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A 2700 cal yr BP extreme flood event revealed by sediment accumulation in Amazon floodplains

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ABSTRACT

Climatic conditions are one of the most important factors affecting hydrological processes in fluvial systems. Higher discharges are responsible for higher erosion, greater transport, and also higher deposition. Consequently, sediment accumulation in Amazonia floodplain river-connected lakes can be directly related to hydrological patterns of the Amazon River mainstream. In this context, we analyzed five sediment cores taken in two floodplain systems situated in the lower Amazon River, to investigate sediment accumulation patterns during the Holocene. Our records show abrupt fluctuations in sedimentation rates in lakes that can reach more than 2 cm/yr during some periods. We find that in all cores, sediment stratigraphy is characterized by packages of sediments of uniform age, which are typically 10–80 cm thick and present a variegated color. The ^{14}C age of the upper package is about 2700 cal yr BP. During this abrupt event, sediment accumulation rates in floodplain lakes can be at least 200 times higher than those of "normal" periods. This sedimentation event is interpreted as being the consequence of one or several successive extreme floods. The 2700 cal yr BP event has been also observed in other sites in South America and other regions in the world, although different impacts can be observed in each system. This event probably corresponds to a conjunction of favorable conditions for extreme Amazon discharge associated with the Middle to Late Holocene increase of austral summer insolation and shifts of the Intertropical Convergence Zone (ITCZ) from northern to southern positions. In this context, a marked negative peak in solar irradiance at 2700 cal yrs BP seems to have provoked cooling on the continents and a southward shift of the ITCZ associated with a probable reduction in the Atlantic Meridian Overturning Circulation.

1. Introduction

Along its course from the Andes of Peru to the Atlantic Ocean, the Amazon River and its main tributaries are lined by extensive floodplain-connected lakes that periodically oscillate between terrestrial and aquatic phases, with sediments constantly exchanging between river channels and floodplains. The main sedimentary balances in the Amazon Basin, from the upstream to the downstream, allow identification of the zones of transfer, erosion and deposition (Mertes et al., 1996; Dunne et al., 1998; Aalto et al., 2003; Maurice-Bourgoin et al., 2007; Baby et al., 2009; Gautier et al., 2010). All these authors highlight the importance of these floodplain lakes to sediment accumulation. Sediment storage can occur at different timescales (from hundreds to thousands of years) (Dunne et al., 1998; Behling and Costa, 2000; Moreira-Turcq et al., 2004), and it is strongly influenced by the hydrodynamics of the Amazon River (Irion et al., 2006, 2010; Moreira et al., 2012, 2013).

Mertes et al. (1996) estimated that 80% of the material being transported by the Amazon passes through the floodplain lake systems. Most of these suspended sediments in the Amazon River are derived from the tributaries draining the Andes, where high rainfall and steep slopes contribute to the release of stored sediment (Meade et al., 1985). When the river rises, water enters through channels from the downstream end of the islands into the lakes and transports fine-grained suspended loads into the lake basin (Irion et al., 2010). At high water, when most of the floodplain is inundated, relatively coarse sediment is transported into the lakes by the high river flow velocities. When the water level drops and the water drains slowly through the downstream channels, the fine-grained suspended matter, still present in the lake water, is deposited (Irion et al., 2010). Sedimentation rates in the Amazonian floodplains can vary considerably, both temporally and spatially, and are directly related to the geographic location, proximity to the mainstream, channel morphology and duration of connection between floodplain lakes and the river (Aalto et al., 2003; Moreira-Turcq et al., 2004; Gautier et al., 2009).

Gautier et al. (2010) proposed that the construction of the floodplain lakes in the Beni River (Bolivian Amazonia) is the result of two different sedimentary processes that can occur at different times. The first one

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occurs during the "normal" hydrological years when the suspended matter is transferred by advection from the river towards lakes. These sediments are fine-grained and relatively small in quantity, but the sedimentation is made in a regular way. The second process takes place during very large floods. In this case, a great part of the sediments can arrive by overflowing of the main channel on banks (overbank deposition), which can transport coarser material and consequently the sedimentation rates can be very high. Aalto et al. (2003) related sedimentation in the floodplains to climatic changes, more specifically to "La Niña events", which in Amazonia are responsible for heavy rain, and they show that sedimentation is irregular and very dependent on the intensity of the floods. Finally, all these studies show that sediment deposition in Amazonia floodplain lakes is not constant over time and can be influenced strongly by hydrological factors dependent on climate conditions.

The Amazon seasonal flooding is related to the successive floods of the northern tributaries, principally the Branco and Negro rivers, that reflect the heavy precipitation in these regions from May to July and of the southern tributaries, largely the Madeira River, that have heavy rainfall from December to March. Downstream, the annual and regular flood of the Amazon River occurs from April to July (Molinier et al., 1997). Droughts in Amazon discharge have been related to Sea Surface Temperature (SST) anomalies in the tropical Atlantic and to El Niño Southern Oscillation (ENSO) events (Espinoza et al., 2011). On the other hand, high discharge events also occur during heavy La Niña rains in the north and northeast of the Amazon region (Ronchail et al., 2002; Espinoza et al., 2009) and are also influenced by enhancement of South American Monsoon circulation and southward shifts of the Intertropical Convergence Zone (ITCZ) and associated heavy precipitation (Marengo et al., 2011).

Our objective was to study the histories of floodplain sedimentation in two Amazon lakes during the late Holocene, to interpret them in terms of paleohydrology, and to relate them to the climate changes reported for that period.

