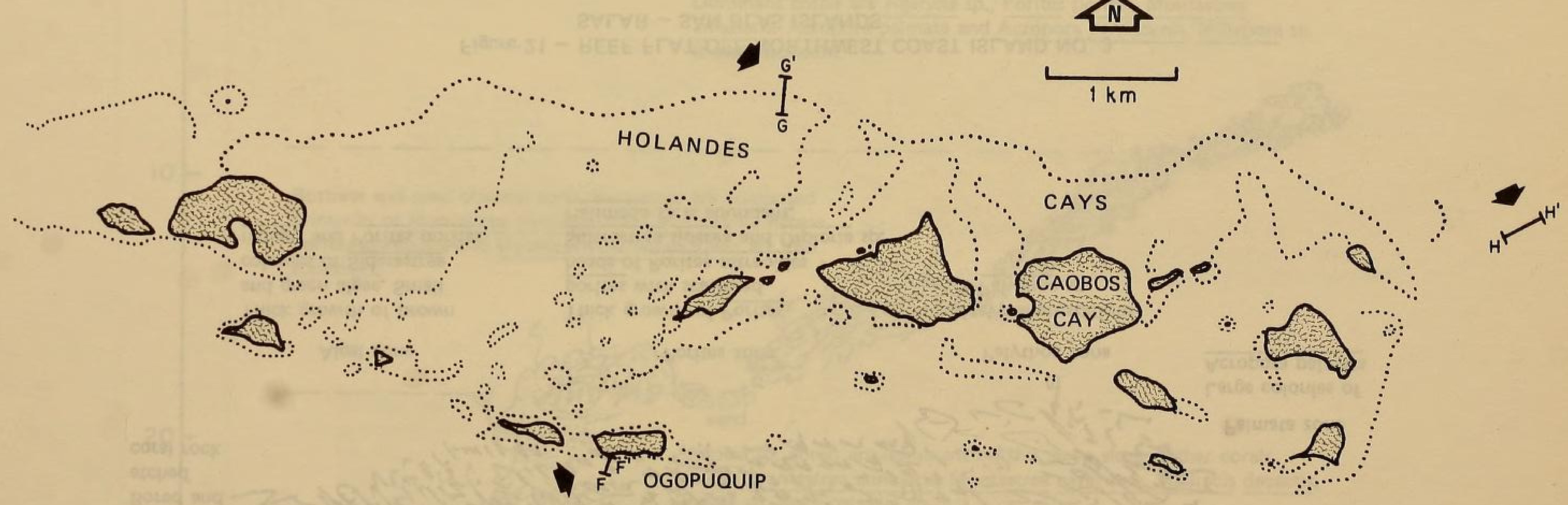
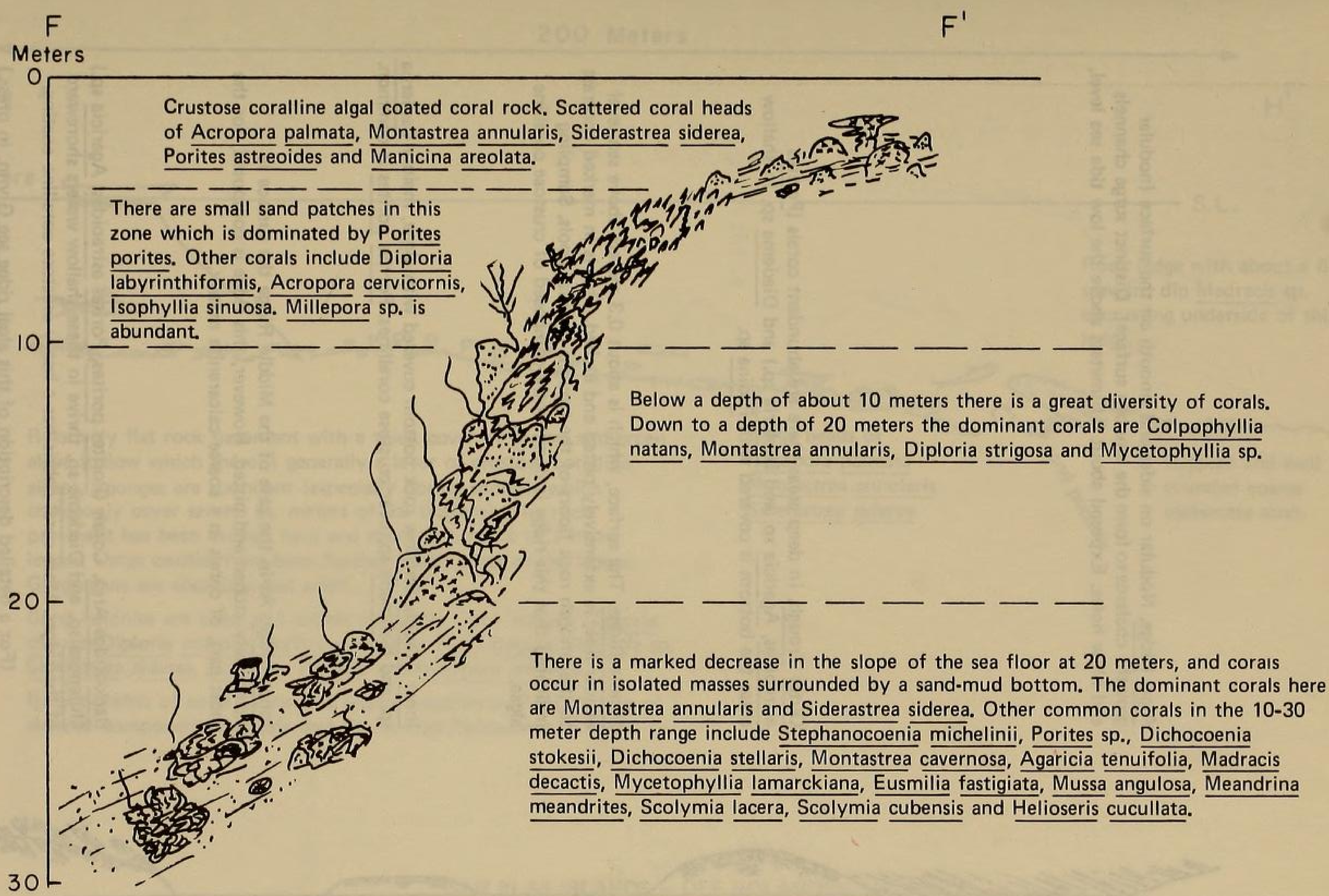
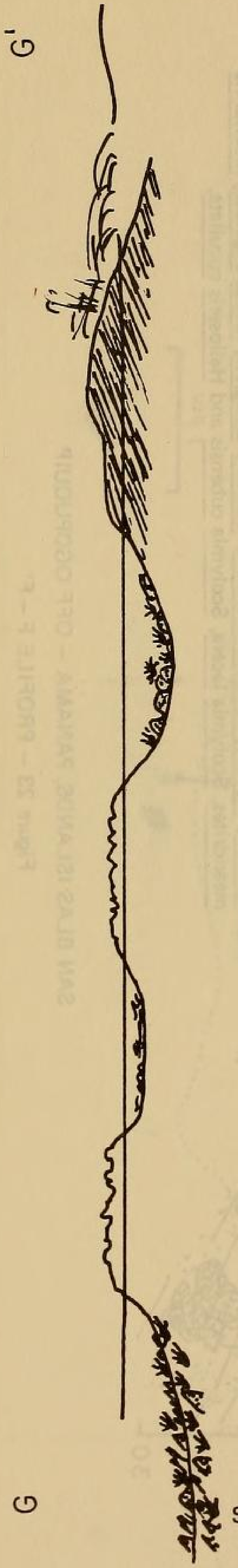


Figure 22 – SAN BLAS ISLANDS
9°35'N 78°43'W



SAN BLAS ISLANDS, PANAMA – OFF OGOPUQUIP

Figure 23 – PROFILE F – F'



Algal Ridge. Nodular on sides and smooth on the surface (nodular growths coalesce to form the smooth surface). Distinct surge channels and blow holes. Exposed about 0.6 meters above the low tide sea level.

Outer Trough. In deep areas there are abundant corals (Porites astreoides, Agaricia sp. and Diploria sp.) and Diadema sp. In shallow areas the bottom is covered with Padina sp.

Middle Ridge. The surface, which is about 0.3 meters above sea level at low tide, is extensively pitted and etched. This is in marked contrast to the smooth rock floors of the troughs or tidal pools. Sampling indicated that this ridge is dominantly composed of crustose coralline algae.

