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RESEARCH PAPER

SEDIMENT ACCUMULATION IN SEPETIBA BAY (BRAZIL) DURING THE HOLOCENE: A REFLEX OF THE HUMAN INFLUENCE

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Abstract

The nature of sedimentation and sediment accumulation rates in Sepetiba Bay, Brazil were interpreted from grain-size patterns, natural radiochemical distributions and seismic stratigraphy. The grain-size analyses showed progressive upward fining of sediment in cores, and a higher percentage of clay in surficial deposits in 1996 than observed during a previous spatial survey in the 1970s. Based on ^{210}Pb geochronology, accumulation rates range from 0.37 cm yr-1 to 2.0 cm yr^{-1} for the last hundred years. In contrast, seismic stratigraphy indicates a range from 0.01 to 0.17 cm yr^{-1} over the last 7000 years. Particularly high accumulation rates are found in the northeast part of the bay, and, as a consequence of these high rates, the shoreline in the northern part of the bay prograded approximately 400 m in the last 100 years. An apparent increase in accumulation rates and a tendency for deposits to fine upward over the last ~100 years are attributed to human disturbance and soil erosion inland, which have been accelerated with economic development since the late 1970s.

Keywords: ^{210}Pb geochronology. Sedimentation. Sepetiba Bay. seismic stratigraphy. Progradation. sediment accumulation rates.

1. Introduction

Sediment accumulation processes in coastal areas can be affected by human activities that change the balance of processes operating in these environments. Such effects, as well as numerous natural changes, can be identified through analysis of sediments from cores and through seismostratigraphy (Borges and Nittrouer, 2016). The southern coast of Brazil in particular has undergone extensive development over the last ~30-50 years (Lacerda et al., 1987; Barcellos and Lacerda, 1994; Molisani et al., 2004).

The objectives of the present paper are: 1) to evaluate sedimentation patterns in Sepetiba Bay, a coastal embayment south of Rio de Janeiro, based on surface sample surveys undertaken in 1976 and 1996; and 2) to identify possible changes in accumulation rates and determine their likely causes and consequences.

Sediment accumulation rates in coastal environments (e.g., coastal lagoons and estuaries) can be determined by a variety of methods. Short-term rates over decades (up to about 100 years) are determined by bathymetric changes of the seabed between successive surveys (Shepard, 1953), a method that reveals spatial patterns of accumulation. 210Pb and 137Cs geochronologies give temporal variations with depth in cores (Thorbjarnarson et al., 1985).

Sediment accumulation rates over millennia are determined by radiocarbon analyses of sediment cores combined with seismic reflection surveys (Nichols, 1989).

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All of these techniques were used in the present study, with an emphasis on ^{210}Pb.

2. Study area

The study area is located in the state of Rio de Janeiro, in the southeastern part of Brazil, in Sepetiba Bay (Figure 1). Sepetiba Bay is an elliptically shaped coastal embayment covering an area of 300 km². It is open to the ocean at two sites: through a tidal channel at Barra de Guaratiba and through gaps in a chain of larger channels at the west end (Figure 1).

The fluvial contribution to Sepetiba Bay comes from the Guandú, Itaguaí, Mazomba, Cabuçú, and Piracão Rivers. Two of these rivers, the Itaguaí and the Guandú, were modified during the 1940s into artificial, fixed channels. After these changes, the largest river, the Guandú, received additional discharge from other small rivers of the region. Sepetiba Bay can be divided into three compartments based on its hydrographic and geographic characteristics: brackish (3-18‰, at Guandú river mouth), hyposaline (18-30‰, most of the bay) and hypersaline (30-40‰, near the islands and northwest and southwest parts of the bay) (Moura et al., 1982).

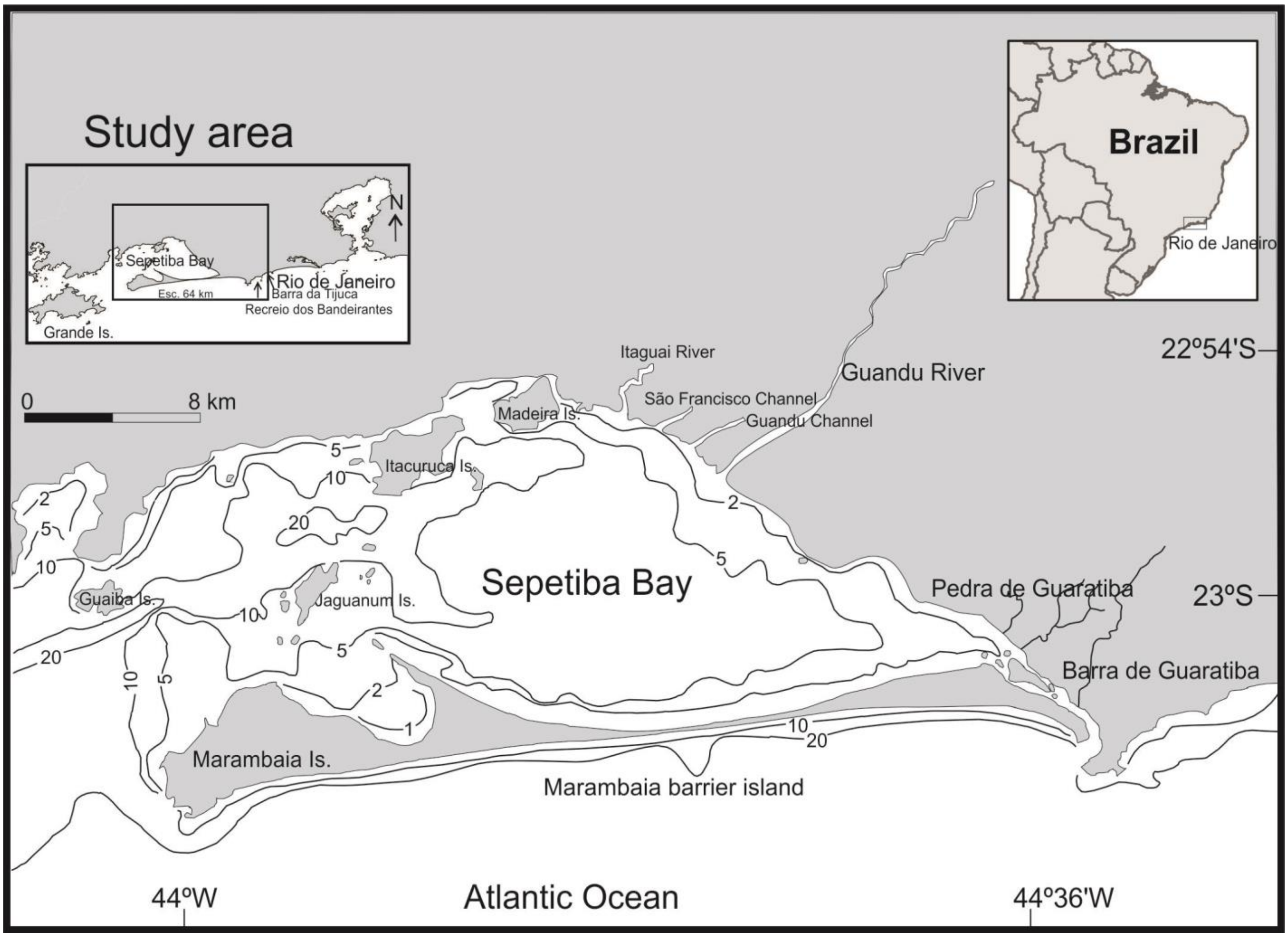

Fig. 1. Sepetiba Bay study area and general bathymetry. Upper right insert shows the area along the south Brazilian coast. Upper left insert shows location of Sepetiba Bay west of Rio de Janeiro City.

The currents inside the bay are driven by tides and can reach maximum speeds of 75 cm/sec in the channels between the islands of Itacuruçá and Jaguanum (DHN, 1986; Villena, 2003). The seawater that enters the bay as a bottom current is relatively cold and dense. It circulates clockwise through the bay, becomes warmer, and exits at the surface between Marambaia Peak and Jaguanum Island (Figure 2). The tide in the area has a range of 110 cm during spring tide

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and 30 cm during neap tide. There is a difference in phase of about 15 minutes between the entrances and the far interior of the bay (DHN, 1986; Villena, 2003; Rocha et al, 2010).

