Laguna Mar Chiquita: A Sedimentary Record of Recent Dry/Wet Intervals in Central Argentina

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Abstract: Laguna Mar Chiquita, Argentina, has experienced substantial lake level changes in recent times. Sedimentological analyses in well-dated cores indicate that total organic carbon and carbonate contents, and the development of evaporites and diatoms through time are proxy for these lake level variations. ^{210}Pb ages show that sedimentation rates have varied according to the stage of the lake. High stands yield low sedimentation rates whereas low stands intervals exhibit comparatively higher sedimentation rates. The combined results presented here point towards the potential of this lake in providing a long record of the hydrological cycle for this region of South America.

INTRODUCTION

Closed-lake basins are sensitive to changes in the hydrological balance. This sensitivity is shown through variations in water levels, the chemistry and biology of the water column and a variety of sedimentary processes.

Laguna Mar Chiquita is a highly variable terminal saline lake within an endorheic basin of ca. 37,500 km^2 that offers a unique site to study these relationships. The lake is located in the Pampean plains of central Argentina (Fig. 1; 30°54'S-62°51'W) and at present is the largest saline lake in South America (ca. 5,000 km^2). Today, this shallow lake (9 m maximum water depth) has a well-mixed water column with permanent anoxic bottom waters (Martinez et al., 1994). It is fed by three major rivers and receives a substantial groundwater input. Mean air temperature during summer is 24.5°C and 11.5°C in winter. Precipitations are concentrated during summer and instrumental data show that annual average values have varied from 650 to 850 mm/ yr clearly defining dry and wet intervals.

The preliminary results presented here reveal that very recent changes in the Evaporation/Precipitation ratio are reflected by sedimentological and mineralogical changes in the lake record. The lake is located in a tectonic depression of middle Pleistocene age (Kröling and Iriondo, 1999) and, therefore, it potentially provides an ideal site to recover long climatic records for this region of South America.

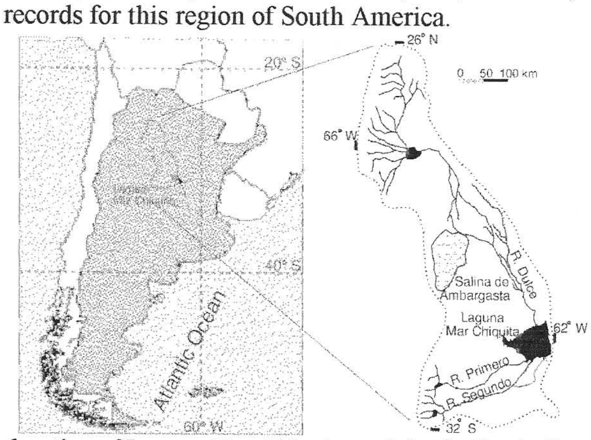

Figure 1. The arrow shows the location of Laguna Mar Chiquita and the dot line indicates catchment area. The detail on the right shows the main rivers feeding the lake. (Mapa de ubicación de la laguna Mar Chiquita -flecha- en Argentina y su cuenca en línea de puntos. El detalle de la derecha muestra los ríos principales que llegan a la laguna).

METHODOLOGY

A multi set of short cores were obtained in the main water body and in a small satellite lake during 1997 (TMC-3, TMC-5 and TMC-14) and 2000 (TMC-00-I). Whole cores petrophysical properties were determined using a Multi Sensor Core Logger (GeoTek®). Lithological units were defined combining a detailed core description using smear slides. A lamination index (LI) was defined in a similar fashion as the bioturbation index of Behl and Kennett (1996). A value of 1 represents continuous laminas up to 2 mm thick; 2, diffuse or discontinuous 2-4 mm thick; 3, thin banded 4-10 mm thick sediments and 4, thick banded greater than 10 mm thick sediments. X-ray radiographies were done in selected intervals of the cores. Total organic and inorganic carbon (TOC and TIC, respectively) where obtained by coulometry. Mineralogical analysis included X-ray diffraction and scanning electron micrographs of selected samples.

Concentration of radionuclides ^{226}Ra and ^{210}Pb were measured and further used to establish a robust chronology that in turn allowed the accurate calculation of sedimentation rates. Ages were calculated using the CRS model (Noller, 2000).

A lake level variation curve was reconstructed combining instrumental and historical data, a very unique situation at this latitudes. Rivers' annual runoff data was standardized using the equation $Q'(Y)= [Q(Y)-Q_M]/Q_M$. Where Q(Y) is the annual runoff and Q_M is the mean annual runoff for the series. The gauging data series correspond to a monthly mean and were obtained at http://www.r-hydronet.sr.unh.edu (Vörösmarty et al., 1998).

