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Late Pleistocene and Holocene vegetation changes in northeastern Brazil determined from carbon isotopes and charcoal records in soils

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ABSTRACT

Northeastern Brazil represents a strategic area in terms of Quaternary records of environmental changes in South America due to its distinct semi-arid climate in near equatorial latitudes. In this study, carbon isotope and charcoal distribution records in soils are used to characterize vegetation dynamics, forest fires and their relation to climate change since the Late Pleistocene in the States of Ceará, Piauí and Paraíba, Northeastern Brazil. At the Ceará site, the carbon isotope record showed an enrichment trend from −24‰ to −19‰ during the early-mid Holocene, indicating an opening of vegetation and expansion of savanna vegetation (C_4 plants) during this period. A trend toward more depleted $\delta^{13}C$ values (~−32‰) in the late Holocene indicates an expansion of forest vegetation (C_3 plants). A similar trend is observed at the Piauí and Paraíba sites where values of ~−24‰ are associated with open forest vegetation during the late Pleistocene. In the early-mid Holocene, $\delta^{13}C$ values of up to −18.0‰ suggest the expansion of C_4 plants. Based on the carbon isotope data, it is postulated that from ~18,000 cal yr B.P. to ~11,800 cal yr B.P.–~10,000 cal yr B.P. arboreal vegetation was dominant in northeastern Brazil and is associated with humid climates. The savanna expanded from ~10,000 cal yr B.P. to ~4500–3200 cal yr B.P. due to a less humid/drier climatic phase, also supported by the significant presence of fires (charcoal fragments in the soil). From approximately 3200–2000 cal yr B.P. to the present, carbon isotope records suggest forest expansion and a more humid phase. These results form part of a regional pattern since they are in agreement with paleovegetation records obtained in regions of Maranhão, northeastern Brazil and in the Amazon and Rondonia States, northern Brazil.

1. Introduction

Important issues concerning the history of neotropics such as biogeographic patterns and past floristic connections and their relations to Late Quaternary climatic variations have been poorly addressed to date by paleocologists in northeastern Brazil. Nonetheless, there is strong evidence of the Atlantic rainforests having former connections with those of Amazonia (Andrade-Lima, 1982; Prance, 1985). In Northeastern this evidence has been supported by paleovegetation studies based on pollen, molecular and leaf fossil analyses (De Oliveira et al., 1999; Behling et al., 2000; Wang et al., 2004; Ledru et al., 2007).

In addition, paleoenvironmental studies in northeastern Brazil further our knowledge of the dynamics of the Inter Tropical Convergence Zone (ITCZ), an important atmospheric system that with insolation controls tropical climate variations (Martin et al., 1997; Ledru et al., 2002; Cruz Junior et al., 2009). Recently results obtained from speleothems attested contrasted climatic patterns along a north–south and east–west transect through South America, characterized by wet/dry climate in northeastern Brazil and dry/wet climate in southeastern Brazil. This general pattern is also confirmed by pollen analysis (Ledru et al., 2007). However pollen and speleothems show different results of the climatic patterns during the mid Holocene in Northeastern Brazil (Ledru et al., 2006; Cruz Junior et al., 2009) and during the glacial in southeastern Brazil (Cruz et al., 2005; Ledru et al., 2009). A wetter climate is attested by the speleothems while no main change in vegetation composition is recorded in the pollen analysis. A progressive expansion of the modern vegetation was observed due to the progressive increase of insolation values which modulated the latitudinal temperature gradient and the seasonal shifts of the ITCZ (Braconnot et al., 2007). More to the south, a pollen study of river valley deposits in the semiarid region of Bahia (De Oliveira et al., 1999) documented a humid and cold period during the Pleistocene/Holocene transition,

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which became progressively drier during the late Holocene. According to these authors, the presence of a modern day tropical forest with Amazonian and Atlantic Forest taxon is explained by enhanced humidity patterns during the early to mid Holocene. Studies on lake sediments from Lagoa do Caçó, Maranhão State (Ledru et al., 2001, 2002) attest late glacial high moisture rates until the end of the Pleistocene with the Younger Dryas (Ledru et al., 2002, 2006), also inferred from carbon isotopes of soil organic matter in a 80 km vegetation transect, 10 km far from Lagoa do Caçó (Pessenda et al., 2004a). Wetter conditions from ~20,500 cal yr BP to ~19,800 cal yr BP in the Caçó lake region, as shown by a 50% decrease in Deuterium/Hydrogen ratios and a marked increase in H isotopic fractionation of leaf waxes were reported by Jacob et al. (2007). Comparisons with other paleoprecipitation records from South American sites indicate late glacial humid conditions controlled by intensification of the ITCZ, and/or a southward shift of its mean position across the study site. The isotope data show only a small rise in aridity during the Younger Dryas event (13–11.5 ka) and D/H ratios of terrestrial and aquatic compounds show near constant offsets, suggesting stable and relatively humid climate conditions during this period. From the early to mid-Holocene, the Lagoa do Cacó level rose gradually despite the lower moisture availability and a distinct dry period until ~6950 cal yr BP (Sifeddine et al., 2003). Microscopic charcoal fragments found at this site during this period (Ledru et al., 2001) indicate interruption of the humidity by dry phases.

