Report

Bruno Turcq, Abdelfettah Sifeddine, Louis Martin, Maria Lucia Absy, Francois Soubies, Kenitiro Suguio and Cecilia Volkmer-Ribeiro

Amazonia Rainforest Fires: A Lacustrine Record of 7000 Years

Although human influence dominates present-day Amazonian rainforest fires, old charcoal fragments, buried in the soils or in lacustrine sediments, confirm that fire has played a major role in the history of Amazonian forests. These fires may have influenced the present-day diversity and structure of the rainforest and if these fire-favorable events of the past reoccur there may be drastic consequences for the future of the Amazonian forests. Detailed studies of Carajás lake sediments permit identification of these past fire events, through microscopic observations of small charcoal fragments. They also permit, through radiocarbon dating, a better definition of their timing and make it possible to relate them to past paleo-environmental and paleoclimatic conditions. The paleodata indicate that fire events were concomitant with short dry climate episodes whose frequency of occurrences has varied during the last 7000 years. These dry events may be related to past climate conditions observed in different regions of tropical South America.

INTRODUCTION

In Amazonia, the presence of charcoal fragments buried in rainforest soils have been reported by several authors during the past 15 years (1–6). Radiocarbon data have been obtained on charcoal fragments collected in the soils, at depths varying between a few centimeters and nearly 1.5 m, in the Alto Rio Negro, within 75 km of San Carlos, Venezuela (1, 2) and in the southeastern part of Brazilian Amazonian forest, along 500 km on the road between Santarem and Cuiaba (3)(Fig.1). The radiocarbon ages indicate that these charcoal fragments date from 6300 to 250 years BP in the San Carlos region, and from 6500 to 3000 years BP in southeastern Amazonia. The presence of charcoal fragments buried over considerable regions and the uneven occurrences, indicate that they cannot be considered as Indian cooking remains (7), like the charcoals encountered in the well-known Terras Pretas (dark soils) of Amazonia. These studies indicate that charcoal fragments are indeed the record of fires affecting the rainforest during the last 7000 years.

Such recent fires have probably conditioned some aspects of the present-day rainforest. Disturbance by fires and the frequency of fire occurrences are fundamental parameters for the comprehension of diversity, structure, and functions of terrestrial ecosystems and to assess the complex relationship between natural and human disturbances (8). For temperate regions, it has been proposed that some disturbances, especially fires, had a profound influence on the survival and regeneration of plant communities. In Amazonia, knowledge of past fires, their regional extent, their timing, and their origin, is important for a better comprehension of present-day forest ecosystems. Present-day Amazonian rainforest fires strongly affect dust dissemination, and represent a significant input of atmospheric CO_2 (9, 10). Consequently, past fires may have contributed significantly to the observed changes in the global environment during the Holocene. The external cause of these extended fires must be identified in order to predict, and eventually, manage (11) the future of the rainforests. Rainforests do not normally burn (12–14) and, with either an anthropogenic or natural origin, the fires could only have propagated over so large area under drier climate conditions. These dry events have occurred under a global climate mode comparable to the present day situation (i.e. completely different from conditions during the glacial stages). Consequently, they may occur again in the future, probably enhanced by the strong concomitant influence of human activities.

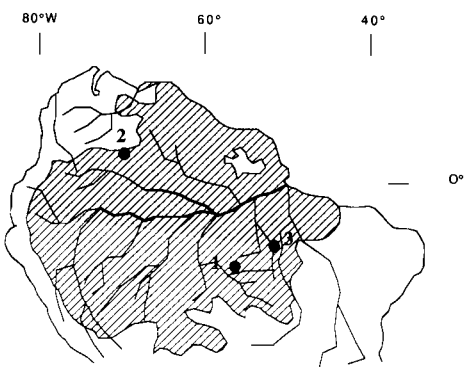

Figure 1. Sites of charcoal occurrences dated by radiocarbon: (1) soils of Eastern Amazonia between Santarem and Cuiaba, Brazil; (2) soils of Alto Rio Negro, near San Carlos, Venezuela; (3) lacustrine sediments of Carajás, Eastern Brazilian Amazonia. The Amazonian rainforest corresponds to hatched area.

