A SURVEY OF SEDIMENT DISCHARGE

AND SHELF REEF CONDITIONS

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INTRODUCTION

Although the coral reef complex is a mass of sedimentary material, coral reefs exist in areas of low sediment influx. There is high natural generation of sedimentary material which varies over the reef environment. The reef complex exists because of the living coral reef framework-- the forereef. This study is directed toward the conditions of coral growth in the wave facing forereef portion of the reef complex between the depths of 0 and 70 meters where environmental parameters are suitable for coral growth. In this region, the wave energies and water conditions generally result in a low sediment environment. Each portion of the reef achieves a balance and a growth pattern typical of a natural sediment input. For example, coral population and coral growth rates are quite different in the leeward or backreef environment than from the forereef.

CORAL REEF SYSTEMS

A coral reef is a complex system developed in relation to a coral framework which consists of a limited number of species. The reef is wave resistant, actively building and creates topographic relief that significantly modifies the environment (Kornicker and Boyd, 1962). Modern reefs developed on a limestone karst surface that was exposed less than 15,000 years before the present and they have grown upward with the change of sea level of about 85 meters (Fig. 1). The forereef, or wave facing part of the reef, is zoned in terms of coral assemblages with water depth. Reef zonation and coral diversity are responses to natural stresses and energy inputs (Rogers, 1977). Reef growth and vertical zonation with depth are related to light input and are in turn, a function of water clarity and water turbidity.

Logan (1969) developed a zonation for the Yucatan reefs based on a community concept which he considered to be a group of organisms dominated

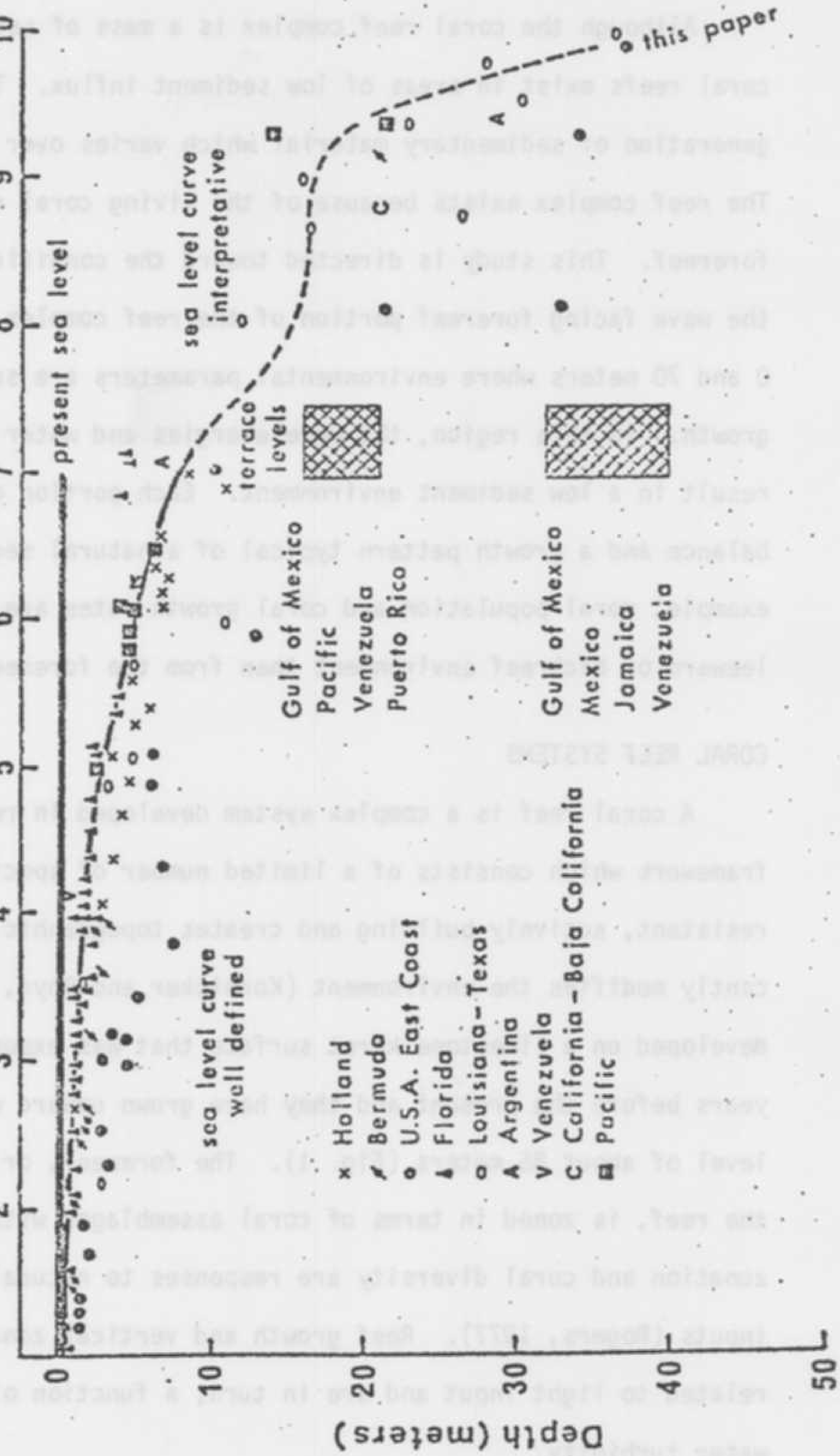

Figure 1. Sea level position for the past 10,000 years

by certain abundant and functionally important components which are consistently associated thoughout a bio-geographic region. These communities are distinguished by the overall biologic composition. The reef systems on the south coast of Puerto Rico are similar to the Yucatan, Bahamian, and Jamaican reefs which were described by Newell and Rigby (1969) and Goreau (1973).

The Parguera reefs serve as a standard against which changes caused by sediment input can be measured. Seven different reefs have been examined in detail and the data synthesized to develop the reef zonation for the southwest coast of Puerto Rico (Table 1). The reef crest is dominated by Millepora and is a relatively narrow, flat wave influenced uppermost portion of the reef. Below the crest, four distinct reef zones can be distinguished. The Acropora Palmata zone is restricted to relatively clear water with moderate to strong wave energy. The zone disappears or is represented by such limited remnants in high sediment input areas that it is not considered or described in detail for comparison in this study.

The mixed coral zone is dominated by Montastrea annularis and Acropora cervicornis. Acropora cervicornis may form a sub zone between the Acorpora palmata and the mixed coral zones in which it is more than 50 percent of the total coral cover. The mixed coral zone occupies a more level part of the forereef and can be mapped on the basis of bathymetry in many instances. There is abundant octacoral and soft organisms associated with this zone and in places the assemblage approaches more of a hard ground facies than a reef environment.

The massive coral zone is dominated by Montastrea, Porities and Diploria species. The Diploria were rare in our transects of the upper part of the massive coral zone, but have been observed in more abundance toward the lower depth limits of the zone. There is generally a break in

Acropora palmata zone	Mixed Coral zone	Massive Coral zone	*Agaricia-Montastrea* zone
Acropora palmata	*Montastrea annularis* *Acropora cervicornis*	*Montastrea annularis* *Montastrea cavernosa* *Diploria spp*	*Agaricia agaricites* *Montastrea cavernosa*
Montastrea annularis *Porites asteroides* *Millepora alcicornis*	*Porites porites* *Millepora alcicornis* *Diploria labyrinthiformis* *Porites asteroides* *Siderastrea siderea* *Agaricia agaricites*	*Agaricia agaricites* *Porites asteroides* *Mycetophyllia lamarckiana* *Colpophyllia natans* *Mycetophyllia ferox*	*Siderastrea siderea* *Solenastrea spp*
Agaricia agaricites *Favia fragum* *Diploria spp*	*Isophyllia sinuosa* *Dendrogyra cylindrus* *Dichocoenia stokesii* *Madracis mirabilis* *Diploria stringosa* *Colpophyllia natans* *Eusmilia fastigiata* *Montastrea cavernosa*	*Solenastrea spp* *Acropora cervicornis* *Madracis decactis* *Favia fragum* *Siderastrea siderea*	*Agaricia fragilis* *Porites asteroides* *Dichocoenia stellaris*
high cover, low diversity	moderate to low cover high diversity	moderate cover moderate diversity	moderate to low cover low diversity
0 to 6 meters	5 to 10 meters	9 to 24 meters	22 to 37 meters
	very abundant octacoral becomes hard ground at many areas	bare areas, sediment fill between heads	rocky surface, thin sediment fill between heads
	less slope, almost a terrace	drop-off, fairly steep slope	fairly high angle slope
	scattered, small heads, still abundant branching	massive, interlocking heads	platy, fragile forms, isolated heads

Table 1. Coral reef zonation

slope between the mixed coral and the massive coral zones with the massive coral growing on a relatively steep slope. At Parguera, this zone forms the lower part of the shelf reefs and is the upper part of the shelf edge submerged reef.

