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Holocene vegetation and fire dynamics in central-eastern Brazil: Molecular records from the Pau de Fruta peatland

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ABSTRACT

Tropical climate dynamics play a major role in the global climate system. Precipitation patterns in the Serra do Espinhaço Meridional (Minas Gerais, Brazil) are influenced by both the South Atlantic Convergence Zone (SACZ) and the Inter Tropical Convergence Zone (ITCZ). This makes the area important for the interpretation of climate dynamics. The composition of the Holocene Pau de Fruta peat deposit was analysed using pyrolysis–gas chromatography–mass spectrometry (Py–GC–MS). Molecular records agreed well with $\delta^{13}C$ and $\delta^{15}N$ stable isotopes, C content and mineral content, and pollen records. Changes in peatland plant species composition and fire occurrence indicated several wet and dry periods for the Pau de Fruta peatland during the Holocene; from the beginning of the Holocene to 7400 cal yr BP (phase I; dry and cold), from 7400 to 4200 cal yr BP (phase II; wet and warm), from 4200 to 1000 cal yr BP (phase III; dry and warm), from 1000 to 400 cal yrBP (phase IV; wet and warm) and from 400 cal yr BP to the present (V). The hydrological shifts showed a chronology comparable with that described in other palaeoclimatic studies for central-eastern Brazil, indicating that local conditions agree with regional ones. Analytical Py of the peat deposit provided a multi-proxy record via the identification of specific markers for both peatland plants (vegetation) and charred material (fire), whereas the general chemistry provided information on the degree of decomposition of the organic matter. Molecular chemistry of the peat core sampled at high resolution provided insight into peatland C dynamics, which is important for the interpretation of C sequestration in tropical peatlands. Molecular aspects accurately reflected local environmental change. The general agreement of Py data with pollen and inorganic chemistry supports the use of the molecular approach, because it provides local proxy indicators for peatlands, avoiding a mixture of local and regional signals.

1. Introduction

Tropical climate dynamics play a major role in the global climate system. Precipitation patterns in the Serra do Espinhaço Meridional (Minas Gerais, Brazil) are affected by the Inter Tropical Convergence Zone (ITCZ) and the South Atlantic Convergence Zone (SACZ; Stríkis et al., 2011; Prado et al., 2012). This makes the area important for the interpretation of climate dynamics, though palaeoclimatic knowledge from northeastern and central-eastern Brazil is largely non-existent (Jacob et al., 2006; Chiessi et al., 2013) and is based mainly on pollen and speleothems (Stríkis et al., 2011). The Serra do Espinhaço Meridional harbours some well preserved peatlands, the formation and general characteristics of which have been thoroughly studied (Silva et al., 2008, 2009a,b, 2013a,b; Campos et al., 2010, 2011, 2012; Horák et al., 2011). Recent geochemical and pollen data from a peatland 35 km from the Pau de Fruta peatland (Horák-Terra, 2014) indicated similar wet/dry cycles to those recorded from northeastern Brazil, where dry/wet cycles oppose those of other south American data. Although pollen and inorganic chemistry provide information on vegetation history and regional events, respectively, such proxies are influenced by both local and regional factors, making their environmental interpretation intricate (Markgraf and Huber, 2010; Biester et al., 2012).

The composition of organic matter (OM) provides information about local environmental conditions. Peatland vegetation composition (Fraga et al., 2001), degree of decomposition (Chambers

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et al., 2012) and frequency of wildfires (Markgraf and Huber, 2010) are directly related to climatic conditions. This information is stored in the peat, because the OM composition is determined by its source material and the transformation during decomposition and wildfires. One method for characterising complex mixtures of OM is pyrolysis–gas chromatography–mass spectrometry (Py–GC–MS; Almendros et al., 1998). It provides detailed information on the structure of biopolymers and has been successfully applied to relate the chemical signature of peat deposits to past vegetation composition, the degree of decomposition and fire occurrence (Boon et al., 1986; Huang et al., 1998; Kuder and Kruge, 1998; Buurman et al., 2006; Schellekens et al., 2009, 2011, 2012; McClymont et al., 2011; Biester et al., 2014). The purpose of this study was to reconstruct local environmental conditions for the Pau de Fruta peatland, using depth records of molecular parameters that reflect vegetation composition, degree of decomposition and fire occurrence. The findings were compared with records of other proxies obtained from the same peatland.

In addition to its application in climate reconstruction, Py–GC–MS can be used to obtain information on processes that control C sequestration, which is a crucial element in the global C cycle (Clymo et al., 1998). Because most research on peatlands concentrates on records from boreal and temperate zones (Chambers et al., 2012), insight into tropical peatlands remains scant. Studies that apply a geochemical approach to tropical peatlands use only a limited number of samples and lack comparison with other proxies (Calvert et al., 1991; Dehmer, 1993). As a result, detailed insight into OM dynamics in tropical peatlands is largely non-existent. Therefore, the second objective was to study the relationship between peat composition and climatic fluctuation in a core from a tropical peatland ecosystem.

