A model of recent sedimentation in the Cananeia–Iguape estuary, Brazil

R.T. Saito[a], R.C.L. Figueira[b,c], M.G. Tessler[c], I.I.L. Cunha[a,*]

[a] *Radiochemistry Division, IPEN-CNEN, São Paulo, Brazil*
[b] *Cruzeiro do Sul University (UNICSUL), São Paulo, Brazil*
[c] *Instituto Oceanográfico, Universidade de São Paulo, São Paulo, Brazil*

Abstract

Coastal systems, in particular estuaries, are the first depositional environment to receive sediments transported by rivers to the coastal ocean. As a consequence of the geochemical processes involved, a part of the sediment may be deposited in the estuary and the remainder flows into the ocean, being transported and deposited under the influence of tides and maritime currents. This study was carried out in the Cananeia–Iguape estuary on the southern coast of São Paulo state, Brazil. The vertical distribution of ^{210}Pb and ^{137}Cs in sediments has been used as a tool for estimating the sedimentation rates in the coastal environment. Concentrations of ^{210}Pb and ^{137}Cs, as well as heavy metals (lead, zinc, copper) were determined in four sediment cores collected in the Cananeia–Iguape estuary. The estimated sedimentation rates were from 5.3 mm yr^{-1} to 12.7 mm yr^{-1}. The highest sedimentation rate obtained for Valo Grande corresponds with an accelerated expansion of the sand and clay banks of the Mar Pequeno channel, a growth of the mangrove areas, and a decrease in the depth of the main channel of navigation, a fact that has been affecting the navigation in the area very seriously. The data obtained for the metals showed a sedimentary dynamics in agreement with that obtained in the studies of sedimentation rates, thus contributing to the understanding of the hydrodynamic mechanisms of the system.

Keywords: Radionuclides, ^{210}Pb dating, ^{137}Cs, Heavy metals, Coastal sediment, Estuary, Sedimentation model, Brazil

1. Introduction

Intensive human activities in the estuarine regions in recent decades, have significantly increased sediment inflows at these sites and, consequently, of the accumulation of sediment in the estuarine channels and in the coastal ocean. The use of ^{210}Pb to date sediments up to 100 years old is a very important tool for establishing a geochronology of the coastal environment (Ravichandran et al., 1995). Other radionuclides, such as ^{137}Cs, are often used to determine sedimentation rates in addition to the data provided by ^{210}Pb measurements (Somayajulu et al., 1999).

* Corresponding author. Address: Rua Manoel Alonso Esteves 66 – Jardim Bonfiglioli, São Paulo Capital, CEP 05589-020, Brazil; e-mail: iedacunha@ig.com.br

This paper presents and discuss radionuclide levels, as well as contents of heavy metals in sediment cores collected from the Cananeia–Iguape estuary. Sedimentation rates have been evaluated at these locations from the unsupported ^{210}Pb and ^{137}Cs profiles. The main objective of this paper is to elucidate the sedimentation process in the Cananeia–Iguape estuary and to develop a suitable sedimentation model.

1.1. *Cananeia–Iguape estuary*

The estuary consists of several channels, the most important of them being the Mar Pequeno, Iguape, Cubatão and Cananeia; several islands, such as Comprida, Iguape, Cananeia and Cardoso; there are also rivers, such as the Ribeira of Iguape. Near the discharge of the Ribeira of Iguape River, there is a group of islands close to the continent, separated by a series of narrow channels, which are interconnected and flow into the Atlantic Ocean through three outlets (Ararapira, Cananeia and Icapara).

Comprida Island, a barrier island approximately 70 km long, separates the Cananeia–Iguape (25°S, 48°W) system from the ocean. The mouth of the Ribeira of Iguape River is located in the northeast of this system. The largest drainage system of the south-eastern Brazilian seashore, draining all the crystalline coastal mountainous complex behind the coastal plain, is connected to the Cananeia–Iguape estuary only by the Valo Grande channel. This artificial channel connects the Ribeira of Iguape River directly to the Mar Pequeno channel.

About 60% of the Ribeira of Iguape River discharge flows at present through the internal channels of the Cananeia–Iguape estuary, causing an increasing silting up of the channels by the deposition of the muddy sediments in suspension carried by the drainage of the Ribeira of Iguape. Thus, the continental material is transferred to the maritime system on the southern seashore of São Paulo State, not only at the mouth of the Ribeira of Iguape River but also at the river mouths of the Cananeia–Iguape estuary.

