ELSEVIER

The Science of the Total Environment 293 (2002) 247–256

the Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Man

www.elsevier.com/locate/scitotenv

Forest fire indicators and mercury deposition in an intense land use change region in the Brazilian Amazon (Alta Floresta, MT)

R.C. Cordeiro[a,*], B. Turcq[b], M.G. Ribeiro[a], L.D. Lacerda[a], J. Capitâneo[a], A. Oliveira da Silva[a], A. Sifeddine[a,b], P.M. Turcq[b]

[a]*Programa de Geoquímica, Universidade Federal Fluminense, Outeiro de São João Batista s/n, Centro Niteroi, RJ, 24020-007 Brazil*

[b]*Institute de Recherche pour le Development, Henry Varagnat, Bondy Cedex, France*

Received 6 August 2001; accepted 20 December 2001

Abstract

Black carbon, charcoal and mercury fluxes were measured from sediment cores taken in an artificial water dam in an intense land use change area in the Alta Floresta district in the Brazilian Amazon, in order to characterize the differences in the evolution of human occupation patterns in the region during the last 18 years. A positive correlation between the black carbon and charcoal particle fluxes and the evolution of the Brazilian gross domestic production (GDP) was observed. Mercury fluxes showed a positive correlation with gold production and exhibited a distinct evolution pattern when compared to in relation to the forest fires indicators and Brazilian GDP. The fluxes of forest fires markers showed an increase in deforestation activities in the region after 1993. Mercury deposition showed a substantial decrease after 1994. The patterns of distribution in both forest fires tracers and gold mining tracers indicate substitution of the regional economic model. It also marked different antropogenic impact type in the ecosystem.

Keywords: Amazon; Tropical forest; Colonization; Fires; Mercury

1. Introduction

The slashing and burning of forested areas is a common practice of Brazilian ranchers and farmers when preparing the land for agriculture and principally cattle pasture. Today, large areas are being burned and converting an ecosystem with high diversity and biomass into an ecosystem with low diversity and biomass. Burning activities produce large amounts of CO_2 emissions to the atmosphere (Houghton and Woodwell, 1989; Fearnside, 1996). In the Amazon, approximately 13% of 5×10^6 km^2 of the rain forest was cleared (Brasil, 1998). This forest conversion process started in the 1970s mostly transforming the forest ecosystems into pasture. This process was not accompanied by sustained management projects for the regional forest resources. The wood industry plays a significant role by removing as quickly as possible the timber of economic value, despising species of

*Corresponding author. Fax: +55-217-174189.
E-mail address: rcampello@yahoo.com (R.C. Cordeiro).

0048-9697/02/$ - see front matter
PII: S0048-9697(02)00045-1

lower economic value. The abundance of wood, the lack of a program of forest management and the hope of fast profits lead to great amounts of biomass being burned without wealth creation. When the colonization plans were initiated for the Amazon region in the 1980s, the conversion of the forest (a 'unproductive system' according to the formerly vision) into pasture (a 'productive system' according to the same vision) was considered the first priority to occupy vast areas, assuring the land property without taking into consideration the ecological aspects of the ecosystems (Fearnside et al., 1993). This type of deforestation process in the Amazon causes a reduction of the ecosystems in the carbon content (Nepstad et al., 1999), increasing the carbon emissions to the atmosphere in approximately 0.2 PgC $year^{-1}$ (Houghton et al., 2000). In the Amazon, the particulate material coming from the burning biomass is taken by intense convective aerial masses that carry the particulate material to the upper atmosphere (Garstang et al., 1988; Freitas et al., 2000), where aerial currents promote its dispersion for long distances (Andreae, 1983; Freitas et al., 2000). Black carbon is the major constituent of the particulate emission and has the property of being chemically and microbiologically inert (Kulhlbush and Crutzen, 1996). This property makes it a good tracer of forest fires events in paleoecological studies (Verardo and Ruddiman, 1996).

Concurrent with the deforestation, an intense gold rush occurred with the exploration of riverbed sediments. The disaggregated and dredged materials of the alluvium deposits are sieved and then amalgamated with mercury. These amalgams are burned and the mercury released to the atmosphere and dispersed according to the circulation pattern of air masses. The separation of the gold and mercury is generally done without the use of equipment that recycles the volatile mercury. Lacerda and Marins (1997) estimated that approximately 1.3 kg of mercury is released into the atmosphere for each kilogram of gold extracted.

More recently, the artesanal exploitation of gold in the Amazon region has been indicated as being the main source of anthropogenic Hg to the atmosphere in Brazil (Lacerda, 1995; Lacerda and Salomons, 1998). In spite of most of the emitted Hg being deposited in the neighboring areas, a significant proportion may be transported to the upper atmosphere (Artaxo et al., 1993).

This study aims to understand the atmospheric deposition rates of charcoal particles and mercury in an area of an intense land use change, where forest ecosystems are converted to agriculture and pasture ecosystems through the use of the fire and where intense gold mining activity occurred simultaneously.

