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PALEOENVIRONMENTAL RECORD FROM LAKE SAN LORENZO, MONETBELLO, CHIAPAS, MEXICO

Registro paleoambiental del lago San Lorenzo, lagunas de Montebello, Chiapas, México

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Key words: human impact, paleolimnology, tropical lakes, eutrophication

ABSTRACT

Lake San Lorenzo is one of the lakes at the NW karstic plain of the "Parque Nacional Lagunas de Montebello", Chiapas, Mexico, that currently have eutrophic, turbid waters. To understand the recent history of this lake, multi-elemental contents determined by X-ray fluorescence analysis, organic matter and carbonate contents -determined by loss on ignition-, C_{org}/N ratios and diatom analyses from a 41 cm-long sedimentary sequence, were performed. The chronology of the sequence was established by one ^{14}C date from the basal sediments, which allowed establishing that the studied record began in 1956. These new data are consistent with previously published analysis of a profile from the nearby Lake Balamtetik, that could not be dated by ^{14}C, therefore this work provides a better chronological resolution of events. The diatom community along the Lake San Lorenzo sequence was dominated by high nutrient tolerant species, which allows inferring that the lake was already turbid and eutrophic since 1956. Erosion indicators (titanium and magnetic susceptibility) allowed identifying two episodes of basin-wide erosion associated with long distance sediment transport to the lake (very likely through the "Río Grande de Comitán") the first episode from 1970 to 1985 and the second one from 1990 to 2000.

Palabras clave: impacto humano, paleolimnología, lagos tropicales, eutrofización

RESUMEN

El lago San Lorenzo es uno de los lagos de planicie en la zona NW del Parque Nacional Lagunas de Montebello, Chiapas, México, que actualmente tienen aguas turbias y con elevado contenido de nutrientes. Para reconstruir su historia reciente se usaron análisis multi-elemental por fluorescencia de rayos-X, susceptibilidad magnética, contenidos de materia orgánica y carbonatos, obtenidos por pérdida de peso por ignición, relación C_{org}/N y contenido de diatomeas en un perfil sedimentario de 41 cm de longitud. Para el control cronológico se realizó una datación por ^{14}C en los sedimentos basales, lo que permitió establecer que la secuencia estudiada inicia en el año 1956. Estos nuevos datos son congruentes con los previamente publicados para un perfil sedimentario del lago Balamtetik que no fue posible datar por ^{14}C, por lo tanto, esta nueva secuencia permite mejorar la cronología de los eventos registrados. Las diatomeas a lo largo del perfil del lago San Lorenzo fueron dominadas por especies tolerantes a condiciones de aguas turbias y elevadas concentraciones de nutrientes, lo que indica que el lago ya era turbio y eutrófico desde 1956. Los indicadores de erosión como susceptibilidad magnética y titanio indican que hubo dos periodos de elevada erosión y transporte de sedimento al lago (muy posiblemente a través del Río Grande de Comitán), el primero alrededor de 1970 a 1985 y el segundo aproximadamente entre 1990 a 2000.

INTRODUCTION

The Montebello lakes (ML), in the state of Chiapas, southern Mexico, are a popular tourist destination, mostly because they have very clear waters with multiple tones of blue. However, in recent decades some of these lakes have changed and nowadays, their waters are turbid. To evaluate this process of environmental change a research team from the Institutes of Geophysics and Geology from the National University of Mexico (UNAM), recovered sedimentary profiles from several lakes to undertake paleolimnological studies. Previously published results from one of the ML, Lake Balamtetik, showed repeated pulses of anthropogenic disruption during the last ~70 years (Caballero et al. 2020), however the chronology of the sediment sequence from this lake was poor, as neither ^{210}Pb or ^{14}C age models could be established and dating relayed only on ^{137}Cs profiles. In this paper we present geochemistry and diatoms results from the sedimentary sequence of another of the ML, Lake San Lorenzo, where a ^{14}C and ^{137}Cs based chronology was developed giving a better time line of the anthropogenic disruption events in the region.

