Dating of lacustrine and marine recent sediments using ^{210}Pb method: some Brazilian examples

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Introduction

The use of natural radionuclides from the U and Th decay series in environmental studies has been increased since the middle of the 20th century. Natural decay series studies have contributed to the development of a quantitative understanding of the rates from physical, geochemical and biological processes in the environment, such as determination of sedimentation rates in lacustrine and marine environments. Over the past four decades there has been an increase in the research based on the use of these natural radionuclides in the environment, mainly the study of recent sediments. The study of recent sediments is important for tracing man's activities in the environment; wich has been mostly impacted over the last 150 years.

Lake and estuarine sediments provide a basis for reconstructing many aspects of this impact estimating rates of change (Othman et al., 2000; Roulet et al., 2000). The knowledge of the rate at which sediments have been accumulating over the past several hundreds of years is of fundamental importance in understanding aquatic and sedimentary geochemical processes (Robbins &Edgington, 1975).

^{210}Pb is a naturally occurring radioactive element, from the ^{238}U radioactive decay series, can be used in these studies to determine the accumulation rate of recent sediments in lakes, estuaries and oceans. The methodology used is based on the fact that the ^{210}Pb precipitated from the atmosphere accumulates in the surface of soils, glaciers, lakes and marine sediments. When where succeeding layers of material are buried by later deposits, such as glaciers, lake and marine sediments, the fallout ^{210}Pb incorporated in a given layer reduces exponentially with time in accordance with the radioactive decay law. Calculating the initial ^{210}Pb activity of a layer, this value can be used to determine the age of the surface deposit (Goldberg, 1963).

The most important radioactive isotopes of lead that occur as members of the uranium and thorium decay series are: ^{214}Pb and ^{210}Pb from the ^{238}U decay series, ^{211}Pb from the ^{235}U decay series and ^{212}Pb from the ^{232}Th decay series, but only the isotopes ^{210}Pb, ^{214}Pb and ^{212}Pb are important in terms of geochemical and geophysical applications because they are transferred from the earth's crust to the atmosphere. ^{210}Pb, daughter of the chemically inert radioactive gas radon, is formed when its parent, diffuse out of the crust and is transported by turbulence and advection through the atmosphere. Because of its comparatively long half-life (3.8 days), it can reach the upper troposphere and the stratosphere before decaying (Robbins, 1978). The ^{222}Rn decay products are all heavy metal atoms and they rapidly become attached to natural aerosols and return to earth through atmospheric scavenging processes.

The lead in the atmosphere becomes attached to aerosols and has a mean atmospheric residence time of the order of 5-10 days (Krishnaswami & Lal, 1978). The aerosol ^{210}Pb that

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settles into lake or marine waters is adsorbed by suspended sediment and subsequently incorporated in the sediments. ^{210}Pb is rapidly removed from the dissolved state to the lake sediments and the concentration of dissolved ^{210}Pb in lake and estuarine waters is virtually zero (Benninger et al, 1975). The ^{210}Pb, which is incorporated into the sediments as a result of atmospheric fallout, is called unsupported or excess ^{210}Pb and it is not in equilibrium with its parent ^{226}Ra.

Other source of the ^{210}Pb in sediments is from the decay of ^{226}Ra and its daughter ^{222}Rn that is trapped in the sediment. The presence of uranium and its daughters in the sediments will result in a continuous supply of ^{210}Pb. Then this ^{210}Pb that come from of its parent ^{226}Ra is supposed to be in equilibrium and it is called supported ^{210}Pb. Therefore the activity of supported ^{210}Pb can be determined by measuring ^{226}Ra, while the unsupported activity may be calculated by subtracting the ^{210}Pb activity from the total ^{210}Pb activity.

The ^{210}Pb dating method was applied to determine sedimentation rates in pristine and impacted environments in Brazil. The pristine environments studied, five lakes, were located in: Amazônia, Fernando de Noronha, Pantanal and São Paulo. The impacted environments, four reservoirs and two estuaries, were located in Pernambuco and Bahia.