STUDY AREA AND METHODS

Serra Sul Dos Carajás (6°30'S, 49°30'W) is a 800-m high plateau covered by a ferralitic crust. Several lakes and bogs occupy small depressions of the plateau surface. Some of them present a few meter-thick sediment, which has been collected using a vibro-coring device. Palynological studies of surficial lacustrine sediments (15) show that the aerial contribution of the rainforest surrounding the plateau is very important. As much as 66% of the pollen input in the lakes comes from trees which are only present in Amazonian forests and totally absent in the local plateau vegetation. The sediment study has been performed through classical sedimentological methods as well as Infra-Red Spectrometry to obtain quantitative mineralogical data (16). Microscopic observations of thin sections from undisturbed sediments impregnated with resin have been used for a detailed observation of sedimentary structures. One core (CSS2) was subjected to palynological studies (15). The core chronology was obtained by radiocarbon dating. The ages are here expressed as conventional ^{14}C years BP.

RESULTS

Palynological studies (15) of a first 6-m long core, CSS2, (Fig. 2) reveal the existence of four periods of forest degradation during the last 60 000 years, marked by low arboreal pollen percentages (related to the total pollen content of the sediment). Sedimentological studies (16) show that these periods correspond to dry climate phases. The first three occurred during Pleistocene glacial times (before 10 000 years BP). They are characterized by an increase of savanna pollen, and by the deposition of clastic layers rich in kaolinite, quartz and siderite, which sometimes form centimetric nodules. Microscopical analyses indicate a structureless (poorly preserved) organic matter in these layers, corresponding to aerobic degradation and, therefore, low lake level. These deposition events are marked, at their base, by sharp contacts. Radiocarbon ages for the upper clastic layer indicate that the sharp contact is due to interruption of sedimentation interpreted as complete drying of the lake (Fig. 2). By contrast, forest development phases are marked by organic-rich deposits (50% of total organic carbon or more) with well-preserved

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organic fragments. The last Pleistocene dry period has been dated between 22 000 and 12 000 yrs BP and therefore corresponds to the Last Glacial Maximum. The two older Pleistocene dry phases certainly also correspond to older marked glacial stages. Glacial stages have been characterized by low temperature values and low levels of atmospheric CO_2 (17, 18). Both parameters, together with the dryness shown in our study, should have influenced the rainforest ecosystem.

The fourth and younger period of forest degradation occurred between 7000 and 4000 yrs BP (Fig. 2). The sediment corresponding with this period in CSS2 core, presents completely different characteristics compared with the earlier episodes of forest degradation: it does not show any marked increase in the percentage of savanna pollen, and shows only a very faint increase of clastic fluxes. This part of the core also corresponds to the highest carbon flux and to the highest concentration of biogenic silica (measured by infrared spectrometry and relative to sediment dry weight). Moreover, the dominant arboreal pollen during that period is from *Piper* which is a low shrub pioneer of the rainforest. *Piper* pollen is 45% of the total pollen content during the period, while it remained under 5% during the other phases of forest degradation and regeneration.

These deposit characteristics clearly show that the last phase of forest degradation suffered paleo-environmental conditions completely different from the three Pleistocene ones. A microscopical study of these sediments reveals that the high total organic carbon fluxes may be related to the deposition of very small charcoal fragments (lower than 20 μm) incorporated in the well-preserved vegetal tissues, dominant in the organic-rich layers. Such a pattern indicates that the bog vegetation itself did not burn and that the micro-charcoal fragments came from external input, most probably aerial, considering their small size. As the ^{13}C values of organic matter (–28‰) show no increase during that period, the origin of charcoals does not seem to be grasses surrounding the lake. The high concentration of biogenic silica is related to the presence of sponge spicules from a single species: *Corvomeyenia thumi*, which is present from 7000 yrs BP until the top of the core, and is characteristic of ephemeral lakes. During the 7000–4000 yrs BP period, the spicules and, especially, their reproductive elements are incompletely developed. This may be due to a short duration of inundation events or to a lack of water and nutrient supply. Both cases correspond to low rainfall episodes.

