THE SEDIMENTARY AND PHYSICAL DYNAMIC PROCESSES OF SELECTED ESTUARIES AND RIVER INLETS OF PUERTO RICO

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OCEANOGRAPHY AND PATTERNS OF SHELF SEDIMENTS MAYAGUEZ, PUERTO RICO

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ABSTRACT

Three rivers discharge onto the narrow insular shelf of Mayaguez and Añasco bays on the west coast of Puerto Rico. The bays are bounded offshore by a discontinuous line of reefs. The resulting pattern of carbonate and terrigenous sediments reflects both the source materials and the physical processes distributing sediments.

The carbonate sediments are found only near and on elevated reef structures. Terrigenous sediments are widely distributed and are encroaching over the coral reef areas. A change in sediment distribution is occurring that will eventually result in loss of the reef environment except on the shelf edge. This change is due to increased sediment load in the rivers.

LOCATION AND PHYSIOGRAPHY

Mayaguez and Añasco bays are near the center of the west coast of Puerto Rico (Fig. 1). The shoreline of the two bays meet at Algarrobo

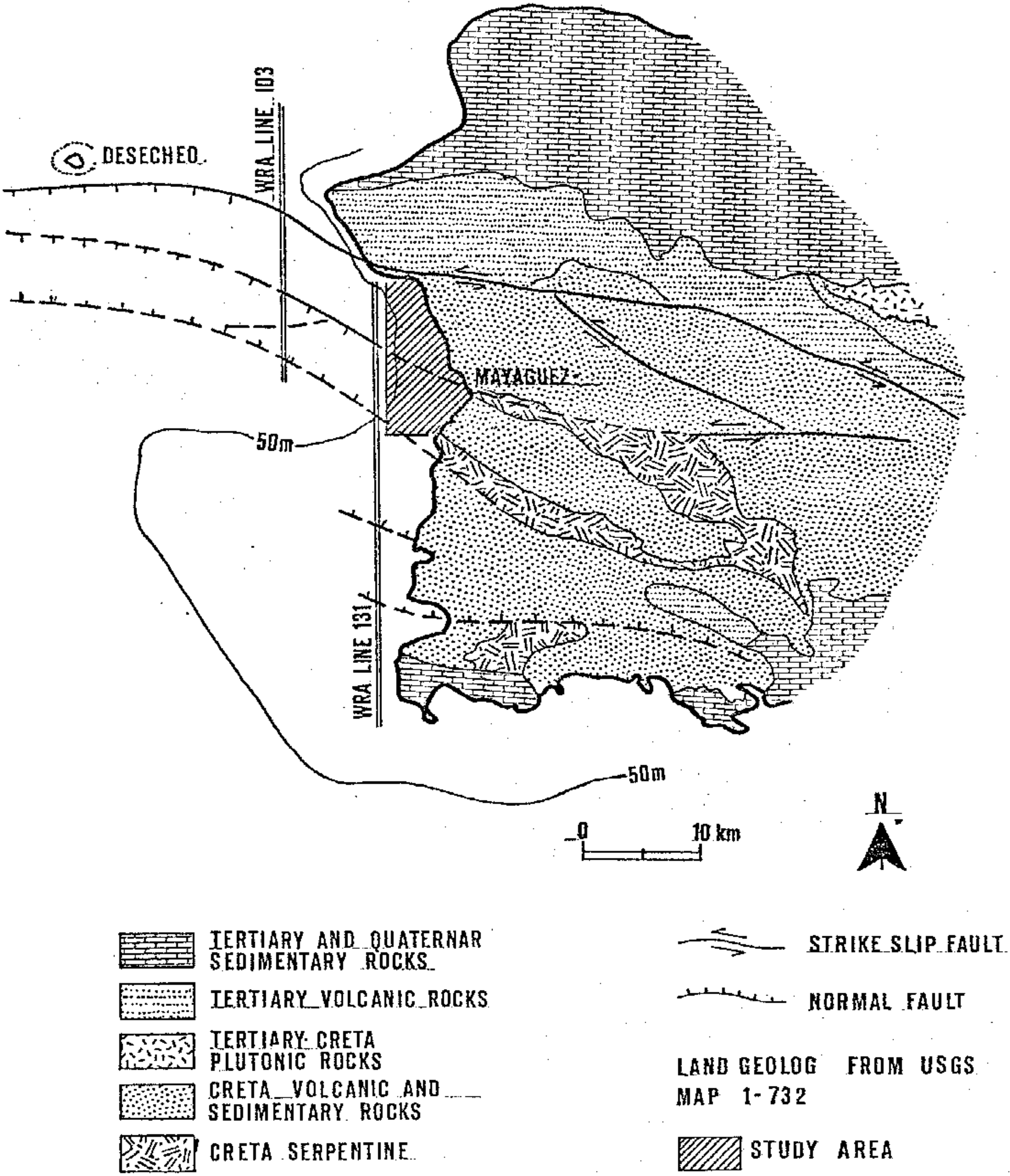


FIG. 1 REGIONAL GEOLOGY & FAULT PATTERNS

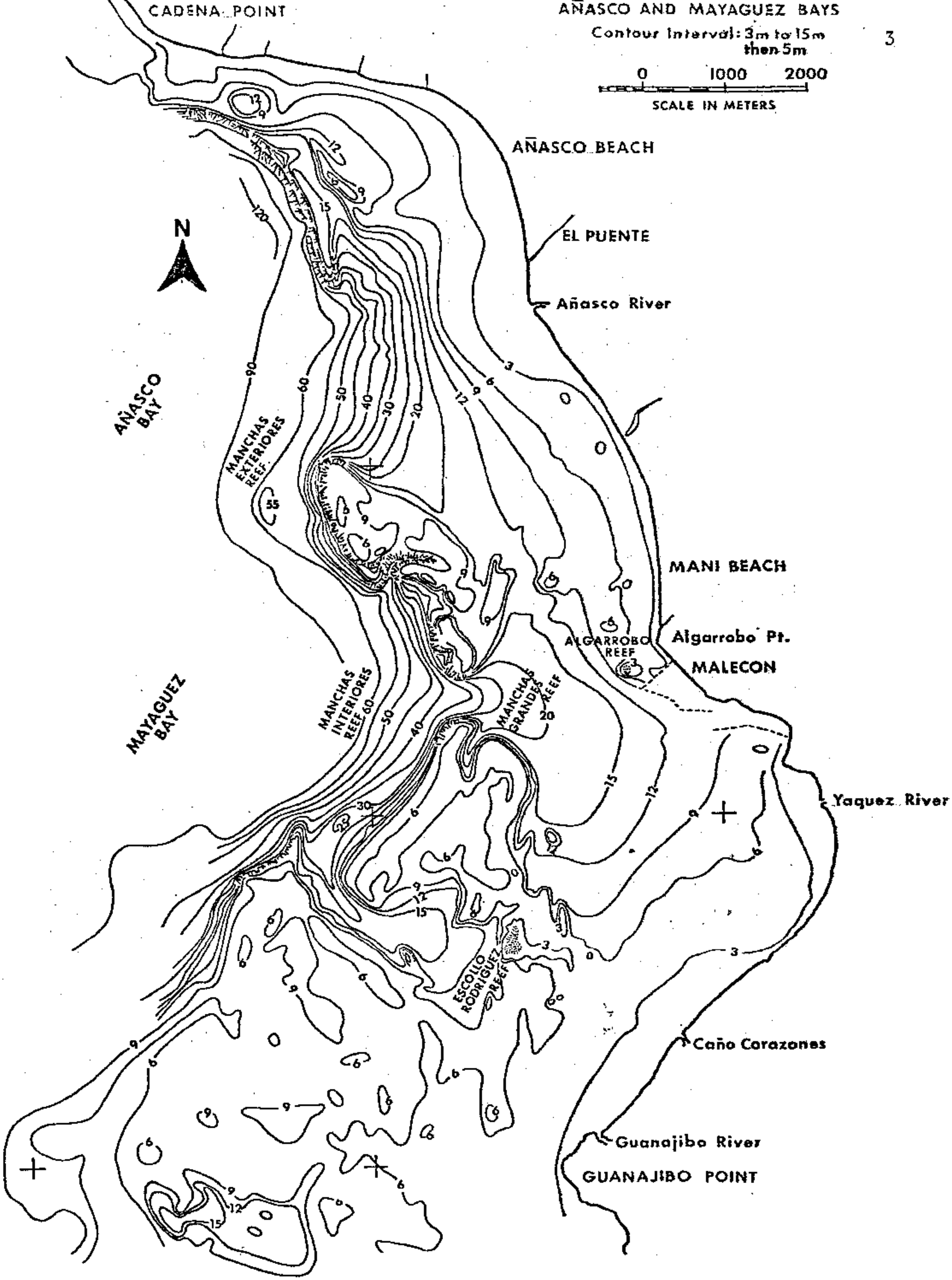


FIG. 2 SHELF BATHYMETRY

Point, but offshore there is no physical separation of the bays (Fig. 2). The Añasco, Yaguez, and Guanajibo rivers supply terrigenous sediments derived from igneous rock environments. Reefs on the shelf margin and patch reefs supply biogenic sediments.

The insular shelf is 2 to 4 km wide at Añasco Bay and 5 to 6 km wide at Mayaguez Bay. Water depth at the shelf break is 15 to 25 m. The Cabo Rojo Platform south of the study area is a broad shelf dominated by modern carbonate deposition. A submerged barrier reef system (Macintyre, 1972) forms the shelf break in Añasco and Mayaguez bays, except for gaps in the barrier located off the mouths of the rivers. The shallowest depth along the barrier reef is 6 m.

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 km^2. The apex of the foothill surrounded flood plain is about 6 km from the river mouth. Mayaguez Bay has the Yaguez River at the north and the Guanajibo River at the south. The flood plains of the two bays are separated by a low range of hills that extend to the coast at Algarrobo Point.

GEOLOGICAL SETTING

Bedrock in the river valleys ranges upward in age from Cretaceous, and are mainly weathered andesite, volcaniclastics, and mudstones (Mattson, 1960). The Great Southern Puerto Rico Fault forms the northern boundary of the Añasco Valley and insular shelf. It has been extended offshore past Desecheo Island by Garrison et al. (1972). Two other faults mapped onshore (Garrison et al, 1972) are identifiable in the Water Resources Authority (WRA) seismic lines (Fig. 3). These faults and the Great Southern Puerto Rico Fault form a graben that affects the offshore morphology and sedimentation of the bays.

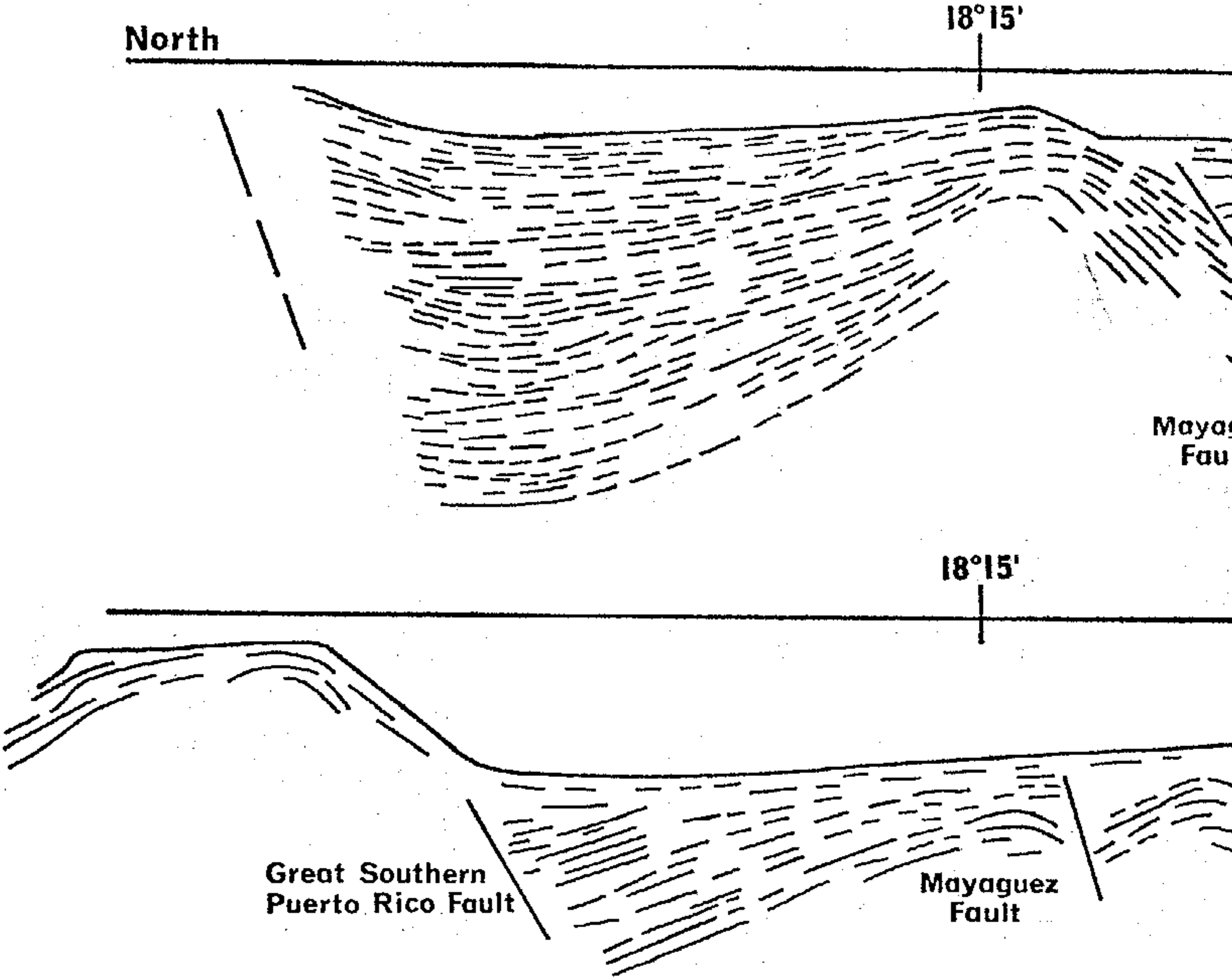


FIG. 3 INTERPRETED SEISMIC PROFILE LINES OFFSHORE FROM MAYAGUEZ
(from records of Water Resources Authority)

CLIMATE AND HYDROLOGY

The average annual precipitation ranges from 200 to 250 cm in the Añasco-Mayaguez area. The vegetation in the hills is lowland to lower montane rain forest (Danserau, 1966). The valleys and coastal plain are primarily sugar cane fields interspersed with urban areas.

Data are available on the discharge of the Añasco River for the past 15 years (Rickher et al., 1970), but measurements of flow in the Yaguez and Guanajibo rivers have been infrequent. Seasonal fluctuations in rainfall result in maximum river discharges from September through November and minimum flows in February and March (Fig. 4). Recorded for the Añasco River range from 575 m^3 to a low of 0.33 m^3/sec discharge. Five major floods have occurred since 1899.

The winds are part of an island sea breeze system superimposed on the easterly trade wind system. The mountains to the east provide shelter from much of the trade winds.

CURRENTS AND WAVES

Coastal currents are the driving force in the transport and distribution of the shelf sediments and act in concert with wave energies. The current components in the general circulation pattern in the Añasco and Mayaguez bays are wind drift, wave driven, tidal, and inertial components. Wave driven and tidal components are the most influential in distribution of the sediments in these bays.

Current data taken from prior investigations in Añasco and Mayaguez bays (Colón, 1971; P.R. Dept. of Public Works, 1974; Guzmán and Assoc., 1974, Fomento, 1975) and this study are summarized in figure 5. The range of measured current speeds was from 2 to 38 cm/sec., We found a definite vertical velocity gradient with mean velocities of 23 cm/sec at the surface and 3 cm/sec at 10 m water depth. Surface speeds ranged from 13 to 38 cm/sec.

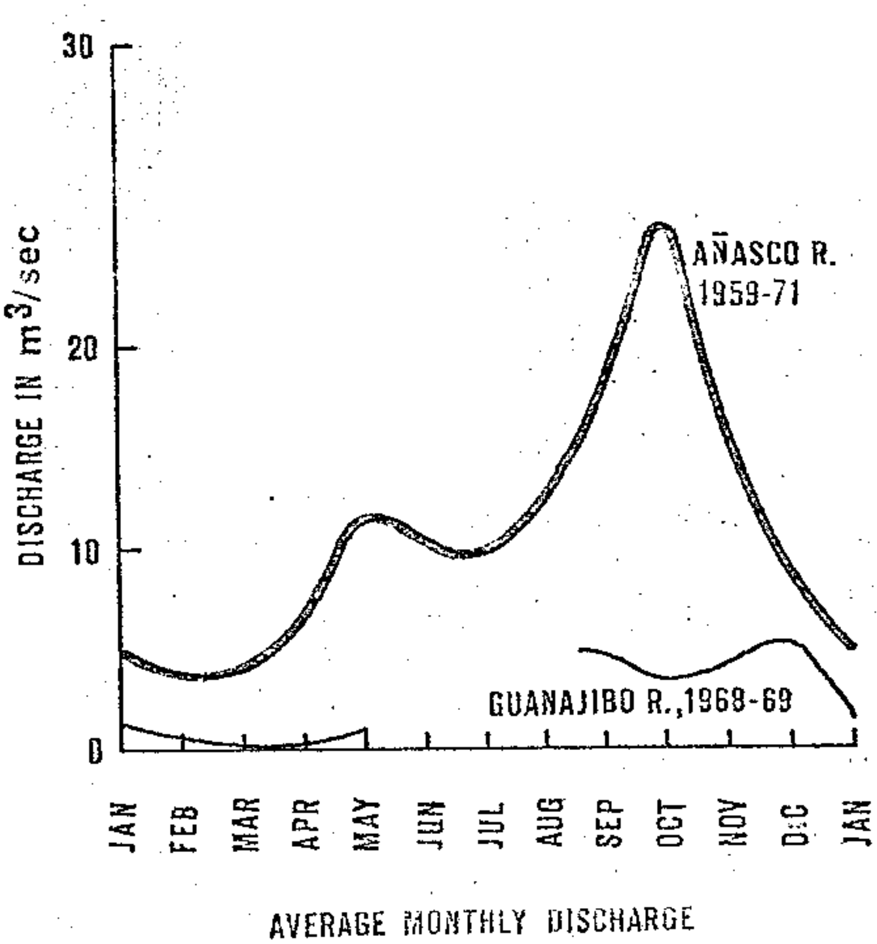
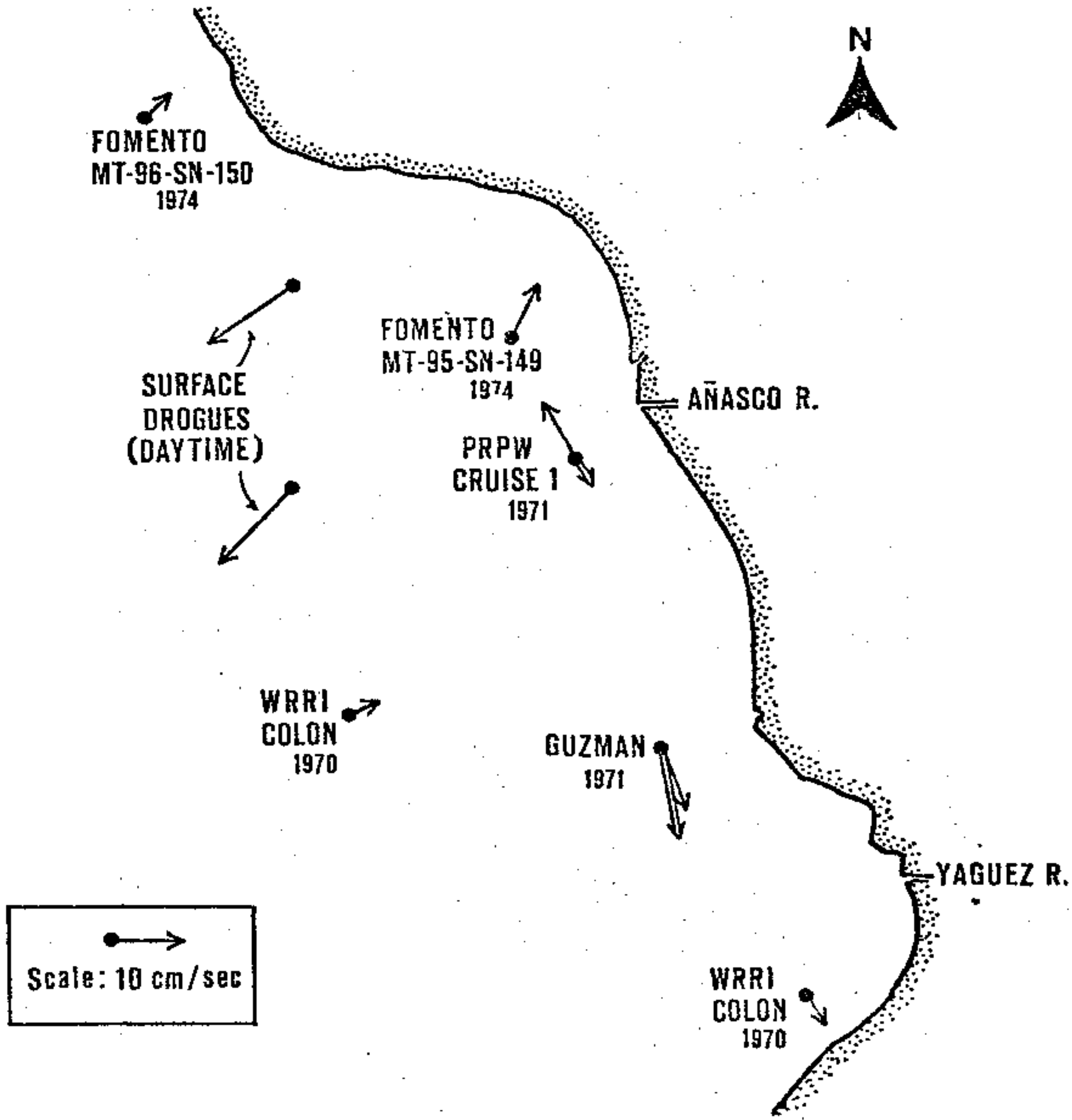