3. Background

Two major sedimentological surveys were conducted in Sepetiba Bay in the late 1970s (Ponçano, 1976; Roncarati and Barrocas, 1978) and 2000s (Pereira et al., 2003, 2012; Villena, 2003). Previous grain-size analyzes using a standard mechanical dry-sieve-shaking method and pipette techniques, showed a surface sediment distribution with predominance of silt (ϕ4-ϕ7) (Figure 3). Clay (≤ϕ8) occurs in the north at the mouth of the Itaguaí River, on the east side of Itacuruçá Island, and at the mouth of a stream entering Marambaia Bay. Very fine (ϕ3-ϕ4) sand is found at the entrance of Sepetiba Bay, in the channel between Itacuruçá and Jaguanum islands, and in two isolated areas near the center of the bay. Medium sand (ϕ1-ϕ2) occurs along the barrier beach and coarse sand (ϕ0-ϕ1) is found at the main entrance of Sepetiba Bay.

Bathymetric studies (Borges et al., 1989; Borges, 1990) have shown progradation of 395 m of the Guaratiba shoreline from 1868 to 1981 (Figure 4) and the creation of an extensive tidal flat, which replaced sandy beaches (Argento and Vieira, 1989). These long-term differences in bottom topography and coastline do not resolve the quantitative details of sedimentation.

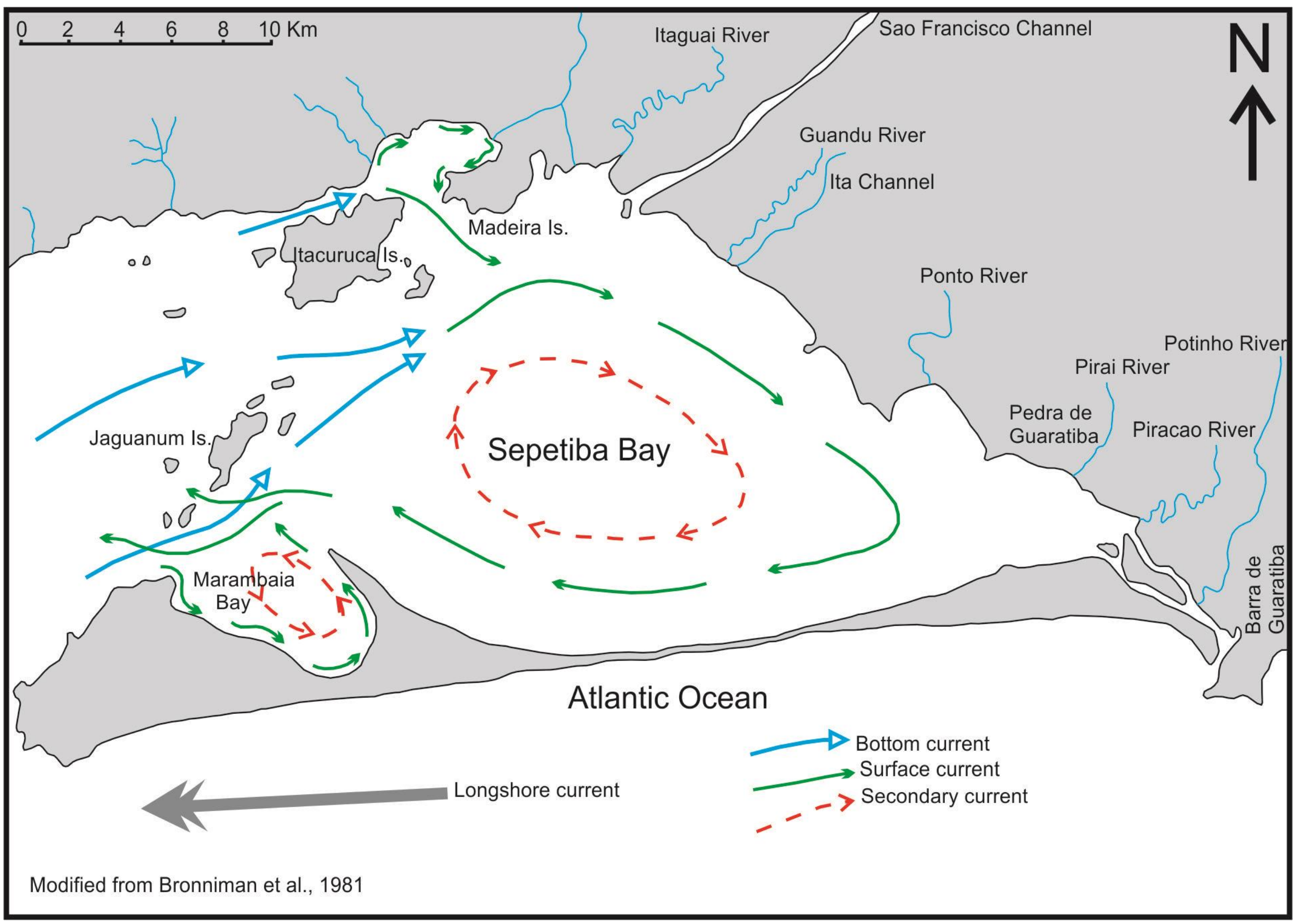

Fig. 2. Generalized current system in Sepetiba Bay. The cold and dense water enters the bay as bottom currents, circulates clockwise through the bay, becomes warmer, and exits as surface currents.

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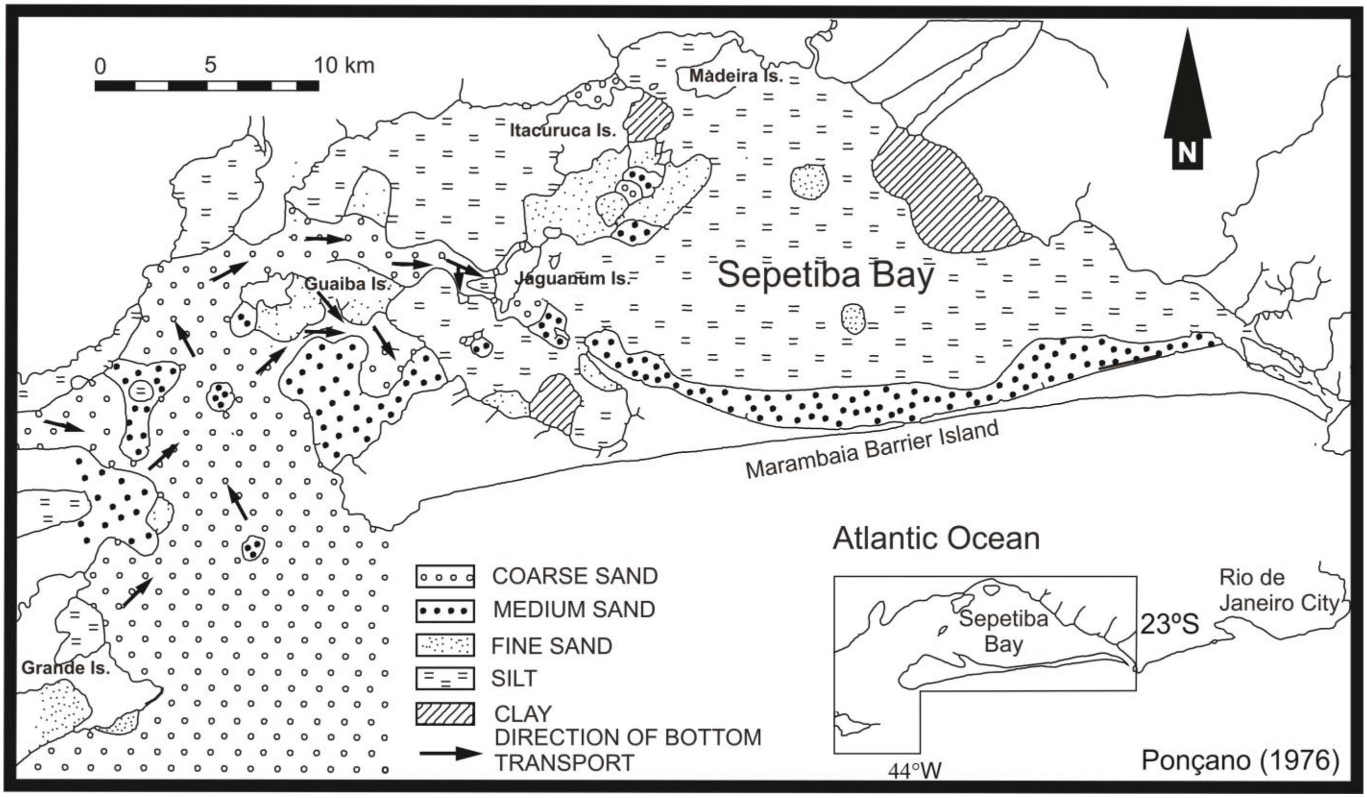

Fig. 3. Map showing sediment distribution in Sepetiba Bay published by Ponçano (1976). The surface sediment distribution in Sepetiba Bay shows predominance of silt. Clay occurs in the north of the bay at the mouth of the Guandú River, on the east side of Itacuruçá Island, and at the mouth of a stream entering Marambaia Bay. Very fine sand is found at the entrance of Sepetiba Bay, in the channel between Itacuruçá and Jaguanum islands, and in two isolated areas near the center of the bay. Medium sand occurs along the barrier beach and coarse sand at the main entrance of Sepetiba Bay.

