ABSTRACT

The coastal region off Santos (State of São Paulo, Southeastern Brazil), one of the most strategical Brazilian areas, where is placed the main port terminal has had an accelerated process of industrial and harbor improvement during the second half of the 20th century. An evolution of the depositional (sedimentary) processes in the context of this accelerated growth can be verified by sedimentation rates and the variation of heavy metal levels in the sedimentary columns from the upper estuary as well as in the Santos bay. The sedimentary changes were evaluated from the analysis of the texture as well as the variations of the concentrations of the metallic elements (Pb, Cu, Zn and others).

The sedimentation rates were obtained by 210Pb and 137Cs. The most representative sedimentary column from the area of the Santos bay (core S2T3) presented a segmentation of the sedimentation between 10 and 14 cm of depth. The value obtained for the uppermost sequence is about 0.91 mm.y-1 while the lower sequence presented a higher value rate (3.8 mm.y-1). This rate change represents a modification in the sedimentary pattern of the area, as one sequence of thin sandy sediments is replaced by the depositional of finer sediments (medium to fine silt). The higher sedimentation rate values from the area of the upper estuary, 4.0 mm.y-1 to 210Pb (Barnabe Island), correspondes to an approximate time range of 100 years. For 137Cs the sedimentation rate is 5.6 mm.y-1 which represents the last 40 years. The increases of the concentration of the metallic elements in the sedimentary columns from these areas point to a change in the sedimentary dynamics and the concentration of the sediments starting at 10 cm. From this, it was possible to develop a history of the contamination by levels over that area.

ADDITIONAL INDEX WORDS: Sedimentation rates, heavy metal levels, sedimentary processes.
The upper and medium estuary from Santos configures a general process of sedimentation, in a low energy environment, where muddy sedimentation predominates.

An evaluation of the depositional processes in the context of the intense sedimentary dynamics in the Santos estuary and bay, throughout the last 70 years, was developed using recent sedimentation rates obtained by gamma spectrometry (\(^{210}\)Pb and \(^{137}\)Cs) and by the variation of heavy metals levels along four cores collected in the area of the bay (S2T3 and 6945) and in the upper estuary (Barnabe Island and Santa Rita Inlet). These areas are presented in Figure 1.

The cores were sliced every 2 cm, freeze-dried, homogenized and transferred to appropriate plastic pots to the counting in the gamma-ray spectrometer, low background Ge detector, EG&G Ortec, GEM 60120 P model, with the resolution of 1.9 keV at 1332.40 keV photopeak of \(^{60}\)Co. The methodology of analysis and data acquisition is described by Figueira et al. (1997) and SAITO et al. (2001a, 2001b).

Chemical analysis of the heavy metals in the sediments was carried out by CEIMIC Corporation laboratory. The samples were digested using EPA 3050A Method (USEPA, 1996) and analyzed by Perkin Elmer Optima 4300 ICP-OES. Grain size of

**METHODS**

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Figure 2. Sedimentation rate for the shallow sedimentary column S2T3. The values of \(^{137}\)Cs were corrected by mud level.

Figure 4. Sedimentation rate for Barnabe Island shallow sedimentary column. The values of \(^{137}\)Cs were corrected by mud level.

Figure 3. Sedimentation rate for the shallow sedimentary column 6945. The values of \(^{137}\)Cs were corrected by mud level.

Figure 5. Sedimentation rate for Santa Rita Inlet shallow sedimentary column. The values of \(^{137}\)Cs were corrected by mud level.
the collected sediments was obtained according to Suguo (1973).