FIG. 4 RIO AÑASCO & RIO GUANAJIBO DISCHARGE



MEAN RESULTANT CURRENT VECTORS

FIG. 5 CURRENT METER DATA FROM PRIOR STUDIES

Surface current flow was offshore, but the next flow of the total water column was landward, toward the north and northeast. The suspended sediment from the Añasco River is first carried offshore and then as it settles, is moved over the shelf and reef area in the northern part of the bay.

Variability in wind direction and velocity and the small tidal range do not allow generation of currents strong enough to influence the transport of bottom sediments. The surface layer and deeper current system does transport and distribute the clays and silts brought by river run-off as suspended load.

The wave refraction analyses were done with a FORTRAN IV program designed by Dobson (1967) and modified by Coleman and Wright (1971). Wave direction inputs from the southwest and northwest were used. The intervals between orthogonals were determined by resolution levels and scaling limitations of the bathymetric map.

Only waves from the northwest contribute sufficient energy to the shelf to have an effect on sediment distribution. Swells approaching from the southwest occur infrequently and are attentuated over the shallow shelf south of the bays. Analysis of figure 6 shows that Mani Beach is receiving only slightly refracted normal waves that spread the energy uniformly along theshoreline. A convergence of highly refracted waves occurs at Malecón due to translation over complex offshore bathymetry. Under moderate storm conditions, wave convergence occurs in the southern Mani Beach and the north Malecón area has divergence of wave orthogonals. The northern part of Mani Beach and the Yaguez River shore are low energy zones due to the extreme divergence of wave orthogonals. Under extreme storm conditions, similar distribution of energies occurs.

Refraction and wave breaking on shoals some distance from shore result in a marked decrease in shore wave power as compared to input wave condi-

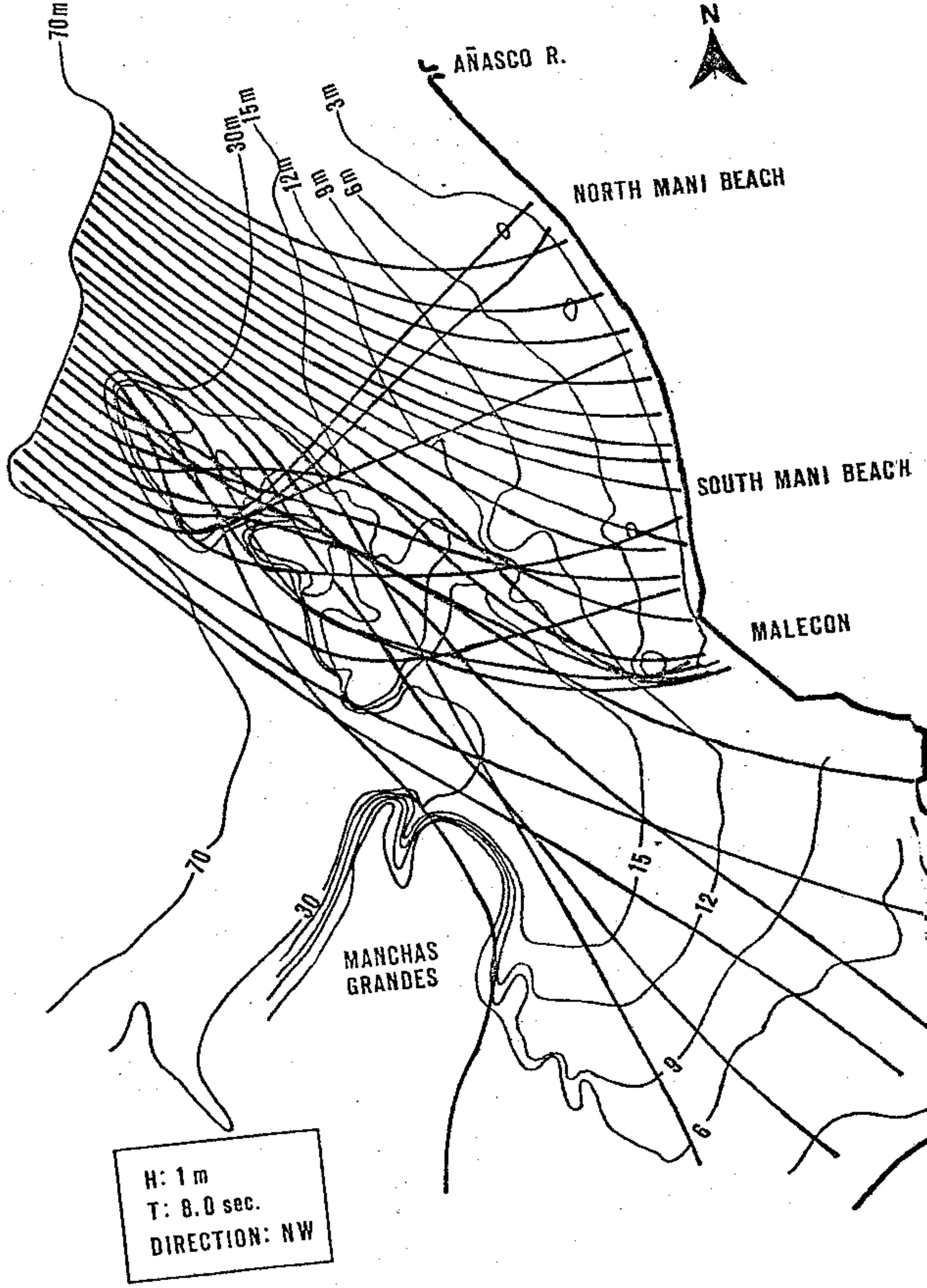


FIGURE 6-WAVE DIFRACTION STUDIES

tions in both bays. Most of the energy in Añasco Bay is directed into the Malecón area of the shore. The longshore power deduced from the wave refraction study shows a longshore drift of beach sediments to the south.

BATHYMETRY

The shelf bathymetry is fairly irregular due to structural and sedimentological processes, and later reef growth. The rivers discharged their sediments directly on the insular slope during the Wisconsion low sea level and the shelf was exposed to sub-aerial erosion. The paths taken by the rivers are partly preserved in the bottom bathymetry as channels on the outer shelf and breaks in the submerged barrier reef. The Añasco channel and nearshore reaches of the Yaguez and Guanajibo rivers have been filled with sediments. Shoreward of the barriers, the Añasco shelf is a gently sloping plain except for areas of patch reefs.

A terrace is present along the forereef at 55 to 60 m (Fig. 7). Maximum terrace width is off the northern tip of Manchas Exteriores reef (profile 3, Fig. 7A) where Grove (1977) described a reef-like structure on the slope. Sieglie (1968) identified reef foraminifera assemblages from the 55 m level and also from 80 m. The profile line in Mayaguez Bay (Fig. 7B) shows a possible reef structure at 75 m partially covered with sediment fill.

SEDIMENTS

Grab samples were collected from the shelf in order to study distribution patterns of sediment texture and composition (Fig. 8). Size facies distribution does not fit the normal triangle diagram classes (Shepard, 1954), but instead fall into three natural classes of sand and gravel, silty sand, and mud, which is defined as the mixture of clay- and silt-sized material.

Sediments of the beach system are sand-sized. These extend only to

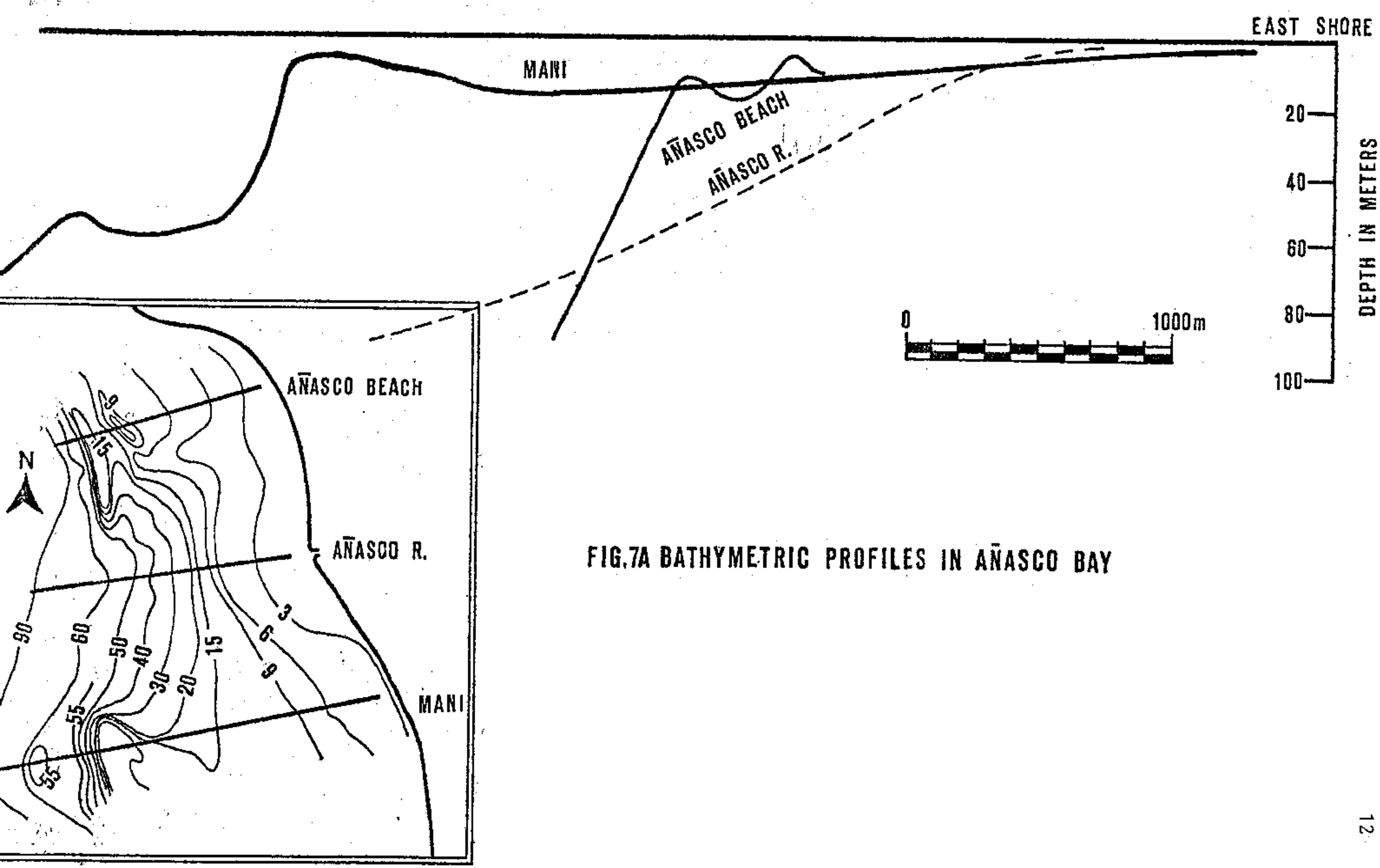


FIG.7A BATHYMETRIC PROFILES IN AÑASCO BAY

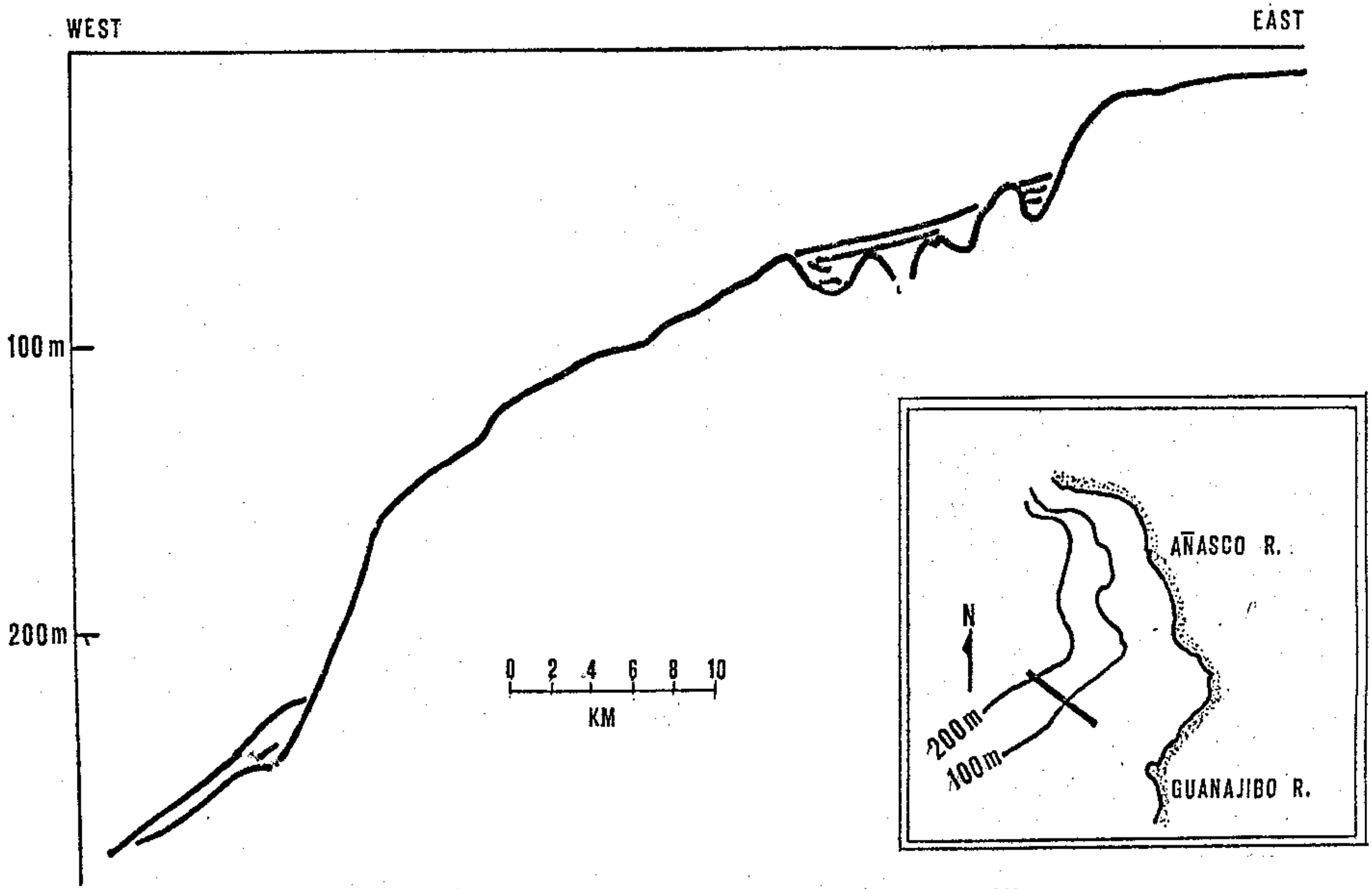


FIG.7B INTERPRETED SEISMIC PROFILE OF SHELF EDGE IN MAYAGUEZ BAY the 3 m depth contour and cover a limited area. Deposits of mud and sandy mud (10 to 30% sand) cover most of the central and northern parts of Añasco Bay and the eastern part of Mayaguez Bay. In the southern part of Añasco Bay, the fine sediments grade into muddy sands. Part of the submarine canyon of the Guanajibo River has muddy sand sediments. This size facies also forms a discontinuous transition belt between the beach sands and the shelf muds, and the upper slope sediments off Manchas Exteriores reef.

The coarsest textures are associated with the shelf edge reefs and patch reefs. Some of the samples near these features are more than 50 percent gravel size. Sand and gravelly sand are found on the reef platforms grading into muddy sand texture on the surrounding reef slopes. The carbonate-covered platform south of Mayaguez Bay is sand and gravel except for minor amounts of fine material trapped in local pockets.

The percent carbonate content and the bathymetry are directly related (Fig. 9). The carbonate sources are patch reefs and the shelf edge reefs which form bathymetric highs. Since non-reef carbonate material in the form of pelagic and benthic shells is less than 10% of the sediment, carbonate content greater than this is an indication of reef proximity.

The constituents of the sand and gravel fraction and their relative abundance, condition, and distribution have been used to interpret sediment provenance, distribution patterns, and environmental conditions. The grains can be divided into three major composition categories: terrigenous, skeletal, and authogenic. The authogenic component, glauconite, does not exceed 10% in any of the samples.

