Development and Erosion in the Brazilian Amazon: A Geochronological Case Study

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ABSTRACT: A $^{210}$Po chronology of sedimentation in a small floodplain lake in the Jamari river basin (Rondonia, Brazil) provided insight into the relationship between development and erosion in the Brazilian Amazon. Positive correlations between increased sedimentation in the lake and levels of deforestation and mining in the Jamari basin suggested a major increase in erosion associated with these activities. This increase in erosion could diminish agricultural yields in the basin and significantly reduce the useful life of a hydro-electric plant recently built on the river.

Introduction

Deforestation is increasing in the Brazilian Amazon as a consequence of rapid human development (Fearnside 1982, 1984). With the destruction of the original vegetation cover, erosion is likely to increase (Fearnside 1986). The expansion of mining and other extractive industries could accelerate the erosion process. The resulting loss of topsoil could cause irreparable damage to existing ecosystems (Herrera et al. 1978) and reduce agricultural yields (Fearnside 1985). Increased erosion could also reduce the useful lifespans of hydro-electric plants in the region by accelerating reservoir siltation rates (Szolgay et al. 1986).

The relationship between human development and erosion in the Brazilian Amazon is difficult to quantify. Both deforestation (Fearnside 1982, 1984) and mining (Ministerio de Minas e Energia, Departamento Nacional de Produção Mineral, DNPM, Manaus, Brazil) have increased significantly in the past 20 years. However, direct estimates of the erosion generated by these activities are rare (Fearnside 1986). There is also a lack of historical data on river sediment loads to determine whether sediment export has increased with development. The analysis of sedimentation patterns in floodplain lakes provides an alternative method for documenting the history of erosion in the region. The history of sedimentation in a lake generally reflects the history of erosion in its drainage basin (Flower et al. 1984). Floodplain lakes normally receive a large part of their water and sediment load from a neighboring river during seasonal floods. Thus, their sedimentation histories tend to reflect the pattern of erosion over the entire upstream portion of the river's drainage basin. An analysis of sedimentation in a single lake, then, can provide information about the history of erosion in an extensive area. By correlating these data with records of human activity in the same region it is possible to investigate the relationship between human development and erosion.

We examine here the history of sedimentation in Lago Paca, a small floodplain lake in the Jamari river Basin, a region of intense human activity in the Brazilian state of Rondonia. The results provide insight into the history of erosion in the Jamari basin and its relationship to human development.

Description of the Study Site

Lago Paca is located on the Jamari river (Rondonia, Brazil), 6 km upstream from its mouth (Fig 1). It is connected to the river by a short (approx. 200–300 m)
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channel. The lake has a surface area of approximately 10 ha, a small, undisturbed (forested and uninhabited) local drainage basin and apparently receives most of its water and sediment from the Jamari river during seasonal floods. Several large agricultural colonies and tin mines, as well as a recently constructed hydro-electric plant are located upstream from the lake (Fig 1).

Methods

The recent history of sedimentation in the lake was determined geochronologically by analyzing the vertical distribution of $^{210}$Pb in its sediments. The lake was cored during January of 1986 while the river level was rising. Three 1 m cores were taken near the center of the lake at a depth of 10 m with a 5 cm diameter gravity corer. All three cores were composed of fine-grained organic clay sediment and contained no obvious stratigraphic features. The cores were sectioned at 1 cm intervals in the field and composited at each depth in order to obtain enough material for analysis. The remaining sample was dried at 60°C and analyzed for $^{210}$Pb, $^{226}$Ra, and $^{137}$Cs at the Instituto de Radioproteção e Dosimetria (IRD) in Rio de Janeiro. $^{210}$Pb, $^{226}$Ra, and $^{137}$Cs activities were determined by direct gamma spectrometry. Fifteen grams of dry sediment were assayed in an intrinsic germanium detector (Ortec GAMMA-NP Ge. 15% relative counting efficiency) coupled to a Nuclear Data (ND-65) multichannel analyzer. $^{226}$Ra was determined using the 352 KeV $^{214}$Pb and 609 KeV $^{214}$Bi lines one month after mounting the samples. The detection limit of the $^{210}$Pb and $^{226}$Ra determinations was 1.5 pCi/g while that for $^{137}$Cs was 0.20 pCi/g. $^{226}$Ra activity was relatively constant with depth with an average value of 4.46 ± 0.16 pCi/g. Unsupported $^{210}$Pb activity was calculated by subtracting this value from the total $^{210}$Pb activity at each depth. A known volume of wet sediment from each depth was also dried separately and weighed to determine cumulative dry weight.