At about 22 meters, the composition of the reef changes and a fourth community can be distinguished. This is the Agaricia-Montastrea zone. Because of the depth, this is found only on the shelf edge reef. Although Agaricia species are common in all of the other zones, there is a distinct change to their dominance and also a change from Montastrea annularis to Montastrea cavernosa as the most common coral. There is also a change in growth form from rounded hemispherical coral to a flater platy growth patterns. Below 37 meters, there is less coral and an assemblage of Gypsina plana and Lithothamnium species similar to that described by Logan (1969) at Alacran. The two lower zones have been studied by photo-transects and diver observations so that more details were observed than in the grab surveys at Alacran, but there is a remarkable similarity in description.

With an increase in depth, there is a distinct change from a more rapid growing branching coral to massive coral types and then to the flat platy growth forms. With respect to light, the mixed zone is more favorable environment than the deeper reef slope (Rogers, 1977). However, there is less over in the mixed zone and more of the space in occupied by octacorals. Light is the primary energy source for the reef, the slope of course gets less light under normal conditions. On a wider shelf, there may be a freedom from sediment turbidity that reduces this difference. There is a reduction in cover, smaller colonies with more separation, and general absence of branching forms as we approach the deeper limits of coral growth.

Coral reefs form an important part of the marine environment. They: 1) are one of the most biologically productive and taxonomically diverse

The reef community contains representatives of every phylum of the animal kingdom and many members of the plant kingdom. Coral accounts for less than 25 percent of the total reef community (Pettijohn, 1949) but is essential, for when the coral dies, the reef community degenerates due to death or migration of the associated fauna. Because the reef ceases to grow, it is less resistant to wave action and actual physical deterioration is accelerated. The resistance of a reef community to environmental stresses cannot exceed that of the coral component.

Coral are limited by physical factors in the environment, but often exist in areas where conditions are close to the limit. The reef is a sensitive indicator of environmental stresses because of its response to these stresses. Because of this, the reef can give us a look in time at former baseline conditions where we do not have data in an area before development has occurred. As the environment degrades, mobile organisms leave or die and are buried, but the coral is frozen in place as a permanet record. The presence of a dead reef complex implies a specific range of conditions once existed, or the reef would not have developed. The coral can be dated and individual corals studied to determine when changes occurred that caused the death of the reef. The reef is a time machine which will allow us to make interpretations of the prior environment.

EFFECTS OF SEDIMENTS

Individual species of coral have resistance to sediment stress up to certain critical levels. There are differences in tolerances and these have been reported in a number of papers. These differences should be directly reflected in the changes in ecology of a stressed reef, and are to a certain extent. Sediments are a natural part of the reef environment and reef corals have adapted to this, but above a low input of outside terrigenous sediment, there is energy drain and the coral is stressed.

Temperature, salinity, wave regime, ambient light, and relatively pure water quality are requisites for reef growth. Reefs have developed primarily in low sediment input areas, and although some are found near river outlet environments, those reefs are existing at a toleration limit. Some of the problems associated with the influx of sediment into a reef system are: 1) smothering of the reef by sediment, 2) scouring of the reef by sediment laden waters, 3) loss of bottom area suitable for settlement of larvae, and 4) reduced light intensity due to turbidity. The latter problem results in shifting of the zonation and an upward migration of depth limitations. The loss of light is more critical to the deeper coral assemblages, and a chronic increase in turbidity can be expected to reduce coral growth in deeper waters and thus cause changes in the species dominance. Further shifts in the ecology result in the different corals having differences in toleration to direct sediment application.

A change in the environmental parameters beyond tolerable limits or to a point of adaptable stress will shift the entire ecosystem and a new and less competitive coral assemblage may result which was the recovery of coral reefs from extreme siltation, oil pollution, hurricane damage, etc., there has been recovery only where the faster growing shallow water types of coral were present. The conditions of high sediment input result in a shift to deeper water types which are slower growing and therefore less likely to survive (Table 2).

Table 2.

DEPTH OCCURRANCE ( )	NORMAL CORAL ZONES: PARGUERA AREA *AGARICIA ZONE* (>24M)	NORMAL CORAL ZONES: PARGUERA AREA MASSIVE ZONE (8 TO 24 M)	STRESSED CORAL ZONES: GUANICA AND PTA. VENTANA AREA CANYON ZONE (9 TO 15 M)	STRESSED CORAL ZONES: GUAYANILLA AND TALLABOA AREA CHANNEL ZONE (9 TO 15 M)
MONTASTREA ANNULARIS		DOMINANT	COMMON	PRESENT
M. CAVERNOSA	DOMINANT	DOMINANT	DOMINANT	COMMON
DIPLORIA SPS.		COMMON	PRESENT	PRESENT
AGARICIA AGARICITES	DOMINANT	COMMON	COMMON	
PORITES ASTEROIDES	PRESENT	COMMON		
MYCETOPHYLLIA SPS.		PRESENT	PRESENT	
COLPOPHYLLIA NATANS		PRESENT	PRESENT	PRESENT
SIDERASTREA SIDEREA	COMMON	PRESENT	COMMON	COMMON
SOLENASTREA SPS.	COMMON	PRESENT	PRESENT	PRESENT
ACROPORA CERVICORNIS		PRESENT		
PORITES PORITES		PRESENT	PRESENT	
MEANDRINA MEANDRITES		PRESENT	PRESENT	
DICHOCOENIA STOKESII	PRESENT		PRESENT	

DOMINANT COMMON PRESENT

One of the major problems of sedimentation is the reduction of potential for future establishment of coral. As the old coral surface dies, it is covered with algae, including filimentous greens that trap and hold sediment to form an algal mat. This is a completely unsuitable surface for coral colonization.

SUBMARINE CANYON REEFS

At La Parguera, coral growth is greatly reduced below 40 meters. At Mayaguez and Guayanilla, submerged shelf edge reef areas have a limit of coral growth closer to 25 meters. Both of these areas are closer to shore and receive coastal waters with a higher sediment load. These are more typical of the reefs described by Macintyre (1972) as Caribbean submerged shelf edge reefs. There is a reduction in total coral coverage and less variety of species.

The submarine canyon reefs present a further change in conditions and ecology. These receive a higher direct sediment input and reduced light levels due to water turbidity. The coral coverage is slightly to moderately reduced from the nearer shore shelf edge submerged reefs, and the coverage and ecology is influenced by the relationship of the canyon trend to prevailing wave and current conditions. Since the reefs studied at Guayanilla are of this type, a submarine canyon reef type has been developed as a control or substandard to use rather than directly applying the criteria developed at La Parguera (Table 3).

The canyon wall assemblages were measured between 12 and 17 meters, which is in the depth range of the massive coral zone. The environment is different, however. There is a higher sediment load, resulting in reduced light levels and direct sediment stress on the coral; there is less wave action and reduced circulation. There is a distinct difference geomorphology of these reefs as opposed to the shelf barrier reefs of La Parguera.

Punta Ventana Canyon	Guanica Canyon
Montastrea cavernosa	*Montastrea covernosa*
Montastrea annularis	*Montastrea annularis*
Siderastrea siderea	*Agricia agaricites*
Meandrina meandrites	*Siderastrea siderea*
Porites sps	*Porites porites*
Solenastrea bournoni	*Diploria labyrinthiformis*
Dichocoenia stokesi	*Mycetophylia lamarckiana*
	Meandrina meandrites
	Agaricia fragilis

Table 3. Canyon Wall Coral Reef Assemblages

The latter reefs rise upward from a platform of about 18 meters. Sediment moved from the bottom by wave action must be carried upward to the reef, and with continued wave action will be removed quickly. The canyon walls lie below a 10 to 12 meter surface and sediments are dropped from above by wave action, a decidedly disadvantageous situation. The relatively quiet wave environment of the canyon requires that the coral remove the sediments without wave assistance.

There are some distinct changes in the ecology and the submarine canyon reefs show elements of the massive coral zone and the Agaricia-Montastrea zone. The dominant coral is now Montastrea cavernosa, and Montastrea annularis is second in abundance. There is an increase in Siderastrea abundance, and the shape and growth of Agaricia is modified. These changes reflect sediment stress and lowered light level adaptations of the community. The coral system is now living close to the limits of tolerance. This is the system that is probably the most susceptible to increased levels of sediment in the waters and is the least studied of the coral reef types.

GUAYANILLA CANYON

The Guayanilla canyon system occupies an indentation of the insular shelf between Guánica and Playa de Ponce (Fig. 2). The shelf is only three kilometers wide in comparison to about ten kilometers on either side of the canyon system. This is also an area of concentration of river systems, and the canyon heads are generally opposite modern or ancient river channels. The three canyons discussed in this study are tributaries of the main channel, Guayanilla Canyon.

