PARTICLE CHARACTERISTICS AND DISPERSAL PATTERNS OF SUGAR CANE WASTES IN SELECTED RIVERS AND ESTUARIES OF PUERTO RICO

PROJECT A-042-PR

By

Dr. Jack Morelock
Associate Professor, Marine Sciences
University of Puerto Rico
Mayaguez

and

Kurt Grove
Research Assistant, Marine Sciences
University of Puerto Rico
Mayaguez

From

Water Resources Research Institute
Division of Research & Special Programs
College of Engineering
University of Puerto Rico
Mayaguez Campus

to

Office of Water Research and Technology
U. S. Department of the Interior
Washington, D. C.

"The work upon which this publication is based was supported in part by funds provided by the United States Department of the Interior as authorized under the Water Resources Research Act of 1964, Public Law 88-379."

February, 1976

ABSTRACT

The Rio Grande de Añasco has a drainage area of approximately 370 square kilometers. The last 3.5 km of the river is a straight channel with a width of 16 meters and a seaward increasing depth of 1.5 to 3 meters. The lower 2.5 km is an estuary with a well developed salt wedge. Due to the small tidal fluctuations in Puerto Rico, salt wedge movement is mainly dependent on river discharge. During the dry season, the salt wedge extends 2.5 km upstream. During the rainy season, the salt wedge may be entirely removed, but averages a position about 1 km upstream.

The river empties into Añasco Bay. The insular shelf is very narrow, and is marked by a line of submerged coral reefs about 1.5 km offshore, except for a break west of the river mouth. A sand bar across the mouth of the river restricts the flow. During dry seasons, this bar may isolate the river from the sea. It is partly removed and migrates offshore during periods of high discharge.

Igualdad sugar mill is located on the Añasco River 2.5 km from the mouth. The solid wastes produced in the refining process are woody cane fiber called *bagasse*, a high B.O.D. filter cake called *cachaza*, and cinders formed by the burning of bagasse to heat boilers. To study the distribution patterns of bagasse, 15 stations were established in the river and 60 grab samples were collected from Añasco Bay. Sedimentary and hydrographic analyses were made.

During low flow, the suspended material in the salt wedge was 0.008 to 0.059 g/l. This is about 10 times less than the amounts (0.099 to 0.334 g/l) found in the river water underlying the salt wedge. This

suspended load is composed mainly of fine organic debris (bagasse) and silt and clay. Concentrations in the river waters above the mill were only 0.009.

The salt wedge has a profound influence on the sediments of the river. In the estuary, the sediment is fine grained, poorly sorted clay, silt, or silty sand composed of terrigenous and calcareous components of marine origin, such as pelecypod fragments and foraminifera. The sediments in the river above the estuary are coarser and are mainly moderately sorted sands and gravel. The organic content of sediments collected below the sugar mill during sugar production is over 90%. Farther downstream in the estuary, organic content is low and the organic debris is much finer. Most of the traction and siltation load are deposited at the salt wedge head. At the semi-permanent wedge termination 1 km inland, this sedimentation resulted in deposition of a bar over 0.6 high above the bottom.

The suspension load is partly deposited in the estuary as a result of flocculation at the mixing boundary. During the low discharge period, very little water movement or mixing occurs, and the finer organic debris is subjected to gravitational settling. During high river flow, the suspended material is carried over the shelf and is deposited as a mud blanket in Añasco Bay.

Sediments in the Bay are derived from the coral reefs, erosion of the alluvial plain of the Añasco River, and from the discharge of the Añasco River. These modern sediments are mixed with relict sediments deposited during the lower sea level of the Wisconsin glaciation. As a result of these diverse sources and irregular bathymetry, there are distinct sedimentary facies in the Bay.

The two major facies are carbonate reef deposits and terrigenous sediments. The carbonate reef sediments may be divided into two sub-facies; areas of bare rock and thin patches of shell sand and gravel, and near reef sediments with a gravelly sand texture and relatively high carbonate content that are mixed with terrigenous sands.

The other major facies is terrigenous, composed of quartz, serpentine, feldspar and volcanic rock fragments of sand and silt size and clay minerals derived from the Añasco River. The carbonate content is less than 15 percent. There are four distinct sub-facies that are based on textural characteristics.

The beach system facies lies between the shore and the 3 meter contour. This is an active zone of longshore transport and cyclic onshore-offshore movement of fine to medium grained sand. Terrigenous sands and silty sand dominate the open shelf south of the Añasco River. North of the river, there is a mud facies of silts and clay with less than 20 percent sand. This is the area of deposition of the Añasco River sediments and is the site of most of the organic debris carried out of the river. The fourth facies is sandy muds that are found on the outer shelf and slope. These also contain some organic debris.

The distribution of these sediments and the organic debris reflects the pattern of wave refraction and current circulation in Añasco Bay. Each of the facies can be correlated with the topography, current and wave patterns, and general physical characteristics of the shelf area.

Results of the study indicate that estuaries are poor disposal sites for organic pollutants. Most of the wastes deposited in an estuary remain there for long periods and are only partly removed during periods of high river discharge. The seasonal migration of the salt wedge over large distances should be considered by agencies planning to use the river waters for agricultural and industrial purposes.

ACKNOWLEDGMENTS

This project was initiated by Dr. Nahum Schneidermann who has continued to offer suggestions during the investigations. Dr. Roberto Vazquez has given help and cooperation throughout the research period. Appreciation is also expressed to Rafael Caraballo Diaz of the W.R.R.I. and to the staff of secretaries and technicians.

The Department of Marine Sciences has made equipment and ship time available which contributed to the study. Particular thanks are given to Dr. M. L. Hernandez-Ávila who assisted in analysis of the physical parameters.

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Introduction

Sugarcane is a major agricultural product of Puerto Rico. During the cane season, January to July, sugar and molasses are produced in approximately 20 mills (centrals), which are generally located close to a river or bay.

At Central Igualdad on the Añasco River, 2.5 km. from the mouth (fig. 1), sugar is refined from raw cane. Major solid wastes produced in the refining are:

1. the woody fiber of the cane - "bagasse"
2. a high B.O.D. filter cake - "cachaza" - formed as a flocculant during the juice clarification
3. cinders formed from the burning of bagasse to heat boilers

The bagasse is produced during juice extraction when the cane is cut and crushed. About 220 pounds of bagasse are produced from each ton of raw cane (Biaggi, 1967). Part of the fiber is used to fire boilers. The excess bagasse is piled along the south bank of the Añasco River, east of the plant (fig. 2). An exothermic reaction associated with residual sugar causes frequent spontaneous combustion in the bagasse pile (fig. 3). Control of this burning consists of bulldozing the burning bagasse into the river.

The filter cake is disposed of through a series of holding lagoons (fig. 4). About 30 kg of cachaza are produced per ton of raw cane. The average B.O.D. of the cachaza is 15,842 mg/l (Biaggi, 1967). Settling and oxidation reduced the B.O.D. and particulate matter as the water goes through a series of lagoons before discharge into the Añasco River.

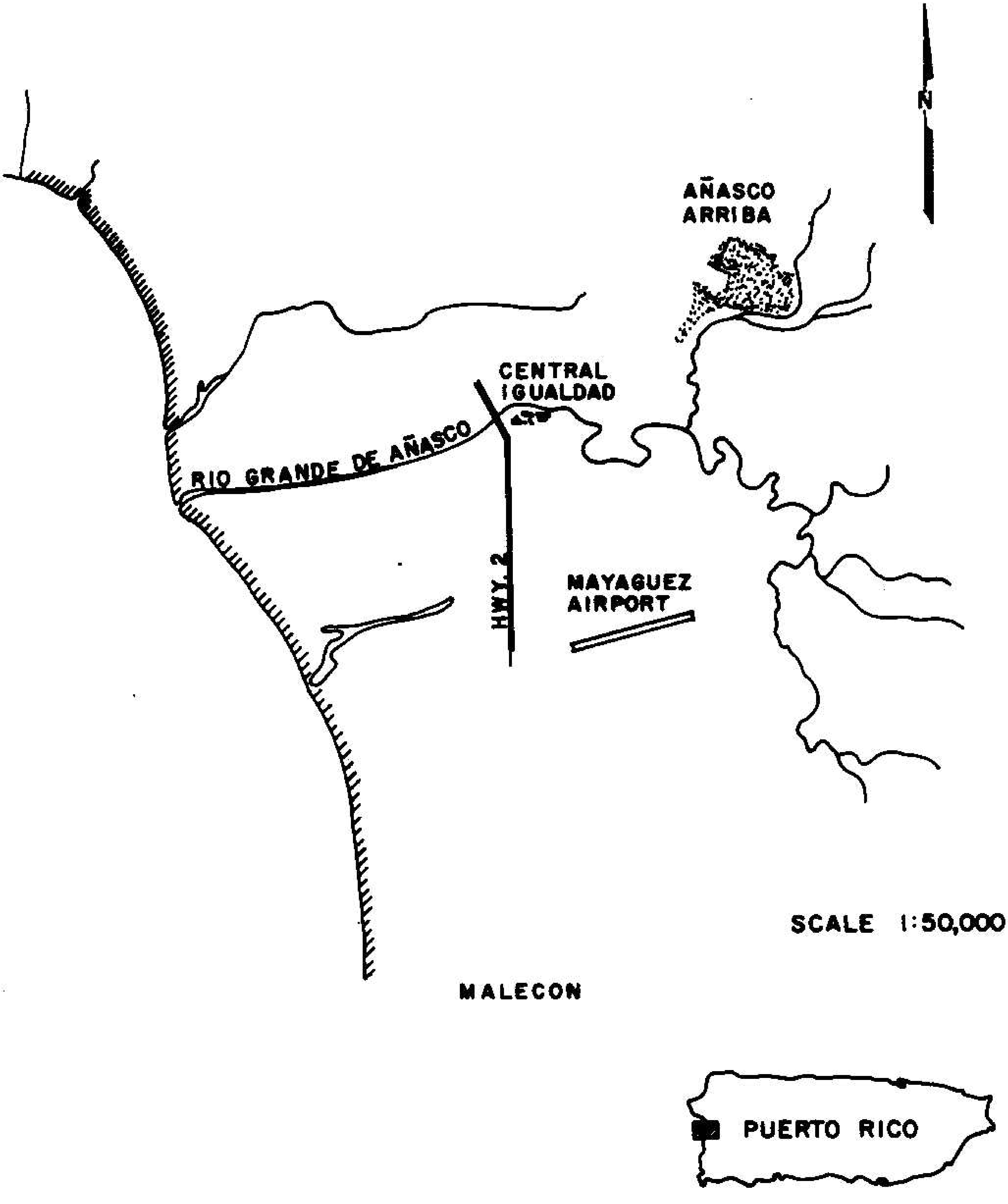

FIG. 1

Location map of study area

Fig. 2 Central Igualdad bagasse dump

Fig. 3 Spontaneous combustion in bagasse dump

Fig. 4 Holding lagoon system at Central Igualdad

By burning the bagasse to fire boilers, fuel cost and waste volume are reduced. However, residual clays and a high silica content in the cane fiber produces a glass scale on the boilers which must be removed. This scale, once removed, is dumped into the river. Although this is not an important chemical pollutant, the residue contributes in filling the river channel.

This report will describe the Añasco disposal site, supply monitoring data, and describe the distribution of solid sugar cane waste in the estuary and bay.

Study Area:

The Rio Grande de Añasco is the largest river on the west coast of Puerto Rico, and drains an area of about 370 square kilometers (fig. 5). The lower part of the river is an estuary with a well developed salt wedge. For the last 3.5 km. the channel is straight, with a constant width of about 16 m, and a seaward increasing depth of 1.5 to 3 meters. Upstream the channel is contorted into a series of tight meanders. At the river mouth in Bahia de Añasco, the outflow is restricted by a bar. When the river is under low flow regime, discharge is restricted by the bar to a channel about 3 m wide and 0.5 m deep. This channel curves to the south in the direction of littoral drift. During higher river discharges, the bar channel is extended seaward.

