BEHAVIOR OF FINE SEDIMENTS AT SEPETIBA BAY-BRAZIL

Pedro Edmundo Aun*
Jefferson Vianna Bandeira*

1. General Information

Sepetiba Bay is in the south-eastern region of Brazil, at about 100km west from Rio de Janeiro. Its mean approximate dimensions are 25km (E-W) and 12.5km (N-S), with a surface of about 312.5km^2. The bay is relatively well protected from wave disturbances of the open sea, this protection being provided mainly by Restinga da Marambaia, a barrier beach with about 40km in a E.W direction, Fig. 1. Its principal entrance is located in its western region, through passageways and channels between the mainland and several islands. In terms of water circulation, the eastern entrance through Barra de Guaratiba, is unimportant, due to its very small depth. Rivers Itaguai and Guandu and several channels, with low flow rates, drain into the bay the region located SW from Rio de Janeiro.

Local tides are semi-diurnal, with maximum spring tidal ranges of about 1.5m.

Sea generated by local winds do not exceed 0.8m in height, and the periods are short (2.5s to 3s).

Maximum wind velocities amount to some 20 knots and occur in the winter months, when it blows mainly from southerly directions. In general, mean wind velocities are about 7 to 10 knots.

Salinity and temperature measurements showed relatively unimportant vertical variations, except near the river region (1).

An iron-ore and coal terminal will be built in Sepetiba Bay, in a region south of Madeira Island. This project is being enlarged, so that an important harbour will come into being to serve as an alternative to Rio de Janeiro port. Dredging will be necessary for the establishment of an approach channel and a turning basin. These facts induced a series of hydraulic and sedimentological studies, aimed at

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a better understanding of bottom behaviour, the measurement of suspended sediment concentrations, the determination of hydraulic actions in the bay, the location of dumping sites for dredged materials, etc. In this paper, several aspects of the problem are presented, including a general view of the geomorphology of the region, analyses of current measurements, an overall view of general water circulation and studies of the sedimentology of the bay by conventional methods and by radioactive tracers.

2. Geology and Sedimentology

2.1. Geomorphology of the region.

The formation of Sepetiba Bay and that of Restinga da Marambaia are related, since this barrier beach gives the bay the characteristics of a semi-confined water body. Restinga da Marambaia is a barrier beach formed by frontal wave action on the continental shelf after the rise in sea level that followed the end of the Ice Ages.

In the present conditions, Sepetiba bay is bound in the N and E by the mainland, in the S by Restinga da Marambaia and in the W by a string of islands that stretches out From Pompeba point to Madeira Island. Tidal flow between the ocean and the bay takes place through two regions: between the islands that form its western border and through the channels of Guaratiba bar. In geological terms (2), Sepetiba bay is characterized as a semi-confined body of water undergoing a deposition process. This diagnosis must be analyzed in detail, since a harbour is planned for the region. This analysis has begun by an examination of the history of the bed configuration and by the study of the distribution, the characteristics and the sources of existing sediments.

2.2. Analysis of Hydrographic Surveys. (2)

A hydrographic survey made by the French Navy in 1868 has been compared to the Brazilian naval chart, corrected to 1973. An analysis of the present bed configurations has also been made. Areas in which depth and morphological changes occurred are presented in Fig. 2.

At present, several channels exist in the floor of Sepetiba and Ilha Grande bays. This characteristic results from fluvial erosion, that happened when the ocean was below its present level, during the last Ice Age. Communication between Sepetiba and Ilha Grande bays is made through ancient narrow and deep valleys which expose to erosion the cenozoic sedimentary column through which they have been excavated. This channel, with depths from 15 to 25m, comes from Ilha Grande bay, passes between Ilha Grande and the mainland and enters Sepetiba bay by a main channel between Itacuruçá and Jaguanum islands and by secondary channels, between the mainland and Itacuruçá island as well as between Jaguanum island and Pompeba point. In the internal region of the bay, depths decrease gradually from W to E and from the center to its outer regions.

2.3. Analysis of bed sediments. (2)

About 300 bed samples were collected in Sepetiba bay, in Mangaratiba bay and E of Ilha Grande island; later on, 20 more samples were collected, in the region of the approach channel and of the turning basin. They were analyzed for mean diameter, curtosis, skewness, sorting, clay distribution, distribution of the fraction silt plus clay, distribution of clay pellets, organic matter content and heavy minerals distribution. A brief treatment will be given here for the parameters which enabled the more important conclusions.

The analysis of clay pellets, originated from the erosion of the sedimentary cenozoic substratum by the currents, indicates that sediment enters Sepetiba bay through a region that runs between Guaiba island and Marambaia hill, goes on to NE and passes between Itacuruçá and Jaguanum islands.

The mean diameter of the samples shows the energy involved in the process of deposition of the material. Distribution of mean diameters is shown in Fig. 3 and can be divided into 2 regions: the area W of Marambaia and Jaguanum islands and the internal area of Sepetiba bay. In the first one, the energy involved is more important, while the second shows characteristics of a semi-confined water body. There are well marked limits between areas of greater movement, characterized by sand, and areas of small energy, with fine sand and silt.

Clay areas are, in general, surrounded by silt areas. The clayish zone between Itá channel and Sepetiba town is due to fluvial influences. Areas of very fine sand in the center of the bay reflect terminal points of the currents that prevail in the southeastern area of Itacuruçá island, producing eddies.

From the analysis of mean diameter distribution the conclusion is reached that sedimentation in Sepetiba bay area is dominated almost entirely by marine circulation, which influence prevails up to the central part of the bay.

Fluvial contribution is small and restricted to the area between Madeira island and Sepetiba town.

Curtosis analysis is based on the dependence of a size distribution curve on the dinamics involved in sedimentation processes. This kind of analysis shows three principal sources for the sediments that enter the bay. The first and less important one is formed by the channels at Guaratiba bar. The second in importance is formed by the region between Ilha Grande island and Marambaia hill. The most important comes from Ilha Grande bay, passing between this island and the mainland. The fluvial contribution being unimportant, the biggest contribution of sediments to the area would be external, from the continental platform.

