

^{210}Pb and ^{137}Cs levels in marine sediment samples from the southeastern coast of Brazil, South Atlantic area

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Abstract

The Brazilian coastal region has no significant sources of radioactive pollution, with the exception of the area Angra dos Reis, where there are two nuclear plants. Due to the low activity of radionuclides in marine sediments, few data on radioactivity levels have been reported for the Brazilian coast. Nevertheless it is essential to monitor radionuclides in this area in order to establish background values and to recognize specific causes for any alteration. This paper presents the levels of ^{210}Pb and ^{137}Cs in marine sediments from the southeastern coast of Brazil. 1997 through 2002. Fifteen cores and fifteen bottom surface samples were collected at depths varying from 1 to 500 m. The cores were sliced every 2 cm, and these sub-samples were counted in a gamma detector for approximately 120,000 s. The results varied from 9.68 to 344.40 Bq.kg⁻¹ for ^{210}Pb and from 0.17 to 3.19 Bq.kg⁻¹ for ^{137}Cs , the decay being corrected to 2002. ^{137}Cs levels have been related to the atmospheric fallout of nuclear tests in the past. It was possible therefore, to calculate the sedimentation rates using the levels of ^{137}Cs . The average value for the continental shelf was 2.63 (\pm 0.83) mm.y⁻¹, corroborating with ^{210}Pb method 2.02 (\pm 0.57) mm.y⁻¹ at a 5% significance level. The results indicated that the levels of ^{210}Pb and ^{137}Cs are within those to be expected for the Southern Hemisphere. Moreover, both radionuclides are thus confirmed as important tools for marine dynamics studies on the Brazilian coast.

1. Introduction

Since its rise in the 40's, nuclear energy has been the cause of debate all over the world because of its ambiguous character. It may be used to produce weapons of mass destruction as well as electric power, a necessary for developed and developing countries.

The importance of monitoring artificial and natural radionuclides is related to the impact of these elements on the environment. Radioactive pollution, as well as other forms of pollution, is extremely harmful, mainly to the marine environment, as seas and oceans have been the major repositories of different kinds of pollution worldwide. Radioactive isotope research has greatly increased since the period of nuclear tests: several radionuclides have been used in environmental studies, especially in marine processes and have become important tools in oceanography.

^{210}Pb is one of the most important natural radionuclides used in studies on marine dynamics and sedimentation rates. This element has a half-life of 22.3 years, making it possible to obtain data for the last 150 years. ^{137}Cs is an artificial radionuclide, is an important fission product with half-life of 30 years. Besides its biological importance, because its behavior is similar to that of K in biological processes, ^{137}Cs has been used as a tracer in marine circulation studies and recent sedimentation rates for the last 40 or 50 years.

The Brazilian marine coast has no significant sources of radioactive pollution, apart from the area of Angra dos Reis, where there are two nuclear plants. The main source of radioactive contamination in Brazilian marine samples has been atmospheric fallout from past nuclear tests. There are some reports of artificial radionuclides in seawater, fish and marine sediments from the Brazilian coast environment [1-4] and levels of natural radionuclides in marine samples and some researches on sedimentation rates using ^{210}Pb [5-9].

This study presents ^{210}Pb and ^{137}Cs levels in marine sediments from the Brazilian southeastern coast. Two kinds of samples were collected: bottom surface and core. The sampling was carried out between

1997 and 2002. It has been possible, from the levels of radioactive nuclides, to create a data bank on the radioactive contamination for this area and on the increase in the sedimentation rate from ^{137}Cs .

2. Study area and sampling

The study area (Figure 1) is located in the center of an arc-shaped of Brazilian margin known as São Paulo Bight [10] which extends from latitude $23^{\circ}00'S$ to $28^{\circ}30'S$ and from Cabo de Santa Marta ($28^{\circ}30'S - 49^{\circ}00'W$) to Cabo Frio ($23^{\circ}00'S - 42^{\circ}00'S$). In this area the shelf presents its maximum width (231 km) and a declivity of 1:1333. The shelf break is located between 160 and 180 meters depth and gives way to a relatively gentle continental slope.

