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Rio de la Plata Estuary Environments

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ABSTRACT

The Rio de la Plata is an estuary 220 kilometers long and 35 to 230 kilometers wide. The upper river has a fresh-water environment where the Uruguay and Parana River systems converge. The Parana River is building a delta in the upper Rio de la Plata. The hydraulic system has an average yearly discharge of 25×10^3 cubic meters per second, which is controlled in part by wind and tidal action.

The mouth of this estuary is open to the sea. Because the tide, tidal currents, wind, and waves affect the fluvial discharge, the river flow is not continuous.

More than 2,000 measurements of suspended load show that solid sedimentation is jointly affected by tide and currents, and apparently the salt water influence on sedimentation is less than that of dynamic action.

The collection of more than 1,000 bottom samples shows that over the estuary bottom lie silty sand and silty clay. The river sediment supply consists mainly of silt and clay. In the upper estuary the sand is scarce and localized to banks, bars, and northern coast beaches. In the outer estuary a sand carpet extends from the inner continental shelf into the estuary. These are relict sands of the last Holocene transgression which invaded the estuary between 7,000 and 3,000 years B.P. After Holocene time fluvial mud facies covered, in part, the transgressive sands. The south coastal environment is estuarine, with its maximum development in Samborombon Bay. The north coast is rocky and sandy with pocket beaches. The regional estuarine environment is mostly fluvial, but the mixing of ocean waters creates a gradual change from fluvial in the upper river to fluvio-marine and marine in the outer river.

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INTRODUCTION

The Rio de la Plata is a large, funnel-shaped estuary found at lat 35° S. on the east coast of South America. It is the focus of drainage of the vast Parana-Uruguay hydrographic basin, largest in South America after the Amazon River. This hydrographic complex drains a basin of 3,170,000 square kilometers which originates in Brazil in the Sierra do Mar, the Mato Grosso Plateau (200 to 700 meters in altitude), and in the Subandean Ranges in the northwest of Argentina

Figure 1. Physiography, geography, and prevailing winds in the Rio de la Plata area. 1 = Brazilian shield; 2 = Pampas Plains; 3 = Parana delta and delta plain; 4 = Southern Entre Rios coastal plain; 5 = Buenos Aires coastal plain.

URIEN, FIGURE 1
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and the south of Bolivia (3,500 to 4,000 meters in altitude). Runoff from this hydraulic basin flows through the Parana-Uruguay junction at an average discharge of 23,000 to 28,000 cubic meters per second.

The Plata is located between latitude 34° and 36°10′ S. and between longitude 55° and 58°10′W. It covers 35,000 square kilometers, is 270 kilometers long, and its width varies from 32 to 230 kilometers (Fig. 1). The width of 230 kilometers is taken at the outer boundary of the river by agreement between Argentine and Uruguayan governments. This water body is formed by the junction of the Parana and Uruguay Rivers. The former is currently building a modern delta into the upper Plata.

This investigation was carried out by the Argentine Hydrographical Service during the years 1963 to 1967. This paper deals with part of the hydrographic, oceanographic, and geological aspects of the problem and is, in fact, a compilation of several reports outlining the characteristics of the region (Ottman and Urien, 1965a, 1965b; Urien, 1966, 1967; Urien and Mouzo, 1967).

About 1,000 bottom samples were studied to learn the general sedimentary distribution, and more than 2,000 water samples were collected for suspended load and salinity determinations.

GENERAL SETTING

Geology

The Brazilian shield is the fundamental geotectonic unit in eastern South America. This positive and rigid crystalline mass includes the Uruguayan nucleus, the western border of which is scalloped where the Parana basin lies. This is an inter-cratonic basin (Harrington, 1956) with epicontinental structure. The initial deposition occurred during Devonian time (Gondwanic series) and was followed by basaltic lavas and red beds. Finally, marine continental Tertiary sediment filled the basin. The Uruguay basement, southernmost sequence of the Brazilian shield, is interrupted on the south by an east-west fault which controls the shape of the Salado basin. More than 7,000 meters of Cretaceous to Tertiary sediments were deposited in this basin, and then they were covered by Pleistocene loesslike silt (Pampeano Formation).

Recent movements along the east-to-west trending faults and recent tilting were responsible for the formation of Rio de la Plata immediately north of the Salado basin axis, during the upper Tertiary and Quaternary. As a result of this tectonic pattern the Rio de la Plata lies against the southern border of the Brazilian shield.

Older rock outcrops exist only on the Uruguay coast, while the southern (Argentine) side of the Plata is exclusively covered by reworked Quaternary sediments, primarily loess. The latest elements of the geologic column are completed with the modern sediments of the Plata region and associated coastal plain. They date from late Pleistocene to Holocene. This stratigraphical succession, as inferred from outcrops, surface samples, water wells, acoustic profiles, and radiocarbon dates is as follows:

	Depositional environment	*Sediment type*
Modern suite (Holocene)	Modern Parana delta	Sand to silty sand
	Samborombon Bay and beaches	Clay to silty clay and sand
Old sands (late Pleistocene lower Holocene)	Inner shelf deposits	Sand, shells
	Barrier complex	Shelly sand
	Coastal plain	Sand, copious silts

The terms *modern suite* and *old sands* are used to differentiate two contrasting bodies of sediments. Thus the old sand, dated by radiocarbon between 11,000 and 6,000 years B.P., is a very well defined blanket-shaped body which corresponds to the Holocene transgression. The modern suite results from deposition after sea level was established about 3,000 years ago. Deposition took place in the upper Rio de la Plata where the modern delta is building and created an offlap onto the old estuarine sediments.

Climate

The climate is humid, temperate, and rainy. The median annual temperature is 16°C with a maximum temperature of 43°C and a minimum temperature of -5.6°C.

The yearly average rainfall is 960 millimeters with precipitation of 111.9 millimeters in March (rainy season) and 48 millimeters in July (dry season). The evaporation rates are high (1,181 millimeters per year).

The predominant wind directions are from the southwest in the upper river and from the northeast at Montevideo, Uruguay (Fig. 1). Additionally, a sporadic onshore wind from the southeast is important in that it is a good wave generator and significantly modifies tides and river flow. The southwestern, cold, dry wind blows out of the Argentine plains. When this wind contacts the humid, warm Brazilian air mass, a zone of instability is created and precipitation occurs.

BATHYMETRY OF THE ESTUARY

The estuary is limited in the north by the Uruguayan highlands and by the Buenos Aires Pampas Plains in the south (Fig. 1). At the eastern end the Parana River is building a modern delta at a rate of 1.6 square kilometers per year, with two principal distributaries, Parana Guazu and Palmas. The estuary is very shallow and has an average depth of about 1.20 meters in the upper river and 16.5 meters in the outer river.

The most important channel is the continuation within the upper Plata of the Uruguay and Parana River junction. This channel follows the north coast, a course that subsurface geology indicates is structurally controlled. It has a deep channel and bars system. Near Colonia the "principal channel" bifurcates. A small channel flows between the Uruguayan coast and the Ortiz bank with a depth of about 3 to 6 meters. The main channel crosses the estuary toward La Plata and continues parallel to the coast seaward with an average depth of 8 meters. It limits the southern flank of the Ortiz bank, and it is in this channel that most of the river flow is concentrated. It is the only navigable route into the estuary.

At the boundary with the outer Plata estuary, the channel is deflected against the Uruguayan coast by the Archimedes and English banks. This channel, bordering the northern coast, has a depth of around 40 meters. This channel has been traced onto the inner continental shelf by bottom profiling as far north as the vicinity of the Rio Grande. In that section it is called Pozos de Fango (Mud Well, Fig. 1).

Major Bathymetric Zones

The Rio de la Plata is divided into three zones: upper, intermediate, and outer.

In the upper estuary (Fig. 2), the lobate submarine delta platform is limited in the north by the Martin Garcia pass, the main channel. The delta platform has a fan with a very gentle slope and a depth of 1 to 4 meters (Playa Honda).