The chart presenting clay distribution, Fig. 4,which pictures regions of smaller energy, will be examined now. Areas with 60 to 100% of clay are mainly located in the inner part of Sepetiba bay. In this area, the terminal eddy SE of Itacuruçá island is again apparent. An area of greater movement is apparent, SE of Jaguanum island; this area includes the region of the currents that are eroding Pompeba point and that extends into the internal beaches of Restinga da Marambaia.

2.4. Conclusions.

The elements analyzed indicate 3 principal sources,of oceanic origin, for the sediments that enter Sepetiba bay, as cited above. Sediments of the two last sources mix up as they enter the bay and their circulation is done by the following passageways: between Itacuruçá and Jaguanum islands, between Jaguanum Island and Marambaia hill and between Batuque and Itacuruçá islands, opening into Saco da Coroa Grande. From these entries,sedimentation fronts are formed, tending to fill up the bay. Mechanisms of the eddy type give rise to significant local depositions. Contribution of fluvial sediment is small in the bay, being important only near the rivers and channel openings.

The processes of current circulation and sedimentation thus characterize the bay as an area of prevailing marine characteristics. The more representative bottom sediment is silt. Clay fraction is important in the area of fluvial influence.

Sepetiba bay, in geological terms, can thus be characterized as a semi-confined area, undergoing a sedimentation process. In this area, the most favourable condition for the building of an approach channel is located between Itacuruçá and Jaguanum islands. These conclusions must be confirmed by other studies.

3. Hydraulic Measurements

Between September 74 and September 75, currents were measured in Sepetiba bay, along the verticals of several points, during full tidal cycles, covering spring, neap and mean tides*. During radioactive tracer work, currents were also measured, near injection points, to relate the behavior of bed material to the prevailing hydrodynamic actions (3).

A systematic analysis of current measurements was made, with the following main purposes:

a) Determination of the over-all picture of water circulation in the bay, in different hydraulic and meteorological conditions.

b) Determination on the relative influence of hydraulic agents (tides, winds, salinity and temperature gradients, etc) in general water circulation.

Currents in Sepetiba bay are of low intensity, being a velocity of 0.8m/s, at the surface, the greatest value recorded, in the region between Martins and Itacuruçá islands. In the harbor area, currents are still weaker, with a maximum velocity of 0.25m/s at 1 meter above the bottom and v_{max} = 0.50m/s on the surface (3).

The main current direction is E-W, with variations caused by bottom topography; tide is the principal hydraulic agent that govern the currents.

Flow inversions occur near high water and low water. Relatively stronger currents, between low water and high water, occur between Jaguanum island and the mainland, in its northern part.

This fact causes a clockwise general circulation of the currents between low and high water, Fig. 5.a. Eddies are formed in the central region of the bay, due to the interaction of the weaker currents that enter between Jaguanum and Pompeba islands with part of the stronger currents that, entering through the northen part, are directed westwards by the coastal configuration in the NE of the bay, and by Restinga da Marambaia.

These eddies are more pronounced at mean high water. At mean low water, current behavior has, in general, the general configuration of the figure 5.b.

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* Measurements performed by Instituto de Pesquisas Hidroviárias, Portobrás, Rio de Janeiro.

Local winds are of low intensity and alternate mainly between NE, S and SW. Greater velocities occur in winter months (June to September) and are always less than 20 knots. Velocities of this magnitude are infrequent and do not appear as a continuous wind.

Fig. 6 presents annual frequencies of directions and velocities, based in wind recordings through a 10 year period.

Studies made to detect wind influences in current circulation showed that this agent is of secondary importance relative to the tide. The same occurs in relation to the effects of thermal and saline gradients. Water circulation in the bay seems to favour the dumping of dredged material on the eastern side of Pompeba island, in depths greater than 10m, from the viewpoint of avoiding its return to the dredged sites. Probably, this region will be studied in a near future. If this hypothesis is confirmed, dredging costs will be sharply cut down. Sepetiba bay is thus an excellent location for the installation of a maritime terminal, as it is well protected from the sea, presents low current velocities and offers almost adequate natural, relatively stable depths.

4. Studies with Radioactive Tracers (4)

These studies were initiated in the beginning of 1975, with the collection of bottom and suspended samples, at 20 points in the harbour area.

Measurements of suspended sediment content, confirming previous studies, showed very small values for suspended sediment, even performing sampling during the rainy season. Analysis of grain size distribution, measurements of settling velocities and determinations of solids content of the samples have also been made. It was verified that pratically all the region of interest had a bottom of cohesive material, with silt and clay concentrations in the range of 300g/l to 500g/l. To get an estimate of the movement to be expected, criteria developed by Migniot (5) for erosion of cohesive materials by currents have been applied, since it is not to be expected that sea generated by local winds will disturb the bed material.

This method is based in the determination of the initial rigidity τ_y of the material, as determined by the required torque to initiate the movement of a rotor imerged in the material. This method defines the critical shear stress τ_c as being equal to τ_y. The critical scour velocity u_* is given by

$$u_* = 0,032\tau_y$$

Values of τ_y for the samples collected in the harbor region varied between 1 and $10N/m^2$. Values of u_* will vary between 3cm/s and 10cm/s, on the bottom. If the logarithmic law for velocity distributions is accepted, it is possible to compute the values of current velocities at 1m above the bottom (depth in which currents were recorded) that would produce these values of u_* on the bottom. It is verified that, at 1m above the bottom, values of current velocities do not occur which would produce the shear stresses necessary to put the bed material into suspension. A very small movement of bed material, in this area, must then be expected.

To confirm these results, two radioactive-tracer injections were made, at points PI_1 and PI_2, Fig. 1. The injections were made at high water of spring tides. To ensure that the tracer would be representative, bed material was collected at the injection points and directly labelled with a radioactive tracer. A previous sieving to sort out coarse material has been made. As little movement was expected, an injection device was developed, which can distribute the labelled material along a line, in uniform way, Fig. 7. The labelled material is placed on the injection chamber, on board of the boat used in the work and the injection device is lowered to the bottom. The boat then is slowly movea far away from the injection device, until a distance equal to the desired injection length.