METHODS

Study area

The ML are located in southern Mexico, in the state of Chiapas, near the border with Guatemala (**Fig. 1a**), and most of them are part of the protected area "Parque Nacional Lagunas de Montebello". The ML are in a karstic region, where the outcropping rocks are partially or totally dolomitized Cretaceous limestones (Quezada-Muñetón 1987). The climate in the region ranges from temperate sub-humid to the NW to temperate humid to the SE (CFE 2012), with annual average temperatures of ~17ºC, precipitation concentrated between June and October, with mean annual precipitation ranging from ~1180 to ~2500 mm/yr (data from weather stations 7231-Tziscao and 7374-La Esperanza; SMN 2019). The ML can be divided in two main areas, the lower altitude NW karstic plain, and the higher altitude SE hills (Durán Calderón et al. 2014, Mora-Palomino et al. 2016). The vegetation in the area is highly altered, mostly in the NW karstic plain where agriculture is extended. Vegetation was dominated by *Pinus-Quercus-Liquidambar* and montane forests but currently it is very fragmented, and the montane forests have nearly disappeared as intense deforestation has transformed the landscape during the last decades (March and Flamenco 1996, CONAP 2007).

Lake San Lorenzo (16º09' N, 91º46´ W, 1460 m above sea level) is part of a sequence of lakes on the NW karstic plain that are interconnected by a system of channels. The first is lake Balamtetik (**Fig. 1b**), where a previous paleolimnological study was undertaken (Caballero et al. 2020). This lake receives the discharge of the "Río Grande de Comitán" (RGC), a river that runs along a semi endorheic basin of 810 km^2. Many of the NW plain lakes are currently turbid and eutrophic (Vera-Franco et al. 2015) while the SE hill lakes, which are not superficially connected, have mostly clear, oligotrophic waters. San Lorenzo is a turbid, eutrophic to hypertrophic lake, and in July 2013 it had a Secchi disk visibility of 0.5 m and chlorophyll a concentration of 31.7 mg/m^3. The lake has an elongated shape (**Fig. 1**), with an area of 181 ha, a maximum depth of 67 m and an average depth of 11.8 m (Alcocer et al. 2016).

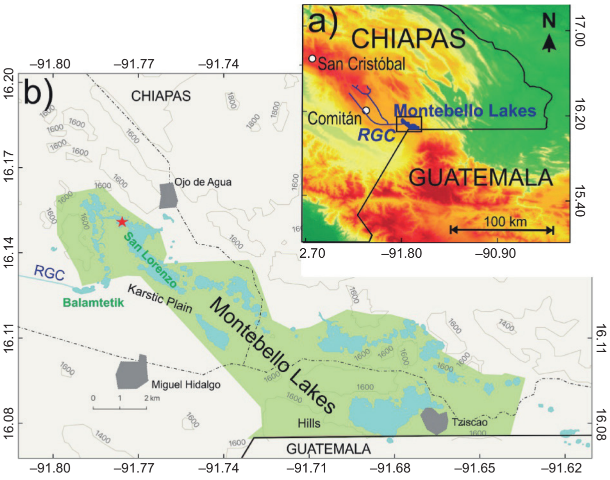

Fig. 1. Location maps a) Southern Chiapas with the Río Grande de Comitán (RGC) and the Montebello Lakes, near the border with Guatemala. b) The Montebello lakes with the locations of lakes Balamtetik and San Lorenzo, the red star marks the coring site in Lake San Lorenzo. The shaded area corresponds to the protected area “Parque Nacional Lagunas de Montebello”.

Sediment sampling

The sedimentary profile for this study was retrieved in July 2013 from the northern area of Lake San Lorenzo, using a UWITEC gravity corer at a depth of 12 m (**Fig.1b**). The recovered profile (VA13GII, 41 cm long) was sampled every 1 cm for geochemistry, geochronology, diatoms and other bioindicators, samples for metagenomics analyses were also collected but these results will be published elsewhere. During sampling, physical characteristics such as color and texture were described.

Analytical methods

Sediment samples for ^{210}Pb, ^{137}Cs, magnetic susceptibility and geochemical analyses were freeze-dried and homogenized by grinding with an agate mortar. Besides, the sample from the bottom of the sequence (41 cm) was sent to a commercial laboratory (Beta Analytic) for radiocarbon dating, and the result was calibrated to calendar years using the CALIBomb program (Reimer et al. 2004). For ^{210}Pb dating (Oldfield and Appleby 1984) 10 samples were analyzed by alpha spectrometry to determine ^{210}Po (radioactive descendant of ^{210}Pb), assuming secular equilibrium (Ruiz-Fernández and Hillaire-Marcel 2009). For ^{137}Cs, all sediment samples (40) were measured using a Gamma Beta Spectrometer (ATOMEX AT1357).