Inner Trough. Shallow rock bottom covered with algae, mainly Caulerpa sp. and Halimeda sp. over crustose corallines. Porites porites is common.

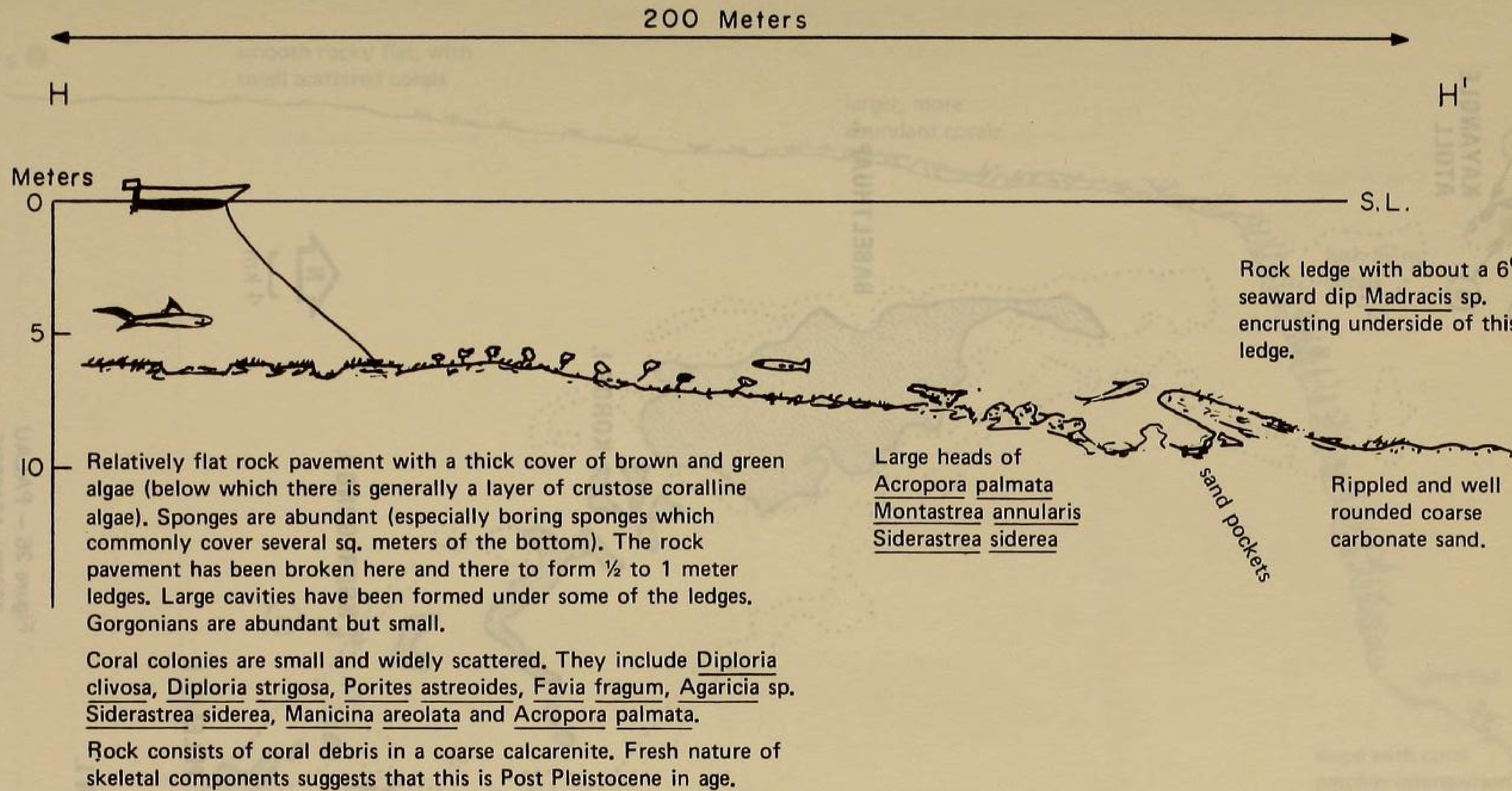
Inner Ridge. As in the case of the Middle Ridge the surface is extensively etched and pitted. However, this ridge is composed, for the most part, of corals in a coarse calcarenite matrix.

Back-Ridge Area. Corals (Porites porites, Porites astreoides, Agaricia sp.) Millepora sp. and Diadema sp. thrive in these shallow waters shoreward of the ridges. Most coral debris has a heavy crustose coralline coating.

(For a detailed description of this algal ridge see Glynn, in press.)

SAN BLAS ISLANDS, PANAMA – HOLANDES CAYS ALGAL RIDGE

Figure 24 – PROFILE G – G'



SAN BLAS ISLANDS – OFF HOLANDES CAYS

Figure 25 – PROFILE H – H'