Due to the small tidal fluctuations characteristic of low latitude regions (approximately 30 cm in Puerto Rico), salt wedge movement is mainly dependent on river discharge. This, in turn,

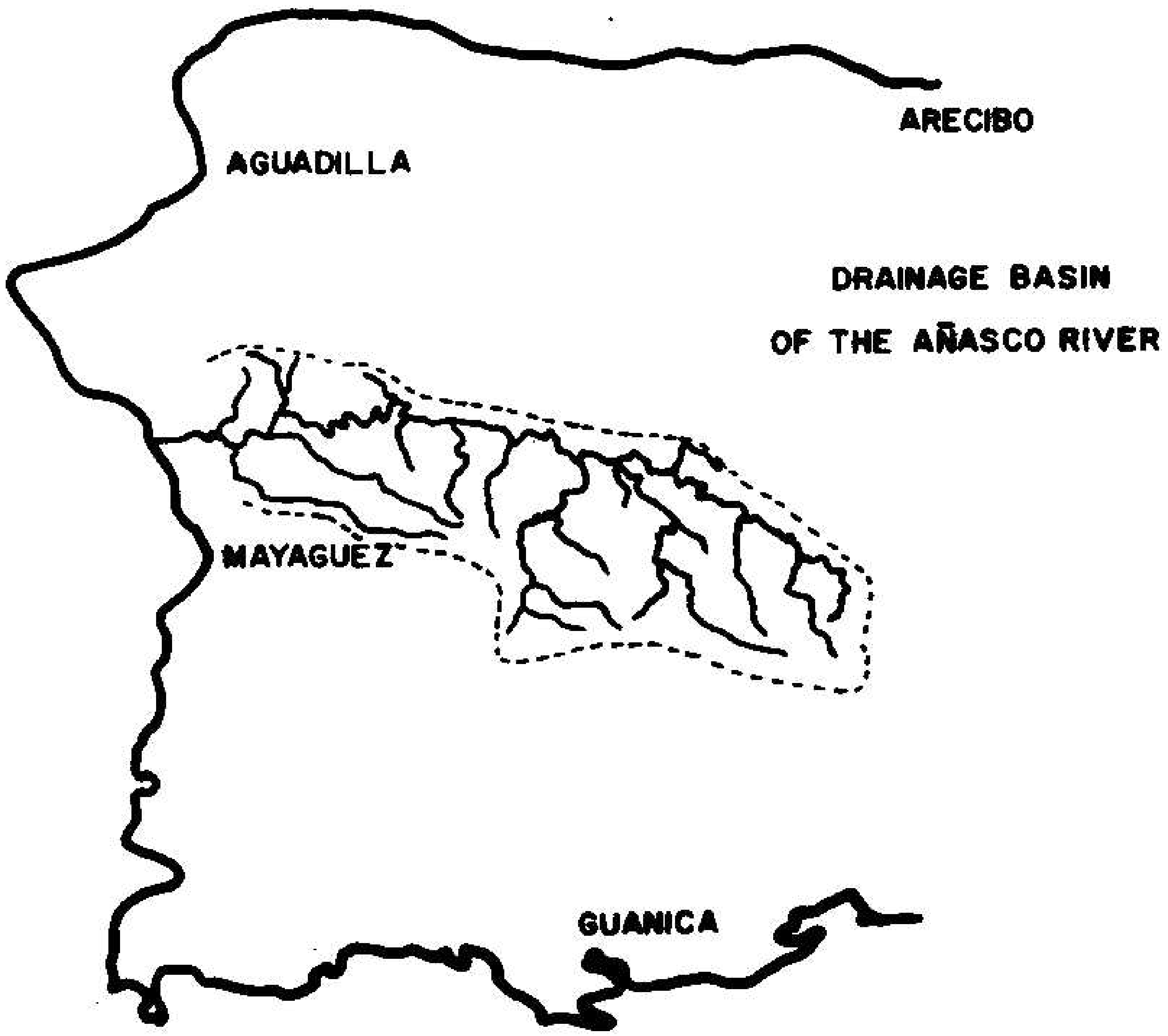

Fig. 5 Drainage basin of the Río Grande de Añasco

is related to rainfall in the drainage basin. In Puerto Rico, rain falls in seasonal cycles. The rainy season extends from approximately June thru December. From 1964 to 1967, discharge value for the rainy season ranged from 4.2 to 28 cubic meters per second with a mean value of 11 m^3/sec. (Rickher *et al*, 1970). The months from January to May are typically dry, and low river discharge may persist for weeks. Rates as low as 1.6 cubic meter per second have been recorded (Rickher *et al*, 1970).

Procedure:

In order to monitor the distribution of the cane wastes, 17 permanent stations were established along the lower length of the Añasco River to a point east of the sugar mill (fig. 6). At each station, sedimentological and hydrographic data was obtained during both rainy and dry seasons. Grain size was analyzed in accordance with Folk (1968). Salinities were measured using an A & O refractometer. Oxygen and temperature was recorded using a Yellow Springs meter. Water samples taken for suspended sediment were run through a 0.45 m. millipore filter. Organic content was determined by oxidation with potassium dichromate and concentrated sulfuric acid following the procedure of Gaudette *et al* (1974). Petrographic observations and estimates of the dominate organic constituents were made using a Bausch and Lomb binocular microscope.

Hydrographic Conditions:

Throughout the year, as samples and measurements were taken, the position of the salt wedge was found to vary considerably. During

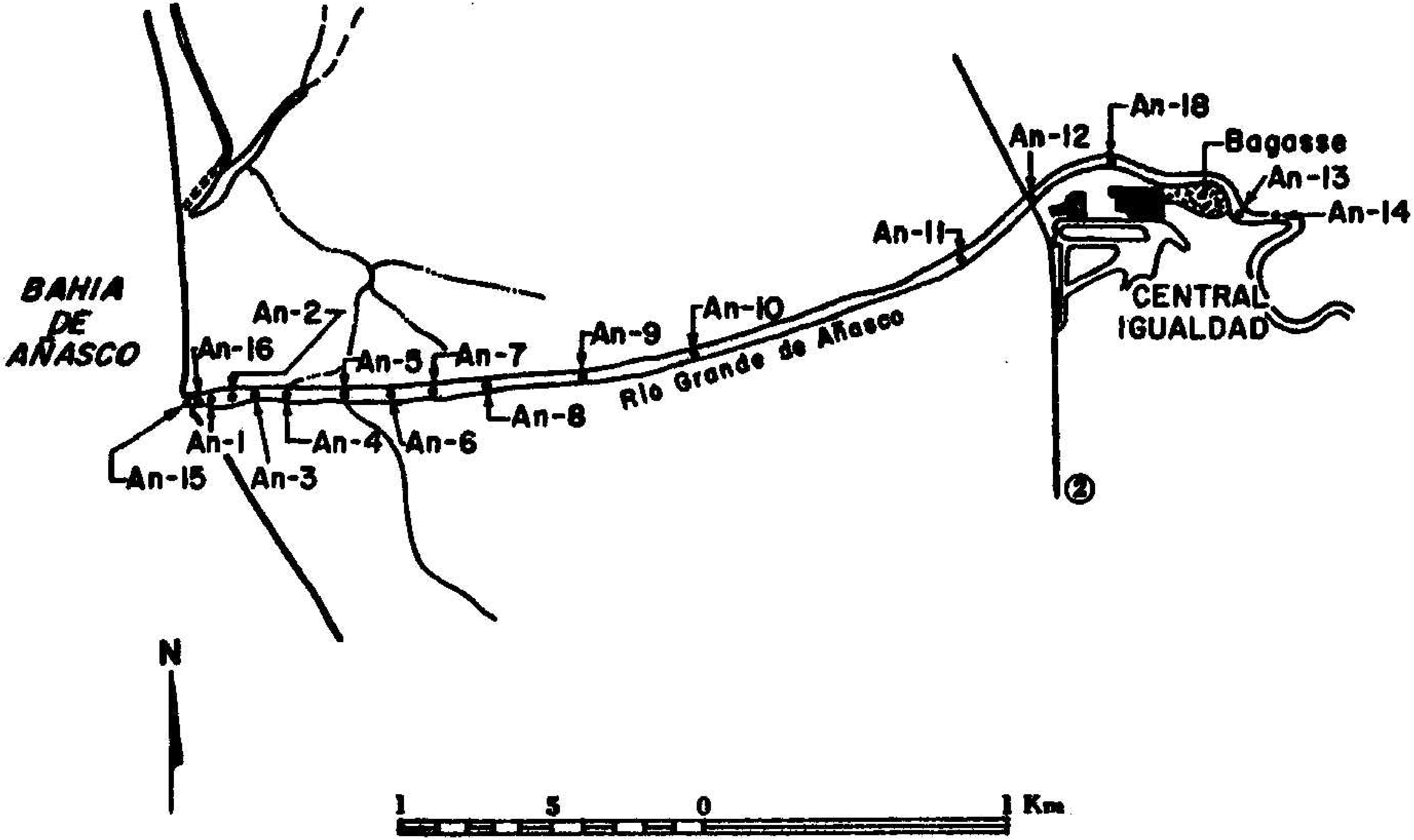

Fig. 6 Sample stations on the Añasco

the dryest periods sampled, April 19 and May 5, 1974, the salt wedge extended almost 3 km upstream. Following periods of rain, there were higher river flows. Under these conditions, the salt wedge extended less than one kilometer landward. Salinity and temperature profiles taken on May 5, 1974 represent the lowest discharge sampled (Table 1). Near the head of the wedge, which extended 3 km inland, marked stratification with respect to salinity and temperature was observed. In a section made across the width of the river, about 75 m west of station AN-12 (fig. 7), the most rapid change in salinity occurred near the south bank where the water was fresh to a depth of 75 cm, while from 75 to 90 cm salinity increased to 25%. From 1.2 meters to the bottom (1.8 meters) the salinity was 26%. In the same interval from 75 to 90 cm depth, temperature dropped from 30 to 28.5°C.

Samples collected on May 30, August 4, and December 11, 1974 were taken after periods of rain, and are characterized by higher discharges than those sampled April 19 and May 5, 1974.