4. Methods

4.1. Core and surface sediments

Gravity cores and 41 surface-sediment samples were obtained in Sepetiba Bay between 1996 and 1997 (Figure 5). The gravity cores and bottom samples were collected from a small vessel, and stations were located by GPS positioning. Samples for sedimentological and radiochemical analysis from seven cores were taken at 2-cm intervals down 80-cm long push and gravity cores, and then homogenized.

4.2. Seismic profiles

The seismic field data for this study consist of 41 single-channel high-resolution seismic-reflection profiles (Figure 6) collected in 1996 and 1997 with a 200-kHz acoustic source and recorded by analog techniques (Model SH-20, Senbon Denki Co., Numazu, Japan). The seismic-reflection profiles were plotted on a nautical chart with positions obtained by a Global Positioning System (GPS).

4.3. Identification of seismic units

Discontinuity-bounded sequences were mapped on all seismic profiles and their distribution in the area was plotted on a seismic navigation track. The depositional events and processes were interpreted by analyzing the configuration of these discontinuities and the nature of the boundary reflectors.

4.4. Laboratory

Grain-size analyses were performed for all samples, surface and sub-surface, with a SediGraph model 5100ET for fine grain samples (Coakley and Syvitski, 1991), and 180-cm settling tube for coarse samples (Syvitski et al., 1991) and on samples over 15-cm depth intervals in the gravity cores.

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A modified version of the Nittrouer et al. (1979) method was used for ^{210}Pb analysis. Samples were weighed, then dried at 60ºC. Porosity was calculated from the weight loss of water. Approximately 5g of sediment were spiked with ^{209}Po (as a yield determinant). Samples were then leached with HNO_3 and HCl solutions, and plated onto silver planchets. ^{210}Pb activities were measured by alpha spectrometry from decay of the ^{210}Po daughter. Samples were corrected for salt content and normalized to a representative porosity (75%).

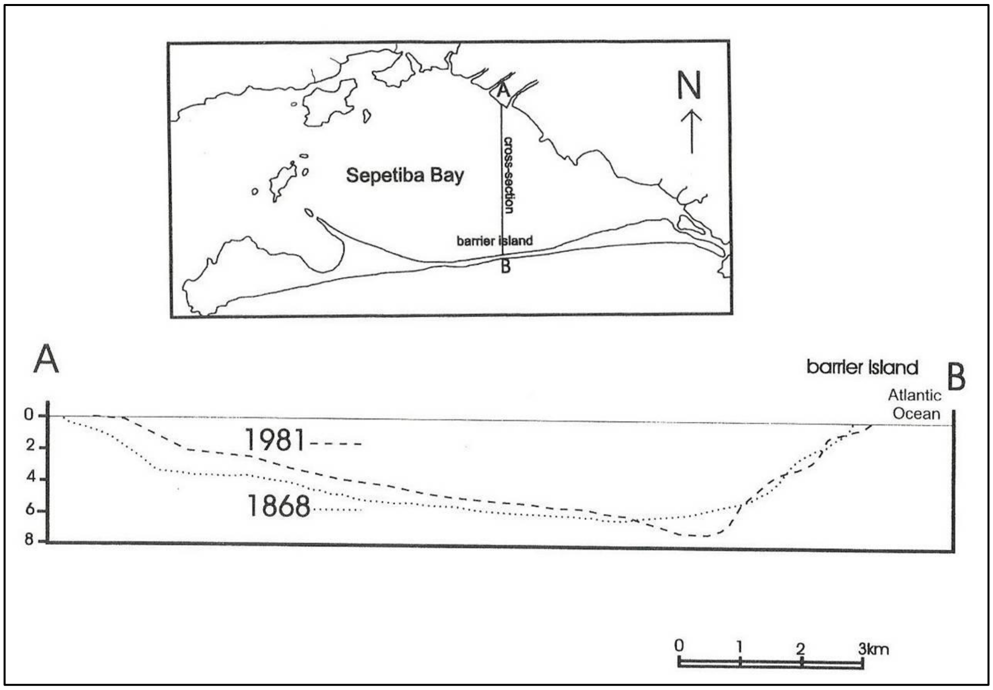

Fig. 4. Cross-section showing the shoreline progradation of 395 m at Guaratiba tidal flat from 1868 to 1981 (Borges, 1990).

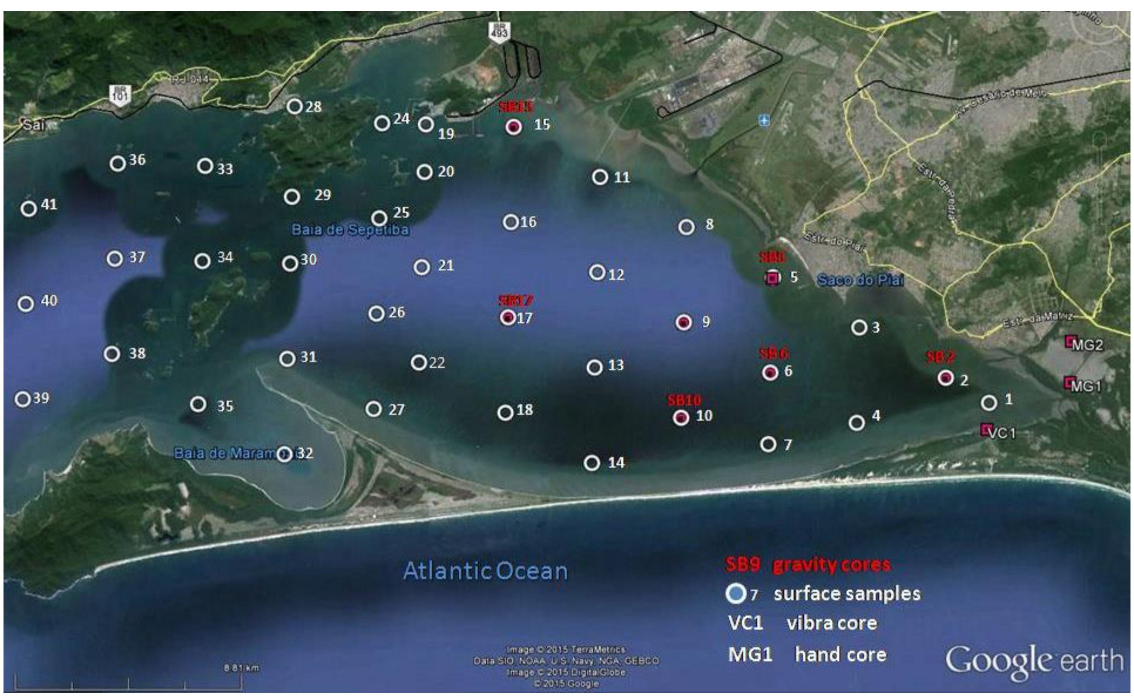

Fig. 5. Geographical locations of surface samples and gravity cores, collected in 1996 and 1997. Locations SB2, SB5, SB6, SB9, SB10, SB15 and SB17 are both gravity core and surface samples.