The injection device was then pulled to the boat, towed by a cable, sliding over the bottom. This movement induces the action of a piston that pulls the tracer out of the injection chamber. As the movement of the piston is caused by the rear wheels of the injection device, this can be pulled at any speed, producing always a uniform injection. The equipment can work with fine material (silt or clay) or with coarser materials (sand, glass), simply changing the injection chamber.

After each injection, several detections were made. Each detection covered all the radioactive cloud produced by the tracer using a scintillation counter, attached to a sledge towed by the boat. The probe was connected to a ratemeter, to a scaler and to a printer, and electrical current was supplied by a portable generator. The boat covered the cloud by parallel lines, separated by distances between 5m to 50m. Position of the boat at each instant was determined by theodolites, in communication with the boat by portable radio-transmitters.

During all the work with radioactive tracers, direction and velocity of the currents were recorded, both continuously, at a fixed depth and at different points of a vertical, at a fixed point.

To obtain quantitative results, the detection probe was calibrated in a brick box, filled with bed material, and traversed by aluminum tubes regularly spaced, through which a small radioactive source is passed at a constant speed. In this way, it is determined the counting rate provided by the probe, for an unitary activity, uniformly distributed at a given depth.

Analysis was performed by the tracer balance method (6), using programmable table calculators fed by perforated tape. Results showed that, at both injection points, movement was very small, throughout the detection period.

Another studies with radioactive tracers are being planned to define a location for the dumping of dredged material. Present sites for the disposal of this material are located outside the bay, which causes long trips of the dredges. One location to be studied is the region of eddies near Pompeba point and these measurements are programmed for the second semestre of 1976.

5. General Conclusions

In geological terms, Sepetiba bay has been characterized as a semi-confined area of prevailing marine characteristics, undergoing a sedimentation process. The more representative bottom sediment is silt, the clay fraction being important only in the area of fluvial influence.

From a hydraulic viewpoint, it has been determined that currents in the bay are of low intensity, being E-W their main direction. Tide is the most important hydraulic agent. The current circulation pattern induces eddies in the central part of the bay, between low and high water. It also seems to indicate that the region SE of Jaguanum island is adequate for dredged material disposal. From a hydraulic viewpoint, Sepetiba bay is thus a good location for harbour installation, as it is well protected from open sea agitation, presents low current velocities, offers almost adequate natural depths, and it is located in a strategic region for the Brazilian development.

From radioactive tracer studies, it has been determined that hydraulic actions are unable to induce movement in the bed material, at both injection points, in the harbour region.

Further studies will be made to define a location for the dumping of dredged material.

All the results obtained in this study seem to indicate that the region under consideration presents good conditions for harbour construction. Rio de Janeiro State plans to begin dredging work in mid 1976.

6. Acknowledgements

This work was performed for Instituto de Pesquisas Hidroviárias, Portobrás, Rio de Janeiro, whose permission to publish this paper is gratefully acknowledged.