On May 30, 1974, the salt wedge extended to only 1.5 km inland. The head of the salt wedge was located between stations An-9 and An-10. The profile at An-9 shows the largest variation in salinity (from 2 to 29%), which occurred from 1.7 to 1.8 meters in depth (Table 2, sta. An-9). Conditions on August 4, 1974 were such that the salt wedge extended almost 1.8 km inland. The maximum extent of salt water was about 30 m east of station An-10. At An-10, the water was fresh to a depth of 1.2 meters, from 1.2 to 1.5 meters salinity increased from 2 to 5%, from 1.5 to 1.8 meters an increase from 5 to 22% was observed (Table 3, sta. An-10). Temperature variation between the

Table 1: Profile data 5/5/74 (axial section low flow)

Station: 200 ft. west of east of station An-12

depth (ft)	Temperature (°C)	Salinity (°/°°)
0	30.5	0
1	29.75	0
2	29.5	2
3	28.25	18
4	27.75	26
5	27.75	Bottom

Station An-2

depth (ft)	Temperature (°C)	Salinity (°/°°)
0	30.5	0
1	30.25	2
2	29.25	11
3	28.25	27
4	28.25	30
5	27.75	31
6	27.50	31
7	27.0	Bottom

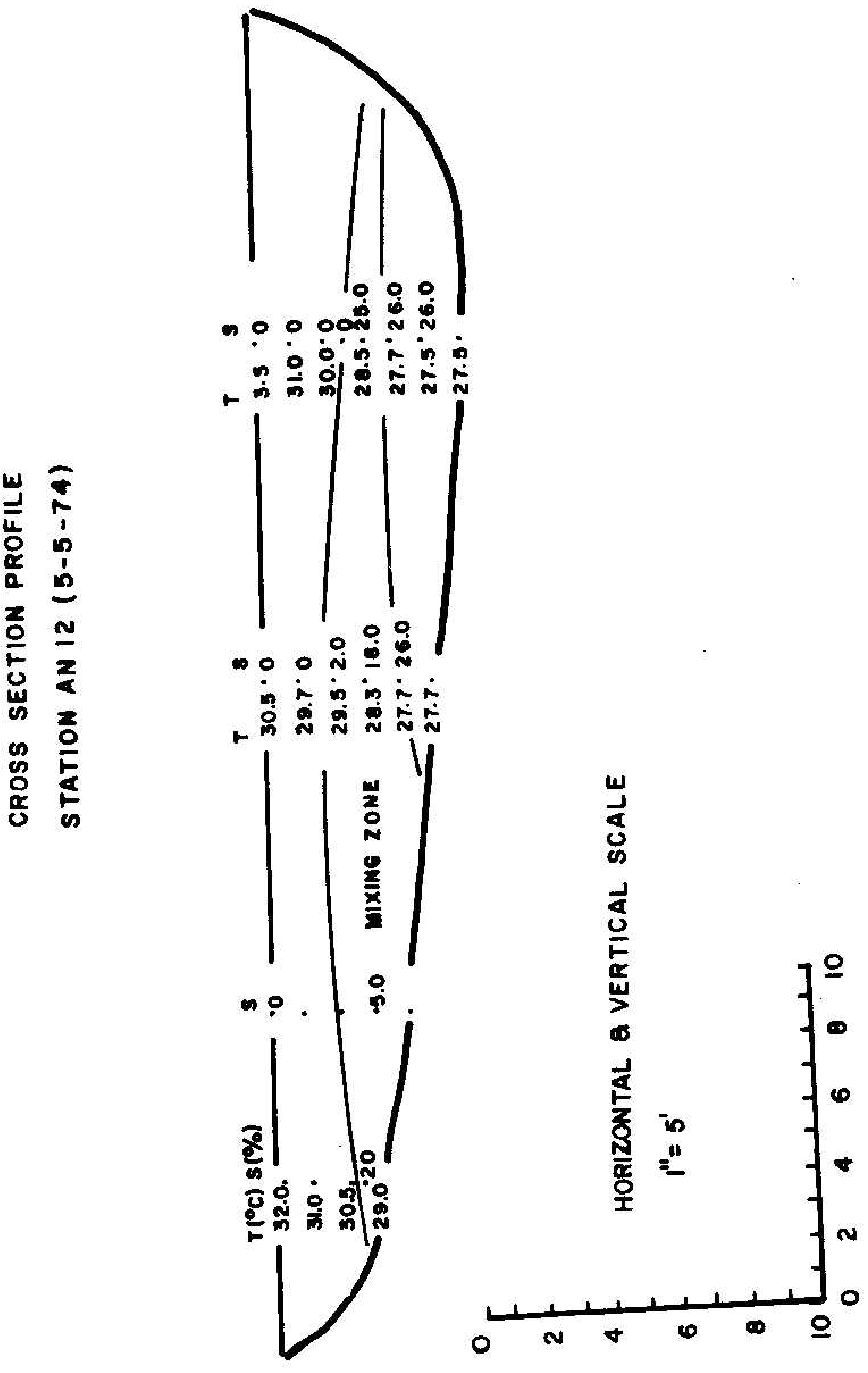

Fig. 7 Cross section of salinity structure near station An-12

Table 2: Profile data 5/30/74 (axial section, high flow)

Station	depth (ft.)	Temperature (°C)	Salinity (°/₀₀)
Station An-9	0	28.5	0
	5	28.0	0
	5.5	-	2
	6	28.0	29
	6.5	28.0	30
	7	Bottom	
Station An-8	0	28.0	0
	4	28.0	0
	5	28.0	14
	6	28.0	25
	6.5	Bottom	
Station An-5	0	28	0
	3	28.5	0
	4	29	7
	5	28.5	16
	6	29	25
	7	29.5	28
	7.5	Bottom	
Station An-2	0	28	0
	3	28	0
	4	28	2
	5	28	6
	6	28	28
	7	28	30
	7.5	Bottom	
Station An-1	0	27	0
	1	28	0
	2	28	1
	3	27.5	2
	4	27.5	3
	5	27	6
	6	28	28
	6.5	Bottom	

Table 3: Profile data 8/4/74 (axial section)

Station: An-1	depth (ft.)	Temperature °C	Salinity (°/₀₀)
	0	29.0	x
	1	29.0	x
	2	29.0	x
	3	29.0	2
	4	28.5	3
	5	28.0	18
	6	28.0	22
	7	Bottom	
Station: An-2	0	28.0	5
	6	28.0	26
	7	Bottom	
Station: An-4	0	29.0	2
	6.5	28.0	26
	7.5	Bottom	
Station: An-5	0	29.0	x
	6.5	28.0	22
	7	Bottom	
Station: An-8	0	27.0	x
	1	27.0	x
	2	27.0	x
	3	27.5	x
	4	28.0	x
	5	28.0	16
	5.5	28.0	21
	6	Bottom	
Station: An-9	0	28.0	x
	6	28.0	24
	6.5	Bottom	
Station: An-10	0	28.0	x
	1		x
	2	27.0	x
	3		x
	4		2
	5.5		5
	6	27.0	22
	6.5	Bottom	
200 feet east Station An-10			
	0		x
	6		2
	6.5		Bottom

Remaining stations upstream all fresh water

x - indicates freshwater

fresh and salt waters was not present during the higher flow regimes measured on May 30 and August 4, 1974. On December 11, 1974, high flow conditions were again monitored. At this time, no salt water was present in the river.

Sediment Distribution:

The sediments of the Añasco River are composed mainly of material derived from volcanic or resedimented volcanic rocks which outcrop on either side of the Añasco River Valley. At the mouth of the river, the sediment consists of light colored sands with abundant quartz, feldspar, and biogenic carbonate. Darker igneous rock fragments and minor amounts of vari-colored glass from the sugar mill give the sand a salt and pepper appearance. During the months of March and April, relatively long period waves (9-12 seconds) are common along the west coast of Puerto Rico. Under these conditions, fragments of marine organisms can be observed in sediment deposited about 30 meters behind the bar at the river mouth and a high carbonate content is measured near the bar.

The position of the salt wedge plays a major role in the distribution of sediment. The most contrasting differences can be seen from the grain size distribution of samples taken under higher flow conditions. Gravel, sand, silt and clay percentages from sampling periods under different flow regimes are presented in Table 4. From these ratios, general trends in sedimentation can be observed. During low river discharge, silt and clay were deposited in both the salt wedge and in the river above the salt wedge (fig. 8). Gravel

Table 4. Grain Size (% by weight)

date	station	gravel	sand	silt	clay	silt & clay	gravel & sand
4/19/75	An-15	1.7	98.3				
	An-1		73.9	12.8	13.3	26.1	
	An-2		1.7	44.4	53.9	98.3	
	An-4		0.9	49.3	49.8	99.1	
	An-5		1.1	59.0	40.0	99.0	
	An-6		2.9	45.9	51.2	97.1	
	An-8		4.8	54.9	40.4	95.2	
	An-9		30.9	36.6	32.4	69.0	
	An-10		29.1	36.4	34.5	70.9	
	An-11	12.9	75.3	6.4	5.4	11.8	88.2
	An-12		1.3	49.2	49.5	98.7	
	An-18		8.5	45.3	46.2	91.5	
	An-13		20.4	50.6	29.0	79.6	
	An-14	85.3	2.5	6.5	5.7	12.2	87.8
8/4/74	An-15	4.0	92.7	1.4	1.9	3.3	
	An-1		9.5	32.5	58.0	90.5	
	An-2		2.6	39.8	57.6	97.4	
	An-4		20.1	37.2	42.7	79.9	
	An-5		62.4	19.7	17.9	37.6	
	An-6		7.0	47.5	45.4	92.9	
	An-8		76.9	11.7	11.4	23.1	
	An-9	0.1	41.7	26.1	32.1	58.2	41.8
	An-10	7.5	88.5	2.6	1.4	4.0	96.0
	An-11	21.6	75.6	2.7	0.1	2.8	97.2
	An-12	10.5	81.3	5.0	3.2	8.2	91.8
	An-18	12.6	81.9	3.3	2.2	5.5	94.5
	An-13	77.9	19.1	1.7	1.2	29.	97.0
	An-14	88.9	9.0	1.4	0.7	2.1	97.9
12/11/74	An-1		4.25	46.30	49.47		
	An-2		13.57	54.49	31.92	86.41	
	An-4		13.72	52.60	33.70		
	An-5		25.53	46.28	28.21		
	An-8	9.87	82.07	4.55	3.52	8.06	91.94
	An-9		93.08	4.87	3.02		
	An-10	68.45	29.67	0.85	1.06	1.91	98.10
	An-11	79.40	20.13	-	-	0.48	
	An-12	18.77	79.31	0.57	1.36	1.93	98.08
	An-18	17.38	81.10	0.33	1.21	1.53	98.38
	An-13	36.62	61.06	0.96	1.37	2.33	97.67
	An-14	76.25	20.57	1.47	1.73	3.20	96.81

(continued next page)

Table 4. Grain Size (% by weight) continued

date	station	gravel	sand	silt	clay	silt & clay	gravel & sand
3/15/75	An-15		98.8	0.3	0.9		
	An-1		90.6	4.7	4.7		
	An-2		3.7	56.7	39.6		
	An-4		3.2	59.6	37.2		
	An-5		7.7	62.4	29.9		
	An-6		7.4	57.9	34.7		
	An-8		33.8	33.0	33.2		
	An-9		8.2	52.3	39.5		
	An-10	49.0	28.2	13.6	9.2	22.8	77.2
	An-11	52.0	34.6	8.2	5.2	13.4	86.6
	An-12	8.3	32.6	37.7	21.4	59.1	40.9
	An-13		42.8	35.0	22.2		
	An-14	69.0	18.4	8.1	4.5	12.6	87.4
5/30/74	An-15	1.4	93.4	0.1	5.1	5.2	94.8
	An-1		17.2	33.2	49.6		
	An-2		16.2	25.2	58.6		
	An-4		25.2	37.1	37.7		
	An-5		12.1	32.4	55.5		
	An-6		5.6	33.8	60.6		
	An-9		80.7	6.6	12.7		
	An-10		20.8	47.3	31.9		
	An-11	50.6	43.5	1.6	4.3	5.9	94.1
	An-12	39.8	54.0	2.2	4.0	6.2	93.8
	An-18	19.0	63.4	6.4	11.2	17.6	82.4
	An-13		30.5	29.1	40.4		
	An-14	31.5	62.7	2.0	3.8	5.8	94.2

