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LATE HOLOCENE PALEOENVIRONMENTAL CHANGES IN NORTHEAST BRAZIL RECORDED BY LACUSTRINE SEDIMENTS OF LAKE BOQUEIRÃO.

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Lake Boqueirão is located at 5°S latitude, on the Brazilian Atlantic coast, a region where the climate is directly influenced by the Intertropical Convergence Zone (ITCZ) displacements. A short (1m) core "Boqc0701" was collected at 7.5m water depth based on a seismic survey. Granulometry, Total Organic Carbon, Organic matter Rock Eval (Hydrogen Index (HI), Oxygen Index (OI)) allowed us discriminating five sedimentary intervals through the last 3000 cal yrs BP. Phase E (3000 to 2050 cal yr BP) presents the largest Granulometry, TOC, HI and OI fluctuations of the entire core. The most probable cause of these variations is a great instability of the lake level during this period. Phase D (2050 to 1830 cal yr BP) is marked by an increase in sedimentation rate and a higher contribution of a well preserved OM, of algal origin, that this interpreted as a higher and more stable lake level. During phase C (1830 to 1550 cal yrs BP), low HI and high OI indicate the input of more oxidized, degraded and detrital OM, reflecting a lower lake level. In phase B (1550 to 1470 cal yr BP) OM quality and quantity (HI and TOC) indicates an algal contribution. During phase A the high stability of Rock Eval proxies contrasts with variations of TOC and Granulometry. These changes in lake level can be compared with other tropical South America high resolution records. It seems that there is a correspondence between phases of low ENSO, cool North Atlantic Ocean and Boqueirão wet phases. A prolonged dryness occurred in Lake Boqueirão since 570 cal yrs BP, till the last decades. This phase corresponds to the Little Ice Age characterized by a cooler North Atlantic Ocean (Mann et al., 2009). These data indicate that the teleconnection pattern between tropical Atlantic, ENSO and Northeast Brazil rainfalls has changed in the past 3000 years.

1. INTRODUCTION

Northeast Brazil represents a strategic area in terms of Quaternary records of environmental changes in South America due to its distinct semi-arid climate in near equatorial latitudes. Paleoclimate studies showed that the Northeastern part of Brazil is influenced by variations in insolation and is sensitive to abrupt climate change during the late glacial (Cheng et al., 2009; Cruz et al., 2009). However, more recent climate variability of this region, especially during the Late Holocene, is still poorly studied (e.g. Mann et al., 2009). In an attempt to fill this lack of information, we studied lacustrine sediments of Lake Boqueirão which is located at 5°S latitude, on the Brazilian Atlantic coast and is directly influenced by the intertropical convergence zone (ITCZ) displacements.

2. STUDY SITE

Lake Boqueirão is located in Northeastern Brazil (State of Rio Grande do Norte) about 8 km from the Atlantic coast (5° 14' 57.1"S, 35° 32' 42.5"W, Fig. 1a). Catchment area occupies a small basin, approximately 250 km^2 with poor runoff. The surrounding landscape is composed by Cenozoic clastic consolidated sediments from Barreiras formation. The creation of lake occurred by Pleistocene beaches ridges damming a small river. The local present-day climate is tropical semi-humid with pronounced seasonality links to seasonal changes of the ITCZ. Precipitation occurs during the rainy season, from November to May (800 $mm.yr^{-1}$, approximately) and the mean annual temperature is 27 °C. The maximum water depth is 10 m during the wet season (austral summer) and 9 m during the dry season (austral winter).

3. RESULTS

The seismic profiles the Lake Boqueirão deposits showed no evidence of neotectonic perturbation or discordance . Two depositional zones can be recognized, one in the center and one near the lake margin. In the center, the seismic profile of the sampling area indicates a 4-m thick clear band. The 1m long Boqc0701 core was taken in the center of the lake. Boqc0701 sediment is homogeneous dark organic clay that shows no lithological variations. The radiocarbon ages showed that the sedimentation was continuous from 3000 to 570 Cal yrs BP (Fig.1c). ^{210}Pb analysis performed on the first eighteen centimetres confirmed that the top of the core is very recent, thus evidencing a sedimentation hiatus since 570 BP until the last decades.

The paleoenvironmental and paleohydrological changes that affected Lake Boqueirão during the Late Holocene can be examined in the light of five phases evidenced by the analysis of core Boqc0701.

- Phase E (3000 to 2050 cal yr BP): rapid switches of dry and wet events.

Phase E presents the largest Granulometry, TOC, HI and OI fluctuations recorded along the entire core. The most probable cause of these variations is a great instability of the lake level during this period. High HI and low OI values indicate the presence of well-preserved

OM During the events of low lake level, the main source of OM supply to the lake is the drainage basin.

- Phase D (2050 to 1830 cal yrs BP): characterized by a high water column.

Phase D begins and ends with peaks of sedimentation rate and granulometry. High HI and TOC values together with low OI indicate a higher contribution of a well preserved OM of probable algal origin. All these parameters correspond to a higher lake level.

- Phase C (1830 to 1550 cal yrs BP): lowering of the water column.