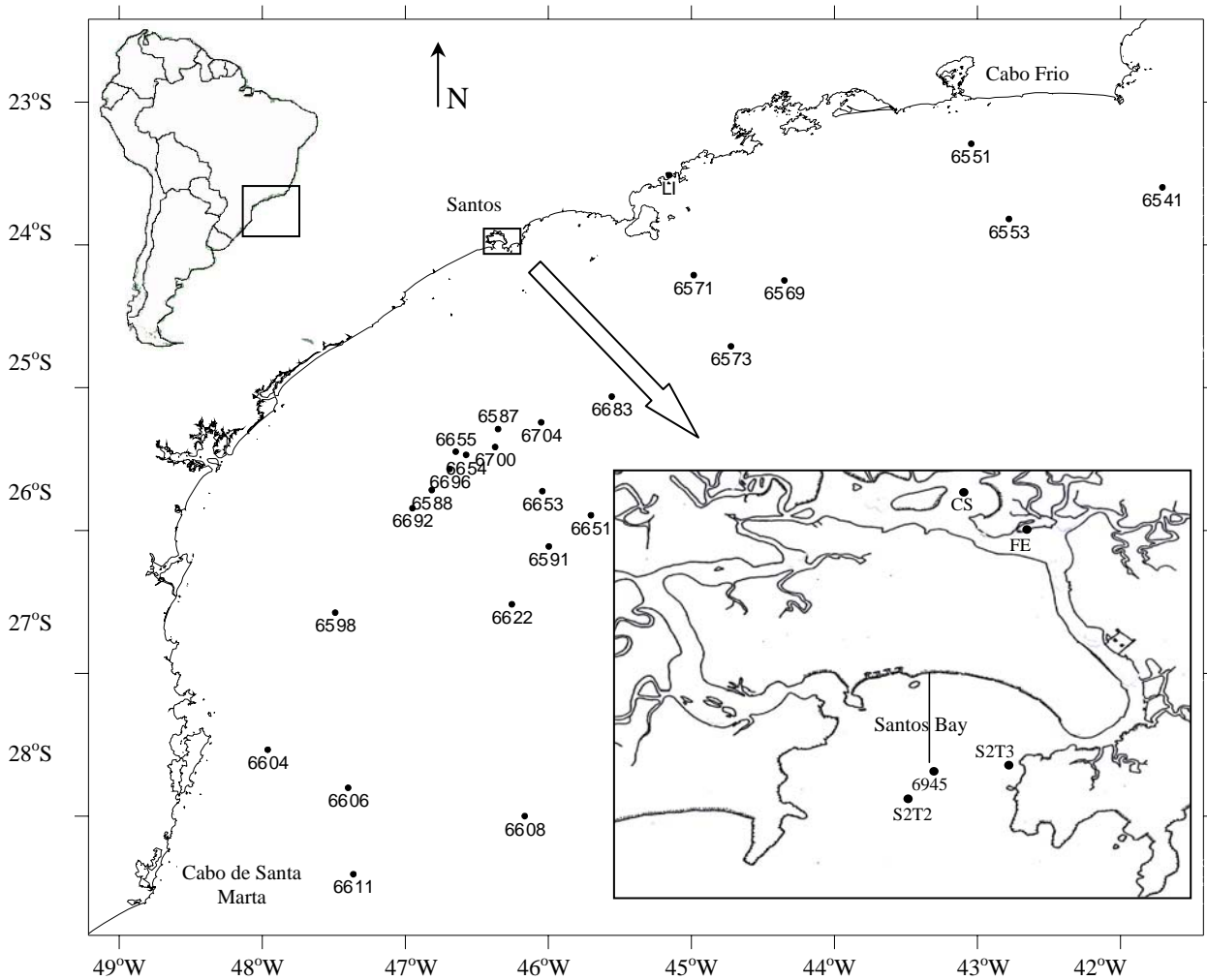


FIG. 1. Sampling area of the Brazilian southeastern coast.

The geological evolution of the São Paulo Bight has resulted from the interaction between the Mesozoic-Cenozoic development of the Brazilian margin, of typical by Atlantic type, and the series of climatic cycles, especially those related to the Quaternary. A succession of drownings and desiccations of the shelf have resulted in the sedimentation of thick layer of transgressive and regressive deposits. The present sedimentation is essentially terrigenous, being constituted of quartzose, sands and muds. The inner and middle shelf dynamics are determined by the displacement of three water masses, which present strong seasonal variation [11].

The Santos area corresponds to the sector of the coast immediately adjacent to the Santos Channel which receives the discharge from the estuarine system in which the most important industrial complex of the Brazilian coast is located.

In this area 15 core samples, taken from water depths varying from 80 to 150 meters. Fifteen bottom surface samples were taken with a Van Veen grab sampler. Each core was described and sampled continuously at 2 cm intervals. Sub-samples were kept frozen for later freeze-drying. Water content was determined by weight difference prior to and after freeze-drying of the samples. Grain size was determined from the sand and mud found in each sample.

3. Experimental

3.1 Equipment

Gamma-ray spectrometers, low background HPGe detector, EG&ORTEC, GEM60120P and GMX25120P models, with a resolution of 1.9 keV at 1332.40 keV in the photopeak of ^{60}Co . The spectrometers are linked to an 8K MCA with spectrum stabilizer. Spectra were analyzed with MAESTRO[®] from EG&ORTEC.

3.2 Analysis of ^{210}Pb and ^{137}Cs

The samples, containing from 5 to 40 g of marine sediment were dried, homogenized and transferred to appropriate plastic containers for gamma counting. ^{210}Pb and ^{137}Cs were assayed by their mean photopeaks: 47 keV and 661.6 keV, respectively. The method consisted of detector calibration, determination of detector counting efficiency, cumulative counting of both background and samples in regular intervals of counting time, photopeak smoothing and linear regression. The methods of analysis and data acquisition are described in Figueira et al. [12] and Saito et al. [8, 9].

4. Results and discussion

The results obtained for the levels of ^{137}Cs and ^{210}Pb in the bottom surface samples are presented in Table I, decay being corrected to 2002. The levels of ^{137}Cs varied between 0.27 and 3.19 Bq.kg⁻¹ with a mean value of 1.35 Bq.kg⁻¹. For the total activity of the ^{210}Pb , the values were between 9.68 and 344.30 Bq.kg⁻¹, with a mean value of 123.61 Bq.kg⁻¹. Figure 2 presents a box-plot of ^{137}Cs and ^{210}Pb levels in the bottom surface samples collected along the Brazilian southeastern coast.

In Figure 3 the levels of ^{137}Cs and ^{210}Pb are presented as a function of sampling depth. The activity of ^{137}Cs increased up to approximately 100 m depth and then decreased again gradually down to 500 m depth. ^{210}Pb activity increased considerably to the bottom due to the more intense dynamics of the coastal area, with a higher sedimentation rate than that of the continental shelf.

Table I. Levels of ^{137}Cs and ^{210}Pb in bottom surface sediment samples from the Brazilian southeastern coast.

| Sample | Sampling Year | Bottom surface (m) | ^{137}Cs (Bq.kg ⁻¹) ⁽¹⁾ | SD ⁽¹⁾ | ^{210}Pb (Bq.kg ⁻¹) ⁽¹⁾ | SD ⁽¹⁾ | Mud (%) |
|---------------|---------------|--------------------|---|-------------------|---|-------------------|---------|
| CS | 2002 | 1 | 1.74 | 0.14 | 37.5 | 3.7 | |
| FE | 2000 | 1 | 0.61 | 0.06 | 21.1 | 2.0 | 13.6 |
| LI | 2001 | 9 | 1.74 | 0.11 | 43.8 | 3.9 | 45.3 |
| 6945 | 2001 | 10 | 2.02 | 0.04 | 51.5 | 4.5 | 79.8 |
| S2T3 | 2002 | 10 | 1.91 | 0.05 | 17.4 | 1.5 | 39.2 |
| S2T2 | 2002 | 12 | 1.18 | 0.10 | 9.7 | 1.0 | 1.2 |
| 6571 | 1997 | 79 | 0.39 | 0.10 | | | 25.4 |
| 6655 | 1998 | 80 | 2.01 | 0.17 | 69.2 | 21.7 | 57.6 |
| 6587 | 1997 | 84 | 1.59 | 0.09 | | | 24.7 |
| 6654 | 1998 | 90 | 2.19 | 0.18 | 185.3 | 46.2 | 41 |
| 6696 | 1998 | 92 | 3.19 | 0.26 | 72.6 | 18.1 | 73 |
| 6704 | 1998 | 97 | 2.37 | 0.20 | 344.3 | 85.8 | 80.2 |
| 6598 | 1997 | 97 | 1.35 | 0.15 | | | 43.7 |
| 6604 | 1997 | 98 | 1.24 | 0.06 | | | 38.4 |
| 6551 | 1997 | 99 | 1.47 | 0.20 | | | 73.4 |
| 6683 | 1998 | 100 | 2.28 | 0.19 | 226.4 | 56.4 | 68.1 |
| 6692 | 1998 | 100 | 2.01 | 0.17 | 163.4 | 40.7 | 82.6 |
| 6700 | 1998 | 100 | 2.28 | 0.19 | 134.5 | 33.6 | 41.1 |
| 6588 | 1997 | 100 | 1.28 | 0.11 | | | 99.5 |
| 6541 | 1997 | 143 | 0.49 | 0.08 | | | 71.1 |
| 6569 | 1997 | 147 | 0.27 | 0.08 | | | 23.3 |
| 6573 | 1997 | 155 | 0.55 | 0.06 | | | 79.5 |
| 6653 | 1998 | 155 | 1.46 | 0.12 | 219.5 | 54.7 | 34.5 |
| 6606 | 1997 | 176 | 0.50 | 0.06 | | | 10.3 |
| 6611 | 1997 | 197 | 0.45 | 0.10 | | | 95.9 |
| 6553 | 1997 | 225 | 0.45 | 0.07 | | | 15.1 |
| 6591 | 1997 | 450 | 0.78 | 0.09 | | | 97.8 |
| 6651 | 1998 | 256 | 0.82 | 0.07 | 258.0 | 64.3 | 36.9 |
| 6622 | 1997 | 474 | 1.05 | 0.07 | | | 85.4 |
| 6608 | 1997 | 500 | 0.74 | 0.08 | | | 38.1 |
| Mean | | | 1.35 | | 123.61 | | |
| SD | | | 0.75 | | 103.97 | | |
| Median | | | 1.32 | | 72.59 | | |
| Max | | | 3.19 | | 344.30 | | |
| Min | | | 0.27 | | 9.68 | | |