The Ortiz bank (Fig. 1) and principal channel are the two most important features in the intermediate river. The Ortiz bank, separated from the Uruguayan coast by the minor north channel, is a very extensive shoal, perhaps a submerged coastal plain, which is only 3 meters at its deepest.

The outer river (Fig. 1) is the most extensive zone of the region and has four distinctive features: (1) a deep northern channel already described; (2) Archimedes and English banks, very stable banks composed of indurated sediments that are exposed at low tide and that divide water movements in the estuary; (3) Samborombon Bay, which is very shallow (2 to 5 meters) and is limited on the north by Punta Piedras, a Pleistocene wave-cut platform, and on the south by Punta Rasa, a sandy spit; and (4) in the central outer estuary, a very gentle plain that extends to the south continuously out to the inner continental shelf. To the northeast is found a system of sandy-shelly ridges trending northeast that form a submerged barrier coast complex (Urien, 1967; Urien and Mouzo, 1967).

OCEANOGRAPHY

Tides and Salinity

The dimensions of the Rio de la Plata are such that its natural period of oscillation is nearly that of the semidiurnal tide. The incoming tide is deflected toward the south shore of the estuary (Coriolis effect; Balay, 1961), yielding greater tidal amplitudes than along the north shore (Table 1). In Samborombon Bay there is a counterclockwise system of residual tidal currents which flow seaward following the coastline together with fluvial drainage (Fig. 3A). On the northern coast of the outer estuary, river discharge continues to flow out through the north channel while the tide is rising until the full tide reaches a line from Piedras to Montevideo. At the time of full tide the Plata discharge is completely stopped at this point.

Because the normal tidal interval is 12 hours 30 minutes and the estuary is so long, two or three tidal stands exist within the estuary at any given time. These tides are not symmetrical, because the ebb tide time (7 hours 17 minutes) is greater than the flood tide time. Thus, when it is low tide in Buenos Aires City in the west and Cabo San Antonio in the east, it is high tide in El Codillo (middle of the section), and vice-versa. The astronomic tide is modified by wind particularly from the northwest and southeast sector. It retards or advances the predicted tides.

The tide is also modified by isolated waves like tsunamis or earthquakes, with catastrophic effects in the lowlands on some occasions. Naturally the shallowness

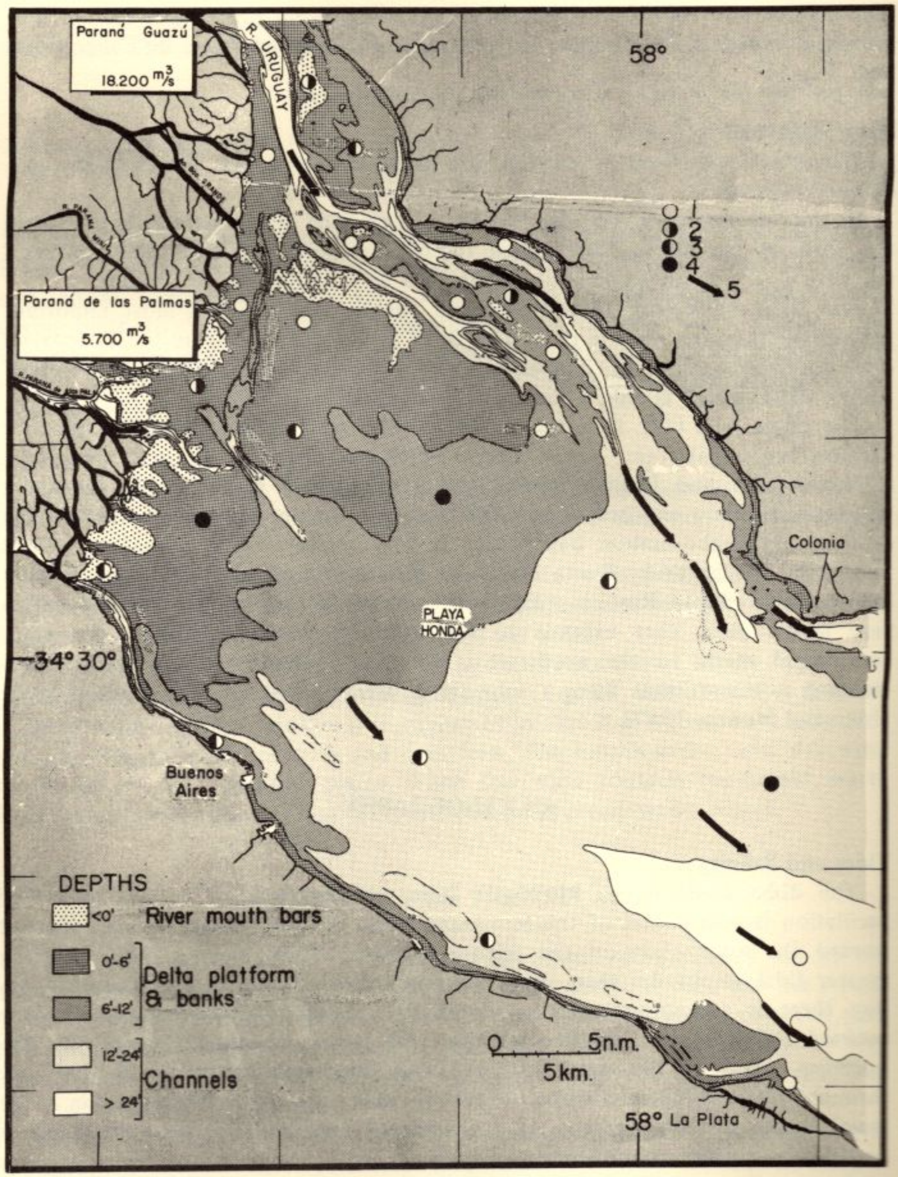


Figure 2. Upper Rio de la Plata bottom morphology and representative bottom sediment types. 1 = sand; 2 = sandy silt; 3 = silty sand; 4 = silt; 5 = directions of ebb currents indicated by arrows.

of the shelf and estuary has a significant moderating effect, damping the energy generated by these waves. One of these phenomena is described by Delaney (1967, p. 7-8) on the occasion of the Good Friday Alaskan earthquake on March 28, 1964. This wave was registered in the mareographs of Montevideo, Mar del Plata, Buenos Aires City and Rio Grande de Sul (Brazil). This wave joined with a strong southeast wind, filled the estuary and covered in part the coastal plain and

TABLE 1. TIDAL FLUCTUATIONS IN THE RIO DE LA PLATA ESTUARY

Locality	Average tide range (meters)
Montevideo, Uruguay	0.6 0,43
C. S. Antonio, Argentina	1.1
Buenos Aires, Argentina	0.8 0,44 - 0,46
Colonia, Uruguay	0.6 0,76
Martin Garcia, Uruguay	0.6 0,47 – 0,30

delta. The superposition of this wave on the tide caused the anomalous rise of the upper estuary level.

The tide helps move marine water into the estuary. The saline water movement is greater on the northern coast through the deep northern channel (Fig. 4a). In Samborombon Bay the saline water movement is quite restricted (Fig. 4b) due to the shallowness of the area. In this way the tide plays an important role in the outer estuary by carrying saline water up to El Codillo under normal conditions. After stormy southeast winds, however, high salinity has been detected near La Plata, but these are exceptional conditions.

A large number of salinity measurements were made in the outer river. One fixed station near Archimedes bank was made for 15 consecutive days (each hour) during each season in three consecutive years (Ottman and Urien, 1965a). At times of westerly winds, when the wind is in the direction of the flowing water, a fresh-water layer is found at the surface. In light wind or absence of wind, the variations in the degree of salinity follow the tide, ranging between 0 to 35°/oo at the surface and 15 to 36°/oo at the bottom (average 21°/oo). Currents are closely related to the tides, in general.