Sediments continue to be deposited in the channels and internal seas, mainly in the Mar Pequeno channel, and along the islands in the channels. The silting up of the area is taking place so fast that whereas, some decades ago large ships were able to dock in Iguape city, crossing the Cananeia bar, this is now impossible, due to the increasing obstruction at two regions towards the Icapara bar and at Cananeia. In consequence, the present depth of the lagoons and channels is of less than 15 m. The Valo Grande channel was completed in 1852, then about 4 meters wide and 7 meters deep. Now, it is 250 m wide and 15 m deep.

1.2. *Dynamics of the channels*

The Cananeia–Iguape system is formed predominantly of sandy sediments disposed along the surfaces of bottom of all of the channels. This general pattern is only modified in the concave banks of the channel's bends and in the Mar Pequeno channel, where equal mixtures of thick and fine sediments are found beside sandy sediments due to an alternation of energy flows, resulting from the changes in the direction and intensity of currents, that make the deposition of fine sediments, loaded in suspension, mainly from the Ribeira of Iguape River and also from the mangroves areas, possible. Beginning in this area, towards Iguape city, the mixed sediments are gradually replaced by silt and clay sediments, until Valo Grande, where very fine sediments (loamy silts), originating from the Ribeira of Iguape River are deposited.

2. Experimental

2.1. *Sediment sampling*

The core samples were collected by the Oceanographic Institute of the University of São Paulo, Brazil, at four estuary stations, that show different sediment inflows to the coastal system (Fig. 1): T1 (Ponta do Arrozal, in the south of Cananeia Island, between Cananeia Island and Cardoso Island); T2 (Ponta do Frade, along the Comprida Island); T3 (Valo Grande, near the mouth of Ribeira of Iguape, at Mar Pequeno channel); and T4 (Carapara River, NW of Cananeia Island). The sediment was collected with a cylindrical PVC container of 50 cm height and 7 cm in diameter. The cores were sliced into 2 cm thick layers, dried and homogenized, and transferred to plastic containers appropriate for gamma-ray spectrometry measurements. The sand and mud contents (silt and clay) were analyzed, as well as organic matter contents and humidity were determined in each core.

2.2. *Methodology for ^{210}Pb, ^{226}Ra and ^{137}Cs analysis*

A low background HPGe gamma-ray spectrometer (ORTEC), with a resolution of 1.9 keV at 1332.40 keV photopeak of Co-60, together with MAESTRO II software was used for analysis of gamma-ray emitters. ^{210}Pb was assayed by means of its 47 keV photopeak. The method consisted of detector calibration, determination of detector counting efficiency, cumulative

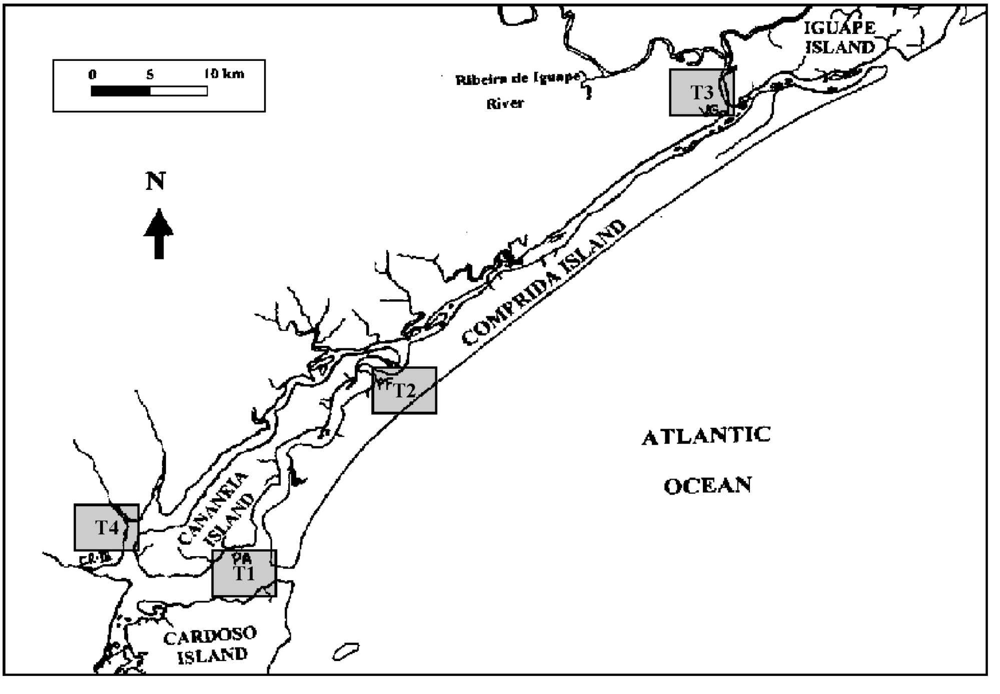

Fig. 1. Cananeia–Iguape estuary and the sampling sites (T1, T2, T3 and T4).