The use of carbon isotopes in studies of soil organic matter (SOM) dynamics has been used in different areas in Brazil to document vegetation changes during the Holocene period (Volkoff and Cerri, 1987; Victoria et al., 1995; Desjardins et al., 1996; Pessenda et al., 1996a,b, 1998a,b, 2001a; Freitas et al., 2001; Gouveia et al., 2002; Pessenda et al., 2004a,b, 2005). However, few studies using this approach have been developed in northeastern Brazil due to difficulties in finding preserved native vegetation areas, which are fundamental to the use of soil carbon isotopes in paleovegetation studies. The rationale behind the use of carbon isotopes in paleovegetation studies is well established.

In this paper, carbon isotope and charcoal records collected northeastern Brazilian soils are used to reconstruct vegetation changes and paleofire history and their relation to climate changes in this region. The soils were collected under natural vegetation in the States of Ceará, Piauí and Paraiba, covering a linear distance of ~900 km. The soil records also provide information on understanding the dynamics of the ITCZ and its seasonal displacement near the Atlantic Ocean and on the Amazon Basin border (Ledru et al., 2002; Sifeddine et al., 2003; Pessenda et al., 2004a), and document paleoenvironmental changes that significantly influenced the South American continent.

2. Study areas

The study sites are located in protected areas under the umbrella of the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) in the northeastern region (Fig. 1, Table 1). The present study was developed at the National Forest of Araripe (FLONA), National Park of Sete Cidades (PARNA) and in the Biological Reservation of Guaribas (REBIO). The distance between these regions is ~500 km (FLONA-REBIO) and ~1400 km (REBIO-PARNA).

The FLONA site is located on the Araripe Plateau at 700–900 m elevation, between the coordinates 7°11′42″–7°28′38″S and 39°13′28″–39°36′33″W in the state of Ceará. Its forest vegetation is maintained by frequent humid winds and consequently by orographic rainfall, which according to Austregésilo Filho et al. (2001) is the main factor controlling the occurrence of these highland forest islands within the semi-arid realm of the Brazilian caatinga.

The soil in the study area is classified as Oxisol according to American Soil Taxonomy (USDA classification). The present climate is tropical, warm and humid and is defined as Aw' type according to Köppen classification. Mean annual precipitation values are ~1100 mm, and are concentrated in the rainy season (January to June) with maximum values occurring in March and April. The lowest precipitation values occur in October. The mean annual temperature is ~24 °C, ranging from 22.1 °C in the coldest month (July) to 25.8 °C in the warmest month (November) (Brasil, 1981).

Modern vegetation at FLONA consists of tropical rainforest, Cerrado (woody savanna), and "Carrasco", composed of trees of ~10 to 25 m in height with an arboreal density of ~1800 trees/ha. The latter is a closed, tall-shrubby, xerophilous vegetation community occurring on quartz sand soils between 700 and 900 m on Araripe and Ibiapaba plateaus in the Brazilian semi-arid domain (Araújo et al., 1999). The more important forest species are *Ocotea duckei*, *Parkia platycephala*, *Byrsonima sericea* and *Bowdichia virgilioides*. The Cerrado is characterized by herbaceous C_4 taxa such as *Aristida setifolia,*

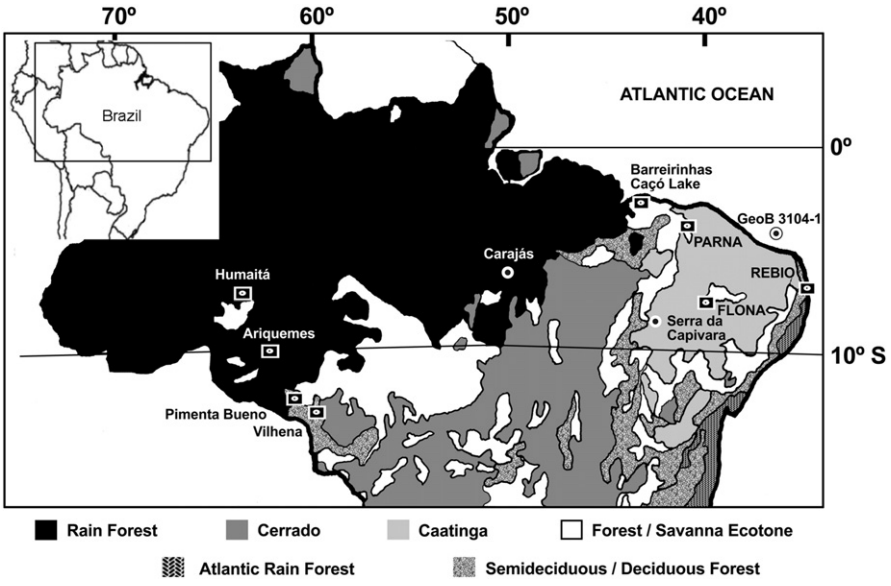

Fig. 1. Map of Brazil showing the present vegetation distribution in the Northeastern Brazil, the study sites (FLONA, REBIO, PARNA), previous study sites and analyzed materials (■ soil organic matter; ● lake sediment). Buried charcoal fragments were dated at Serra da Capivara.