Total N concentrations were determined by dry combustion in a Perkin Elmer 2400 analyzer. Concentrations of organic matter and carbonates were also determined by loss on ignition at 550 ºC (LOI_{550}) and 950 ºC (LOI_{950}), respectively. Organic matter (LOI_{550}) was transformed to organic carbon (C_{org}) multiplying by a correction factor of 0.58 (Jensen et al. 2018) and then used to estimate the C_{org}/N ratios. Magnetic susceptibility was measured using a Bartington Magnetic Susceptibility Meter® coupled with a single frequency sensor MS2G. Elemental concentrations of Ti, Fe, and Ca were determined by X-Ray fluorescence (FRX) using a portable Niton XL3t 95.

For diatom analysis 18 samples were freeze dried and 0.5 g subsamples were treated with HCl (10 %) and H_2O_2 (30 %) until all carbonates and organic matter were eliminated. Permanent slides were mounted using Naphrax and diatom counts of a minimum of 100 valves were undertaken at 1000x using an Olympus BX50 microscope with interferential phase contrast. Diatom identification was based on specialized literature (Krammer and Lange-Bertalot 1986, 1991, 1991, Novelo et al. 2007).

RESULTS AND DISCUSSION

Chronology

Lake San Lorenzo had comparable ^{210}Pb results as Lake Balamtetik (Caballero et al. 2020), with relatively constant high activity values along the sequence (60 to 90 Bq/kg, **Fig. 2**), suggesting that the bottom sediments of the profiles from both lakes are too young to allow significant ^{210}Pb to decay and reach the lower, supported levels. The calibrated radiocarbon determination (41 cm, Beta-376719, 102.8 ± 0.3 pMC) allowed dating the bottom of the San Lorenzo sequence to the year 1956; therefore, despite of this sequence being shorter (41 cm), it seems to cover a similar time window as the previously studied sequence (80 cm) from Lake Balamtetik (Caballero et al. 2020). This is likely because Lake Balamtetik is directly receiving the sediment discharge of the RGC while Lake San Lorenzo is located further downstream, and would be expected to have a lower sedimentation rate. Considering that the surface sediments from the Lake San Lorenzo core date to the year of collection (2013) an age model based on linear interpolation is presented in **figure 2**. The ^{137}Cs activity values in the sediments from San Lorenzo ranged from 0 to 50 Bq/kg with several maxima along the sequence (**Fig. 2**). The presence of low ^{137}Cs values along the full sequence suggests that the whole core postdates the beginning of the nuclear testing in 1945,