(1) decay corrected to 2002

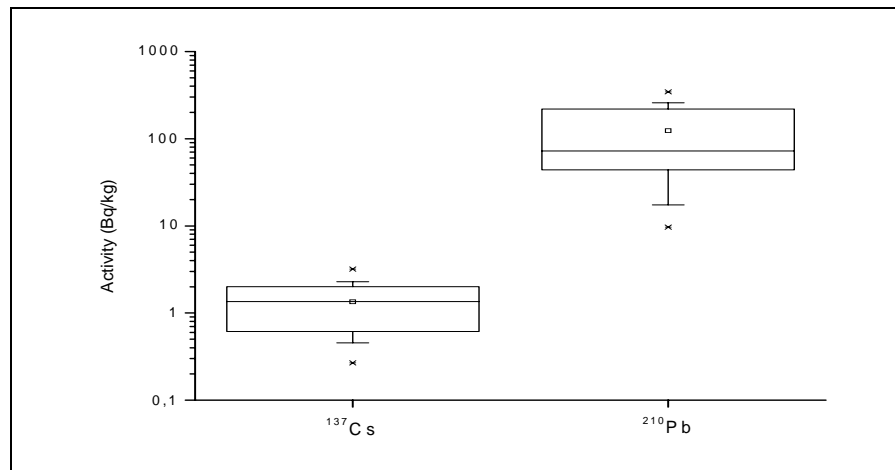


FIG. 2. Box-plot of ^{137}Cs and ^{210}Pb levels in bottom surface sediment samples.

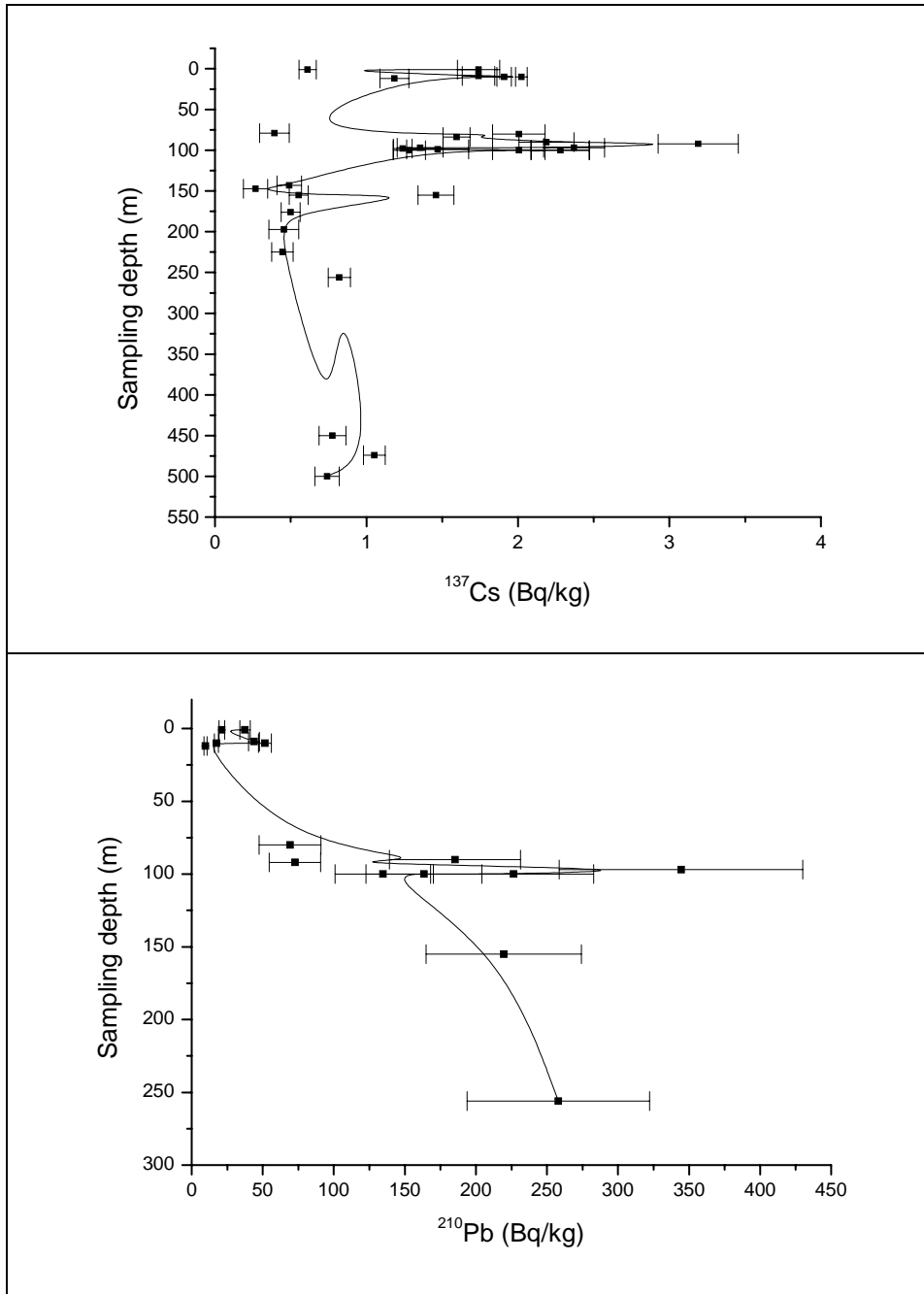


FIG. 3. Variation of ^{137}Cs and ^{210}Pb levels in function of sampling depth.

In Table II are presented the ^{137}Cs and ^{210}Pb levels in the cores collected of the Brazilian southeastern coast. The results obtained for ^{137}Cs were from 0.15 to 4.50 Bq.kg⁻¹ and for ^{210}Pb from 3.8 to 389.9 Bq.kg⁻¹.