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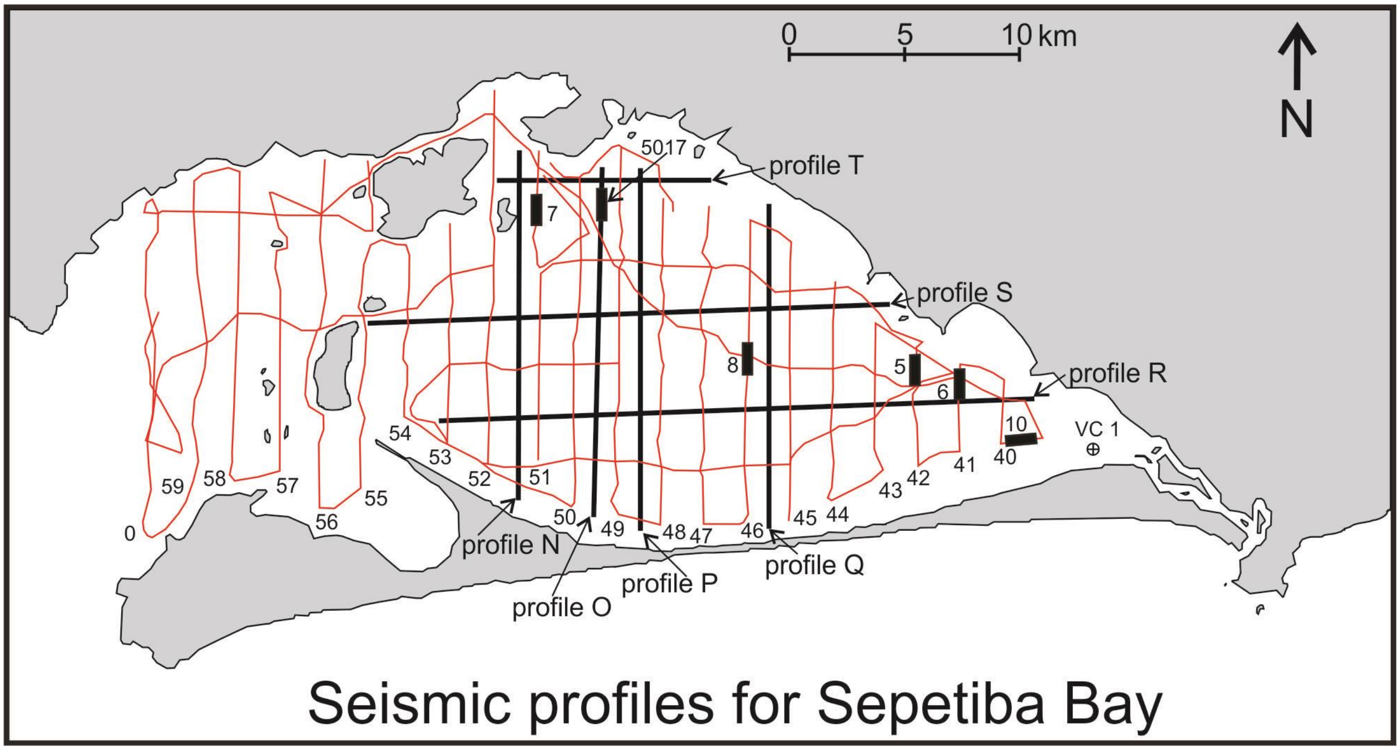

Fig. 6. Ship track of seismic profiles for Sepetiba Bay collected during 1996 and 1997, and geographical location of Vibracore (VC1). Profiles followed lines corresponding to minutes of latitude and longitude, parallel and perpendicular to Marambaia Barrier Island.

4.5. Regression statistics

BIOMstat 3.2a, F-test and Excel software were used to evaluate whether the different calculated slopes of ^{210}Pb activity versus depth are statistically different one from another.

4.6. Radiochemistry

Accumulation rates were determined by ^{210}Pb geochronology and calculated using the advection-diffusion equation, assuming steady state and no compaction:

$$D\frac{\partial^2 C}{\partial^2 z^2} - A\frac{\partial C}{\partial z} - \lambda C = 0 \qquad \text{Eq. (1)}$$

mixing accumulation decay

where C = activity of radioisotope in sediment (dpm/g; dpm = disintegrations per minute);

D = particle mixing coefficient (cm^2/yr);

A = sediment accumulation rate (cm/yr);

λ = decay constant for radioisotope (yr^{-1}) = 0.693 (half life)$^{-1}$; and

z = depth below sediment surface (cm).

Assuming that flux of sediment and a radioisotope to seabed were constant, and mixing coefficient negligible (D = 0) over an interval $z>z_1$, then the solution to Eq.(1) for $z>z_1$ is an exponential function $C(z) = C(z_1)\ e^{-(\lambda/A)z}$. The vertical activity profile of the radioisotope can be then used to estimate accumulation rate (A) using the relationship:

$$\ln\frac{C(z)}{C(z_1)} = -\left(\frac{\lambda}{A}\right)z \qquad \text{Eq. (2)}$$

where $C(z_1)$ = activity of radioisotope at fixed upper level of the profile $z = z_1$; $C(z)$ = activity of radioisotope at a distance z below level of C_0; and λ = decay constant of radioisotope

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= 0.693 (half life)$^{-1}$ (Nittrouer and Sternberg, 1981; Nittrouer et al., 1984).

5. Results

5.1. Sedimentology

Sediment distribution in Sepetiba Bay observed from the 1996 survey shows a predominance of fine sediments, clay and silt, relative to coarser material (Borges, 1996). Coarse sediments, fine sand and very fine sand, are concentrated in the region west of Itacuruçá Island and east of Jaguanum Island. Very fine sand also is present, as a small fraction in eight samples.

The SB2 core, collected from the tidal flat (Figure 7), showed a regular increase in silt from 8% at the top of the core to 22% at 15 cm depth, continuing as such to the bottom of the core. The SB5 core (Figure 7) also showed an increase in silt with depth. The clay percentage in the SB5 core varies from 75-97%; the silt content varies from 3-25%. In core percentage varies from 6-20%; clay varies from 80-94%. Core SB9 (Figure 7), collected at the center of the bay, revealed clay and silt contents of 81-86% and 14-19%, respectively. In core SB10 (Figure 7), clay increases with depth, from 77%-85%. The SB15 core was collected east of Sepetiba Port (Figure 5), an area frequently affected by dredging. The top of the core has 20% of fine sand, 32% of silt, and 48% of clay. From 16 cm to the bottom of the core, silt and clay ranges from 19-23% to 75-81% respectively. Core SB17 (Figure 5), the shortest collected in the area, is composed equally of silt and clay.

The five-meter-long vibracore collected at the entrance of the tidal channel in Barra de Guaratiba showed two distinct layers, a muddy layer and a sandy layer (Figure 8). A sequence of layers was present from the top of the core to a depth of 3.17 m in the muddy layer, changing down core from laminated mud to bioturbated mud with shell fragments, sandy mud, mud with shells, laminations, and finally to bioturbated mud at the bottom of the layer. A wood fragment was found at the contact of the muddy and the sandy layers, and was analyzed for radiocarbon age. The layer deeper than 3.17 cm was composed of medium sand, semiconsolidated at the bottom of the core.

5.2. Seismostratigraphy

Two seismic stratigraphic units were identified in the geophysical survey of Sepetiba Bay. These two seismic units top and bottom units, are separated by a discontinuity surface. The layer represented by the top unit is distributed throughout the bay (Figure 9). Its thickness varies from 9 to 11 m in the north, becoming thinner toward the barrier island, where it ends. The top of the bottom unit is defined by a discontinuity surface, which is present on all profiles. The thickness of the bottom unit is variable and difficult to evaluate from the seismic record. It can be measured only in regions where bedrock is shallow.

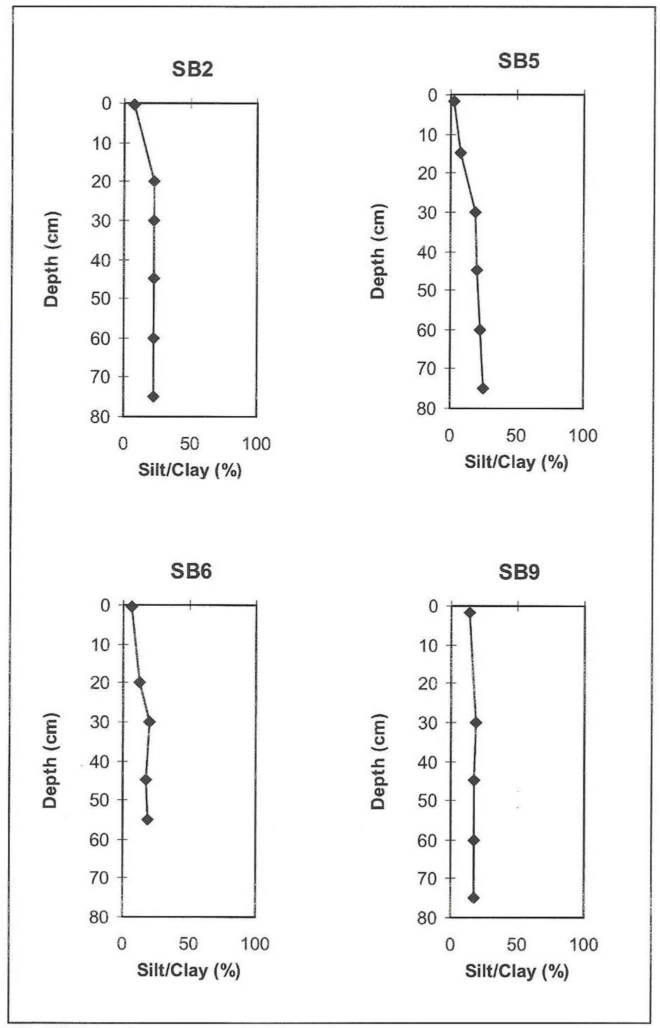

Fig. 7. Sediment distribution in along four cores collected at Sepetiba Bay in the 1996 survey. The grain size distribution shows a general fining up of sediments from 50-30 cm interval to the top of the cores.

5.3. Radiochemistry

Profiles of ^{210}Pb activity with depth for the seven cores are presented in Figure 10.