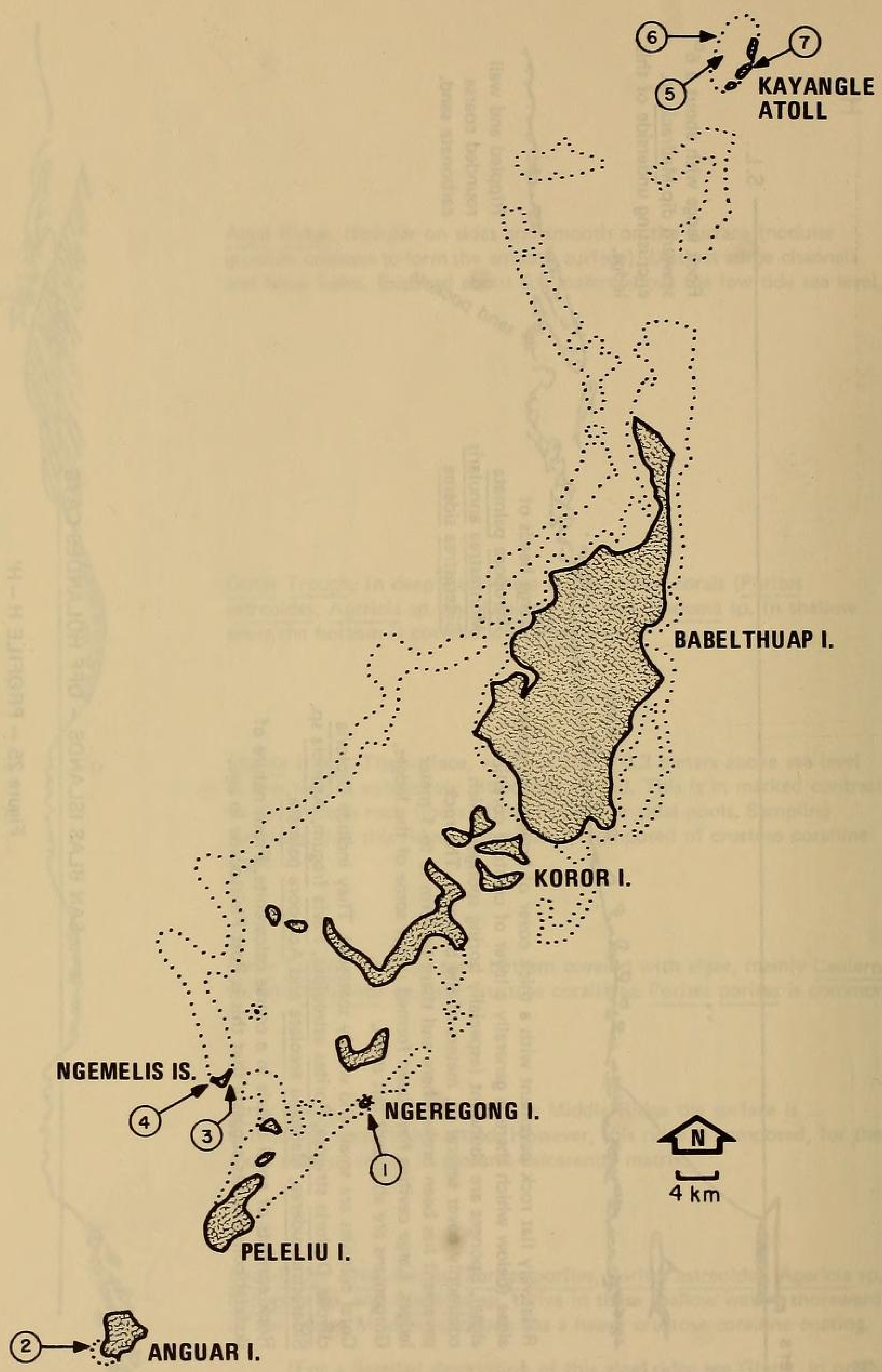


Figure 26 – PALAU
7°30'N 134°30'E

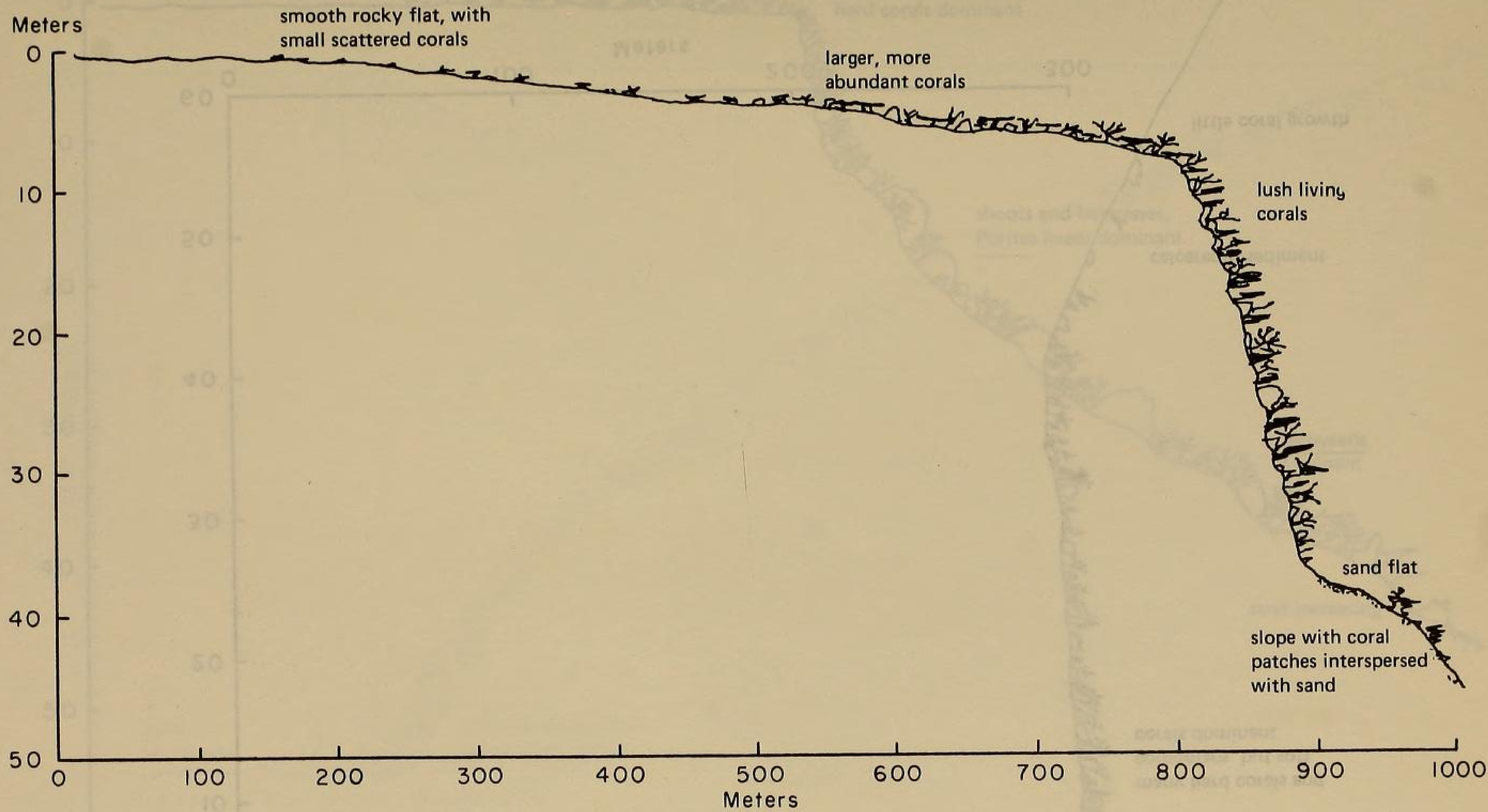


Figure 27 – SITE 2 - ANGAUR

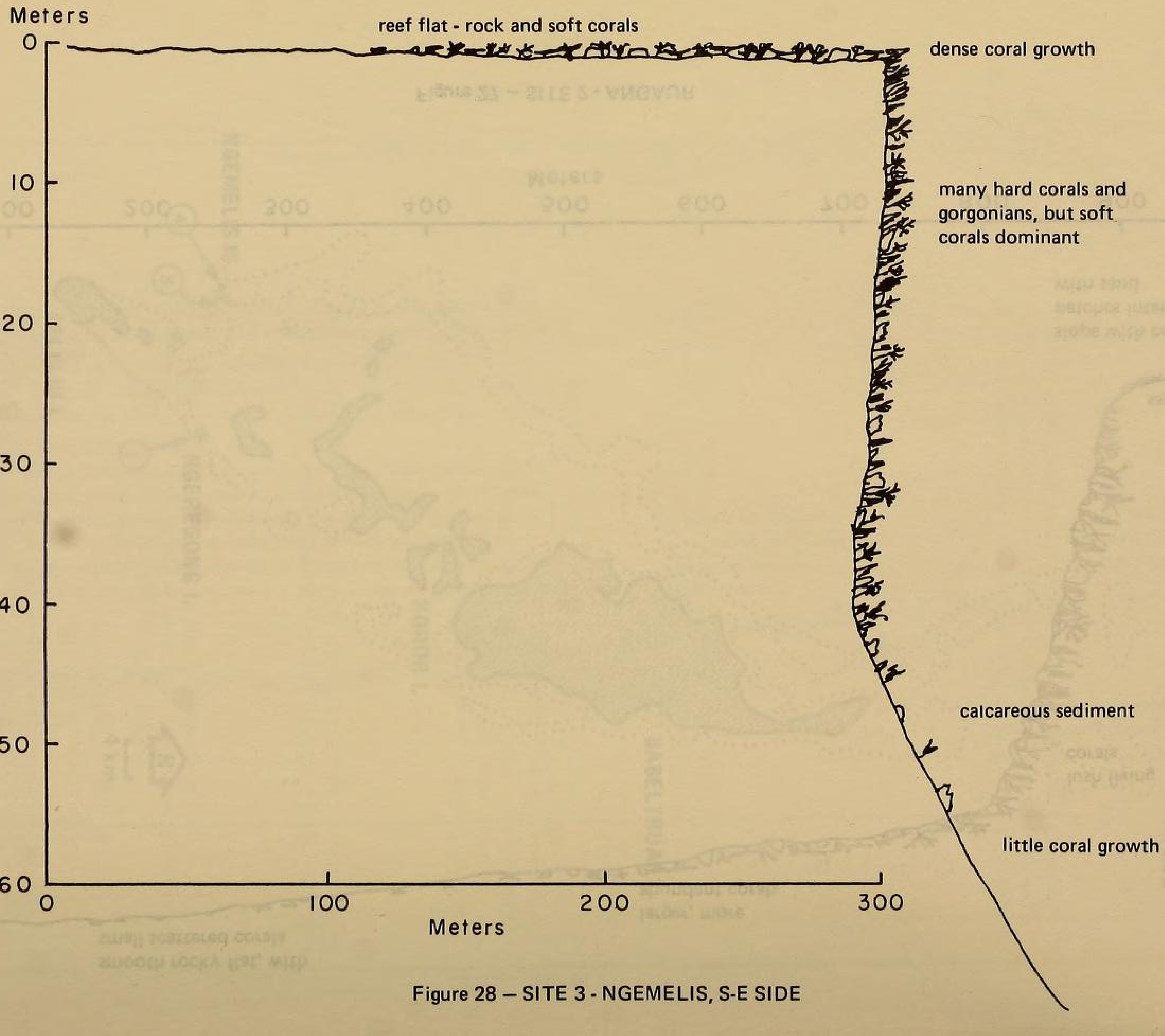