The results of the ^{137}Cs and ^{210}Pb levels in the cores were classified for the coastal area (CS, FE, LI, S2T2, S2T3 and 6945) and the continental shelf (6651 to 6704). Table III presents median, maximum and minimum levels calculated for these cores. ^{137}Cs values did not vary significantly as between the two areas though ^{210}Pb values showed a noteworthy variation as between coastal area and continental shelf. The dynamics of this region are the factor responsible for the observed variation, as the sedimentation rates in the coastal area are higher those on the continental shelf.

Table II. Levels of ^{137}Cs and ^{210}Pb in cores collected from the Brazilian southeastern coast.

| Core | Depth (cm) | ^{137}Cs (Bq.kg ⁻¹) | SD | ^{210}Pb (Bq.kg ⁻¹) | SD | Mud (%) | |
|---------------|---------------|--|-------------|--|-------------|-------------|-------------|
| CS | 0 - 2 | 1.74 | 0.14 | 37.5 | 3.7 | | |
| | 2 - 4 | 0.87 | 0.15 | 54.7 | 4.8 | | |
| | 4 - 6 | 1.55 | 0.15 | 61.4 | 5.4 | | |
| | 6 - 8 | 3.53 | 0.14 | 55.3 | 4.9 | | |
| | 8 - 10 | 2.90 | 0.15 | 63.9 | 9.1 | | |
| | 10 - 12 | 3.97 | 0.08 | 50.9 | 4.5 | | |
| | 12 - 14 | 1.82 | 0.16 | 11.3 | 1.3 | | |
| | 14 - 16 | 3.39 | 0.08 | 29.3 | 3.0 | | |
| | 16 - 18 | 3.08 | 0.10 | 3.9 | 1.2 | | |
| | 18 - 20 | 3.45 | 0.14 | 34.4 | 3.4 | | |
| Mean | | 2.63 | | 40.3 | | | |
| SD | | 1.04 | | 20.8 | | | |
| Median | | 2.99 | | 44.2 | | | |
| Max | | 3.97 | | 63.9 | | | |
| Min | | 0.87 | | 3.9 | | | |
| FE | 0 - 2 | 0.64 | 0.06 | 22.5 | 2.1 | 13.6 | |
| | 2 - 4 | 0.15 | 0.02 | 23.4 | 2.2 | 15.7 | |
| | 4 - 6 | 0.25 | 0.04 | 17.6 | 1.7 | 21.7 | |
| | 6 - 8 | 0.50 | 0.06 | 28.3 | 2.5 | 34.8 | |
| | 8 - 10 | 1.04 | 0.13 | 38.6 | 3.4 | 47.8 | |
| | 10 - 12 | 0.85 | 0.10 | 24.3 | 2.6 | 59.7 | |
| | 12 - 14 | 0.74 | 0.10 | 11.2 | 1.2 | 52.2 | |
| | 14 - 16 | 1.02 | 0.10 | 19.7 | 1.8 | 37.3 | |
| | 16 - 18 | 1.08 | 0.10 | 16.7 | 2.2 | 33.5 | |
| | 18 - 20 | 0.53 | 0.11 | 23.2 | 2.8 | 10.5 | |
| | 20 - 22 | 1.09 | 0.18 | 22.8 | 3.0 | 32.2 | |
| | 22 - 24 | 0.19 | 0.05 | 39.9 | 3.5 | 39.8 | |
| | 24 - 26 | 0.25 | 0.10 | 15.8 | 1.7 | 29.7 | |
| | 26 - 28 | 0.72 | 0.08 | 16.9 | 1.9 | 33.3 | |
| | 28 - 30 | 1.53 | 0.15 | 20.0 | 1.8 | 29.7 | |
| | Mean | | 0.71 | | 22.7 | | 32.8 |
| | SD | | 0.40 | | 7.9 | | 13.9 |
| | Median | | 0.72 | | 22.5 | | 33.3 |
| Max | | 1.53 | | 39.9 | | 59.7 | |
| Min | | 0.15 | | 11.2 | | 10.5 | |
| LI | 0 - 2 | 1.78 | 0.11 | 45.2 | 4.0 | 45.3 | |
| | 2 - 4 | 2.48 | 0.11 | 32.6 | 3.1 | 56.8 | |
| | 4 - 6 | 2.26 | 0.10 | 27.9 | 2.6 | 40.7 | |
| | 6 - 8 | 2.21 | 0.14 | 23.4 | 3.8 | 41.5 | |
| | 8 - 10 | 1.83 | 0.05 | 14.6 | 1.4 | 46.8 | |
| | 10 - 12 | 2.01 | 0.07 | 18.1 | 1.6 | 47.4 | |
| | 12 - 14 | 1.03 | 0.06 | 16.5 | 1.8 | 45.0 | |
| | 14 - 16 | 1.76 | 0.04 | 14.4 | 1.3 | 49.6 | |
| | 16 - 18 | 1.40 | 0.04 | 13.7 | 1.4 | 47.9 | |
| | 18 - 20 | 0.91 | 0.05 | 18.3 | 1.6 | 34.5 | |
| Mean | | 1.77 | | 22.5 | | 45.5 | |
| SD | | 0.52 | | 10.2 | | 5.9 | |
| Median | | 1.80 | | 18.2 | | 46.0 | |
| Max | | 2.48 | | 45.2 | | 56.8 | |
| Min | | 0.91 | | 13.7 | | 34.5 | |
| S2T2 | 0 - 2 | 1.24 | 0.10 | 10.3 | 1.1 | 1.2 | |
| | 2 - 4 | 0.88 | 0.03 | 12.5 | 1.2 | 2.2 | |
| | 4 - 6 | 0.90 | 0.02 | 15.0 | 1.3 | 2.2 | |
| | 6 - 8 | 0.66 | | 20.9 | | 2.5 | |
| | 8 - 10 | 0.74 | | 20.4 | | 3.2 | |
| | 10 - 12 | 0.76 | 0.04 | 11.0 | 1.0 | 3.8 | |
| | 12 - 14 | 0.93 | 0.02 | 3.0 | 0.3 | 3.8 | |
| | 14 - 16 | 1.04 | 0.06 | 13.4 | 1.5 | 6.3 | |