2. Study area

This study was carried out in the Alta Floresta region located in the northern portion of the state of Mato Grosso, central Brazil. The region is part of the Central Crystalline Plateau and it is covered by dense tropical forest. The urban area of Alta Floresta is situated (09°52′ S; 56°06′ W, alt. 288 m) 800 km away from Cuiabá the capital of the Maro Grosso state. Alta Floresta was set up in 1976 by private initiative, with the objective of colonization of the upper Tapajós river area (Fig. 1). The Alta Floresta municipal district was created in 1982 to serve as a support and services center for an urban and rural population of an area of approximately 200 000 ha (Hacon, 1996). The district presented a fast colonization process in the 1980s, mostly due to gold mining and wood exploration.

The Alta Floresta area has a climate, humid with a very intense dry season, between June and August. Deforestation as well as gold mining peaks occurred during the dry season. Deforestation starts in August and is followed by burning of the slashed biomass, and the fire spreads over vast areas, with consequent emission of charcoal particles to the atmosphere. These particles are dispersed throughout the atmosphere and deposited all over the area. The deposition pattern depends on the particle size and the regional circulation processes. As well as the emission of these charcoal particles, mercury deposited on soils may also be released during forest burning.

Manmade water reservoirs (dams) are receiving bodies of the burning products of the forest biomass and mercury associates with the atmosphere particulate. The lake formed by the barrier effect

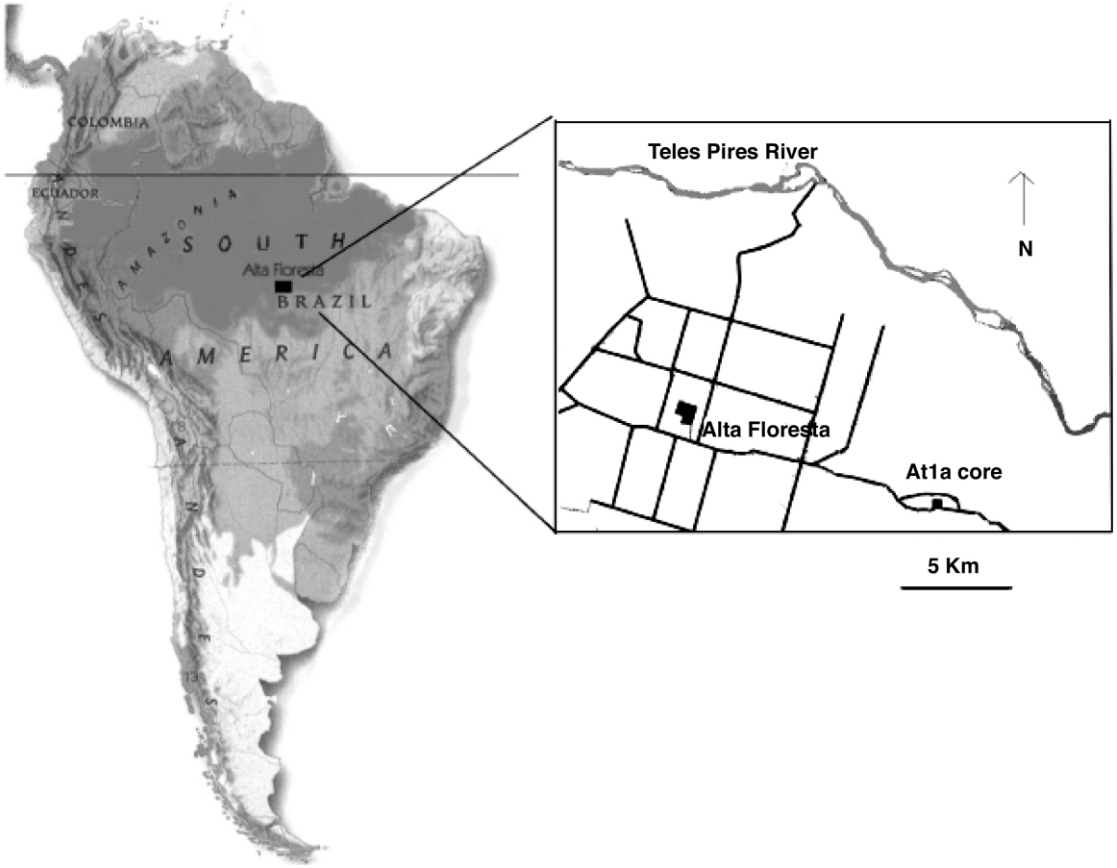

Fig. 1. Alta Floresta, localization in South American. Location of the AT1a sediment core nearby the BR208 highway.

of the road embankment where the core AT1a was collected is located at lat. 9°58′ S and long. 55°49′ W, beside the highway BR-208 built in 1978 (Fig. 1). The sampling point of the core AT1a flooded after the construction of the highway in 1978. The lake is shallow (<0.5-m depth), has a small surface area (<100 m^2) and a drainage basin of approximately 7.3 km^2. The water of the lake has a conductivity of 38.7 $\mu S\ cm^{-1}$ and is slightly acidic (pH=6.33).

3. Methods

3.1. Sampling procedure

The samples were collected manually with 1.5-m-long acrylic tube cores (9.0 cm in diameter). Each core was sliced in 1.0-cm layers in the first 3 cm; in 2.0-cm layers from 3–5 cm; and in 5.0-cm layers thereafter. The samples were stored in plastic bags and frozen for transport. Sediment samples were dried at 50 °C, homogenized and powered using an agate mortar and pistil and stored in polyethylene flasks for further analysis.