Figure 28 — SITE 3 - NGEMELIS, S-E SIDE

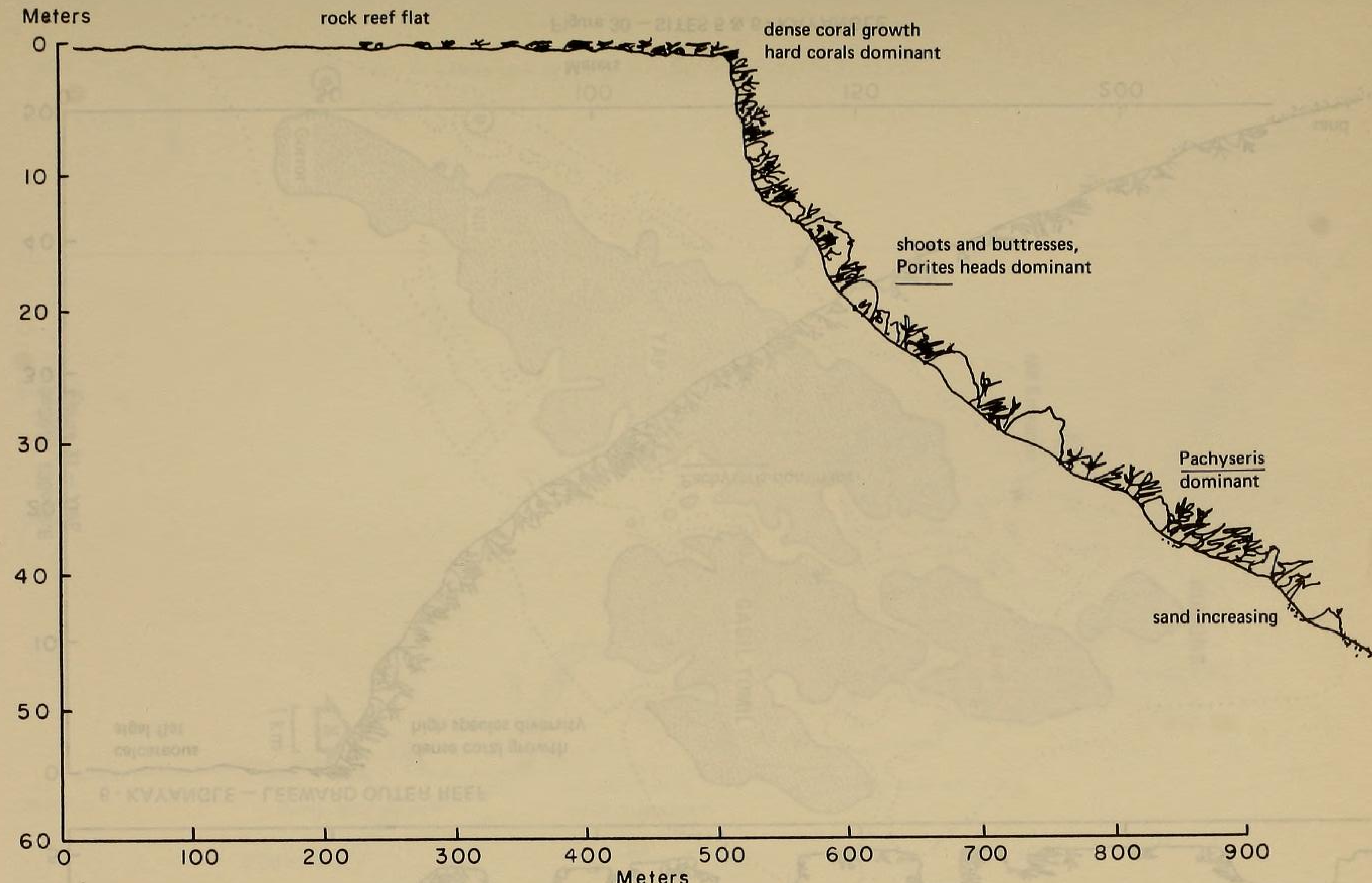


Figure 29 – SITE 4 · NGEMELIS, WEST SIDE

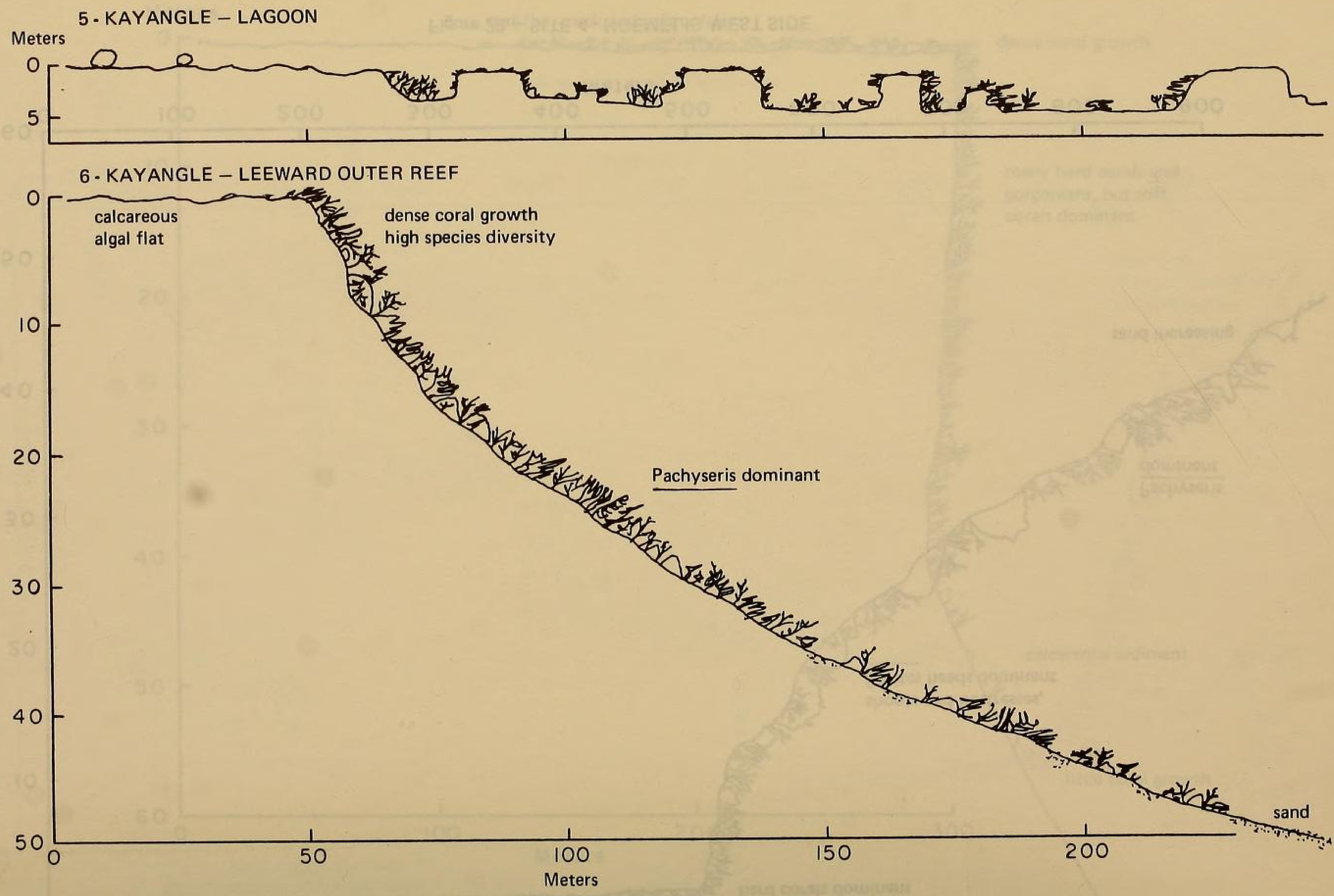


Figure 30 – SITES 5 & 6 - KAYANGLE