countings of both background and samples in regular intervals, photopeak smoothing and linear regression (Figueira et al., 1997; Saito et al., 2001). ^{226}Ra was assayed by means of 609 keV photopeak (^{214}Bi), and 661 keV peak was used for analysis of ^{137}Cs. For ^{226}Ra measurements, the packed samples were stored for 20 days at least in order to reach radioactive equilibrium. Unsupported ^{210}Pb was calculated by subtracting the ^{226}Ra (supported ^{210}Pb) activity from the ^{210}Pb total activity profile (Ravichandran et al., 1995). The analytical quality control was achieved by regular participation in international intercomparison exercises organized by the International Atomic Energy Agency (IAEA) as well as by analyzing reference materials.

3. Results and discussion

3.1. ^{210}*Pb*, ^{226}*Ra and* ^{137}*Cs in sediment cores*

Results of radionuclide analyses of sediment cores collected in the Cananeia–Iguape estuary are given in Fig. 2. ^{210}Pb levels in the estuary varied from 6.1 to 167 Bq kg^{-1}. The lowest values were observed in the T2 core (from 6.1 to 53 Bq kg^{-1}), and the highest in the T1 (from 9.8 to 167 Bq kg^{-1}) and T3 (from 31 to 120 Bq kg^{-1}) cores. The ^{210}Pb levels were much higher in the upper layers of the core and decreased with the depth. These results are consistent with observations published in the literature. The ^{137}Cs levels obtained in the Cananeia–Iguape estuary ranged from 0.28 to 6.1 Bq kg^{-1}. The presence of ^{137}Cs in the Brazilian sediments is due to global fallout.

The content of organic matter and the grain size composition are showed in Tables 1 and 2. The mud (silt–clay) content varied from 2.0 to 83.3%. The lowest values were found in the T2 core and the highest in T3. The sediments of the T1 core presented a prevalence of mud up to a depth of 6 cm, later it was noticed a gradual increase of fine sand. The T2 core presented a prevalence of fine sand along the whole sediment column. The T3 core was the only one that presented a prevalence of mud in the whole sediment column. The T4 core presented a prevalence of fine sand, with a gradual increase of this component along the sediment column.

The grain size composition of the cores reflects the dynamics of the circulation in the channels. The T3 core receives the largest load of fine sediments from the discharge of the Ribeira of Iguape River. The other three points are located opposite the Cananeia–Iguape system and are not so affected by the discharges from this river, but they are receiving loads from small local rivers.

The organic matter content presented a great variation along all of the cores analyzed, with levels varying from 0.4 to 10.6%. The lowest and the highest values were observed in the T4 and T1 cores, respectively. The higher levels of organic matter reflect the intense local biological activity, furthermore, the cores were collected close to the mangrove.

The statistical treatment of data showed a correlation between the ^{210}Pb levels and the mud (silt–clay) content. In relation to the organic matter levels, no correlation was observed as the biological activity might have affected these values. Samples collected close to the mangrove might have increased organic matter content. In general, the grain size composition followed the expected pattern, the sediments with higher levels of mud (silt–clay) had higher radionuclide concentrations.