High sand content, low TOC, low HI and high OI support the input of more oxidized OM, more degraded and more detrital, reflecting a lower lake level.

- Phase B (1550 to 1470 cal yr BP): Rise of the water column and development of macrophytes communities.

Phase B begins with a sedimentation rate and sand content peak. Geochemical and petrographical OM characteristics were similar to Phase D. Quality and quantity of OM (HI and TOC) increase corroborating a more algal contribution.

- Phase A (1470 to 570 cal yr BP): deep lacustrine environment.

During most of this phase, sedimentation rate remains slow except at its end. HI, OI and TOC are very stable with a slight increasing trend towards the top. The high stability of organic proxies during this phase may be due to a persistent deep environment where OM fluctuations, which where due to changes in the proportion of marginal vegetation contribution during the preceding phases, are strongly buffered. Contrastingly, granulometry points to changes during this phase with a progressive fining-up that may correspond to the water highering.

The phase ended by a sedimentation hiatus which was probably due to a drying episode of the lake. This dry phase extended until the latest decades as it is testified by people living in the region. The modern deep phase characterized by low sand content and high HI last only for a few decades.

4. CONCLUSIONS FOR REGIONAL PALEOCLIMATE

The Boqc0701 core begins by a period of high variability of the proxies, certainly due to a high variability of the lake level, between 3000 and 2050 yrs BP. It coincides with the period of high variability of Titanium concentration in Cariaco basin (Haug et al., 2001). Ti content in Cariaco Basin sediment is a proxy for precipitation in the northern part of South America. In this region precipitations occur in boreal summer and are linked to a northern position of ITCZ. Therefore, Cariaco record registers the position – or the intensity – of ITCZ during boreal summer. The long term trend of this position is a shift toward the South during the Holocene (Haug et al., 2001). The high variability of Ti contents between 3800 and 2300 yrs cal BP is interpreted as an increase in ENSO variability. Indeed, during El Niño events the warmer East Pacific waters displace ITCZ boreal position to the South (Fedorov & Philander, 2000). On the other hand, El Niño also provokes and intensification of atmospheric

subsidence and a decrease of precipitation over Northeast Brazil. Another record of past El Niño events has been proposed by Moy et al. (2002) based on the reconstruction of intense rainfall events in the Ecuadorian lake Pallcacocha. It indicates a frequent occurrence of El Niño events between 3500 and 2600 cal yrs BP. It seems that the period of high variability in Lake Boqueirão ended later than in the two other records but uncertainty in these levels is in the order of 200-300 yrs (Fig. 1).

In Lake Boqueirão two phases of high lake level (D and B) are recorded during the 2050-1830 and 1550-1470 cal yrs BP intervals. In the Pallcacocha records these are periods of few El Niño occurrences which would be in agreement with a wetter Northeast Brazil. Nothing special appears on the Cariaco record during these periods. In Lake Titicaca (Baker et al, 2005) these two periods are also marked by lake level high stands. Baker et al. (2005) observed that lake level variations at a centennial to millennial scale in Lake Titicaca are correlated to Bond events. These authors hypothesised that during Bond events the colder temperature of the Northern hemisphere due to the decrease of Atlantic Meridional Overturning Circulation (AMOC) reduced the interhemispheric temperature gradient and displaced the ITCZ to the South driving an increase of precipitations at Lake Titicaca. Indeed Atlantic variability is today a greater forcing on Northeast Brazil precipitation than El Niño (Hastenrath, et al. 2006). Again the ^{14}C uncertainties, for all these records, do not allow discriminating between ENSO and Atlantic ITCZ as the main driver of the observed climate fluctuation in Northeast Brazil. Both mechanisms may have influence the precipitation/evaporation budget in the region. The fact that Cariaco record does not evidence any change at that time would also mean that Northern and Southern positions of ITCZ could present independent variations in the past.

The sedimentation ended abruptly at 570 cal yrs BP. It is due to a drying of the lake which corresponds to the beginning of the Little Ice Age, LIA (Mann et al., 2009). During this period, the North Atlantic Sea Surface Temperature anomaly (Mann et al., 2009) became negative and remained negative till the 20^{th} century driving a negative anomaly of North Atlantic Oscillation (Trouet et al., 2009; Mann et al., 2009). This period matches the dry period of Lake Boqueirão although a cold North Atlantic should have bring the ITCZ to the South and should have entailed more precipitation in Boqueirão region. Cariaco record indicates a lowering of precipitations during LIA interpreted as a southward shift of the ITCZ (Haug et al., 2001). It seems again that boreal and austral positions of the ITCZ are not moving similarly in that phase. A decrease of precipitations in the northern and southern tropics of South America during LIA could correspond to an intensification of El Niño anomaly. It would be on the same line of Trouet et al. (2009) that describe the Medieval Warm Period (MCA) as a permanent La Ninã. Nonetheless, Pallcacocha record shows an intense El Niño activity during MCA and, to a lower degree, during LIA. A decrease in precipitations in Cariaco and Boqueirão would indicate that LIA was a phase of low ITCZ activity in the eastern tropical Atlantic.

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