3.2. Calculation of sedimentation rate and age

The ages of the sedimentary sections in the AT1a core were calculated considering the beginning of the lake sedimentation as the year of the highway construction—1978. Determination of the lacustrine sedimentation coincided with an increase of the total carbon organic concentration in the sediment profile (Fig. 2). A depth of 10.0-cm

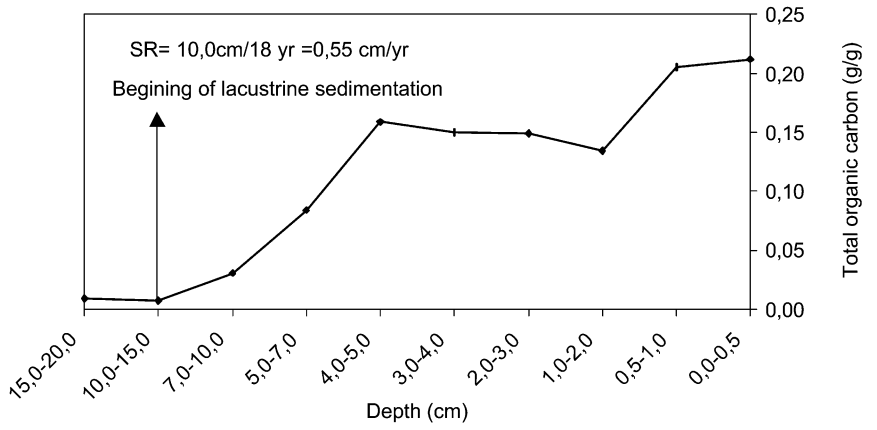

Fig. 2. Organic carbon content in the AT1a sediment core. The marked points were used as the base for the sedimentation rate calculations.

layer was chosen as the beginning of the lacustrine environment, as it is the depth where the total organic carbon increases. Therefore, its age was considered the date of the highway construction (1978). Assuming a constant sedimentation rate and considering that the core was collected in 1996, sedimentation rate (SR) was calculated as follow:

$$SR = 10.0 \text{ cm}/18 \text{ years} = 0.55 \text{ cm/year}.$$

The sedimentation rate calculated here as well as the associated calculated ages (Table 1) probably present some uncertainties due to the resolution of the analyzed sedimentary sections.

3.3. Calculation of bulk density

Bulk density of each layer was obtained by taking out 0.5 cm^3 of a wet sediment section in the polyethylene frame and drying it at 60 °C until constant weight. The core profile contained in the polyethylene frames was sliced taking into account the litologic contact.

3.4. Preparation of the sections slides

The humid sediment sample was digested with a 5% (w/v) NaOH solution to remove the humic material to allow a better visualization of the material. The residue was diluted in distilled water, in a proportion of 0.1% (w/v). The suspension was homogenized and a 2-ml aliquot was taken with a micropipet and filtered through a cellulose acetate Millipore filter (HAWP02500), dried and weighed. The filters with the sediment were dried and prepared in Plexiglas sheets without laminule use for better identification of the charcoal particles with reflected light. Then one is laminated with area and mass of the known analyzed material allowing the determination of the concentration of the studied elements (Cordeiro, 1995; Cordeiro et al., 1997). Counting and measurement of elements were made through a system constituted by a microscope Leitz Diaplan in transmitted and reflected white light, connected to a camera and monitor.

3.5. Black carbon determination

The method used in this work was adapted from Lim and Cachier (1996) and it is based on the isolation of the black carbon through successive steps in order to eliminate the humic acid fraction (NaOH 5%), the carbonate fraction (HCl 3 M), the silicate fraction (HF 10 M/HCl 1 M) and the labile organic matter (H_2SO_4 2 M/$Cr_2O_7^-$ 0.1 M). Black carbon differs to humina due to its greater resistance to oxidation in an acid medium, presenting a half-life ranging from 1500 to 2000 h as opposed to 5 h for the humin (Kulhlbush and Crutzen, 1996). The methodology used in this work presents the following steps: (1) alkaline attacks to eliminate the humic acid, acid attacks to

Table 1
Sedimentary sections, lapse of time in relation to the year of collection (1996), their correspondents age esteemed in relation to the middle of the interval and the intervals of corresponding ages

Interval depth	Average values of the interval (cm)	Age before 1996 (years)	Average age of the interval (AC/DC)	Age range of the section
0.0–0.5	0.25	0.45	1996	1996–1994
0.5–1.0	0.75	1.35	1995	1994–1993
1.0–2.0	1.5	2.70	1993	1993–1992
2.0–3.0	2.5	4.50	1992	1992–1990
3.0–4.0	3.5	6.30	1990	1990–1988
4.0–5.0	4.5	8.10	1988	1988–1985
5.0–7.0	6	10.80	1985	1985–1981
7.0–10.0	8.5	15.30	1981	1981–1978
10.0–15.0[a]	10	18.00	1978	1978

[a] This sediment section corresponds to the soil before the flooding of the dam. The top of the section at 10.0 cm acts as the initial moment of the sedimentation process in 1978.

eliminate silicates and carbonates; (2) oxidation of humina (resistant insoluble carbon to the acid attack); (3) analysis of the carbonaceous material in the CHN analyzer.