Materials and methods

Sites

The sites studied are located in Brazil, Figure 1, a country of temperate tropical climate and situated in the Southern Hemisphere. The pounds are: Viração Pound, in Fernando de Noronha archipelago, Pernabuco, Infernão and Frutal pounds in São Paulo, Meio Pound in Pantanal, Mato Grosso do Sul and Puruzinho Pound in Amazônioa, Rondônia. The estuaries are Aratu Estuary in Bahia and Botafogo River Estuary, Pernambuco. The reservoirs are Guarapiranga Reservoir and Rio Grande Reservoir, both located in São Paulo.

Figure1.- *Brazil map with the studied sites.*

Sampling

Two cores from Aratu estuary, one core from Guarapiranga reservoir and four cores from Rio Grande reservoirs were collected using a Piston Corer sediment sampler. In the other sites the cores were hand-collected using a PVC tube. All cores were sliced every 2 cm, the samples were dried at 60^{o}C in a ventilated oven and then they were sifted in 0.063 mm sieves (230 mesh) with Milli-Q water and dried, and finally homogenized in a glass mortar.

Radiochemical determination
The measurement of the radionuclides ^{226}Ra and ^{210}Pb were used to determine the dates and sedimentation rate. These radionuclides were determined in each slice of the core. For the radionuclides determination, 1.00 g of the samples, in duplicate, were dissolved in mineral acids, HNO_3conc. and HF 40%, and H_2O_2 30%, in a microwave digestor and submitted to the radiochemical procedure, where Ra and Pb are precipitated as Ba(^{226}Ra)SO_4 and $^{210}PbCrO_4$ respectively. The concentrations were determined by gross alpha counting for ^{226}Ra and for ^{210}Pb through its decay product, ^{210}Bi, by measuring the gross beta activity. The chemical yields were determined by gravimetric analysis. Both radionuclides were determined in a low background gas flow proportional detector (Moreira, et al. 2003). The dates were calculated by the Constant Rate of Supply (CRS) model (Ivanovich and Harmon, 1992, Noller, 2000)

Results and Discussion

Botafogo River estuary
The Botafogo River cuts through Recife's Metropolitan region, in Pernambuco. This region is the most important supplier of sea food for the local population. A sediment core was collected on November 2004, near the mouth of the Botafogo River, in its estuarine area to determine sedimentation rates to assess the evolution of environmental impacts in the region (Figure 2a). The age of sedimentary colum was about 150 years and the sedimentation rate was estimated in 0.3 cm y^{-1} (Fávaro et al, 2007).

Aratu Estuary
Aratu estuary is a small system that is connected to Baía de Todos os Santos. Several industries and port facilities are located in this channel and Aratu estuary. Polluted riverine discharge and direct release of toxic residuals by harbor operations makes the area one of the most polluted areas within Baía de Todos os Santos. Two sedimet cores were collected in 1999 to identify and characterise areas of silt deposition that can cause navigation problems. Figures 2b and 3b show the sedimentation rates obtained for two differents points in Aratu estuary. The age of sedimentary colum for point BA 01 was about 80 years and for point BA 06 was 10 years. The sedimentation rates were estimated in 0.9 cm y^{-1} for point BA 01 and 7.0 cm y^{-1} for point BA 06 (Moreira et al, 2000).