After 4000 yrs BP the pollen diagram shows a marked decrease in *Piper* and nonarboreal vegetation (Fig. 2). In spite of their lower concentrations, micro-charcoal fragments and sponge spicules are still present in this upper part of the core. During that period the arboreal pollen (more than 80% of the total pollen content) consists principally of higher pioneer elements of the rainforest. These data indicate that fire events still influenced

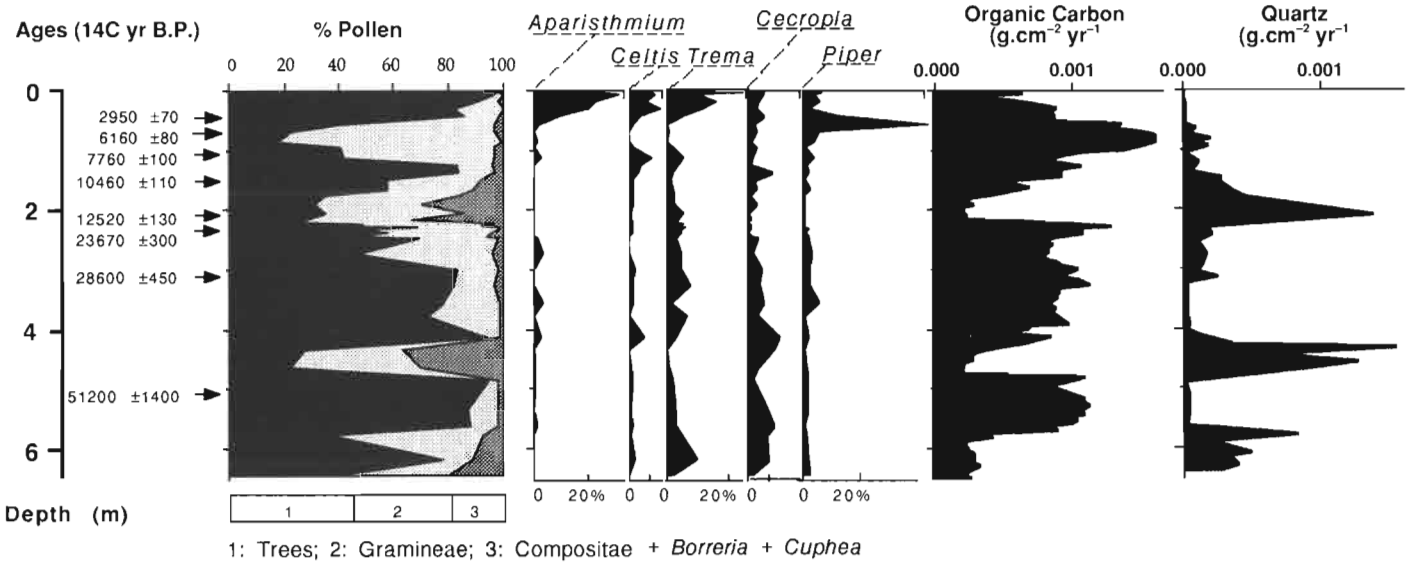
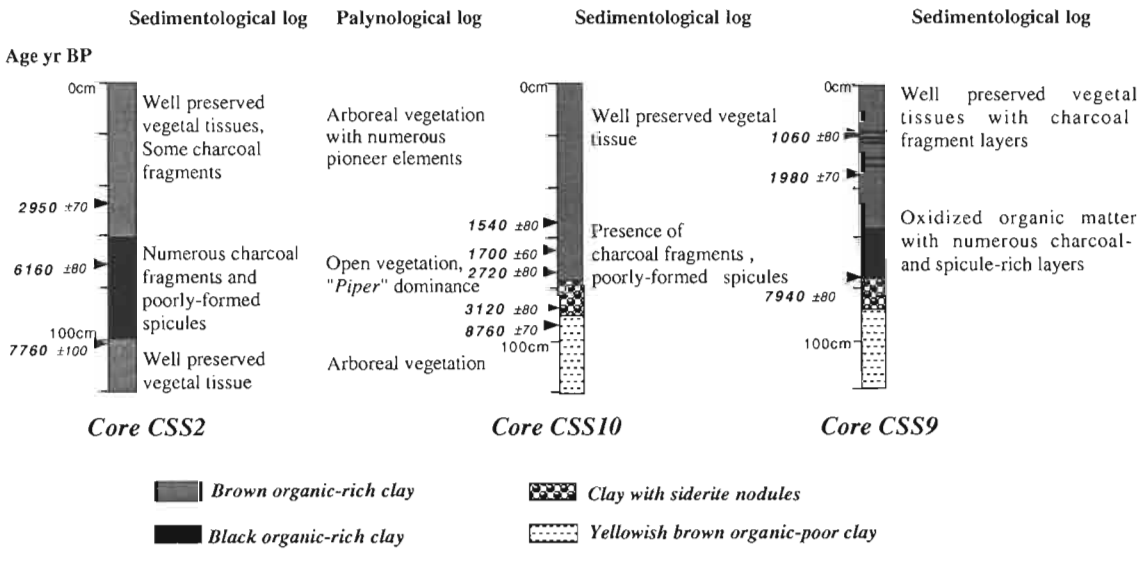