The bathymetry was mapped from NOAA smooth sheets, the Guayanilla harbor map, and data recorded with a Raytheon fathometer . The

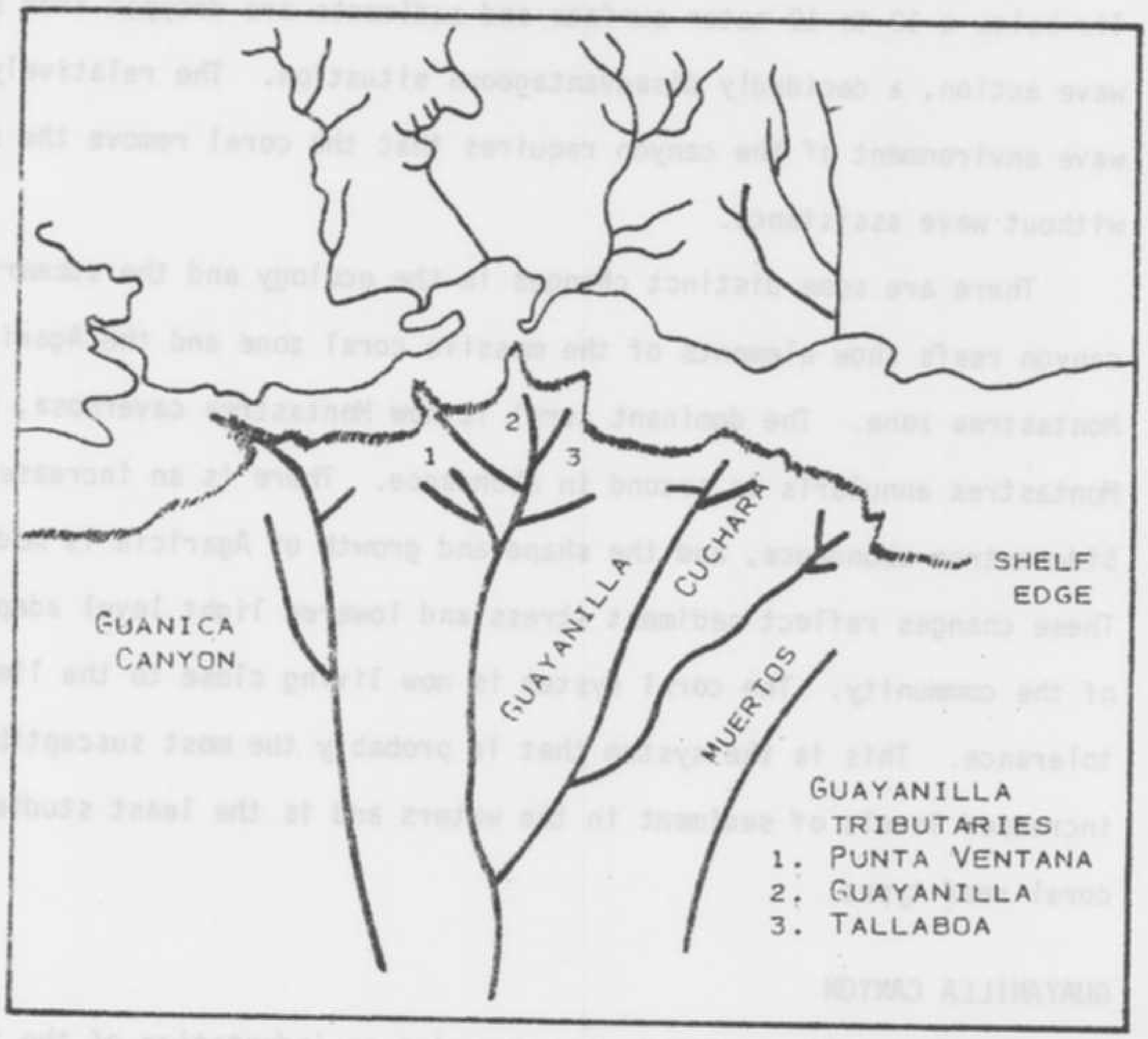

Figure 2. Guayanilla Canyon system

shelf gradually deepends seaward to 16 to 20 meters at a grade of 1:160 (.3°). The irregularities of the surface are related to subaerial erosion and development of the canyons, a karst topography, and subsequently to the growth of reefs on this topography as sea level came back upward some ten thousand years ago. The shelf is cut into the Miocene limestone that outcrops in the Guayanilla area. There is a thin veneer of sands and some patches of coral over the shallow platforms, and fine sands and muds of terrigenous origin on the canyon floors and the inner bays of Guayanilla and Tallaboa . Most of the hard bottom is covered with soft coral, gorgonians, alcyonarians, sponges, and algae. Low mounds of massive coral and encrusting coralline algae are common.

The shelf break and the descent into the lower reaches of the canyon occurs at about 15 to 18 meters water depth. The slope gradient is between 1:4 and 1:2 (14 to 27°). The submarine canyon walls have gradients between 1:4 and 1:6 (14 to 9°). The floor of the canyons are a mixture of fine to silty and sandy silts and muds that are both terrigenous and carbonate shell material. There is a failry deep accumulation of sediment on the floors of the canyons (Fig.3), but the walls are limestone covered with dead coral, coralline algae, living coral, and a thin veneer of sediments.

The sediments on the canyon walls are fine grained sands, silts, and clays with Foraminifera tests, mullusca fragments, and fragments of coral, coralline algae, Halimeda, spicules, and planktonic Foraminifera. This is a fine sediment that is being winnowed from the shelf an deposited in the quiet water of the canyon. Since the movement of these sediments is westward with the current and wave patterns, there is more material dumped on the reefs of the eastern wall of the submarine canyons.

Wind driven and tidal currents operate in the canyon areas, setting up a dominant northwest current. Because of the wind pattern and diurnal

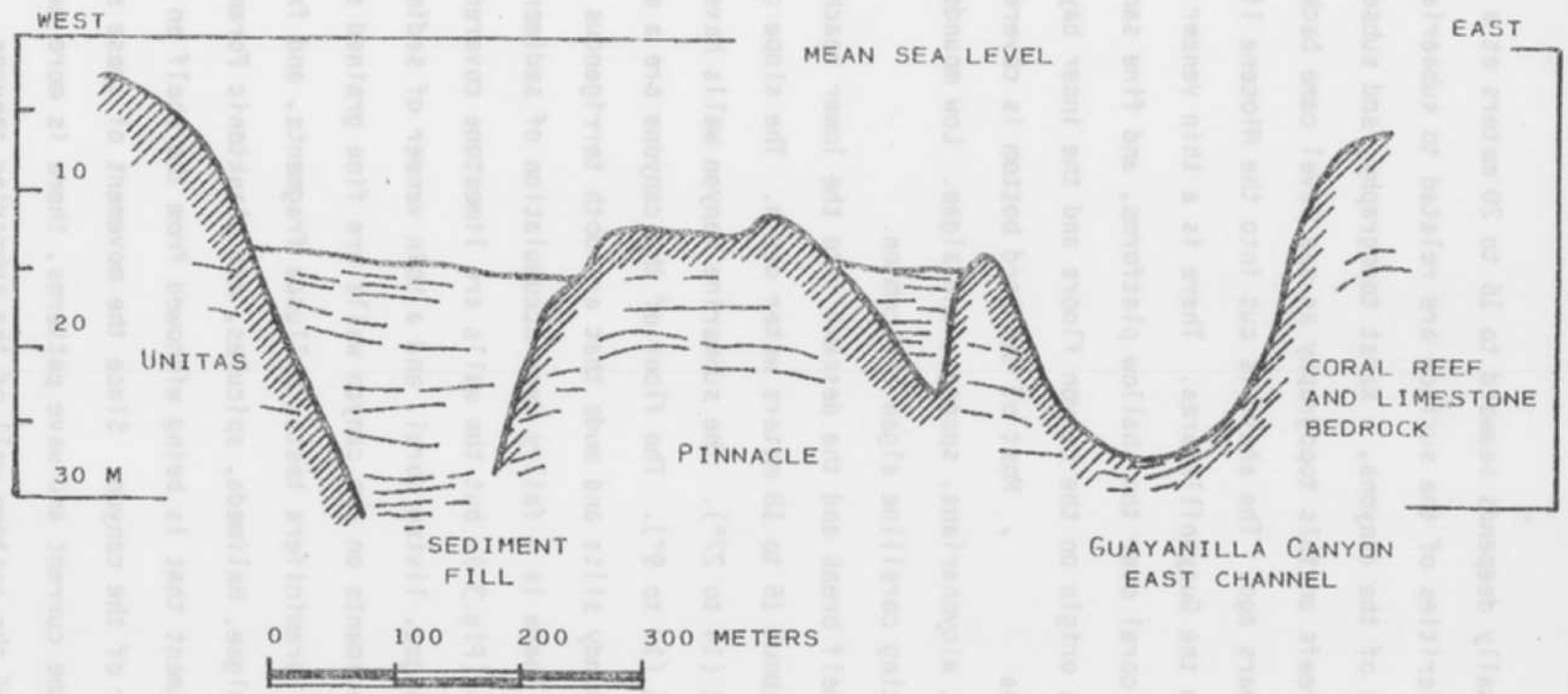

Figure 3. Cross section from seismic profiling in Guayanilla Canyon.