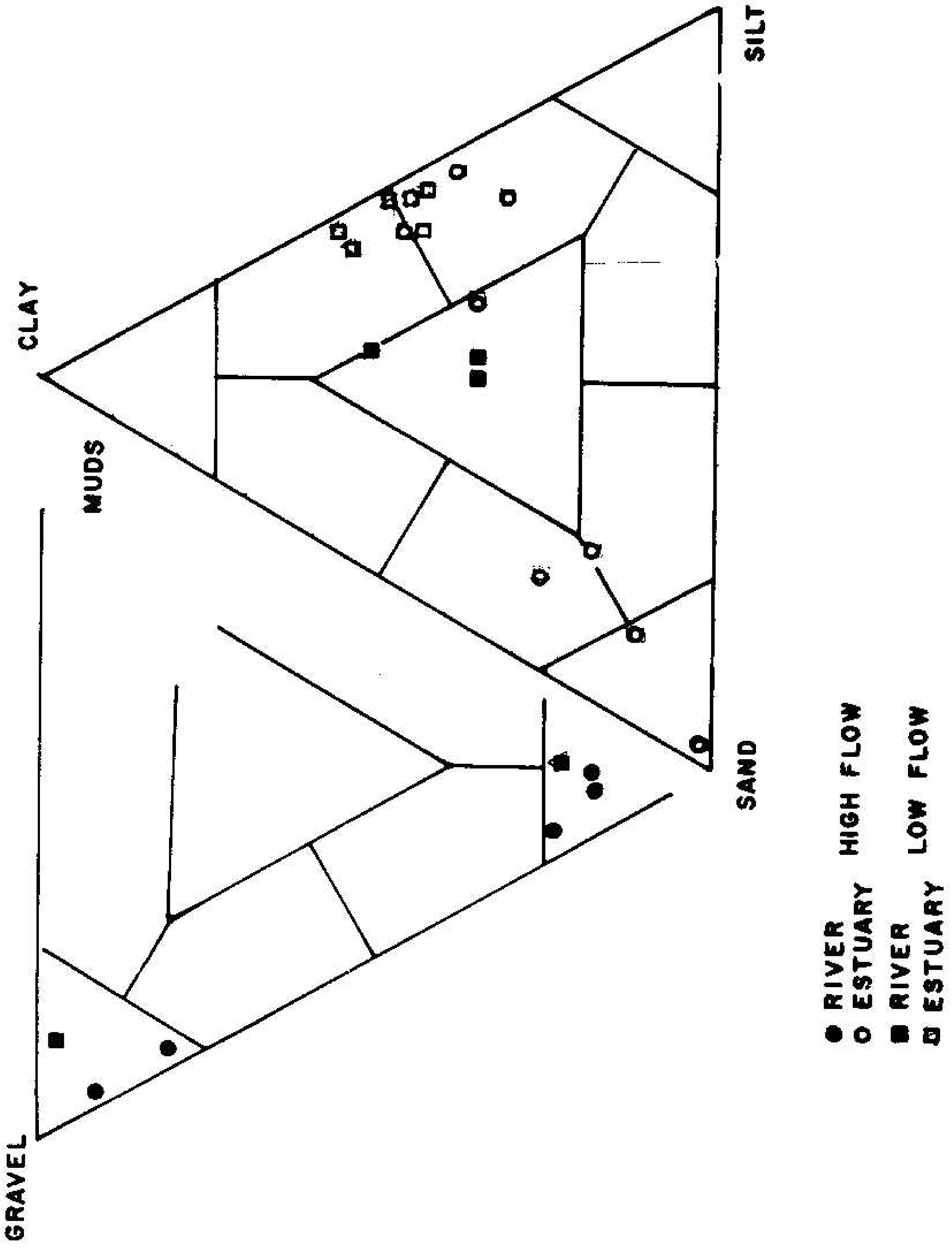

Fig. 8 Sediment grain size facies

and sand found at stations An-11 and An-14 are residual from previous high flow conditions. The bimodal distribution of the sample from An-14 supports this thesis. A comparison of sediment grain size and salt wedge position under varying flow conditions is presented in figure 9. The general trend is for finer sediments to accumulate near the river's mouth where the salt wedge is present most of the time.

During times of high river discharge, the sediment above the salt wedge is composed mainly of sand and gravel. Within the salt wedge, silt and clay predominate. Sandy sediments have been observed within the salt wedge on several instances (fig. 8, see graph 5/4/74 stations An-5 and An-8). This coarse material is often bounded on both landward and seaward sides by areas of mud deposition. They are probably relict sand bars formed during higher flow regimes when the salt wedge was displaced closer to the mouth of the river. The presence of isolated sand layers may indicate a degree of heterogeneity in deposition of silt and clay within the salt wedge.

During the time of lowest river discharges sampled on April 19, 1974, sediment was fine grained silt and clay along the entire sampled length of the river. Stations An-11 and An-14 (An-8 graph 4/19/74) showed high sand and gravel content which represents material relict from higher flow conditions.

The bathymetry of the Añasco River is variable and changes in response to flow regimes. Profiles for the sampling dates are

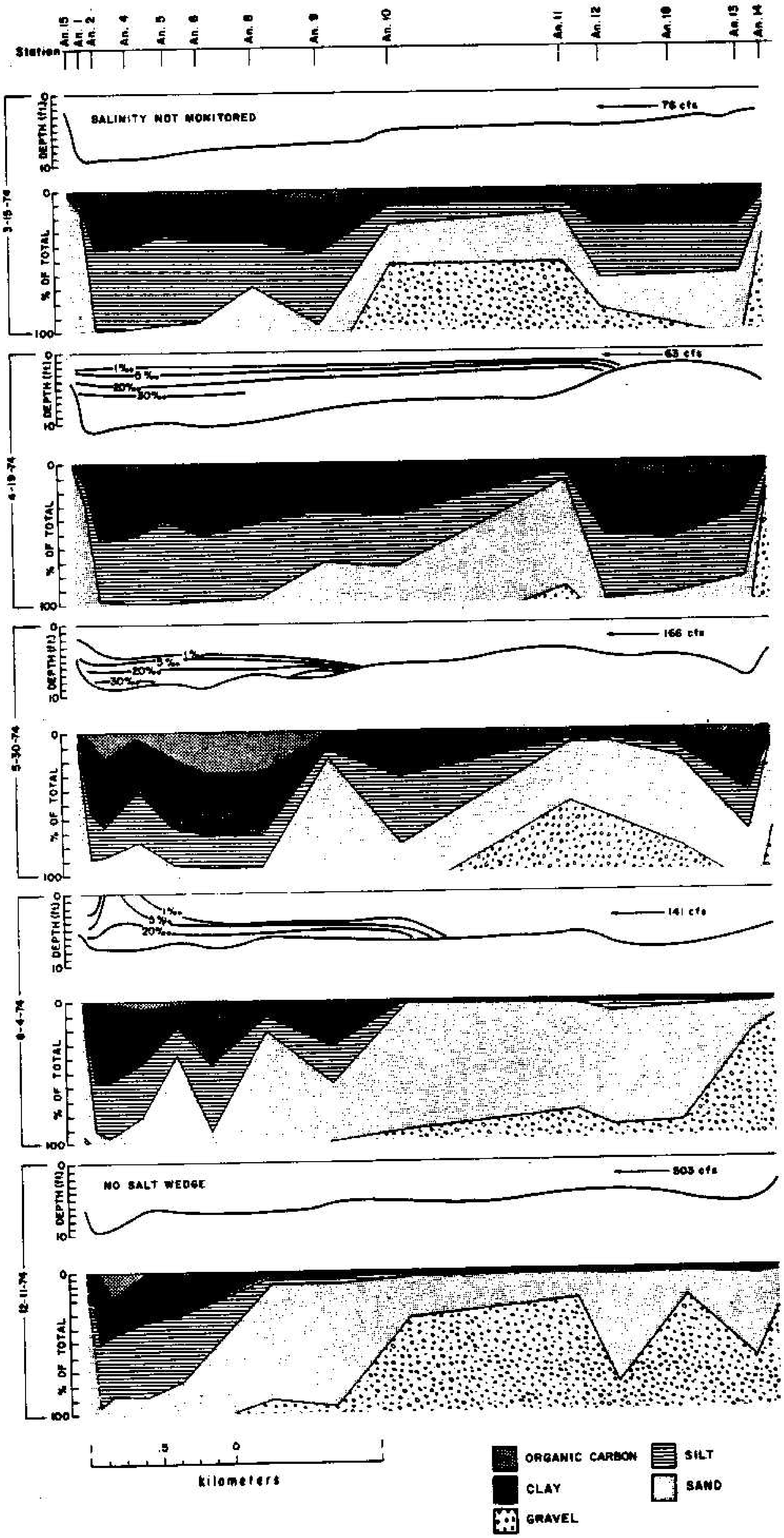

Fig. 9 Salinities, bathymetry, and sediment distribution profiles for the Añasco estuary

presented in figure 9. In each profile, certain features seem to persist. The bar at the mouth of the river is always present, but varies in form depending on river velocities, wave conditions, and the longshore transport of sediments. Along the river bed, bars are common features. Their relief may be as much as 0.5 m, and they are generally composed of sand (fig. 9, 8/4/74 stations An-5 and An-8). These features may represent semi-permanent stands of the salt wedge where traction and saltation bed load sediments are deposited across the channel at the head of the salt wedge.

Suspended Sediment:

Surface and bottom suspended samples were collected on three separate occasions from the Añasco River (Table 5).

The samples collected on April 19, 1974 were taken during the sugar cane season under low river discharge. The highest values above the sugar mill's discharges were taken at station An-13 where the suspended material reached 17 mg/l. Below the discharges of the sugar mill, the concentration of suspended sediment rose abruptly. Surface water concentrations ranged from 89 to 159 mg/l with a mean at 113 mg/l. In bottom samples collected near the mill, concentrations as high as 334 mg/l were recorded. Within the salt wedge at this time, suspended sediment was significantly lower than in the overlying fresh water. Concentrations ranged from 9 to 59 mg/l with a mean of 32 mg/l.

Samples taken during the higher discharge conditions on May 30 and August 4, 1974 had higher suspended sediment concentrations at

Table 5. Suspended Sediment (mg/l)

	4/19/74 low discharge		5/30/74		8/4/74 high discharge	
Station	Surface	Bottom	Surface	Bottom	Surface	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.

stations above the sugar mill than measured during low flow conditions. The influence of the sugar mill on suspended material below the mill was not observed under the high flow regimes. In the freshwater samples taken on May 30, suspended sediment concentrations ranged from 46 to 77 mg/l with a mean of 62 mg/l. On August 4, concentrations ranged from 37 to 68 mg/l with a mean of 62 mg/l In the salt wedge, suspended sediment concentrations ranged from 19 to 28 mg/l on May 30, and 62 to 96 mg/l on August 4. The higher values observed in the August 4 samples may be the result of higher velocities within the salt wedge resuspending some of the bottom sediment. The resuspended material could conceivably be entrained into the seaward fresh water flow and be transported out of the estuarine system into the Bay. The process of salt water entrainment by breaking internal waves has been discussed by Keulegan (1966, p 559). Depending on how often velocities in the salt wedge reach values high enough to resuspend the bottom sediments, this process may play a significant role in cleaning the estuary of deposited pollutants.

The composition of the suspended sediment has been examined to a limited extent in smear slides of the fine sediment fraction. During the low flow period sampled on April 19, 1974, the suspended sediment above the discharges of the sugar mill (station An-14) was composed of fine material beyond the resolution of the microscope, mainly red clay. At and below the sugar mill, organic detritus became a common component. Most of the material was still beyond the resolution of the microscope but scattered silt size flakes of organic material were common. These flakes exhibited a gray to yellow birefringence characteristic of very fine cane fibers taken from bagasse as it leaves the mill. Under the higher flow regimes, suspended material was very fine grained; only a very small amount of cane detritus was observed in the samples. The samples were mainly composed of red clays. Kaolinite and montmorillonite are the dominant clay minerals (fig. 10).

Distribution of Organic Detritus and Dissolved Oxygen:

To measure the amount of organic detritus, powdered samples were oxidized in potassium dichromate and concentrated sulfuric acid following the procedure outlined by Gaudette *et al* (1974). The amount of organic detritus was found to vary considerably between each station and each sampling period (Table 6). Most of the samples taken through both rainy and dry seasons contained less than 2% organic detritus.