Texture and composition were used to delineate six distinct sediment facies (Fig. 10). Two of the facies are dominated by biogenic deposits associated with the reefs. The reef sand facies is a relatively pure and member of the mixture of carbonate and terrigenous sediments. In places

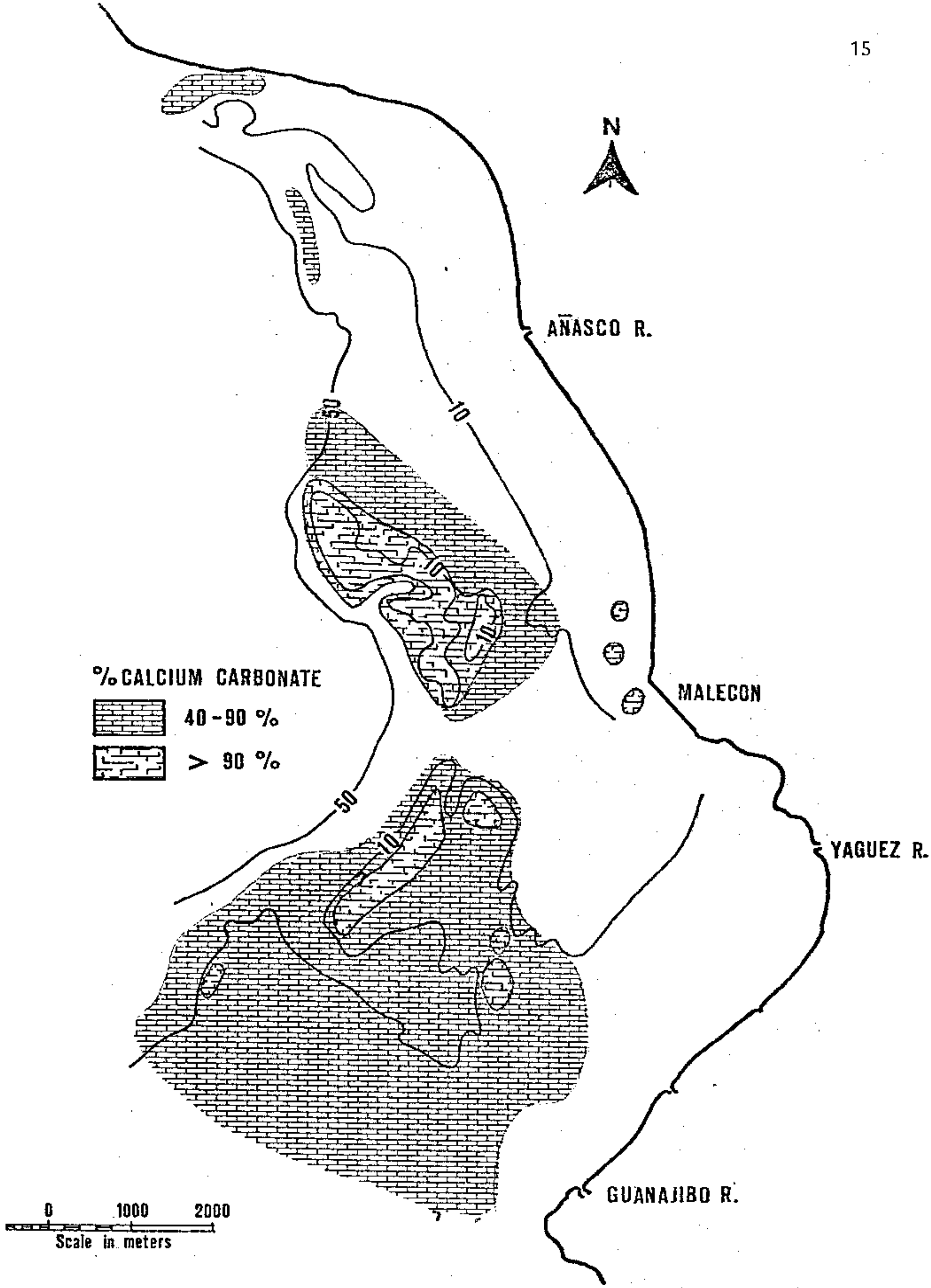


FIG. 9 PERCENT CALCIUM CARBONATE SHELL MATERIAL IN THE SEDIMENTS

this facies is reef or hard bottom. The submerged barrier reefs and patch reefs roughly mark the extent of the reef sand facies. The sands are coarse grained with gravel constituting 30 to 40% of the total. The mud fraction is less than 3%. The mud is found as a thin layer of reddish brown terrigenous sediment that settles on the reef from the river discharge plumes.

The skeletal material is dominated by coral and calcareous algae grains. Mollusc fragments are the next most abundant component. As much as 15% of the skeletal grains are darkened and are interpreted as being relict sediments (Sieglie, 1968; Saunders, 1973).

Coral growth forms small topographic highs along the seaward margin of the reefs. The reefs are cut by sand filled channels on the leeward side which funnel sand into larger patches that cover much of the backreef area. This pattern is also found in other areas of submerged barrier reef in Puerto Rico (Morelock, et al., 1977). The reef fauna includes colonies of Acropora palmata interspersed between clusters of octacorals and sponges. A few colonies of Acropora cervicornis and Dendrogyra cylindrus are present. The top and forereef corals are primarily small heads of Montastrea cavernosa, Diploria sp and Agaricia sp that are typical of a sediment-stressed massive coral zone (Morelock et al., 1980). The reefs are shallow enough that an Acropora palmata zone could have formed and grown to the surface during the last half century. The branching corals show extreme sensitivity to sediment input, however, and it is unlikely that growth will occur.

The reef-influenced sediment facies is a muddy sand with both terrigenous and skeletal components. This facies is in the deeper water areas around elevated reef structures. The skeletal fraction is dominated by a coral and calcareous algae assemblage similar to the reef sand facies. The terrigenous component is mainly mud with some fine-grained sands. Sediment texture is variable, with sand and gravel averaging about 60% of the sediment. The sands are mixed with reddish brown muds from the rivers.

The four terrigenous sediment dominated facies are distinguished by texture, mineral composition, physiographic location, and environmental parameters. The beach facies is more than 98% sand-size grains. These sands do not extend beyond the 3 m contour except the northwest corner of Añasco Bay. Mineral composition of the beaches in Añasco and Mayaguez bays is strinkingly different, emphasizing the difference in source materials, physical processes, and lack of transport between the two beaches (Fig. 11).

The terrigenous component of the Añasco beach sand is variable, averaging about 69% of the total. The gradual increase in terrigenous sediment to the south reflect both the increased importance of river sediment source and the southward of sediments by longshore currents. The terrigenous sediments are quartz rich. About 25% of the quartz grains are subrounded and frosted, and grain polishing is common in both skeletal and terrigenous components. The skeletal grains are a coaralline algae and mollusc assemblage. Since the adjacent offshore facies are terrigenous muds and muddy sand with low skeletal content, the carbonate material is probably from a small patch reef area that is just northwest of the study area.

The Mayaguez beach system is composed of dark, igneous rock fragments and minerals. The deep channel of the Yaguez River effectively stops any southward transport of the Añasco beach sediments. The low amount of carbonate grains in the beach and the presence of marine muds beyond the 3 m depth preclude offshore contribution to the beach sediments.

The shelf terrigenous muddy sand facies occurs off the Añasco River and in the nearshore southern part of Añasco Bay, and off Guanajibo Point. Terrigenous minerals average about 97% of the sand fraction in contrast to the reef influenced facies in which the sand fraction is dominantly carbonate sheyl material. The terrigenous sands are distributed in these areas primarily during flood conditions which flush coarse material out of the river-estuary system onto the shelf. Distribution of this material by wave and current action, including longshore drift is limited to the shallow nearshore south of the Añasco and Guanajibo rivers. Although the silt- and clay-laden plumes of the rivers pass over these areas, there is much less mud deposition than in the sheltered mud deposit areas. Wave induced turbulence is sufficient to cause continued suspension of the mud.

Silt- and clay-sized terrigenous minerals average 88% of the shelf terrigenous mud facies. The coarse fraction is mainly very fine sands. The sediment is reddish-brown to brown and the terrigenous sand component is similar in composition to the river sands. The skeletal components in the sand fraction are calcareous benthic foraminifera and some mollusc shell fragments. The organic carbon content is significantly higher in the sediments of this facies compared to the other five facies (Grove, 1977). Most of the organic detritus is vascular plant material from a land source.

The terrigenous mud is the most extensive facies on the shelf. Even close to the mouths of rivers, the sands of this facies are very fine-grained. Both the river mouth bars and the salt wedges in the lower length of the river channels stop the seaward transport of coarse river bed load except during flood conditions. The fine sands, silt, and clay of the suspended river load pass to form the shelf terrigenous muds. The clay minerals in the Añasco River are kaolinite and montmorillonite and the offshore clays in Añasco Bay are illite, chlorite, kaolinite, and montmorillonite (Pirie, 1967). Distribution of the terrigenous mud facies is consistent with the surface current patterns and the distribution of areas of reduced wave energy.

The slope facies is defined by textural and compositional characteristics. The facies occurs deeper than 40 meters in areas west of the mouths of the Añasco and Yaguez rivers and on the seaward slopes of the shelf marging reefs below the limit of coral growth. The sediments are silty and clayey sands that are coarser in texture than the shallower adjacent shelf terrigenous mud facies. Gravel averages 7% of the sediment total, and sand content averages 56%. Terrigenous components make up 30 to 84% of the sand fraction. The carbonate component increases near the shelf margin reefs.

The constituents of the coarse fraction are extremely diverse and are a mixture of terrigenous, skeletal, and authigenic components. Several features of these sands are indicative of relict sediments, and the upper deposits of the slope facies were probably formed as nearshore or beach facies in a transgressive sand sheet.

HISTORY OF SHELF SEDIMENTATION

Several long-term changes in the depositional environment can be ascertained from the shelf morphology, sediment characteristics, seismic profiles, and bore holes made for engineering studies. The Wisconsin glacial period courses of the rivers can be seen on the bathymetry, even though obscured by sediment fill. The relict terrigenous components of the slope facies are rounded and polished sand and gravel grains that have a composition similar to the modern beach system. These are transgressive sands, and their presence at the sediment surface indicates low rates of post-transgression sedimentation.

Two foraminifera assemblages are present on Manchas Exteriores and Manchas Interiores reefs (Grove, 1977):

1. relatively fresh tests (unabraded and unstained) dominated by Amphistegina gibbosa and including

Homotrema rubrum, Rotorbinella rosea, Asterigerina carinata.

2. an assemblage of stained and abraded tests dominated by Cyclorbiculina compressa with Articulina mexicana and Quinqueloculina sp.

The Cyclobiculina assemblage is usually found in shallow backreef environments (Seiglie, 1968), so it is a population relict from lower sea level. The reef was colonized by the deeper water Amphistegina assemblage as sea level rose. The presence of relict backreef foraminifera in the surface sands of the reef platform indicates a low rate of carbonate production since submergence of the reef. Saunders (1973) found a similar condition on the nearshore reefs of the south coast of Puerto Rico.

Sediment on the crest of the northern submerged shelf edge reef (15 m deep) shows recent changes in the sedimentary environment. The carbonate reef material is mixed with more than 20% terrigenous muds. This reef and the small reef to the northeast have less than 5% living coral cover. Both reef environments are being replaced by spreading of the terrigenous mud facies.

Both Algarrobo reef and Escollo Rodríguez reef are being silted over, with the likelihood of future burial by sediments. Algarrobo has less than 2% living coral and only two coral species Porites asteroides and Montastrea cavernosa together with Millepora alcicornis are living. These are restricted to the upper 70 cm of water depth. Escollo Rodríguez reef has a very sediment-stressed forereff (west side). The backreef has up to 1 m of fine silt and clay deposited over dead coral. The general pattern is one of increasing sedimentation causing death of the coral framework of the nearshore reefs and subsequent encroachment of the mud facies. A change in total area of living coral can be seen in many shelf areas in Puerto Rico.

The increase in fine sediment load in the rivers is probably due to intensive cultivation of the land for sugar cane production in the past 300 years. Soil erosion with consequent increased fine sediment load has been accelerated by intensive urban development in coastal areas.

The two terrigenous sediment zones in the Algarrobo Point bore holes (Fig. 12) are similar in lithology and texture to the surface facies in this area, and probably result from similar depositional environments. They have more fine material than the surface facies, including deposition in quieter water. The carbonate facies is similar to the near reef sand facies except for more fine material. The clayey silt zone at the bottom of bore hole 2 has fragments of mangrove. This deposit is probably part of a mangrove swamp formed during lower sea level when the mangrove had migrated across the shelf to a point beyond bore hole 2.

The pattern of terrigenous sediment deposition in Añasco and Mayaguez bays is similar to that off the La Plata River described by Pilkey et al. (1978). The transport of sand-sized material onto the shelf occurs only during river flooding. A massive movement of river sediment onto the shelf is slowly redeposited by wave and current action. This results in the presence of thin and areally limited bodies of sand surrounded by finer-grained sediments.

SUMMARY AND CONCLUSIONS

Sediment deposition on the Añasco-Mayaguez shelf reflects sea level rise over a subaerially developed surface interacting with carbonate reef and river sediment sources. Wave and current patterns have played a role in distribution of the sediments. As sea level rose, a transgressive sea deposited blanket sands across the erosional surface and filled most of the submerging river channels. Coral reefs formed on local highs and contributed skeletal components to the sediment. Deepening sea level changed

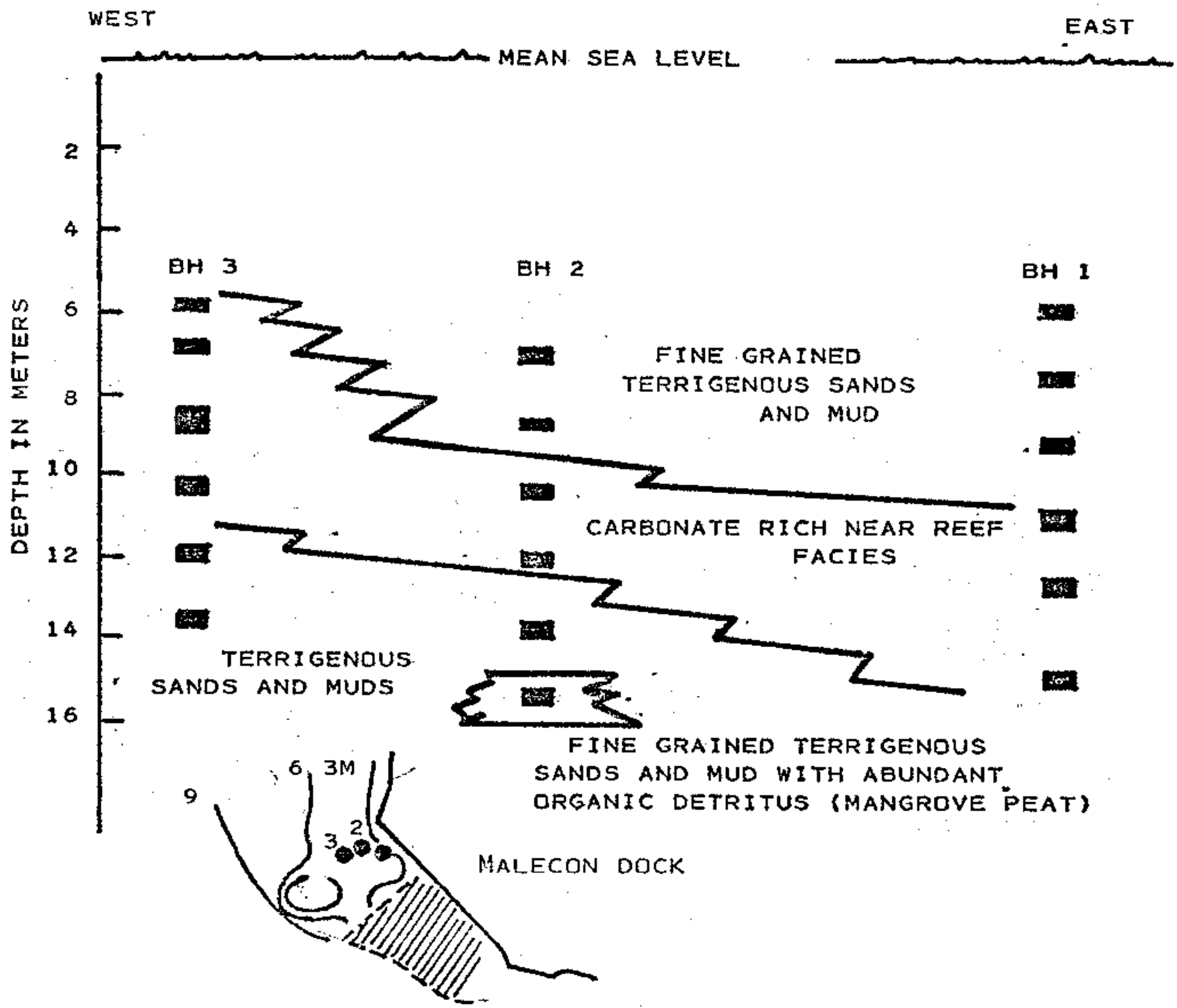


FIG. 12 SEDIMENT FACIES FROM MALECON DOCK AREA BORE HOLES

the character of the terrigenous deposits and reef sediments. As sea level approached the present level, patterns of modern sediment deposition began. In the modern environment, the dominant facies are the mud and sandy mud sediments from the rivers.

With the intensive cultivation of land for sugar cane and modern urbanization and industrialization of the Island, there have been changes in the sediment patterns. The numerous patch reefs near the shore indicate that the water must have been much less turbid at an earlier time. Increased siltation has resulted in the loss of reef-growth capability and seaward encorachment of the terrigenous mud facies. The loss of inshore reefs and ultimate filling of the shelf will eventually result in a smooth shelf platform floored by sandy muds and muddy sediments behind a buried shelf edge reef. The final pattern will resemble many examples in the subsurface of the Atlantic shelf off the southern United States.

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PART II

GEOLOGICAL PHASE

INTRODUCTION

The geological and physical conditions in the river-estuary system of Puerto Rico is considerably different than that found in temperate latitudes. Because of the small tidal range, the estuaries are not tidal dominated and a salt wedge is maintained in the lower reaches for most of the time. This results in the trapping of much of the sediment load in the river itself rather than being spread out upon the insular shelf. Under conditions of high rainfall with heavy river flow, the salt wedge is pushed out of the river mouth and some of the sediment deposits are eroded and carried offshore. The conditions of high rainfall and sediment discharge are often accompanied by turbulent weather conditions in the marine environment with heavy wave action so that most of these sediments do not remain on the shelf, but are moved offshore to the insular slope. This is especially true for the fine grained material.

The sediment load of the rivers basically moves in a series of discrete jumps. The bulk of the material is deposited within the river near the mouth with part of it forming a bar across the mouth of the river. The fine grained fraction, (smaller than 63 μ) which moves out over the bar, is deposited both in the near shore environment and carried outward to the insular slope.

PART I

PHYSICAL OCEANOGRAPHY PHASE

AÑASCO RIVER

Precipitation in the Añasco drainage basin averages annually from 250 cm in the inland extremes to about 200 cm in the lower valley. The vegetation of the area is dense and is classified lowland to lower montain rain forest. The natural floor of the lower floodplain has been eliminated by extensive agriculture. The discharge of the Añasco River has been monitored for more than 15 years and published data is available for 1960 through 1971 (Fig. 1). Seasonal fluctuations in Puerto Rico are related mainly to variations in the amount of rainfall. This variation is reflected in the Añasco River discharge. Minimum rainfall occurs during February and March and maximum rainfall in September, October and November. Discharge values has been recorded as high as 575 cubic meters per second and as low as .9 cubic meters per second. The flood plain of the lower Añasco River has been inundated extensively at least five times since 1900.

Ocean swell approaches the west coast of Puerto Rico dominantly from the north or northwest. Storm wave directions are generally from the north or northwest during the winter. Waves from the northeast are believed to affect the west coast by refraction around the northwest coast of the island. After refraction, the northeast swell approaches the embayment coast as a north or northwest wave train.