2. Material and methods

2.1. Study area

The Serra do Espinhaço Meridional region contains a large area of peatlands (12,800 ha). They are located between 1200 and 2000 m above sea level (a.s.l.) and are developed on flat depressions in quartzite rocks (Abreu, 1982; Campos et al., 2010). Because of the low nutrient content of quartzite rocks, the peat can be considered to be oligotrophic. The Pau de Fruta peatland covers 82 ha and is at 1350 m a.s.l. (18°15′27.08″S43°40′3.64″W; Fig. 1). The mire is surrounded by slopes on three sides and contains an outlet on one side. Water continuously flows from this outlet (Campos et al., 2010, 2012). Average annual precipitation is 1500 mm (Nimer, 1977). The monsoon period is from December to February, while rainfall almost ceases from May to October. The seasonality of the rainfall is influenced by the position of the SACZ and ITCZ.

The vegetation on mineral soil in the area is characterised by a Cerrado Biome (savannah) and, apart from the climate, is predominantly determined by the lithology. The quartzitic soils are resistant to weathering and have a low water holding capacity (Santos et al., 2011). The vegetation of the peatland is dominated by graminoids and herbaceous species, but also contains patches of trees, regionally called “Capões”. The word does not refer to a specific botanical composition but indicates a group of trees within an open landscape, as illustrated in Fig. 1B. This characteristic vegetation (Capões) is typical for the peatlands in the area and is also found in other wetlands of Brazil (Pantanal and Amazonia). Contrary to boreal and temperate peatlands, where woody species occur on the drier spots, the Capões are located in relatively wet places with running water (Prance and Schaller, 1982; Munhoz and Felfili, 2008; Santos et al., 2011). The peatlands in the area have a relatively high biodiversity compared with boreal and temperate peatlands and, among others, include species from the Poaceae, Cyperaceae, Araceae, Eriocaulaceae, Xiridaceae, Myrsinaceae, Burseraceae and Melastomaceae families; the Poaceae include both C_3 and C_4 types (Meguro et al., 1996; Silva et al., 2013a).

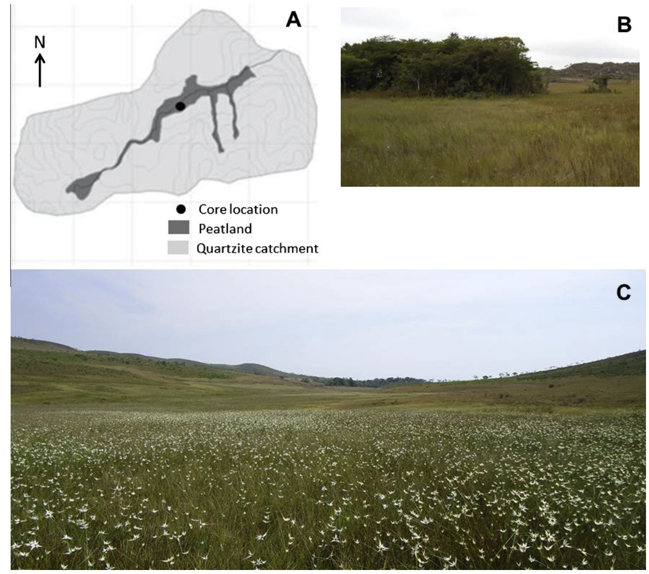

Fig. 1. Map of Pau de Fruta peatland, after Campos et al. (2010) (A); typical Capões within the peatland (B) and peatland (C) in the Serra do Espinhaço Meridional. Photographs: José Ricardo Campos.

2.2. Sampling

The core had been analysed for pollen, stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) and elemental composition. These data were used to provide support for interpretation of the OM chemistry. A selection of samples had been dated using ^{14}C, and enabled chronological interpretation of the data (Horák et al., 2011). Sampling was done in 2008 using a vibra corer and a 428 cm core was recovered. After determination of the stratigraphy, described with exact depth values (cm), the core was divided into slices of 10 cm. Air dried samples were ball milled for homogenisation and used without further pre-treatment for all analyses, except pollen. Pollen analysis was performed on untreated 1 cm samples at intervals of 20 cm. Thus, pollen results reflect only the upper 1 cm of each 20 cm interval, while other analyses reflect a mixture of 10 cm of peat material.

The presence of mineral matter may influence the abundance and type of pyrolysis products (Alcañiz et al., 1989; Miltner and Zech, 1997). The mineral matter in the Pau de Fruta peatland is composed almost completely of quartz sand, clay minerals being absent (Campos et al., 2010; Horák et al., 2011). Therefore, even though the ash content varied between 21% and 99%, the effect of minerals is not relevant for the studied peat record and bulk samples were used for pyrolysis. The data quality was further evidenced by the absence of correlation between groups of pyrolysis products and Si, Al and Fe ($r^2 < 0.2$). Good agreement between depth records of molecular plant markers (with a very low abundance) and the ecological preferences of the various species provided support that pyrolysate composition was not influenced by the abundance or composition of minerals.

2.3. Py–GC–MS

Py–GC–MS was performed with a Pt filament Pyroprobe 5000 (Chemical Data Systems, Oxford, USA) coupled to a 6890N gas