3.6. Mercury analyses

Of each sample, 1 g was digested with a 20-ml 50% diluted 'aqua régia' in a closed system. Mercury concentration was measured in the sediment extracts using a cold vapor atomic absorption spectrophotometer Bacharach (Coleman® Model 50 D). Simultaneously, the same procedure was performed with a reference standard (National Institute of Standards and Technology—NIST—Buffalo River sediment Catalog number 8406) content of 60 μg Hg kg^{-1} of 1 g of sediment. We obtained a concentration of $58 \pm \pm 5$ μg Hg kg^{-1} ($N=15$).

4. Results and discussions

4.1. Sediment litology

The AT1a sediment core showed a red clay with organic matter from the top to 10 cm, and a white clay representing the original soil, from 10 to 40 cm. This change in the litology probably represents the beginning of the lacustrine sedimentation around 1978. Assuming this, the results presented here represent the following layers: 0–0.5 cm, 0.5–1.0 cm, 1.0–2.0 cm, 2.0–3.0 cm, 3.0–4.0 cm, 4.0–5.0 cm, 5.0–7.0 cm, 7.0–10.0 cm, 10.0–15.0 cm; corresponding to the following dates: 1996–1995, 1995–1993, 1993–1992, 1992–1990, 1990–1988, 1988–1985, 1985–1981, 1981–1978, with 1978 being the year of the beginning of the sedimentation process (Table 1).

4.2. Microscopic charcoal analysis

Charcoal particles were present along the entire lacustrine faces of the core. These particles mainly originated from atmospheric deposition because the particles have an angular shape and a small size. An estimate of atmospheric deposition fluxes in the Siberia Region showed great similarity with the charcoal deposition in the Alta Floresta sediments (Clark et al., 1998). In the Amazon, a comparable study of atmospheric charcoal deposition and sediment cores showed similarities in the size and shape of charcoal particles (Cordeiro, 2000). The size distribution of charcoal particles permits assessment of their origin. Large particles are considered to have originated in the lake's basin, whereas fine particles are generally associated with long-range transport (Clark and Dan Royall, 1995). Two distinct size distribution phases can be distinguished in the AT1a core. From 1978 to 1985, charcoal particles are smaller (average 214 μm^2), suggesting an external contribution to the lake's basin. From 1985 to present, charcoal particles are larger (average 423 μm^2) suggesting

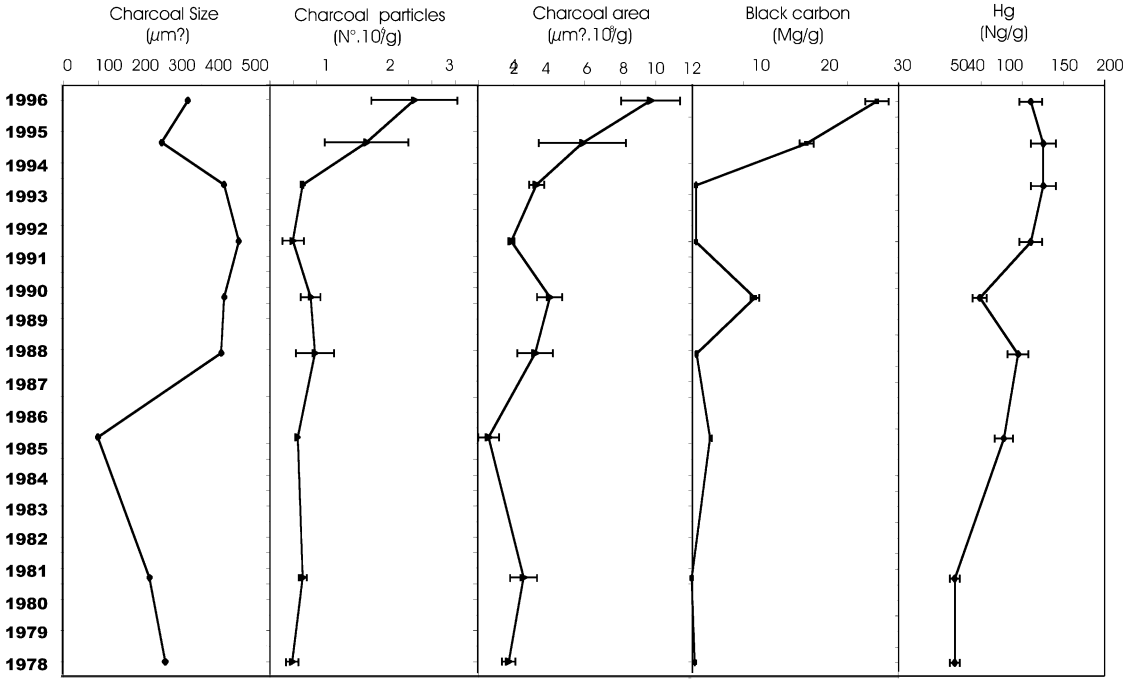

Fig. 3. Distribution of charcoal particle sizes, concentration of number of charcoal particles, area of charcoal particles, black carbon and Hg.

local forest burning as the major source of black carbon to the lake sediments (Fig. 3).

