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Dynamics of floodplain lakes in the Upper Amazon Basin during the late Holocene

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A B S T R A C T

To better understand the impact of channel migration processes and climate change on the depositional dynamics of floodplain lakes of the upper Amazon Basin during the late Holocene, we collected three sediment cores from floodplain lakes of the Ucayali River and one from the Marañón River. The cores were dated with ^{14}C, radiographed and described. Bulk density, grain size analysis and total organic carbon (TOC) were determined. The results show that sedimentation in Ucayali floodplain lakes was marked by variations during the late Holocene, with periods of intense hydrodynamic energy and abrupt accumulations, a gap in the record between about 2870 and 690 cal yr BP, and periods of more lacustrine conditions. These changes in sedimentation were associated with variations in the river's influence related to changes in its meandering course (2870 cal yr BP) and a period of severe flooding between 3550 and 3000 cal yr BP. Lake Lagarto on the Marañón River floodplain exhibits a different sedimentary environment of low hydrodynamics with palm trees and macrophytes. Apparently, the lake has not experienced intense migration processes during the last 600 cal yr BP (base of the core). Nevertheless, the river sediment flux to the lake was important from 600 to 500 cal yr BP, although it decreased thereafter until the present. This decrease in the mineral accumulation rate indicates a decrease in river discharge since 500 cal yr BP, which coincides with precipitation records from the central Andes. In the upper part of the three Ucayali floodplain cores, a 30- to 250-cm-thick layer of reworked sediments has been deposited since 1950 AD (post-bomb). In Lake Carmen, this layer is associated with invasion of the lake by the levee of a migrating meander of the Ucayali. In Lakes Hubos and La Moringa, however, the river is still far away and the deposition must be interpreted as the result of extreme flooding. The beginning of the Ucayali meander migration is dated back to 2000 AD, suggesting that these extreme floods could be very recent and linked to hydrologic extremes registered instrumentally in the Amazon Basin.

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1. Introduction

The main source of sediment in the Amazon River and its major tributaries is Andean erosion (Filizola and Guyot, 2009; Filizola et al., 2011; Gibbs, 1967; Martinez et al., 2009; Meade et al., 1979). Most of the rivers originating in the Andes Mountains present a high-suspended load (80%) and low bed load (20%) (Meade et al., 1985). During transport from the Andes to the Atlantic Ocean, sediments are exposed to many processes: sedimentation, temporary storage, resuspension and reworking (Dunne et al., 1998; Moreira-Turcq et al., 2014; Santini et al., 2014). It indicates that this transport through lowland Amazonia involves sediment exchanges between the channel and the floodplain. These exchanges occur through bank erosion, bar deposition, and overbank sedimentation in floodplain (Irion et al., 2006; Moreira-Turcq et al., 2014). Sediment dynamics are complex, and floodplain deposits have been reworked and incorporated into Amazonian streams. The estimated rates of recycling are less than 5000 yr in the case of the modern floodplain of the downstream Óbidos in lower Amazon Basin and 2000 cal yr BP upstream (Mertes et al., 1996).

The lowland Amazon Basin shows a relatively immobile channel, unlike the strongly active migration processes and sedimentary dynamics in the upper Amazon (Quintana, 2015). Floodplains in the upper Amazon Basin are impacted by channel migrations that can be triggered by flood events (Jerolmack and Mohrig, 2007), sediment loads (Constantine et al., 2014) or drainage network segmentation induced by tectonic activity (Costa et al., 2001). Past fluvial dynamics are not well documented in this region. In general, channel lateral migration is related to Holocene neotectonics, which suggests that the shifting of rivers may be caused by either tilting of the basin surface or subsidence of blocks in the basin basement (Dumont, 1996; Dumont and Fournier, 1994; Franzinelli and Igreja, 2002; Latrubesse and Franzinelli, 2002; Räsänen et al., 1990). However, hydrological changes are also important, Constantine et al. (2014) suggested that rivers with high sediment loads experience annual migration rates greater than those of rivers with lower sediment loads. Meander cut-off occurred more frequently along rivers with higher sediment loads, and the authors concluded that the imposed sediment loads influenced the changes in fluvial processes in the lower Amazon Basin. Nevertheless, Quintana (2015) points out the importance of temporal and spatial scales to study fluvial dynamics. Finally, all these studies show that sediment deposition in Amazonia floodplain lakes is not constant over time and can be influenced strongly by several factors. Understanding how paleoclimatic changes and geomorphological processes can affect sedimentation in the Amazonian floodplain lakes remains a challenge.

The main purpose of this work is to understand and determine the main processes responsible for lacustrine deposition in floodplain lakes of the upper Amazon Basin during the late Holocene. For this, was collected four sedimentary cores in floodplain lakes from the Ucayali and Marañon meandering rivers, which present different characteristics in terms of sediment load, sinuosity and water flux.

2. Material and methods

2.1. Study area

The Amazon River drains the largest basin of the planet, with an estimated area of 6.1×10^6 km^2 (Goulding et al., 2003) and is formed at the confluence of the Ucayali and Marañón Rivers in Peruvian Amazonia (Fig. 1A). The Ucayali River drains the southern part of the Peruvian Andean Cordillera and flows into the Marañón River, draining 360,000 km^2, with a mean annual discharge of approximately 11,200 m^3·s^{-1}. The Marañón River drains 350,000 km^2 from the northern and central parts of the Peruvian Andean Cordillera to its confluence with the Ucayali, with a mean annual discharge of 16,200 m^3·s^{-1} (Espinoza-Villar et al., 2012).

The suspended sediment load varies according to the season. The annual average concentration of suspended sediment is 395 mg·L^{-1} at the Requena station (Ucayali River) and 173 mg·L^{-1} at the San Regis station (Marañón River) (Armijos et al., 2013). The width of the Ucayali River varies from 500 m to 1250 m. The average sinuosity is 1.94, the belt meandering current is 30 km wide and is characterized by multiple abandoned channels (Dumont, 1996). The width of the Marañón River varies from 1000 to 2500 m, with numerous islands in the straight sections. The average sinuosity is 1.33. The Marañón's flow is 14% greater than that of the Ucayali River. Average annual rainfall between 1946 and 1994 was of about 3080 mm·yr^{-1} (Marengo et al., 1998). Precipitation is most intense between January and May. The hydrological cycle is very similar in the Marañón and Ucayali rivers, with flood peaks occurring between March and May, and low waters between August and October.

The study area is in Peruvian Amazonia, in the department of Loreto between 5°00'S–74°40'W and 4°00'S–73°20'W (Fig. 1B). This study analysed three lakes in the Ucayali River floodplain: Lakes Hubos and La Moringa (Fig. 1C1), Lake Carmen (Fig. 1C2), and one lake in the Marañón River floodplain, Lake Lagarto (Fig. 1C3), which is located 200 km from the confluence with the Ucayali River.

2.2. Sampling and analyses

Four cores were collected in the upper Amazon Basin (Fig. 1). The CAR2 (4°35'23"S and 73°28'.45"W) and HUB1 (4°30'29.19"S and 73°23'.40"W) cores were collected in Lakes Carmen and Hubos using a "vibro-core." The MOR1 (4°28'48.61"S and 73°24'11.04"W) and LAG1 (4°31'04.81"S and 74°34'55.15"W) cores were collected manually in Lakes La Moringa and Lagarto, respectively. All cores were collected using aluminium tubes 7.5 cm in diameter. The CAR2, HUB1, MOR1 and LAG1 cores (measuring 600, 140, 120 and 98 cm, respectively) were opened, described and analysed with SCOPIX X-ray equipment at the EPOC ("Environnements et paléoenvi-