ELSEVIER

Nuclear Instruments and Methods in Physics Research B 172 (2000) 761–766

NIM B
Beam Interactions with Materials & Atoms

www.elsevier.nl/locate/nimb

^{14}C AMS dating of fires in the central Amazon rain forest

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Abstract

Soil samples were collected in tierra firme upland and lowland areas of the Km 41 reserve near Manaus (20°30′S and 60°W), in Central Brazilian Amazon, within a 1700 m transect, at eight different depth ranges, from surface to 100 cm. The highest charcoal concentrations were found at the depth range of 20–50 cm. AMS radiocarbon dating of 31 samples were performed at the ANU. The ages of the charcoals were found to vary within the 130 to 2400 years BP range, mostly between 1200 and 1400 years BP, one of the known Holocene dry periods of the Amazon region. The results show that the fires have regional dimensions and are associated with climate regional changes.

PACS: 07.75.+h; 89.60.+x; 92.70.Gt; 93.30.Vs
Keywords: Paleoclimate; Holocene; Tropical forest; Mass spectrometry

1. Introduction

The Amazon region is one of the key ecosystems under investigation as part of the global change research program. The present study is concerned with the determination of rain forest fires in this region, and the climatic changes that may have originated them. It is not well understood yet how the tropical ecosystems reacted to the last climatic changes. One needs to know that, in order to predict how they will react to the current and future climatic changes.

Charcoal occurrences associated to vegetation burn events were evidenced at several areas in South America. Charcoal in the soil of the eastern Amazon was dated [1] as between 6000 and 3000 years BP, indicating the occurrence of Holocene forest fires in that area. Charcoal was dated in forest soils in High Rio Negro, with ages corresponding to the last 6000 years [2]. The occurrence of fires from medium Holocene, in several types of forests in High Rio Negro region, was associated to climatic changes and anthropic action [3]. Sifeddine et al. [4] demonstrated intense charcoal occurrences between 7000 and 4000 years BP,

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0168-583X/00/$ - see front matter
PII: S0168-583X(00)00234-2

through the measurement of the reflectance index of the organic particles in a lake core of South Mountain of Carajás (south-west Amazon). A continuous register of high temporally resolution, obtained for the last 7500 years, through the quantification of microcharcoal fluxes in lacustrine sediment in North Mountains of Carajás [5,6], corroborated the medium Holocen dry phase and showed the occurrence of fires in the upper Holocene. Dating of charcoal and humin in soils and organic matter carbon isotopic composition was determined in several sites in Brazil, and they have shown substantial changes in the vegetation distribution, occurrence of forest fires and climatic evolution [7,8].

The charcoal quantification in areas of the Amazon region will allow the determination of the relative magnitude of the forest fires, probably associated to climatic changes during the Holocene. However, one major difficult task in the study of paleofires is to describe their occurrences temporally and spatially, inclusive at meso-scale. A reason for that is the difficulty to sample a sufficient amount of charcoals, in different soil layers and different soil profiles.

2. Charcoal sample collection at central Amazon

In Manaus region (2°30′S and 60°W – see Fig. 1(a)), a wet part of central Amazon, with average annual precipitation from 1900 to 2400 mm, charcoal fragments were collected in tropical rain forest soil profile corresponding to different geomorphologic positions, in upland and lowland areas of tierra firme of the Km 41 reserve (Fig. 1(b)) of the Instituto de Pesquisas da Amazonia (INPA). Tierra firme is a non-flooded forest, and the predominant soil in the area is the latossolo yellow alico (oxisol). A soil auger was used to collect the samples. In a transect of 1700 m in length, six areas of different altitudes were selected. The samples were collected at the "line Q" of the reserve (see Fig. 1(b)), in the following points, with their respective altitudes: $Q_6 = 245$ m (upland), $Q_9 = 210$ m (shoal), $Q_{11} = 240$ m (upland), $Q_{13} = 200$ m (shoal), $Q_{19} = 195$ m (shoal) and $Q_{21} = 215$ m (upland).

The material was separated with a manual auger, in depths from the surface to 1 m deep, in the range of 0–20 cm and subsequent 10 cm ranges. Then, samples of 5 cm thickness were removed and conditioned in plastic bags. They were homogenized, sifted for the retreat of roots and retired aliquots for quantification of charcoals.