Currents

Unfortunately we have insufficient current measurements in the estuary to give a complete current pattern, but the Hydrographic Survey is currently completing the field work. It is, however, possible to distinguish two kinds of currents: tidal and fluvial. Both are strongly interrelated. Tidal currents follow the astronomical tide, with some retardation by friction and fluvial influence. They reach 1.5 meters per second in the outer estuary and from 0.2 to 0.7 meter per second in the upper estuary (Fig. 3B). Tidal current has an important influence on salinity distribution and variations.

The fluvial current was measured in the mouths of the Parana distributaries as well as at some locations upstream. No current inversions are registered as far downstream as the delta distributaries, which experience only a reduction in their flow at high tide.

In the upper estuary the highest current values are found along the north coast in the Martin Garcia pass (1.7 to 2.0 meters per second). This is because of the junction of Parana Guazu River group with the Uruguay some kilometers upstream from Martin Garcia (Fig. 1).

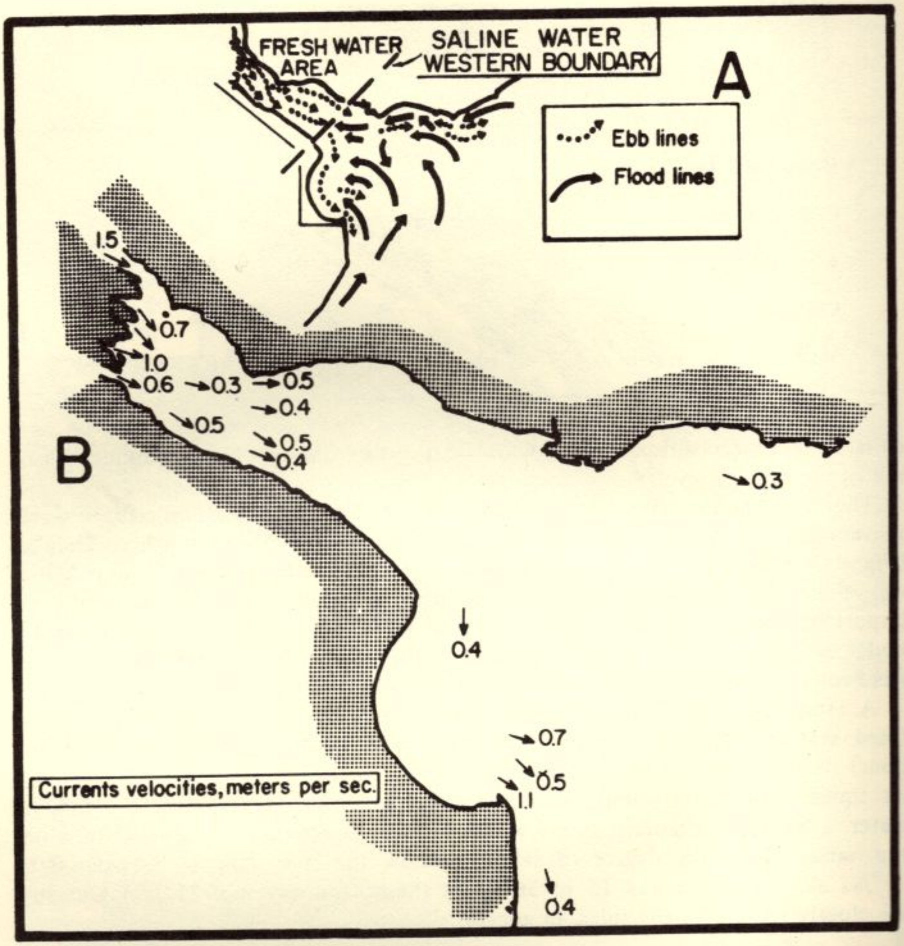


Figure 3. Circulation patterns and ebb current directions in the Rio de la Plata estuary. A = directions of net ebb- and flood-water movements; B = ebb current velocities at different stations.

Slight rotary tidal currents are observed in the outer river. They follow a counterclockwise direction and join so that ebbing fluvial water moving seaward meet, flooding the marine water (Fig. 3a). Perhaps these residual tidal currents are responsible for the sediment deposition in the inner Samborombon Bay (Fig. 5).

SEDIMENT SUPPLY AND DISTRIBUTION

According to the present surface sedimentary pattern shown in Figure 5, and the fluvial and marine influence on the estuary, three sources of sediment supply may be distinguished: (1) sediments carried from the Parana River system, mostly silty clay and minor amounts of sand (Urien, 1966); (2) sand transported by the Uruguay River and sand derived from wave action along the northern Plata River coast; and (3) relict sand and shell sediment, which filled the estuary during the Holocene sea level transgression (Ottman and Urien, 1965b; Urien, 1967).

TABLE 2. AVERAGE SUSPENDED SEDIMENT LOAD OF THE PARANA RIVER DISTRIBUTARIES AND THE URUGUAY RIVER

Locality	Discharge m^3/sec.	Total load tons/day
Parana Guazu River at Point Constanza	17,000	164,851
Parana Palmas River, near mouth	5,100	34,560
Uruguay River at Point Gorda	4,200	19,000

Parana River Sediments

During the course of this study more than 2,000 suspended sediment load measurements were taken in the Parana distributaries, the Uruguay River, and the Plata estuary. Those measurements show that the bulk of sediments are carried by the Parana River to the Rio de la Plata (Table 2). The suspended load delivered to the upper Plata is between 75 and 150 milligrams per liter. It consists of 75 percent coarse-to-medium silt, 15 percent fine-to-very fine silt, and 10 percent clay, and has a mean diameter of about 5.8 ϕ (0.017 millimeter).

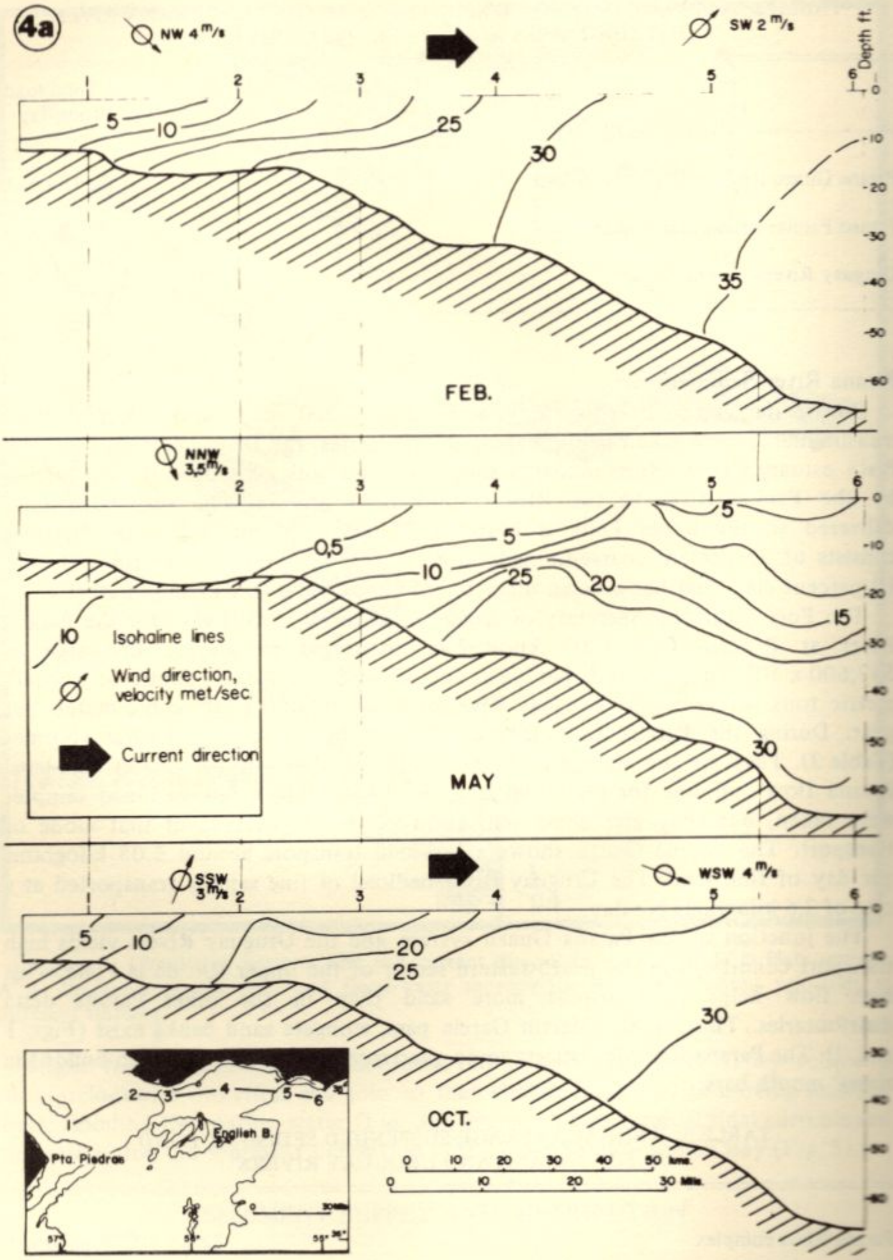
The Port Authority Secretary of Argentina (Tossini, 1959) gave for the Parana River at Rosario City (200 kilometers upstream) an average discharge of 547,600 x 10^6 cubic meters per year and a solid volume of about 55.7 x 10^6 metric tons per year. The Uruguay River delivers 132,800 x 10^6 cubic meters per year. During the Parana Delta Survey the author found very similar volumes (Table 3). They are the average of three periods of observations: two at high-level Parana flow and one for high-level Uruguay flow. Only a few bed-load samples were taken, but they give some indication of the importance of that mode of transport. The Parana Guazu shows a bed-load transport around 6.05 kilograms per day of fine sand. The Uruguay River bedload of fine sand is transported at a rate of 2.6 kilograms per day.