Figure 2. Palynological and sedimentological data from CSS2 core. Pollen percentages are based on total pollen sum. Fluxes of organic carbon and quartz have been calculated from their concentrations in the sediment, sedimentation rate and *in situ* density of the sediment.

Figure 3. Descriptions of the three studied cores, ages, and relevant sedimentological, and palynological observations.



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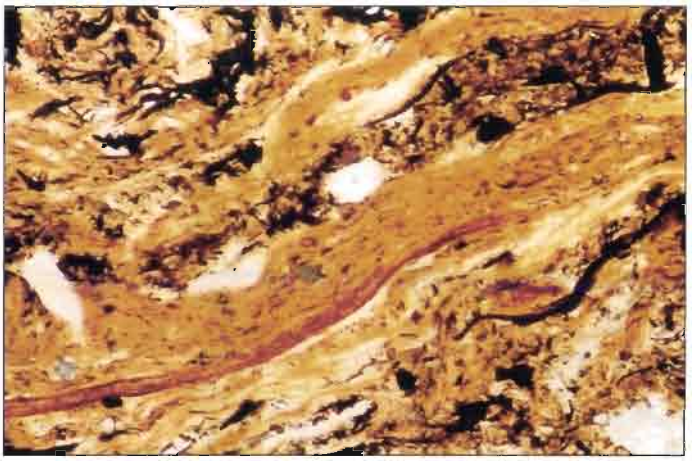
A view of "Serra Sul" in the Carajás region. On the plateau, sustained by a ferralitic crust, the vegetation is mainly steppic. The plateau relief is irregular and lakes developed in the depressions. Amazonian forest is restricted to the slopes, but analysis of present-day pollen sedimentation indicates that rainforest pollen dominates the pollen assemblages in the lake surficial sediments. Photo: L. Martin.

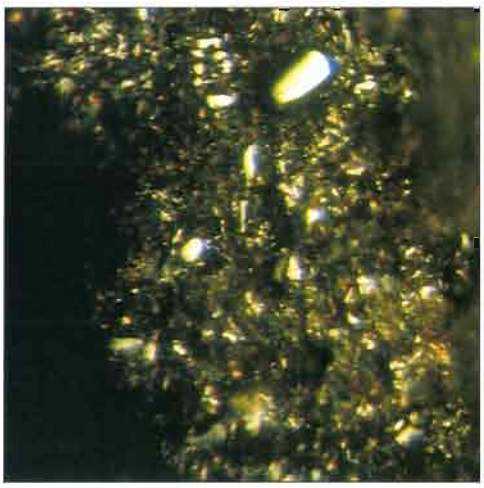


A detailed view of a charcoal layer shows interstratification of charcoals and well-preserved vegetal remains, indicating that charcoal layers were formed by multiple fire events. The photograph height represents 0.6 mm. Photo: A. Sifeddine.

