



Late Miocene sedimentary environments in south-western Amazonia (Solimões Formation; Brazil)

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ABSTRACT

In Miocene times a vast wetland existed in Western Amazonia. Whereas the general development of this amazing ecosystem is well established, many questions remain open on sedimentary environments, stratigraphical correlations as well as its palaeogeographical configuration. Several outcrops located in a barely studied region around Eirunepé (SW Amazonas state, Brazil) were investigated to obtain basic sedimentological data. The observed deposits belong to the upper part of the Solimões Formation and are biostratigraphically dated to the Late Miocene. Vertically as well as laterally highly variable fine-grained clastic successions were recorded. Based on the lithofacies assemblages, these sediments represent fluvial deposits, possibly of an anastomosing river system. Sand bodies formed within active channels and dominant overbank fines are described (levees, crevasse splays/channels/deltas, abandoned channels, backswamps, floodplain paleosols). Lacustrine environments are restricted to local floodplain ponds/lakes. The mollusc and ostracod content as well as very light $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values, measured on ostracod valves, refer to exclusively freshwater conditions. Based on palaeontological and geological results the existence of a long-lived lake ("Lake Pebas") or any influx of marine waters can be excluded for that region during the Late Miocene.

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1. Introduction

The geological and (palaeo-)biological evolution of lowland Amazonia during Neogene and Quaternary times remains fascinating since the early days of Natural Sciences (for summaries of research history see e.g., Loczy, 1963 and Wesselingh, 2008). Many, but partly highly controversial models have been introduced to explain its historical development (for recent compilations see e.g., Lundberg et al., 1998; Campbell et al., 2006; Wesselingh and Salo, 2006; Rossetti and Mann de Toledo, 2007; Haffer, 2008; Hoorn and Wesselingh, 2010; Hoorn et al., 2010; Latrubesse et al., 2010).

Generally, it is widely accepted that around the onset of the Miocene (~23 Ma) a mega-wetland ("Pebas system", also called "Lake Pebas") developed in western Amazonia due to the subsiding Subandean foreland (e.g., Hoorn, 1994, 2006; Wesselingh et al.,

2002; Wesselingh and Salo, 2006; Shephard et al., 2010). Short-lived marine incursions or even a transcontinental seaway from the Caribbean Sea through the Venezuelan/Columbian Llanos Basin southwards to the Argentinean Paraná Basin are proposed (e.g., Räsänen et al., 1995; Gingras et al., 2002; Hovikoski et al., 2007, 2010; Uba et al., 2009) but heavily disputed (e.g., Campbell et al., 2006; Cozzuol, 2006; Westaway, 2006; Latrubesse et al., 2007, 2010; compare also discussions in Vonhof et al., 2003; Hoorn and Vonhof, 2006; Wesselingh, 2006). In the Late Miocene this mega-wetland disintegrated due to enhanced uplift of the Northern/Central Andes. The drainage pattern of northern South America started to reverse completely to today's easterly course and the modern "Amazon system" became established during the Early Pliocene (Hoorn, 2006; Figueiredo et al., 2009; Hoorn et al., 2010; Latrubesse et al., 2010).

Beside the vast size of Amazonia and the still fragmentary regional coverage with field surveys, there are considerable inconsistencies in palaeoenvironmental reconstructions and, in particular, in the chronology and correlation of scattered outcrops. Wesselingh (2008, p. 5) stated: "The lack of geological data has led

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to the emergence of many grand theories about the origin of present-day Amazon system and its highly diversity, often based on dubious interpretations of the little data available".

The present paper aims to contribute basic sedimentological data from a barely studied region (Eirunepé, ~2.000 km SW Manaus; Fig. 1a), which is supposed to be placed at the south-eastern margin of the "Pebas system" (Wesselingh and Ramos, 2010). We demonstrate that there is no evidence for a long-lived lake (sensu Gorthner, 1994) or any marine influx. Conversely, we document a well-structured, aggrading fluvial system of Late Miocene age, which is in agreement with the sedimentation model and chronology proposed by Latrubesse et al. (2007, 2010).

2. Working area and geological background

The studied sections are located along the Juruá and Tarauacá River, NE respectively SE of the city Eirunepé (state of Amazonia, western Brazil; ~245 km S of Benjamin Constant; Fig. 1a and b).

Delineations and subdivisions of basins in western Amazonia diverge notably and several authors attribute the region of Eirunepé to the Solimões Basin (Eirunepé Subbasin; e.g., Caputo, 1991; Roddaz et al., 2005; Ramos, 2006; Wesselingh and Salo, 2006; Wesselingh et al., 2006a; Barata and Caputo, 2007). However, based on subsurface information, obtained by extensive hydrocarbon and coal exploration campaigns during the 1970's, this region is situated west of a basement high (Miura, 1972; "Iquitos arch"; corresponds to the "Carauari arch" of Caputo, 1991) on the eastern margin of the Acre Basin (e.g., Del' Arco et al., 1977; Maia et al., 1977; Latrubesse et al., 2010; Fig. 1a and b).

Beside Quaternary deposits (terraces, alluvium), the scattered outcrops along river banks expose sediments of the upper parts of the Solimões Formation (Del' Arco et al., 1977; Maia et al., 1977; Paz et al., in press). The Solimões Fm. comprises more than 1000 m thick, largely pelitic–sandy alternations with lignitic intercalations and covers a huge part of western Amazonia (Fig. 1a). Uncertainties in its definition, its stratigraphical and geographical extent as well as its depositional environments basically reflect the ongoing

debate about Amazonia's history through Neogene times. Comprehensive reviews of the Solimões Fm. provide for example: Del' Arco et al. (1977), Hoorn (1993, 1994), Latrubesse et al. (1997, 2010) and Silva-Caminha et al. (2010).