The junction of the Parana Guazu system and the Uruguay Rivers yields high transport conditions in the northwestern sector of the upper Rio de la Plata. This high flow helps to transport more sand than in the other Parana delta distributaries. Thus, in the Martin Garcia pass, elongate sand banks exist (Figs. 1 and 2). The Parana River transports some quartzose sand in its bed which builds the rivers' mouth bars.

TABLE 3. ANNUAL AVERAGE SUSPENDED SEDIMENT LOAD OF THE PARANA AND URUGUAY RIVERS

Parana River complex	72.8 x 10^6 tons/year*
Uruguay River	7.0 x 10^6 tons/year
	79.8 x 10^6 tons/year

*These values correspond to the lower Parana River at Puerto Constanza.



Figures 2 and 5 show that sand is deposited close to the distributary river mouths (bars and banks) and in general remains on the delta platform where the sediment is mostly sandy silt and silty sand with a sand content of 50 to 100 percent (Fig. 6). The mean diameter of these sediments is between 2 ϕ and 5 ϕ. Here the minerals are composed of quartz, epidote, garnet, mica, and iron

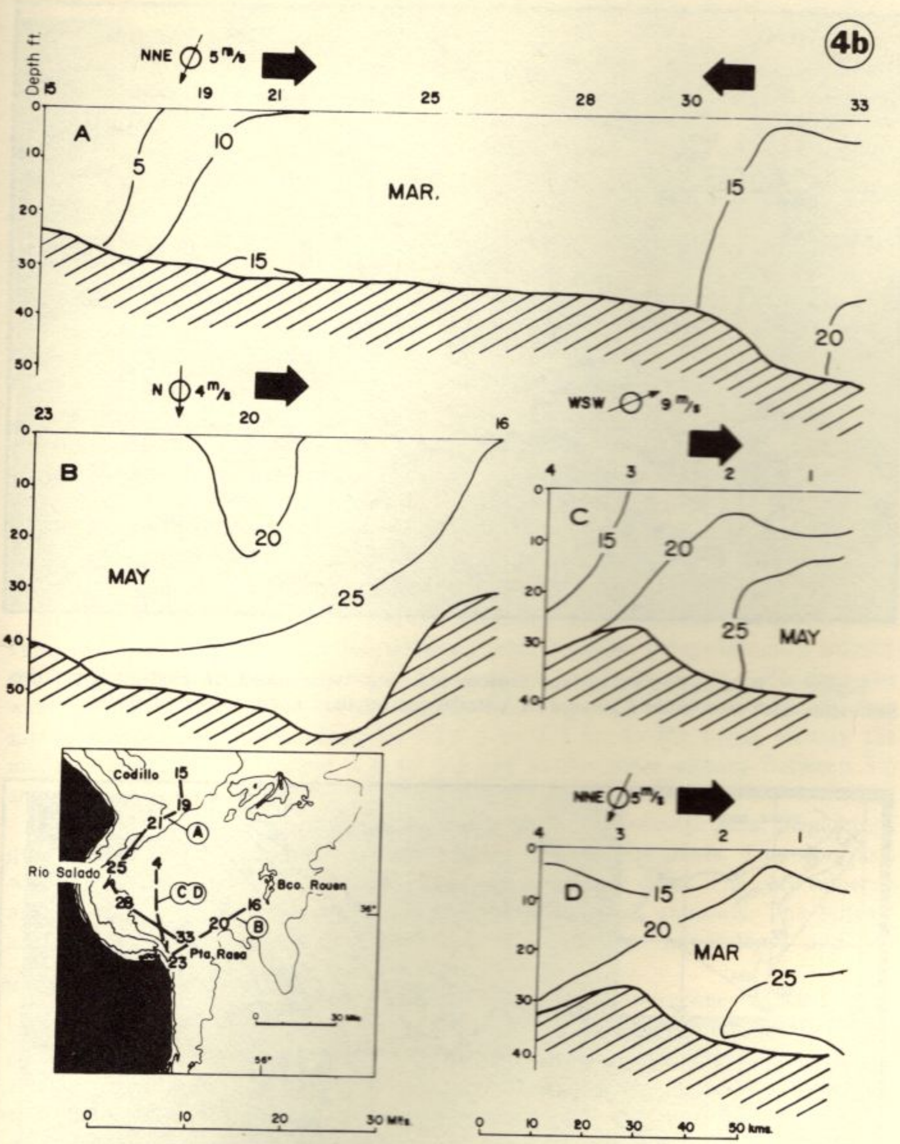


Figure 4. Salinity sections in the northern channel and Samborombon Bay at various seasons. 4a = northern channel in February, May, and October, brackish water rises over saline water wedge; 4b = Samborombon Bay in March and May for two different sections, shallowness of the bay inhibits salt water influx.

aggregates, mostly derived from acid rock (gneiss and granites). One concludes that current velocities in the upper Plata are insufficient for a high sand transport; therefore the bulk of sediments transported into the Rio de la Plata is silt and clay.

The silt covers a very extensive surface in the upper and intermediate Plata,

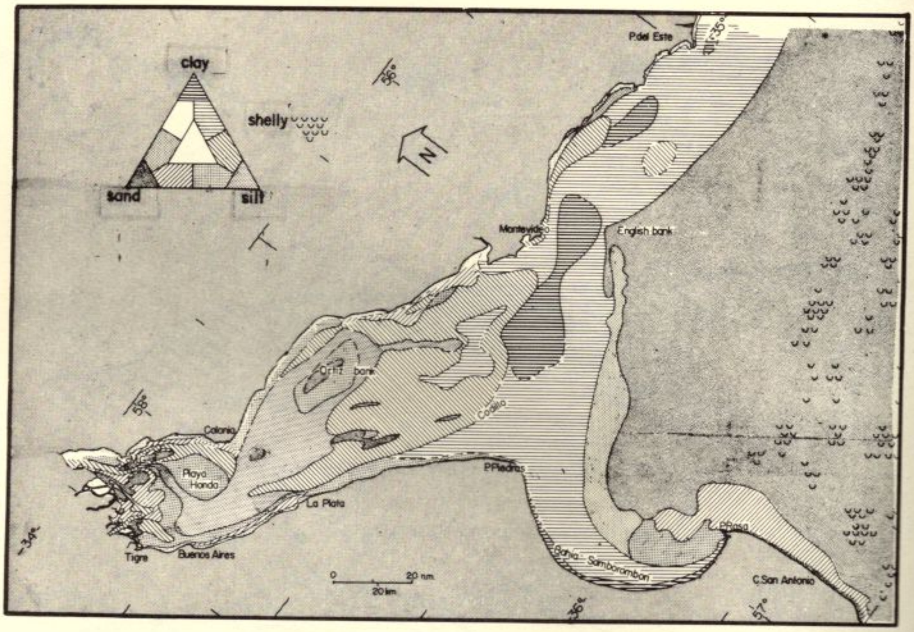


Figure 5. Distribution of surface bottom sediment types based on sand-silt-clay ratios. Sediments with more than 5 percent of material coarser than 1 mm are called shelly.