Fig. 2 shows the average charcoal density (charcoal (mg)/soil (g)) for the upland and shoal sites. One can see that the average charcoal distribution is quite similar in both situations. The highest charcoal concentrations have been observed at the upland sites, and were more frequent at 40–50 cm depth in all the sites collected. These results are in agreement with other studies in the region, and show that the soil auger method can be

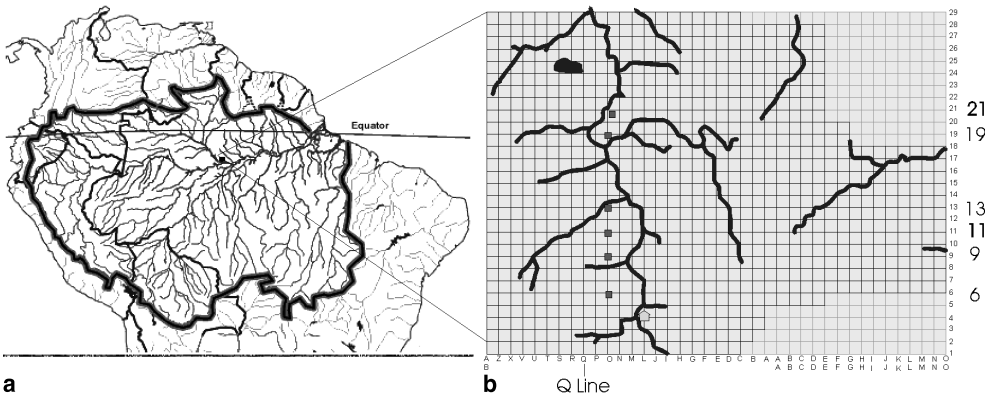

Fig. 1. (a) Amazon map, with localization of the present study (Manaus). (b) Details of the Km 41 reserve.

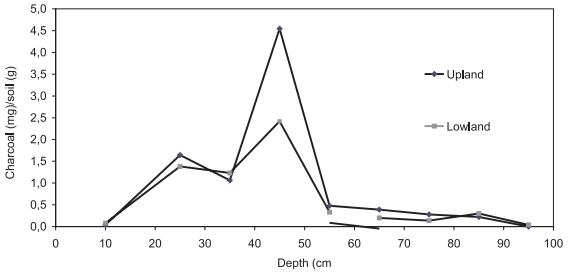

Fig. 2. Average charcoal density (charcoal (mg)/soil (g)) for the upland and shoal sites.

used to obtain, in a very fast way, data on the vertical and lateral distribution of charcoal. The average charcoal distributions along the profiles show that those situated in the upland areas have larger values than in the lowland, corresponding to more severe fires.

3. Charcoal sample dating

The AMS was the suitable technique to be used in the investigation of the ages of the fires, due to the small quantities of the charcoal samples.

Considering, as a reference, an average accumulation rate of 0.032 cm/year observed by Saldarriaga and West [2] in the San Carlos do Rio Negro region, with roughly the same kind of soil (oxisol) and average annual precipitation (2000 mm), the estimated age at the depth of 45 cm should correspond to 1500 years BP. For the range of accumulation rate between 0.014 and 0.053 cm/year, one should be able to determine ages from modern to 7000 years, within the 100 cm profile.

The dry soil samples were taken to ANU, where they passed through the preparation and graphitization processes and analysis. Thirty-one samples were prepared as well seven standard ANU samples (ANU sucrose) and three blank samples (Sri Lank graphite).

The standard ANU procedures for the transmission and analysis of the samples were followed. Table 1 shows the determined ages of the charcoal samples. Fig. 3 shows the radiocarbon ages versus depth for the different profiles. One can notice that, apart from the Q_{13} group, all the ages are within the range 1000–2400 years, corresponding to reported dry periods of the Amazon region [3,9]. One can also notice that there is not a clear pattern for the charcoal dates by depth. This phenomenon is due to the intense remobilization process, that is usually found in charcoal dating of soils and there are several explanations for that [2].