RESULTS

1. HYDROLOGY

Variations in the hydrological budget have produced important water-level fluctuations in the recent history of the lake (Fig. 2a). Low water stands (gray areas) characterized almost the entire first 3/4 of the XX century, with salinities up to 360 gL^{-1}, 291 gL^{-1} and 270 gL^{-1} in 1911, 1953 and 1970, respectively.

Short-term high stand occurred during 1932 as well as the 1959-1961interval, which match positive variations from the long-term mean values of river discharge. In 1972 started a substantial rising in both lake level and runoff of the rivers that feed the lake (black areas in Fig 2a-d). This is synchronic with increasing mean regional precipitation values as documented by instrumental data. Comparatively lower salinities (ca 30 gL^{-1}) were reported during this last high stand (Martinez et al., 1994)

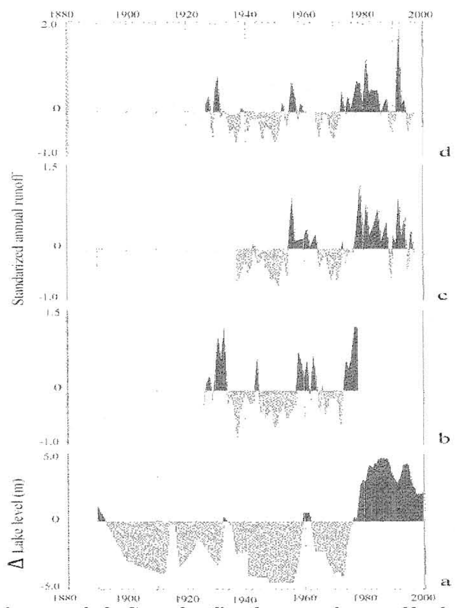

Figure 2 – a: Lake level fluctuations. b, c and d: Standardized annual runoff of rivers Dulce, Segundo and Primero, respectively. (a: Fluctuaciones del nivel de la laguna. b, c y d: Descargas anuales estandarizadas de los ríos Dulce, Segundo y Primero respectivamente).

2. CHRONOLOGY AND SEDIMENTATION RATES

Pb-210 ages profiles (Fig. 3) show that sedimentation rates have changed according to the lake level stage of the basin. These sedimentation rates have been calculated using a linear regressions of the data.

The last high stand (i.e., 1976-1997) yields lower sedimentation rates ranging from 0.6 to 1.1 cm yr^{-1}, whereas low stand intervals (e.g., 1973-1964) exhibits rates varying from 0.8 to 2.2 cm yr^{-1}. However, long-term average sedimentation rates (ASR in Fig. 2) are lower when compared to recent rates. This may be related to decreasing sedimentation or to the presence of hiatus during extreme low stand intervals.

The strongest droughts of the XX century are well-documented in this area of Southeastern South America and have occurred during the 40's (Genta et al., 1998). These droughts have been recorded in the sedimentary record as a strong Pb-210 anomaly below the 36-38 cm in core TMC-3 (Fig.3). The observed Pb enrichment during this interval could be attributed to a long sub aerial exposure of the satellite lake floor during those years. An age of 1762 AD years can be estimated for the basal sediments of core TMC-00-I when the chronological model for the uppermost sediments is extrapolated to the base of the core (Figure 4).

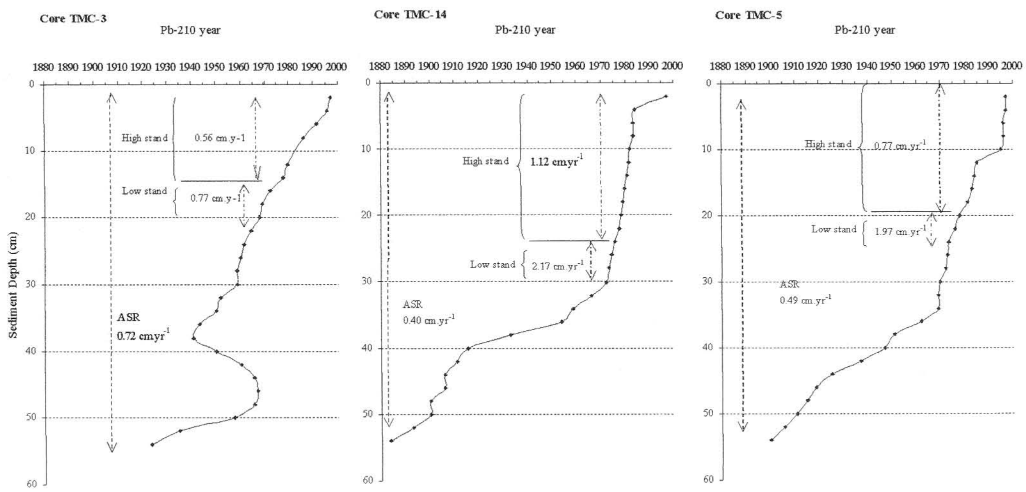

Figure 3 – Pb-210 profiles and sedimentation rates. ASR: average sedimentation rate. (Gráficos de edades Pb-210 y tasas de sedimentación. ASR: Tasa de sedimentación promedio para el testigo)