| | 16 - 18 | 1.13 | 0.04 | 19.7 | 1.7 | 5.1 | |
| | 18 - 20 | 0.97 | 0.03 | 19.3 | 1.7 | 2.2 | |
| Mean | | 0.92 | | 14.5 | | 3.2 | |
| SD | | 0.18 | | 5.7 | | 1.5 | |
| Median | | 0.92 | | 14.2 | | 2.9 | |
| Max | | 1.24 | | 20.9 | | 6.3 | |
| Min | | 0.66 | | 3.0 | | 1.2 | |
| S2T3 | 0 - 2 | 2.00 | 0.05 | 18.5 | 1.6 | 39.2 | |
| | 2 - 4 | 1.11 | 0.10 | 19.2 | 1.8 | 37.2 | |
| | 4 - 6 | 1.27 | 0.18 | 12.7 | 1.4 | 42.6 | |
| | 6 - 8 | 1.58 | 0.16 | 21.0 | 1.8 | 47.4 | |
| | 8 - 10 | 1.75 | 0.05 | 13.9 | 1.5 | 43.6 | |
| | 10 - 12 | 1.37 | 0.08 | 12.1 | 1.2 | 64.9 | |
| | 12 - 14 | 2.50 | 0.08 | 32.2 | 2.9 | 49.9 | |
| | 14 - 16 | 1.70 | 0.12 | 21.6 | 2.1 | 55.8 | |
| | 16 - 18 | 1.74 | 0.04 | 20.5 | 1.8 | 42.9 | |
| | 18 - 20 | 1.67 | 0.15 | 7.8 | 2.0 | 53.9 | |
| Mean | | 1.67 | | 18.0 | | 47.7 | |
| SD | | 0.39 | | 6.8 | | 8.5 | |
| Median | | 1.69 | | 18.9 | | 45.5 | |
| Max | | 2.50 | | 32.2 | | 64.9 | |
| Min | | 1.11 | | 7.8 | | 37.2 | |
| 6651 | 0 - 2 | 0.90 | 0.08 | 292.2 | 72.8 | | |
| | 2 - 4 | 1.10 | 0.09 | 142.2 | 44.6 | 36.9 | |
| | 4 - 6 | 1.10 | 0.09 | 154.0 | 38.4 | 33.0 | |
| | 6 - 8 | 1.70 | 0.14 | 57.3 | 18.0 | 31.7 | |
| | 8 - 10 | 0.90 | 0.08 | 67.5 | 16.8 | 28.8 | |
| | 10 - 12 | 0.50 | 0.04 | 40.4 | 12.7 | 29.0 | |
| | 12 - 14 | 1.00 | 0.08 | 38.7 | 12.1 | 34.4 | |
| | 14 - 16 | 0.50 | 0.04 | 22.9 | 7.2 | 32.0 | |
| | 16 - 18 | 0.60 | 0.05 | 23.4 | 7.3 | 33.5 | |
| | 18 - 20 | 0.40 | 0.03 | 26.2 | 8.2 | 31.9 | |
| 20 - 22 | | | 34.9 | 10.9 | 34.2 | | |
| 22 - 24 | | | 22.9 | 7.2 | 33.5 | | |
| 24 - 26 | | | 53.7 | 13.4 | 29.8 | | |
| Mean | | 0.87 | | 75.1 | | 32.4 | |
| SD | | 0.39 | | 78.2 | | 32.0 | |
| Median | | 0.90 | | 40.4 | | 31.9 | |
| Max | | 1.70 | | 292.2 | | 32.0 | |
| Min | | 0.40 | | 22.9 | | 32.2 | |
| 6653 | 0 - 2 | 1.60 | 0.13 | 248.6 | 61.9 | 34.5 | |
| | 2 - 4 | 0.90 | 0.08 | 78.5 | 24.6 | 36.1 | |
| | 4 - 6 | 1.20 | 0.10 | 40.1 | 12.6 | 31.1 | |
| | 6 - 8 | 0.70 | 0.06 | 21.5 | 6.7 | 29.5 | |
| | 8 - 10 | 1.00 | 0.08 | 23.2 | 7.3 | 32.5 | |
| | 10 - 12 | 1.00 | 0.08 | 18.6 | 5.8 | 30.2 | |
| | 12 - 14 | 0.90 | 0.08 | 10.7 | 3.4 | 26.8 | |
| | 14 - 16 | 0.60 | 0.05 | 16.9 | 5.3 | 34.7 | |
| | 16 - 18 | 1.00 | 0.08 | 18.5 | 5.8 | 37.3 | |
| | 18 - 20 | 1.30 | 0.11 | 17.3 | 5.4 | 32.7 | |
| Mean | | 1.02 | | 49.4 | | 32.5 | |
| SD | | 0.29 | | 72.7 | | 3.2 | |
| Median | | 1.00 | | 20.0 | | 32.6 | |
| Max | | 1.60 | | 248.6 | | 37.3 | |
| Min | | 0.60 | | 10.7 | | 26.8 | |
| 6654 | 0 - 2 | 2.40 | 0.20 | 209.8 | 52.3 | - | |
| | 2 - 4 | 2.00 | 0.17 | 170.4 | 42.5 | 41.0 | |
| | 4 - 6 | 1.90 | 0.16 | 139.8 | 34.8 | 39.8 | |
| | 6 - 8 | 2.40 | 0.20 | 138.0 | 33.1 | 39.9 | |
| | 8 - 10 | 1.50 | 0.13 | 134.0 | 33.4 | 40.1 | |
| | 10 - 12 | 2.40 | 0.20 | 85.8 | 21.4 | 42.2 | |
| | 12 - 14 | 1.10 | 0.09 | 67.1 | 16.7 | 43.5 | |
| | 14 - 16 | 1.60 | 0.13 | 57.6 | 14.4 | 41.4 | |
| | 16 - 18 | 1.30 | 0.11 | 42.8 | 13.4 | 45.6 | |
| | 18 - 20 | 1.00 | 0.08 | 33.9 | 10.6 | 40.2 | |
| 20 - 22 | 1.20 | 0.10 | 39.1 | 12.3 | 50.0 | | |
| 22 - 24 | 0.80 | 0.07 | 46.4 | 14.5 | 53.0 | | |
| 24 - 26 | 1.30 | 0.11 | 40.2 | 12.6 | 52.3 | | |
| 26 - 28 | 1.10 | 0.09 | 35.4 | 11.1 | 45.4 | | |
| 28 - 30 | 0.60 | 0.05 | 32.0 | 10.1 | 52.4 | | |
| Mean | | 1.51 | | 84.8 | 22.2 | 44.8 | |
| SD | | 0.59 | | 58.2 | 13.5 | 45.0 | |
| Median | | 1.30 | | 57.6 | 14.5 | 45.4 | |
| Max | | 2.40 | | 209.8 | 52.3 | 45.8 | |
| Min | | 0.60 | | 32.0 | 10.1 | 46.2 | |