Table 1
Radiocarbon age results for the Amazon charcoal samples

Depth (cm)	Radiocarbon age (years BP)	Age error (years)
$Q_6 = 245$ m		
20–30	1170	120
30–40	1190	140
40–50	1480	240
$Q_9 = 210$ m		
00–20	130	140
20–30	1270	120
30–40	1280	150
40–50	1270	120
50–60	970	140
60–70	980	120
70–80	1080	140
80–90	1140	130
90–100	1430	130
$Q_{11} = 240$ m		
20–30	1510	190
40–50	1530	120
60–70	1470	160
$Q_{13} = 200$ m		
20–30	340	120
30–40	680	220
40–50	520	120
50–60	580	120
60–70	890	170
70–80	470	130
80–90	590	390
90–100	1050	220
$Q_{19} = 195$ m		
50–60	1400	120
$Q_{21} = 215$ m		
20–30	1280	120
30–40	1430	140
40–50	1170	280
–65	1750	230
70–80	2410	120
80–90	1670	140
90–100	1800	190

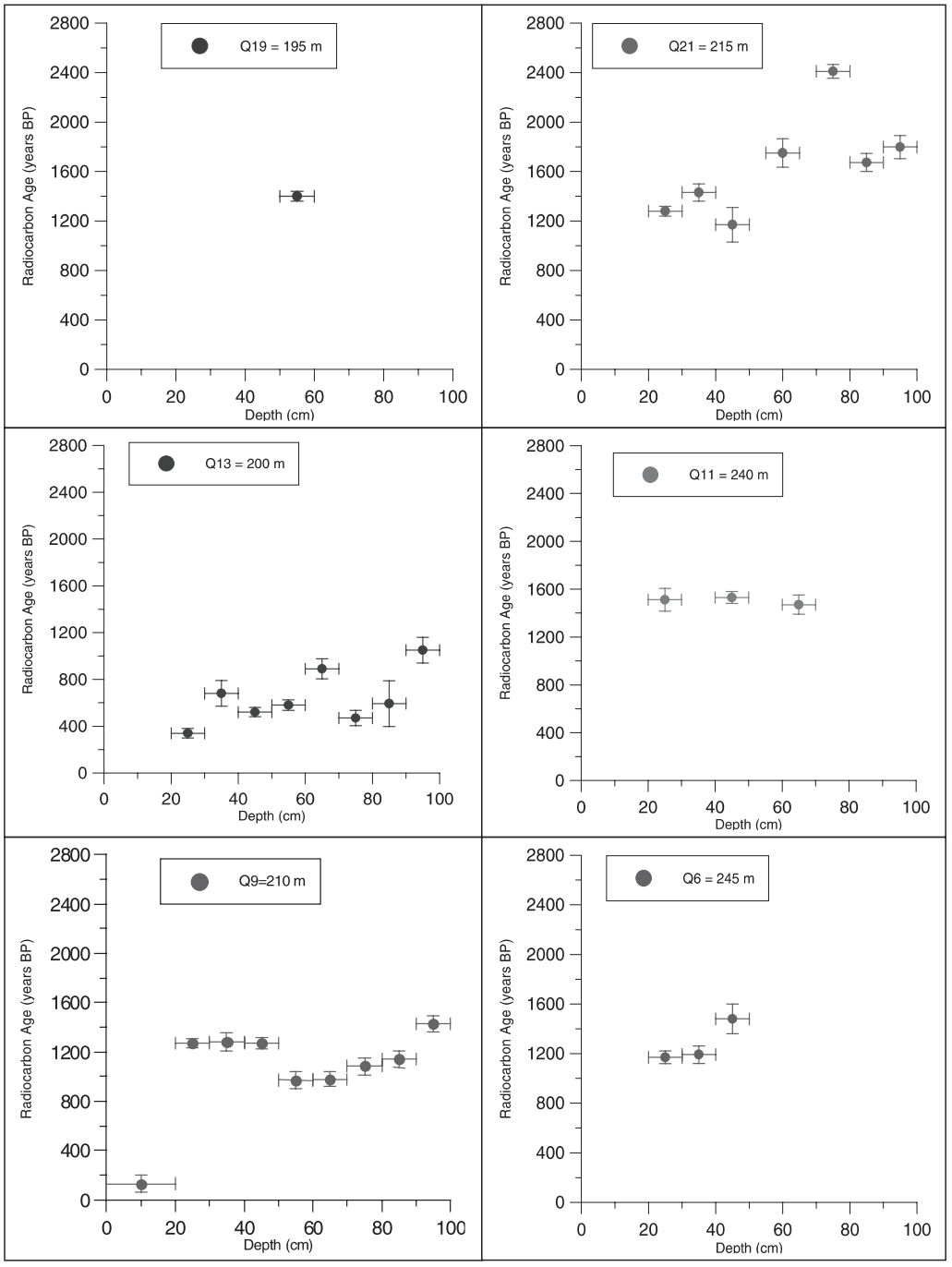

Fig. 3. Radiocarbon ages versus depth, for the different profiles.