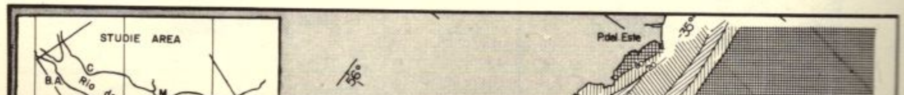


Figure 6. Distribution of percent sand in bottom sediments of Rio de la Plata estuary.

and the average clay content starts to increase markedly at about La Plata. Figure 6 shows that in the intermediate Plata estuary, sand content is low (between 5 and 50 percent). Silt and silty clay are the predominant sediments and lie in general on the eastern side of the Ortiz bank. Sand and silty sand are only present on the western side of the Ortiz bank and on the bank proper. It is believed that the Ortiz bank sand does not result from the present sedimentary regime. This may be a relict sand form from the Holocene transgression, reworked by waves and "cleaned" of clay.

The sediments of the northern shore are sandy and rich in quartz and epidote. They have mean diameters of $2.1\ \phi$ to $1.3\ \phi$. On the southern shore, by comparison, sediments are poor in sand (lower than 20 percent). This silty sand and silty clay ($3.9\ \phi$ to $7.8\ \phi$) is rich in basic rock minerals, which comprise the bulk of the Ortiz bank sands, but north of the bank there is a gradual change from basic to acid rock in the mineral content of the sediments.

Transverse and longitudinal sections in this zone show a suspended load ranging between 5 and 400 milligrams per liter, mostly silt and some clay (Table 4). A possible explanation of this increase in the suspended load from La Plata down to El Codillo is the rising of high-suspended-load currents from near the channel bottom upon the more dense saline wedge at high tide (Fig. 7). This forms a "muddy cloud" in the El Codillo region, which ebb currents move seaward.

Figures 8 and 9 are sections in the northern and southern outer Rio de la Plata which show that suspended solid material increases proportional to salinity rise. High concentrations are near the coast, whereas in the middle river the water is more "clear" than on the shores. The suspended solids are mostly fine silt to coarse clay (modal diameter = $5.6\ \phi$ to $6.5\ \phi$). In the upper estuary the mode is concentrated around $4\ \phi$ to $5\ \phi$ and in the outer estuary between $5\ \phi$ and $8\ \phi$.

The silt fraction in general in the estuary is rich in volcanic glass, plagioclase, quartz, basic heavy minerals, spicules, diatoms, and fiberplants. This contrasts with the acidic nature of the sands in the upper estuary delta. The clay minerals are mostly illite, kaolinite, and montmorillonite in equal amounts. The bottom sediments are similar to the suspended load in clay mineralogy, and the montmorillonite shows some increase seaward.

Urien (1967) and Sieguel and others (1968) show two zones for the outer estuary. One, southwest (Samborombon), is rich in montmorillonite and contains equal parts of illite and kaolinite. The other, northwest (Uruguay), has approximately equal proportions of the three clay minerals. Leveratto (personal commun.) found for the upper river suspended solids that illite plus kaolinite is more abundant than montmorillonite. For the outer estuary the montmorillonite increases relative to the illite and kaolinite. These differences are due perhaps to differential settling velocities of the flocculated clays.

Bonorino (1966) describes the Pampas Plains soils (uplands) as being rich in illite, whereas the coastal plain soils contain a mixture of montmorillonite, kaolinite, and illite in approximately equal amounts. He considers the illite of the Pampeano Formation to have originated mostly from the weathered old acid rock from the Pampean Ranges (Lower Cambrian and Triassic) transported by fluvial and wind action.

Biscaye (this volume), based on the isotopic Sr^{87} to Sr^{86} ratios of whole bottom sediment samples, found for the upper channel high ratios that indicate

TABLE 4. AVERAGE SURFACE SUSPENDED SEDIMENT LOAD AND SALINITY IN THE RIO DE LA PLATA ESTUARY

Locality	Sediment concentration mg/1	Salinity range °/₀₀
Buenos Aires-Colonia		
Spring	55- 75	0-0
Fall	16-100	0-0
El Codillo	57-388	0.2-25.0
Archimedes Bank	23- 87	0.5-20.1
Montevideo (North Channel)	40-120	1.3-27.0
Punta del Este	40-283	8.0-33.0
Samborombon Bay	72-514	10.0-25.0

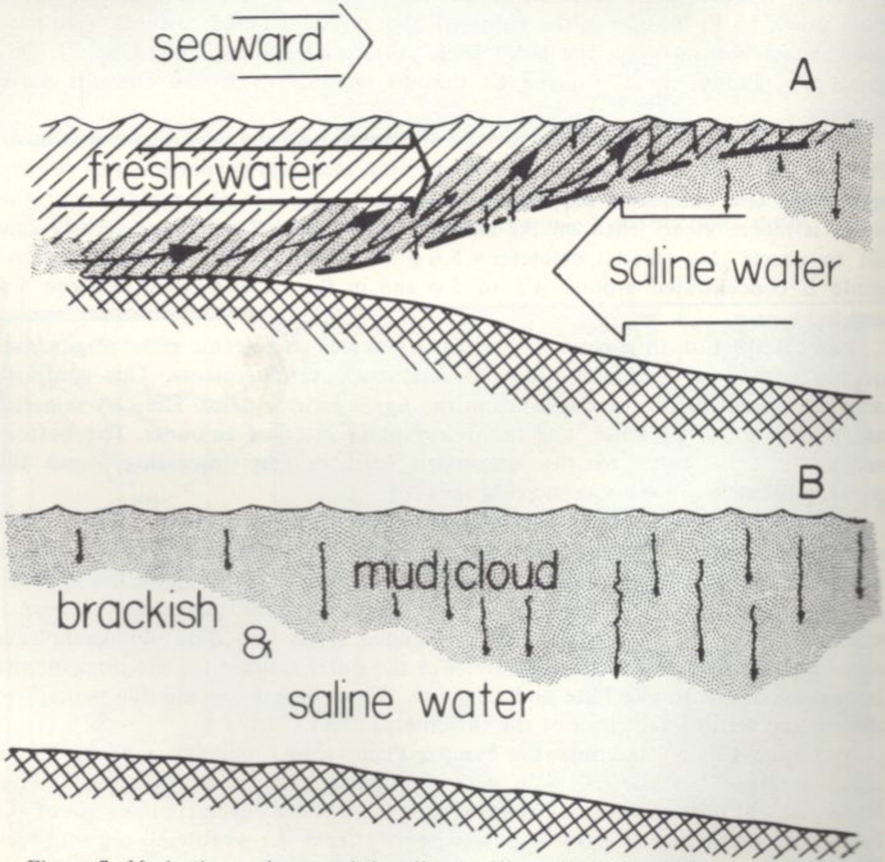


Figure 7. Mechanisms of suspended sediment dispersal and deposition in the Rio de la Plata estuary. A = schematic section showing the saline wedge raising the suspended sediment load derived from the fresh-water upper river; B = schematic section showing settling of the sediment cloud in the saline and brackish water zone as a result of electrolytic action.

acid source rock and for the southern and eastern part of the estuary lower ratios more characteristic of basaltic source rocks.