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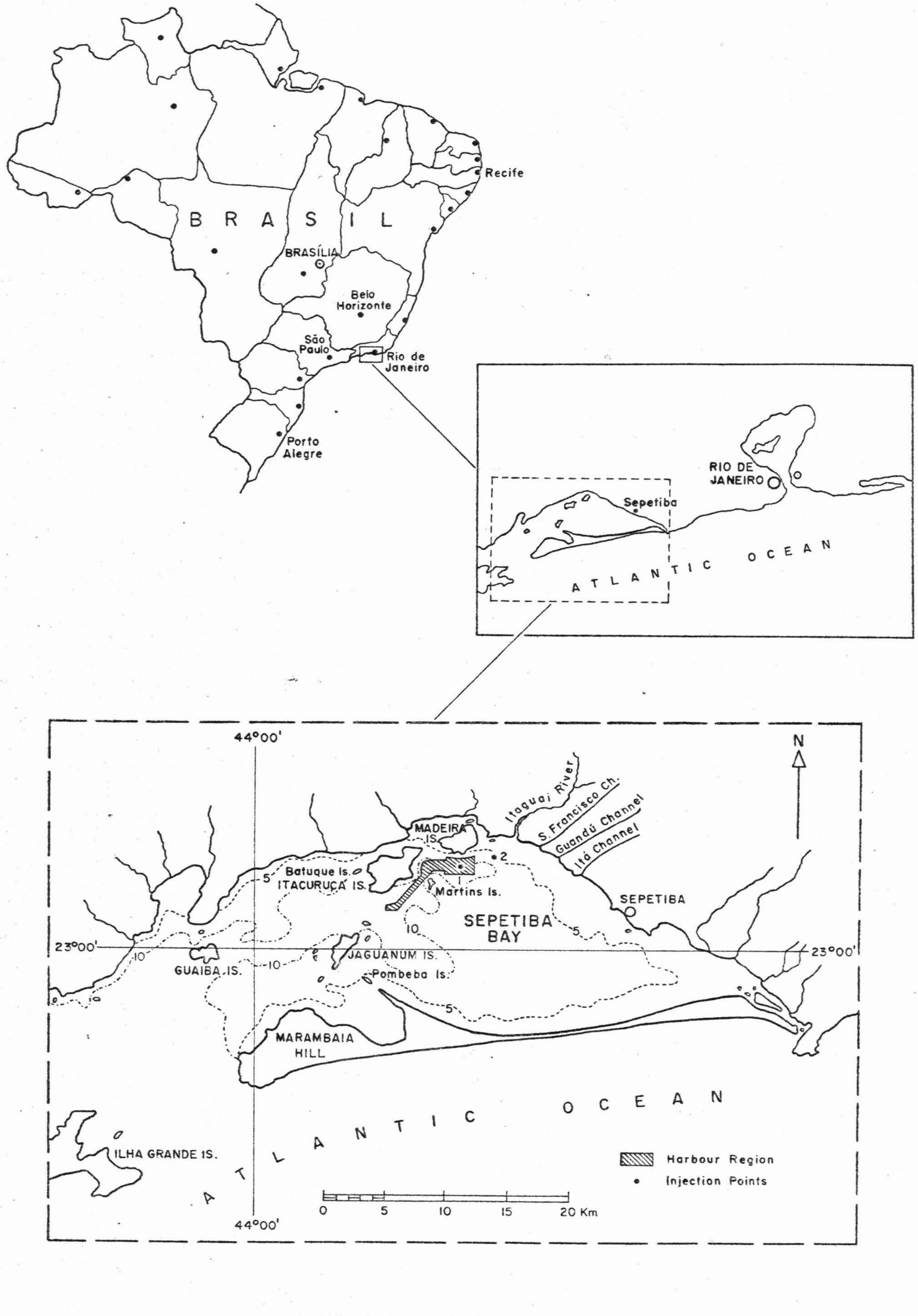
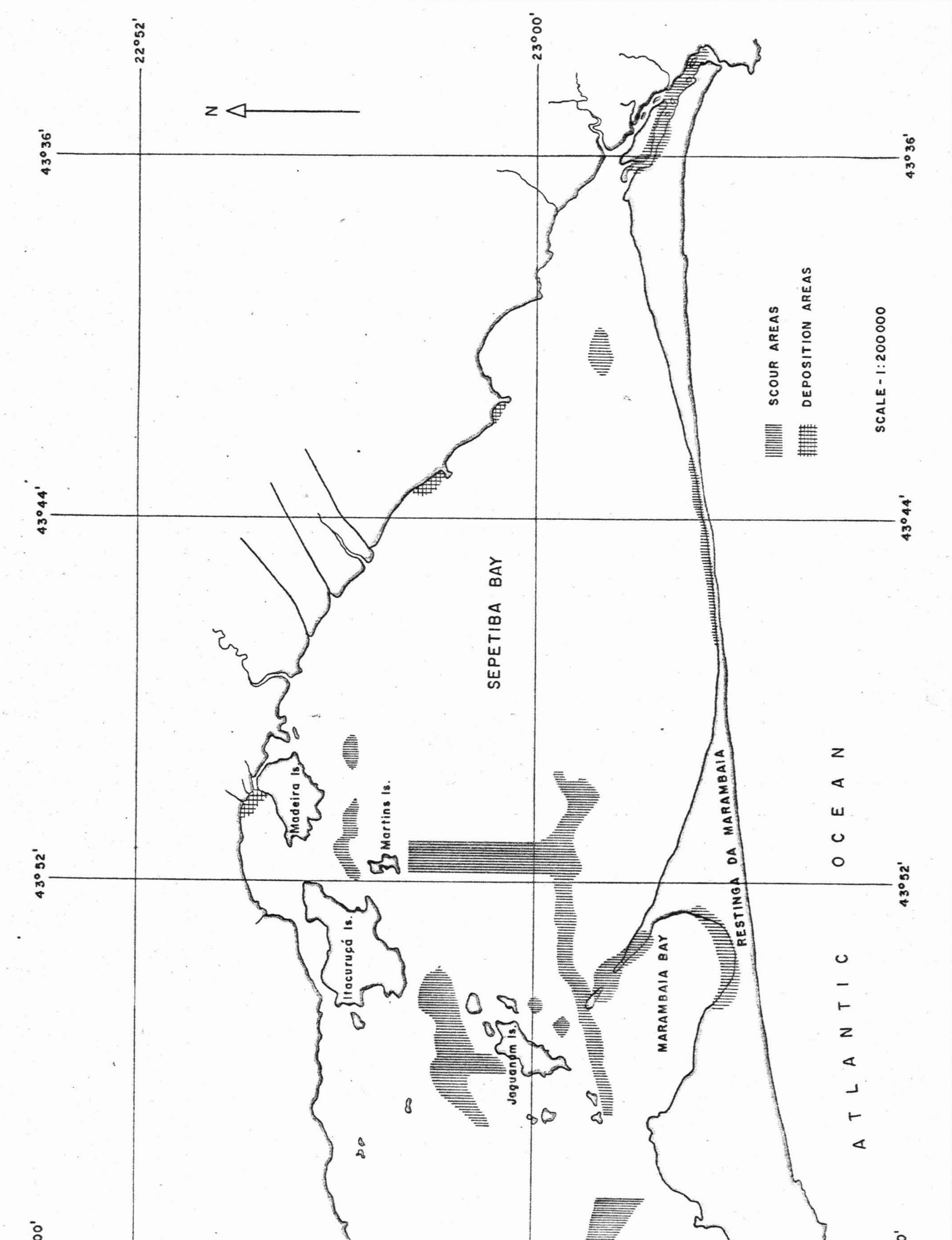