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5.4. ^{210}Pb Profiles

Core SB2 (Figure 10) has a layer of near constant activity ~12-cm thick, below this layer to ~50 cm is a region of decreasing activity interpreted as primary due to radioactive decay. ^{210}Pb background levels are found below 50 cm in the core. Core SB5, collected near the shore, has a 10-cm mixed layer, which is presumably due to physical reworking (no evidence of biogenic structures). The top 3-cm in this profile has a scattered distribution of ^{210}Pb activity, which could be related to pulse input of sediment. The region of net decay in this profile is 60 cm thick and can be divided into two sections. Constant background levels of ^{210}Pb are found from 70 cm to the bottom of the core.

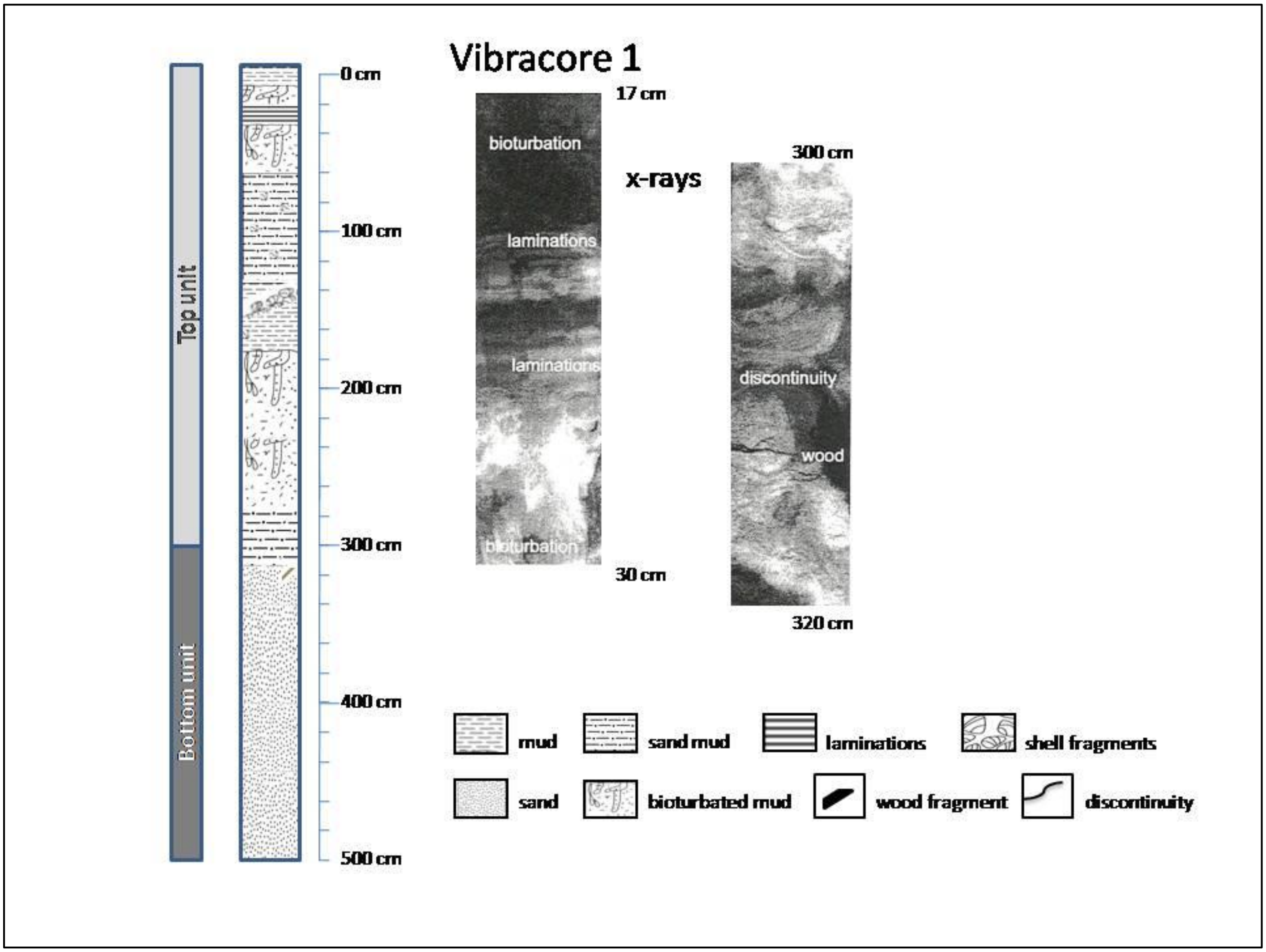

Fig. 8. Sedimentary facies identified along the vibracore, X-rays of sections showing laminations, bioturbation, and shells and wood fragments. Correlation of seismic units and the sedimentary environments is shown on the left side of the Vibracore.

The ^{210}Pb profile of the SB6 core (Figure 10), located at center of the bay (Figure 5), is similar to that of the SB5 core. Its profile has a 12-cm-thick mixed layer with scattered distribution of ^{210}Pb activity at the top of the core (Figure 10). The region of decay is 45 cm thick, and apparent background levels are found deeper in this core. Two distinct regions of decay can be identified in this profile.

Core SB9 was collected at the limit of the surficial clay distribution (Figures 5 and 6) and near to the mouth of Guandú River. Its ^{210}Pb profile is similar to that of the cores previously described, with a 13-cm-thick mixed layer, a region of decay from this depth to 55 cm (with two distinct sections), and background levels detected deeper in the core (Figure 10).

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Core SB10 was not deep enough to sample the region of decay (Figure 11). Its profile has a 40-cm thick region with scattered distribution of ^{210}Pb activity at the top of the core. The bottom 10 cm of the core shows what is probably the top of the region of net decay.

Core SB15, 110 cm long, has a ^{210}Pb-activity profile with a thick mixed layer, approximately 40 cm, a region of decay from 40 to 70 cm. Below 70 cm in the core, ^{210}Pb activity increases again (Figure 11). As mentioned before, the region where this core was collected, at Guandú River mouth (east of Sepetiba Port) is a region that is constantly dredged.

The distribution of ^{210}Pb activity in this profile is probably reflecting the highly non steady state disturbances in the environment and not natural accumulation. Core SB17, is the shortest core and was collected at the center of the bay (Figure 11). Its profile shows a mixed layer with scattered distribution of ^{210}Pb-activity ≥ 20 cm deep and did not reach the region of decay.