Uruguay Coastal Sediments

The Uruguayan coast is essentially sandy (with mean diameters of 1.4 to 2.5 ϕ). However, this sand is not derived from the Parana-Uruguay system, but is locally eroded by wave cutting action. Here sand movement is localized on the beach zone by wave transport. Nevertheless, at the present time sand transport is small. The mineral components in the coarse fraction are predominantly acid and metamorphic (quartz, feldspar, iron aggregates, epidote, hornblende, garnet, and zircon). Clay fraction (less than 50 percent) is only found in the channels and with the same characteristics already described.

Relict Sand and Shelly Sediments in the Outer Estuary

In the outer estuary a large sand body extends from the inner shelf into the river. This sand is very uniform in grain size (modal diameter = 2 ϕ to 3 ϕ) and in composition and in certain areas is rich in shell fragments. It has a very particular mineral assemblage corresponding to the classic Pampean-Patagonian suite in which plagioclase, volcanic glass, and basic rock fragments predominate over quartz content. The heavy minerals (augite, hypersthene, and others) are scarce. These outer Plata sands are similar to assemblages on the neighboring Argentine continental shelf and to Buenos Aires beach sands (Teruggi and others, 1959). Obviously, this sand was not transported by the Parana-Uruguay Rivers system but by the sea.

During the Holocene rise in sea level, the marine influence extended into the Plata estuary and produced widespread deposits along the advancing shore line. These deposits could not have been made by the existing current regime, because in Samborombon Bay no westward long-shore process exists. In the neighboring inner shelf the surface sediments are rich in shells and calcareous fragments. They are related to a barrier island complex called the Plata Shoals (Urien, 1967; Urien and Mouzo, 1967), presently covered by the sea. Carbon-14 dates from the surface sediments on this barrier complex suggest no sedimentation during the last 1,600 years.

SEDIMENT DISTRIBUTION AND DEPOSITIONAL ENVIRONMENTS

The environments of Rio de la Plata can be divided into continental, marginal, and marine (Fig. 10). Subenvironments are found also in relation to specific morphologic features.

Continental Environments

The inner fluvial environment corresponds to the upper river delta front platform. Here sand forms river mouth bars (Fig. 2), but sand becomes much less abundant away from the delta front (Urien, 1966). The delta platform is mostly sandy silt and silty sand. In this zone fresh-water conditions predominate and the tide is the only oceanic manifestation.

The outer fluvial environment corresponds to the intermediate river between Colonia, La Plata, and El Codillo (Fig. 1). In this environment the fluvial influence decreases seaward because increased wave development and tidal

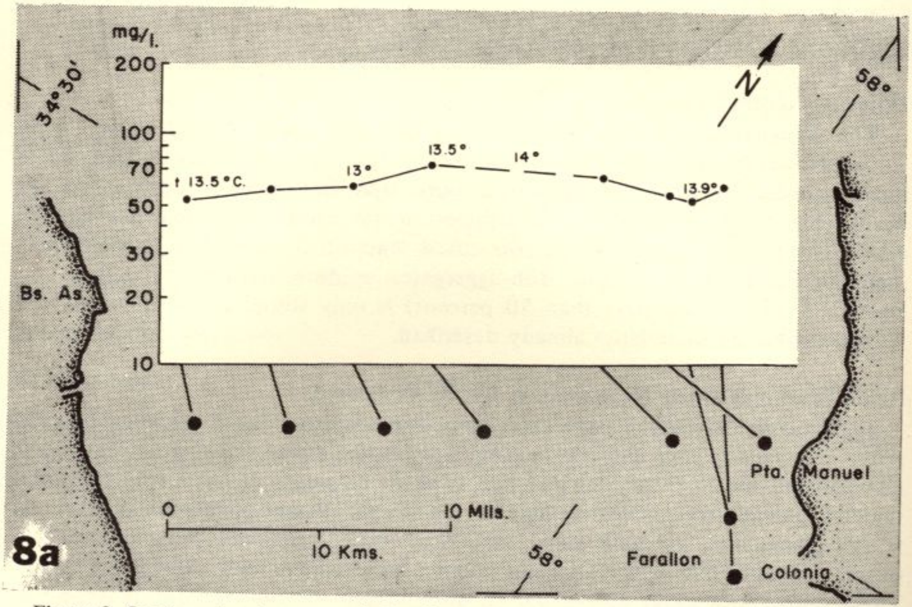


Figure 8. Sections showing suspended sediment load (mg/liter), and temperature (°C) in the middle Rio de la Plata estuary stations in black dots. 8a = section from Buenos Aires to Colonia; 8b = section from La Plata to Colonia; 8c = section from Punta Atalaya to Puerto Sauce; 8d = section from Punta Rasa to Punta del Este (observe the increase in suspended sediment load and salinity near the coast). For geographical location, *see* Figure 1.

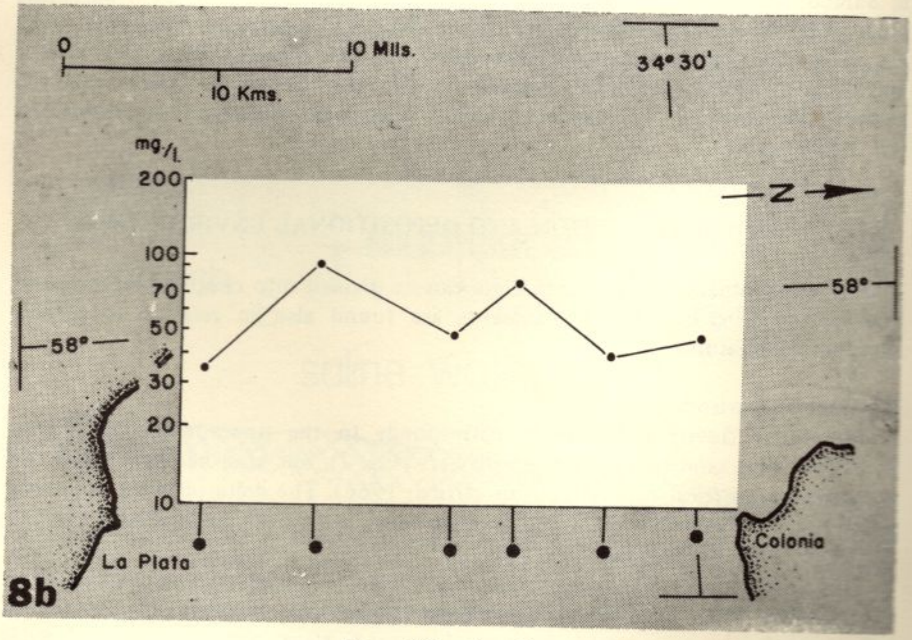


Figure 8 (continued)

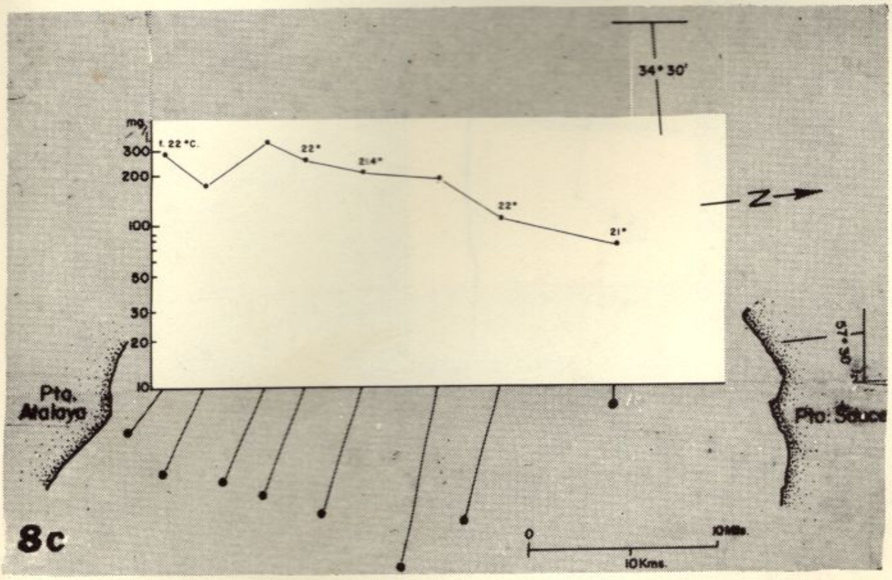
currents affect the river discharge. Some saline water is found in the eastern boundary, but this is also predominantly a fresh-water environment.