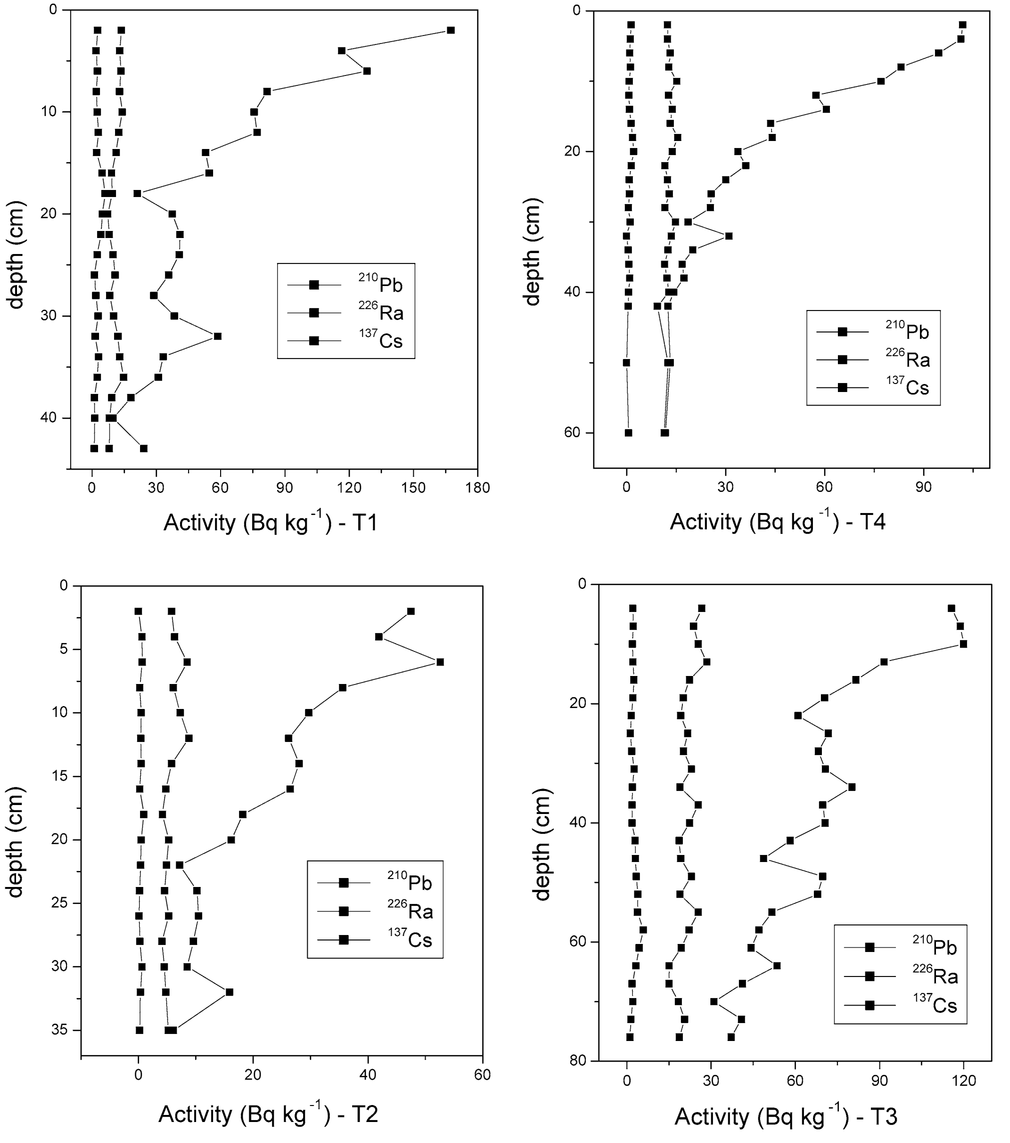

Fig. 2. Massic activities of radionuclides in sediment cores.

3.2. *Sedimentation rates*

Figure 3 presents the levels of unsupported ^{210}Pb and ^{137}Cs as a function of the core depth. The sedimentation rates derived by the ^{210}Pb method 5.3 (T1), 9.8 (T2), 12.7 (T3) and 6.2 (T4) mm yr^{-1}. The ^{137}Cs profiles showed distinct peaks corresponding to the maximum global fallout observed in 1963–1964. The sedimentation rates were therefore estimated using

Table 1
Contents of organic matter (OM) and grain size composition (T1 and T2 cores)

Depth (cm)	T1			T2		
	OM (%)	Sand (%)	Mud (%)	OM (%)	Sand (%)	Mud (%)
0–2	6.8	20.2	59.1	1.0	91.1	4.7
2–4	6.4	17.8	61.7	2.9	90.7	3.8
4–6	10.6	34.3	50.2	3.2	87.0	5.3
6–8	6.4	48.6	37.9	3.5	72.2	5.3
8–10	9.2	51.1	36.3	1.4	72.4	3.0
10–12	3.1	50.0	37.1	1.2	85.3	4.3
12–14	5.2	61.2	27.8	5.0	89.9	4.4
14–16	5.4	66.7	23.8	4.2	87.9	5.2
16–18	5.2	69.0	22.0	2.9	87.5	6.6
18–20	2.7	69.3	22.0	4.3	92.8	2.8
20–22	2.7	73.7	18.7	2.8	90.7	3.6
22–24	3.1	67.6	23.9	4.0	91.6	3.9
24–26	1.5	51.3	38.8	3.4	91.3	3.5
26–28	2.2	43.7	43.6	2.4	92.3	2.9
28–30	6.1	49.5	38.4	3.7	93.4	2.9
30–32	9.3	42.8	43.0	5.1	93.0	2.1
32–34	7.9	43.0	44.6	2.7	93.3	2.2
34–36	4.7	65.2	26.8			
36–38	2.4	59.6	30.0			
38–40	1.4	83.6	11.3			