KEY MAP OF SEPETIBA BAY

FIG. 1



COMPARISON OF THE DEPTH SURVEYS OF 1868 AND 1973

FIG. 2

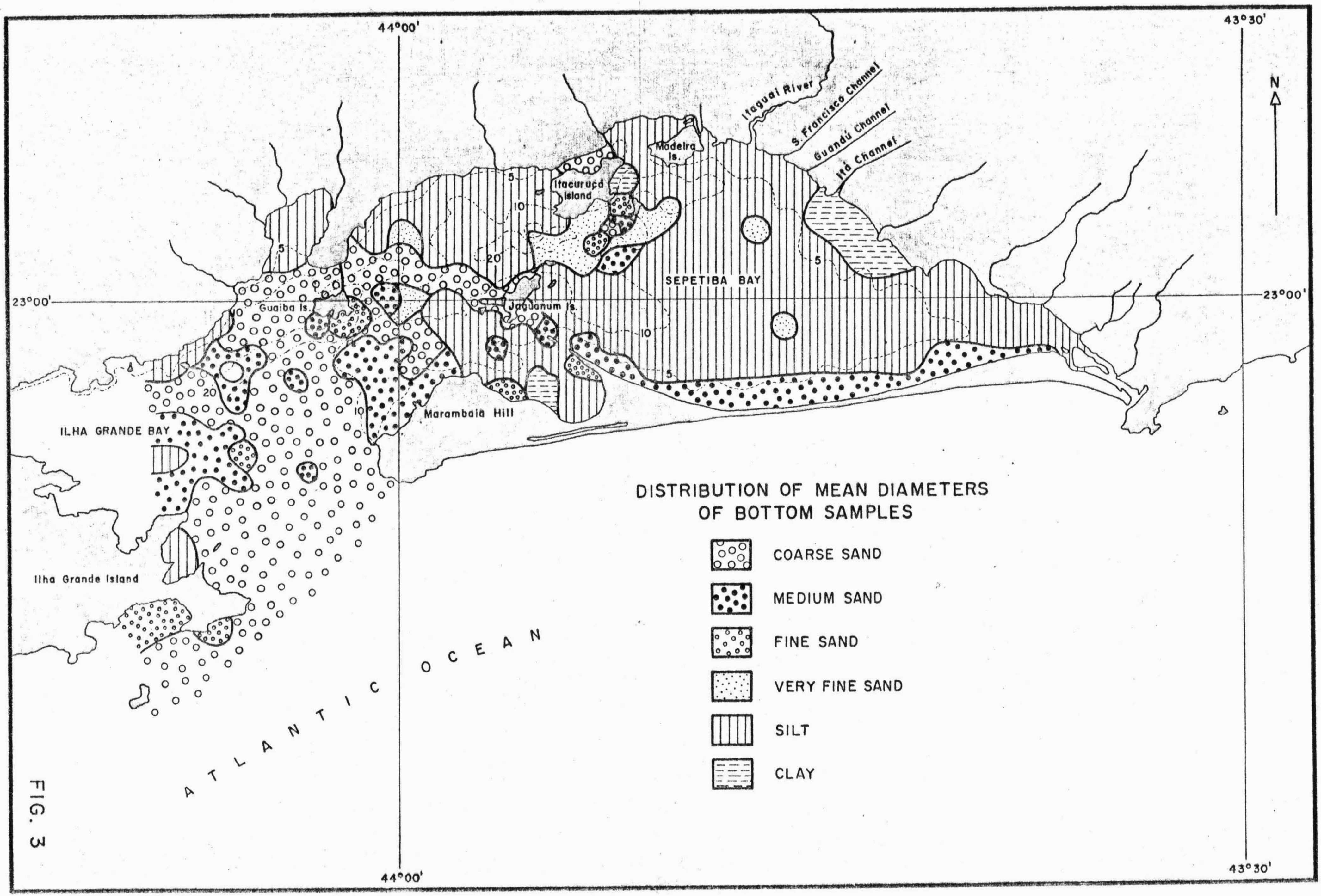
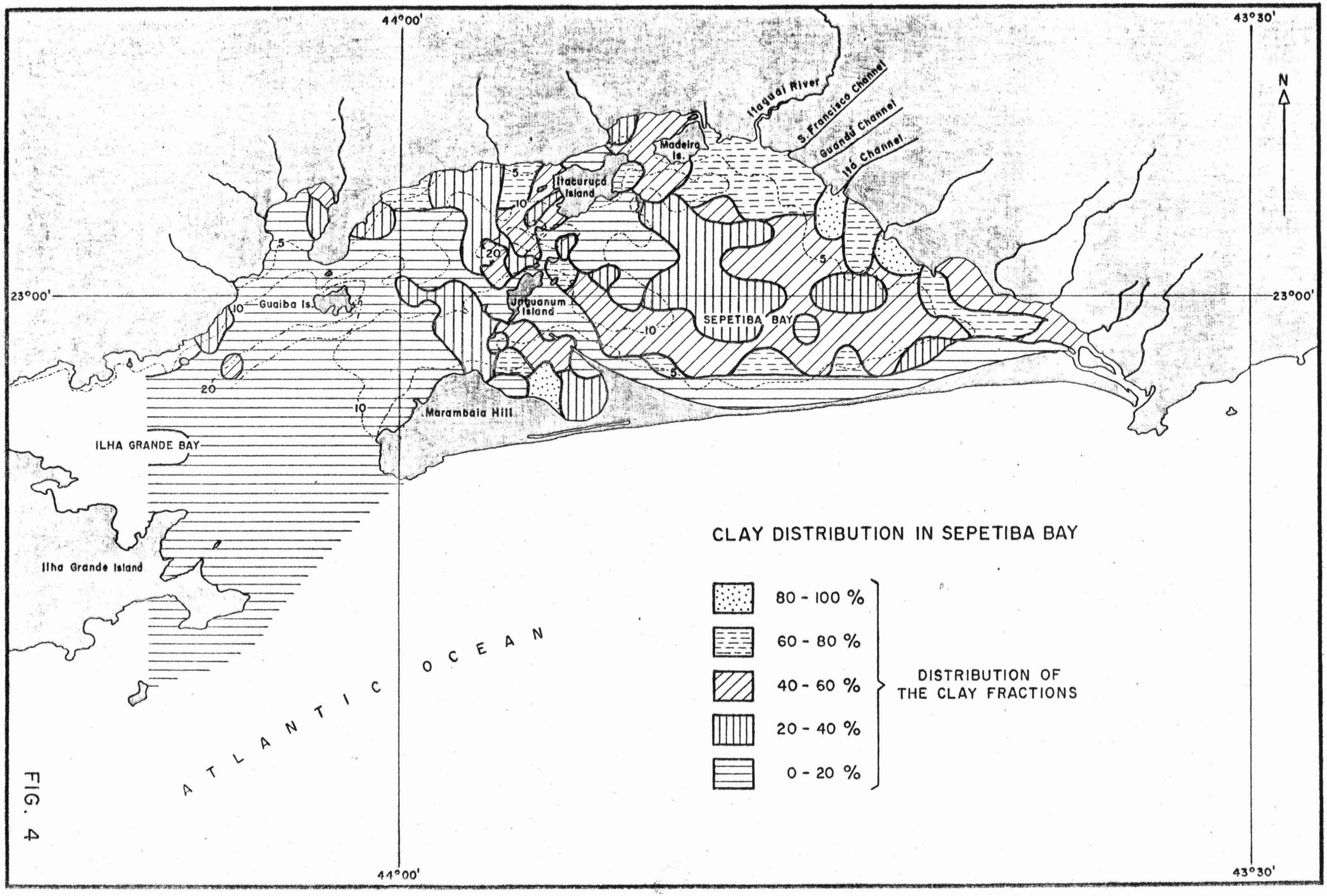
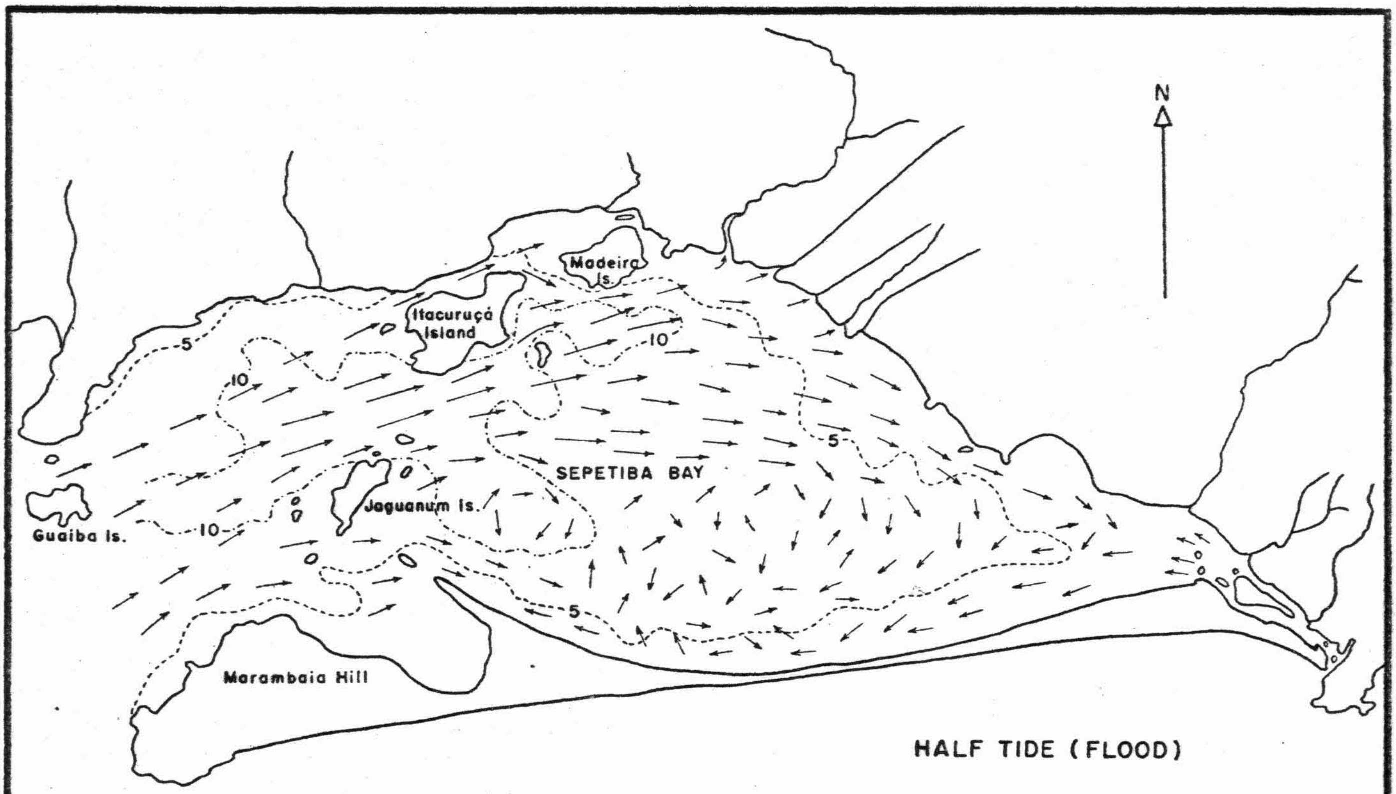