In river sediment above the salt wedge, the highest values, which reached 12 to 13 percent by weight, were samples from low flow conditions during the peak of the milling season (April 19, 1974). Owing to the low stage of the river, sugarcane detritus from the mill was accumulating on the river bottom without much transport taking place. Dissolved oxygen, at this time, was 4.9 - 5.6 ppm east of the discharges of the mill (Table 7). At and below the sugar mill discharge

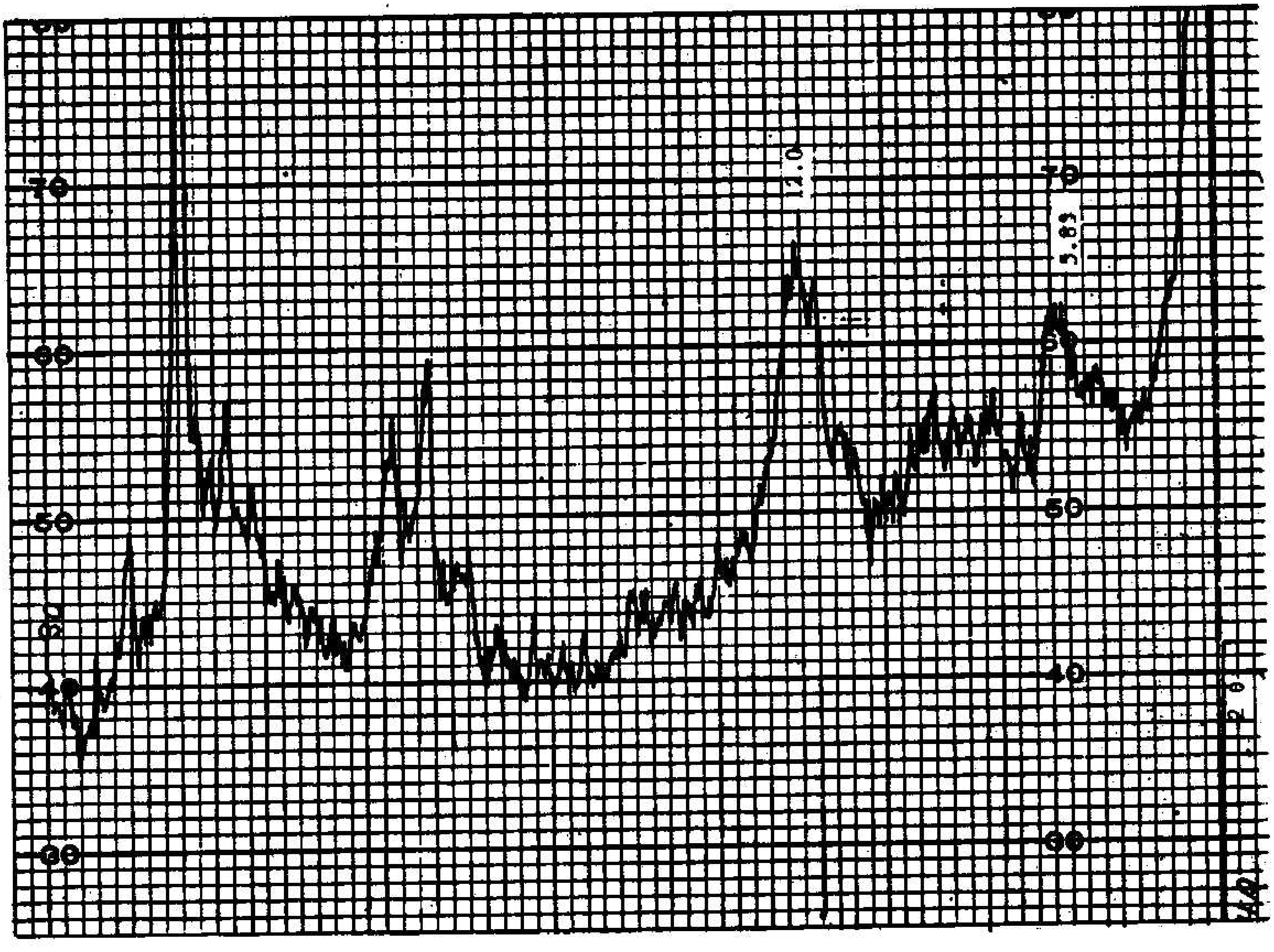

Fig. 10 Clay mineralogy of the Añasco River sediments

Table 6. Organic detritus percent
weight by wet combustion
Añasco river & estuary sediments

Station #	3/15/74	4/19/74	5/30/74	8/4/74	12/11/74
An-15	0.1	0.33	x	0.11	x
An-16	1.18	0.70	1.02	x	x
An-1	1.53	0.83	3.84	1.89	1.09
An-2	1.53	1.41	18.19	1.32	20.22
An-4	1.68	2.06	3.84	4.27	1.25
An-5	1.29	1.18	18.03	1.22	3.21
An-6	1.41	1.76	27.88	1.27	x
An-8	1.13	1.50		0.39	0.68
An-9	6.37 ----	1.40	1.00 ----	0.99	0.75
An-10	0.77	1.29	1.14	0.40 ----	0.38
An-11	1.23	0.62	1.81	0.23	0.47
An-12	3.16	3.34 ----	1.08	1.20	1.73
An-18		13.21	0.72	0.24	0.04
An-13	2.76	11.39	5.76	0.06	4.03
An-14	0.72	0.77	0.78	0.26	0.42

----Denotes position of salt wedge

Table 7: Dissolved oxygen (ppm)

	3/15/74		5/30/74		8/4/74	
Station	Surface	Bottom	Surface	Bottom	Surface	Bottom
An-16	0.6	2.2	4.1	5.2	8.2	5.8
An-1	x	x	4.9	2.9	8.1	2.2
An-2	0.6	0.3	4.0	2.1	8.4	3.1
An-3	0.6	0.7	x	x	x	x
An-4	0.7	0.7	4.3	5.1	8.5	1.0
An-5	0.6	0.6	4.8	4.2	8.2	2.4
An-6	0.8	0.5	4.7	4.4	8.7	1.0
An-8	0.7	0.4	4.9	4.4	5.9	4.7
An-9	x	x	3.5	2.9	8.7	5.0
An-10	x	x	3.9	4.1	8.5	4.5
An-11	x	x	4.8	4.4	8.7	8.7
An-12	x	x	4.5	5.1	8.9	6.8
An-18	x	x	3.7	4.3	8.9	8.3
An-13	x	x	4.3	4.3	7.2	8.4
An-14	5.6	4.9	5.0	5.0	7.3	7.3

pipes, oxygen rarely exceeded 1 ppm for the entire lower course of the river. The low oxygen values are probably the result of contamination by high B.O.D. condenser water and cachaza, rather than the bagasse.

During higher flow conditions, the highest content of organic detritus was found to be associated with the fine grained estuarine deposits. Samples taken within the salt wedge on May 30, 1974 ranged from 0.7 to 27.9 percent. Three of the seven stations within the salt wedge contained greater than 18 percent organic detritus. Dissolved oxygen ranged from 3.5 to 5.1 ppm in the fresh water and 2.1 to 5.2 ppm in samples taken 20 cm above the bottom within the salt wedge.

Compositional differences were observed in samples taken during the dry season as compared to those taken later in the year, during the rainy season. From the sample collected on April 19, 1974, petrographic observation of the sand sized fraction showed bagasse to be the dominant component of the organic fraction for the entire sampled length of the river. Near the sugar mill at station An-18 and An-13, the cane fibers were coarse and ranged up to 10 cm in length. Further downstream, mainly in salt wedge sediments, the organic fraction was predominately small cane fibers. The smaller size of the fibers reflects the low river stage. Although most of the detritus was cane fiber, several stations within the salt wedge (An-9 and An-10) revealed a mixed assemblage of detrital material.

Small fibers of cane were present with coarser detritus-derived from indigenous sources (mainly bamboo). The coarser detritus was probably deposited during an earlier higher flow.

Samples from May 30, 1974 were taken after a period of rain. The distribution and composition changed under the high flow conditions. In the river sediments above the salt wedge, organic detritus ranged from 1 to 27% (Table 6); higher values may be found under certain conditions. The detritus was very coarse ranging up to 10 cm in length, generally no greater than 5 cm. This coarse detritus, mainly bagasse, but also some twigs of native flora, was found primarily at stations An-8 and An-9 (fig. 11). Because of the proximity of these two stations to the head of the salt wedge, the detritus sampled probably represents bed load material deposited upon contact with the salt wedge. Closer to the mouth of the river, fiber size was not as large, but the detritus still was dominantly bagasse.

During this same period (May 30, 1974), the composition of the detritus in the river sediments above the salt wedge was in sharp contrast to that within the salt wedge. The river sediments contained no cane fiber; the organic material was mainly twigs and seed pods of native flora.

Petrographic observations of the samples taken on August 4 and December 11, 1974 showed the organic detritus to consist of woody twigs, seed pods and leaves of flora indigenous to the river banks.

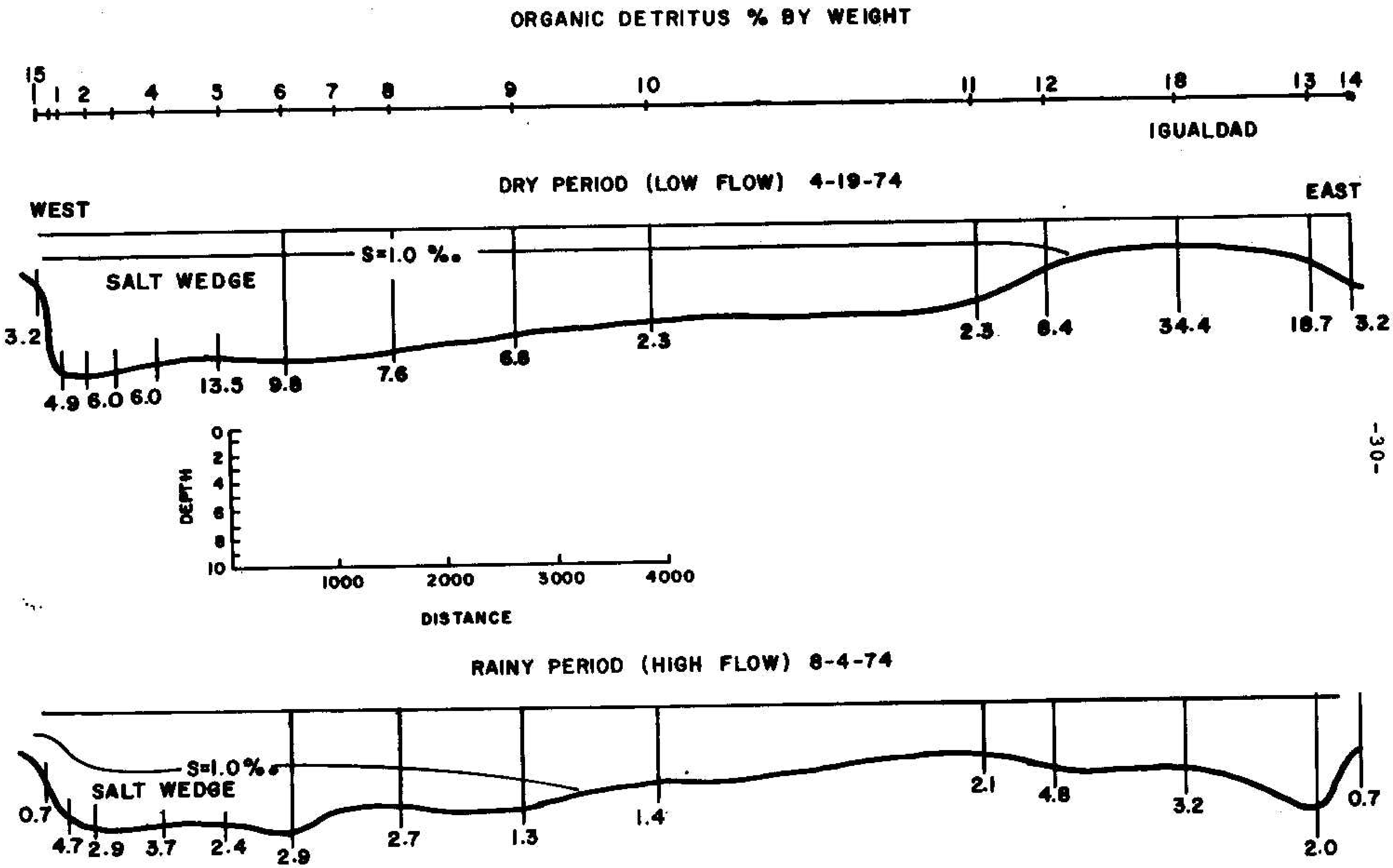

Fig. 11 Organic detritus % by weight

The measured organic content was less than 2 percent. Station An-2 on December 11, 1974 was 20 percent organic, but consisted primarily of bamboo leaves.