A thin section of resin-impregnated sediment from core CSS9 shows a 1-mm thick charcoal layer (the photograph height represents 9 mm). Internal laminations are well-marked in the charcoal layer. Photo: A. Sifeddine.

Sponge spicules of *Corvomeyenia thumi* species are frequently associated with charcoal layers. This sponge species, when encountered alone, is characteristic of ephemeral lakes. The association between *C. thumi* and charcoal demonstrates that fire events are directly related to dry climate events. The photograph height represents 0.6 mm. Photo: A. Sifeddine.

Sedimentary charcoals have been identified by their high reflectivity under microscope reflected light. Charcoal fragment size is lower than 20 μm, much lower than the other vegetal remains present in the sediment. The small size would indicate that charcoals come from Amazonian forest fires through atmospheric deposition. The photograph height represents 0.22 mm. Photo: A. Sifeddine.



the rainforest ecosystem after 4000 yrs BP. A second core (CSS10) from another lake of the Serra Sul dos Carajas, reveals a high charcoal and spicules content between 2700 and 1500 yrs BP (Fig. 3). In the third core studied (CSS9, Fig. 3), we observed the sediment micro-texture on thin sections of sediment impregnated with resin. This provided better information about sediment texture and depositional patterns of micro-charcoals fragments, and sponge spicules. Between 0 and 3800 yrs BP the sediment is mainly formed by well-preserved vegetal tissues. This homogeneous texture is interrupted by well-individualized millimetric micro-charcoal layers. The thicker layers (around 1 mm) are formed by micrometric charcoal layers separated by thinner layers of sponge spicules. Before 4000 yrs BP, the sediment consists of poorly preserved (oxidized) vegetal tissues, charcoal fragments and sponge spicules. Oxidation turns vegetal tissues opaque and the predominance of such vegetal remains may be due either to a long exposure under aerial conditions (i.e. dryness of the bog or lake), or to burning of the bog itself. In both cases, it indicates occurrences of dry climate events. This is in accordance with CSS2 core data for the same period.

DISCUSSION AND CONCLUSION

Data from the Carajás lakes indicate that, if forest element pollen are always present during the last 7000 yrs, they are poorly represented between 7000 and 4000 yrs BP. Moreover, at that time, the arboreal pollen is dominated by *Piper*. In this region, *Piper* is a low shrub, one of the first pioneers of forest regeneration. Its dominance during almost 3000 yrs appears abnormal and needed special environmental conditions. It seems that the regeneration cycle of the forest has been continuously interrupted by repeated abrupt forest degradation events. The higher sediment content in micro-charcoal during the same period, points to fires as the most obvious explanation for the repetitive interruptions of rainforest regeneration. The sponge spicule characteristics, as well as the repeated fires, are indicators of dry climate-event occurrences during the 7000–4000 yrs BP period. The presence of rainforest elements and the absence of savanna pollen (other than graminea, Fig. 2) indicate that the average climatic conditions were favorable to rainforest development, which was only limited by repeated occurrences of fires and dry climate events.

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After 4000 yrs BP, the charcoal content in the sediment, and therefore the frequency of fire occurrences, is lower. Micro-charcoal layers are still associated with sponge spicules and indicate infrequent dry climate events. During this period the arboreal pollen became dominant, but was composed of taller pioneer elements of the rainforest.