Ventana Canyon. The water solumn can be considered a thoroughly mixed layer to at least 20 meters.

The dominant direction of wave approach is from the southeast. This has a strong effect on the transport of sediments into the canyon and on the reef sediment stress pattern. Most of the wave power is expended along the 10 meter contour at the edges of the canyon. The eastern walls of the canyons are leeward and receive little of the energy compared to the western walls.

Since Punta Ventana Canyon will be used as an ecological model for comparison to the Guayanilla and Tallaboa Canyon systems; the quality of the environments compared is important. Sandza (1976) reported no coliforms, no Kjeldahl nitrogen, low nitrate, low phosphorous, and absence of chemical or bacteriological contaminants, except for mercury, which was 0.35 µg/g in the canyon sediments. There was no evidence of petroleum hydrocarbons (López, 1978). Data from López (1979) shows similar mercury values near the site of the Guayanilla tributary transects, and extremely low values of petroleum hydrocarbons in the nearest measured samples. It is probable that chemical and bacteriological pollutants do not reach the transect sites and are not a factor in the coral reef ecology, based on available data.

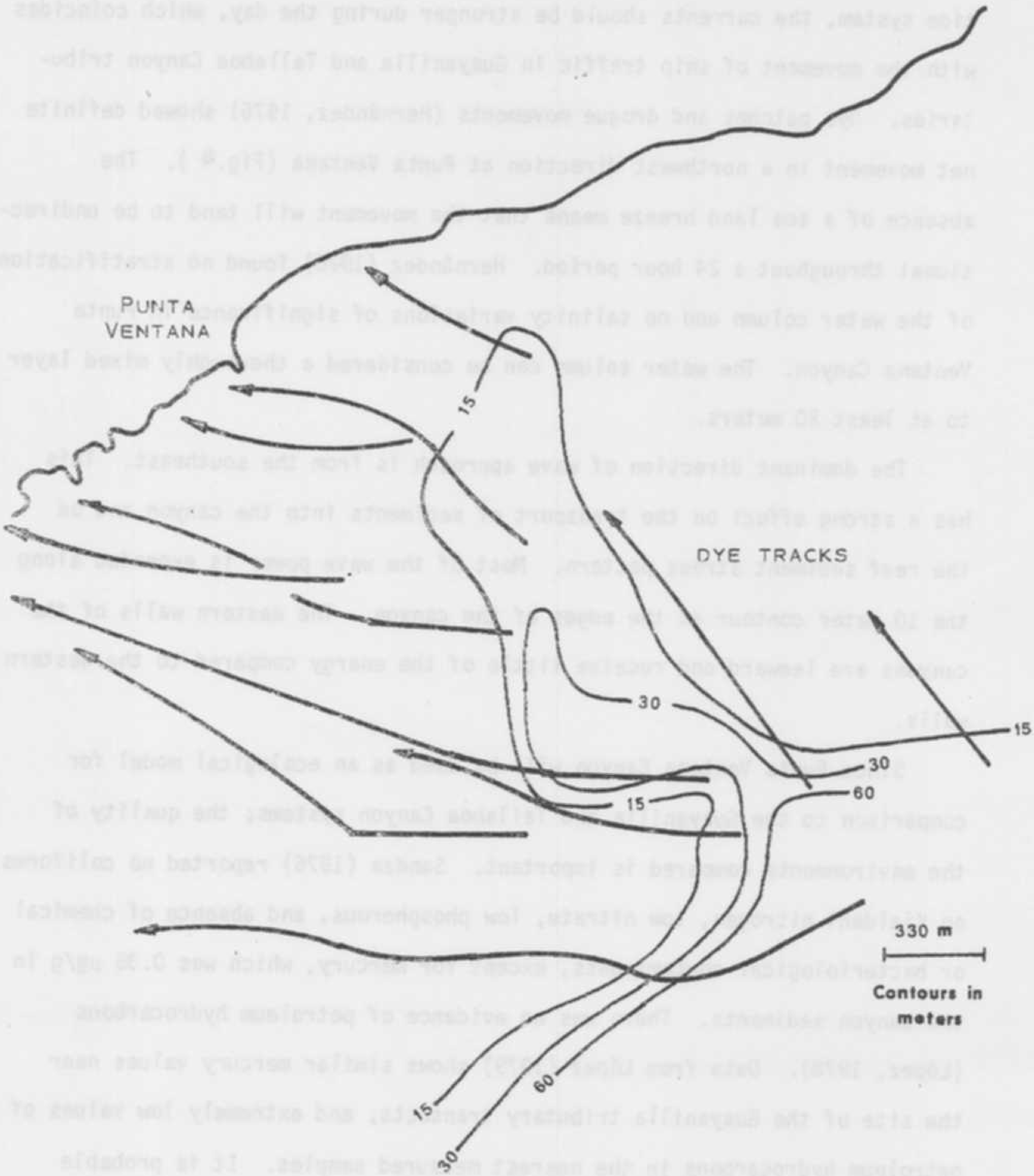

Figure 4. Surface current tracks at Punta Ventana Canyon

Modern terrigenous sediments are found near shore and in the canyons, and carbonate sediments are dominant on the outer shelf . Modern reef growth is localized in areas of hard bottom with bathymetric reef. Until very recent time, reef growth was far more vigorous than in the present environment, and numerous patch reefs were present in the bay areas. During the last century, the terrigenous sediment input has changed and the distribution of growing reefs has been altered. The present Guayanilla and Tallaboa Bays are turbid-water areas with Secchi visibilities of only three to four meters. Many patch reefs are now shoal mounds of rubble covered with grass beds. Reef growth is restricted to shallow-water areas of the open shelf. Little of this reef growth is thriving, and the community ecology of the reef resembles a much deeper water assemblage. Living coral occupies only 15 to 20 percent of the canyon walls and upper shopes below 10 meters, and the figure is less than five percent in areas subject to heavy ship traffic.

Both the Yauco and Guayanilla Rivers discharge into Guayanilla Bay, but the discharge volume is normally low with only small amounts of mud and fine sand carried into the bay. However, during the rainy season and hurricane-generated flooding, large amounts of sand and mud are swept out of the rivers into the bay. These modern terrigenous muds mask the terrigenous relict sands on the floor of the canyon. Very little sediment is trapped on the rocky canyon walls, which are occupied by organisms typical of hard-bottom environments. The sands are deposited near shore and are reworked into thin stringers of sand interbedded with muds. The muds are carried to stangnant areas of the bay and onto the floors of the canyons. After deposition, they are relatively stable in these deeper water areas. Some of the muds are transported to the shelf edge and are deposited on the insular slope.

The outer shelf is relatively shallow, with depths predominantly from 10 to 20 meters. The surface of the shelf is acted upon by fairly strong wave motion which moves fine carbonate and terrigenous material from the shelf surface and is subsequently deposited on the deeper, quiet-water canyon floors. Since the canyon axes are almost normal to the dominantly northwestward wave and current movement, they form a trap for the sediments.

Many areas of once flourishing reef are now dead on the inner shelf and canyon tributary walls, and the total extent of coral growth has been greatly reduced. Ten locations have been picked for transects. Three of these show the marked changes that occur with increased sediment stress beyond the normal canyon conditions . The eastern wall of Punta Ventana Canyon shows a total coverage of 12 percent living coral. There has been a marked increase in the domonance of Montastrea cavernosa compared to the same depth zone at Turromote Reef (La Parguera); it is 6 percent of the coral cover, or 53 percent of the living coral present. This is the least advantageous of the two walls, and data for the Punta Ventana Canyon west wall gives an average of 19 percent total coral cover, with more species diversity and less dominance by Montastrea cavernosa. The favorable west walls of Guayanilla and Tallaboa tributaries give values of 2 percent and 3 percent, respectively. The number of species has been reduced to less than five, with only three recorded on the transects.

The marked difference between the coral reef cover and variety of species on the west walls of these canyons can only result from ship traffic.

The western wall should be the better developed since the current system moves sediment onto the lee side (the east side) and the west wall would normally receive less sediment. The east wall in these canyons is comparable to the east wall of Punta Ventana Canyon, but the west wall is under extreme stress and is no longer a coral reef assemblage. It is concluded that west moving currents and wave drift move the ship traffic generated sediments to the west over these reefs. Although the sediment input is much less than that measured at Escollo Rodríguez at Mayaguez, the reef is in far worse shape, probably due to a chronic state of suspended sediment stress in contrast to the episodic condition at Mayaguez.