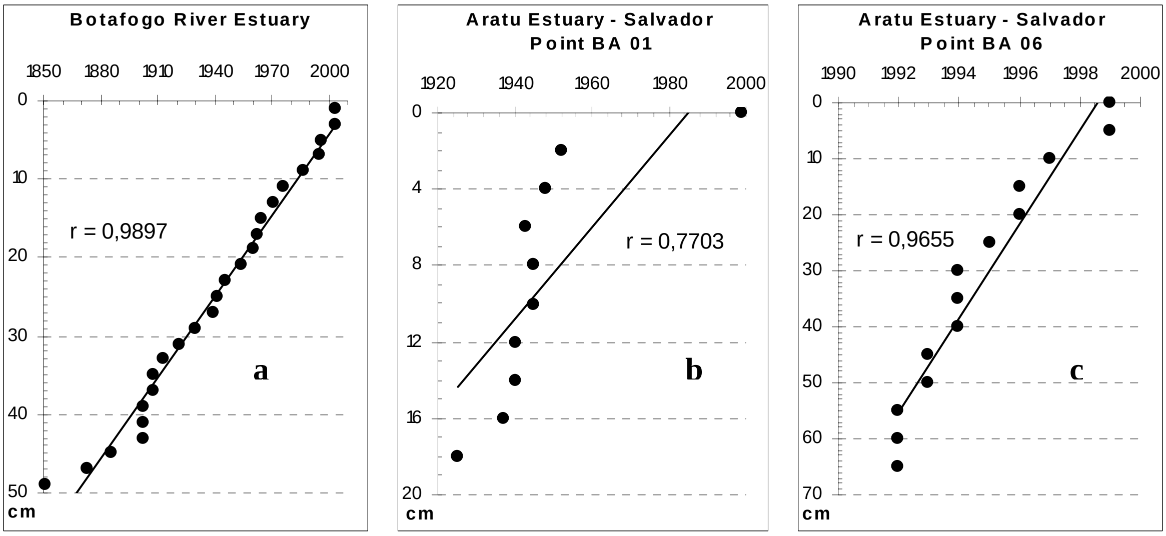

Figure 2- Age-depth relationship for: a)Botafogo Estuary - Pernambuco, b) BA 01 Aratu Estuary - Bahia, c) BA 06 Aratu Estuary - Bahia

Viração Pound

Viração Pound, a small lake located at the Fernando de Noronha archipelago, South Equatorial Atlantic, Recife, Pernanbuco. It is a pristine small lake located in the main island of the archipelago and is situated at 20 meters above the sea level. This archipelago is a protected and isolated habitat with restricts access. The age of sedimentary colum, for the sediment core collected in 2002, was about 150 years and the sedimentation rate was estimated in 0.4 cm y^{-1} (Figure 3a) (Damatto et al, 2003 a).

Infernão and Frutal Pounds

Two sediment cores were collected in Infernão and Frutal pounds, located in Jataí Ecological Station in São Paulo in 1996, with the objective of verify if the sediments layers have preserved a historical record of Moji-Guaçu River whose waters overflow yearly these pounds (Figure 3b and 3c). The age of sedimentary colum for Infernão pound was about 180 years and for Frutal pound was 170 years. The sedimentation rates were estimated in 0.18 cm y^{-1} for Infernão pound and 0.25 cm y^{-1} for Frutal pound (Gatti et al, 1997).