The tides along the Añasco shelf are essentially semi-diurnal with a small tidal range. The mean tidal range is 24 cm. The tidal currents trend northwest southeast along the shelf at an angle to the shoreline. Currents generated by tides are usually less than 18 cm per second.

The circulation pattern in the estuary system is related to physical phenomena which includes river flow, tidal velocities and the physical geography. In the Añasco River, the physical environment which has been

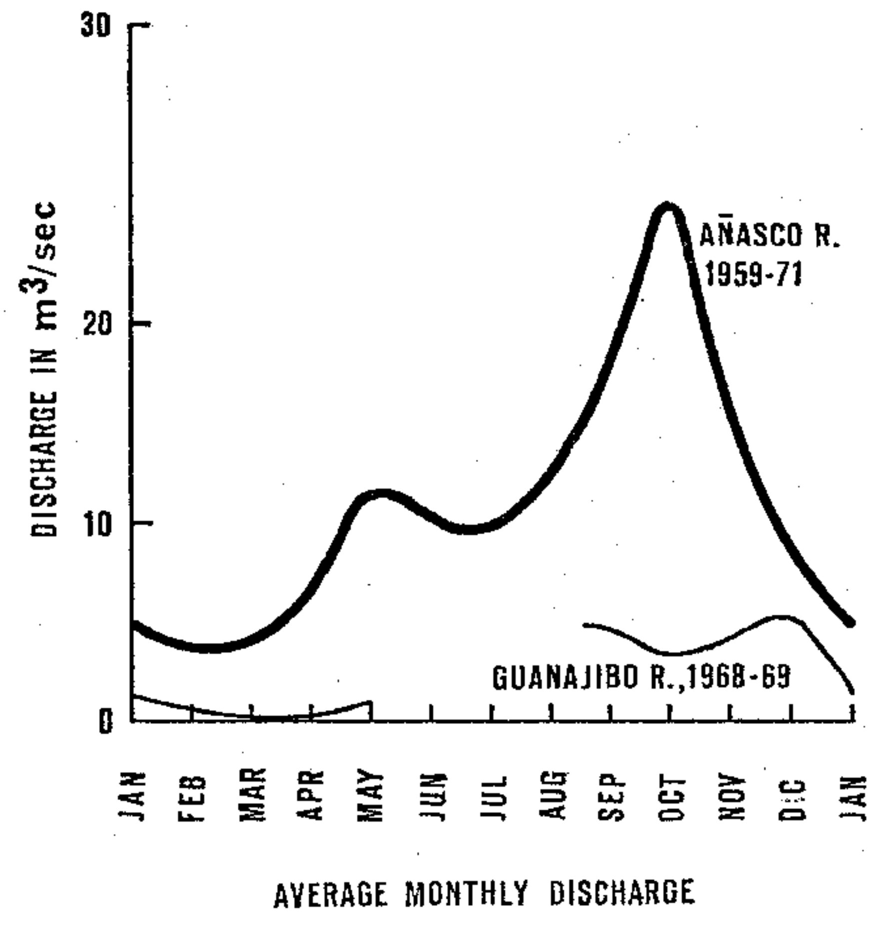


FIG. 1 RIO AÑASCO & RIO GUANAJIBO DISCHARGE

analyzed, includes bathymetry, river discharge, tides and salinity distribution. Because of the effect that these factors have on patterns of circulation and sediment transport, long term changes can be observed by studying the sediment distribution.

The Añasco river is relatively straight for about 3-1/2 km. up-stream (Fig. 2). Above this point, the river has a series of tight meanders. Just behind the bar at the river mouth, the channel is about 20 meters wide. This width gradually decreases to about 15 meters three kilometers upstream.

During the survey of the lower length of the Añasco River, considerable variation in bathymetry was measured (Fig. 3). Depths were generally greatest directly behind the river mouth bar where they ranged from two to three meters. Further upstream, near the highway 2 bridge, depths were from 1.3 to 1.6 meters throughout the year. The depths were considerably more variable at the furtherest station upstream due to cut and fill areas associated with the meandering course. Barlike bed forms were found below or near the head of the salt wedge during several of the sampling periods.

A well developed bar extends across the mouth of the river during periods of low river discharge and flow is restricted to a narrow, shallow channel .6 to 1 meter in depth curving to the south. In the west season, increased discharge widens and deepends the bar channel.

The lower length of the Añasco River is an estuary with salt wedge circulation. The salt wedge consists of a layer of heavier salt water flowing underneath the fresh water discharge. The distribution of salt water and temperature within the lower length of the Añasco River varies with response to river discharge and tidal forces (Fig. 4).

The maximum salt wedge intrusion of three kilometers correlates with the lowest discharge rates. The minimum observed intrusion which as characterized by complete exclusion of salt water from the river channel occurred

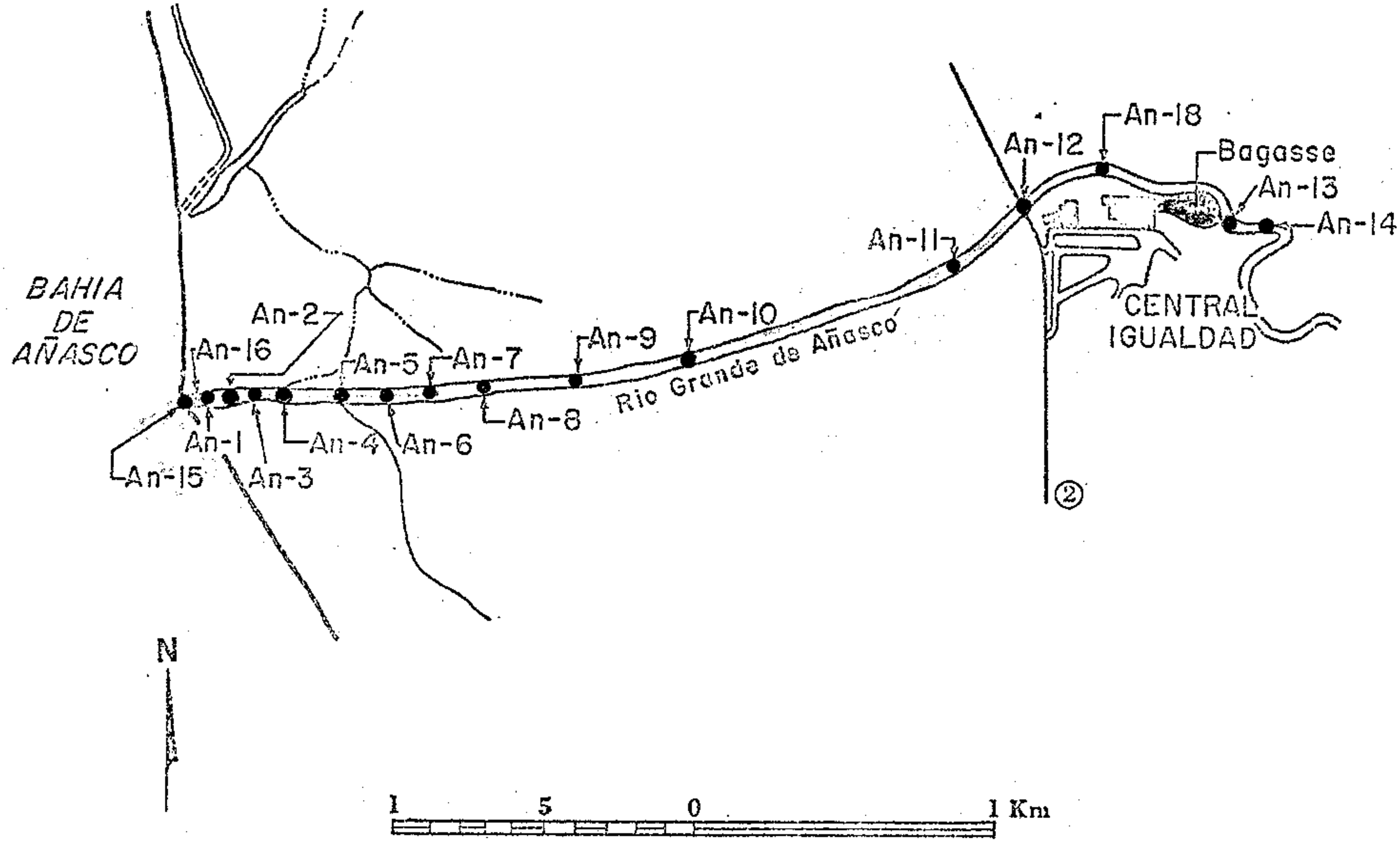
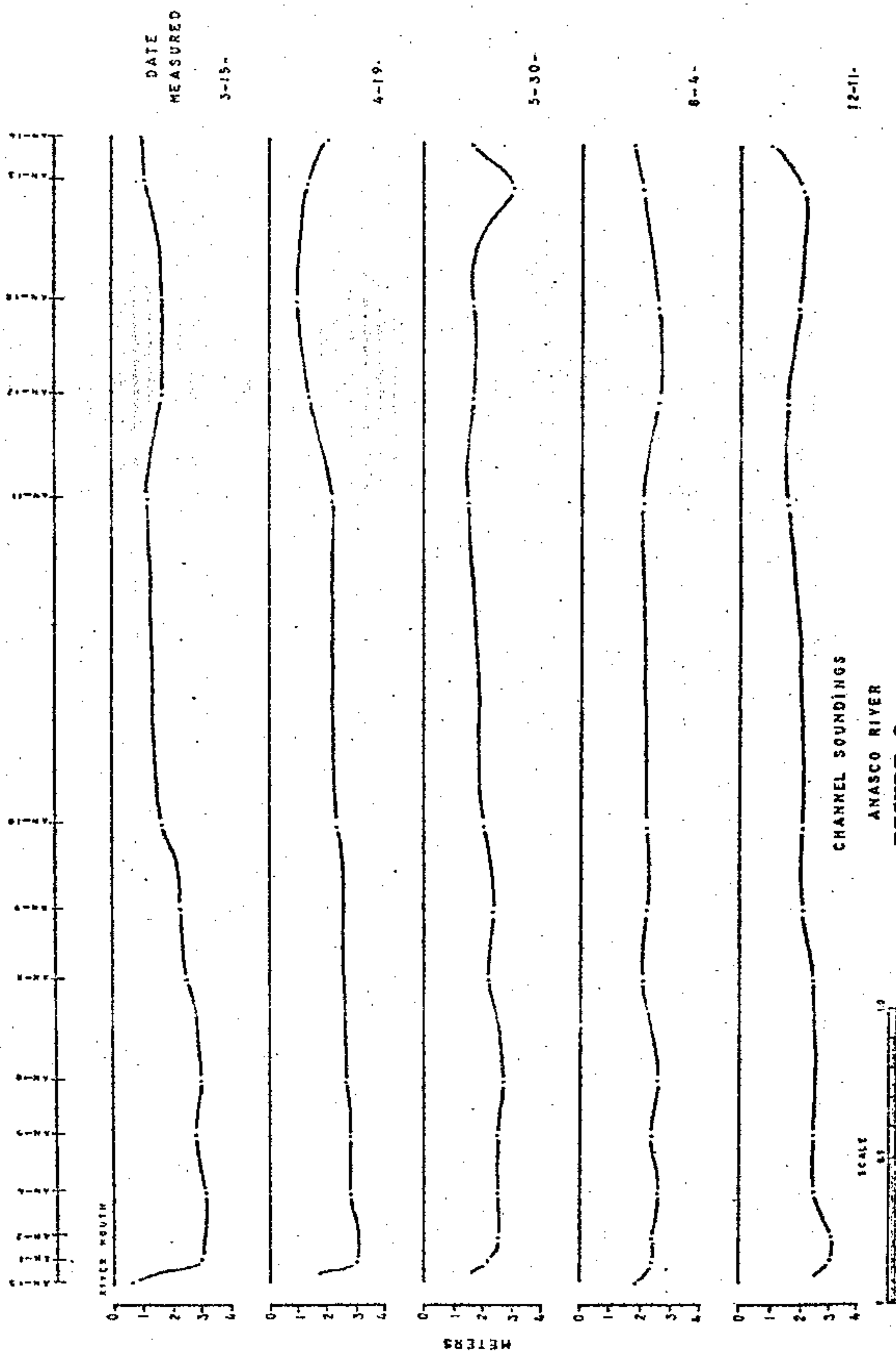


FIG. 2 SAMPLE LOCATIONS



CHANNEL SOUNDINGS
ANASCO RIVER
FIGURE 3

during the highest period of discharge. Because of the small tidal range in the Mayaguez-Añasco area, the river discharge appears to be the primary factor controlling salt water intrusion into the river.

The highest salinities in the core of the salt wedge range from 28 to 33 parts per thousand compared to the salinity of Añasco Bay which is about 35.5 parts per mil. Slighly reduced salinity values along the bottom of the salt wedge behind the river mouth apperar to indicate mixing of fresh salt water.

The minimum major discharge capable of pushing the salt wedge completely out of the river channel is 14 m^3 per second. Analysis of the Añasco River surface water records shows that daily mean discharge of 14 m^3 per second, or greater, occurs about 77 days out of the year, or 21 percent of the time. Discharge of this magnitude is generally restricted to the months of September, October and November so the salt wedge exclusion will be expected to occur more frequently during these months.

Concentrations of suspended sediment range from 8 to 334 m/1 (Table 1). The high values result from discharge by the sugar mill located on the Añasco River. Measurements upstream of the mill discharge showed concentrations of only 8 to 17 m/1 which is the river's normal suspended sediment load. At and downstream from the mill discharge, the concentration of suspended sediments in fresh water rose abruptly, ranging from 83 to 334 m/1. At the time of measurement, the salt wedge extended 3 kilometers upstream and the concentration of suspended sediment along the channel bottom in the salt wedge ranged from 9 to 59 m/1 which contrasted sharply with the high concentration of suspended sediment in the overlying fresh water. As seen from figure 5, no linear relationship exists between suspended concentrations and river discharge. The lack of a 1 to 1 correspondence is the results of variability in sediment source which depends on a number of

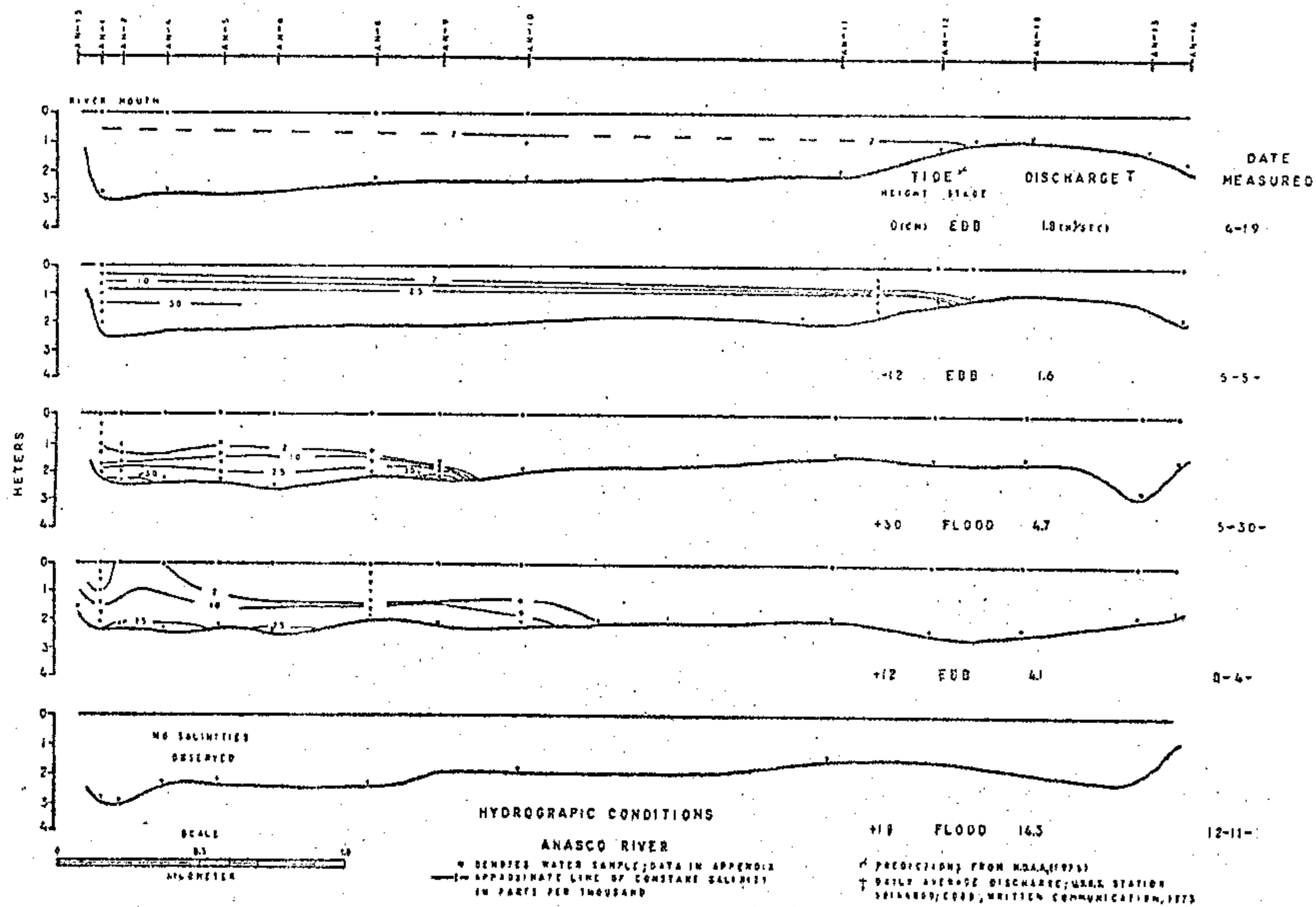

RIVER MOUTH
METERS
TIDE
HEIGHT STAGE
DISCHARGE
DATE MEASURED
0(cm) EBB 1.8(m³/sec) 4-19
+12 EBB 1.6 5-5
+30 FLOOD 4.7 5-30
+12 EBB 4.1 8-4
+18 FLOOD 14.3 12-11
NO SALINITIES OBSERVED
SCALE
KILOMETER
HYDROGRAPIC CONDITIONS
ANASCO RIVER
DENOTES WATER SAMPLE; DATA IN APPENDIX
APPROXIMATE LINE OF CONSTANT SALINITY IN PARTS PER THOUSAND

FIGURE 4

TABLE I

Suspended Sediment (mg/l)

Station	April 19,		May 30,		August 4,	
	Surf.	Bottom	Surf.	Bottom	Surf.	Bottom
AN-1			61	28*	68	96*
AN-2			54	23*		
AN-4	114	22*				
AN-5						
AN-6	100					
AN-8	104	38*	72	19*		
AN-9			46	19*		
AN-10	113	9*			45	62*
AN-11	159	59*				62
AN-12	117					
AN-18	83	334	60	51	67	35
AN-13	9	17				
AN-14		8	77	73	52	45