There are a few, unpublished, prehistoric studies for the region. No register of human occupation has been observed on the plateau where we sampled lake deposits, but remains of human occupation do exist on a similar plateau situated 40 km to the north. This occupation seems to begin 6000 years ago, after the major fire occurrences (7500–6000 yrs BP). Detailed studies on presettlement human influence and paleofires, reconstructed from lacustrine sediments in North America (19), reveal that human influence was superimposed on climate fluctuations and only provoked local higher charcoal input. The similarities between the three different lakes we studied point to natural causes for fire occurrences. However, human occupation as well as the presence of a steppic vegetation, may have favored the initiation of fires.

Dry climate events in Amazonia are also indicated in paleohydrologic (20) and anthropologic (7) records for the last few thousands of years. There is evidence of other climate perturbations in South America during the last 7000 years (21). They have provoked littoral drift reversals on the central Brazilian coast (22), falls in Titicaca lake level in Bolivia (23), increases in sand in Sechura desert rivers in northern Peru, and probably, the dry climate events observed in Amazonia. Such a regional pattern is similar to present-day El Niño events, but the paleodata indicates that the past climate anomalies must have had longer durations (tens to hundreds of years) than the present-day El Niño events (7, 21). For this reason they have been denominated "El Niño-like conditions". These conditions probably correspond to long-duration low phases of the Southern Oscillation. El Niño-like conditions were very frequent before 4000–3600 yrs BP, absent or nonrecorded between 4000–3600 and 2800–2500 yrs BP, and have occurred infrequently since 2800–2500 yrs BP.

Such abrupt climate variations which promote not only fire propagation in southeastern Amazonia, but also deep environmental changes in other South American regions—and probably other climate anomalies in the tropics—need deeper investigation with respect to their mechanisms. In particular, the relationship to oceanic circulation needs to be studied since this is likely to be an important element in the prediction of future climate and environmental change in the tropics.

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Bruno Turcq has been professor in the graduate program of environmental geochemistry, Universidade Federal Fluminense, since 1984. He joined ORSTOM (the French Institute of Scientific Research for Development) in 1985, and has dedicated his studies to Brazilian paleoclimates. His address: Departamento de Geoquímica, UFF, Morro do Valonguinho, s/n°, 24020-007, Niterói, RJ, Brazil.
e-mail: geoturc@vm.uff.br

Abdelfettah Sifeddine did his PhD thesis in 1991 on Carajás lacustrine deposits. He has been a researcher at ORSTOM since 1994. His address: Departamento de Geoquímica, UFF, Morro do Valonguinho, s/n°, 24020-007, Niterói,
e-mail: geosife@vm.uff.br

Louis Martin is senior researcher at ORSTOM. He is studying coastal and continental deposits of the Brazilian Quaternary since 1975. His address: PPPG, Instituto de Geociências, UFBA, Rua Caetano Moura 123, 40210-340 Salvador, BA, Brazil.
e-mail: lmartin@pppg.ufba.br

Maria Lucia Absy is a researcher at INPA (Instituto Nacional de Pesquisas Amazônicas) She has documented the largest part of available palynological studies in Brazilian Amazon. Her address: INPA Departamento de Botânica, CP 478, 69011 Manaus, AM, Brazil.
luciabsy@rnp.am.br

François Soubies is pedologist in ORSTOM, and was the first to use radiocarbon dating of soil charcoals in Amazon. His address: Université Paul Sabatier, Laboratoire de Minéralogie, 39 Allée Jules Guesdes, 31400 Toulouse, France.
e-mail: Soubies@orstom.fr

Kenitiro Suguio is sedimentologist, specialist in Brazilian Quaternary. He is a full professor at São Paulo University and a member of the Brazilian Academy of Sciences. His address: Instituto de Geociências, USP, CP 11348, 05422-970 São Paulo, SP, Brazil.

Cecilia Volkmer-Ribeiro, is a zoologist, specialist of South American Porifera. She is senior researcher at the Fundação Zoobotânica do Rio Grande do Sul. Her address: FZR, Rua Dr Salvador França, 1427, 90610-000 Porto Alegre, RS, Brazil.
e-mail: pitoni@pampa.tche.br

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