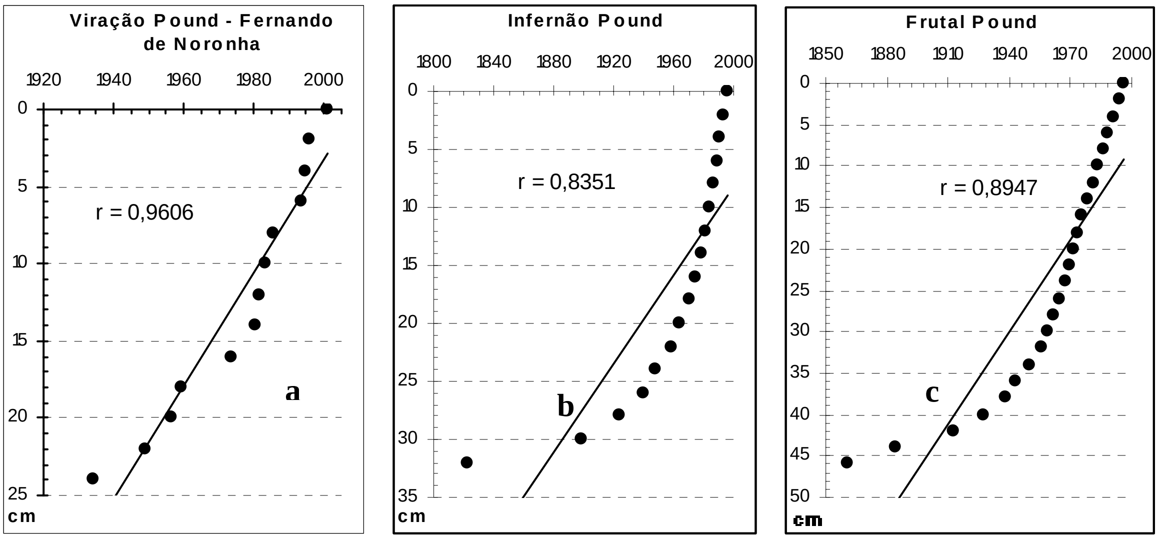

Figure 3- Age-depth relationship for: a)Viração Pound, Fernando de Noronha archipelago - Pernambuco, b) Infernão Pound - São Paulo, c) Frutal Pound – São Paulo

Guarapiranga Reservoir

The Guarapiranga Reservoir is a reservoir located in the southern area of São Paulo city. It was constructed in 1906 originally to attend the necessities of the production of electrical energy. The reservoir is supplied by the River Guarapiranga and other smaller rivers and brooks, traversing areas of the cities of São Paulo.In 1928, Guarapiranga started to be used as a reservoir for potable water distribution and it is currently utilized as water supply of the Greater São Paulo. Between the 1980s and the 1990s the absence of clear political laws determining use and occupation of the area contributed to the creation of clandestine and irregular neighborhoods around the reservoir. One sediment core was collected in 1998 with the objective of determine sedimentation rates and to verify whether the sediments contain an historical registration of antropic activit. The results obtained were not reliable due to the urban occupation, with irregular use of the land, that causes siltation problems (Figure 4a) (Moreira et al, 1999).

Rio Grande Reservoir

The Rio Grande reservoir is responsible for the water supply of four cities (São Bernardo do Campo, São Caetano do Sul, Santo André and Diadema) and has been seriously affected by the urban expansion of the metropolitan area of São Paulo, due to the chaotic urban occupation, with irregular use of the land. Four sediment cores were collected in 1998 with the objective of determine sedimentation rates in different parts of the reservoir and also to verify whether the sediments contain an historical registration of antropic activity. The sedimentation rates varied for each point colleted (Figure 4b). The highest value found was 1.3cmy^{-1}, year 1932, and the lowest was 0.6cmy^{-1}, year 1910. Lower rates were related to the period prior to the water dam, when the loading of the sediments was kept constant. The larger rates are related with the damming of the waters in 1935, with the urban expansion and consequent high erosion in the basin (Moreira et al, 2003).

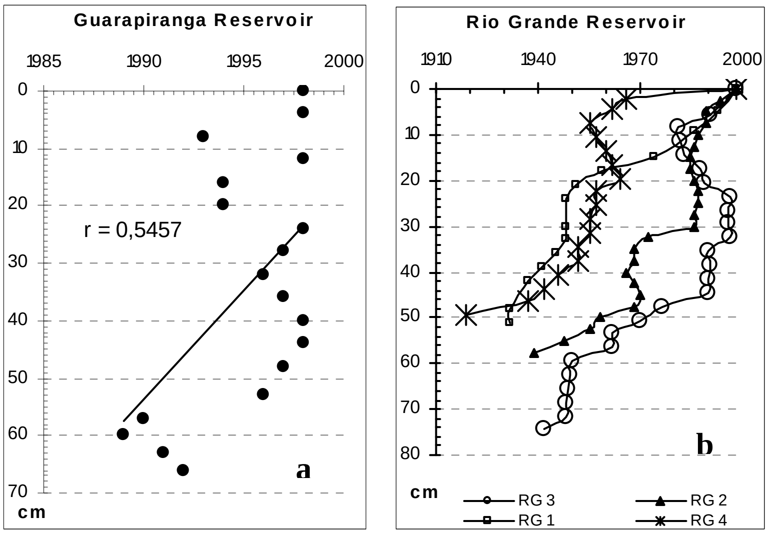

Figure 4- Age-depth relationship for: a)Guarapiranga reservoir - São Paulo, b) Rio Grande reservoir – São Paulo