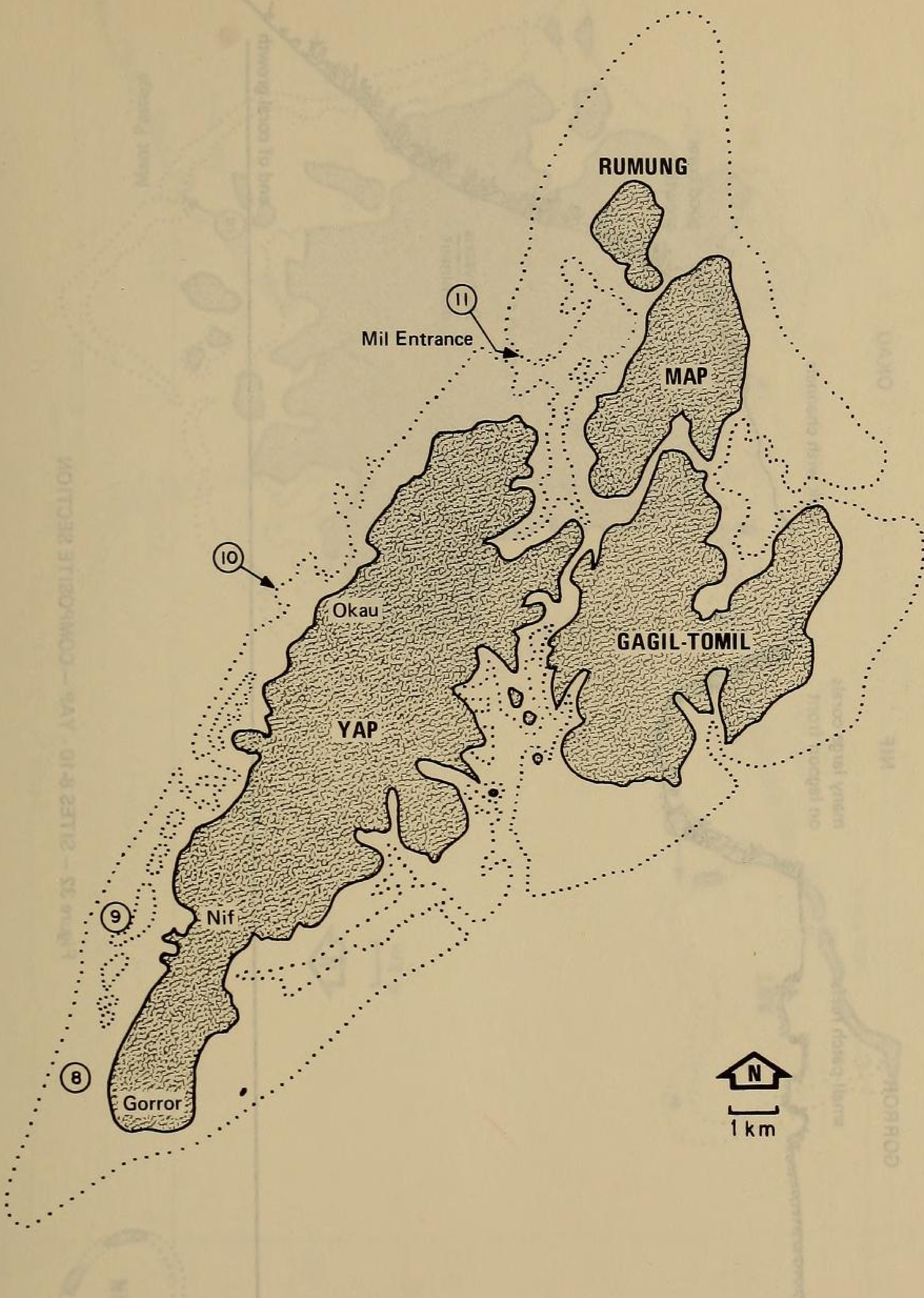


Figure 31 — YAP
9°30'N 138°05'E

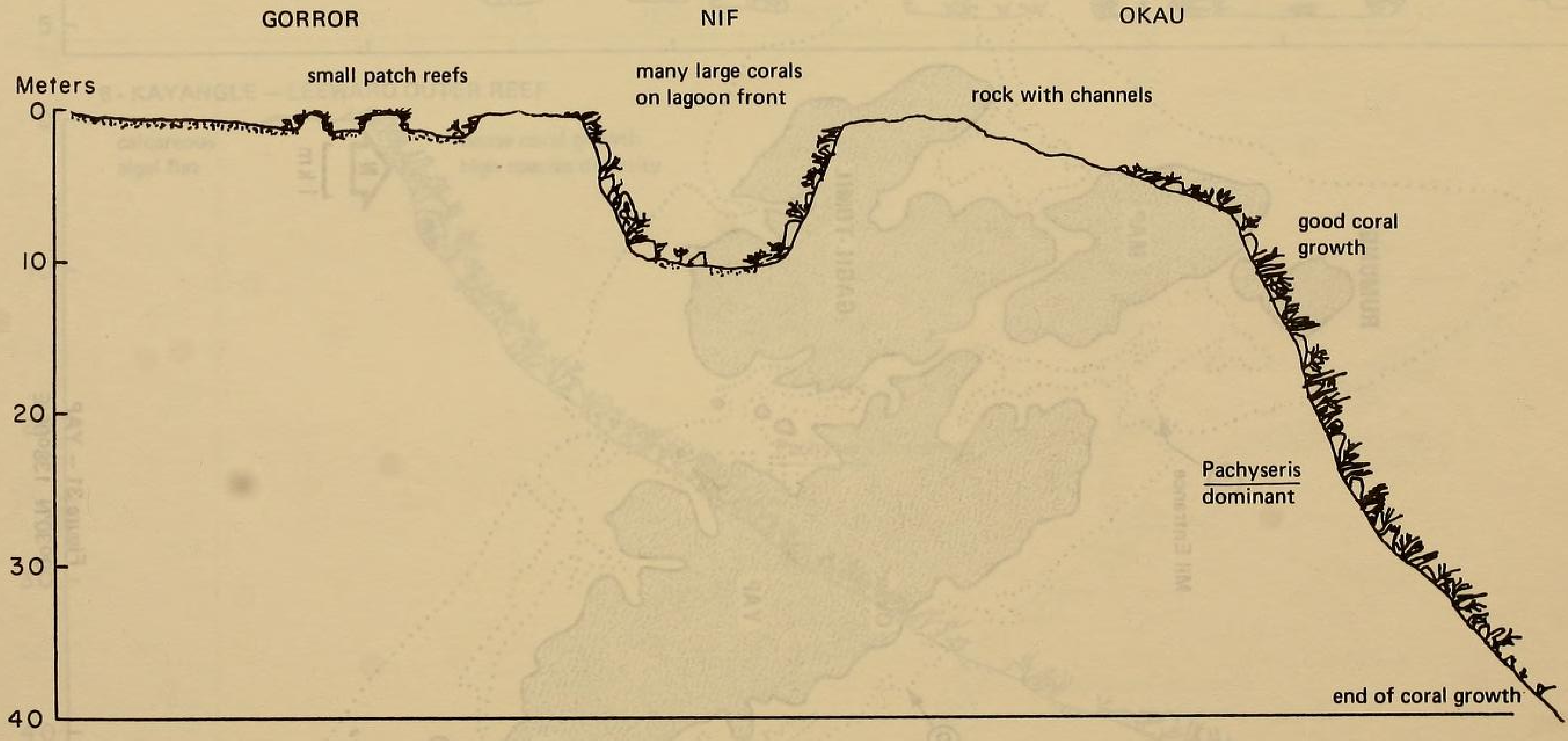


Figure 32 – SITES 8-10 - YAP – COMPOSITE SECTION

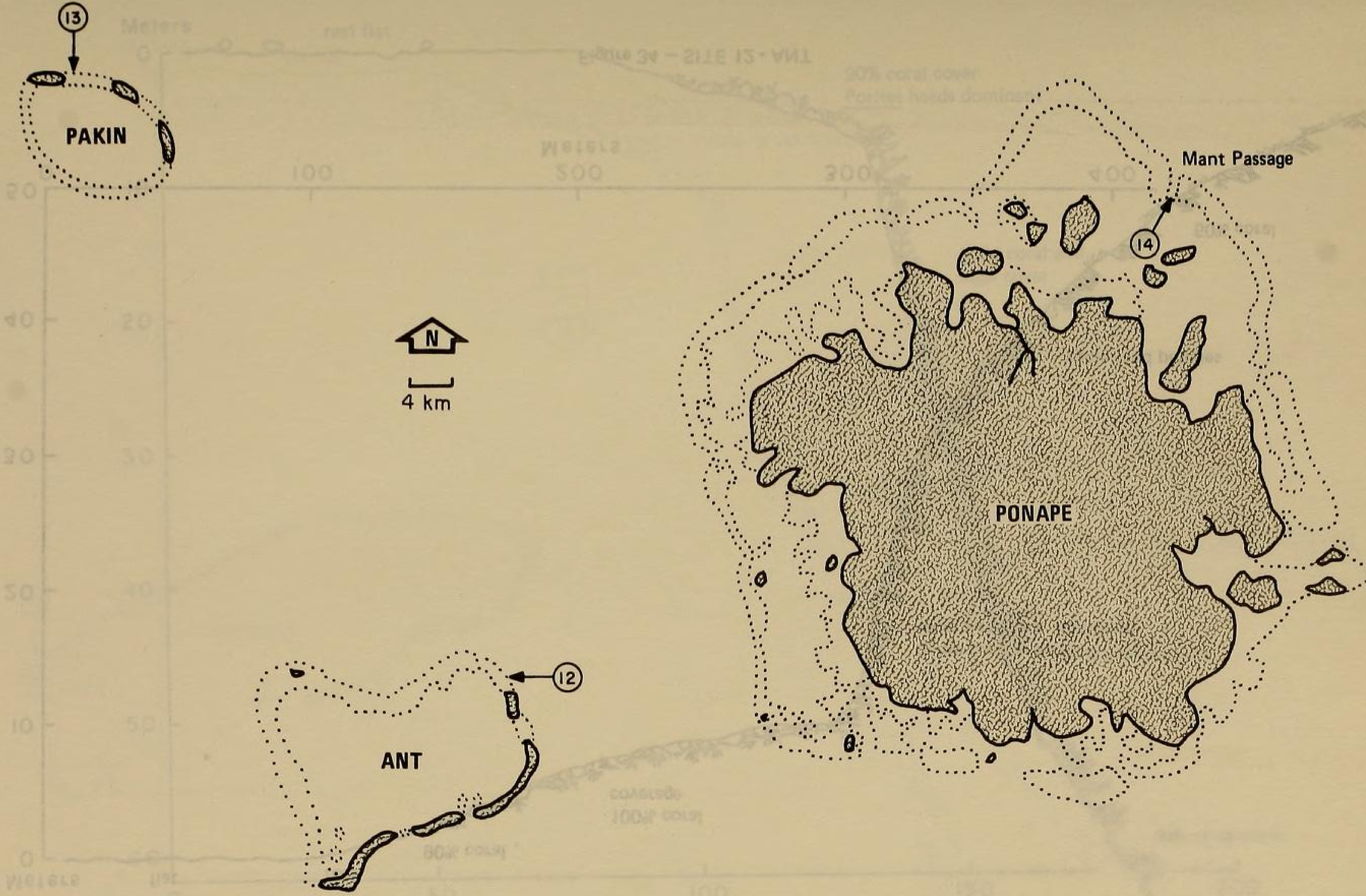