the ^{137}Cs method as well (Huh and Su, 1999), and they were in good agreement (within the uncertainties, which varied up to 10%) with the ^{210}Pb estimations.

The core sampled at Valo Grande (T3) presented the highest sedimentation rate (12.7 mm yr^{-1}). This is the site directly influenced by the drainage of the Ribeira of Iguape River, which is the main source of sediments discharged into the coastal system (Tessler et al., 1987). The Carapara River core (T4) and that of the Ponta do Arrozal (T1) are representative of a deposition environment, with a prevalence of recent marine conditions and of continental sediments originating from the crystalline coastal mountain complex and from the quaternary sandy formations of the coastal plain. These continental sources have contributed with smaller amounts of sediments than those deposited in Valo Grande. The Ponta do Frade (T2) is located at an intermediate site of the system, and presented an intermediate value of sedimentation rate (9.8 mm yr^{-1}) compared to the sampling stations T1 and T3. These results indicate that this area of Ponta do Frade receives muddy sediments resulting from the drainage of the Ribeira of Iguape River, transported by the ebb tide towards to Cananeia Island. The values obtained reflect both the dynamics of the circulation of the estuarine channels and the contribution of the main sources of the sediments found in the Cananeia–Iguape system.

The sedimentation rate (12.7 mm yr^{-1}) obtained for Valo Grande (T3) is higher than for any of the other sites. It confirms three local events: an accelerated expansion in recent decades of the sand and clay banks of the Mar Pequeno channel; a growth of the mangrove areas; and

Table 2
Contents of organic matter (OM) and grain size composition (T3 and T4 cores)

T3				T4			
Depth (cm)	OM (%)	Sand (%)	Mud (%)	Depth (cm)	OM (%)	Sand (%)	Mud (%)
0–4	2.6	15.2	77.2	0–2	1.1	59.2	28.6
4–7	4.1	14.7	78.1	2–4	3.8	47.8	36.9
7–10	9.8	14.5	75.8	4–6	2.8	60.6	29.2
10–13	3.9	17.5	74.1	6–8	1.7	56.7	30.2
13–16	4.1	13.8	76.6	8–10	0.7	72.8	16.2
16–19	6.3	10.4	79.3	10–12	0.7	80.9	11.3
19–22	6.8	11.2	77.9	12–14	0.6	77.7	14.2
22–25	6.2	10.5	80.3	14–16	1.0	76.3	16.4
25–28	4.2	15.8	75.3	16–18	1.6	72.2	17.9
28–31	5.6	16.4	74.4	18–20	0.4	74.5	17.1
31–34	5.3	13.2	76.5	20–22	1.6	76.1	16.3
34–37	5.5	7.7	80.5	22–24	0.6	79.5	13.9
37–40	7.0	10.2	80.0	24–26	0.6	82.6	10.9
40–43	5.3	9.9	78.9	26–28	0.8	84.2	9.8
43–46	6.3	10.7	77.7	28–30	0.4	83.4	10.3
46–49	6.7	6.6	82.0	30–32	3.9	85.8	7.9
49–52	8.0	4.4	83.3	32–34	3.1	91.6	3.3
52–55	8.0	9.8	78.5	34–36	2.6	91.8	3.1
55–58	7.3	14.6	74.9	36–38	2.0	93.4	2.0
58–61	5.0	16.5	72.3	38–40	2.1	89.7	4.1
61–64	6.4	10.5	78.7	40–42	3.1	88.5	
64–67	5.8	18.6	69.3	48–50	3.0	90.4	3.6
67–70	6.1	13.5	75.8	58–60	1.8	91.2	3.8

a decrease in the depth of the main channel of navigation, a fact that has been affecting the navigation in the area very seriously.