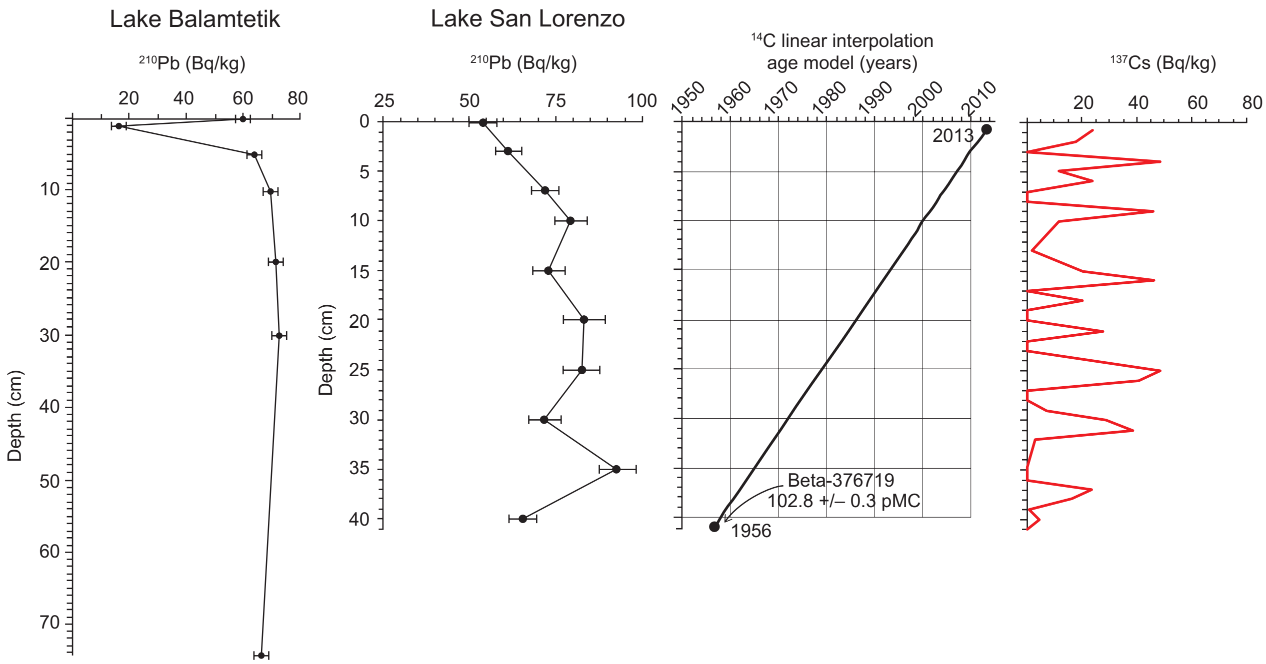

Fig. 2. ^{210}Pb depth profiles from lakes Balamtetik and San Lorenzo, and ^{14}C age depth model and ^{137}Cs depth profile from Lake San Lorenzo, Montebello lakes, Chiapas, Mexico. Pb= lead, Bq=Becquerels, kg= kilograms, C= carbon, Cs= cesium, pMC = post modern carbon.

this agrees with the radiocarbon age model. The presence of numerous ^{137}Cs peaks makes it difficult to identify individual events and suggest that in this lake, soils that have been previously contaminated with ^{137}Cs have eroded from the catchment (Poreba 2006, Appleby et al. 2019).

The geochemical record

The sediments from Lake San Lorenzo consist of massive gray to black clayey silts. The organic matter content (LOI_{550}) is relatively high along the sequence, ranging from 13 to 17.4 %, while the C_{org}/N ratio is more variable (**Fig. 3**). In general, high C_{org}/N ratios are indicative of larger inputs of terrestrial organic matter to the lake while lower values suggest a higher contribution of phytoplankton organic matter (Meyers 2003). The C_{org}/N ratio ranges from 16 to 46, and has two main intervals with values higher than average (> 29), inhigher-than-averageease in terrestrial organic input to the lake, the first from 32 to 22 cm (~1969 to 1987) and the second from 17 to 11 cm (~1990 to 2000; **Fig. 3**). Concentrations of carbonates (LOI_{950}) and Ca show nearly identical depth profiles along the sequence (**Fig. 3**), indicating the presence of calcium carbonate. Carbonate concentrations range from 4 to 21% while Ca ranges from 2 to 25 %, both show three intervals with higher-thanaverage values, from 39 to 34 cm (~1960 to 1967), from 22 to 19 cm (~1985 to 1988) and from 10 to 3 cm (~2001 to 2011); and two intervening intervals of low values (34 to 22 cm and 19 to 10 cm) which correspond with the times of higher C_{org}/N ratios (**Fig. 3**).

Magnetic susceptibility (MS), and terrigenous elements Ti and Fe (not shown) have nearly identical depth profiles (**Fig. 3**). These indicators are related to the erosion of crystalline rocks, however in the ML, where the dominant local rocks are limestones, these elements very likely come from outside the local catchment and are considered to be indicative of increased sediment discharge to the lakes through the RGC. High MS and Ti values also correspond with high C_{org}/N ratios, indicative of larger inputs of terrestrial organic matter from the regional vegetation and soils. A pattern emerges in which there are two periods of high MS, Fe, Ti and C_{org}/N values, indicative of high sediment and soil organic matter discharge to the lake system through the RGC during times of widespread catchment disturbance. According to our age model the times for these two widespread catchment disturbance events are from around 1970 to 1985 and from about 1990 to 2000. The first period corresponds to the important deforestation documented between the 1970s and 1990s (March and Flamenco 1996) and with the intense