Añasco Bay Sediment Distribution:

The bathymetry of Añasco Bay was mapped using data from boat sheets and fathometer surveys conducted as part of this project.

The insular shelf is narrow in the Añasco area. A line of submerged coral reefs, about one mile offshore, marks the edge of the shelf (fig. 12). The shelf bathymetry is fairly irregular due to the structural and sedimentological history of the region. During lower sea level, the Añasco River discharged sediments directly on the insular slope, and the shelf area was exposed to subaerial erosion. The path taken by the river is marked on the bathymetry by broad areas of gentle terrigenous sediment deposits in the modern environment.

As sea level rose, the higher topography at the edge of the shelf on either side of the river chanel was colonized by reef corals. Many other high areas were colonized at the same time. These may have been erosional remnants or former beach lines. The Añasco River channel has been filled with river sediments where it crosses the shelf, but the former canyon occupied by the river can be seen in seismic profile lines (fig. 13). There is no evidence from the seismic data that faulting has played any part in the formation of this canyon.

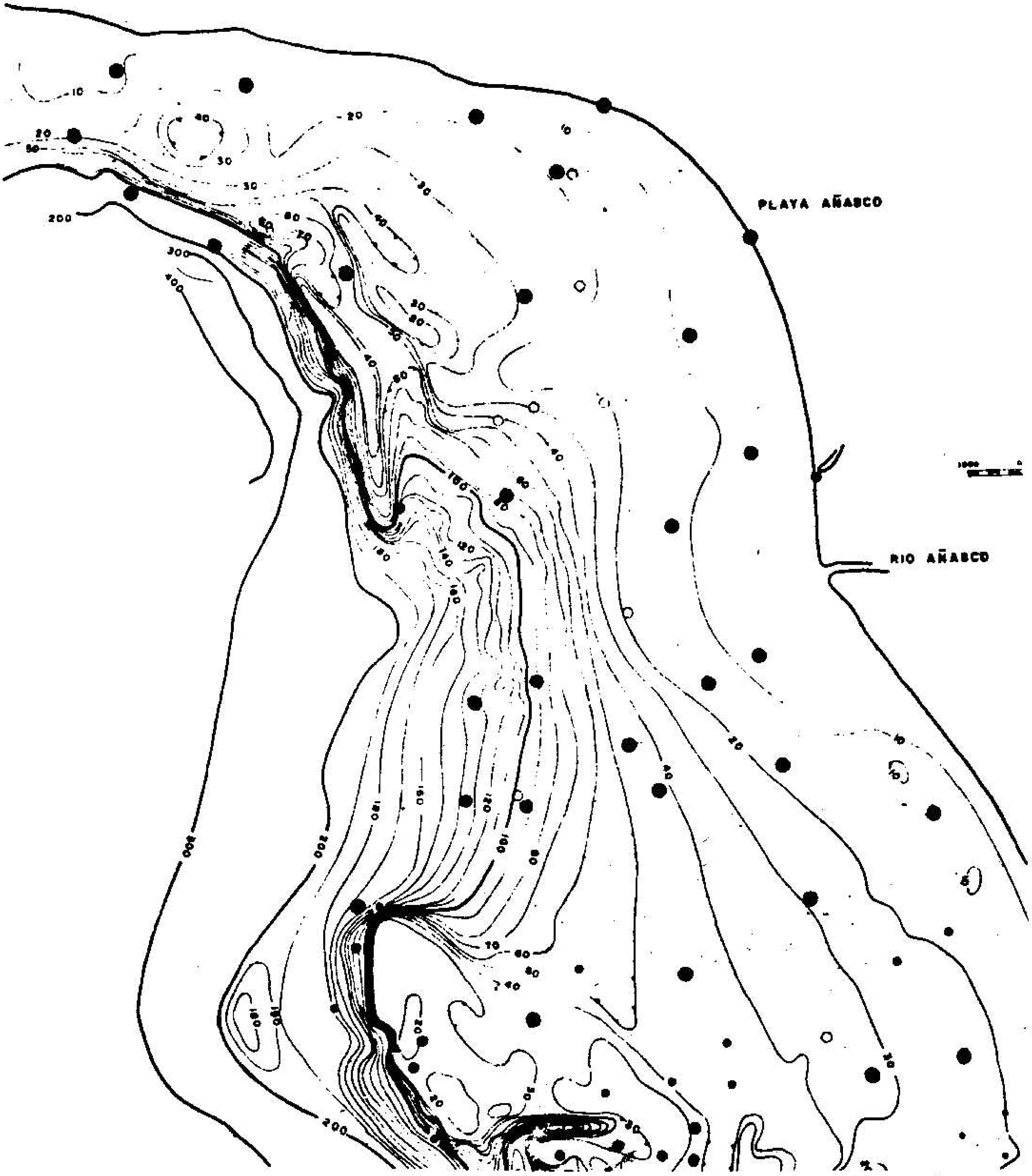

Fig. 12 Añasco Bay bathymetry

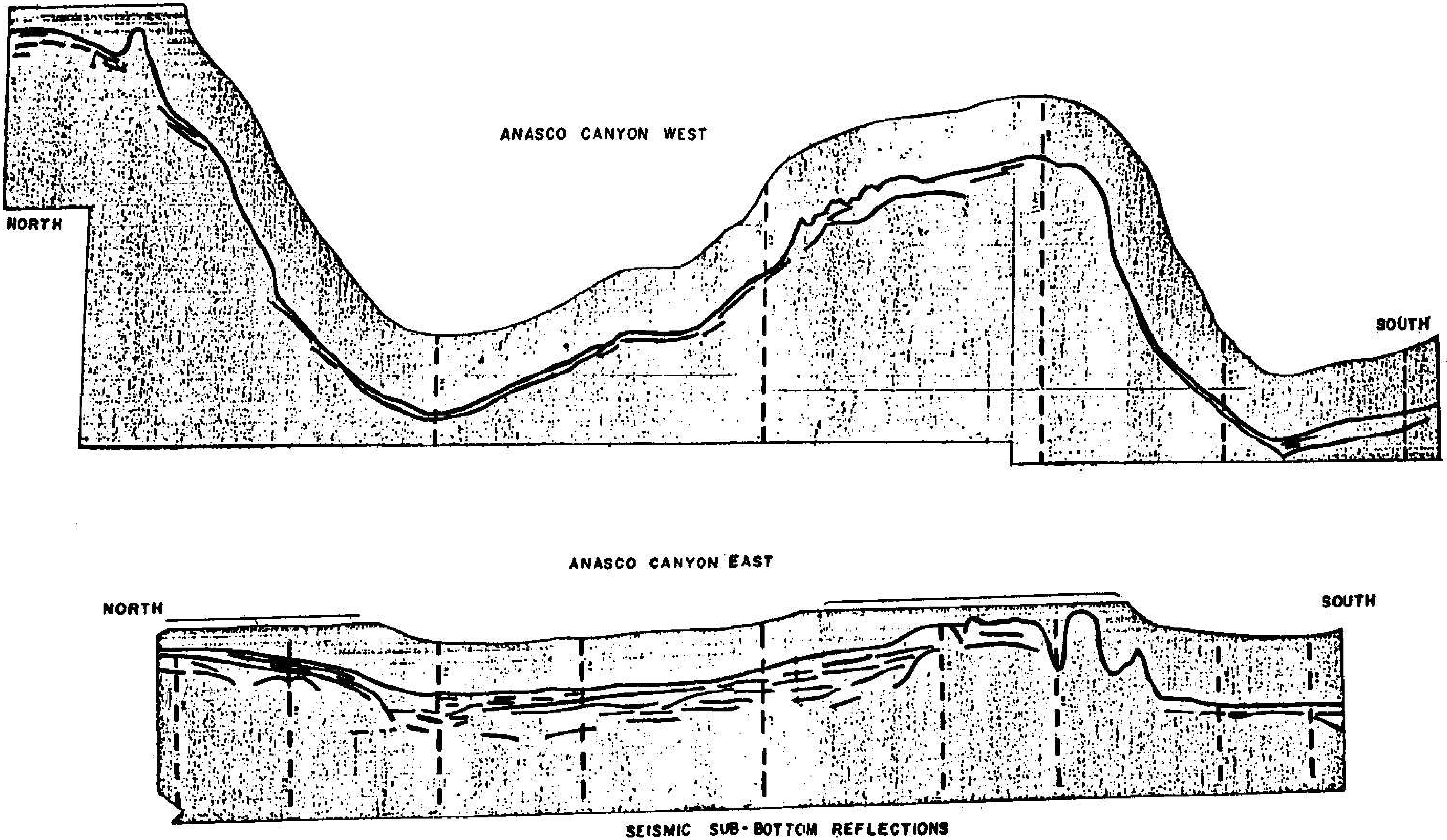

Fig. 13 Shallow sediment stratification in Añasco canyon

Although the northern boundary of the bay is formed by a major fault, seismic surveys done during this study show no evidence of marked faulting in the rest of Añasco Bay.

Current data collected in Añasco Bay has been analyzed by Dr. M. Hernández Avila. This data is summarized in figures 14 and 15. There is a general movement of the surface and near surface waters to the north and northeast in that part of the bay receiving the Añasco River discharge.

Sediment samples have been collected from Añasco Bay. Analysis of grain size, percent calcium carbonate, and organic carbon have been made. Tracing of bagasse fibers was attempted by binocular microscope study. Because of the fine size of organic detritus on the shelf, sugar cane fiber identification could not be done with the binocular microscope.

There are two major facies of sediment deposition in Añasco Bay (fig. 16). The carbonate reef facies are biogenic deposits formed by coral and associated reef organisms. This facies may be divided into two sub-facies; areas of bare rock and thin patches of shell sand and gravel, and near reef sediments with a gravelly sand texture and high carbonate content mixed with terrigenous sands. This facies is limited to the vicinity of active or recently active coral reefs. These sediments are more than 50 percent calcium carbonate and are biogenic sediments formed in the reef and near reef environment. The sediment pattern and bottom topography are directly related, and all of the topographic highs are a result of biogenic activity except for the accumulation of terrigenous sands at the mouth of the Añasco River (fig. 17).