During heavy rainfall conditions (Hurricane Eloise, 1975; June, 1979 flooding, flooding associated with Hurricane David, 1980 and Hurricane Allen, 1981) there is a heavy discharge of sediment into the coastal waters, and high turbidity conditions exist well beyond the shelf edge. These conditions may persist for several weeks, but represent an intermittant acute stress rather than a chronic condition and are less damaging to coral growth. There is a generally higher level of sediment turbidity due to the narrow shelf at Guayanilla.

The values of sediment input and light transparency measured at Guayanilla offer an interest contrast . The suspended sediment is relatively high in relation to La Parguera and is higher in Guayanilla and Tallaboa tributaries than Punta Ventana Canyon, but still below critical levels. The material collected in the sediment traps at Guayanilla is low in quantity which is probably related to the low river input and the limited area of the shelf platform. The secchi disk readings, however, are within tolerable levels for Punta Ventana Canyon but are at or below levels for successful reef growth over Guayanilla and Tallaboa tributaries (Fig.5). This seeming contradiction reinforces the idea that the problems of sediment generation is related to ship traffic through Guayanilla and Tallaboa tributaries. The size of ships using the ports results in stirring of bottom sediments and regeneration of suspended sediment with each passing. This will affect the sediment trap in the same manner as the bottom, an the same sediment is apparently thrown into suspension repeatedly.

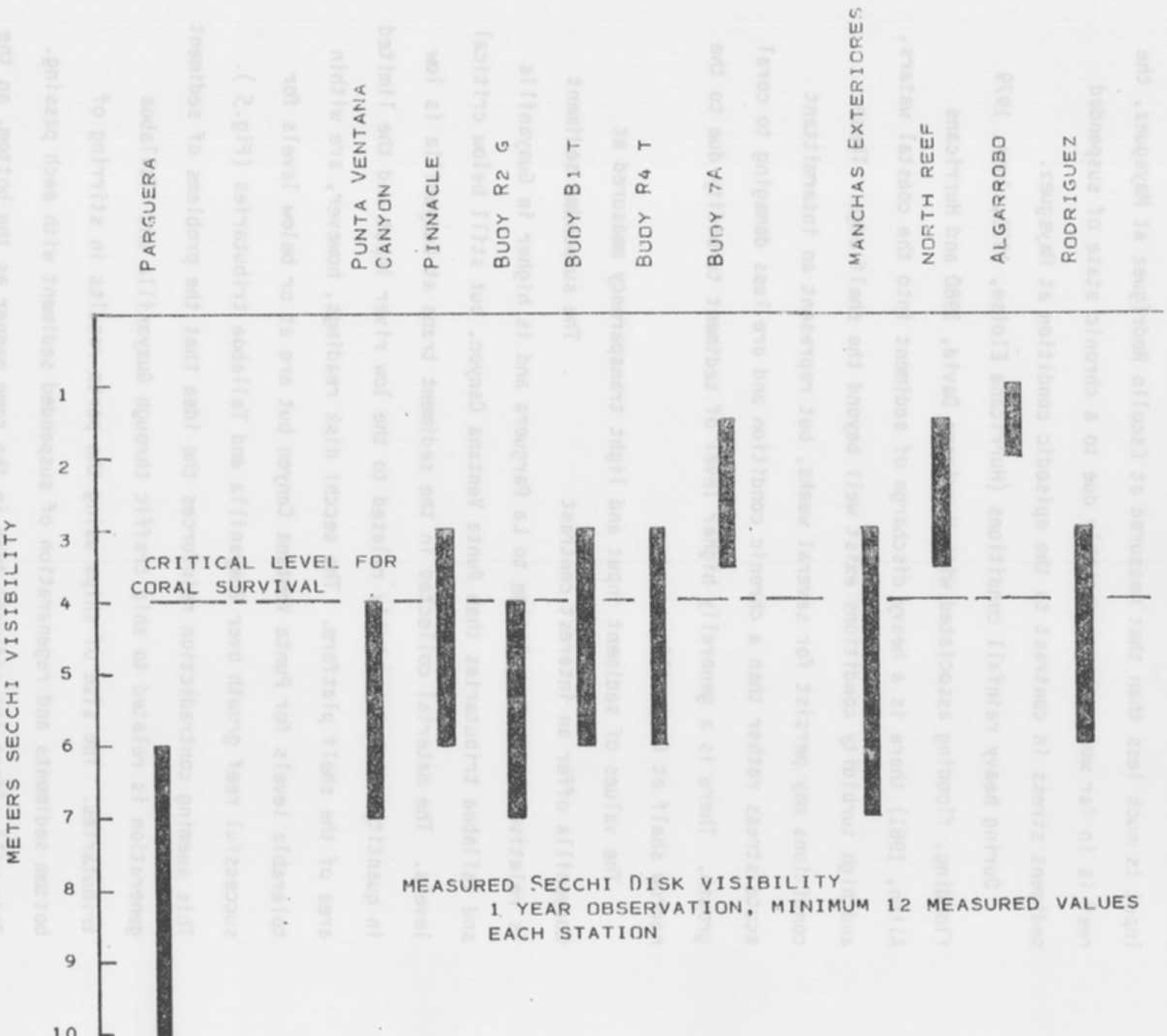

Figure 5. Measured Secchi values at survey sites

MAYAGUEZ CORAL REEFS

Mayaguez and Añasco Bays are near the center of the west coast of Puerto Rico. There are three rivers that supply terrigenous sediments derived from igneous rock environments. The Añasco River discharges onto the shelf near the center of Añasco Bay. This is the largest river on the west coast and it drains an area of about 340 square kilometers. The monthly discharge varies and reaches a peak during September and October (Fig. 6). The Guanajibo River mouth is at the south end of the study area and although the discharge is much lower than that of the Añasco River, significant amounts of sediment are discharged during flood or high water conditions.

The insular shelf at Añasco Bay is only two to four kilometers wide and only five to six kilometers wide at Mayaguez Bay (Fig. 7). Water depth at the shelf break is 15 to 30 meters. There is a submerged barrier reef system (Macintyre, 1972) forming the shelf break in Añasco and Mayaguez Bays. The shallowest depth along the barrier reef is six meters. There are gaps in the barrier system off the mounts of the Añasco, Yaguez and Guanajibo Rivers.

Coastal currents are the main driving force in the transport and distribution of shelf sediments. The main current components acting in the general circulation in the Mayaguez and Añasco area are wind drift, wave driven, tidal and inertial components. The most influencial in terms of sediment distribution and transport are the wave driven an tidal components.

In Añasco Bay, the surface flow is offshore, to the west, but the net flow of the total water column is toward the north and northeast. This means that the suspended sediment discharge from the Añasco River is carried offshore and then as it settles, moves over the shelf and and reef area in the northern part of the Añasco Bay.