Table II continuation

| Core | Depth (cm) | ¹³⁷ Cs | | ²¹⁰ Pb | | Mud (%) |
|---------------|---------------|------------------------|--------------|------------------------|-------------|-------------|
| | | (Bq.kg ⁻¹) | SD | (Bq.kg ⁻¹) | SD | |
| 6655 | 0 - 2 | 2.20 | 0.19 | 78.3 | 24.6 | 57.6 |
| | 2 - 4 | 1.60 | 0.13 | 70.3 | 22.1 | 58.6 |
| | 4 - 6 | 1.80 | 0.15 | 44.3 | 13.9 | 57.2 |
| | 6 - 8 | 1.00 | 0.08 | 27.8 | 8.7 | 54.2 |
| | 8 - 10 | 1.30 | 0.11 | 35.0 | 11.0 | 58.8 |
| | 10 - 12 | 1.50 | 0.13 | 19.8 | 11.3 | 59.6 |
| | 12 - 14 | 1.80 | 0.15 | 21.4 | 6.7 | 53.8 |
| | 14 - 16 | 1.50 | 0.13 | 23.7 | 7.4 | 58.6 |
| | 16 - 18 | 1.70 | 0.14 | 25.8 | 6.4 | 58.8 |
| | 18 - 20 | 1.00 | 0.08 | 30.9 | 7.7 | 56.6 |
| | 20 - 22 | 1.20 | 0.10 | 20.9 | 5.2 | 55.9 |
| | 22 - 24 | 1.80 | 0.15 | 39.2 | 9.8 | 59.4 |
| | 24 - 26 | 1.40 | 0.12 | 26.8 | 8.4 | 58.4 |
| | 26 - 28 | 2.20 | 0.19 | 39.4 | 9.8 | 58.4 |
| | 28 - 30 | 0.90 | 0.08 | 26.5 | 8.3 | 59.2 |
| | 30 - 32 | 1.20 | 0.10 | 20.6 | 5.1 | 61.4 |
| | Mean | 1.51 | | 34.4 | | 57.9 |
| SD | 0.40 | | 17.3 | | 2.0 | |
| Median | 1.50 | | 27.3 | | 58.5 | |
| Max | 2.20 | | 78.3 | | 61.4 | |
| Min | 0.90 | | 19.8 | | 53.8 | |
| 6683 | 0 - 2 | 2.50 | 0.21 | 256.4 | 63.9 | - |
| | 2 - 4 | 2.50 | 0.21 | 205.1 | 51.1 | - |
| | 4 - 6 | 2.10 | 0.18 | 160.8 | 40.1 | 68.1 |
| | 6 - 8 | 1.50 | 0.13 | 165.3 | 41.2 | 64.9 |
| | 8 - 10 | 2.20 | 0.19 | 126.3 | 31.5 | 68.7 |
| | 10 - 12 | 1.50 | 0.13 | 143.7 | 35.8 | 70.3 |
| | 12 - 14 | 2.30 | 0.19 | 122.7 | 30.6 | 67.2 |
| | 14 - 16 | 1.40 | 0.12 | 127.8 | 31.8 | 69.4 |
| | 16 - 18 | 1.00 | 0.08 | 112.8 | 28.1 | 70.1 |
| | 18 - 20 | 0.90 | 0.08 | 102.2 | 25.5 | 68.3 |
| | 20 - 22 | | | 107.0 | 26.7 | 68.8 |
| | 22 - 24 | | | 44.7 | 11.1 | 65.7 |
| | 24 - 26 | | | 34.9 | 8.7 | 64.3 |
| | 26 - 28 | | | 37.7 | 9.4 | 67.7 |
| | 28 - 30 | | | 41.6 | 10.4 | 66.1 |
| | Mean | 1.79 | | 119.3 | | 67.6 |
| | SD | 0.60 | | 63.6 | | 1.9 |
| Median | 1.80 | | 122.7 | | 68.1 | |
| Max | 2.50 | | 256.4 | | 70.3 | |
| Min | 0.90 | | 34.9 | | 64.3 | |
| 6692 | 0 - 2 | 2.20 | 0.19 | 185.0 | 46.1 | 82.6 |
| | 2 - 4 | 2.20 | 0.19 | 111.8 | 27.8 | 82.8 |
| | 4 - 6 | 3.50 | 0.29 | 104.2 | 26.0 | 82.4 |
| | 6 - 8 | 1.40 | 0.12 | 102.9 | 25.6 | 82.0 |
| | 8 - 10 | 1.80 | 0.15 | 53.0 | 16.6 | 82.6 |
| | 10 - 12 | 2.00 | 0.17 | 107.2 | 26.7 | 82.2 |
| | 12 - 14 | 1.60 | 0.13 | 87.4 | 21.8 | 82.4 |
| | 14 - 16 | 1.50 | 0.13 | 44.6 | 11.1 | 82.0 |
| | 16 - 18 | 1.80 | 0.15 | 44.1 | 11.0 | 82.2 |
| | 18 - 20 | 1.20 | 0.10 | 29.2 | 9.2 | 81.6 |
| | 20 - 22 | 1.60 | 0.13 | 46.3 | 11.5 | 82.4 |
| | 22 - 24 | 1.00 | 0.08 | 25.3 | 7.9 | 82.4 |
| | 24 - 26 | 2.30 | 0.19 | 15.8 | 5.0 | 82.8 |
| | 26 - 28 | 1.60 | 0.13 | 26.7 | 6.7 | 81.6 |
| | Mean | 1.84 | | 70.2 | | 82.3 |
| | SD | 0.61 | | 47.7 | | 0.4 |
| | Median | 1.70 | | 49.7 | | 82.4 |
| Max | 3.50 | | 185.0 | | 82.8 | |
| Min | 1.00 | | 15.8 | | 81.6 | |
| 6696 | 0 - 2 | 3.50 | 0.29 | 82.2 | 20.5 | 73.0 |
| | 2 - 4 | 4.50 | 0.38 | 91.3 | 22.8 | 72.4 |
| | 4 - 6 | 2.90 | 0.24 | 87.8 | 21.9 | 73.2 |
| | 6 - 8 | 2.10 | 0.18 | 66.0 | 16.4 | 73.4 |
| | 8 - 10 | 1.70 | 0.14 | 40.7 | 10.9 | 72.6 |
| | 10 - 12 | 2.60 | 0.22 | 91.2 | 22.7 | |
| | 12 - 14 | 1.80 | 0.15 | 56.3 | 14.0 | 72.2 |
| | 14 - 16 | 2.50 | 0.21 | 53.0 | 13.2 | 73.2 |
| | 16 - 18 | 1.10 | 0.09 | 27.3 | 6.8 | 73.4 |
| | 18 - 20 | 1.80 | 0.15 | 22.3 | 7.0 | 73.6 |
| | 20 - 22 | 1.30 | 0.11 | 13.7 | 4.3 | 73.2 |
| | 22 - 24 | 1.80 | 0.15 | 15.2 | 4.8 | 74.2 |
| | 24 - 26 | 2.00 | 0.17 | 21.3 | 6.7 | 73.6 |
| | 26 - 28 | 2.00 | 0.17 | 18.2 | 5.7 | 74.4 |
| | Mean | 2.26 | | 49.0 | | 73.3 |
| | SD | 0.90 | | 30.2 | | 0.6 |
| | Median | 2.00 | | 46.8 | | 73.2 |
| Max | 4.50 | | 91.3 | | 74.4 | |
| Min | 1.10 | | 13.7 | | 72.2 | |