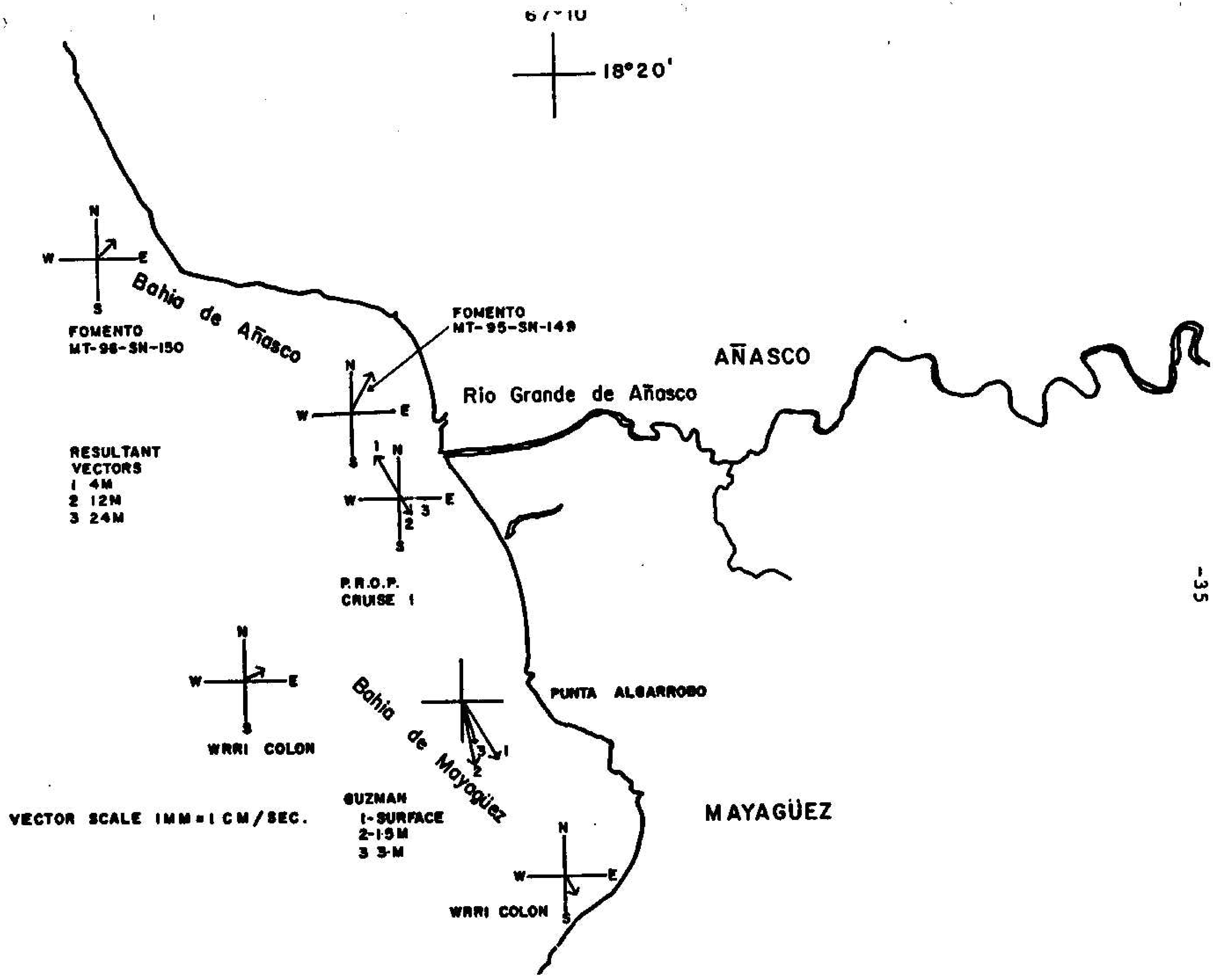

Fig. 14 Current mean resultant vectors in Añasco-Mayaguez Bays

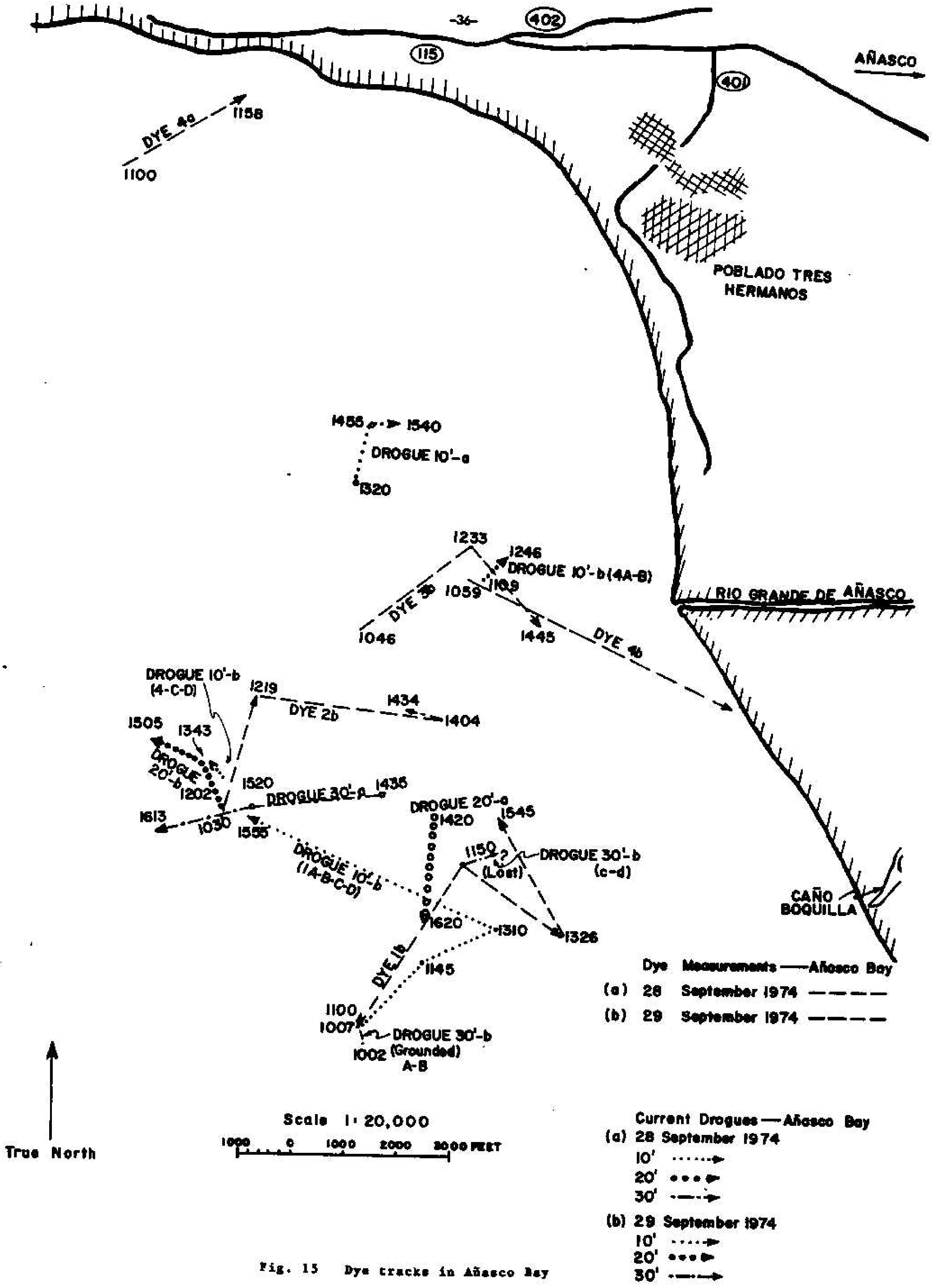

Fig. 15 Dye tracks in Añasco Bay

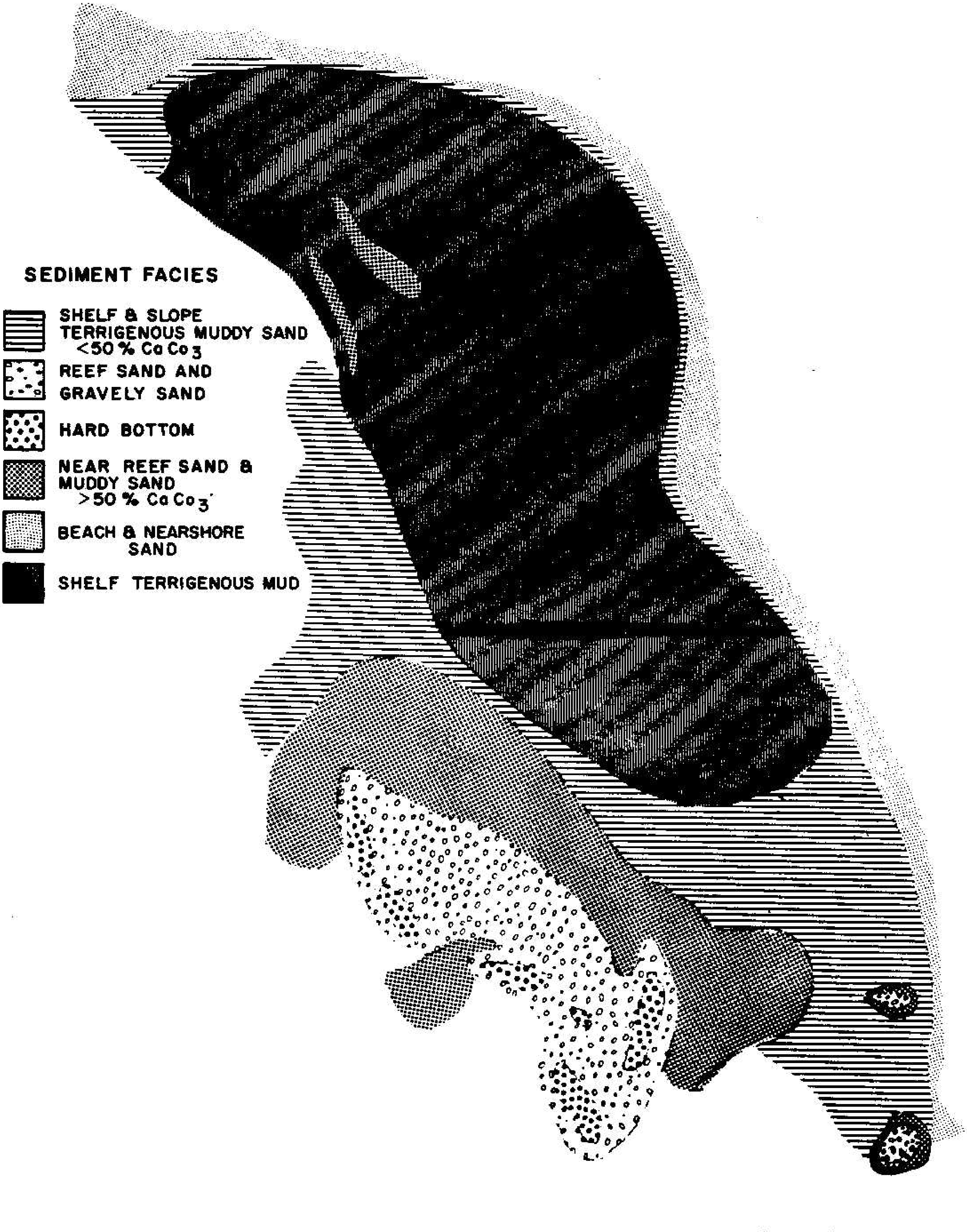

Fig. 16 Sedimentary facies in Añasco Bay

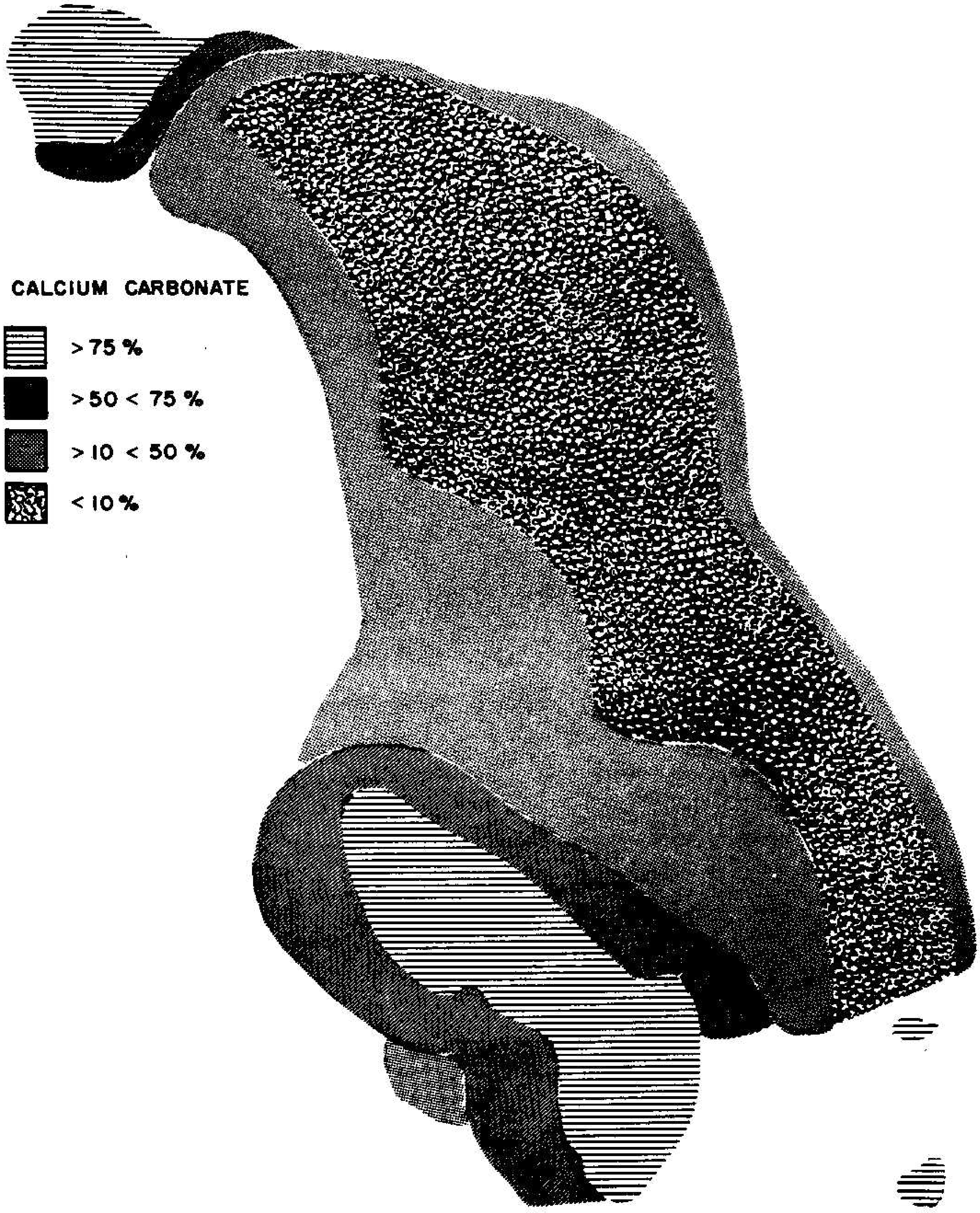

Fig. 17 Distribution of calcium carbonate in Añasco Bay

and alluvial plain.

Sediments from the river are well sorted, fine-grained terrigenous sand composed of rock fragments of volcanics (andesite and basalt) and fragments of volcanic clastics. The dominant red-brown color is due to oxidized material, possibly laterite, which is quickly removed after short transport in the beach system. There are three distinct sub-facies on the basis of textural characteristics (fig. 18). Each of these sub-facies is similar in mineralogical composition and common in having a low calcium carbonate content, but the size distribution is distinctly different.

The beach sand system lies between the shore and the 10-foot contour line. This is an active zone of longshore transport and cyclic onshore-offshore sand movement. The beach and nearshore sediments are fine to medium grained well sorted siliceous sediments derived from the Añasco River drainage basin. The dominant components are quartz, volcanic rock fragments, and feldspar. There is some shell material in the bar, approximately 30% by grain count and recent carbonates consisting of fragments of coralline algae, echinoderm spines, and mollusk shell material. Foraminifera are common, and the tests of *Rotorbinella rosa* predominate.

Terrigenous sands and muddy sands dominate the southern shelf and the Añasco slope. These are derived from the river directly from the offshore migration of the beach sands and, in part, from the

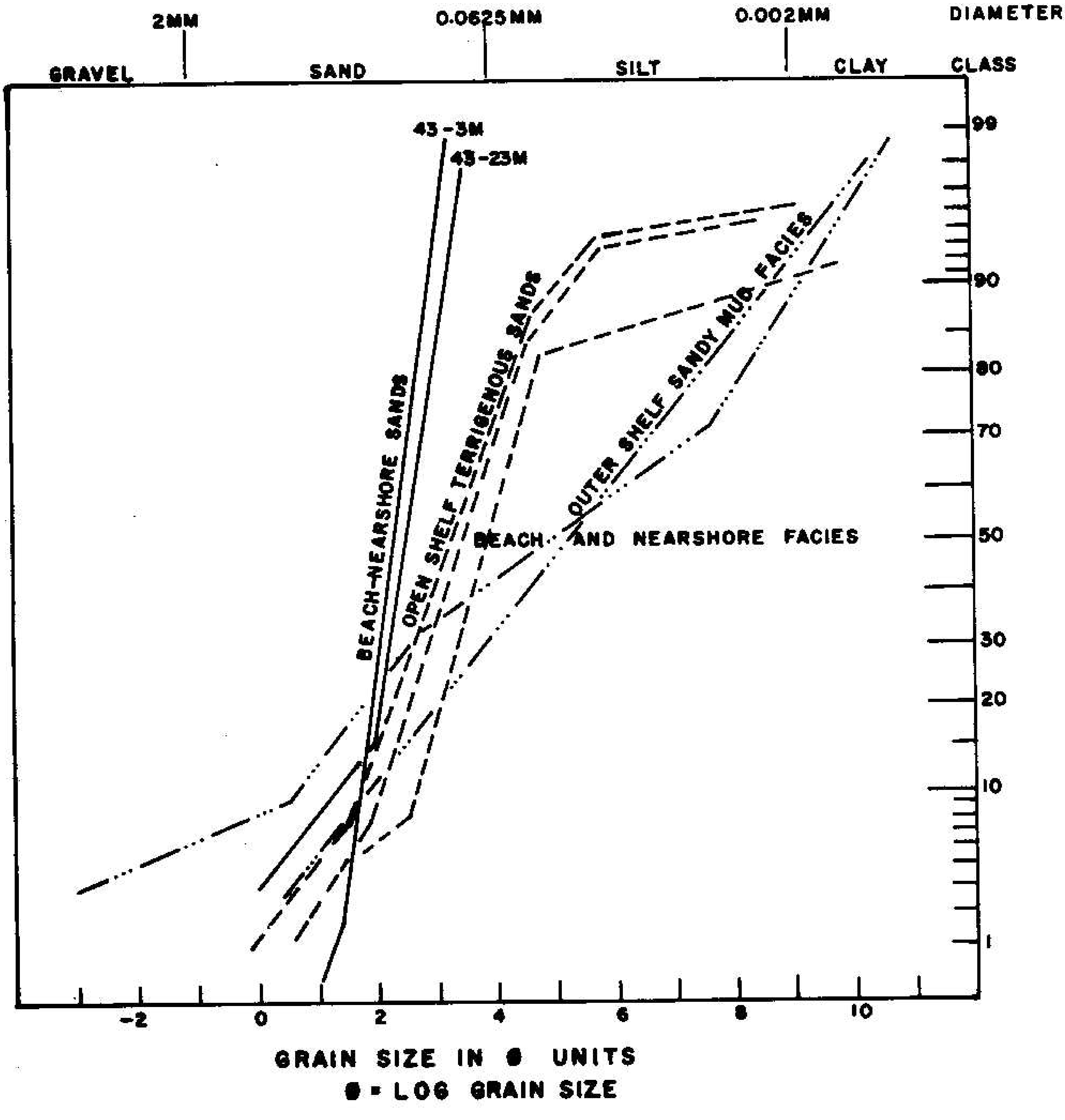

Fig. 18 Terrigenous sediment sub facies

reworking of relict sands of beach lines left behind by the advancing seashore as sea level rose. These sands are poorly sorted and generally finer grained. The third sub-facies are muds of similar mineralogical composition found in the river and on the southern shelf. These are very poorly sorted sediments.

The textural parameters are summarized in Table 8. The first two sub-facies (beach and shelf slope muddy sands) contain almost no organic material. Wave energies are sufficiently high to prevent the deposition of organic debris. There are scattered organic debris in the fine grained shelf mud facies. Figure 19 shows that stations associated with the shelf mud facies contain up to 2.5% organic carbon. Study of the organic fraction under the binocular microscope revealed that most of the detritus was derived from vascular plants indicating a land source. Although detritus from various sources was observed owing to the small size, no definite identification could be made for the components of the fraction.