RESULTS

In Santos bay the core S2T3 presents a significant change in the sedimentary pattern in the interval between 10 and 14 cm of depth. The sedimentary sequence is constituted of muddy sediments containing biogenic material. The upper sedimentary sequence (top 10 cm) presents a sedimentation rate of 0.91 mm.y⁻¹ related to the radioactive decay of ²¹⁰Pb. The lower sequence presented a higher value rate (3.8 mm.y⁻¹), with a precision error significantly larger than the computed value. ¹³⁷Cs analysis confirmed the change in the sedimentation pattern in the range between 10 and 14 cm. The sedimentary sequence presented a sedimentation rate of 4.0 mm.y⁻¹ (0.05 mm.y⁻¹) with a maximum value at 14 cm of depth, corresponding to 1964 and 1965, characterized as the period of larger emission of this radionuclide in the atmosphere from nuclear tests on surface. Figure 2 shows the sedimentation rate for ²¹⁰Pb and ¹³⁷Cs in shallow sedimentary column S2T3. The core 6945 presents mud contents varying from 21.7% (6 cm of depth) to 43.2% (16 cm of depth). The sedimentation rate related to ²¹⁰Pb radionuclide was not determined in core 6945, once its radioactive decay column was homogenized, either by remobilization of sedimentary package or by percolation of...
fluids along the column. However, no difficulty was presented by $^{137}$Cs method (Figure 3) making possible to obtain a sedimentation rate of $2.7 \text{ mm.y}^{-1}$, with a maximum value of radioactive fallout at 12 cm of depth.

The sedimentary sequences obtained in the cores of the upper estuary, Barnabe Island and Santa Rita Inlet, were homogeneous, being constituted of muddy sediments, and a solid structure without the presence of bioturbations or shells.

In the upper estuary area, the Barnabe Island shallow sedimentary column presented a pattern of continuous radioactive decay for $^{210}$Pb, with a sedimentation rate value of $4.0 \text{ mm.y}^{-1}$ ($1.8 \text{ mm.y}^{-1}$). For $^{137}$Cs the rate was slightly higher $5.6 \text{ mm.y}^{-1}$ ($1.2 \text{ mm.y}^{-1}$), with the maximum emission being detected at the 20-22 cm of depth (Figure 4).

The rate obtained by the $^{137}$Pb technique for the Santa Rita core was of $1.5 \text{ mm.y}^{-1}$ ($0.4 \text{ mm.y}^{-1}$); using the $^{137}$Cs technique the found value was similar ($1.7 \text{ mm.y}^{-1}$) (Figure 5).

A homogeneous behavior of the metallic elements in the sampled shallow sedimentary columns of Santos bay, is observed, along the basal sequences of the cores S2T3 and 6945. A change in the levels of some metals (Pb, Cu, Cr and Zn), that were normalized by Sc levels (UNEP, 1995), occur in the direction on the top, presenting a little enrichment. The samples dating, from sedimentation rate indicated that the highest levels are related to the beginning of the 1950's, it was a period of intense industrialization in Santos area.

Figure 7. Normalized metals values by Al and Sc for shallow sedimentary columns S2T3, 6945, Barnabe Island and Santa Rita Inlet.
In the upper estuary area the levels of the metallic elements (Pb, Zn and Cu), normalized by Sc, on the top of the shallowsedimentary columns presented higher results than Santos bay. Figures 6 and 7 present the levels of metals and the normalized factor by Sc in the region studied.

CONCLUSIONS

$^{137}$Cs showed to be the most appropriate radionuclide to obtain the recent sedimentation rates for the studied cores. The difference between the results from $^{210}$Pb and $^{137}$Cs techniques may be due to the low content of mud along the sampled sequences. The increase of mud levels on the top of the cores, the presence of radioactive fallout of $^{137}$Cs in this depth and its longer half-life (about 30 years) contributed to a more reliable analysis.

The obtained values in the upper estuary sequences by $^{210}$Pb and $^{137}$Cs techniques are in agreement. Sedimentation rates are slightly higher in Barnabe Island when compared to other areas of the upper estuary and Santos bay.

It was also observed that an enrichment of Pb, Cu and Zn occurred from 1950. This enrichment was more significant in the upper estuary area (Barnabe Island and Santa Rita Inlet) than in Santos bay (S2T3 and 6945).

The sedimentation rates and the metallic elements values obtained along the cores of the upper estuary and the Santos bay allowed us to obtain a history of sedimentary deposition for the period of intense industrialization in Santos area.

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LITERATURE CITED