| Core | Depth (cm) | ¹³⁷ Cs | | ²¹⁰ Pb | | Mud (%) |
|---------------|---------------|------------------------|--------------|------------------------|-------------|-------------|
| | | (Bq.kg ⁻¹) | SD | (Bq.kg ⁻¹) | SD | |
| 6700 | 0 - 2 | 2.50 | 0.21 | 152.3 | 38.0 | 79.8 |
| | 2 - 4 | 1.90 | 0.16 | 152.3 | 37.9 | 79.8 |
| | 4 - 6 | 2.30 | 0.19 | 117.6 | 29.3 | 79.0 |
| | 6 - 8 | 2.50 | 0.21 | 68.6 | 17.1 | 79.6 |
| | 8 - 10 | 1.30 | 0.11 | 58.3 | 14.5 | 78.6 |
| | 10 - 12 | 2.60 | 0.22 | 45.4 | 11.3 | 79.2 |
| | 12 - 14 | 1.70 | 0.14 | 25.6 | 8.0 | 78.8 |
| | 14 - 16 | 1.70 | 0.14 | 27.3 | 6.8 | 79.6 |
| | 16 - 18 | 1.00 | 0.08 | 40.2 | 10.0 | 78.6 |
| | 18 - 20 | 1.70 | 0.14 | 30.1 | 7.5 | 78.4 |
| | 20 - 22 | 1.40 | 0.12 | 37.4 | 9.3 | 78.6 |
| | 22 - 24 | 1.50 | 0.13 | 29.6 | 7.4 | 80.4 |
| | 24 - 26 | 1.70 | 0.14 | 31.2 | 7.8 | 80.0 |
| | 26 - 28 | 1.40 | 0.12 | 26.8 | 6.7 | 80.0 |
| | 28 - 30 | 1.70 | 0.14 | 28.0 | 7.0 | 80.4 |
| | Mean | 1.79 | | 58.0 | | 79.4 |
| | SD | 0.48 | | 45.1 | | 0.7 |
| Median | 1.70 | | 37.4 | | 79.6 | |
| Max | 2.60 | | 152.3 | | 80.4 | |
| Min | 1.00 | | 25.6 | | 78.4 | |
| 6704 | 0 - 2 | 2.60 | 0.22 | 389.9 | 97.1 | |
| | 2 - 4 | 3.80 | 0.32 | | | |
| | 4 - 6 | 3.80 | 0.32 | 190.8 | 47.5 | |
| | 6 - 8 | 1.40 | 0.12 | 194.5 | 48.5 | 80.2 |
| | 8 - 10 | 1.90 | 0.16 | 234.8 | 58.5 | 80.0 |
| | 10 - 12 | 2.60 | 0.22 | 208.4 | 51.9 | 81.2 |
| | 12 - 14 | 1.80 | 0.15 | 155.0 | 38.6 | 80.2 |
| | 14 - 16 | 1.50 | 0.13 | 143.9 | 35.9 | 79.2 |
| | 16 - 18 | 1.50 | 0.13 | 90.8 | 22.6 | 80.6 |
| | 18 - 20 | 1.70 | 0.14 | 92.7 | 23.1 | 79.4 |
| | 20 - 22 | 1.30 | 0.11 | 75.5 | 18.8 | 80.2 |
| | 22 - 24 | 1.60 | 0.13 | 53.0 | 16.6 | 78.8 |
| | 24 - 26 | 1.10 | 0.09 | 30.5 | 9.6 | 81.0 |
| | 26 - 28 | 1.50 | 0.13 | 49.5 | 15.5 | 80.6 |
| | 28 - 30 | 0.90 | 0.08 | 49.6 | 12.4 | 79.6 |
| | Mean | 1.93 | | 139.9 | | 80.1 |
| | SD | 0.89 | | 98.7 | | 0.7 |
| Median | 1.60 | | 118.3 | | 80.2 | |
| Max | 3.80 | | 389.9 | | 81.2 | |
| Min | 1.10 | | 30.5 | | 78.8 | |
| 6945 | 0 - 2 | 2.07 | 0.04 | 53.1 | 4.6 | 41.1 |
| | 2 - 4 | 1.83 | 0.08 | 37.6 | 3.4 | 36.8 |
| | 4 - 6 | 0.96 | 0.06 | 34.7 | 3.2 | 21.8 |
| | 6 - 8 | 2.49 | 0.07 | 63.1 | 6.2 | 30.6 |
| | 8 - 10 | 2.95 | 0.10 | 48.1 | 4.3 | 30.6 |
| | 10 - 12 | 1.51 | 0.03 | 54.6 | 4.8 | 29.4 |
| | 12 - 14 | 0.40 | 0.10 | 57.0 | 5.0 | 29.4 |
| | 14 - 16 | 1.54 | 0.08 | 61.2 | 5.4 | 43.2 |
| | 16 - 18 | 3.73 | 0.15 | 48.6 | 4.3 | 35.5 |
| | Mean | 1.94 | | 50.91 | | 33.1 |
| | SD | 1.01 | | 9.8 | | 6.6 |
| | Median | 1.83 | | 53.1 | | 30.6 |
| | Max | 3.73 | | 63.1 | | 43.2 |
| | Min | 0.40 | | 34.7 | | 21.8 |

Table III. Median values for ^{137}Cs and ^{210}Pb in cores from coastal area and continental shelf.

| <i>Core (coastal region)</i> | ^{137}Cs (Bq.kg^{-1}) ⁽¹⁾ | ^{210}Pb (Bq.kg^{-1}) ⁽¹⁾ |
|------------------------------|--|--|
| CS | 2.99 | 44.22 |
| FE | 0.72 | 22.51 |
| LI | 1.80 | 18.18 |
| S2T2 | 0.92 | 14.20 |
| S2T3 | 1.69 | 18.86 |
| 6945 | 1.83 | 53.10 |
| Median | 1.75 | 20.69 |
| Max | 2.99 | 53.10 |
| Min | 0.72 | 14.20 |

| <i>Core (continental shelf)</i> | ^{137}Cs (Bq.kg^{-1}) | ^{210}Pb (Bq.kg^{-1}) |
|---------------------------------|---|---|
| 6651 | 0.90 | 40.40 |
| 6653 | 1.00 | 20.04 |
| 6654 | 1.30 | 57.65 |
| 6655 | 1.50 | 27.33 |
| 6683 | 1.80 | 122.66 |
| 6692 | 1.70 | 49.65 |
| 6696 | 2.00 | 46.83 |
| 6700 | 1.70 | 37.41 |
| 6704 | 1.60 | 118.31 |
| Median | 1.70 | 48.24 |
| Max | 2.00 | 122.66 |
| Min | 1.50 | 27.33 |

(1) median values of cores

4.1 ^{137}Cs sedimentation rates

From the levels of ^{137}Cs in the sedimentary column it was possible to obtain the sedimentation rates for this area of the southeastern coast of Brazil. Sample depths were corrected for porosity [13]. The activity of ^{137}Cs was corrected by mud level in the sediment sample, because this fraction has a great capacity for metal and radionuclide retention due to its larger specific area.