The Añasco river is the only major source of vascular plant detritus to the Añasco shelf. The distribution of bagasse from the surgar mill should then follow a pattern similar to that determined for easily oxidizable organic carbon (fig. 19). The contribution of cane waste to this fraction, however, could not be determined.

There is a definite correlation between sediment grain size and organic content on the Añasco shelf. The organic detritus is basically limited to areas of muddy sediment deposition.

Table 8. Grain size parameters for sediment grab samples

Environment	Sample Number	Mean Size ϕ Units	Sorting ϕ Units	Descriptive
offshore & dredge	1	6.9	3.7	very poorly sorted
	9	7.23	2.72	very poorly sorted
open shelf	6	2.63	1.15	poorly sorted
	19	2.67	1.3	poorly sorted
	31	3.43	1.15	poorly sorted
	32	3.27	1.15	poorly sorted
	34	4.10	1.25	poorly sorted
reef areas	2	1.17	1.35	poorly sorted
	3	.57	1.75	poorly sorted
	4	.43	2.25	very poorly sorted
	41	3.53	.90	moderately sorted
nearshore	29	3.03	.45	well sorted
beach	43.3	1.2	.47	well sorted

Fig. 19 Distribution of organic debris in Añasco Bay

SUMMARY AND CONCLUSIONS

Research data show periodic degradation of water quality in the lower Añasco River as a result of pollution from sugar cane wastes. The combination of sugar cane milling and low river discharge during the dry season results in accumulation of organic waste within the estuary. This accumulation is largely controlled by position of the salt wedge. During this period, dissolved oxygen levels are extremely low and anoxic conditions are approached.

There is also a physical filling of the river channel during this period.

During the rainy season, higher flow conditions result in a flushing out of the organic debris and a restoration of higher oxygen levels. The debris are carried into Añasco Bay and spread with the fine grained sediments. Most of the material is deposited in the northeast corner of the Bay where current, wave, and geomorphic features result in a quiet water bottom regime.

The general level of organic accumulation in Añasco Bay is low, and no adverse effects on the environment have been noted.

The seasonal migration of the salt wedge over large distances should be considered by the agencies planning to use river water for agricultural and industrial purposes.

It is suggested that more extensive physical studies be made concerning the salinity distribution and circulation in the estuaries of Puerto Rico. Permanent monitoring stations should be established in the vicinity of pumping stations to record velocities and follow the movement of salt waters upstream.

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