The $^{210}$Pb data were analysed using the constant rate of supply (CRS) model of Appleby and Oldfield (1978, 1983). This model is used to calculate sediment age and settling rates in lakes where sedimentation has varied over time. It is based on two assumptions: 1) $^{210}$Pb is supplied to the sediment surface at a constant rate, and 2) it decays at a constant rate once it is deposited. This sedimented $^{210}$Pb is called "unsupported" to distinguish if from $^{210}$Pb derived in-situ from the decay of $^{226}$Ra ("supported"). When the assumptions hold, integral unsupported $^{210}$Pb activity, $A_z$ (pCi-cm$^{-2}$), below any depth, z (cm), in the sediments varies as

$$A_z = A_0 e^{-kt}$$

where $A_0$ is the total integral $^{210}$Pb activity below the sediment surface (pCi-cm$^{-2}$), t is the age (y BP) of the sediments at depth z, and k is the exponential decay rate for $^{210}$Pb (0.03114-y$^{-1}$). The rate of sedimentation, r (g-cm$^{-2}$-y$^{-1}$), at each depth in the core is calculated as

$$r = \frac{kA_z}{C_z}$$

where $C_z$ is the unsupported $^{210}$Pb activity at depth z (pCi-g$^{-1}$), and the age of the sediments at each depth is given by

$$t = \frac{1}{k} \ln \frac{A_0}{A_z}$$

$A_z$ values for these calculations are determined by integrating the relationship between unsupported $^{210}$Pb activity and cumulative dry weight below each depth.

Deforestation in the Jamari basin was calculated from data obtained from the Instituto Brasileiro de
Desenvolvimento Florestal (IBDF 1980, 1982, 1985). They estimated deforestation in the state of Rondonia in four different years by monoscopic interpretation of LANDSAT MSS images (channels 5 and 7) and presented results for each 1° x 1° quadrat. We used their 1:1,000,000 scale map of deforestation in Rondonia for 1983 (MA-BDF-DE-PMCFB, Brazil, 1985) to estimate the proportion of deforestation in each quadrat which occurred in the Jamari basin and, assuming these proportions constant, used them to calculate deforestation throughout the development period.

Results and Discussion

Unsupported 210Pb activity was detectable to a depth of 30 cm in the composite core (Fig 2A). The activity-depth profile deviated significantly from the exponential relationship expected for a constant rate of sedimentation (Fig 2A and 2B). The abrupt decline in activity near the surface reflects a major dilution of 210Pb inputs due to increased sedimentation. The detailed history of sedimentation derived from the analysis of the 210Pb profile is shown in Fig 3A.

During the period 1875–1961 the rate of sedimentation in Lago Paca was relatively constant and low with an average value of 0.12 g dry wt/cm²/yr. Since there was little human activity in the Jamari basin during this period (IBRD 1981), this value is assumed to represent the pre-development sedimentation rate and reflects the low levels of erosion which originally predominated in the area. The small peak in sedimentation during the early 1940's may reflect an increase in rubber farming in the basin associated with the "rubber wars", a brief revival of the Brazilian rubber industry which occurred at the beginning of World War II after the Japanese seized the Malaysian rubber fields (Sarasate 1946).

In 1961 the Cuiaba-Porto Velho Highway (BR-364, Fig 1) was completed, linking the Jamari basin and the rest of the State of Rondonia to the Federal Highway System. This was the first of a series of measures taken by the Brazilian government to stimulate colonization in the region and marks the beginning of a period of rapid growth and development (Leal 1986). After 1961 the rate of sedimentation in Lago Paca increased exponentially reaching a value 10 times greater than the pre-development average by the end of 1985. The post-1961 rise in sedimentation, r (Fig 3B), was directly correlated to increases in deforestation (Fig 3C) and tin mining (data supplied by the Ministerio das Minas e Energia, DNPM, Manaus, Brazil, Fig 3D) in the Jamari basin and apparently reflects a major increase in erosion associated with these activities.