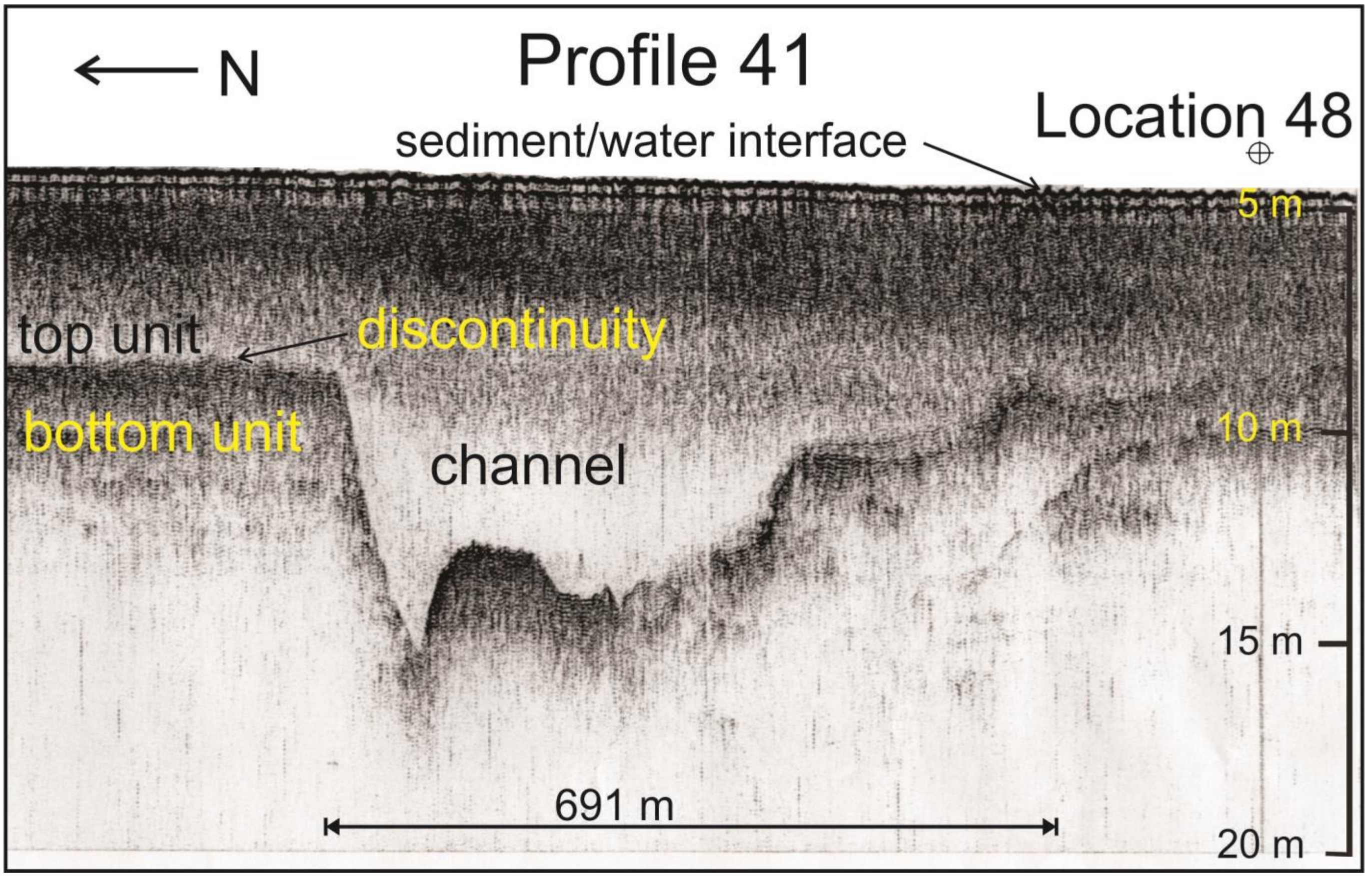

Fig. 9. Seismic record of Profile 41, showing: top and bottom units; discontinuity surface between the units; and a river channel (7-m deep and 390 m width). "Location 48" is a navigation fix.

Sediment accumulation rates in Sepetiba Bay, calculated from the four well-defined ^{210}Pb profiles, varied in each core and with depth. Core SB2 was the only core, among the four, which presented an obvious single accumulation rate of 0.40 cm/yr. Based on perceived breaks in the activity versus depth distribution, two accumulation rates were calculated for SB5: 1.20 cm/yr (10-50 cm depth) and 0.40 cm/yr (50-70 cm depth). In the same way for the SB6 core, accumulation rates were 1.01 cm/yr (10-30 cm depth) and 0.37 cm/yr (30-45 cm depth). Core SB9 shows an accumulation rate of 2.00 cm/yr (10-40 cm depth) in the upper region, the highest accumulation rate in the area, and 0.62 cm/yr (40-55 cm depth).

The approximate times of the accumulation rate change for cores SB5, SB6, and SB9 are 22, 17, and 22 years ago. These average 20±3 years, suggesting that sediment accumulation rates in Sepetiba bay may have changed in the mid- to late 1970s (Figure 10).

The pattern of evolution of the values of Factor Score 1 are similar to that of Th/Sc and is the opposite of Co/Th.

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The lowest values of this Factor Score are coincident with major geochemical changes associated with the sections with finest grained sediments found in this core.

5.5. Regression statistics

First, all activity-depth distributions show high degrees of linear correlation. Comparison of slope intervals at a 95% confidence level demonstrate that upper and lower sections of cores SB5 and SB9 are significantly different than the combined sections composed of all samples.

For core SB6, the inferred upper and lower sections have significantly different slopes, but the lower section slope is not significantly different than the overall average (F-test), shown in Table 1.

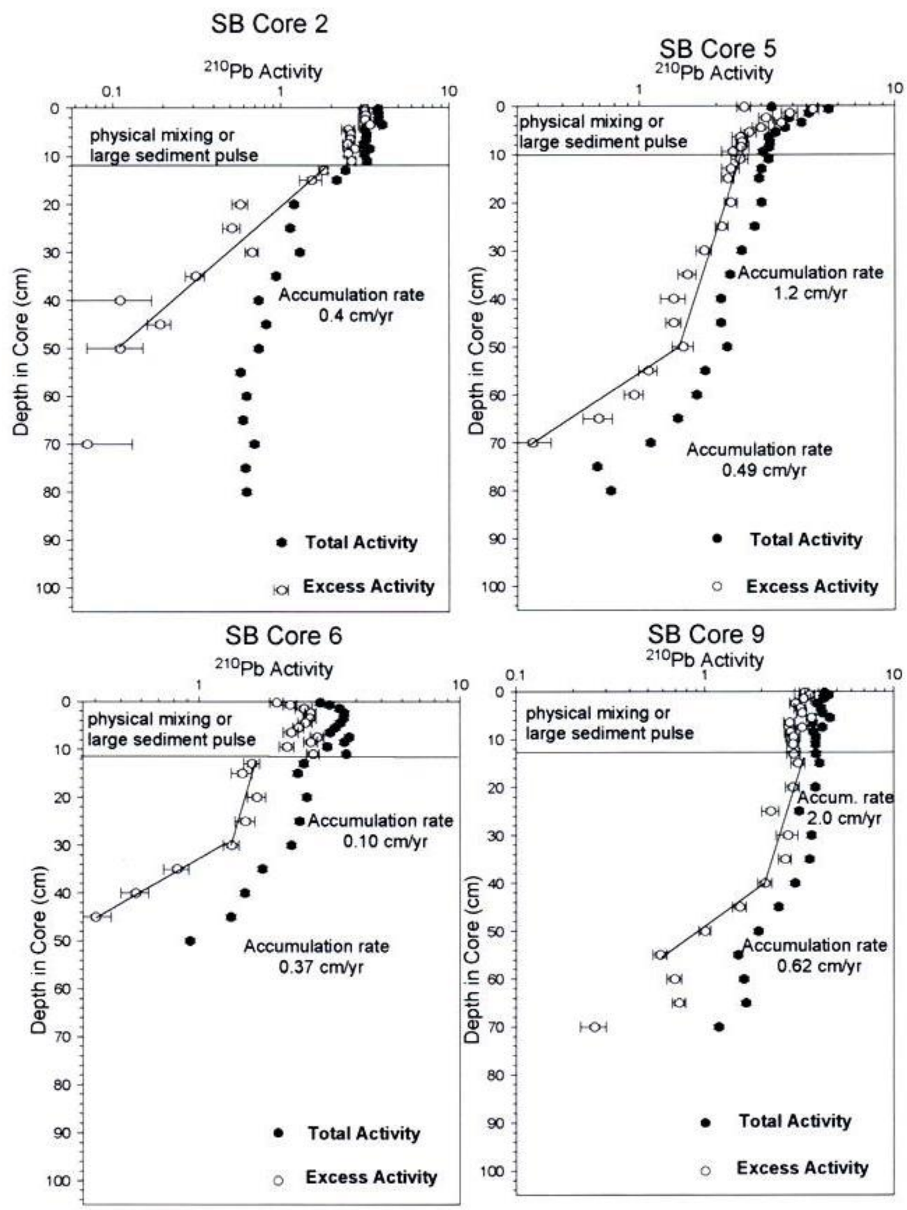

Fig. 10. ^{210}Pb profiles observed in gravity cores collected throughout the study area. Accumulation rates are calculated from profiles of excess activity. Profiles have surface mixed layers approximately 10-cm thick (presumably due to physical or biological reworking) above exponentially decreasing activity. Profiles SB 5, 6 and 9 have a distinct change in slope of exponentially decreasing interval, from which two different accumulation rates were calculated.