Marginal Environments

This environment corresponds to the outer Rio de la Plata. Here marine conditions are predominant (tide, waves, salinity), but the fluvial influence is always present in that the northern channel is the main river extension seaward. This is confirmed through water sampling profiles which show fluvial water draining seaward along the Uruguayan coast. This draining is, as discussed above, influenced by tide and winds. Aerial observations during ebb tide show muddy water branches of the river discharging against the north and south coasts. The southern branch remains semi-enclosed in Samborombon Bay, whereas the northern branch discharges onto the continental shelf. Thus, in the outer estuary the marginal environment may be divided into (1) fluviomarine and (2) bay environments.

Fluviomarine. Most of the river discharge flows out through the northern channel. This channel is covered principally with clay and clayey silt, which extends out onto the continental shelf. On the Uruguayan coast, sand and silty clay cover the near shore area. The south channel side also has increasing sand toward the coast, but here the mineralogical suite is mostly Pampean-Patagonian.

Bay. Samborombon Bay is a shallow open bay in which stable water conditions exist. No high wave action exists in the bay and currents flow far off the shore. The sediments are quite similar to the northern zone. Clay is most abundant in the supratidal mud flats. In the outer bay more than 20 percent sand exists in the surface sediments. This coarse material is brought by waves from the inner continental shelf.



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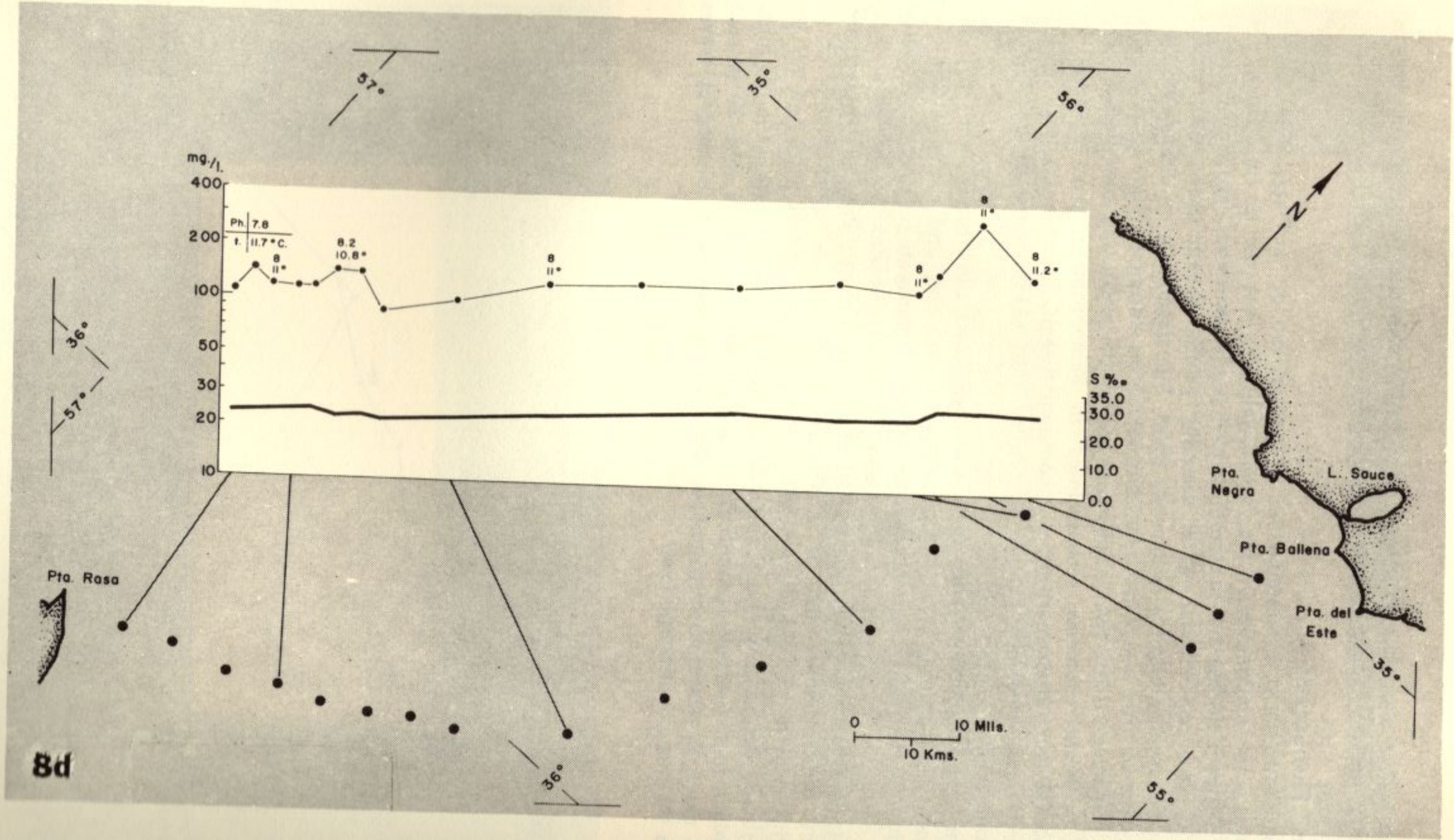

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Figure 8 (continued)

Marine Environments

Here the only river influences are near the northern and southern shores. In the nearshore section sediments carried by the Plata determine the clayey silt and sandy silt textures near the Uruguayan and Cabo San Antonio coast. Along the Uruguayan inner shelf a very deep channel is presently filled by more than 6 to 8 meters of mud as shown by Lamont-Doherty Geological Observatory cores taken in this sector. This is the northern channel extension into the inner shelf.

Except for the channel zone, the marine environment is characterized by a large blanketlike sand body, extending from the inner shelf into the mouth of the Plata. The contact of the sands with the muddy sediments makes a transitional zone of sandy silt and sandy clay textures (Fig. 5). A coarse sedimentary texture is found in the inner shelf with predominance of shells, calcareous fragments, and pebbles. This texture is related to elongate semi-parallel ridges oriented southwest-northeast which correspond to an ancient shore barrier island.

DISCUSSION AND CONCLUSIONS

Three principal sedimentary sources of the Rio de la Plata Recent bottom sediments (Parana-Uruguay Rivers system, Uruguayan coast, and Holocene transgressive sands) can be distinguished by distribution of textures and mineral constituents. The Parana-Uruguay transported sediments and Uruguayan sand beaches are rich in acid-metamorphic rock minerals, whereas the minerals transported from the continental shelf during the recent past are rich in basic elements.

