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Sedimentology and Palynostratigraphy of a Pliocene-Pleistocene (Piacenzian to Gelasian) deposit in the lower Negro River: Implications for the establishment of large rivers in Central Amazonia

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ABSTRACT

The Amazonas fluvial system originates in the Andes and runs ca. 6700 km to the Atlantic Ocean, having as the main affluent the Negro River (second largest in water volume). The Amazonas transcontinental system has been dated to the late Miocene, but the timing of origin and evolutionary processes of its tributaries are still poorly understood. Negro River alluvial deposits have been dated to the middle to late Pleistocene. Recently, we studied a number of boreholes drilled for the building of a bridge at the lower course of the Negro River. A thin (centimetric) sedimentary deposit was found, laterally continuous for about 1800 m, unconformably overlaying middle Miocene strata and unconformably overlain by younger Quaternary deposits. This deposit consists predominantly of brownish-gray sandstones cemented by siderite and with subordinate mudstone and conglomerate beds. Palynological, granulometric, textural and mineralogical data suggest that the initial Negro River aggradation took place in the deep incised valley under anoxic conditions and subsequently along the floodplain, with efficient transport of mixed origin particles (Andean and Amazonic). Angiosperm leaves, wood and pollen are indicative of a tropical continental palaeoenvironment. A well preserved palynoflora that includes *Alnipollenites verus*, *Grimsdalea magnaclavata* and *Paleosantalaceaepites cingulatus* suggests a late Pliocene to early Pleistocene (Piacenzian to Gelasian) age for this unit, which was an age yet unrecorded in the Amazon Basin. These results indicate that by the late Pliocene-early Pleistocene, large scale river activity was occurring in Central Amazonia linking this region with the Andean headwaters, and therefore incompatible with Central Amazonia barriers like the Purus arch.

1. Introduction

The Amazon drainage system is the largest on Earth and supports an outstanding fauna and flora diversity (Silva et al., 2005; Latrubesse, 2008). The geological history of this system has been intensely debated in the literature, with a focus on the timing of transcontinentality (Figueiredo et al., 2009; Shephard et al., 2010; Latrubesse et al., 2010; Gorini et al., 2013; Horbe

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et al., 2013; Sacek, 2014; Rossetti et al., 2015; Caputo and Soares, 2016; Hoorn et al., 2017). Compelling evidence shows that Andean sediments started reaching the mouth of the Amazon in the late Miocene (~9 Ma, million years) (Hoorn et al., 2017), and by the late Pliocene to early Quaternary a modern-like geography was attained (Figueiredo et al., 2009; Latrubesse et al., 2010; Hoorn et al., 2010, 2017; Caputo and Soares, 2016). The origins of individual Amazon River tributaries, however, is less understood but of crucial importance - these rivers archive information on sedimentation styles, channel migration and ultimately on paleoenvironments and paleoclimate (e.g., Latrubesse and Franzinelli, 2005; Rossetti et al., 2014, 2015; Cremon et al., 2016; Sant'Anna et al., 2017), which in turn are pivotal for understanding the distribution of environments and organisms living in them across the continental scale Amazon biome. One key fact, for instance, is how major rivers in Amazonia act as barriers for animal groups and trigger diversification (Ayres and Clutton-Brock, 1992; Ribas et al., 2009, 2012; d'Horta et al., 2013; Ferreira et al., 2017). Therefore, knowledge on age and processes of river channels can have a direct link to biodiversity.

In Amazonia, dating fluvial events has been a challenge owing to limited rock exposure and preservation (due to prevailing incision and erosion), as well as the low range of the radiocarbon method and poor fossil preservation. Recently, optically stimulated luminescence (OSL) dating has been successfully applied and extended some chronologies. Maximum ages from ~240,000 years have been reported for fluvial sands in the main courses of the Solimões-Amazonas and Negro Rivers (Soares et al., 2010; Fiore et al., 2014; Gonçalves et al., 2016; Sant'Anna et al., 2017) near Manaus in Central Amazonia. Similarly, ages varying from ~220,000 to 250,000 years were found in southwestern and northern Amazonian drainages, respectively (Rossetti et al., 2015; Cremon et al., 2016). Altogether, these chronologies point to an active fluvial regime in vast areas of the Amazon basin associated with deposition of the Içá Formation and diverse fluvial terraces during the Middle and Upper Pleistocene.