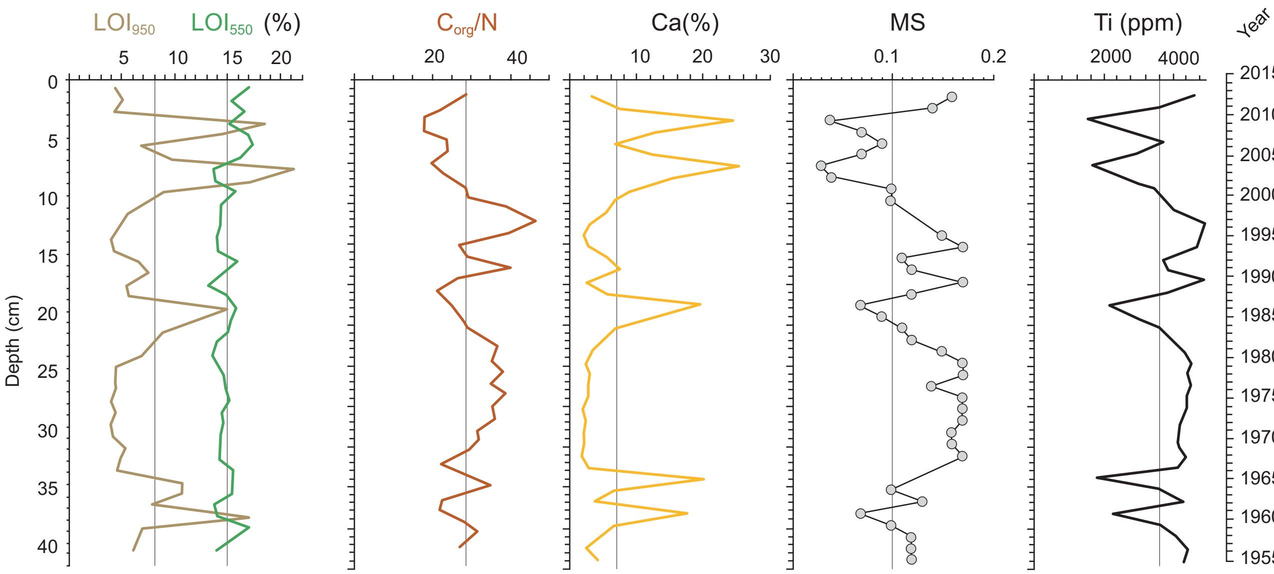

Fig. 3. Geochemistry depth profiles from Lake San Lorenzo, Montebello lakes, Chiapas Mexico. LOI_{950} = carbonates, LOI_{550} = organic matter, C_{org} = organic carbon, N = nitrogen, Ca = calcium, MS = magnetic susceptibility, Ti = titanium, ppm = parts per million.

immigration from Guatemala, associated to political instability in this country that forced thousands of people to cross the Chiapas border from 1980 to 1983, some of them settling permanently in the ML area. The second period of widespread catchment disturbance correspond to recent land use changes in the area, with an increase in the production of greenhouse crops like tomatoes and other vegetables promoted by large transnational corporations and also with an increase in the local population between 2005 and 2010 (INEGI 2018).

Diatom analysis

Diatom concentrations along the profile showed variations from absent to 62 x10^6 valves per gram of dry sediment (v/gds). Absence of diatoms was observed in sediments from 17 to 15 cm (~1990-1993), corresponding to high MS and Ti values, suggesting that large sediment inflow to the lake diluted the diatom concentration in this part of the sequence. On the other hand, diatoms show maximum concentrations in two sections of the sequence, from 40 to 35 cm (before 1965), and from 10 to 5 cm (~2000 to 2008), these periods correlate to low C_{org}/N ratios, pointing to higher contribution of organic matter from the phytoplankton (**Fig. 4**). The diatom assemblages along the core are alternatively dominated by *Aulacoseria granulata, A. granulata* var. *angustissima, Discostella stelligera* and *Stephanodiscus hantzchii* fo. *tennuis*. These planktonic species are common in freshwater lakes with high nutrient levels, and are tolerant to waters with high turbidity (Bennion et al. 1995, Kolmakov et al. 2002, Jeong et al. 2006); the presence of these species during the full record suggest that turbid waters and elevated nutrient levels were present in Lake San Lorenzo since 1956. During the two periods of basin-wide disruption identified by the geochemical record (~1950 to 1985 and ~1990 to 2000), the diatoms had lower abundances but there were slight increases in benthic species (*Diadesmis confervacea* and *Gomphonema* spp.), or in species tolerant to high nutrient loads (*Nitzschia palea*). These changes suggest that during these periods both lake turbidity and nutrient inputs increased.