Figure 33 – PONAPE, ANT & PAKIN
7°00'N 158°00'E

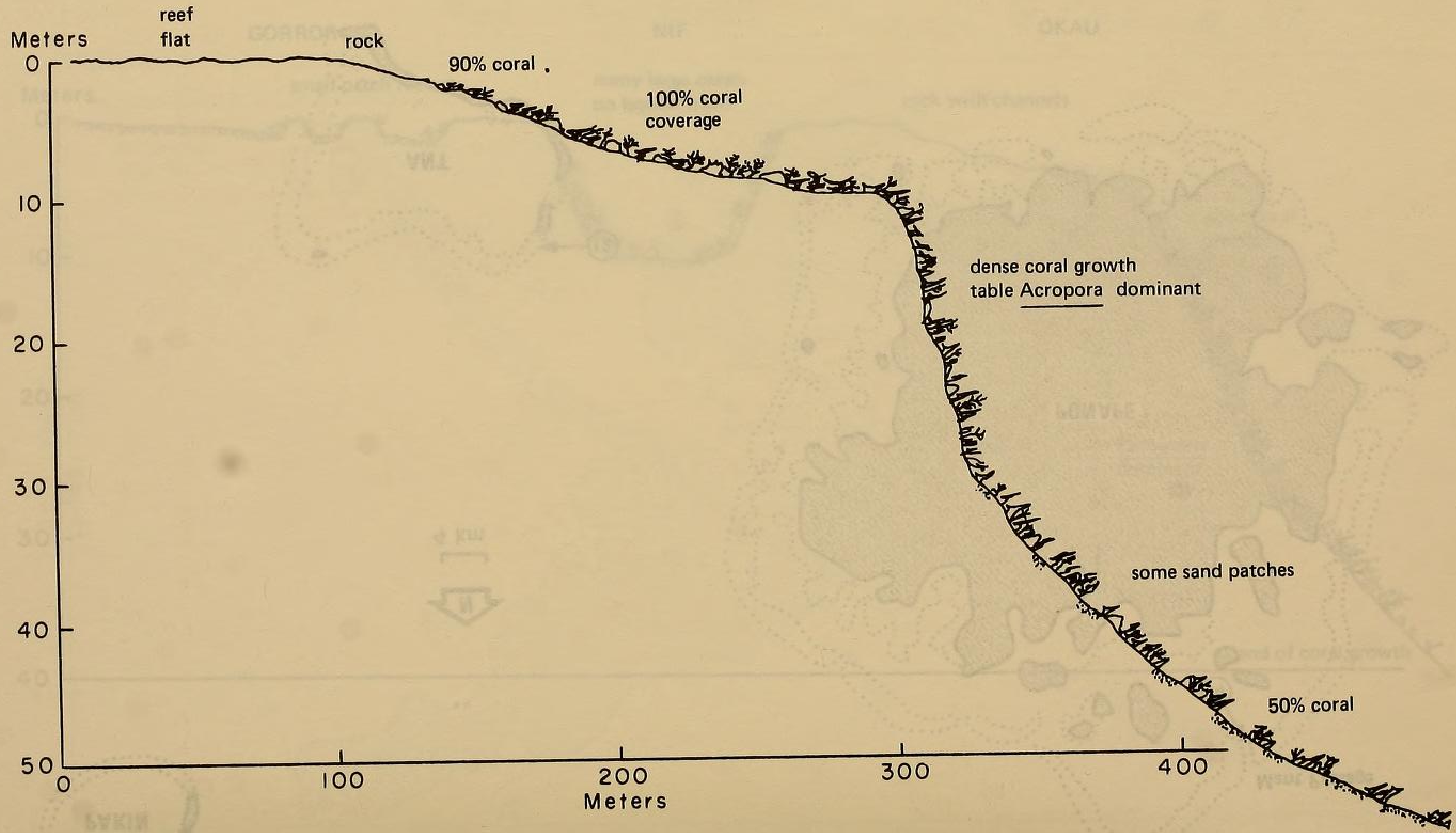


Figure 34 – SITE 12 - ANT

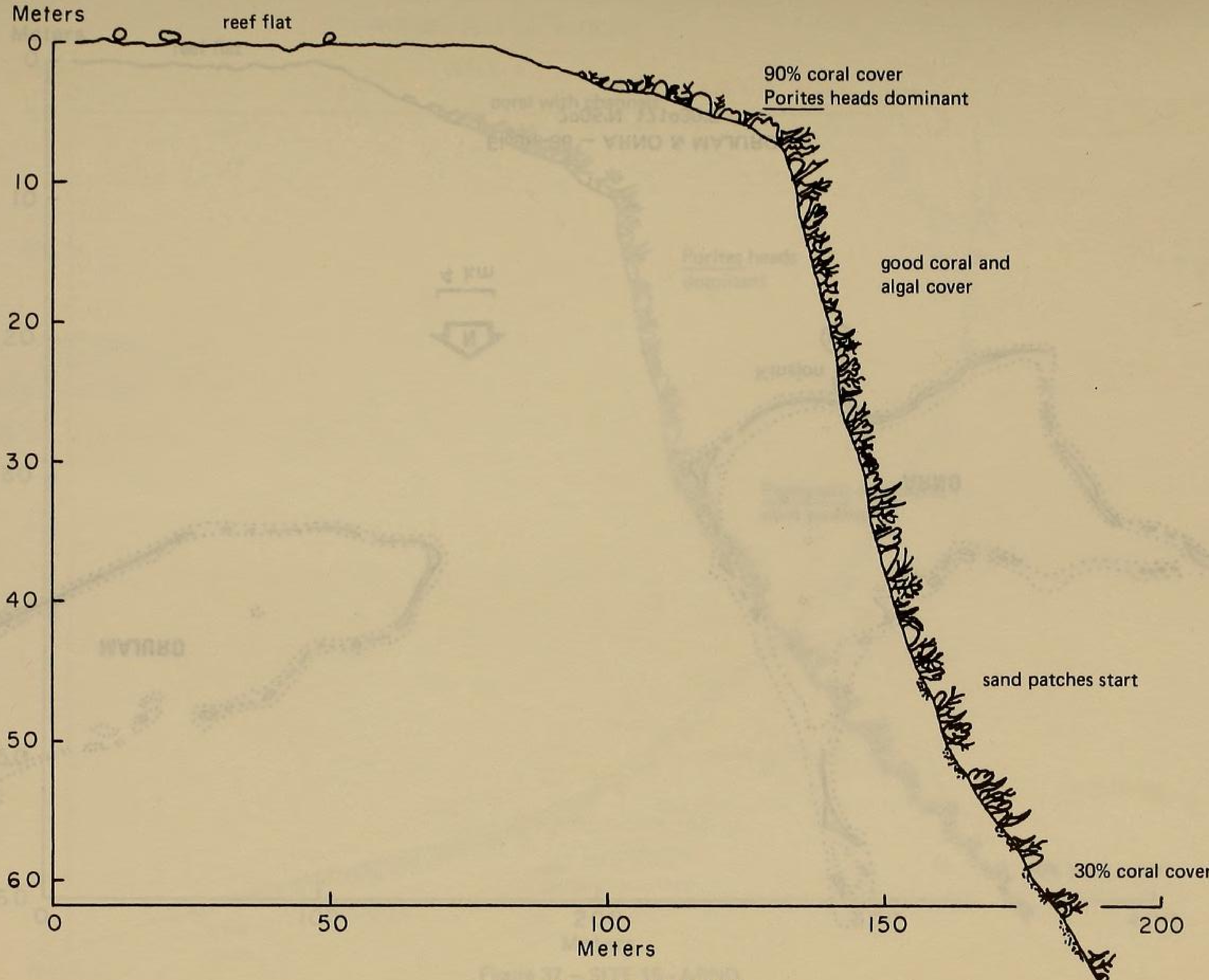


Figure 35 – SITE 13 - PAKIN