*Sample taken within salt wedge

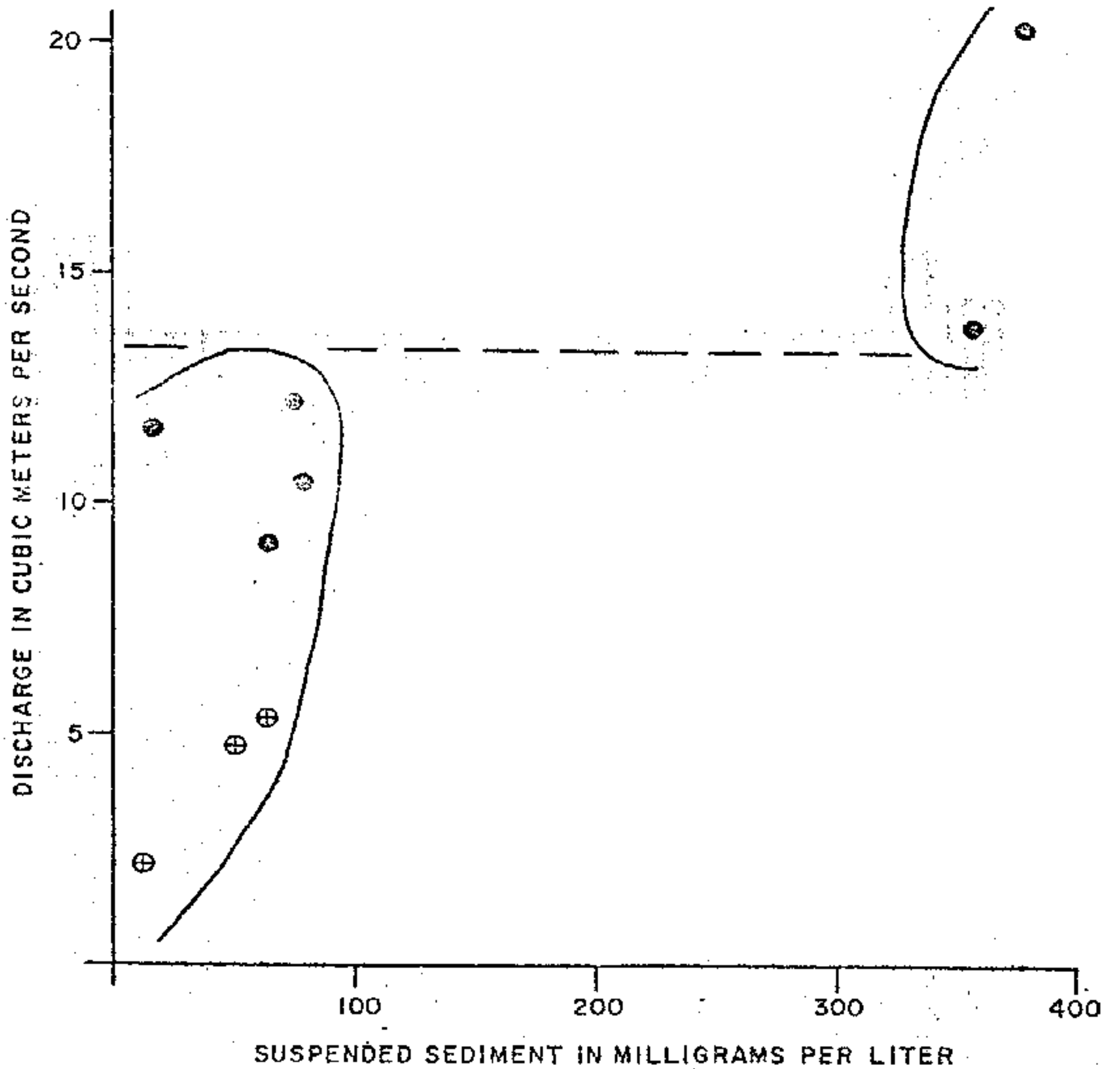


FIGURE 5

SUSPENDED SEDIMENT VS. DISCHARGE, ⊗ DENOTES DATA FROM KIPPLE AND OTHERS (1968) AND RICKHER AND OTHERS (1970), ⊕ DENOTES AUTHORS DATA factors including type of rocks in the drainage basin, climate, and influences of man. In the Añasco Valley, agricultural practices and discharge from the sugar mill are probably the most important man related influences.

The bottom sediments of the Añasco River channel were evaluated for textural variability, organic content and composition of the sand gravel size fraction. The constitutents of the organic component are varied, with vascular plant detritus as dominant (more than 90 percent). The plant detritus is mainly from flora growing along the banks of the river, which includes sugar cane, bamboo, river cane, and water hyacinths. The most abundant contributor of these is sugar.

Throughout the year, the organic carbon content in the sediments shows both temporal and spatial variation in response to changing flow conditions (Table 2). The relationship to flow regime is supported by the tendency for organic debris to be deposited with finer grain sizes which generally corresponds to low velocity conditions (Fig. 6).

The composition of the sand and gravel fraction varies little in time or space in the upper portion of the study area (Table 3). This fraction is dominated by lithic fragments of dark basaltic type rock materials which averages about 75 percent of the total. In the larger gravel sizes, lithic fragments are a mixture of clasts with porphyritic finely crystalline and/or fine grained textures. The porphyritic clasts are probably andesites, the fine crystalline grains are basalt or matrix of the andesites and the fine textured clasts are tufts and mudstones. No limestone fragments were observed in the samples.

A second major grain type in channel sediments are feldspars, which constitute an average of about 16 percent of the total. Typicayly the feldspar is altered and iron stained but generally retains the blocky

TABLE 2

ORGANIC DETRITUS
PERCENT WEIGHT BY WET COMBUSTION

AÑASCO RIVER AND ESTUARY SEDIMENTS

Station #	3/15/[illegible]	4/19/[illegible]	5/30/[illegible]	8/4/[illegible]	12/11/[illegible]
15	0.1	0.3	x	0.1	x
16	1.2	0.7	1.0	x	x
1	1.5	0.8	3.8	1.9	1.1
2	1.5	1.4	18.2	1.3	20.2
4	1.7	2.1	3.8	4.3	1.3
5	1.3	1.2	18.0	1.2	3.2
6	1.4	1.8	27.9	1.3	x
8	1.1	1.5	x	0.4	0.7
9	6.4	1.4	1.0	1.0	0.8
	---		---		
10	0.8	1.3	1.1	0.4	0.4

11	1.2	0.6	5.8	0.2	0.5
12	3.2	3.3	1.1	1.2	1.7

18	x	13.2	0.7	0.2	0.0
13	2.8	11.4	1.8	0.1	4.0
14	0.7	0.8	0.8	0.3	0.4

---denotes position of salt wedge.

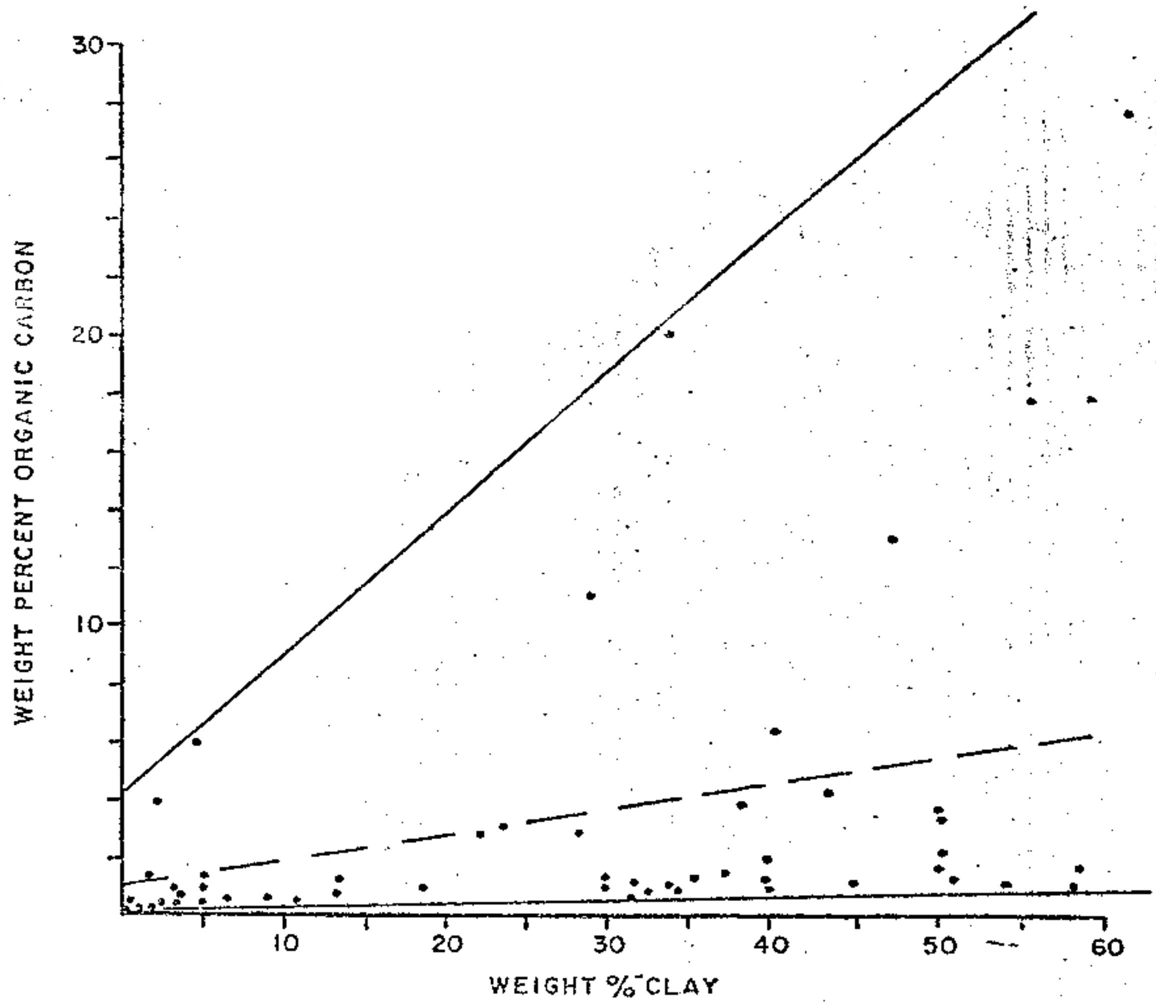


FIGURE 6

PERCENT ORGANIC CARBON VS. PERCENT CLAY FOR AÑASCO RIVER SEDIMENT

TABLE 3

COMPOSITION OF RIVER SAND FRACTIONS

Date	Station	Rock Fragments	Quartz	Feldspar	Magnetite Opaque	Other Mono-mineralics	Mica	Cinder from Sugar Mill	Skeletal	Quartz/Quartz Feldspar
4/19/	AN-1*	70	5	17	3	4	0.5	0	0.5	0.2
	AN-6*	75	3	18	0.5	2	1	0	0.5	0.1
	AN-9*	71	4	19	2.5	4	0	0.5	0	0.2
	AN-14	73	2	19	2	3	0.5	0	0.5	0.1
8/4/	AN-1*	78	2	15	2	3	1	0	0	0.1
	AN-4*	79	2	12	2	3	1	0.5	0.5	0.1
	AN-6*	80	0.5	13	1.5	3	2	0	0	0.0
	AN-9*	54	5	11	16	12	0	1	0	0.3
	AN-10	67	2	13	1	5.5	0.5	11	0	0.1
	AN-18	80	2	13	2	0	0	0	0	0.1
12/11/	AN-1	76	2	16	3	0.5	0.5	0	0.5	0.1
	AN-4	75	4	16	1	0	0	0	0	0.2
	AN-9	74	2	16	3	0.5	0.5	0	0	0.1
Mean°		74.8	2.8	15.6	2.0	3.5	0.6	1.0	0.2	
Standard Deviation		3.8	1.4	2.4	0.8	0.9	0.6	3.2	0.3	

*Denotes sample from salt wedge

°Mean and Standard Deviation do not include sample 8/4/ · Station AN-9.

morphology. Quartz is present in small amounts ranging from less than 1 to 5 percent. The grains are generally small and angular but several large one millimeter rounded grains were observed in samples which a high percentage of quartz material. Magnetite averaged about two percent of the total sand and gravel size material. The other monomineralic grains were predominately mafic materials and averaged about 4 percent.

Skeletal component of the coarse fraction is less than one percent and has a patchy distribution. Although the frequency of occurrence is small, the skeletal component is important for environmental interpretation. The more noticeable forms include a freshwater gastropod -- Goniobasis species which was found only in areas above the salt wedge and a species of arenaceous foraminifera, Ammobaculites salsus found living only along the lower kilometer of the river, associated with the brakish salt water wedge. Other skeletal grains were present in sand fractions about 1/2 kilometer upstream from the mouth. The grains consisted mainly of abraded segments of coralline algae. Coralline algae are a common component of the northern beaches of Añasco Bay and of the bar across the mouth of the river. Their presence upstream indicates occasional landward transport of the finer sand sizes by the salt wedge.

The clay size fraction was analyzed by x-ray diffraction, the dominant minerals are kaolinite, and montmorillionite with little apparent spatial variation in composition.

The grain size distribution of the river sediments reflects hydrodynamic conditions within the river, and consequently textural criteria can be used in interpreting the depositional environment and is a long term indicator of sediment transport patterns. Analysis of the sediments shows three dominant textural classes are present in the river (Fig. 7). Class 1, dominated by silt and clay sizes and commonly is greater than 70 percent

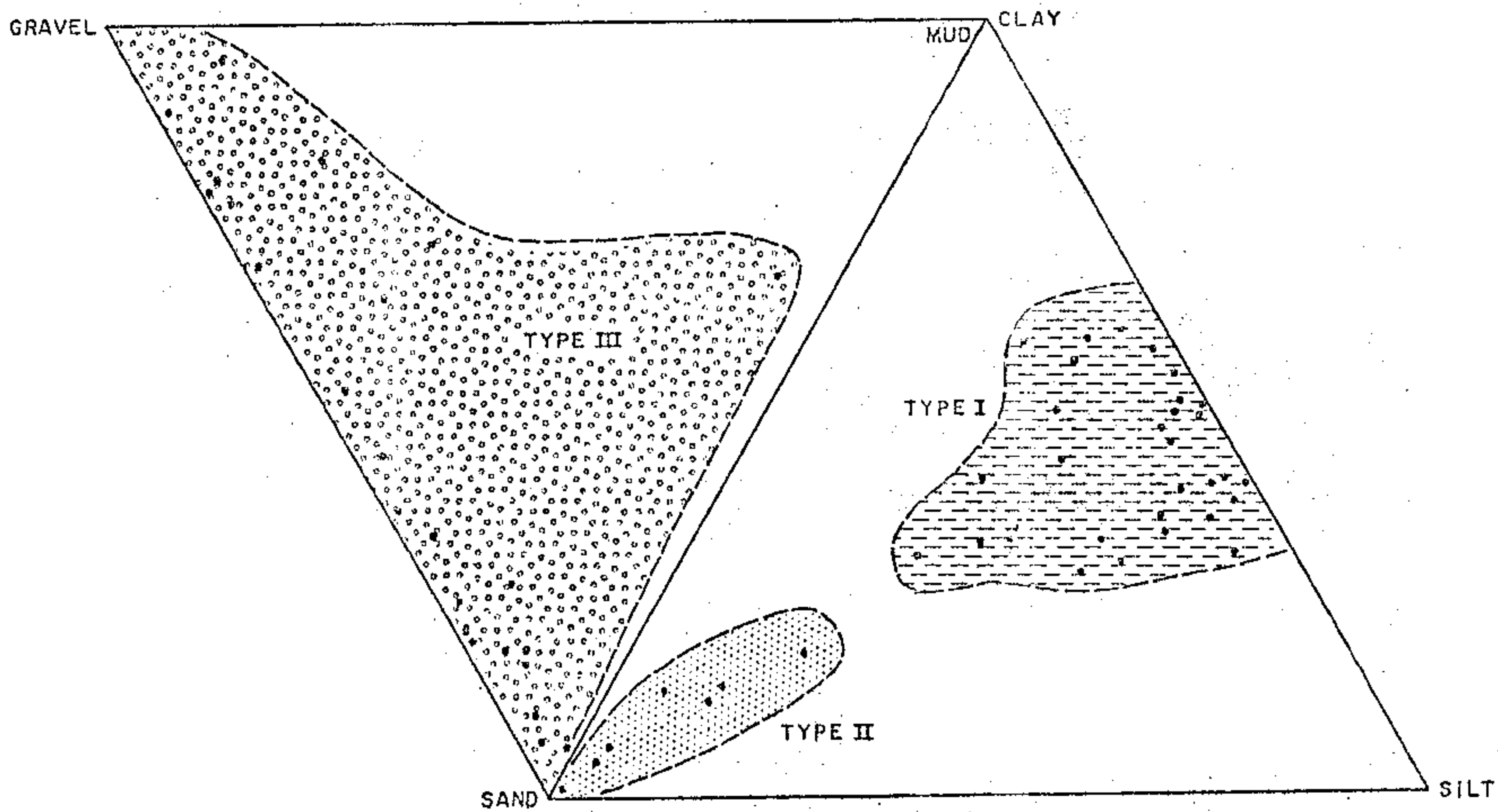


FIGURE 7

TERNARY DIAGRAMS OF TEXTURAL
TYPES FOR AÑASCO RIVER SEDIMENT

of the size. Class 2 is dominately sand but silt and clay may constitute as much as 30 percent of the sediment, no gravel is present. Class 3 is an admixture of sand and gravel.

Under low discharge conditions, the silt and clay dominated clast sediments extends from behind the sand (class 2) of the river mouth bar to about 1.5 km. upstream (Fig. 8). Above this point, the sediment texture alternates between sand and gravel mixtures (class 3) and the silt-clay dominated clasts. The presence of fine grained sediment reflects the low transport capacity during low flow regimes of the dry season while the coarse textures are relict from higher flow regimes.

Under conditions of moderate discharge, the fine grained class 1 sediments extend from behind the sands at the river mouth bar to about a kilometer and a half upstream. Unlike the textural distribution during low river discharge, the class 1 muds alternate with class 2 stands from about 1/2 to 1.5 km. upstream. The sands occur often as small topographic high under the salt wedge and may be bedload transport deposited ahead of the salt wedge during the semi-permanent stand. The process would be similar to that which deposits the gravels further upstream. Both the muds and sand appear to be associated with deposition under the salt wedge. Above 1.5 km. from the mouth, sand-gravel admixtures dominate the sediment. Mud content is typically less than 5 percent. The sediment is affected only by the velocities of fresh water discharge and is bedload and channel lag material.