The Negro River, the main affluent of the Amazon drainage, with the second highest water volume, has been dated to the Middle Pleniglacial (65–25 ka) in its upper reach (Latrubesse and Franzinelli, 2005) and to ~45–65 ka in its lowers course (Soares et al., 2010; Sant'Anna et al., 2017) at the confluence between the Solimões-Amazons and Negro Rivers. The Upper Pleistocene evolution of this river is marked by the combination of climatic and tectonic forcing that led to the current anabranching morphology and the formation of sizable fluvial archipelagos (Latrubesse and Franzinelli, 2002, 2005; Franzinelli and Igreja, 2002; Almeida-Filho and Miranda, 2007). Here, we take advantage of a recently built bridge on the Negro River's lower course to study drilled sediments of a paleochannel. We describe, date and characterize these sediments within a regional stratigraphical and biostratigraphical framework, thus aiming to reconstruct past fluvial activity.

1.1. Geological context

The stratigraphy of post-Paleozoic strata in the Amazonas Basin (Fig. 1) distinguishes records of the Cretaceous (Jazida da Fazendinha Formation), Cenozoic (Alter do Chão and Solimões Formations) and Pleistocene (Içá Formation) (Daemon, 1975; Dino et al., 1999; Caputo, 2011; Caputo and Soares, 2016). In central Amazonia, a significant extent of the rock cover is composed of the Alter do Chão Formation red beds, which have been dated to the Eocene-middle Miocene (Caputo, 2011; Soares et al., 2010, 2015, 2016; Dino et al., 2012; Caputo and Soares, 2016), and where most rivers and alluvial deposits are unconformably installed. Mapping of the upper unit of the Alter do Chão Formation (informally termed Novo Remanso) shows its extension in Central Amazonia for ~300 km from Manacapuru to east of Itacoatiara (Dino et al., 2012; Soares et al., 2015) (Fig. 1).

The Içá Formation covers thousands of kilometers in the Solimões Basin (Fig. 1) and rests unconformably on the Miocene-Pliocene Solimões Formation (Maia et al., 1977; Nogueira et al., 2013). It is composed primarily of sandstone beds and subordinated siltstone, mudstone and conglomerate strata, and was deposited in the middle to Upper Pleistocene (Rossetti et al., 2015). In part, the age of this formation can be correlated with the ages of the Amazon River terraces, obtained by radiocarbon and luminescence methods (see Introduction).

2. Materials and methods

We studied drilled sediments obtained from the Negro River Bridge construction that took place between 2007 and 2011. Sample recovery was achieved with a rotary drill and the unrecovered parts with percussion drill. Basic lithological information was generated from 15 mixed bore holes with depths around 70 m in the central part of the Negro River's channel, spread along 1800 m and oriented in a NE-SW direction (Fig. 1). Analyses to generate sedimentological, stratigraphic, palynological and mineralogical data were performed on available samples recovered from three drill holes (Figs. 1 and 2). Samples analyzed here are from cores that were described focusing on lithology, granulometry, sedimentary structures, fossil content and geological contact between units. Absence of geological information in the percussion drilling parts of the sections partially hampered the elaboration of complete stratigraphic columns.

The stratigraphic placement of the studied unit as well as its regional correlation was based on contact relations and petrographic (thin sections and mineral identification), palynological and mineralogical (x-ray diffraction) data. However, the fragmented aspect of the drilled unit hampered a precise measurement of thickness.

Samples were disaggregated using porcelain mortars and pistils and then washed and separated into very fine (0.062–0.125 mm) and fine (0.125–0.250 mm) sand intervals. The heavy mineral recovery was done with heavy liquid separation (bromoform, 2.89 g/cm^3) and grains were mounted on a slide using Canada balsam. Sedimentological and petrographic analyses were done at the Sedimentology and Microscopy laboratories of DEGEO-UFAM (Federal University of Amazonas). Thin sections and x-ray diffractions were performed at the Thin Section Laboratory of the Geological Survey of Brazil (CPRM-Manaus). For the x-ray diffraction we used a diffractometer X'PERT PRO MPD -PW 3040/60, Panalytical.

Pollen samples were processed following conventional methods (Wood et al., 1996) that consist of digestion of ca. 10 g of sediment in hydrochloridric acid for 12 h (for carbonate extraction), then digestion in hydrofluoric acid for at least 24 h (for silicate extraction). Neutralization with water and decanting were used after each acid digestion step. The dissolved mineral portion was later sieved in 250 μm and 10 μm meshes for elimination of coarser portions. The fraction <10 μm was then disaggregated in an ultrasonic bath and the less dense organic