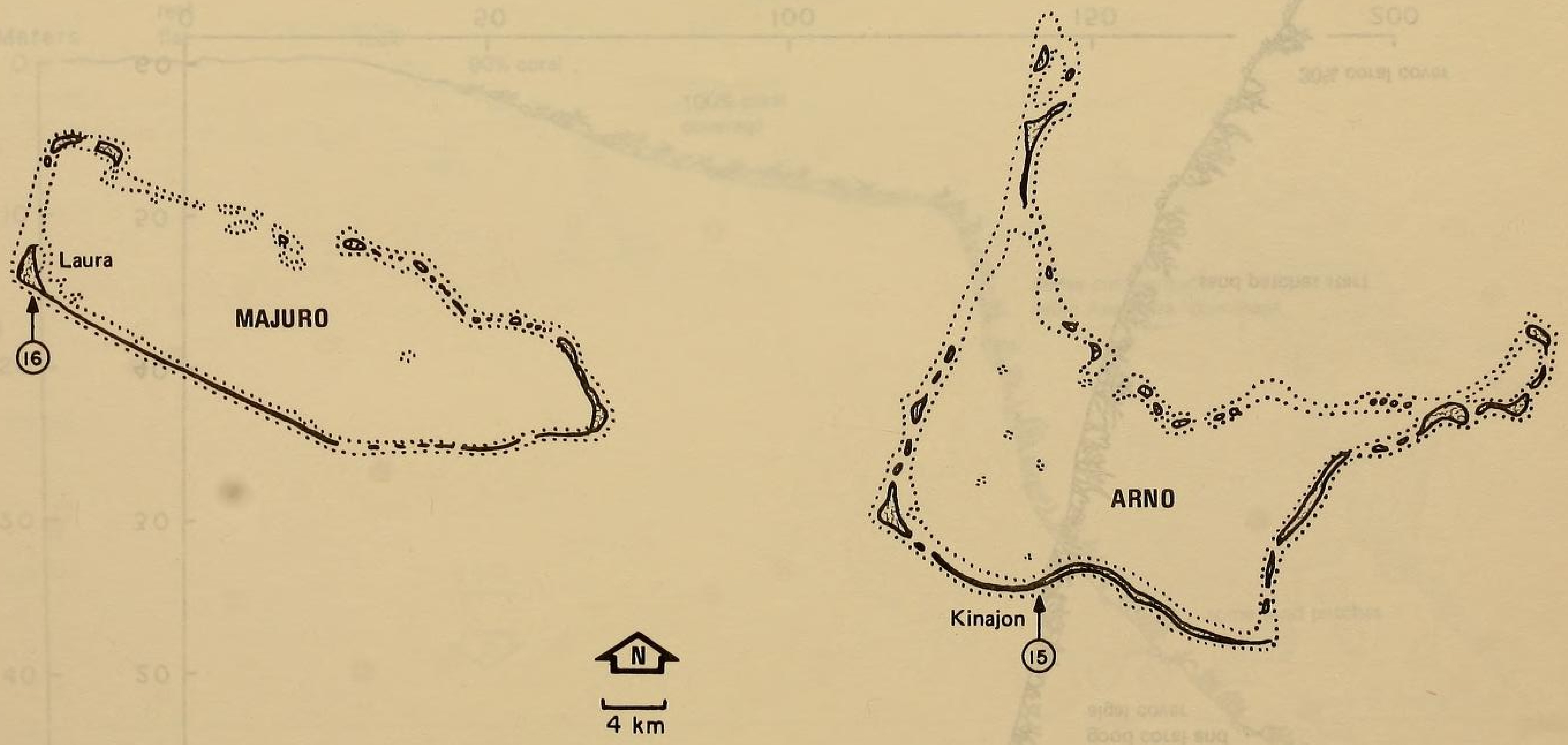


Figure 36 – ARNO & MAJURO
7°05'N 171°30'E

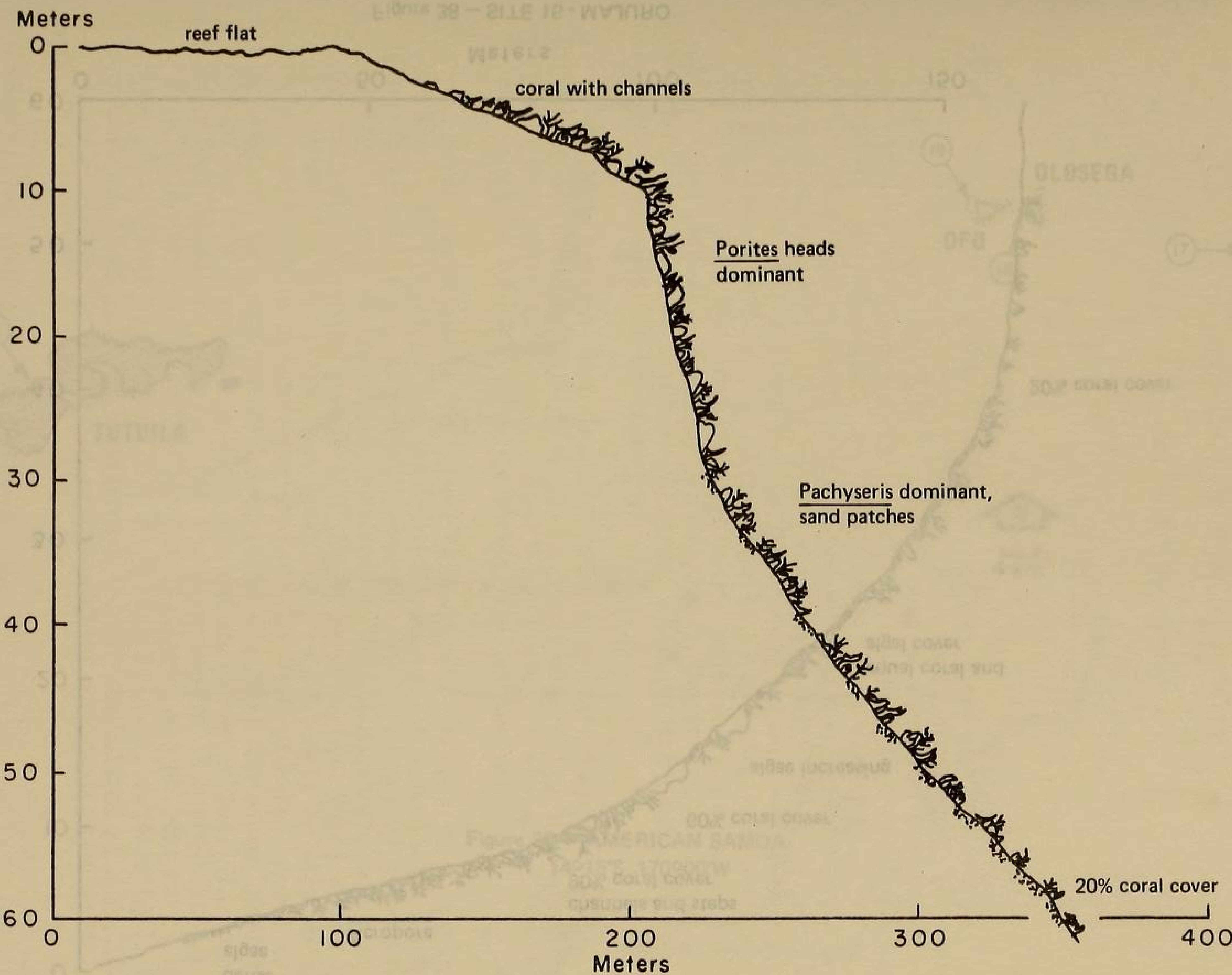


Figure 37 – SITE 15 - ARNO

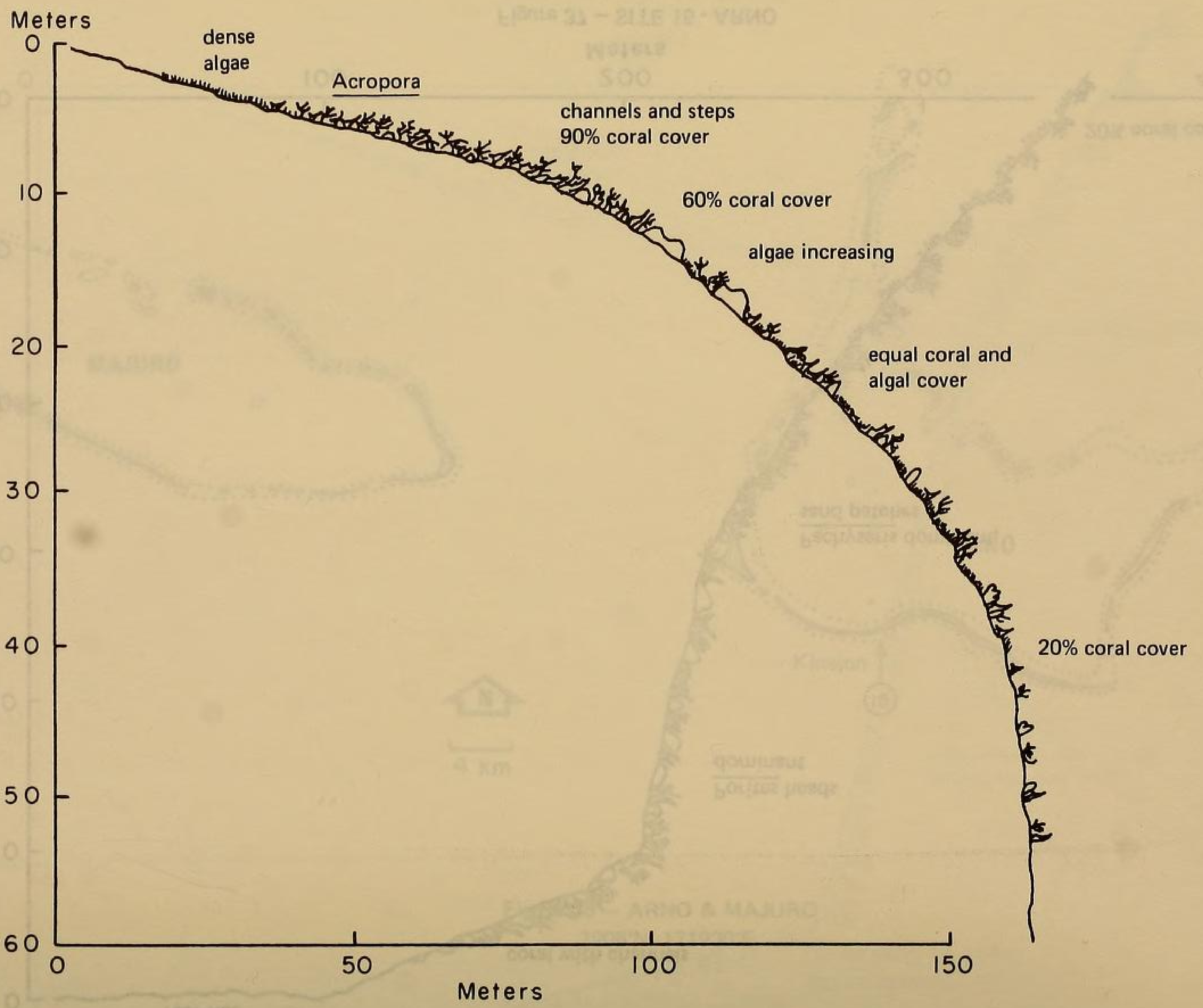