Under higher flow conditions, the salt wedge is not present and only fresh water velocities affect the sediments. Class 1 muds then extend about 1/2 km. upstream. Above this, sand and gravel textures dominate the channel deposits. Fisher (1969) has suggested that log probability curve shape maybe related to the mode of sediment transport and describe shapes

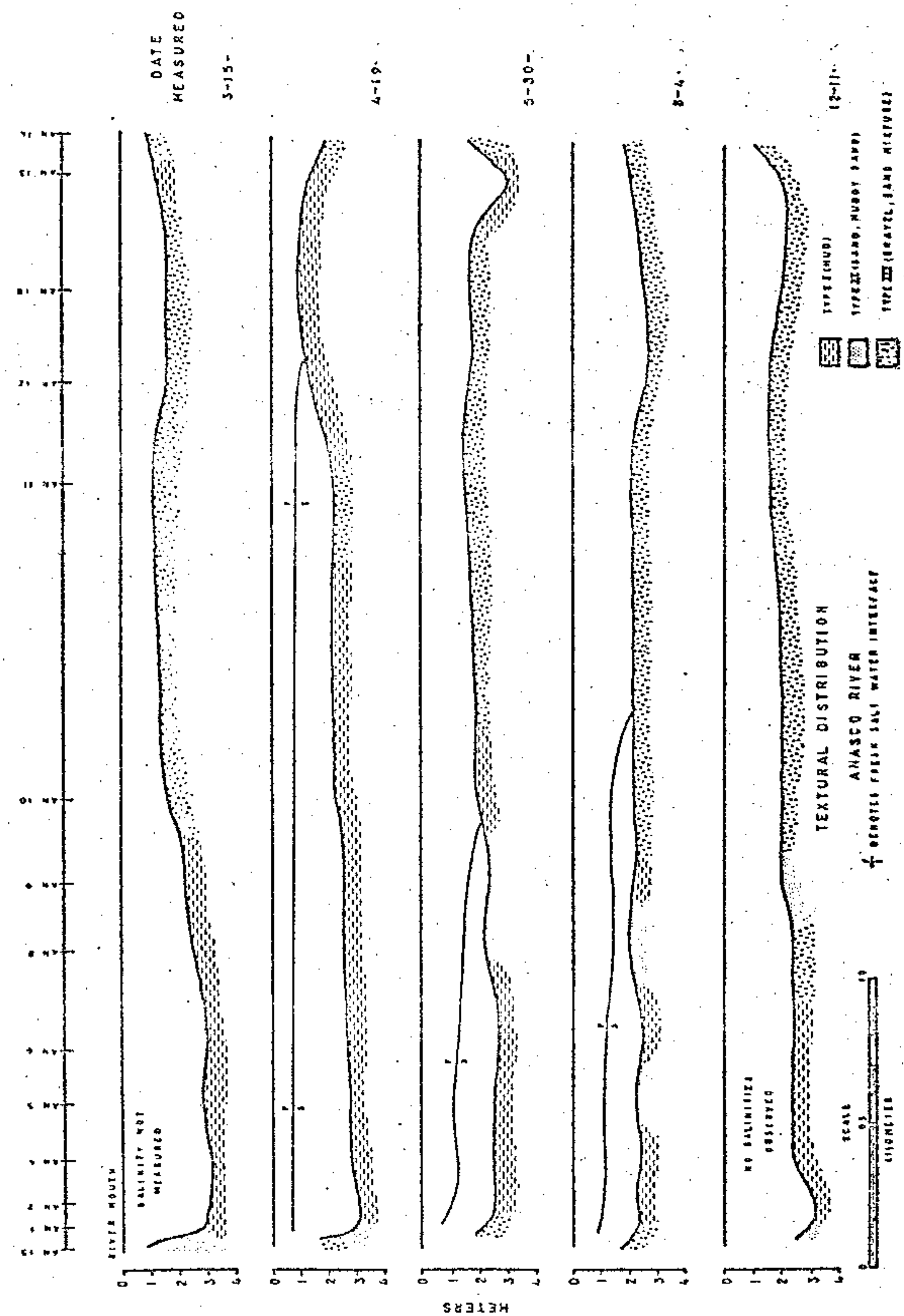

DATE
MEASURED
3-15-
4-19-
5-30-
8-4-
12-11-
RIVER MOUTH
SALINITY NOT
MEASURED
NO SALINITIES
OBSERVED
METERS
TEXTURAL DISTRIBUTION
ANASCO RIVER
DENOTES FRESH SALT WATER INTERFACE
SCALE
KILOMETER

FIGURE 8

associates with seven modes of transports and environments which include: 1) current, 2) wash and backwash, 3) wave, 4) tidal channel, 5) fallout from suspension, 6) turbidity current, and 7) aeolian dune. In order to compliment the textural delineated by the triangle diagrams, comparison of log probability curve shapes have been made (Fig. 9). There were divided into five groups, and appear to have specific relation with depositional environment. The course of sediment in the channel deposits of the Añasco River were found in areas affected by freshwater velocities. The log probability plots are complex but appear to be recognizable as a distinct group. The curves are generally characterized by two sharp inflection points. In all cases, the size corresponds with class 3 sand-gravel admixtures in the triangle diagrams.

Another coarse sediment group have shapes similar to the above sand-gravel mixtures, but have a sharp fine tail occurring at a lower accumulative percentage indicating the relatively greater importance of fine sand, silt and clay components. These represent samples taken during low river discharge and contain coarse channel sediment relict from previous high discharge which is being overlain by fine grained sediments. On the traingle diagram, these samples are within the class 3 group, but have mud percentages greater than 10 percent.

The sands of the river mouth bar are characterized by a steep central section covering 90 percent of the grain size distribution. These bar sands plotted in both class 2 and class 3 textures on the triangle diagrams, but stand out as a distinctly separate environment on the log normal plotting.

The fourth group of sediments are from the sand rich zones overlain by the salt wedge. The curves have a steep initial segment representing the coarser components with a sharp inflection point that separates the coarse and fine size. The processes forming this group are not known, but they

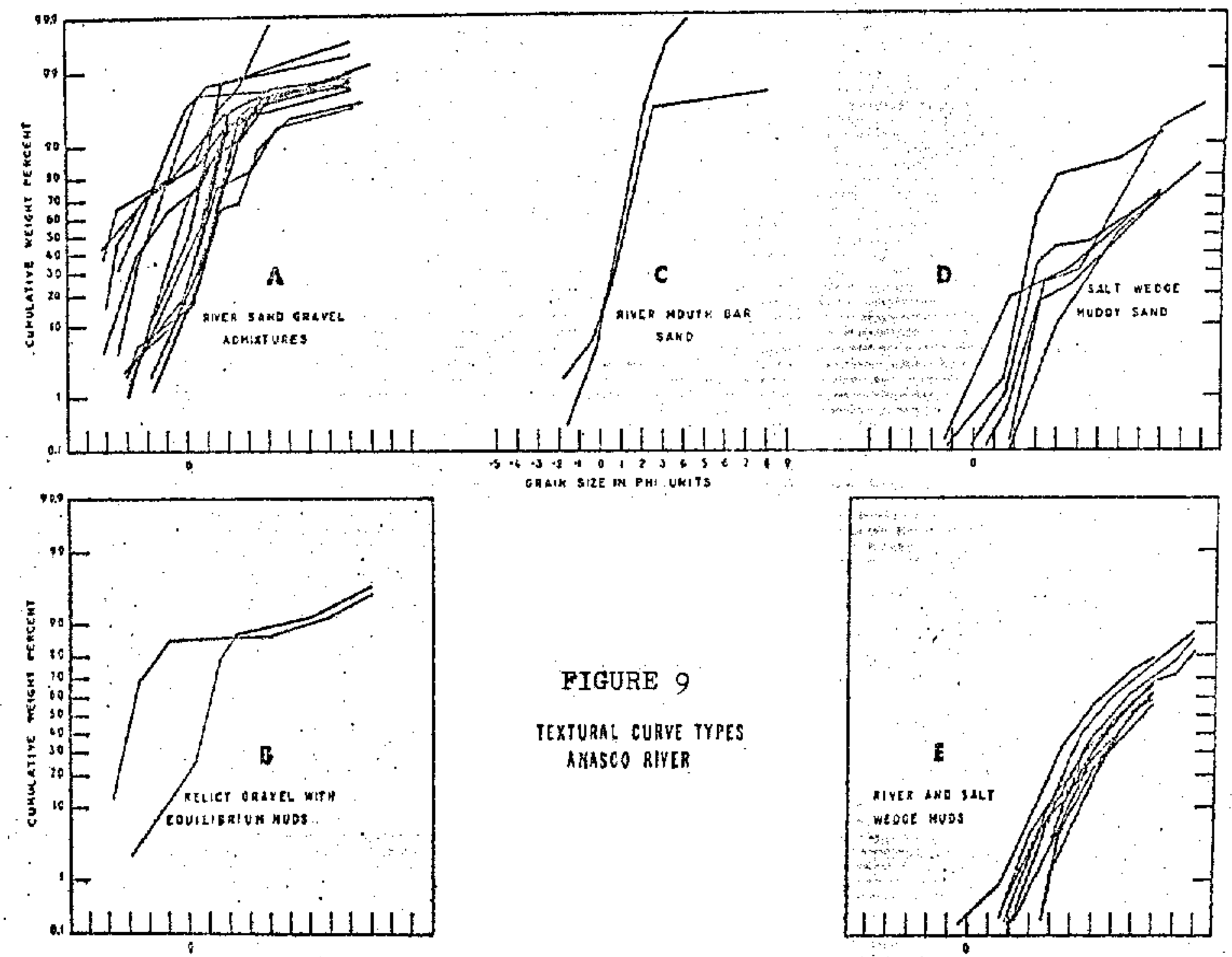


FIGURE 9

TEXTURAL CURVE TYPES
ANASCO RIVER

may represent tidal and hydrastatic influences of sea level. The samples showing this shape did not occur beyond 1.5 km. upstream, which corresponds with the maximum observed salt wedge intrusion during moderate flows. The groups appears to represent a transition between salt wedge muds and coarse river sand and gravel mixtures. The last group of log probability curves are for the finest channel deposits. The samples fall within the mud zone of the triangle diagrams and generally have less than 10 percent sand size material. In relation to environment, the group represents sediments found in areas commonly occupied by the salt wedge, but they may also be deposited in low velocity conditions anywhere along the channel length during low discharge of the dry season.

The geology of Añasco Bay will be published as a paper in the Journal of Sedimentary Petrology. A copy is included in the appendix of this report. Part of the data in this part of the report was collected by Kurt Grove, while supported by W.R.R.I. grant funds.

GUANICA BAY

Guánica Bay is an estuary on the southwest coast of Puerto Rico comprising an area of 2.5 km. square. The bay is bordered by hills on all but the northeast. The inlet portion opens to the Caribbean Sea on the south and narrows irregularly from a maximum width of 1.5 km. near Playa de Guánica to .4 km. near the mouth.

About 27 percent of the inlet is covered by shallow waters less than 2 meters deep and 32 percent is covered by water deeper than 6 meters (Fig. 10). The water deepens slowly from the shoreline, except along the north extremity where the Loco River deltaic deposits extend 200-300 meters into the bay.

Guánica is in the dry, southern coastal lowland region, the most arid part of Puerto Rico. The average rainfall is less than 106 cm per year. Monthly rainfall ranges from 18 mm in January to 145 mm in September (Fig. 11). December through April are the driest months. The lowest rainfall recorded during the 1900s was 29 cm and the highest 135 cm.

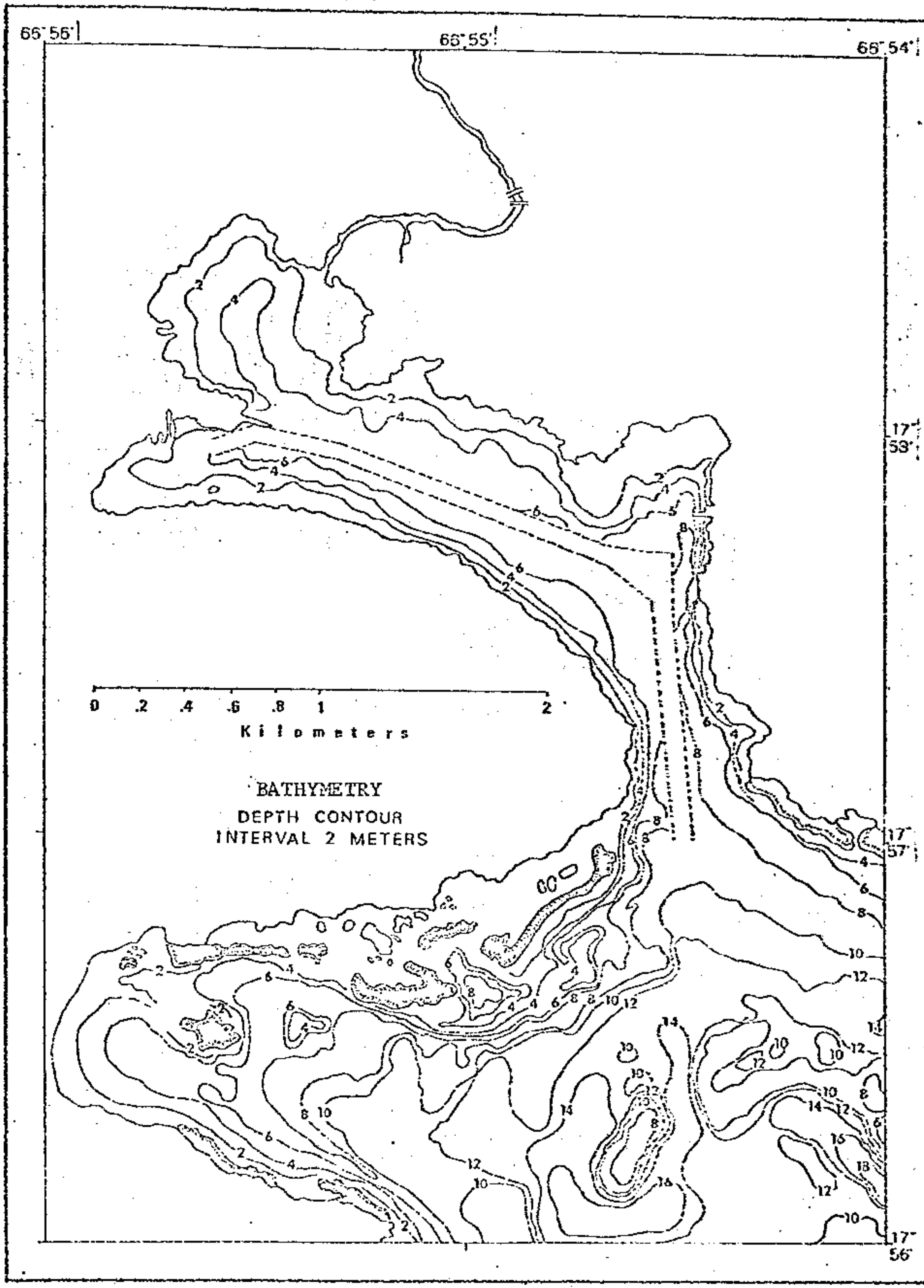
Regional tides have a range of 30 to 34 cm in Puerto Rico. At La Parguera, about 8 miles west of Guánica, tide ranges for 20 to 30 cm are measured. The tides are basically diurnal, but during part of the lunar month, a distinct semi-diurnal perturbation is superimposed on the diurnal phase.

There is a general westward current along the south coast of Puerto Rico caused by the prevailing easterly trade winds. The average velocity of these currents is 10 cm per second. These are expected to continuously exert a suctioning effect on the waters of the bay through its narrow mouth.

The predominant currents in Guánica Bay are from the open sea into the bay during the daytime and from the bay out to the open sea at night following the wind pattern in the area. The water circulation pattern in the bay is a function of surface wind stress combined with tidal action (Fig. 12). Surface current velocities inside the bay depend upon wind direction. The average surface current is 4 cm per second. At depths of 4 m, current velocities range from 1 to 10 m/sec. Outside the bay, surface current velocities are 1 to 30 cm/sec.. In deeper waters, the circulation is a function of tidal forces and water reflection from the coast.

Waves in the bay are highest when the wind is from one of the southern quadrants at which time, the water of the bay is mixed with suspended matter. Northerly winds produce relatively calm water throughout the bay. The wave approach the bay from the open waters of the Caribbean. On coming in contact with the bottom, the waves are refracted so as to expend their energy on each side of the entrance, or penetrate into the bay, where the gentler

FIGURE IO-BATHYMETRY OF BAHUA DE GUANICA



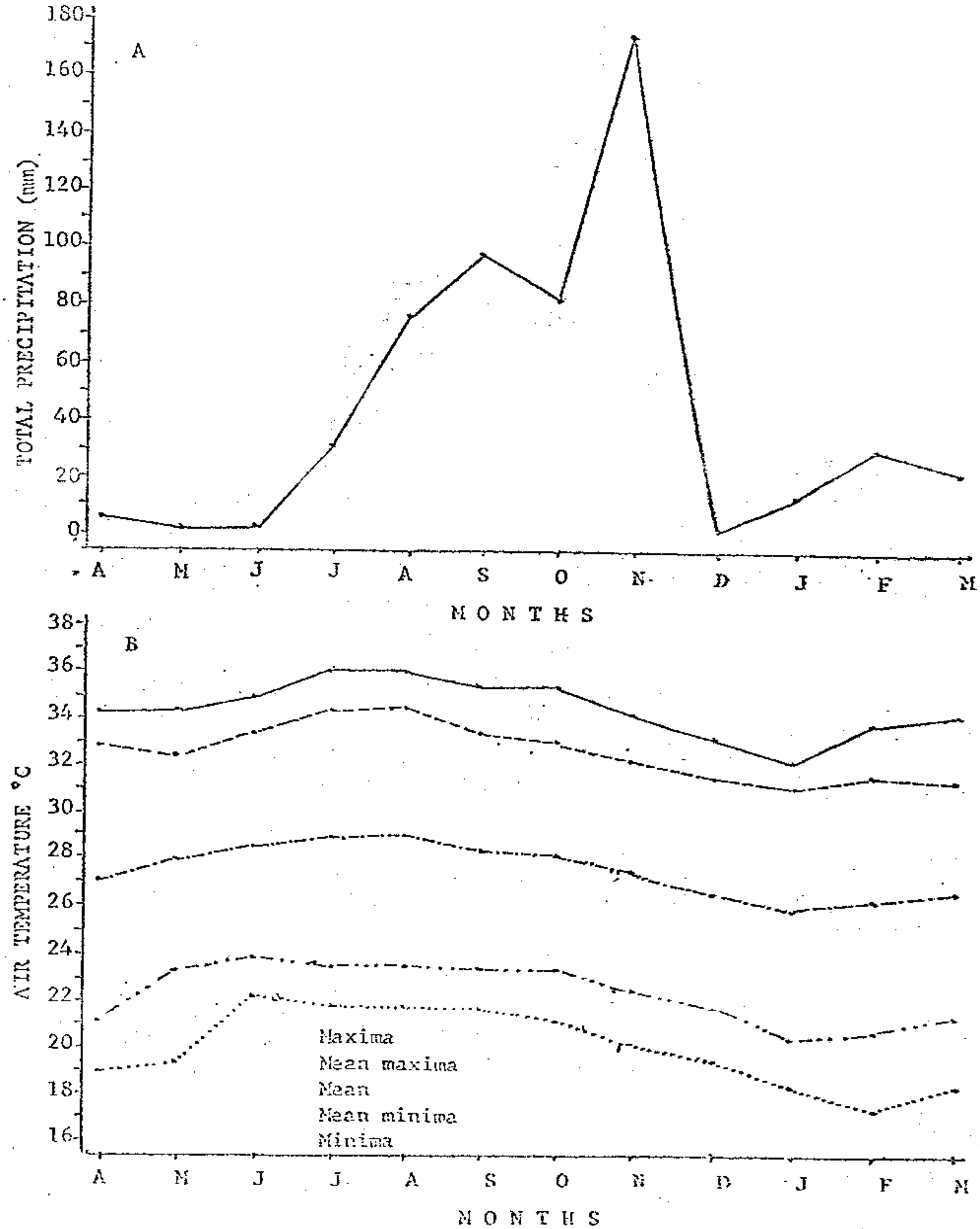
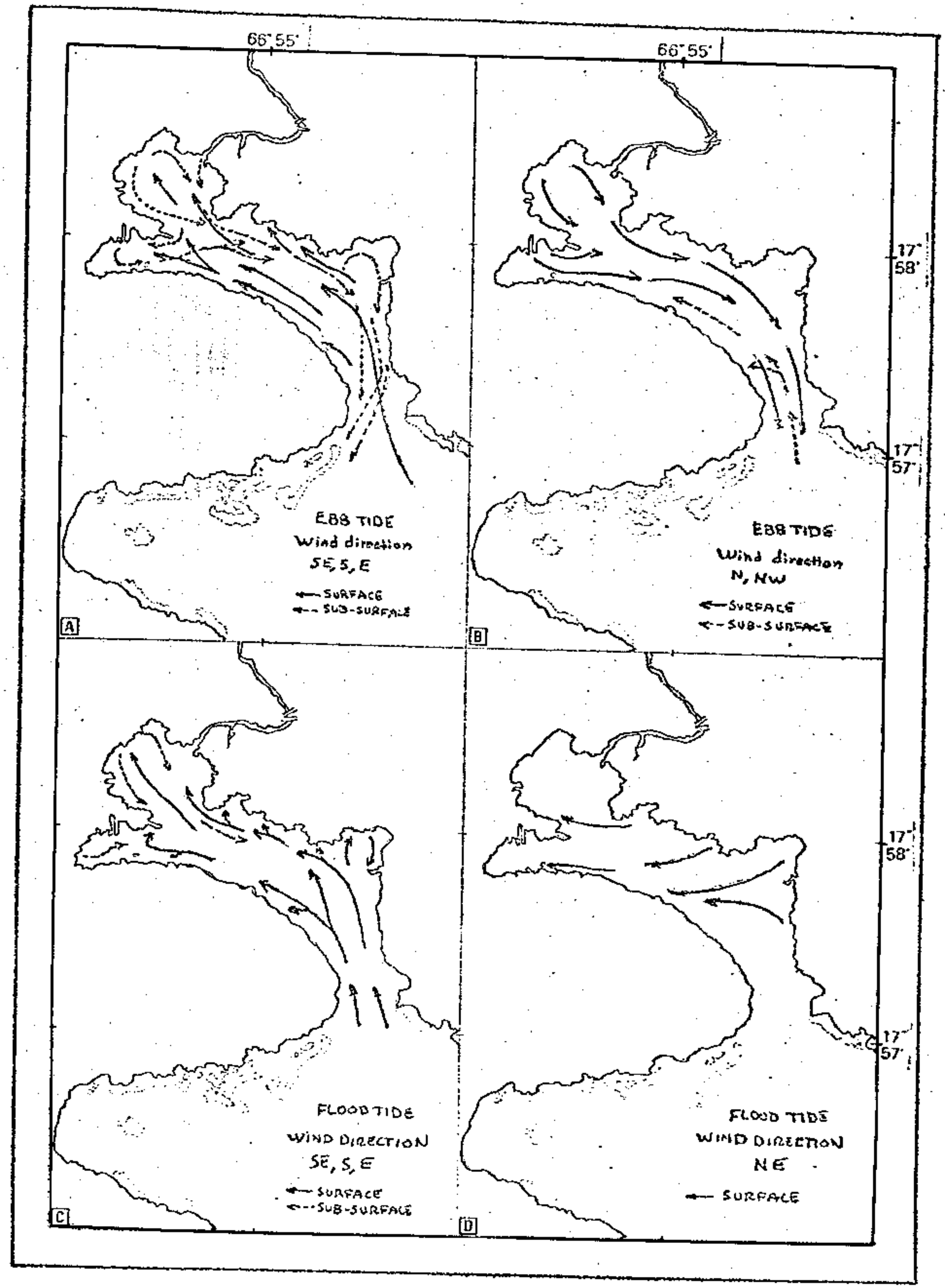