3. Field and laboratory work

The sections were vertically logged by visual inspection of the lithofacies (including colour, grain size, bedding planes, sedimentary structures, macrofossil content). For lithofacies coding the scheme of Miall (1996) was used: capital letters = dominant grain size (G, gravel; S, sand; F, fine sand–clay) followed by a lowercase letter = sedimentary structures and/or biogenic features (c, clast-supported; m, massive/faint lamination; h, horizontal bedding/lamination; t and p, trough and planar cross bedding; r, ripple bedding; s, scour fill; l, lamination; r, rooted; C, coal; P, pedogenic overprint). Additionally the outcrops were mapped laterally as far as possible. Due to poor outcrop conditions an application of the architectural element concept (Miall, 1996) was only loosely possible.

For micropalaeontological investigations bulk samples (~1–2 kg) were taken from all outcrops. 500 g of dried sediment (40 °C, 24 h) were washed by using diluted hydrogen superoxide for disintegration through standard sieves (H₂O₂ : H₂O = 1 : 5; 63/125/250/500 µm). Wet sieve residuals were washed with ethanol prior to drying (40 °C, 24 h). The residuals ≥250 µm were picked out completely. An in-depth taxonomic examination of the obtained microfossils (including the sieve fractions <250 µm) will be subject of further studies.

For preliminary stable isotope analyses (δ¹⁸O, δ¹³C; 18 samples) two or three ostracod valves (~40–60 µg; *Cyprideis* spp.) from earlier sampling campaigns were used (collected by M.I.R). For analyses a Thermo-Finnigan Kiel II automated reaction system and a Thermo-Finnigan Delta Plus isotope-ratio mass spectrometer were used (University of Graz; standard deviation = 0.1‰ relative to NBS-19; results in per mille relative to VPDB). More detailed investigations are in preparation (M. Fonseca/Belém, M. Caporaletti/Graz).

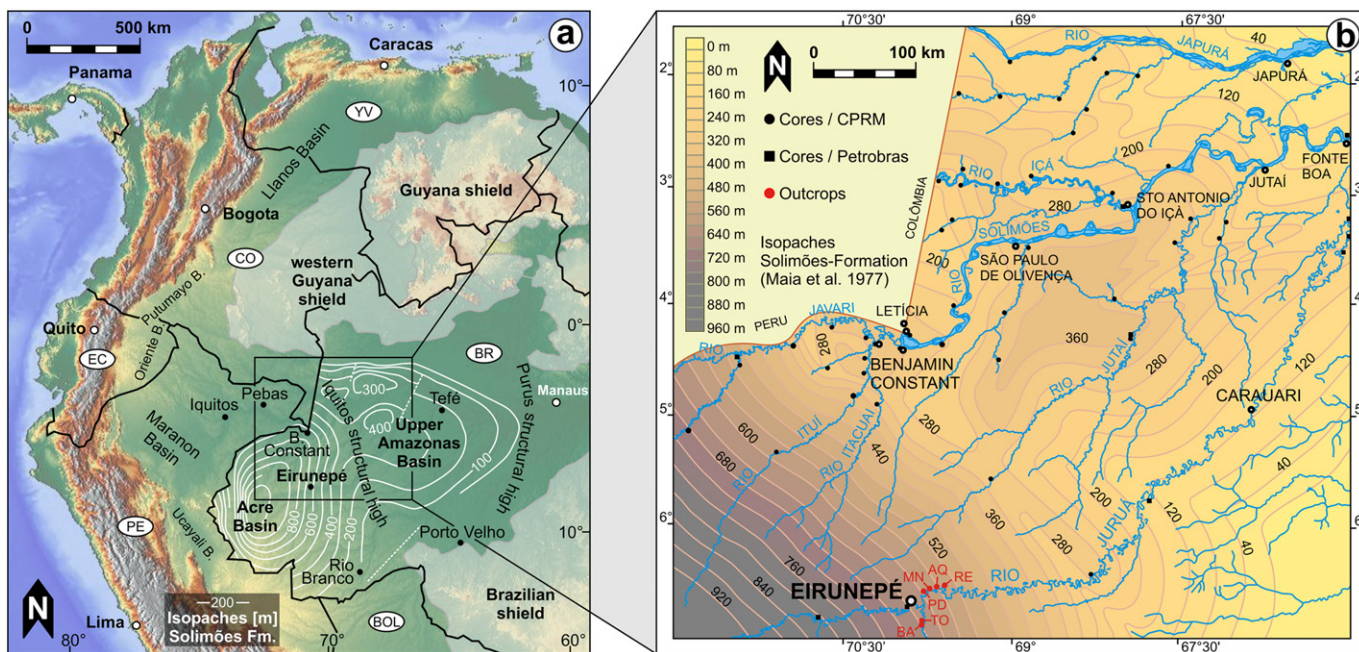


Fig. 1. Location of the study area around Eirunepé (SW Amazonia). (a) Delineation of the Acre and Upper Amazonas Basin (isopaches refer to the thickness of the Solimões Formation; after Latrubesse et al., 2010). (b) Isopaches of the Solimões Fm., position of exploration wells (after Maia et al., 1977) and location of the investigated outcrops (AQ, Aquidabã; BA, Barro Branco; MN, Morada Nova; PD, Pau D'Alho; RE, Remanso; TO, Torre da Lua).

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