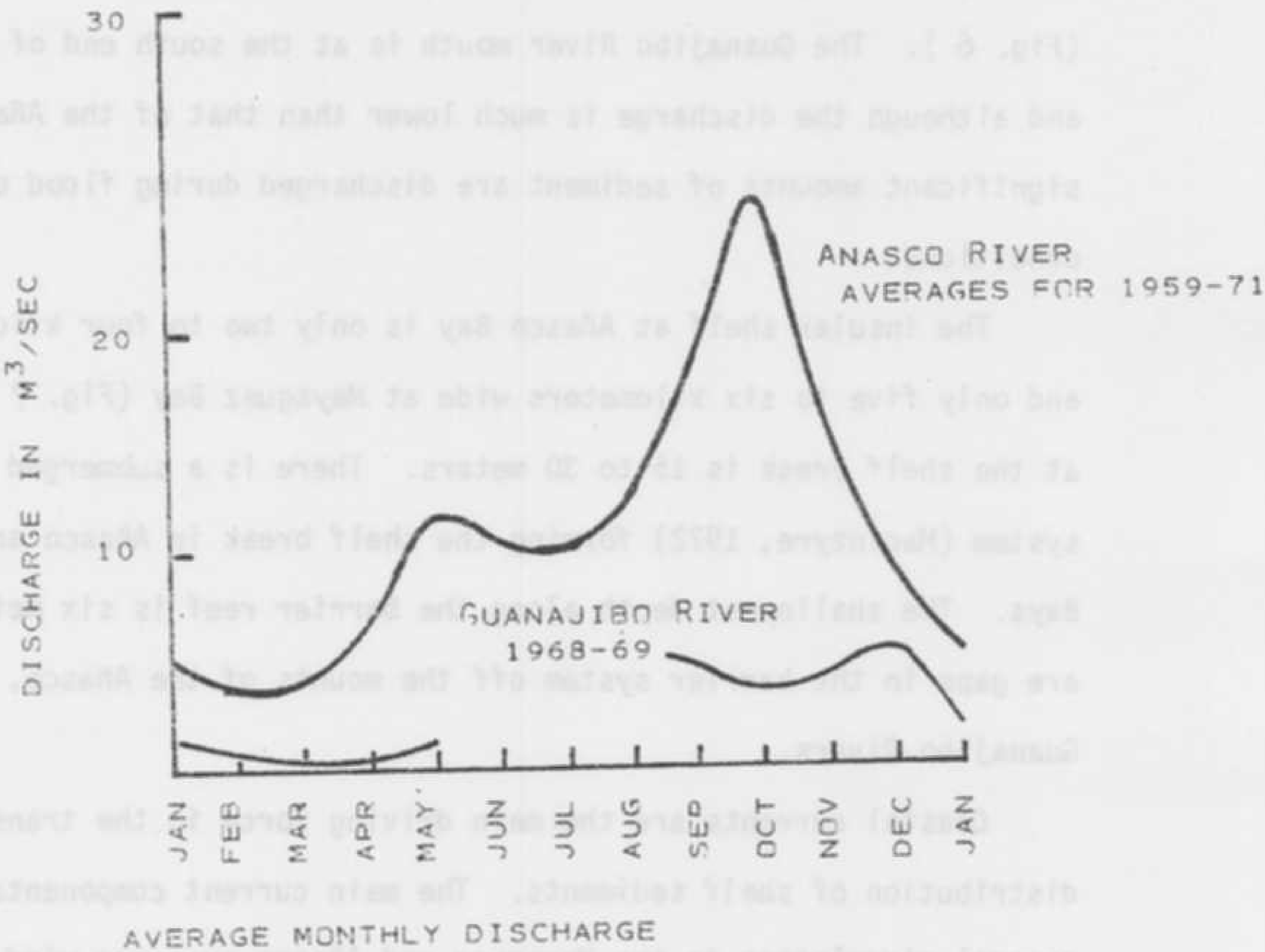

Figure 6 . River discharge at Mayaquez

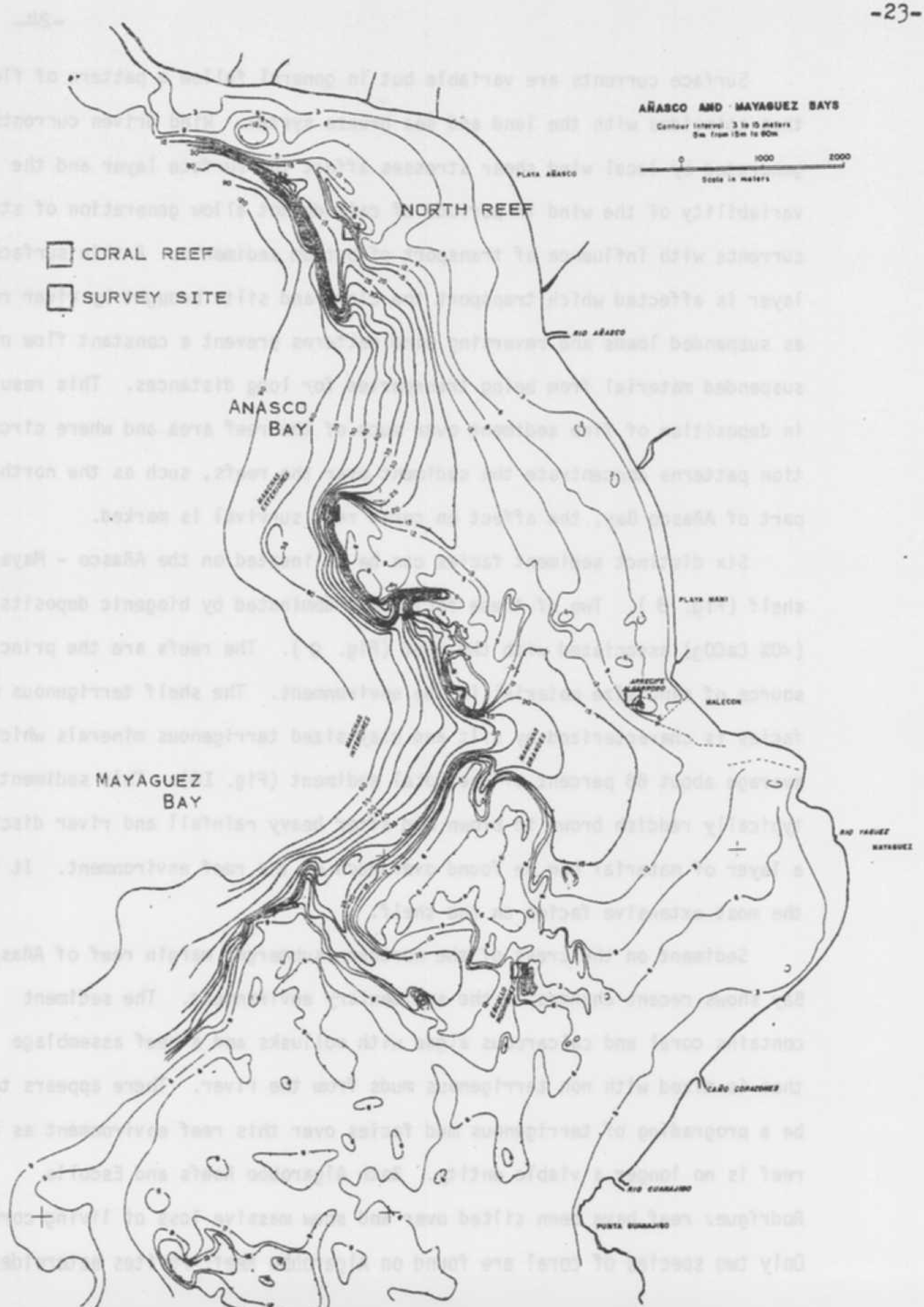

Figure 7 . Coral reefs and survey sites at Mayaguez

Surface currents are variable but in general follow a pattern of flow that coincides with the land and sea breeze system. Wind driven currents generated by local wind shear stresses affect the surface layer and the variability of the wind in periods of calm do not allow generation of strong currents with influence of transport of bottom sediments. A thin surface layer is affected which transport the clays and silts brought by river runoff as suspended loads and reversing wind patterns prevent a constant flow of suspended material from being transported for long distances. This results in deposition of fine sediment over much of the reef area and where circulation patterns concentrate the sediment over the reefs, such as the northern part of Añasco Bay, the affect on coral reef survival is marked.

Six distinct sediment facies can be delineated on the Añasco - Mayaguez shelf (Fig. 8). Two of these facies are dominated by biogenic deposits (<0% $CaCO_3$) associated with the reef (Fig. 9). The reefs are the principal source of sand size material in the environment. The shelf terrigenous mud facies is characterized by silt and clay sized terrigenous minerals which average about 88 percent of the total sediment (Fig. IO). This sediment is typically reddish brown to brown and after heavy rainfall and river discharge, a layer of material can be found over much of the reef environment. It is the most extensive facies on the shelf.

Sediment on the crest of the northern submerged margin reef of Añasco Bay shows recent changes in the sedimentary environment. The sediment contains coral and calcareous algae with mollusks and a reef assemblage that is mixed with non terrigenous muds from the river. There appears to be a prograding of terrigenous mud facies over this reef environment as the reef is no longer a viable entity. Both Algarobbo Reefs and Escollo Rodríguez reef have been silted over and show massive loss of living coral. Only two species of coral are found on Algarobbo Reef: Porites asteroides