3.3. *Geochemical characterization*

The chemical analyses of lead, copper and zinc were carried out by the Actilab Company (Canada), by using the SW 846 EPA 3050B EPA method. The solutions resulting from the acid lixiviation were analyzed by atomic absorption spectrometry. The concentrations obtained for copper, zinc and lead are showed in the Tables 3 and 4. Lead represents one of the most abundant elements and has been intensively mined in the region near the mouth of the Ribeira of Iguape River. The highest levels of these metals were found between the confluence of the Valo Grande and the Mar Pequeno channel, as far as the neighborhood of the Pedra do Tombo, probably, incorporated to the fine sediments loaded in suspension by the Ribeira of Iguape River. Pedra do Tombo (located in the Mar Pequeno channel, in the half of Comprida Island) corresponds to the point of encounter of tides of opposite directions, it avoids the propagation of those fine sediments transported by the Ribeira of Iguape River for all of the lagoon channels. Due to this, the area of Comprida Island shows low lead levels, around

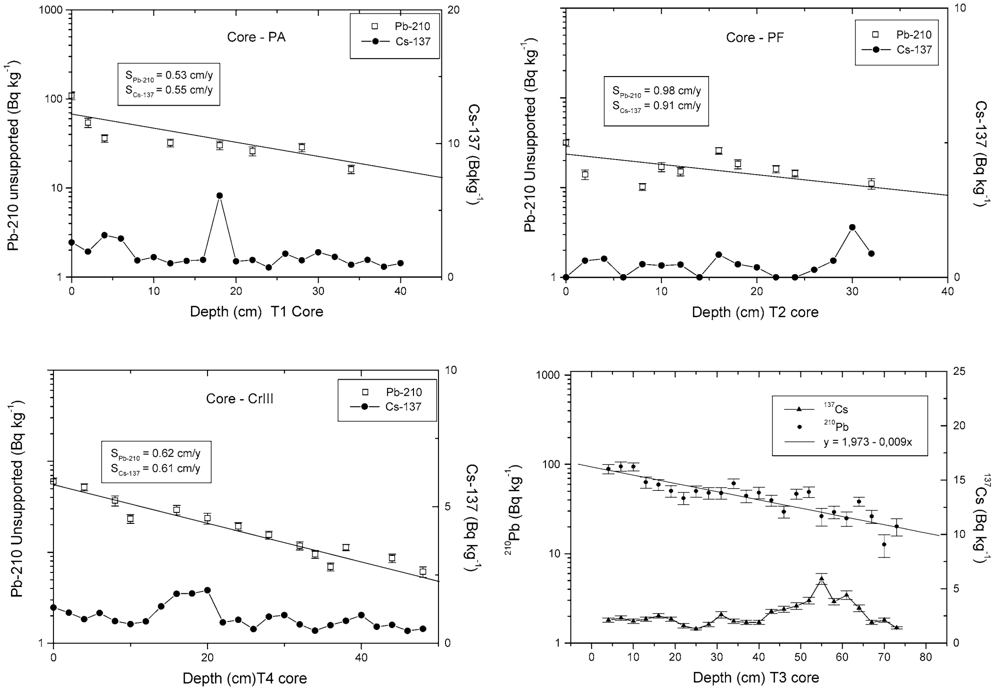

Fig. 3. Massic activities of ^{210}Pb (unsupported) and ^{137}Cs in sediment cores.

Table 3
Concentrations of lead, copper and zinc (µg g^{-1}) in cores T1 and T2 (total uncertainties below 10%)

Depth (cm)	T1			T2		
	Pb	Cu	Zn	Pb	Cu	Zn
0–2	26	15	55	8	8	14
2–4	25	15	57	12	7	18
4–6	19	11	41	11	8	18
6–8	17	10	40	12	7	19
8–10	16	11	40	12	7	18
10–12	18	10	39	8	7	18
12–14	16	9	32	11	7	19
14–16	13	8	29	9	7	18
16–18	12	8	28	9	7	18
18–20	11	7	25	5	6	15
20–22	12	8	26	6	7	16
22–24	12	9	28	4	6	11
24–26	13	9	33	4	7	14
26–28	10	17	43	4	6	13
28–30	16	10	41	3	6	12
30–32	23	12	47	4	6	14
32–34	19	10	44	5	6	13

Table 4
Concentrations of lead, copper and zinc (µg g^{-1}) (T3 and T4 cores)