Figure 4 presents graphs of ^{137}Cs levels in the sedimentary columns from the continental shelf. It is possible to observe the correlation of ^{137}Cs levels with the period of the several atmospheric nuclear tests (1963-65) and subsequent deposition by fallout.

The mean value of the sedimentation rate for ^{137}Cs on the continental shelf was $2.63 (\pm 0.83) \text{ mm.y}^{-1}$. This value was compared to obtained by Tessler [14] using ^{210}Pb ($2.02 \pm 0.57 \text{ mm.y}^{-1}$). The results are in agreement to a 5% level of significance.

The graphs also show the mobility of ^{137}Cs along the sedimentary column. This is mainly related to physical-chemical factors of the diffusion of this element in the sediment and the processes of ionic change in the interstitial water. However, ^{137}Cs behavior in the sedimentary column is controversial, some researchers believe this radionuclide to be immobile in the sediment whereas other authors suppose it to be highly mobile, presenting a diffuse transport by ionic change through the interstitial water [15].

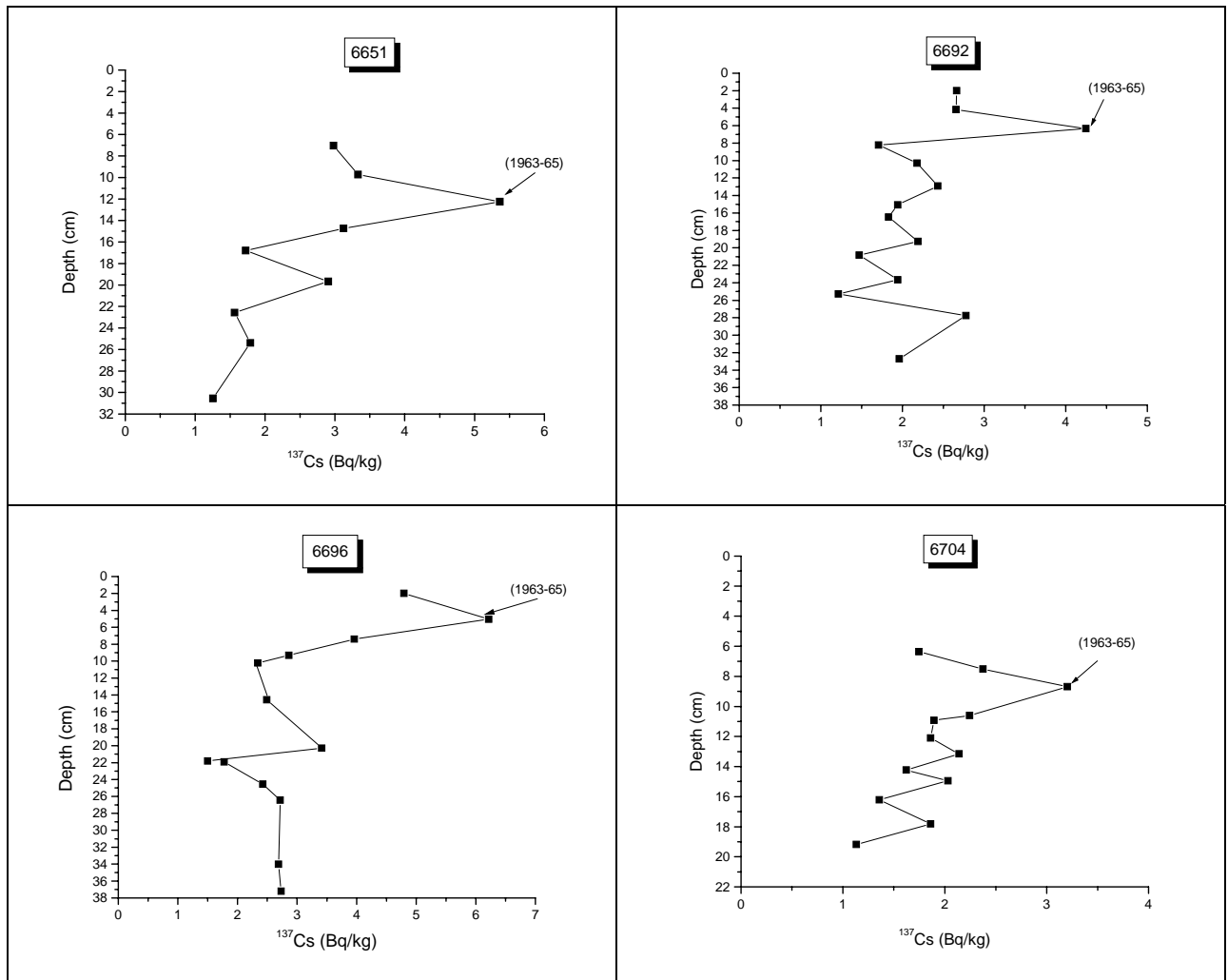


FIG. 4. ^{137}Cs levels in sedimentary column from atmospheric fallout.

4.2 Minimum detectable concentration

When a sample is introduced into the gamma measurement, the term usually associated with detection limits is the minimum detectable concentration (MDC) which can be expressed by equation 1 [16]:

$$MDC = \frac{4.66 \times s_B}{\varepsilon \times P_\gamma \times W} \quad (1)$$

where,

s_b is the estimated standard error of the net count rate;

ε is the counting efficiency of the specific energy of the nuclide;

P_γ is the absolute transition probability by gamma decay through the selected energy

W is the mass of the sample

In this study the MDC values were 0.10 and 1.5 $\text{Bq}\cdot\text{kg}^{-1}$ for ^{137}Cs and ^{210}Pb , respectively.

5. Conclusion

Due to the different processes of oceanic dynamics in the region studied, ^{210}Pb results for the continental shelf were higher than those for the coastal area. ^{137}Cs obtained levels from the southeastern coast were to be expected in the South Hemisphere as the main source of artificial radioactivity is the atmospheric fallout from nuclear tests in the past. The possibility of ^{137}Cs

measurement in sedimentary columns has made this radionuclide an important tool in the determination of sedimentation rates for coastal areas and the continental shelf. ^{137}Cs sedimentation rates were in agreement with ^{210}Pb . This survey made it possible to create a data bank for ^{210}Pb and ^{137}Cs levels for the Brazilian southeastern coast and any alteration in the future way be attributed to specific cause.

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