Meio Pound

Pantanal, located in the central region of South America, is recognized as one of the world's largest freshwater wetlands. In order to verify possible changes in this environment, a study was undertaken in Nhecolândia Pantanal, Mato Grosso do Sul State, Brazil. One sediment core was collecte in 2001 in Meio Pound (Figure 5a). The age of sedimentary colum was about 81 years and the sedimentation rate was estimated in 0.6 cm y^{-1} (Damatto et al, 2003 b).

Puruzinho Pound

A sediment core was collected at Puruzinho Pound, Amazônia Ocidental - Brazil where a Hg contamination was found. This lake is located at the left margin of Madeira river, 20 km far from Humaitá city, Amazonas state (Figure 5b). The age of sedimentary colum was about 90 years and the sedimentation rate was estimated in 0.5 cm y^{-1} (Damatto et al, 2007).

Conclusions

The results obtained in the pristine environments for sedimentation rates and age of the sediments were in agreement with the local history showing that for these cases the ^{210}Pb method can be used as a tool to understand aquatic and sedimentary geochemical processes. For the impacted environments only in one reservoir (São Paulo city) and in the estuaries (Pernambuco and Bahia) the results obtained were in agreement with the local history. Only for the Guarapiranga reservoir was impossible to estimate the sedimentation rates due to the places are heavily polluted and to silting problems, that can cause sediment mixing or bioturbation. The ^{210}Pb method is of maximum utility in unmixed, quiet-water deposits of continuous sedimentation factors that are not found in impacted environments (Noeller, 2000).

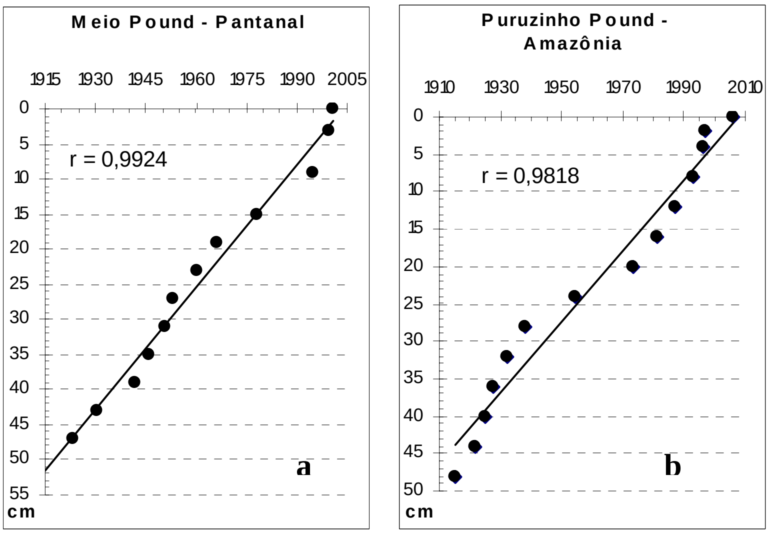

Figure 5- Age-depth relationship for: a) Meio Pound – Pantanal, Mato Grosso do Sul, b) Puruzinho Pound – Amazônia, Rondônia

References

L.K.Benninger. *“^{210}Pb balance in Long Island Sound.”* Geochimica et Cosmochimica Acta, 42 (1978) 1165-1174.