The chemical and microscopic analysis considering the area concentration of the charcoal material presented the same tendency with a strong correlation ($r^2=0.93$, $n=8$). This correlation is similar to the number of charcoal particle concentrations and the black carbon concentration, which also showed a strong correlation coefficient ($r^2=0.96$, $n=8$) (Fig. 3).

4.3. Number and area of charcoal particle fluxes and black carbon

The flux of the charcoal particle expressed in number per area per unit time as well as the black carbon flux shows an increment of the deposition in 1989 and mainly after 1993. Between 1990 and 1992, a decrease of particle fluxes, number of particles and black carbon was observed (Fig. 4). The flux of the forest-burning indicators such as the number of charcoal particles, charcoal area and black carbon remained low up to 1985, with medium values from 1978 to 1985, with 2.6×10^5 particles cm^{-2} $year^{-1}$, 7.0×10^7 μm^2 cm^{-2} $year^{-1}$ and 0.6 mg cm^{-2} $year^{-1}$, respectively. These forest-burning indicator fluxes increase, starting from 1985 to 1989, reaching medium fluxes of 3.4×10^5 particles cm^{-2} $year^{-1}$, corresponding to 1.3×10^8 μm^2 cm^{-2} $year^{-1}$ of charcoal area and 2.4 mg cm^{-2} $year^{-1}$ of black carbon in 1989. After 1990, the fluxes decreased substantially with medium values of 2.3×10^5 particles cm^{-2} $year^{-1}$, 1.0×10^8 μm^2 cm^{-2} $year^{-1}$ and 0.3 mg cm^{-2} $year^{-1}$ from after 1990 to 1992. After 1992, the fluxes of the burning indicators increased exponentially reaching values 7.6×10^5 particles cm^{-2} $year^{-1}$, 2.4×10^8 μm^2 cm^{-2} $year^{-1}$, corresponding to 8.8 mg cm^{-2} $year^{-1}$ of black carbon in 1996 (Fig. 4). A comparison among the fluxes of different phases, showed a substantial decrease in the burning indicators from 1990 to 1992, compared with the mean flux from 1985 to 1996 (Figs. 4 and 5a).

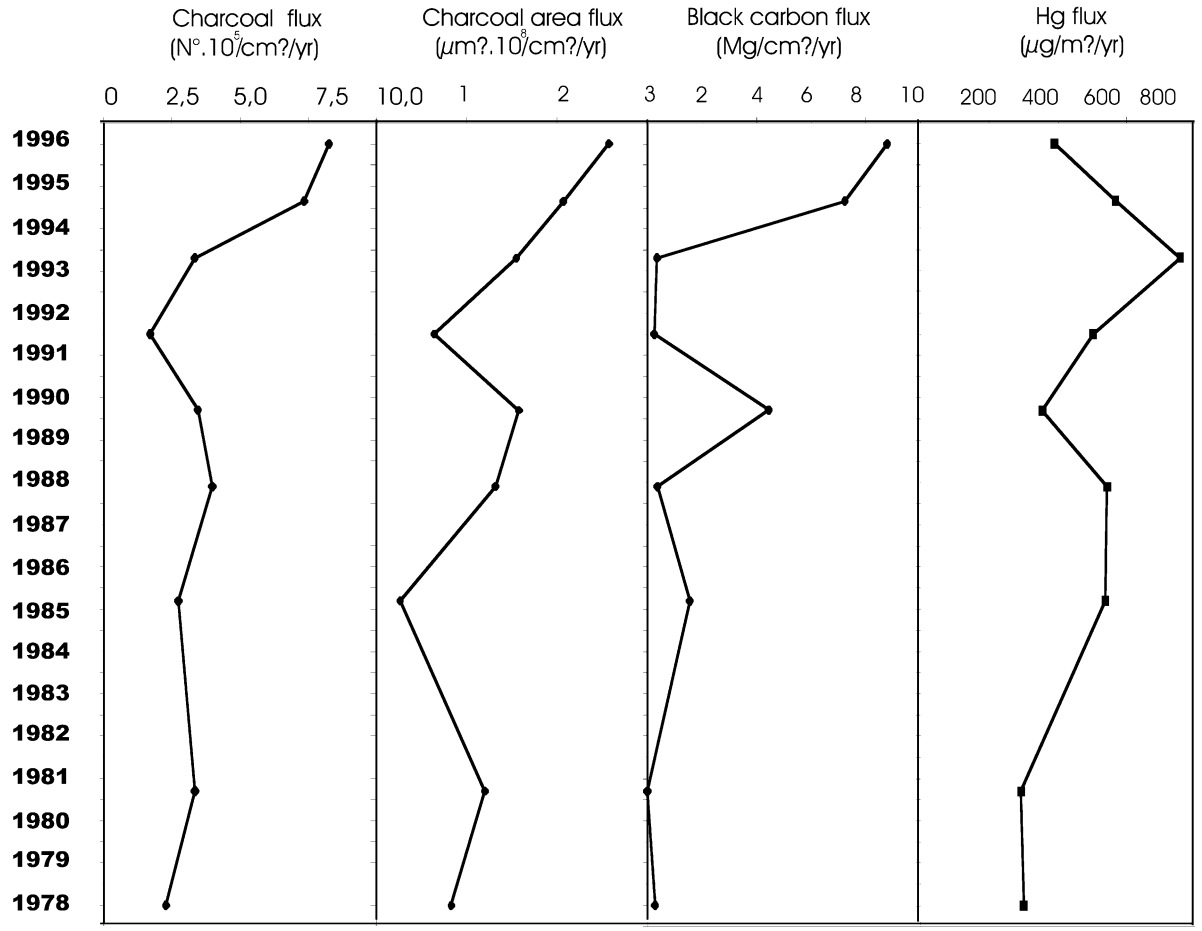

Fig. 4. Fluxes of the burning indicators and Hg demonstrated by the AT1a core.