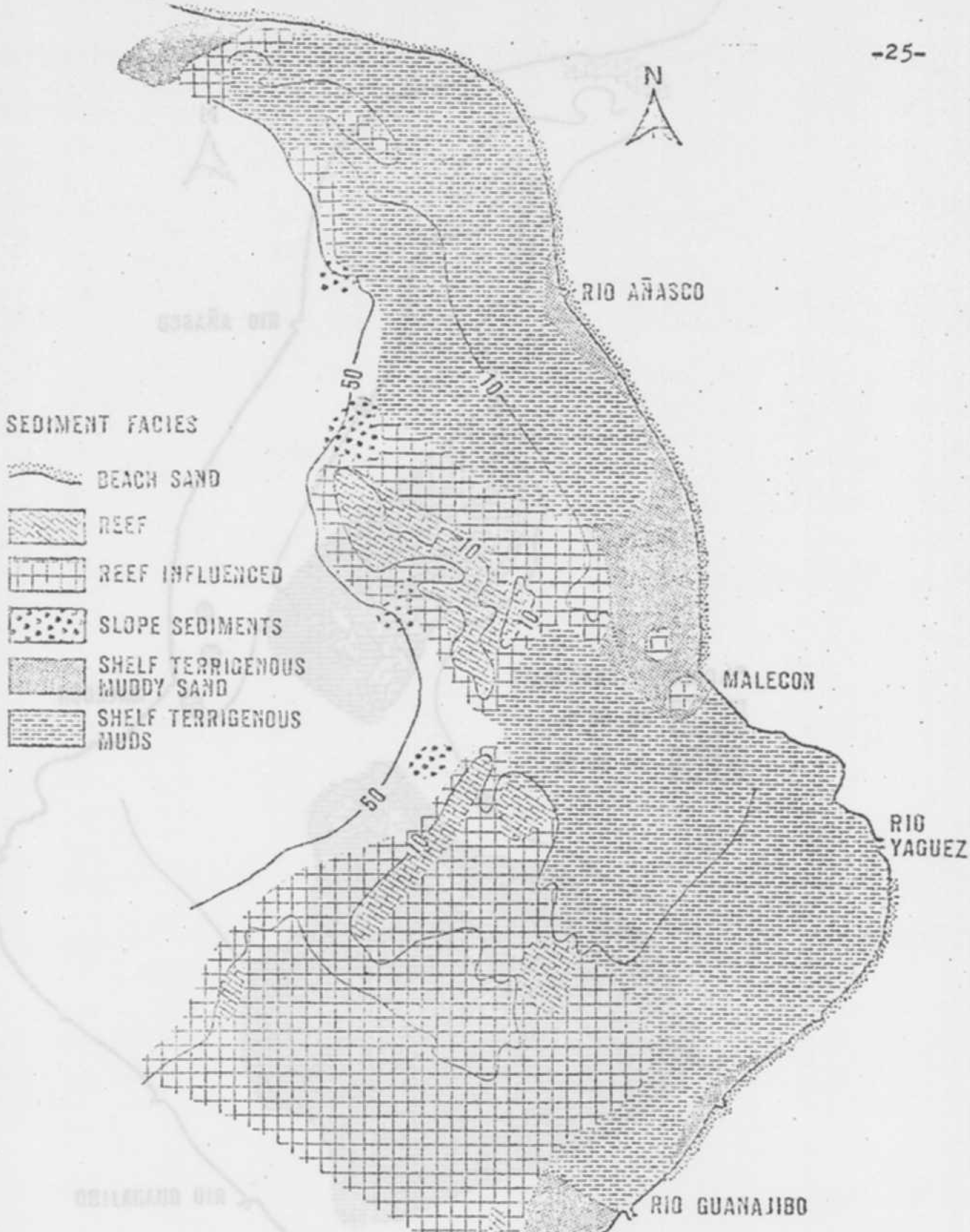

FIG. 8 SEDIMENTARY FACIES

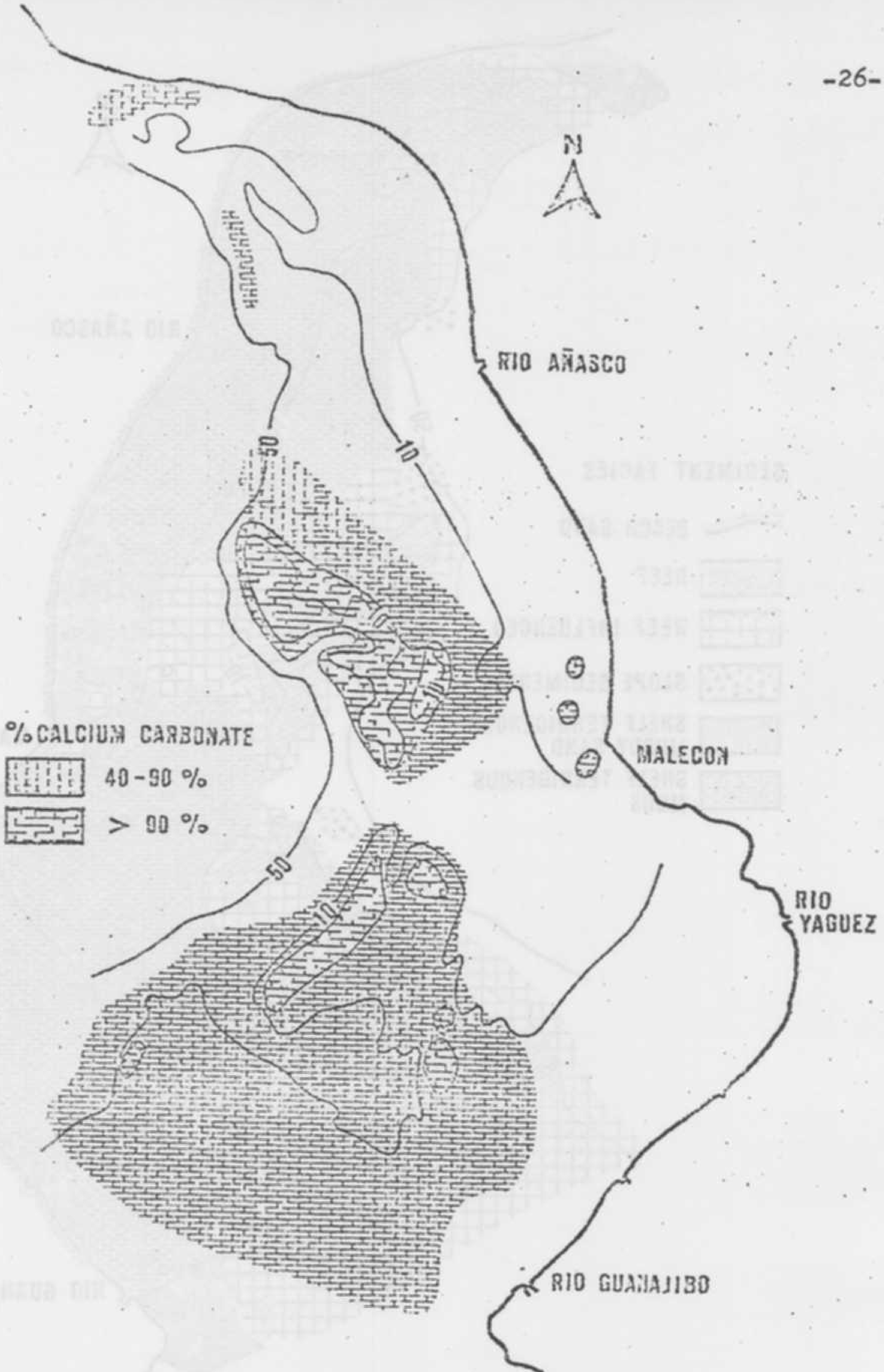

FIG. 9 PERCENT CALCIUM CARBONATE SHELL MATERIAL IN THE SEDIMENTS

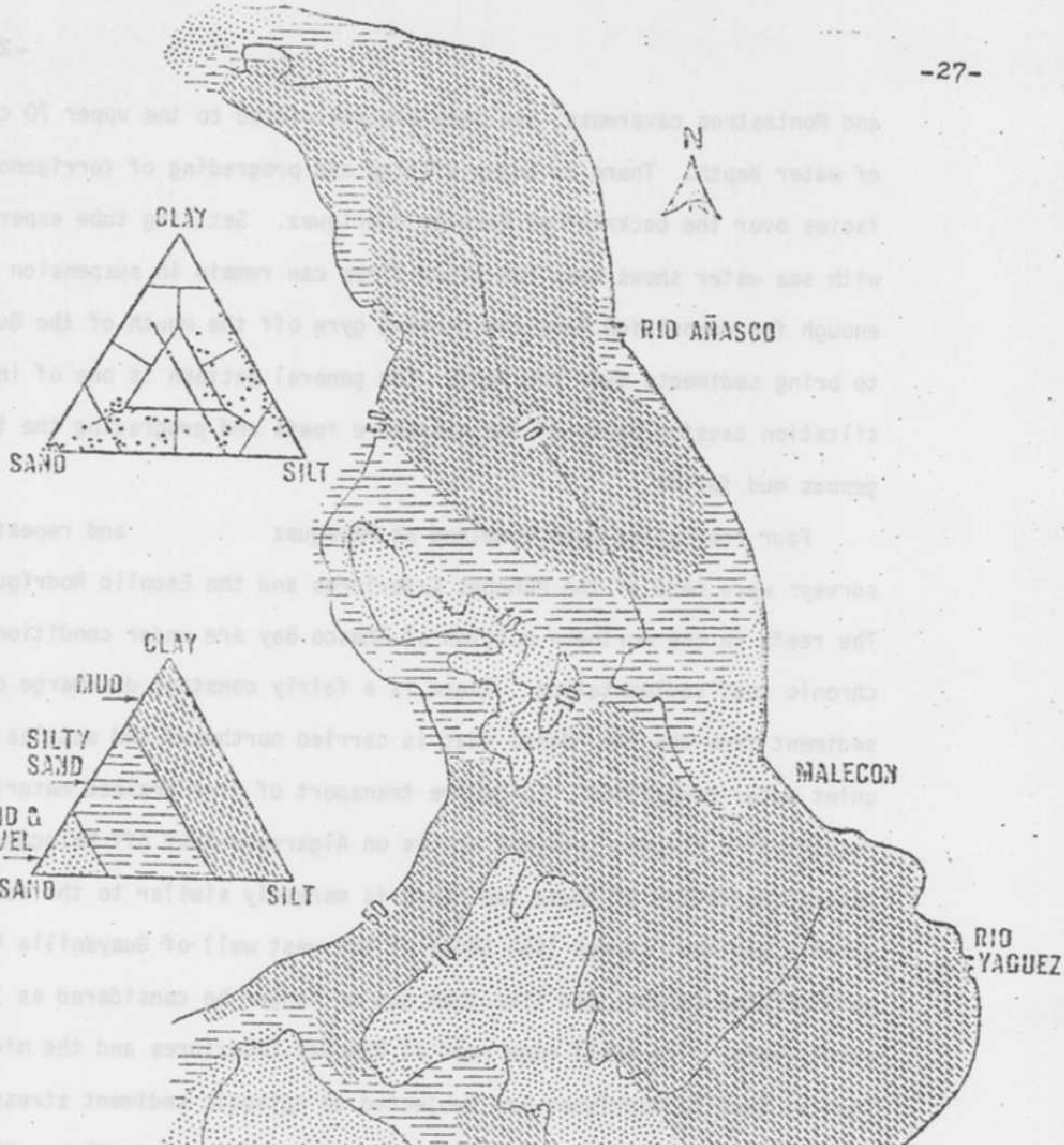

FIG. I SEDIMENT TEXTURAL FACIES

and Montastrea cavernosa, and they are restricted to the upper 70 centimeters of water depth. There is heavy silting and prograding of terrigenous mud facies over the backreef of Escollo Rodríguez. Settling tube experiments with sea water shows that the river fines can remain in suspension long enough for deposition from the current gyre off the mouth of the Guanajibo to bring sediments over the reef. The general pattern is one of increasing siltation causing death of the nearshore reefs and prograding the terrigenous mud facies.

Four reef sites were examined at Mayaguez and repeated surveys were made of the Manches Exteriores and the Escollo Rodríguez sites. The reefs in the northern portion of Añasco Bay are under conditions of chronic reef sedimentation. There is a fairly constant discharge of fine sediment from the Río Añasco that is carried northward and settles in the quiet water conditions. Longshore transport of fine grained material also results in a chronic sediment stress on Algarrobo Reef off Malecón. The general condition of these two reefs is markedly similar to the reefs under chronic sediment stress like those of the west wall of Guayanilla Canyon and Tallaboa Canyon, and like them can no longer be considered as living coral reefs. The shelf edge reef at Manches Exteriores and the mid-shelf reef at Escollo Rodríguez are subjected to episodic sediment stress. Both are beyond the range of normal transport of sediment from the mouths of the Añasco and Guanajibo rivers, but under conditions of heavier rainfall, both are covered with sediments episodically. The actual sediment input to Escollo Rodríguez reef is almost twice that of the Guayanilla and Tallaboa Canyon reefs, but the condition of the reef is better. There appears to be a definite difference in the effect of chronic versus episodic sedimentation.

The Manches Exteriores Reef exists under often tubid water conditions and a fine layer of alluvial sediments overlays a significant layer of hard substratum, possibly rendering the surface unsuitable for further coral colonization and development. Coral cover is relatively low, (less than 12 percent). Many corals appear to be under competitive stress for space occupation with demosponges. The depth limit of coral is approximately 80 feet. Because of reduced light intensity by suspended particles in the water column, organisms that are found in deeper zones of unstressed reefs appear much shallower in the Manches Exteriores Reef. For example, black coral were found in just 15 meters of depth where normally they occur 50 meters or deeper. There were 18 species of coral found with Meandrina meandrites being the most common.

The north reef exists under extremely turbid conditions because of the circulation pattern of the discharge from the Añasco River. The benthic community structure is similar to the structures described in other highly stressed areas. The substrate is relatively even and this may be due to the reduced coral growth. The coral cover is less than one percent. The most common coral is Montastrea cavernosa. Stephanocoenia michelini is also common. Due to reduced illumination, Montastrea exhibits its deep water platelike form. There are practically no gorgonians except for Plexaurella. Hydrozoans and other fouling species are common. There were twelve species of coral identified from this reef.

The Algarrobo is a very small reef just below the surface which appears to be limited in horizontal extension and growth by shigting sand around the reef margin, and high turbidity which puts severe limits on coral reef growth. An excess of nutrients in the water has enhanced the growth of green algae which is common throughout the reef. Scleractinian corals are hard to find within the benthic assemblage due to their very sparse distribution. Dead large fragments of Acropora palmata were found in approximately two meters of water depth and individual speciments of six species of living coral were found, the most common of these again being Montastrea cavernosa. Total coral coverage in this reef is far below one percent.

Escollo Rodríguez is the only emergent reef in this area. The base of the reef is at 9 meters and the floor of shifting sand excludes horizontal extension of the reef. The coral cover in the lower part of this reef is less than three percent and is again dominated by Montastrea cavernosa. There is a heavy cover of sediment over the dead coral structure. The shallow portion of the reef at depths that would normally be Acropora palmata zone is basically a mixed coral zone with coral cover less than 8 percent.