The soil of tierra firme is characterized by a litter layer that in many cases contains a thick layer of roots and has a deposit of partially decomposed organic matter. Under this raw humus layer lies the mineral soil. The remobilization phenomenon is usually present in soft and humid soils, where wood is unevenly distributed on the forest floor and activities by animals and men redistribute the charcoal. Roots of young trees may penetrate the charcoal deposits, as well as burned roots, and contribute to deeper layers being younger than the upper layers, as younger charcoal is introduced in the deeper layers. Intense rainfall in the area washes charcoal out of soil surfaces and buries it down slopes and depressions. Disturbances such as windthrow and fires or periods of floods increase runoff and erosion. Wind and water erosion immediately following a fire or flood deposit large amount of organic and inorganic remains. The ages of the trees may also be an important factor, since radiocarbon ages represent the time carbon was fixed by the tree rather than the time of combustion.

From Fig. 3, one can see that the results for the shoal Q_{13} group present a good correlation between age and depth and that this group shows younger ages than the others. This fact is not yet understood, but the reason might be a particular small remobilization and, consequently, the rate at which the charcoal penetrates the soil is smaller for this site.

4. Conclusions

The fires have occurred along the whole region studied, and were more intense at upland than at lowland. They were probably caused by climatic anomalies, which have changed the structure and dynamics of the vegetation and the ecosystem.

Dry phases have been recorded in the Amazon Basin [3,9], by palynological data, during the periods between 6000 and 4000 years BP, 2700–2100 years BP, 1500–1200 years BP and 700–400 years BP. In the present study, the radiocarbon ages of the charcoals were found to vary within the 130–2400 years BP range, mostly between 1000 and 1500 years BP. The analysis of the charcoal density (charcoal (g)/soil (g)) in the soil for these samples also shows that the fires were more intense from 1200 to 1300 years BP than for earlier and older events, but with large fluctuations within this period.

Under dry climate regimes, wild fires may have been responsible for the destruction of large forest areas, resulting in the present-day pattern of sucessional forests in the Amazon region. The present results also show that the fires have been spread more intensely at dry upland areas than at the shoal areas near the igarapés (small rivers), where the vegetation was not so damaged. These results also show that the fires occurred more recently than expected by some authors [1–3] and strengthen some other results obtained at Carajás region [5], 1200 km away, in the south-east direction. These combined results suggest that the fires have regional dimensions and may be associated with climate regional changes and phenomena similar to "El Niño" lasting tens or even hundreds of years [10], contradicting the hypothesis of steady environment of the Amazon forest in the last 10,000 years [11].

Acknowledgements

The Brazilian authors would like to thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for their financial support.

References

[1] F. Soubies, Cah. ORSTOM, sér. Géologie 1 (1979–1980) 133.
[2] J.G. Saldarriaga, D.C. West, Quat. Res. 26 (1986) 53.
[3] R.L. Sanford, J.G. Saldarriaga, K.E. Clark, C. Uhl, R. Herrera, Science 277 (1985) 358.
[4] A. Siffedine, P. Bertrand, M. Fournier, L. Martin, M. Sevany, F. Soubies, K. Suguio, B.J. Turcq, Bulletin Soc. Geolog. France 165 (6) (1994) 613.
[5] R.C. Cordeiro, M.Sc Thesis. Universidade Federal Fluminense, Niterói, Brazil, 1995.
[6] A. Sifeddine, B.J. Turcq, C.V. Ribeiro, A.O. Silva, Verh Int. Verein. Limnol. 26 (1997) 814.
[7] L.C.R. Pessenda, E.P.E. Valencia, R. Aravena, E.C.C. Teles, R. Boulet, The Holocene 8 (1998) 631.
[8] L.C.R. Pessenda, B.M. Gomes, R. Aravena, A.S. Ribeiro, R. Boulet, in: J.C. Wasserman, E.V. Silva Filho, R. Villas

Boas (Eds.), Environmental Geochemistry in the Tropics, Springer, Berlin, 1998.
[9] M.L. Absy, in: G.T. Prane (Ed.), Biological Diversification in the Tropics, Columbia University Press, New York, 1982, p. 67.
[10] L. Martin, M. Fournier, P. Mourguiart, A. Sifeddine, B.J. Turck, M.L. Absy, J.M. Flexor, Quat. Res. 39 (1993) 338.
[11] P.W. Richards, Sci. Am. 229 (1973) 58.