S.R. Damatto, D.I.T. Favaro, E.A. Menor, A.C. Bononi, A.S. Moraes, B.P. Mazzilli, *“Sedimentation Rates Using Pb-210 Dating Method and Metal Determination by Instrumental Neutron Analysis at Viração Lagoon, Fernando de Noronha Archipelago, Brazil”*. In: 3rd International Limnogeology Congress” Tucson, Arizona, USA, (2003 a)

S.R. Damatto, D.I.T. Favaro, A.Y. Sakamoto, B.P. Mazzilli, *“Datação e Determinação de Metais dos Sedimentos da Lagoa do Meio, Pantanal da Nhecolândia, Mato Grosso do Sul”*. In: IX Congresso Brasileiro de Geoquímica, Belém, Pará, Brazil (2003 b)

S.R.Damatto, R. Almeida, B.P. Mazzilli, J.V.E. Bernardi. *“Datação dos sedimentos recentes do Lago Puruzinho, Amazônia Central”*. In: “XI Congresso Brasileiro de Geoquímica”, Atibaia, São Paulo, Brazil (2007)

D.I.T Favaro, P. Falco, S.R. Damatto, E.A.M. Lima, E. Menor. *“Avaliação do teor de metais e elementos traço em um testemunho de perfil sedimentar no rio Botafogo datado pelo método de ^{210}Pb, Recife, Pernambuco”*. In: “XI Congresso Brasileiro de Geoquímica”, Atibaia, São Paulo, Brazil (2007)

L.V. Gatti, A.A. Mozeto, B.P. Mazzilli, S.R.D. Moreira, R.I.M. Battaglin. *“Geocronologia de Pb-210 nos sedimentos das Lagoas Infernão e Frutal”*. In: VI Congresso Brasileiro de Limnologia”, São Carlos, Brazil (1997)

E.D. Goldberg .*“Geochronology with lead-210”*. In: Radioactive Dating, International Atomic Energy Agency, Vienna. (1963). pp. 121-131

M. Ivanovich, R.S. Harmon. (Eds.) *“Uranium-series disequilibrium: applications to Earth, Marine and Environmental Sciences”*. (1992). Claredon Press- Oxford.
S. Krishnaswani, D.Lal, J.M.Martin, M.Meybeck. *“Geochronology of lake sediments.”* Earth and Plan. Scie. Let. 11 (1971) 407-414

S.R.D. Moreira, F.Campagnoli, B.P.Mazzilli, *“Datação de Sedimentos do Reservatório Billings pelo Método de Pb-210”* In: V Congresso de Geoquímica dos Países de Língua Portuguesa” and “VII Congresso Brasileiro de Geoquímica, Porto Seguro, Bahia, Brazil (1999)

S.R.D. Moreira, D.I.T. Fávaro, F. Campagnoli, B.P. Mazzilli. *“Sedimentation rates and metals in sediments from the reservoir Rio Grande – São Paulo/Brazil”*. Environmental Radiochemical Analysis II, P. Warwick editor, The Royal Society of Chemistry (2003) UK, pp 383-390.

S.R.D. Moreira. *“Determinação de Taxa de Sedimentação e Datação de Sedimentos da Baia De Todos os Santos – Ba”*. Relatório Técnico, Departamento de Radioproteção Ambiental – NA, IPEN (2000)

J.S. Noller. *“Quaternary Geochronology: Methods and Applications”*. J. S. Noller, J. M. Sowers & W. Lettis, Editors. American Geophysical Union, Washington, DC. (2000) pp 115-120

I. Othman, M.S. Al-Masri, A.H. Al-Rayes. *“Sedimentation rates and pollution history of the eastern Mediterranean Sea: Syrian coast.”* The S. Tot. Environ. 248 (2000).27-35.

J.A. Robbins, D.N. Edgington, *“Determination of recent sedimentation rates in Lake Michigan using Pb-210 and Cs-137.”* Geoch. et Cosmochim.Acta, 39 (1975) 285-304.

J.A. Robbins. *“Geochemical and Geophysical applications of radioactive lead.”* In: Nriagu, J.O.(ed), the Biogeochemistry of Lead in the Environment. Part A. Ecological Cycles, (1978) pp 285-393. Elsevier and North-Holland Biomedical Press, Amsterdam.

M. Roulet, M. Lucotte, R. Canuel, N. Farella, M. Courcelles, J-R. D. Guimaraes, D. Mergler, M. Amorim. *“Increase in mercury contamination recorded in lacustrine sediments following deforestation in the central Amazon”*. Chem. Geol. 165 (2000) 243-266