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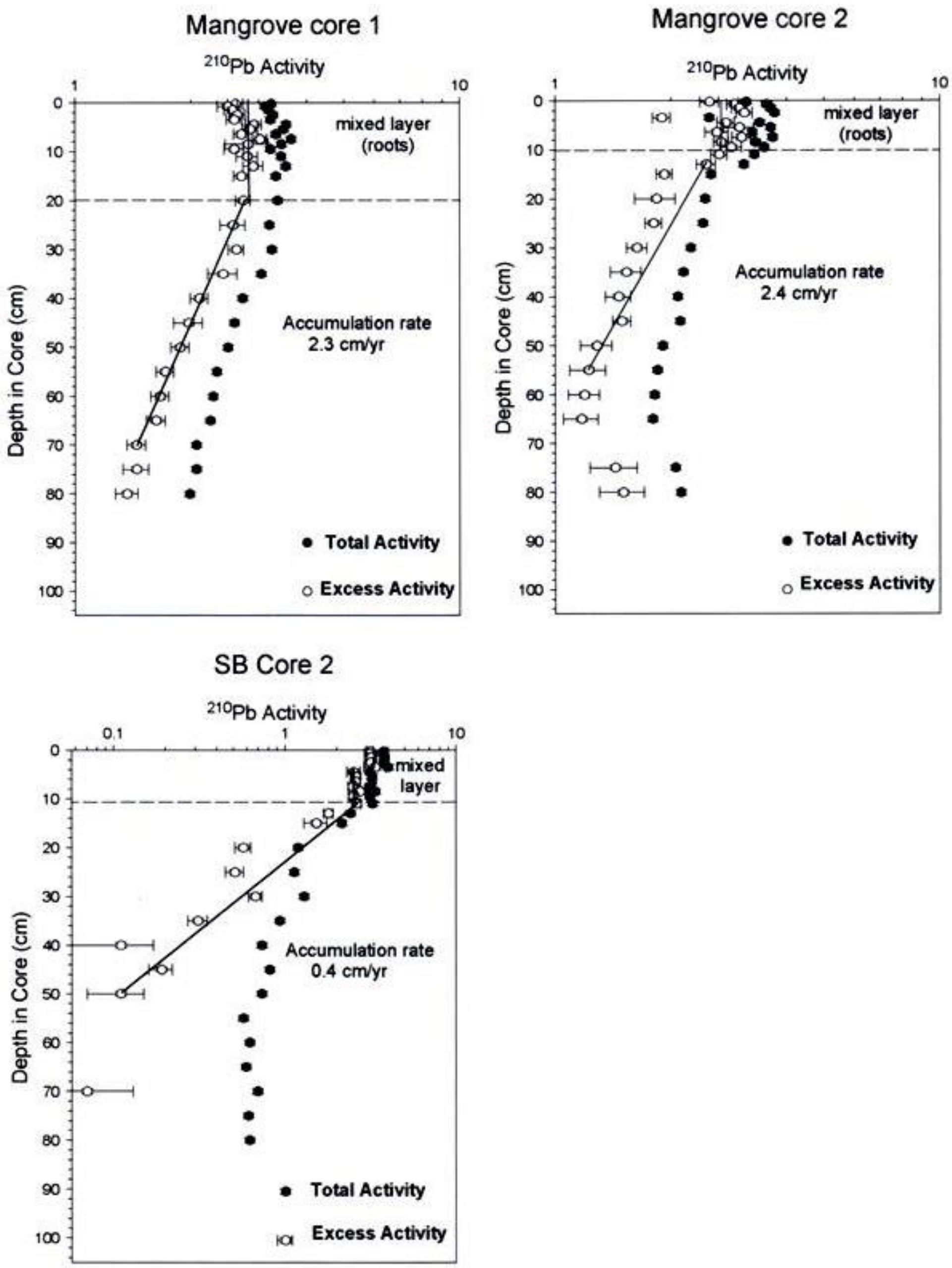

Fig. 11. ^{210}Pb profiles of cores SB 10, SB 15 and SB 17. Core SB 10 and 17 had short penetration, and surface mixed layer is not well defined. In core SB 15, collected at Guandú river mouth, ^{210}Pb activity fluctuates significantly with depth (increase in activity below 70-cm depth) and has no recognizable trend.

5.6. Radiocarbon

The wood fragment collected at 317 cm, just below the discontinuity (Figure 8 and 9), from the vibracore was dated by the ^{14}C method at AMS radiocarbon analysis at the NOSAMS Facility (Woods Hole), and indicated an age of 6890±40 yr. B.P. The age of the sample was placed in a general sea-level curve for the area (Angulo and Lessa, 1997; Fairbanks, 1989) and this date is interpreted to mark the Holocene transgression at this site (Borges and Nittrouer, 2016).

Assuming that this date applies to the corresponding seismic stratigraphic boundary throughout the bay, average long-term accumulation rates can be determined for sediment above the boundary. The thickness of the overlying

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layer, determined from high-resolution seismic profiles, divided by the initial boundary age gives an approximate value of the late Holocene long-term accumulation rate. The distributions of long-term rates are shown in the contour map of Figure 12, along with the upper interval ^{210}Pb accumulation determined at 4 sites. The long-term rates range from 0.01-0.17 cm yr^{-1}, and are 0.03-0.06 cm yr^{-1} in the region where ^{210}Pb dated cores were obtained.

Tab. 1. Results of the statistical analysis of slope intervals for cores SB5, SB6 and SB9.

Core	Interval (5% error)	Standard error	F-test	Sedimentation rate (cm yr^{-1})
SB5	upper	0.0028	Signif. different	1.20
	lower	0.0092	Signif. different	0.49
	overall	0.0036	Signif. different	1.10
SB6	upper	0.0130	Signif. different	1.01
	lower	0.0044	No difference	0.37
	overall	0.0067	No difference	0.58
SB9	upper	0.0028	Signif. different	2.00
	lower	0.0092	Signif. different	0.62
	overall	0.0036	Signif. different	0.20

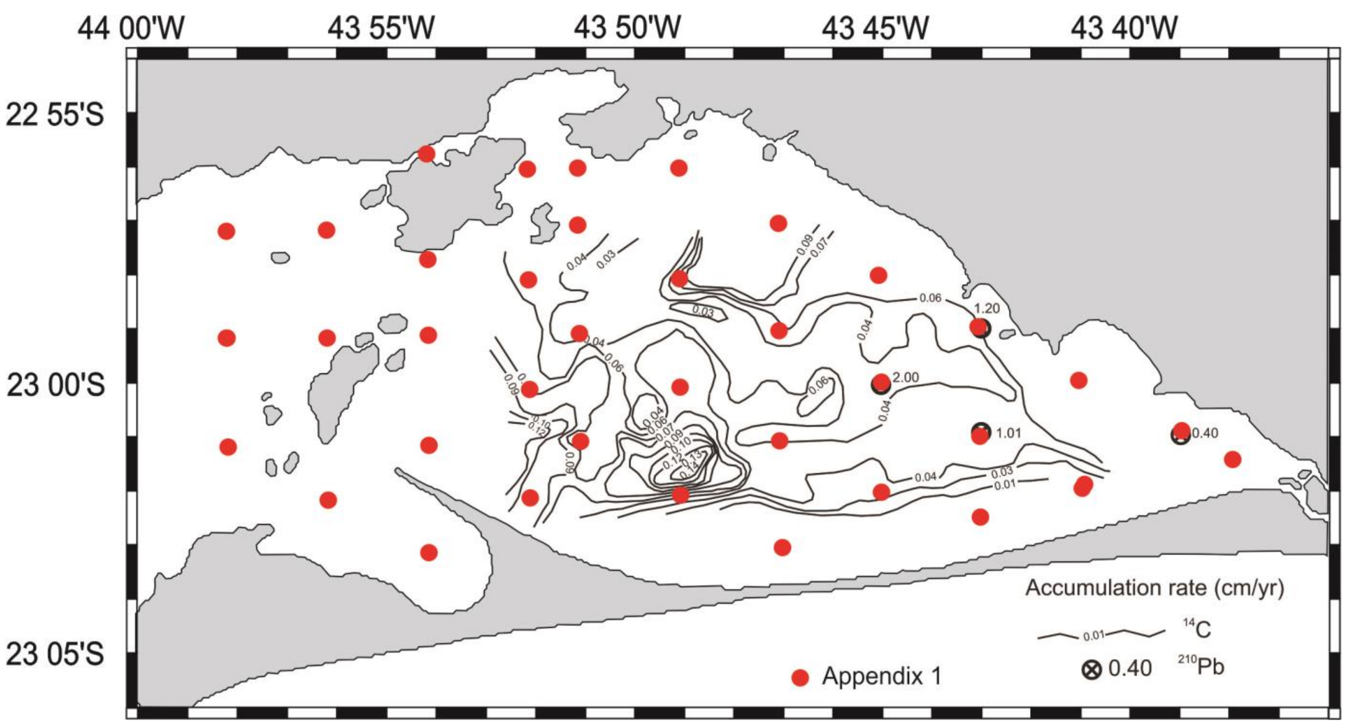

Fig. 12. Long-and short-term accumulation rates calculated from seismic and radiochemical data. Accumulation rates for the last 100 years are plotted in locations where cores were collected in the bay.

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6. Discussion

The sedimentological surveys carried out during the 1970s (Ponçano, 1976; Roncarati and Barrocas, 1978) demonstrated that the bottom of Sepetiba Bay was predominantly composed of fine grain sediments. Silt occurred throughout the north side of the bay, but was restricted in the south by sand near the barrier island. Clay distribution was restricted to the areas east of the river channels. Coarse sediments, very fine sand to medium sand, were found in areas near the barrier island, at the entrance of tidal channels, near islands, and in channels between the islands (west of the bay).

The methodology used in the present grain-size analyses of Sepetiba Bay differs from that done by Ponçano (1976) and Roncarati and Barrocas (1978). However the results of the SediGraph 5100 can also be directly compared to those obtained by the standard mechanical dry-sieve-shaking and pipette methods used in previous surface sediment surveys (Coakley and Syvitski, 1991). A general fining upward of sediments is well documented in the gravity cores analyzed in this study. Although coarse sediments remained constant, fine sediments, silt and clay, obviously changed in distribution in the 1996 relative to the 1970 survey. The same grain size patterns are found in cores analyzed for heavy metals in Sepetiba Bay (FEEMA, 1997). It is clear that in 1996, clay-sized particles cover a much larger area than previously found, forming an extensive tidal flat from the river mouths to Barra de Guaratiba, and that much of the bay has experienced a general fining-upward trend in silt to clay sediment size.