4.4. Mercury concentration and flux

The Hg concentrations at the AT1a sediment core showed a background concentration of 50 to 70 μg Hg kg^{-1} in the low 30 cm, followed by a sharp increase at the first 10 cm, with a maximum value of 175 μg Hg kg^{-1} in the surface layer. The average flux from 1978 to 1998 was 510 μg m^{-2} $year^{-1}$, with maximum flux of 825 μg m^{-2} $year^{-1}$ and minimum flux of 320 μg m^{-2} $year^{-1}$. The Hg fluxes are extremely high when compared to the fluxes calculated in remote areas of the Carajás Mountain (N4 lake, Pará State, 5°50′ S, 49°30′ W, 800 m high), Seis Lagos hill (da Pata Lake, Amazonas state, 360 m high 0°16′ S, 66°40′ W) and Barrerinhas (Caçó lake, 2°58′ S, 43°25′ W, 40 m high), which typically range from 1.7 to 2.6 μg m^{-2} $year^{-1}$ during the early Holocene to 3.0–8.6 μg m^{-2} $year^{-1}$ during the last 40 000 years BP (Lacerda et al., 1999; Santos et al., in press). However, they are in the same range observed in lakes affected by mining tailings in Poconé, central Brazil, which are from 60 to 180 μg m^{-2} $year^{-1}$ (Lacerda and Salomons, 1998).

5. Discussion

The AT1a core shows that the black carbon and Hg deposition are related to changes in the land use change and gold mining. Hg and charcoal

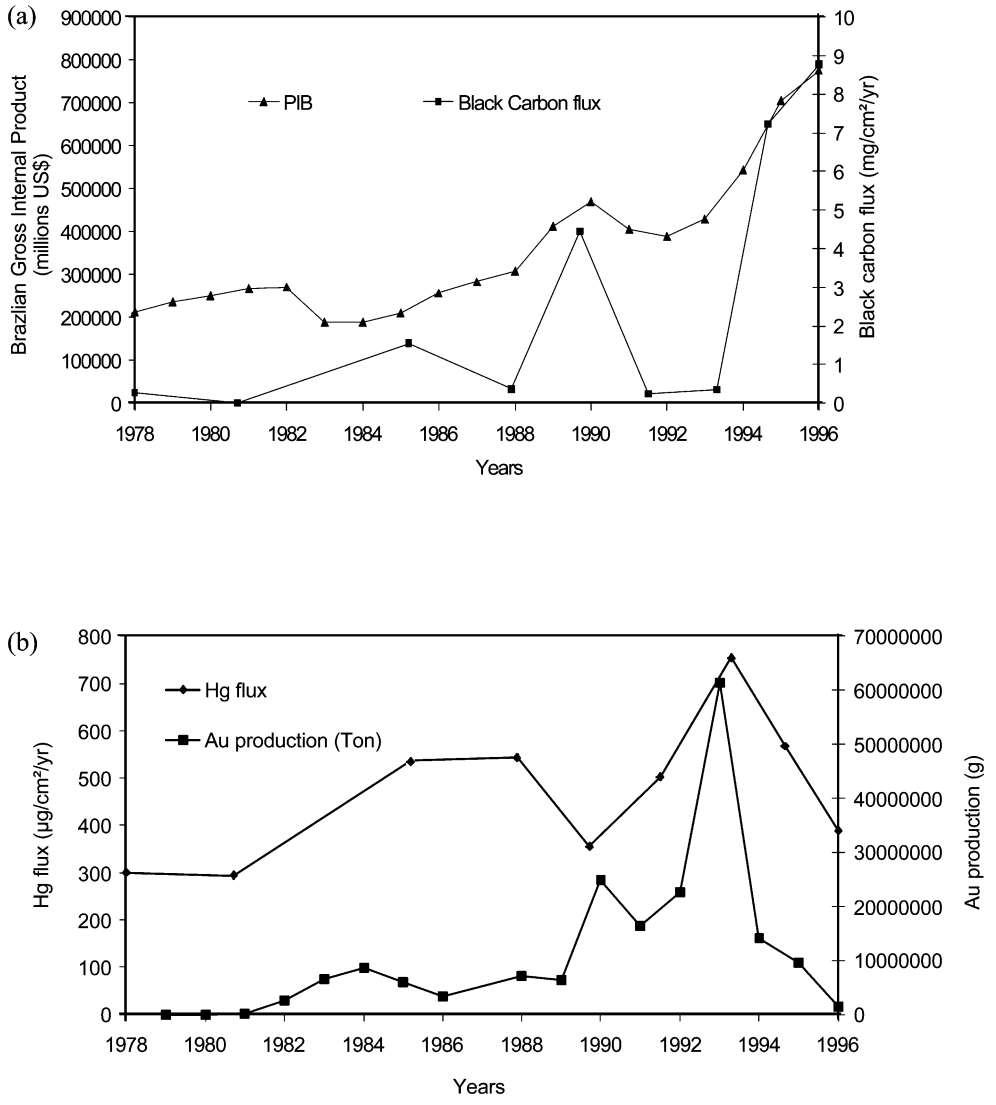

Fig. 5. (a) Black carbon flux and the internal gross production of the Brazilian economy (FGV, 2000); (b) mercury flux and Mato Grosso state gold production (DNPM, 1978–1996).