Figure 38 – SITE 16 - MAJURO

Figure 39 – AMERICAN SAMOA
14°15'S 170°00'W

Figure 40 – SITE 20 - LEONE BAY, TUTUILA

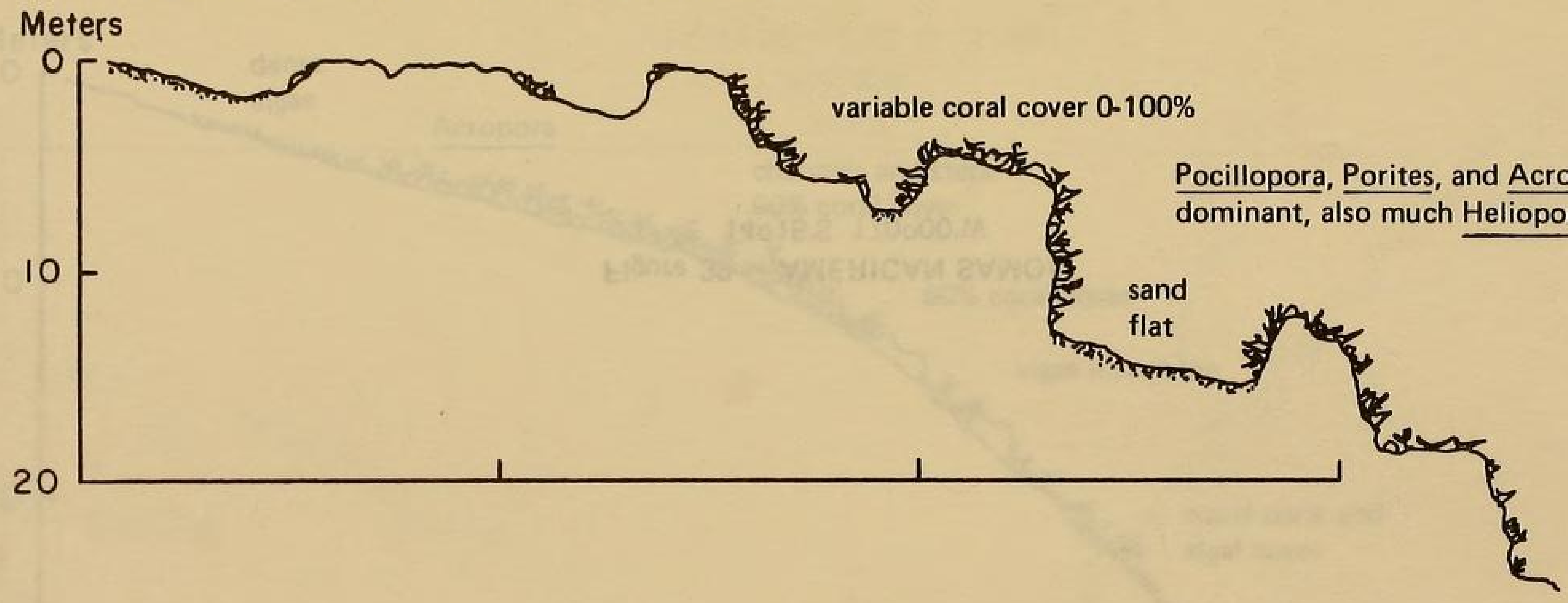


Figure 41 – SITE 21 - OGEGASA POINT, TUTUILA