Depth (cm)	T3			T4		
	Pb	Cu	Zn	Pb	Cu	Zn
0–2	101	37	120	14	9	31
2–4	113	39	126			
4–6	114	39	127	12	7	29
6–8	84	32	113			
8–10	106	36	127	8	6	22
10–12	132	41	133			
12–14	120	35	123	35	7	24
14–16	105	35	117			
16–18	101	32	108	13	7	28
18–20	110	34	115	9	8	25
20–22	127	37	123			
22–24	131	36	121	8	7	18
24–26	141	39	129			
26–28	151	41	126	7	9	22
28–30	144	39	124			
30–32	153	41	121	5	8	16
32–34	150	40	121			
34–36	163	43	124	2	8	12
36–38	159	41	120	4	8	13
38–40	150	38	118	4	7	15
40–42	166	44	133			
42–44	131	36	121	3	5	10

4 µg g^{-1}. No high concentration of the heavy metals, such as those presented at Valo Grande station, for the other regions of the channels, was found.

The lead concentrations found in sediments of the Valo Grande (T3) varied from 84 to 166 µg g^{-1}, above the regional background for the Valo Grande region, that is of 16 µg g^{-1} (CPRN, 1978), considerably above the concentration of 40 µg g^{-1}, threshold concentration given by Prater and Anderson (1977) for highly polluted sediments. It was verified that there is a decrease in the lead concentrations in the upper layers, which probably correlates with the reduction in the metal mining activities in the upper area of the Ribeira valley (Moraes, 1997).

The concentrations of zinc and copper in the sediment collected in Valo Grande (T3) followed the same pattern as that presented by lead. The concentrations of zinc in Valo Grande varied from 108 to 133 µg g^{-1}, much higher than the regional background for this region (46 µg g^{-1}). Copper concentrations varied from 32 to 44 µg g^{-1}, and were also above the background value for the Valo Grande region (18 µg g^{-1}).

3.4. *Sedimentation model*

The small Mandira basin (located southeast) drains into the most inland part of the coastal system, in the Cubatão Sea, a channel between Cananeia Island and the continent. The slope in the plain and the proximity of the crystalline mountainous complex result in a low transport capacity of these water-courses, which contribute predominantly with suspended sediments (mud and organic matter) to the southern most points of the system.

On the other hand, the large drainage basin of the Ribeira of Iguape River, which flows into the channels of this system exclusively through the Valo Grande channel, in the proximity of the Iguape city, is a significant source of finer sediments (silts and clays), loaded in suspension, associated with large amounts of organic matter.

The flood and ebb tide currents propagated in opposite directions, flow to the Mar Pequeno channel, near the Iguape city, and consequently extensive areas of deposition of mud (silts and clays), rich in organic matter, are formed. This area of the most intense sedimentation has also been studied by Souza (1995), who concluded that, besides prolonging this depositional area towards the south, there is a transport of sediments, close to the bottom of the channel, in the direction of the mouth of Cananeia (SE). Thus, the sediments in suspension discharged by the Valo Grande, that are not deposited in the area of Pedra do Tombo by the flood tide, are carried towards the southeastern mouth, through the channels that outline the Cananeia Island (the Cubatão and Cananeia Seas).

The concave curves on the inner sides of the bends (SE region) favor areas of low circulation, resulting in the deposition of mud. Nowadays, the expansion of the mangrove is associated predominantly with these areas in which the sandy substratum is being enriched by the addition of continental mud, and also with the sand banks in the middle of the channels, which result from the erosion of the banks of the convex faces. These sand banks in the middle of the channels are an obstacle to the flow of the waters, leading to a fall in the energy of the transport of the currents and, consequently, to the deposition of the suspended mud.

Tessler et al. (1987) has demonstrated that the coastal system does not present a capacity to export sandy sediments from the bottom of the channels into the ocean, except for the plumes of suspended sediments. As a result of the characteristics of the internal dynamics of the system, most of the sediments loaded by the Ribeira of Iguape River are discharged through the Icarapara mouth (NE). In relation to the suspended sediment loaded by Ribeira of Iguape River towards the Cananeia mouth, a greater part of it is deposited at the bends of Cananeia and Cubatão channels, before it reaches the outlet to the Ocean.

The Cananeia–Iguape system presents a general tendency to an accentuated silting up process as a result of the pronounced contribution of sediments of continental origin. However, the northeastern part of the system is more strongly submitted to the influence of the continental contribution than does southeastern part of the study area.