fluxes presented low values at the beginning of the human occupation (prior to 1978). In the Amazon region, the colonization process generally takes place after the building of a road (Fearnside, 1987). In this study, it was possible to observe this process in the sedimentary record. At the end of the 1970s, fluxes of charcoal were low and the particles came from distant areas. At the same time, Hg deposition was also low. At the beginning of the 1980s, there was an increase in the forest fires and mining activities. These two processes presented two distinct development patterns. The forest fire increased slowly until 1989 when a drastic increase in charcoal fluxes occurred (Fig. 4). Subsequently from 1990 to 1992, a great decrease in charcoal and black carbon fluxes was observed (Figs. 4 and 5a). This period also coincided with the year of the national economic

retraction (FGV, 2000) due to the negative effects of the economic plan implemented by the Fernando Collor de Mello government. This was marked by a reduction in the Brazilian gross domestic product with a substantial reduction in the early 1990s (Fig. 5a). The behavior of great ranchers is very sensitive to the economic changes, such as the interest rates in the finance markets and the return of other investments, governments subsidies for agricultural credit, inflation rate and changes of the land price (Fearnside, 1999). In this case, the decrease of the circulating capital during the Collor Plan probably induced a decrease of the investments in forest conversation to pasture and crops. Obviously, climatic factors such as El Niño events can act synergistically with this process (Kirchhoff and Escada, 1998). We have to consider the occurrence of El Nino events in years 1982–1983, 1986–1987, 1991–1994 (Brasil, 2000) as a synergetic process with the macroeconomic influence. Interestingly, the reducing in charcoal deposition was not accompanied by a reduction in the Hg deposition. An explanation for this fact would be the difference in the type of investment. Agricultural activities demand intense and annual financial support to make the forest clearance and after the burning, crop or pasture implementation. On the contrary, mining activities do not need a continuous investment. At the beginning of this exploration, this activity had an intense return rate, which allowed independence related to the Brazilian economy. Our data suggest that while the Brazilian gross domestic product increased the charcoal deposition also increased. The Hg deposition increased until 1993, when a sharp decrease took place due to the exhaustion of easy prospected gold deposits (Lacerda, in press) (Fig. 5b).

6. Conclusions

Two distinct tendencies were observed in relation to the deposition of the mercury and charcoal particles which originated from the burning of the Amazon forest. These tendencies were observed on the sedimentary record of an artificial lake and reflected the colonization processes in the Alta Floresta district, state of Mato Grosso, central Brazil. In the sedimentary record, it was possible to observe that charcoal particles are representatives of the forest fires produced by ranchers, which in turn are tied to the macroeconomic aspects of the Brazilian economy. However, the mercury deposition from small-scale gold mining (a low investment but with high return of capital and independence of internal economy), showed an increase at times of economic difficulties. This tendency was also observed in other parts of the developing world. A substitution of the economic model in an intense land use change area was also observed, which had a great environmental impact upon the region. In the beginning of the colonization, intense mining activities were substituted by crops and cattle activities with the use of fire as a great modifier of the landscape.

Acknowledgments

The authors would like to thank CNPq (Conselho Nacional de Desnvolvimento Científico e Tecnológico, Brazil-processo 540846/101-5), IRD (Institute de Recherche pour le Development, France). We are grateful to Louis Scott and Hughes Faure (carbon commision of INQUA) for the opportunity to present this work at the INQUA Durban congress in 1999.

References

Andreae MO. Soot carbon and excess fine potassium: long-range transport of combustion derived aerosols. Science 1983;230:1148–1151.

Artaxo P, Yamosoe M, Martins JV, Kocinas S, Carvalho S, Maenhaut W. Case study of atmospheric measurements in Brazil: aerosol emissions from Amazon Basin biomass burning, in fire in the environment: their ecological, atmospheric and climatic importance of vegetation fires. In: Crutzen PJ, Goldammer JG, editors. Climatic importance of vegetation fires. New York: John Wiley, 1993. p. 139–158.

Brasil. Instituto Nacional de Pesquisas Espaciais (INPE). Amazonia: Deforestation 1995–1997. São José dos Campos, São Paulo, Brasil Doccument release via Internet (http//www.inpe.br), 1998.

Brasil. Instituto de Pesquisas espaciais (INPE), El Niños Passados. São José dos Campos, São Paulo, Brasil. Document release via Internet (http//www.cptec.inpe.br), 2000.

Clark J, Dan Royall P. Particle-size evidence for source areas of charcoal accumulation in the late Holocene sediments of eastern north American lakes. Q Res 1995;43:80–89.