Figure II. Monthly rainfall (A) and air temperatures (B) from April, 1977 to March, 1978 as recorded at Ensenada Climatological Station, Guánica.

FIGURE I2- CIRCULATION PATTERNS IN BAHIA DE GUANICA



slope of the shore absorbs nearly all of the waves energies.

Sediment samples (Fig. 13) have been analyzed for texture (Table 4, composition, percent acid insoluble, and percent organic material. Water samples were analyzed for amount of suspended sediment (Table 5). And measures of light transmission were made.

Texture of the sediments was mapped in terms of percentage of sand, size grains and fine or mud size material smaller than 63 μ in diameter (silts and clays). On the basis of size, there are three sediment facies. Sand, muddy sand and muds. Most of the bay is floored with muddy sediments. (Fig. 14). A mixture of silt and clay. The sand in these sediments are mainly carbonate shell material. Increases in grain size to muddy sands and sands are due to an increase in the amount of carbonate shell material.

The shallow area at the shore and just off the shore south of the town, is sand to muddy sand in texture. At the mouth of the bay, there is a transition to carbonate sediments and a change from muds and muddy sands to sands. The shelf sediments outside the bay are all sands with a very low terrigenous sediment content.

The percent carbonate map shows the relative distribution of calcium carbonate shell material and terrigenous, land-derived sediment (Fig. 15). The values were obtained from treating the sediment sample with hydrochloric acid to total digestion. The distribution at the outer part of the bay and the bay entrance is a fairly regular transition from the terrigenous sediments that dominate most of the bay to the carbonate sediments that are characteristics of the shelf area. There are local concentration of shell material in the western part of the bay that reflect concentrations of molluscs that are tolerant of polluted environments.

The composition analysis showed that the terrigenous sands were mainly quartz and feldspar with some dark mafic minerals . The local

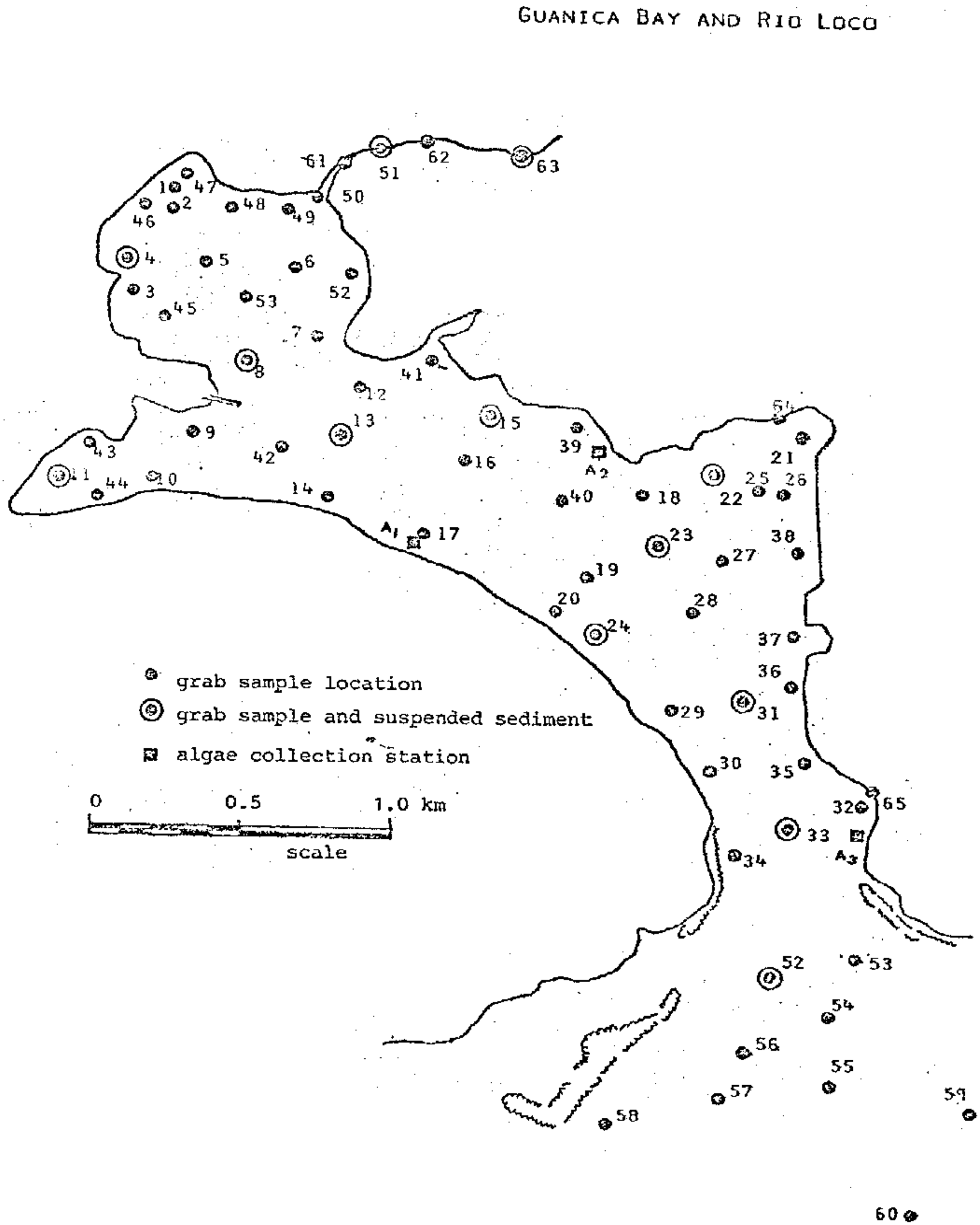

GUANICA BAY AND RIO LOCO
grab sample location
grab sample and suspended sediment
algae collection station
0
0.5
1.0 km
scale
A1
A2
A3

Figure 13.

TABLE 4. SEDIMENT CHARACTERISTICS IN GUANICA BAY

Sample	Mean Size Ø	Sorting	Sand / Silt & Clay	% $CaCo_3$
2	5.5	1.4	0.17	13
3	5.7	1.5	0.05	69
4	4.8	1.4	.11	70
5	5.4	1.6	.21	18
6	5.6	1.6	0.09	15
7	5.5	1.5	.09	26
8	7.7	1.5	0.19	11
9	5.5	1.8	.15	88
10	5.6	1.6	.19	52
11	5.5	1.6	.21	88
13	5.8	1.6	.16	12
17	7.6	1.4	0.19	74
18	1.6	3.8	3.5	31
19	5.2	1.6	0.25	40
21	4.5	3.9	1.0	35
22	4.1	2.0	1.0	5
23	5.3	1.4	0.21	24
24	4.8	1.3	.33	10
26	4.8	1.1	.32	18
27	5.1	1.4	.23	11
28	3.7	1.0	0.35	4

Sample	Mean Size Ø	Sorting	Sand/ Silt & Clay	% $CaCo_3$
29	5.6	1.4	.19	8
30	5.3	1.4	.19	15

TABLE 5. SUSPENDED SEDIMENT CONCENTRATION IN GUANICA BAY, IN MG/L

Station	Surface	Bottom	Surface Salinity
2	1.3	2.6	32.5
3	1.4	3.9	28.5
5	1.3	1.4	32.0
6	5.2	16.3	36.0
7	0.6	1.6	36.5
8	0.03	2.4	
11	4.4	21.1	32.5
15	2.2	1.4	36.0
17	1.7	2.3	34.0
21	2.5	2.8	36.5
23	1.7	2.9	36.9
31	2.9	2.6	36.0
50	0.4	7.6	18.5

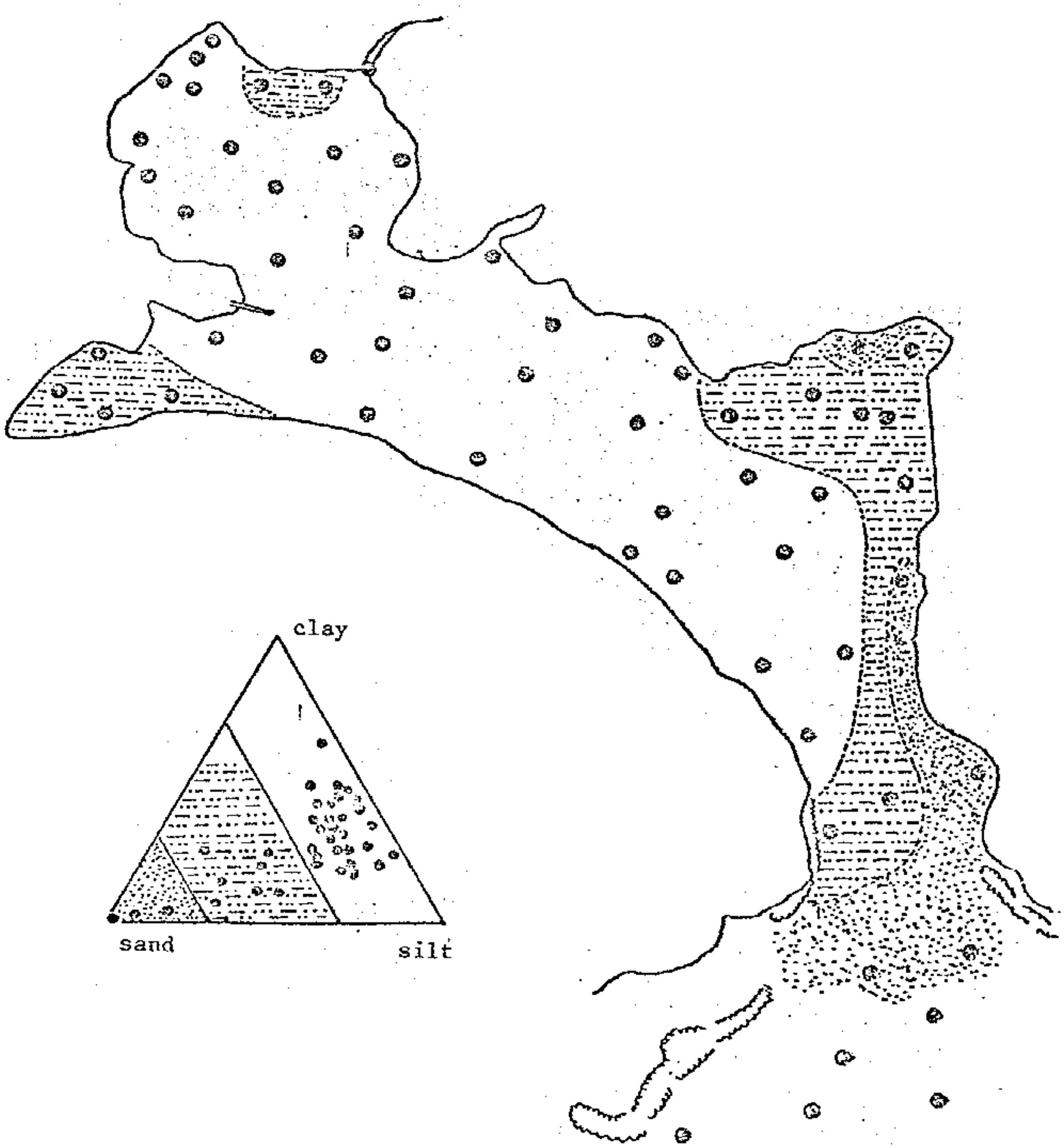


Figure I4. Sediment texture facies.

PERCENT CALCIUM CARBONATE

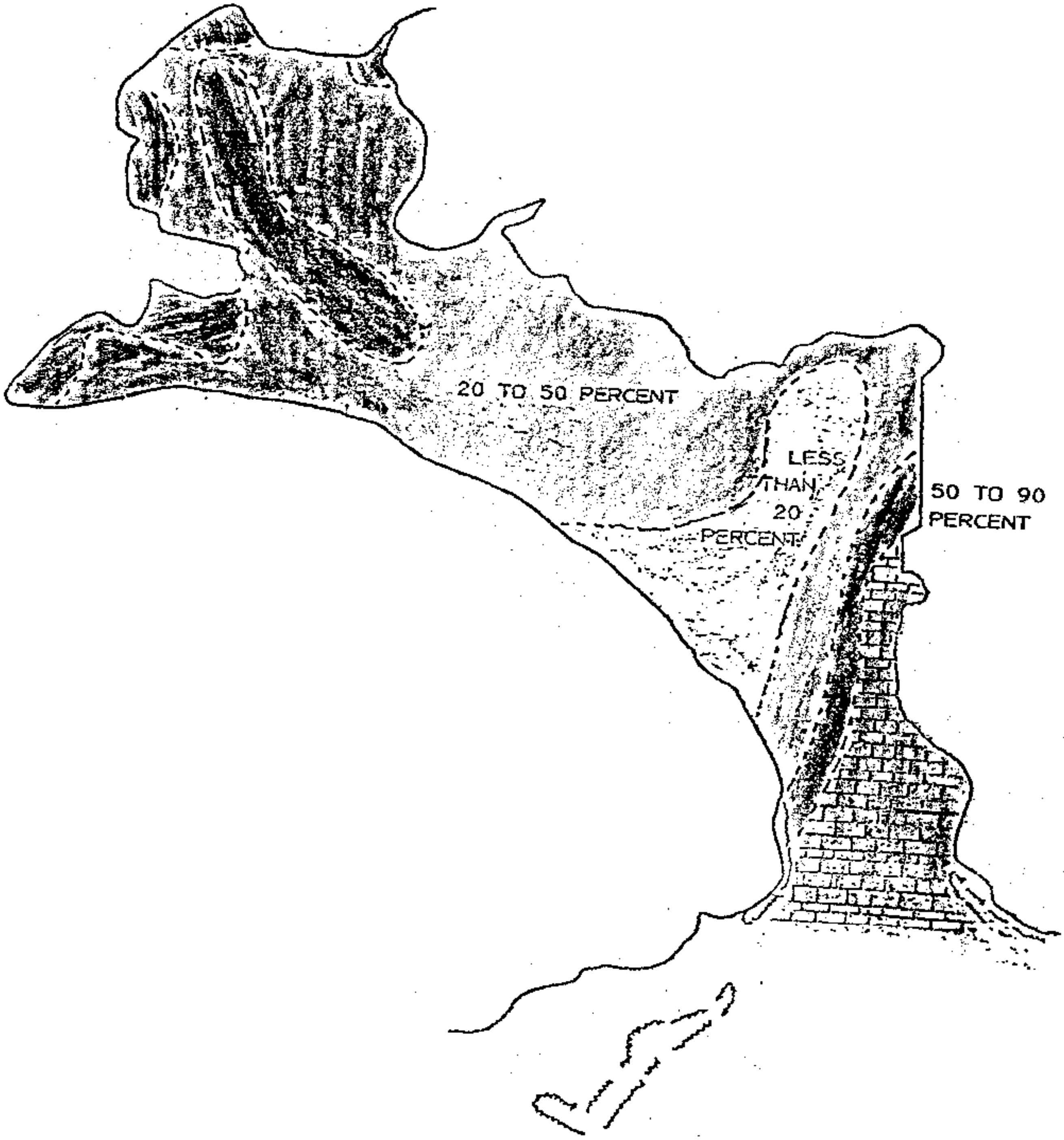


Figure 15

LA PLATA AND NORTH COAST RIVERS

The La Plata River is located on the north coast of Puerto Rico between the towns of Dorado and Mameyal to the west and Sabana Seca to the east. The river mouth is bordered by Punta Boca Juana an eolianite limestone formation west of the mouth and a sand bar spit which extends from a beach plain to the east.

Salinities, suspended sediments, profiles, and sediments samples were collected from stations within the La Plata River (Fig.16). The stations extended approximately 3 km. upstream from the mouth.

The highest values of suspended sediment material from the bottom samples was near the river mouth (Table 6). Relatively high bottom suspension also occurred midway up the river sampling. Bottom concentrations ranged between 7 and 115 mg/l. Surface and intermediate suspended material was lower throughout the sampling area. Surface suspended values were from 12.5 to 30 mg/l.

The La Plata is a two layer estuary where tidal currents are relatively weak as compared with fresh water flow (Fig.17). The nature of the estuary fluctuates in accordance primarily with the river flow but there is some tidal effect. Under certain physical conditions, it may undergo a turbulent defusion or entrainment. The flow at the mouth of the river which moves upriver is basically a process of salt water entrainment. There is a shallow cell at the mouth of the river which aids in maintaining the salt water wedge within the river system.