DISTRIBUTION OF MEAN DIAMETERS OF BOTTOM SAMPLES
COARSE SAND
MEDIUM SAND
FINE SAND
VERY FINE SAND
SILT
CLAY
N
44°00'
43°30'
23°00'
Itaguai River
S. Francisco Channel
Guandú Channel
Itá Channel
Madeira Is.
Itacuruçá Island
SEPETIBA BAY
Jaguanum Is.
Guaiba Is.
Marambaia Hill
ILHA GRANDE BAY
Ilha Grande Island
ATLANTIC OCEAN
5
10
20

FIG. 3

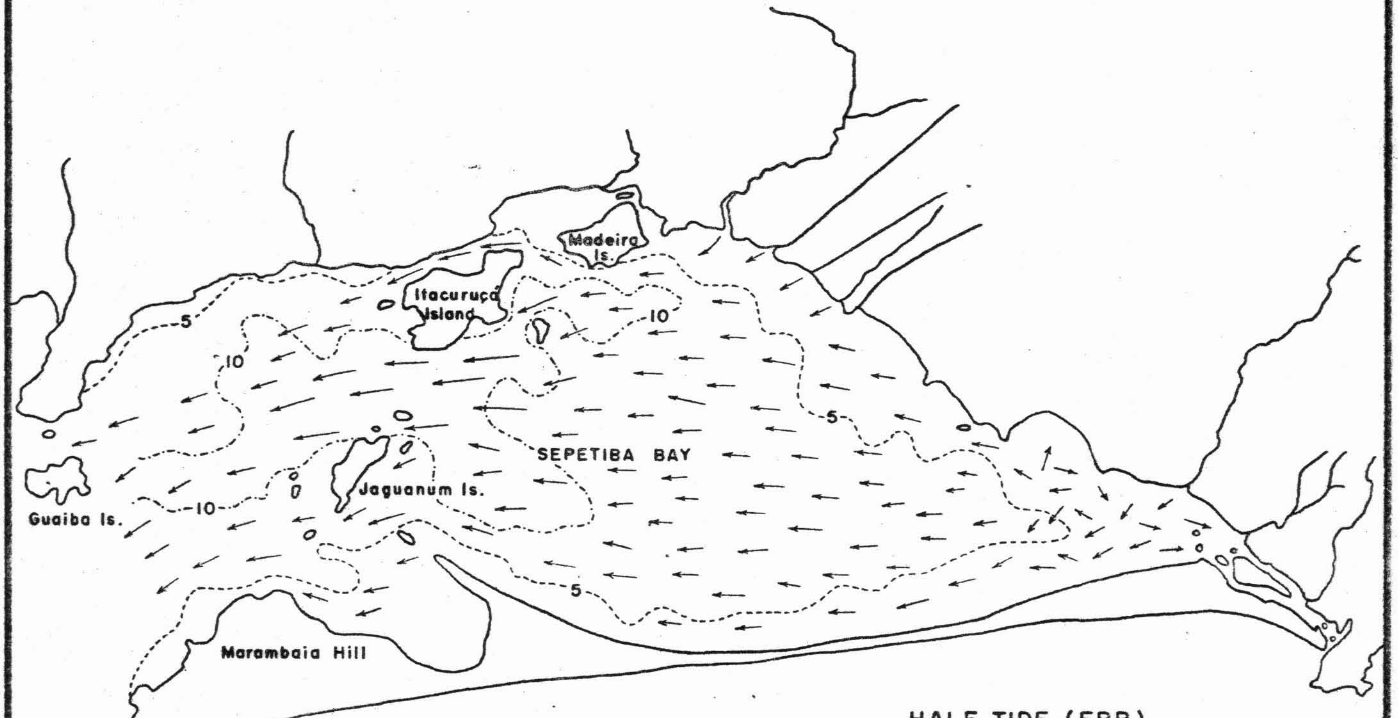


CLAY DISTRIBUTION IN SEPETIBA BAY

FIG. 4



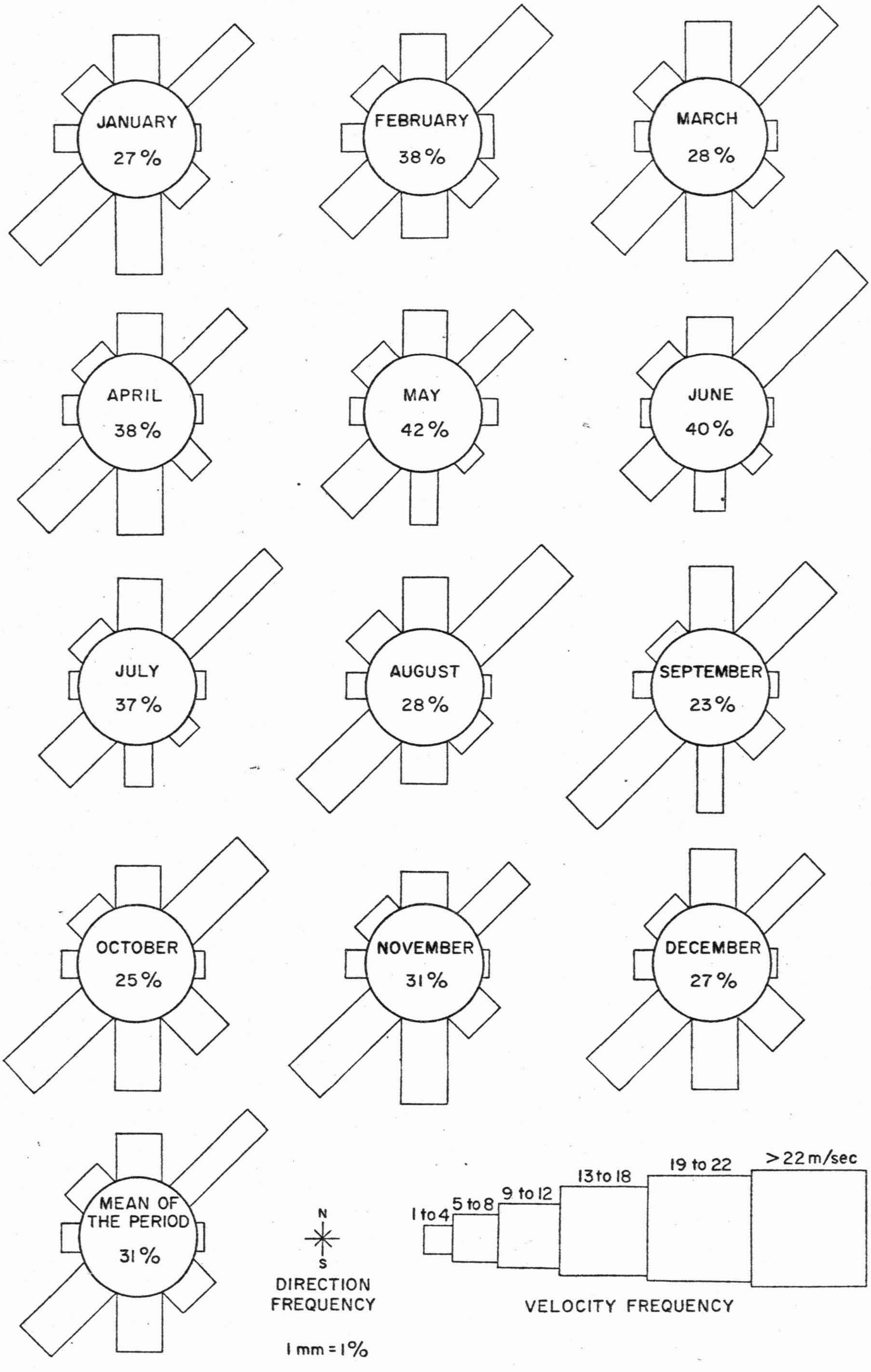
HALF TIDE (FLOOD)



HALF TIDE (EBB)

CURRENT CIRCULATION PATTERN IN SEPETIBA BAY

FIG. 5



ANNUAL WIND FREQUENCIES : DIRECTIONS AND VELOCITIES, COVERING A 10-YEAR PERIOD.