Clark J, Lynch J, Stocks BJ, Goldammer JG. Relationships between charcoal particles in air and sediment in west-central Siberia. Holocene 1998;8(1):19–29.

Cordeiro RC. Mudanças paleoambientais e ocorrência de incêndios nos últimos 7400 anos, na região de Carajás, Pará. Master degree disertation thesis. Niteroi, RJ, Brazil: Federal Fluminense University, 1995. (144 pp).

Cordeiro RC. Ocorrência de Incêndios e Mudanças Paleoambientais de Ecossistemas Amazônicos em diversas escalas temporais. PHD thesis. Niterói, RJ, Brazil: Federal Fluminense University, 2000. p. 250.

Cordeiro RC, Turcq BJ, Suguio K, Ribeiro CV, Silva AO, Siffedine A, Holocene ML. Environmental changes in Carajás region (Pará, Brasil) record by lacustrine deposits. Verh Int Verein Limnol 1997;26:814–817.

DNPM. Anuário Mineral Brasileiro (Brazilian Mineral Yearbook), Departamento Nacional de Produção Mineral. Ministério de Minas e Energia. Brasília, 1978–1996.

Fearnside PM. Causes of deforestation in the Brazilian Amazon. In: Dickinson RF, editor. The geophysiology of Amazônia: vegetation and climate interactions. New York: John Wiley and Sons, 1987. p. 37–61.

Fearnside PM. Amazônia and global warming: annual balance of greenhouse gas emissions from land-use change in Brazil's Amazon region. In: Levine JS, editor. Biomass burning and global change, vol. 2, biomass burning in south America, southeast Asia, and temperate and boreal ecosystems and oil fires of Kuwait. Cambridge: MIT Press, 1996. p. 606–617.

Fearnside PM. Combate ao desmatamento na Amazônia brasileira. Cad biodivers 1999;2(2):35–39.

Fearnside PM, Leal N, Fernandes FM. Rain forest burning and global carbon budget: biomass, combustion efficiency, and charcoal formation in the Brazilian Amazon. J Geophys Res 1993;98(D9):16733–16743.

FGV. Revista Conjuntura Econômica. Jan., 2000:19.

Freitas SR, Silva Dias MA, Silva Dias PL, Longo KM, Artaxo P, Andreae MO, Fischer H. A convective kinematic trajectory technique for low resolution atmospheric models. J Geophys Res 2000;105:24375–24386.

Garstang M, Scala J, Greco S, Harriss R, Beck S, Browell E, Sachse G, Gregory G, Hill G, Simpson J, Tao W-K, Torres A. Trace gas exchanges and convective transports over the Amazonian rain forest. J Geophys Res 1988;93:1528–1550.

Hacon S. PHD thesis. Niterói, RJ, Brazil: Federal Fluminense University, 1996. p. 250.

Houghton RA, Woodwell GM. Global climatic change. Sci Am 1989;260(4):36–44.

Houghton RA, Skole DL, Nobre CA, Hackler JL, Lawrence KT, Chomentowski WH. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. Nature 2000;403:301–304.

Kirchhoff VWJH, Escada PAS. O megaincêndio do século. São José dos Campos SP: TRANSTEC, 1998. (83 pp).

Kulhlbush T, Crutzen PJ. Black carbon, the global carbon cycle, and atmosphere carbon dioxide. In: Levine JS, editor. Biomass burning and the global change, vol. 1MIT Press, 1996. p. 160–169.

Lacerda LD. Amazon mercury emissions. Nature 1995;374:20–21.

Lacerda LD. Updating mercury emissions from small scale gold mining and assessing its environmental impacts. Environ Geol, in press.

Lacerda LD, Marins RV. Antropogenic mercury emissions to the atmosphere in Brazil: the impact of gold mining. J Geochem Explor 1997;58:223–229.

Lacerda LD, Salomons W. Mercury from gold and silver mining: a chemical time-bomb?. Heidelberg: Springer Verlag, 1998. (146 pp).

Lacerda LD, Ribeiro MG, Cordeiro RC, Sifeddine A, Turcq B. Atmospheric mercury deposition over Brazil during the past 30,000 years. Ciência e Cultura. J Braz Soc Adv Sci 1999;51(5/6):363–371.

Lim B, Cachier H. Determination of black carbon by chemical oxidation and thermal treatment in recent marine and lake sediments and Cretaceous–Tertiary clays. Chem Geol 1996;131:143–154.

Nepstad DC, Veríssimo A, Alencar A, Nobre C, Lima E, Lefebvre P, Schlensiger P, Potter C, Moutinho P, Mendoza E, Cochrane M, Brooks V. Large-scale impoverishment of Amazonian forests by logging and fire. Nature 1999;398:505–508.

Santos GM, Cordeiro RC, Silva Filho EV, Turcq B, Lacerda LD, Hausladen PA, Fifield LK, Gomes PRS, Sifeddine A. Chronology of atmospheric mercury in Lagoa Da Pata Lake, Upper Rio Negro region of Brazilian Amazon, in press.

Verardo Dand, Ruddiman WF. Late Pleistocene charcaol in tropical Atlantic deep-sea sediments: climatic and geochemical significance. Geology 1996;24(9):855–857.