In general, higher amounts of suspended material were found between sampling points 1 and 4. The topography of this area indicates a depth of 3.5 meters which is somewhat stagnant and not a part of the normal salt wedge.

TABLE 6 SUSPENDED SEDIMENT CONCENTRATIONS (mg/l) in LA PLATA RIVER

Station	Surface	Intermediate	Bottom
1	1.5	14.2	8.8
2	18.9	29.6	29.6
3	12.5	–	12.7
4	5.1	12.6	82.9
5	4.4	18.9	38.5
6	–	–	36.0
7	1.9	–	26.9
8	5.8	–	36.6
9	7.7	–	114.8
10	–	–	7.0

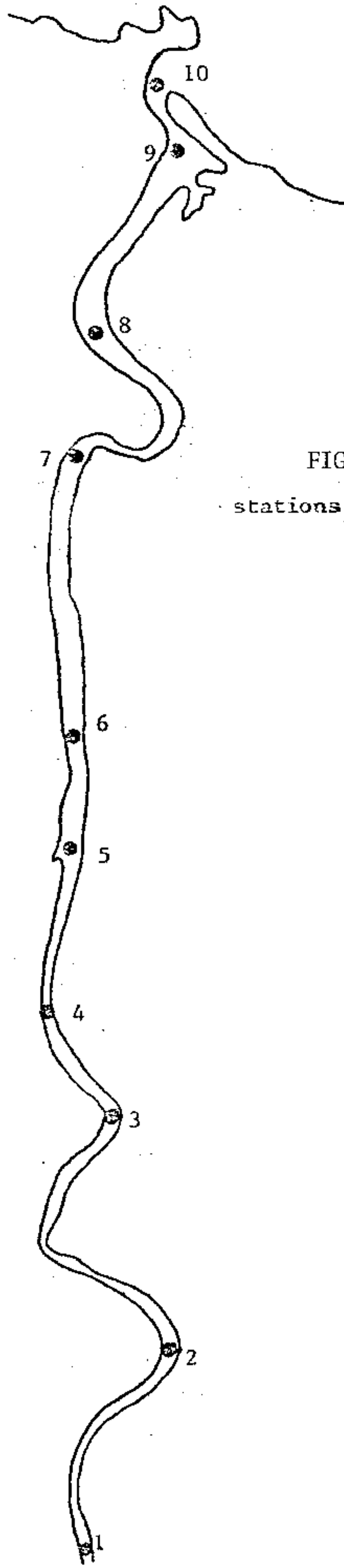


FIGURE 16

stations for grab samples
batnymetric profiles
suspended sediment

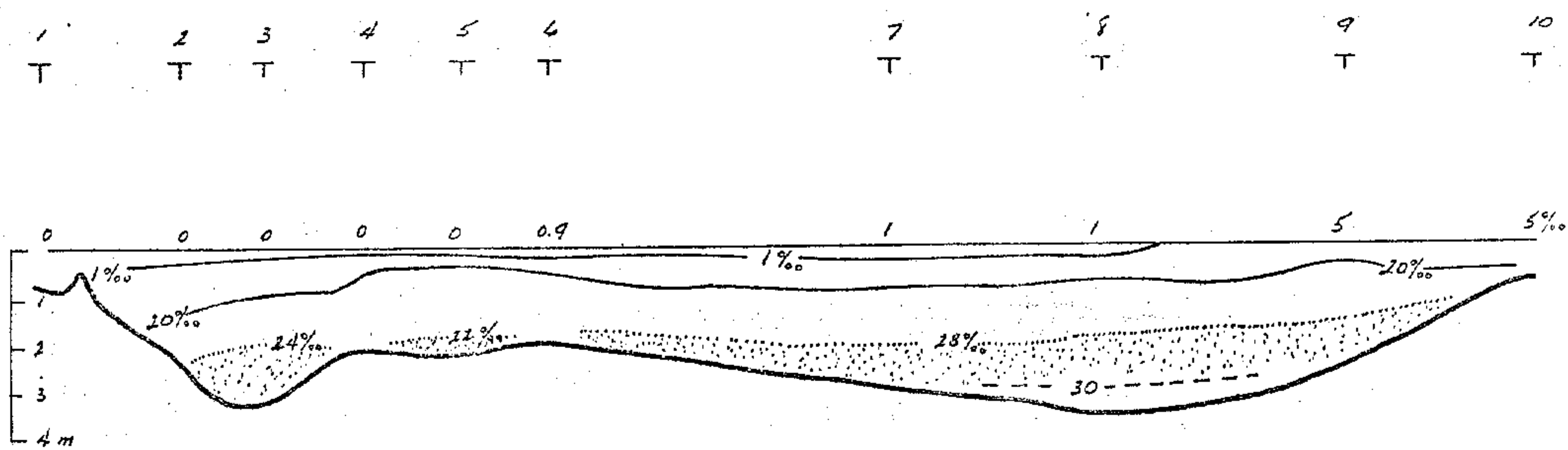


FIGURE 17- SALT WEDGE INTRUSION IN RIO LA PLATA DURING SEDIMENT SAMPLING INCURSIONS

The most abundant particles in the suspended sediment were fiberous plant material probably associated with the large amounts of water hyacinth found growing along the banks of the river and floating in the river.

The average salinity in the salt wedge was from 26 to 30 ppm.

The morphology of the mouth of the La Plata River varies with seasonal coastal conditions, and the bar at the mouth of the river changes. This has a definite influence on circulation within the estuary. Seasonal rains tend to change the morphology and discharge in a similar manner to that described for Añasco. The general shape is shown in Figure 18.

In general, there is a definite salt wedge which fluctuates as for as three km. upstream. There is an upper layer in which net current is directed toward the ocean and a deeper layer which is either stagnant or moving upstream toward the fresh water.

A continuous competition for dominance between river flow and ocean forces at the river outlet is seen in the north coast estuaries. Wherever a sand bar is built laterally across the river inlet reaching an elevation of deposition above sea level, it is certain that ocean forces are dominant. The sediment distribution characteristics, evidences from aerial photographs over a number of years and river flow measurements indicate that these spit bar formations across the river mouths are the product of nearshore processes in the area. The intensity of littoral sediment transport overpowers the weak river flow velocities normally encountered and river forces are dominant only during flood conditions.

Analyses and description of the La Plata River are limited to a single field period. The river stations could not be monitored for second and third surveys because the river has been completely covered with aquatic vegetation throughout the proposed sampling period. Therefore, some measurements were made in the Loiza and other river systems along the north coast

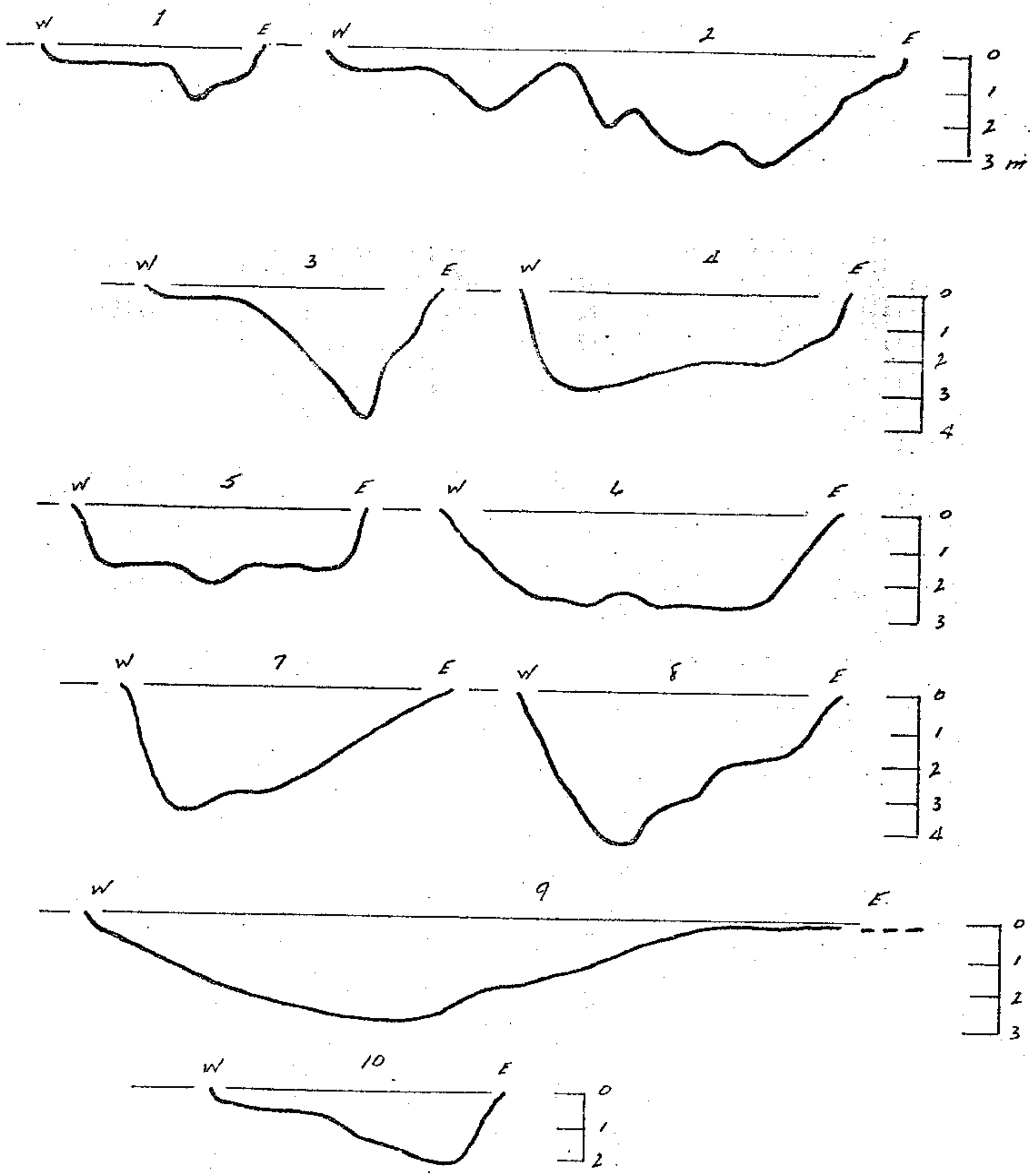


FIGURE 18- BATHYMETRIC PROFILES OF RIO LA PLATA

and are included in this study.

The river sediment samples from the La Plata indicate that most of the river sediment load is being deposited in the river. Suspended sediment samples show nothing coarser than silt being carried over the sill of the spit bar under normal discharge conditions. Offshore samples taken after severe flooding show that river sediments had been carried offshore on mass. Subsequent sample collections showed that masses of sediment on the narrow shelf were being slowly dispersed by offshore waves and current energies (Fig. 19 shows absence of muds in near shore area.) The river carries a relatively high quantity of quartz and igneous rock fragments. The spit bar samples show the presence of this material.

The main processes under interacting and determining the development and endurance of the spit bars across the mouths of rivers are river flow velocity variations, sediment load discharge, and the intensities in opposing force from the ocean. There are three major types of sand bar formation at river inlets. Of these, the dominant type of the north coast of Puerto Rico is the spit bar development across the river mouth. This type development is generally found where discharge from the estuary is negligible and long shore transport deposition across the inlet gaps dominates. The obstruction of the inlet completely, or in part, affects water quality inside the estuary.

In general terms, the development of spit bars across river inlets influence the estuarine processes in several ways. The most important of these is the reduction of stratified flow velocities, or salt wedge circulation an intrusion length of water. There ia also a marked increase in the rate of sediment deposition inside the estuary and the development of periods of stagnant salt wedge, which results in decreased tidal flushing of both sediments and pollutants.

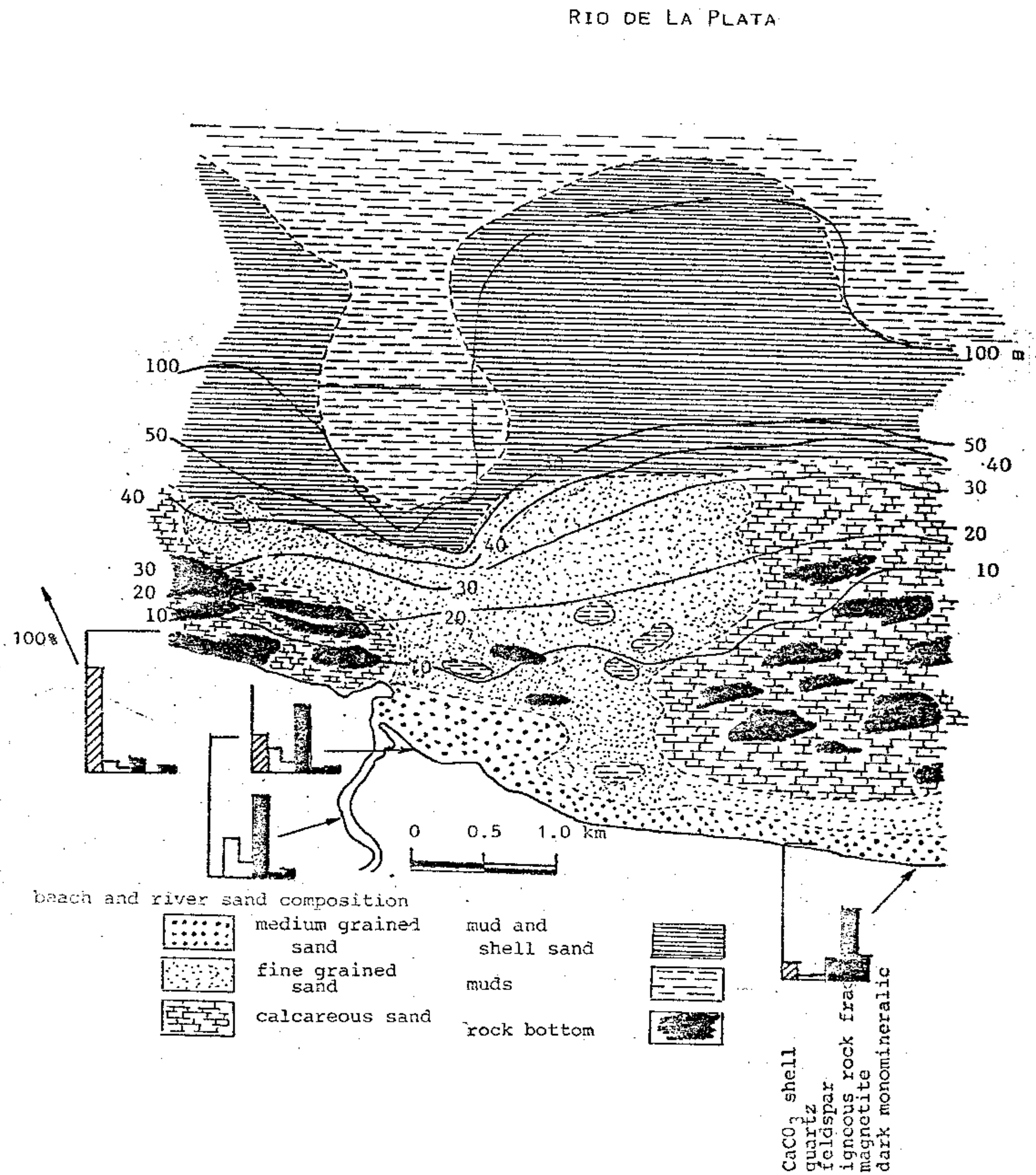


FIGURE 19 -NEAR-SHORE SEDIMENT PATTERN

Salt wedge intrusion length variations can promote differential sediment depositional patterns as a function of sediment properties of size and density. The arrested salt wedges that may be found in these rivers can create sedimentary pollution problems. This is derived from the presence of suspended or deposited sediment particles in tidal waters under the salt wedge. Coarser sediment particles are generally deposited at the landward toe of the salt wedge and finer particles settle slowly along the estuary while suspended silt and clay particles may flow out of the surface fresh water. The size of the sediment particles may vary with the source. Sediments are produced by the discharges from areas stripped for construction, dredging operations, from the mining of sand and gravel, along the river banks and from denuded agricultural lands. All of the above sources are increasing at a rapid rate in the area of study.

Sediment composition from beach analyses show that marine sediment transport plays a dominant role in spit bar development in the area. There is a higher percentage of carbonate grain content in the spit bar structure than in beaches either to the east or west of the river mouth. This carbonate concentration could be the result of wave refraction and converging effects caused by the reef shoals offshore. These shoals convert the wave energy toward the river mouth, carrying suspended carbonate particles by means of momentum transfer and wave induced literal currents inshore. Calcium carbonate material is significantly less east of the river mouth. Quartz sand content increases to the east of the Loiza spit bar. It is surmised that during flood, the high quartz sand is transported to the nearshore zone later to be carried back to the shore by waves and currents. Also, river discharge to the east from the Espiritu Santo River is an additional source of quartz sand. The pattern of spit bar development and distribution of minerals in the beach sands suggests that a westward transport of the beach and river sediments predominates throughout the year along the coastline. Although eastward transport may be significant for periods of time. Analyses of cores taken at the river mouth bar show no change in mineralogy or size characteristics with depth which implies that bar formation is mainly determined by literal currents. The spit bars are medium to fine grained salt and pepper quartz sands containing feldspar, rock fragments, biotite, horneblend and magnetite.

The geomorphology of the coast line at La Plata River inlet contrasts significantly with that of the Loiza River. The spit bar across La Plata is always a line toward the west in contrast to the Loiza bar which may take either an east, west or west alignment. Spit bar breaching by the La Plata River normally takes place on the western side where a relict dune of eolianite is present. Beaches to the east are semilunate with an eolianite relict dune system present offshore. The eolianite structure on the western bank of the La Plata River outlet acts as a sand trap or literal transport barrier. Literal transport is unidirectional toward the west. Bypassing of sand to the beaches west of the river mouth will necessarily be accomplished by nearshore wave current submarine processes.

Beaches east of the river mouth at La Plata are fed by sediment transported easterly during flood conditions when the river sediment plume moves offshore and then toward the east in the nearshore area. This is returned to the beach by prevalent wind and wave induced currents, from easterly directions.

Several general conclusions can be made based on observations of sampling of the Loiza and La Plata Rivers.

1) Literal longshore drift is dominately responsible for the development of spit bars in the river transport system, but only after a sorting process removes the fine sediment for

deposition further offshore, leaving behind sand size material. Approximately 20 percent of the sediment in the spit bars is derived from an offshore marine source.

2) The Loiza River spit bar alignment shifts according to marine processes, seasonal in nature. Directional variations in nearshore currents cause changes in alignment and direction of the bar development.

3) The spit bar formation across the La Plata River outlet is unidirectional. Wave regime and shifting currents in the nearshore influence the size, shape and seaward migration, but do not affect the lateral extension or alignment. Dominant literal sediment transport to the west determines the alignment and length of the bar. The position onshore and offshore may be affected temporarily by flood condition discharge from the river. This effect is rather quickly eliminated by the dominant marine processes.

4) Fine sediments are transported over the sills of the spit bars under normal conditions. The sand bars promote deposition of coarser sediment in the estuary.

5) The river sediment spreads seaward during flood conditions. Wave action and currents later transport those sediments of sand size toward the beaches on both sides of the river mouth. Fine sediment remains in suspension for a longer period of time and is eventually transported outward to the insular shelf. Following one flood condition, two individual pods of fine grained sediment were traced in their migration seaward from the La Plata River and it was found that approximately 40 days were required for complete removal of the fine grained material which resided in depressions on the nearshore shelf in the form of a heavy slurry.