FIG. 6

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Local winds are of low intensity and alternate mainly between NE, S and SW. Greater velocities occur in winter months (June to September) and are always less than 20 knots. Velocities of this magnitude are infrequent and do not appear as a continuous wind.

Fig. 6 presents annual frequencies of directions and velocities, based in wind recordings through a 10 year period.

Studies made to detect wind influences in current circulation showed that this agent is of secondary importance relative to the tide. The same occurs in relation to the effects of thermal and saline gradients. Water circulation in the bay seems to favour the dumping of dredged material on the eastern side of Pompeba island, in depths greater than 10m, from the viewpoint of avoiding its return to the dredged sites. Probably, this region will be studied in a near future. If this hypothesis is confirmed, dredging costs will be sharply cut down. Sepetiba bay is thus an excellent location for the installation of a maritime terminal, as it is well protected from the sea, presents low current velocities and offers almost adequate natural, relatively stable depths.

4. Studies with Radioactive Tracers (4)

These studies were initiated in the beginning of 1975, with the collection of bottom and suspended samples, at 20 points in the harbour area.

Measurements of suspended sediment content, confirming previous studies, showed very small values for suspended sediment, even performing sampling during the rainy season. Analysis of grain size distribution, measurements of settling velocities and determinations of solids content of the samples have also been made. It was verified that pratically all the region of interest had a bottom of cohesive material, with silt and clay concentrations in the range of 300g/l to 500g/l. To get an estimate of the movement to be expected, criteria developed by Migniot (5) for erosion of cohesive materials by currents have been applied, since it is not to be expected that sea generated by local winds will disturb the bed material.

This method is based in the determination of the initial rigidity τ_y of the material, as determined by the required torque to initiate the movement of a rotor imerged in the material. This method defines the critical shear stress τ_c as being equal to τ_y. The critical scour velocity u_* is given by

$$u_* = 0{,}032\tau_y$$

Values of τ_y for the samples collected in the harbor region varied between 1 and $10N/m^2$. Values of u_* will vary between 3cm/s and 10cm/s, on the bottom. If the logarithmic law for velocity distributions is accepted, it is possible to compute the values of current velocities at 1m above the bottom (depth in which currents were recorded) that would produce these values of u_* on the bottom. It is verified that, at 1m above the bottom, values of current velocities do not occur which would produce the shear stresses necessary to put the bed material into suspension. A very small movement of bed material, in this area, must then be expected.

To confirm these results, two radioactive-tracer injections were made, at points PI_1 and PI_2, Fig. 1. The injections were made at high water of spring tides. To ensure that the tracer would be representative, bed material was collected at the injection points and directly labelled with a radioactive tracer. A previous sieving to sort out coarse material has been made. As little movement was expected, an injection device was developed, which can distribute the labelled material along a line, in uniform way, Fig. 7. The labelled material is placed on the injection chamber, on board of the boat used in the work and the injection device is lowered to the bottom. The boat then is slowly movea far away from the injection device, until a distance equal to the desired injection length.

The injection device was then pulled to the boat, towed by a cable, sliding over the bottom. This movement induces the action of a piston that pulls the tracer out of the injection chamber. As the movement of the piston is caused by the rear wheels of the injection device, this can be pulled at any speed, producing always a uniform injection. The equipment can work with fine material (silt or clay) or with coarser materials (sand, glass), simply changing the injection chamber.

After each injection, several detections were made. Each detection covered all the radioactive cloud produced by the tracer using a scintillation counter, attached to a sledge towed by the boat. The probe was connected to a ratemeter, to a scaler and to a printer, and electrical current was supplied by a portable generator. The boat covered the cloud by parallel lines, separated by distances between 5m to 50m. Position of the boat at each instant was determined by theodolites, in communication with the boat by portable radio-transmitters.

During all the work with radioactive tracers, direction and velocity of the currents were recorded, both continuously, at a fixed depth and at different points of a vertical, at a fixed point.

To obtain quantitative results, the detection probe was calibrated in a brick box, filled with bed material, and traversed by aluminum tubes regularly spaced, through which a small radioactive source is passed at a constant speed. In this way, it is determined the counting rate provided by the probe, for an unitary activity, uniformly distributed at a given depth.

Analysis was performed by the tracer balance method (6), using programmable table calculators fed by perforated tape. Results showed that, at both injection points, movement was very small, throughout the detection period.

Another studies with radioactive tracers are being planned to define a location for the dumping of dredged material. Present sites for the disposal of this material are located outside the bay, which causes long trips of the dredges. One location to be studied is the region of eddies near Pompeba point and these measurements are programmed for the second semestre of 1976.

5. General Conclusions

In geological terms, Sepetiba bay has been characterized as a semi-confined area of prevailing marine characteristics, undergoing a sedimentation process. The more representative bottom sediment is silt, the clay fraction being important only in the area of fluvial influence.

From a hydraulic viewpoint, it has been determined that currents in the bay are of low intensity, being E-W their main direction. Tide is the most important hydraulic agent. The current circulation pattern induces eddies in the central part of the bay, between low and high water. It also seems to indicate that the region SE of Jaguanum island is adequate for dredged material disposal. From a hydraulic viewpoint, Sepetiba bay is thus a good location for harbour installation, as it is well protected from open sea agitation, presents low current velocities, offers almost adequate natural depths, and it is located in a strategic region for the Brazilian development.

From radioactive tracer studies, it has been determined that hydraulic actions are unable to induce movement in the bed material, at both injection points, in the harbour region.

Further studies will be made to define a location for the dumping of dredged material.

All the results obtained in this study seem to indicate that the region under consideration presents good conditions for harbour construction. Rio de Janeiro State plans to begin dredging work in mid 1976.

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