CONCLUSIONS

The geochemical and diatom data from Lake San Lorenzo are consistent with previous results from Lake Balamtetic, and together confirm that there is a long history of environmental disruption in the region. The record from Lake San Lorenzo shows that turbid, nutrient rich conditions were present in this lake since at least 1956 (the base of the studied record). The geochemichal record also points to two main phases of basin-wide erosion that we propose are associated to long-distance sediment transport toward the lakes through the RGC. These basin-wide disturbance events date from around 1970 to 1985 and from about 1990 to 2000.

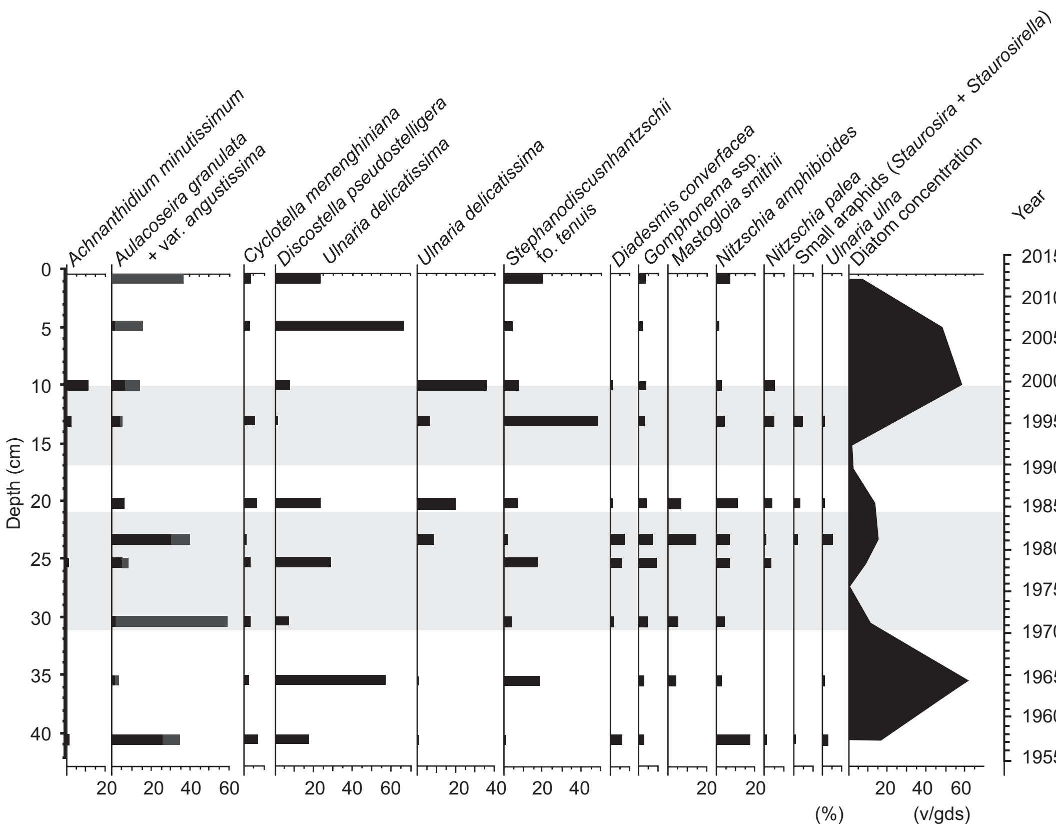

Fig. 4. Diatom species present in the sediments from Lake San Lorenzo, Montebello lakes, Chiapas, Mexico. v/gds = valves per gram of dry sediment.

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