Accumulation rates calculated from ^{210}Pb profiles and ^{14}C dating suggest a recent change in sediment accumulation rate. During the Holocene transgression, and probably until last century, the sedimentation rate in the eastern part of Sepetiba Bay was <0.17 cm yr^{-1} (0.03-0.06). ^{210}Pb data showed an increase of this rate to ~0.37 cm yr-1 in the mid-1970s. Accumulation rates for the last 20 years range even higher, from 0.10-2.00cm yr^{-1}, in the cores collected at the limit of the clay distribution area, to 0.40-1.2 cm yr^{-1} in the tidal flats. The apparent increases in sediment accumulation rates observed in the various cores may be evidence of changes in the coastal environment in the last 100 years.

Grain size distribution along the cores and ^{210}Pb profiles suggested a change in sedimentation patterns in Sepetiba Bay. The timing of this change is calculated to be approximately mid- to late 1970s (Lacerda et al., 1987; Barcellos and Lacerda, 1994; Molisani et al., 2004). This approximate date derived from ^{210}Pb corresponds well with patterns of increased Zinc concentrations in cores collected and analyzed by FEEMA in previous surveys (FEEMA, 1980 and FEEMA, 1997). For example, the break in ^{210}Pb and grain size in core SB5 correlates exactly with the level at which Zn begins to increase (Figure 13). The lack of dramatic change in other metals (e.g. Cd) at the same point, indicates that grain size changes are not the reason for increased Zn but rather implicates a specific source. The Zn smelter industry and increased development on Sepetiba Bay began in the 1970s (Lacerda et al., 1987; Barcellos and Lacerda, 1994; and Molisani et al., 2004). Thus, simultaneous increased Zn, sediment accumulation rates and fining upward are consistent with significantly increased impact of coastal development on sedimentation patterns in Sepetiba Bay beginning in the 1970s.

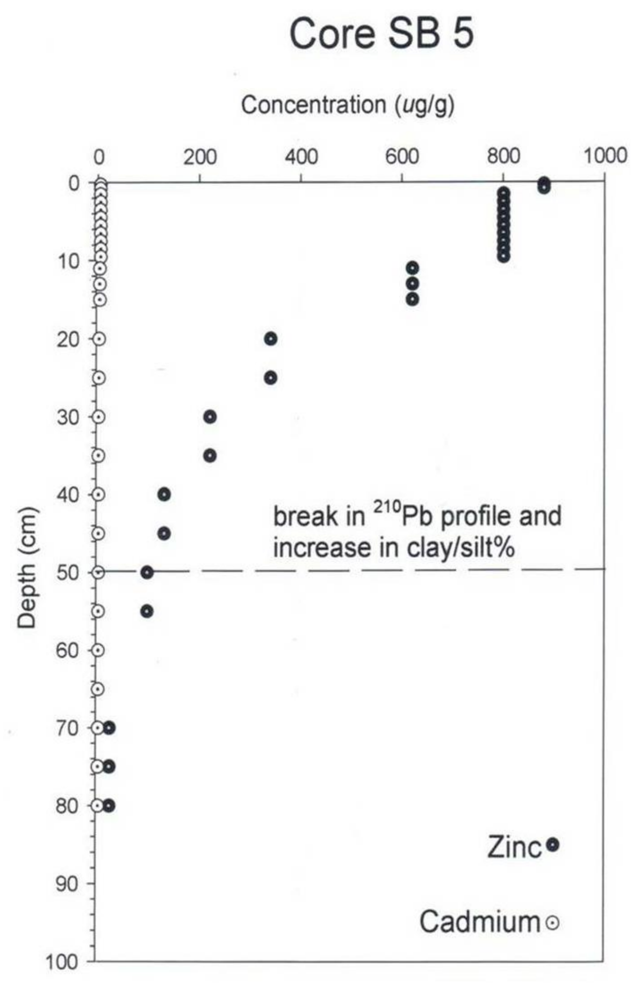

Fig. 13. Plot of Zinc and Cadmium concentrations in μg/g versus depth of samples from core SB 5. The plot shows a large increase in Zinc concentration at 50-cm depth compared to Cadmium concentration, which does not change along the core. Dashed line represents the break in ^{210}Pb slope and increase in clay/silt percentage.

7. Conclusions

Sedimentation in Sepetiba Bay has changed in the last 20-30 years. The clay fraction has increased in relation to silt. High accumulation rates of clay in the northeast area caused changes in the Sepetiba Bay coastline, with progradation of 400 m toward the bay since 1868.

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Supplementary material 1. Sediment samples collected in Sepetiba Bay.

Sample #	Date	Latitude	Longitude
1	07/16/96	23º 01' 30" S	43º 38' 00" W
2	07/16/96	23º 01' 00" S	43º 39' 00" W
3	07/16/96	23º 00' 00" S	43º 41' 00" W
4	07/16/96	23º 02' 00" S	43º 41' 00" W
5	07/16/96	22º 59' 00" S	43º 43' 00" W
6	07/16/96	23º 01' 00" S	43º 43' 00" W
7	07/16/96	23º 02' 30" S	43º 43' 00" W
8	07/16/96	22º 58' 00" S	43º 45' 00" W
9	07/16/96	23º 00' 00" S	43º 45' 00" W
10	07/16/96	23º 02' 00" S	43º 45' 00" W
11	07/16/96	22º 57' 00" S	43º 47' 00" W
12	07/16/96	22º 59' 00" S	43º 47' 00" W
13	07/16/96	23º 01' 00" S	43º 47' 00" W
14	07/16/96	23º 03' 00" S	43º 47' 00" W
15	07/16/96	22º 56' 00" S	43º 49' 00" W
16	07/16/96	22º 58' 00" S	43º 49' 00" W
17	07/16/96	23º 00' 00" S	43º 49' 00" W
18	07/16/96	23º 02' 00" S	43º 49' 00" W
19	07/16/96	22º 56' 00" S	43º 51' 00" W
20	07/16/96	22º 57' 00" S	43º 51' 00" W
21	07/16/96	22º 59' 00" S	43º 51' 00" W
22	07/16/96	23º 01' 00" S	43º 51' 00" W
23	07/16/96	22º 25' 00" S	43º 52' 00" W
24	07/16/96	22º 56' 00" S	43º 52' 00" W
25	07/16/96	22º 58' 00" S	43º 52' 00" W
26	07/16/96	23º 00' 00" S	43º 52' 00" W
27	07/16/96	23º 02' 00" S	43º 52' 00" W
28	07/16/96	22º 55' 42" S	43º 54' 00" W
29	07/16/96	22º 57' 36" S	43º 54' 00" W
30	07/16/96	22º 59' 00" S	43º 54' 00" W
31	07/16/96	23º 01' 00" S	43º 54' 00" W
32	07/16/96	23º 03' 00" S	43º 54' 00" W
33	07/16/96	22º 57' 00" S	43º 56' 00" W
34	07/16/96	22º 59' 00" S	43º 56' 00" W
35	07/16/96	23º 02' 00" S	43º 56' 00" W
36	07/16/96	22º 57' 00" S	43º 58' 00" W
37	07/16/96	22º 59' 00" S	43º 58' 00" W
38	07/16/96	23º 01' 00" S	43º 58' 00" W
39	07/16/96	22º 58' 00" S	44º 00' 00" W
40	07/16/96	23º 00' 00" S	44º 00' 00" W
41	07/16/96	23º 02' 00" S	44º 00' 00" W

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Supplementary material 2. Sediment cores collected in Sepetiba Bay.

Core #	Date	Latitude	Longitude	Length (cm)	Type
2	07/17/96	23º 01' 00" S	43º 39' 00" W	80.0	Gravity
5	07/16/96	22º 59' 00" S	43º 43' 00" W	60.0	Gravity
6	07/16/96	23º 01' 00" S	43º 43' 00" W	54.0	Gravity
9	07/18/96	23º 00' 00" S	43º 45' 00" W	75.0	Gravity
10	07/16/96	23º 02' 00" S	43º 45' 00" W	56.0	Gravity
15	07/16/96	22º 56' 00" S	43º 49' 00" W	120.0	Gravity
17	06/27/96	23º 00' 00" S	43º 49' 00" W	25.0	Gravity
MG1	07/12/96	23º 01' 00" S	43º 36' 09" W	80.0	Hand
MG2	07/12/96	23º 00' 08" S	43º 36' 09" W	80.0	Hand
VC1	08/08/96	23º 02' 02" S	43º 38' 01" W	500.0	Vibra