2. Regional setting

The Amazon Basin (Fig. 1) extends between 5°N and 20°S and from the Andes to the Atlantic Ocean, covering approximately 6,500,000 km^2. Wet and dry seasons in the Amazon basin are induced by the South American monsoon system and fluctuations in the position of the ITCZ (Garcia and Kayano, 2011). Precipitation ranges from <2000 mm yr^{-1} in the extreme northeastern and southern parts of the basin and to 7000 mm yr^{-1} on the east side of the Andes (Salati et al., 1979). Interannual rainfall variability in the Amazon basin partially depends on ENSO events (Ronchail et al., 2002; Espinoza et al., 2009). In particular, below normal rainfall is recorded during El Niño events, whereas excess rainfall occurs during La Niña. The seasonal cycle for sediment passing Obidos indicates a maximum in February that precedes the maximum water discharge by several months and a minimum in October that slightly precedes the minimum water discharge (Richey et al., 1986; Filizola and Guyot, 2009).

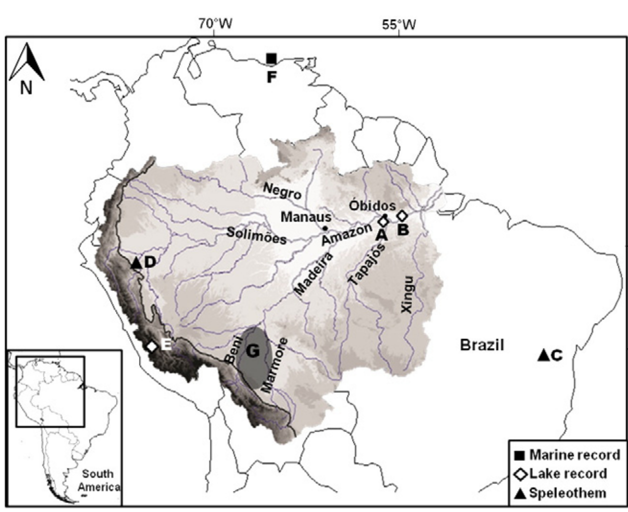

Fig. 1. The Amazon Basin topography from SRTM with the location of the studied sites (A and B) and the records discussed in the text: (A) Curuai floodplain; (B) Maracá and Comprido Lakes; (C) Iraquara City, Bahia State (Novello et al. (2012)); (D) Cueva del Tigre Perdido (van Breukelen et al., 2008); (E) Pumacocha Lake (Bird et al., 2011); (F) Ocean Drilling Program (ODP) Site 1002, Cariaco Basin (Haug et al., 2001); (G) Floodplain lakes studied by Aalto et al., 2003.

The Amazon is the world's largest river in terms of water discharge (18% of the total fresh water entering the ocean) and also the world's largest contributor of fluvial sediments, with an estimated sediment discharge of about 850×10^6 t yr^{-1} (Filizola and Guyot, 2009). Approximately 44% of the area within the Amazon basin is subject to flooding by the Amazon River and its tributaries (Guyot et al., 2007).

Along its course from the Andean piedmont of Peru to the Atlantic Ocean, the fluvial landscape features are dominated by sandbars, floodplains, and older terraces that have been deposited by the river or its tributaries. The Amazon River and its tributaries are lined along their courses by floodplain lakes that total about 6500 in number and cover an area of around 300–500,000 km^2 (5 to 8% of the total surface area of the Amazon Basin). Other estimates suggest that Amazonian wetlands (mostly floodplains) comprise up to 20% (Melack and Hess, 2010). The whole floodplain system is a huge flat plain. The floodplain lakes are built due to the fluctuations in the level of the rivers, which causes the formation of bars and accumulation of sediment carried by the rivers and its tributaries. This accumulation can occur at different time scales (centennial to millennial). At the present time, the two floodplain systems studied in this work are characterized by an intense and permanent river influence.

2.1. Curuai floodplain

The Curuai floodplain is located between 1°50′S–02°15′S and 55°00′W–56°05′W on the southern margin of the Amazon River, 850 km from the mouth of the estuary (Fig. 1). It covers approximately 3500 km^2 (Martinez and Le Toan, 2007) and represents approximately 13% of the total flooded area of the Amazon River between Manaus and Óbidos (Maurice-Bourgoin et al., 2007).

Water and sediment exchanges between this floodplain and the Amazon River are controlled by the mainstream hydrology, local precipitation regimes, and geomorphological characteristics of the channels and lakes. The annual sediment storage in the Curuai floodplain is estimated to be approximately 710×10^3 t/yr, representing between 41% and 53% of the annual flux of sediments entering the floodplain from the mainstream (Maurice-Bourgoin et al., 2007). This positive sediment balance confirms that this Amazonian floodplain acts as a sediment trap, as observed by Moreira-Turcq et al. (2004).

This floodplain comprises more than 30 interconnected lakes, all permanently connected to the Amazon mainstream by small channels. The lakes studied in this work are Salé Lake, Poção Lake and Grande Lake. The flooded area ranged between 575 km^2 and 2090 km^2 as water levels varied between 3.03 m and 9.61 m (the maximum and minimum levels recorded in Curuai since 1997) (Bonnet et al., 2008). The maximum floodable area delimited by the boundary between "Terra Firme" (i.e. unflooded upland) and the Amazon is 2430 km^2, corresponding to a flood stage water level in Curuai of approximately 11.5 m. The local watershed formed by the creeks coming from the "Terra Firme" has a total area of 1370 km^2 and is mostly covered by evergreen forest. Each year, the storage phase of the floodplain starts between November and January and lasts until May–June. The draining phase starts in July and lasts until November; the largest exported volume occurs from August until October (Bonnet et al., 2008).