During the times of low river discharge, sediment influx to this reef is relatively light and fairly clear water conditions prevail. However, with moderate to higher discharge from the river, sediments from the Guanajibo are carried over the reef and secchi disk visibilities are less than three meters. Sediment trap data showed that the highest influx of sediment was to Escollo Rodríguez and to the north reef of Añasco Bay.

CONCLUSIONS

Coral can tolerate turbid conditions and sediment stress to some extent. This was illustrated by Roy and Smith (1971) and other researchers. The zonation of the reef is, however, dependent on light intensities (Graus and Macintyre, 1971) and the corals have different susceptibilities to direct sediment cover. Rogers (1977) found that Acropora palmata was the most sensitive to application of silty sediments in field conditions and that Agaricia agaricites, Porites asteroides, and Acropora cervircornis had lower net productivity after application of silt than other corals. This explains in part that the depth zonation not only changes upward from an increase in turbid water, but the new assemblage is missing some of the deeper water corals and there has been a change in the abundances and dominant species not explained by a simple response to light loss.

The environments of Mayaguez, Añasco and Guayanilla Bays were once favorable to coral development. This is attested to by fairly large, well developed reef tracts in all of these areas. At the present time, more than 50 percent of the original reef area is no longer living and there is no evidence of regeneration or development of new reef areas. There does appear to be a continuous record of loss of total reef area which is likely to continue.

There is a generally accepted thesis that dredging, ship traffic, sand mining, waste disposal, chemical pollutants, etc. are harmful to the reef environment. Some field and laboratory measurements have been made to determine the response of coral to various stresses. There has been very little documentation and evaluation of the long term effect of a change in the environment to stress conditions on a coral reef system. The areas discussed in this study afford an opportunity to develop, understand, and find definite answer if we are to plan the continued development of our economy, we must have reasonable knowledge of the effects of urban, agricultural, and industrial development on reef systems. Only then can we intelligently make a cost evaluation of the value of the development versus of the value of the reef environment or find ways to make the two compatible.

Reconnaissance survey of north coast coral reefs

Field work conducted for the North-Metropolitan 208 areawide waste water treatment management plan afforded an opportunity to gather additional information of the effect of changed sediment discharge patterns on coral reefs. There was an area of coral development off Boca de Cangrejos prior to dreadging of drainage and navigation channel facilities into the mangrove areas.

Sediment circulation patterns and loads in the North Metro 208 region affect significantly the coral reefs. Increased fine sediment loads from the denudation of agricultural lands, construction of urbanizations, storm sewage, and other factors harm coral colonies. It is well documented in the literature that coral are very susceptible to the effects of increased sediment load in the overlying waters. Increased turbidity and deposition of fine sedimentaffect the coral in various ways:

a. loss of light because of turbidity -- coral growth and reproduction are dependent on an adequate supply of light to support the symbiotic Zooxanthellae. The loss reduces calcium carbonate uptake and may kill marginal deeper reef coral.

b. smothering -- sedimentation on the organism can exceed the capacity of the coral to remove sediments by ciliary action.

c. abrasion -- movement of water loaded with sediment particles can cause serious harm to polyps and to soft coral.

d. deposition of silt can reduce the surface on which coral larvae can settle reducing reproduction and recruitment.

The nearshore coral reef structures off Boca de Cangrejos were inspected by SCUBA diving. The conclusion is that the coral reef has been harmed by sedimentation. Most of the coral colonies were of the soft coral type. The hard or stony coral colonies do not seem to be proliferating and are hardly encountered. Personal communication with personnel of the Department of Natural Resources revealed that the Boca de Cangrejos nearshore reefs have been under stress ever since the channel inlet to the Laguna Torrecilla was dredged. A large sandbar inside the entrance to the lagoon was removed to improve a navigation channel. Siltation has increased since that action. Prior to this dredging there was a small but living community of stony coral on the reef.

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