While the evidence for an increase in erosion appears quite strong, several alternative explanations for the apparent increase in sedimentation in Lago Paca must also be considered.

For example, physical or biological mixing of surface sediments might have reduced the 210Pb activity at the top of a profile resulting in an anomalous 210Pb distribution. 137Cs activity is normally used to test for mixing in sediment cores. If no disturbance has occurred, peaks in activity are usually expected at depths in the sediments corresponding to historical peaks in atmospheric atomic bomb testing. Three peaks in atmospheric precipitation of 137Cs have been documented in the southern hemisphere, in 1958, 1964 and 1971, the latter being due to several French tests which occurred in the South Pacific after the International Test-ban Treaty had gone into effect (Longmore et al. 1983). The level of fallout in the S hemisphere, though, was 10 times lower than in the N hemisphere (Longmore et. al. 1983), so the peaks in 137Cs activity are relatively difficult to detect. We were only able to detect significant 137Cs activity in sediments collected at 9–10 cm and 12–13 cm in the core from Lago Paca. According to the 210Pb chronology, these depths correspond to the years 1973 and 1964, coinciding fairly well with the second two peaks in atmospheric fallout. The activity for the 1958 peak was presumably included in the value for 9–10 cm since each cm at this depth integrates about 10 years of sediment. These results together with the steep gradient of 210Pb activity found in the top few centimeters of the profile (Fig 2A) suggests that biological and physical mixing in the core were minimal.

A major violation of the 210Pb model's assumptions could also result in an anomalous 210Pb profile. The assumption of a constant rate of supply for 210Pb is frequently violated (Oldfield and Appleby 1984; Appleby et al. 1985; Murchie 1985). The redistribution of sediments by focussing and other mechanisms often causes supply rates to vary over a lake basin. Sedimentation records in different parts of the lake may thus become distorted and deviate from the average basin wide trend. The average supply rate for the Lago Paca core, calculated from A0, was 1.2 pCi – cm² – y⁻¹. This
An alternative explanation for the increase in sedimentation in Lago Paca is that it was due to a local disturbance. Since the local basin was undisturbed the source of sediment would have to have been upstream from the lake. The only local disturbance which could have significantly altered sediment levels in the Jamari river was the construction of the Samuel hydroelectric dam about 29 km upstream from the lake (Fig 1). The engineers building this dam, though, have taken special precautions to control erosion during construction and the project has apparently had no significant effect on measured river sediment concentrations (Perreirea, F. and Darwich, A. personal communication).

A final factor which could have influenced sedimentation in the lake is river channel migration. If the river was migrating toward the lake the supply of fine sediments and the sedimentation rate might have increased. However Lago Paca is located on the inside of a meander bend with the river migrating away from it (Fig 1). If channel migration occurred, then, it would have acted to isolate the lake from its sediment supply and reduce sedimentation.

Thus, we conclude that the most likely cause for the increase in sedimentation in Lago Paga was a major increase in erosion associated with deforestation and mining activities in the Jamari river basin. While the actual rate of erosion cannot be quantified directly, the sedimentation results suggest that it has increased by an order of magnitude since 1961. These higher erosion rates could have a number of adverse consequences for human development in the region. Most of the deforestation in the Jamari basin has occurred in 2 large agricultural colonies near the city of Ariquemes (Fig 1). Soil losses from these areas could result in reduced crop yields and threaten the survival of these subsistence farming communities. Increased erosion could also reduce the useful life of the Samuel hydroelectric facility by accelerating reservoir siltation rates.

These results illustrate the potential of geochronological methods for investigating erosional processes in the Brazilian Amazon and other large fluvial basins. The analysis of sedimentation in a single lake provided information about the history of erosion in an area of over 30,000 km² (area of the Jamari river basin above Lago Paca). By correlating this information with land-use data derived from LANDSAT imagery and other sources it was possible to investigate the relationship between development and erosion in the area.

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falls just above the range of values commonly found for atmospheric precipitation (0.2—1.0 pCi · cm⁻² · y⁻¹, Oldfield and Appleby 1984) suggesting that some minor focussing and distortion of the sediment record may have occurred. It is unlikely that a slight distortion could explain the ten fold increase in sedimentation observed in the lake. However, it may account for some of the small scale variation in the record and these changes will clearly have to be interpreted with caution.
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