The actual sedimentary pattern is almost controlled by the estuary environments. In the upper and middle river, fluvial fresh-water conditions exist. Here tide and waves come from the east and control the fluvial discharge and sediment dispersion. In the outer river the fluvial discharge has influence only along the

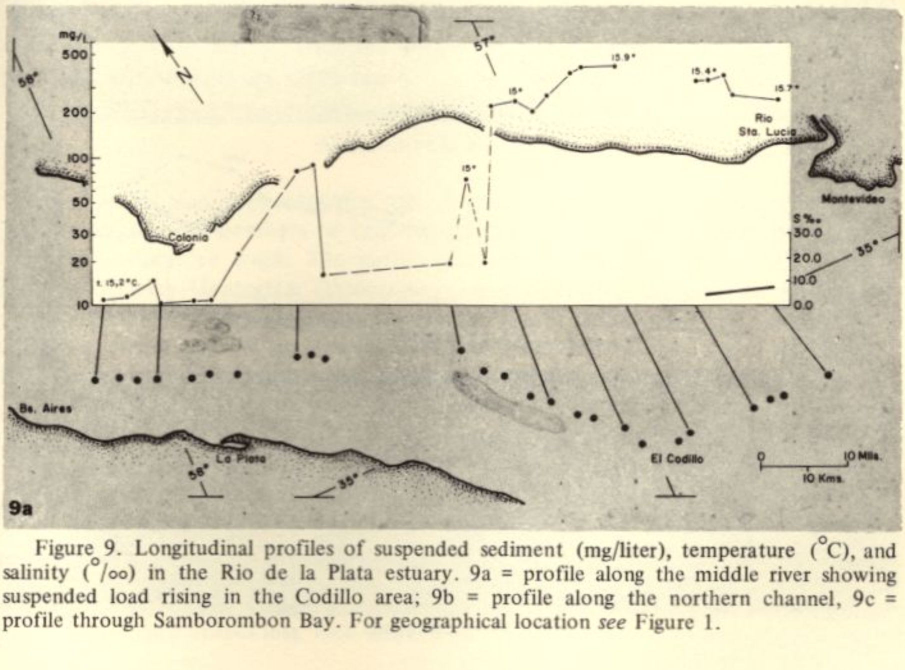
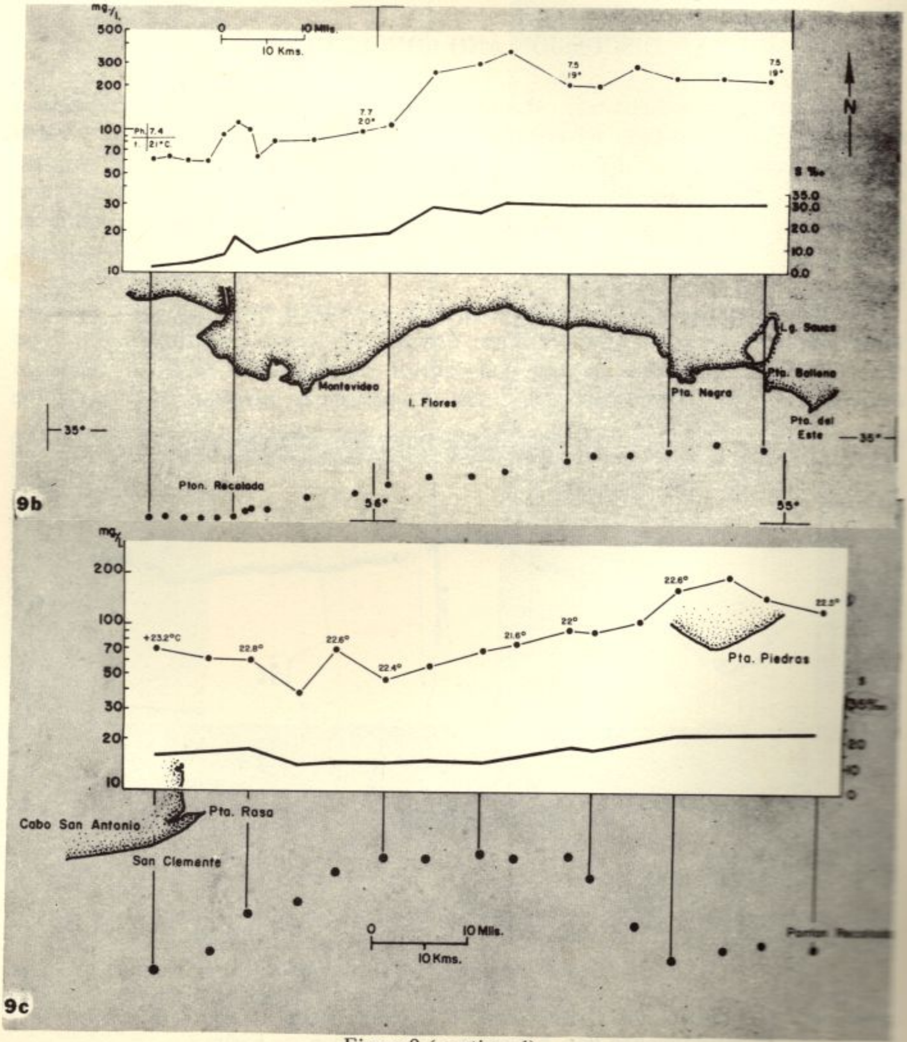


Figure 9. Longitudinal profiles of suspended sediment (mg/liter), temperature (°C), and salinity (°/oo) in the Rio de la Plata estuary. 9a = profile along the middle river showing suspended load rising in the Codillo area; 9b = profile along the northern channel, 9c = profile through Samborombon Bay. For geographical location *see* Figure 1.

coast, particularly helped by the bottom estuary topography. The bulk of fluvial discharge flows out more readily through the northern channel, whereas the shallowness of Samborombon Bay protects it from wave and current action and encourages the deposition of fine sediments. Muddy flats are well developed there.

The contrast between the present sedimentary textures aids in understanding the evolution of estuary events in the last approximately 7,000 years (based on carbon-14 dating). Two very well defined facies can be found here: onlap sandy facies (marine) and offlap silty muddy facies (fluvial). The first was contemporaneous with the Holocene transgression (known in Argentina as Querandino Formation), which advanced within the estuary as far as the present Parana delta plain. With sea-level stabilization, approximately 2,000 years ago, the marine conditions in the upper river were progressively replaced by fresh-water condi-



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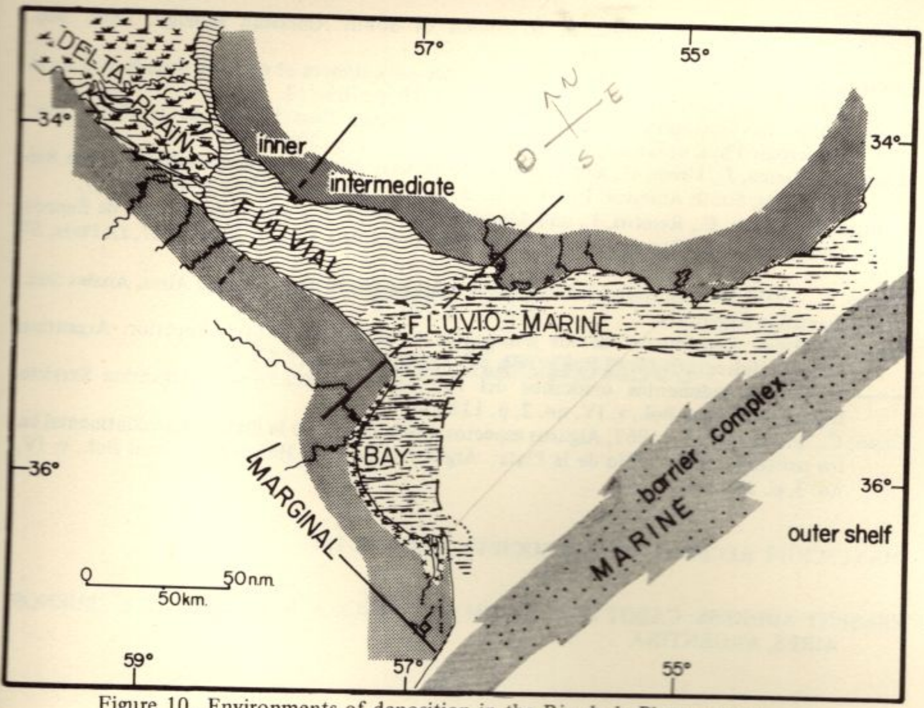

Figure 10. Environments of deposition in the Rio de la Plata estuary.

tions. The general environmental pattern is now fluvial in the upper and middle river, marginal in the external river, and marine in the eastern zone. The sedimentary pattern shows an offlap muddy facies partially covering in the middle and outer river the old, onlap, transgressive sands. This distribution maintains a close relation with the present estuary environments, so that fluvial provenance sediments are restricted to the areas of minor marine influence.

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