4. Conclusions

Several observations made in this study may be summarized as follows:

- The sedimentation rates obtained by the ^{210}Pb method in the sediment columns along the Cananeia–Iguape estuary were of 5.3 mm yr^{-1} (T1), 9.8 mm yr^{-1} (T2), 12.7 mm yr^{-1} (T3) and 6.2 (T4) mm yr^{-1}. The highest sedimentation rate obtained for Valo Grande (T3) corresponds with an accelerated expansion of the sand and clay banks of the Mar Pequeno channel, a growth of the mangrove areas, and a decrease in the depth of the main channel of navigation, a fact that has been affecting the navigation in the area very seriously.

- Data obtained for the metals (lead, copper and zinc) in the sediments showed a sedimentary dynamics in agreement with that obtained in the studies of sedimentation rates, thus contributing to the understanding of the hydrodynamic mechanisms of the system. The highest levels of metals measured in the sediments were a consequence of the mining activities carried out in the upper of the Ribeira valley, that results in an increment in the drainage of the Ribeira of Iguape River of enriched particles of metals originating from the lixiviation of wastes or the washing of ores.
- There are three main sources of sediments in the channels of the Cananeia–Iguape system: the drainage systems that flow directly into the channels (Mandira and Ribeira of Iguape systems), the internal biological production of the system, and the sandy sediments resulting from the erosion of the Cananeia coastal stringers, i.e. of the banks of the concave margins of the channels.
- The fine sediments, transported in suspension from the basin of Ribeira of Iguape River, are deposited predominantly in the channel which separates Comprida Island from the continent, and in the Mar Pequeno channel, close to the Valo Grande channel. During the ebb tide processes, the material not deposited in this channel is mainly transferred to the SE of the area, through the Cananeia Sea channel. Part of the material is deposited in this SE area, in the coincident areas with mangroves, now, undergoing expansion, as observed at the Ponta do Arrozal.
- The other internal channels, that are not directly affected by the drainage of the Ribeira of Iguape River, nor by the ebb tide dynamics of the Mar Pequeno channel present lower sedimentation rates than do the more external channels of the system (Cananeia Sea and Mar Pequeno).

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References

CPRN, Coordenadoria de Pesquisas de Recursos Naturais (1978). Relatório técnico: Projeto Geoquímico no Vale do Ribeira. São Paulo, 326 pp.

Figueira, R.C.L., Silva, L.R.N., Cunha, I.I.L. (1997). Instrumental analysis of low levels of ^{137}Cs in marine samples by gamma-spectrometry. International Conference on the Radiological Accident of Goiania – 10 Years Later, Goiania, Brazil.

Huh, C., Su, C. (1999). Sedimentation dynamics at the East China Sea elucidated from ^{210}Pb, ^{137}Cs and $^{249+241}Pu$. *Marine Geology* **160**, 183–196.

Prater, B.L., Anderson, A. (1977). 96-hour bioassays of Otter Creek. *Journal of the Water Pollution Control Federation* **49**, 2099–2106.

Moraes, R.P., (1997). Transporte de Chumbo e Metais associados no rio Ribeira de Iguape, São Paulo, Brasil. Dissertação de Mestrado. Instituto de Geociências, USP, São Paulo.

Ravichandran, M., Baskaran, M.P., Santschi, P.H., Bianchi, T.S. (1995). Geochronology of sediments in the Sabine–Neches estuary, Texas, USA. *Chem. Geol.* **125**, 291–306.

Saito, R.S., Figueira, R.C.L., Tessler, M.G., Cunha, I.I.L. (2001). Geochronology of sediments in the Cananeia–Iguape estuary in the southern continental shelf of São Paulo State, Brazil. *Journal of Radioanalytical and Nuclear Chemistry* **250**, 109–115.

Somayajulu, B.L.K., Bhushan, R., Sarkar, A., Burr, G.S., Jull, A.J.T. (1999). Sediment deposition rates on the continental margins of the eastern Arabian Sea using ^{210}Pb, ^{137}Cs and ^{14}C. *The Science of the Total Environment* **237/238**, 423–429.

Souza, L.A.P. (1995). A planície costeira Cananéia–Iguape, litoral sul do Estado de São Paulo: um exemplo de utilização de métodos geofísicos no estudo de áreas costeiras. Dissertação (Mestrado). Instituto Oceanográfico, Universidade de São Paulo.

Tessler, M.G., Suguio, K., Robilotta, P.R. (1987). Teores de alguns elementos traços metálicos em sedimentos pelíticos da superfície de fundo no Sistema Cananéia–Iguape (SP). In: Simposio sobre ecosystemas da costasud e sudeste Brasileira, vol. 2, pp. 255–263.