3. STRATIGRAPHY

The lithology of the recovered cores mostly comprises banded to laminated muds. X ray-radiograph revealed the presence of well-developed thin lamination and clustering of dominant color-type laminae. The detailed lithological description presented herein corresponds to core TCM-00-I. Two main lithological units (A and B) have been recognized. Unit B was further subdivided in three sub-units (Fig. 4).

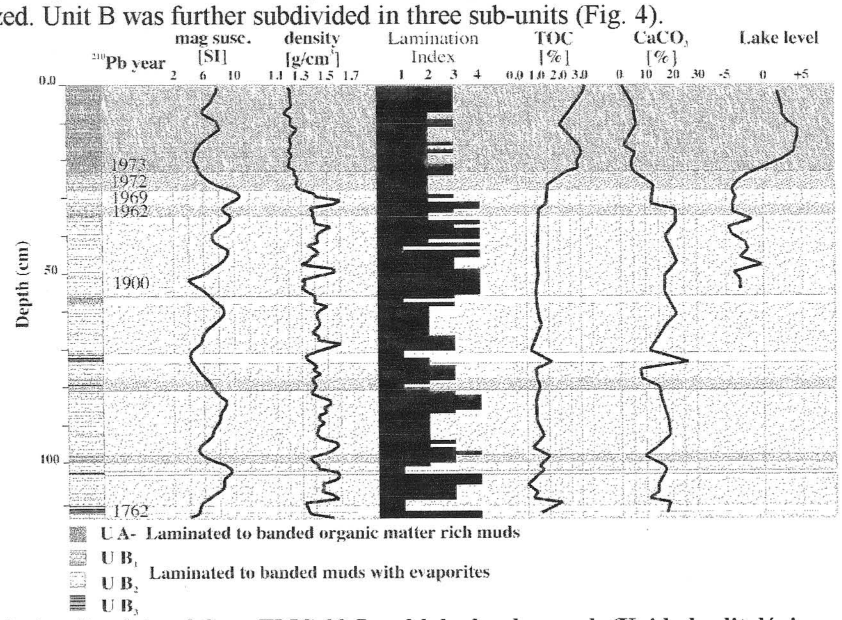

Figure 4 – Lithological units, data of Core TMC-00-I and lake level record. (Unidades litológicas, datos del Testigo TMC-00-I y registro de niveles de la laguna).

Unit A-Banded to laminated organic-rich muds: This unit corresponds to the uppermost part of the core. The sediments are grayish black and olive gray/black and are mainly composed of biogenic components (diatoms up to 55%). The clastic fraction (up to 30%) is dominated by silt and clays with scarce sand. Lamination (diffuse) and thin banded intervals are formed by alternating light and dark sediments. TOC contents are the highest from the core (up to 3.2%) whereas percentages of $CaCO_3$ are the lowest (up to 6.6%). The Pb-210 age model indicates that this unit has been deposited since 1973 to the present during the last high stand.

Unit B-Banded to laminated muds with evaporites, was subdivided into three sub units (B_1, B_2 and B_3).

B_1 is characterized by the presence of abundant dispersed gypsum in a mud matrix. This a transitional sub-unit from organic matter rich sediments (Unit A) to sediments with low contents of TOC (B_2). Percentages of $CaCO_3$ are also transitional. The content of diatoms is up to 40%. B_1 was deposited through the transition from low to high stand between 1972-1976.

B_2 is distinguished by the development of evaporitic layers up 2 cm thick, including gypsum, calcite and halite, that display high density values (Fig. 4). This sub-unit has the lowest values of organic matter (0.5-1.6%) and the maximum calcium carbonate contents (up to 22%). The percentage of diatoms is remarkably lower in the sediments and they disappear in the evaporites. The deposition of B_2 is associated to low stands of the lake, prior to 1972. The age of the sediment hosting evaporites correspond to years of extremely low lake levels. The importance of a low stand can be inferred by the presence of a thick evaporite in the base of the core (1762 AD). This interpreted drought interval is corroborated by the Jesuit cartography of 1760, which shows minor and isolated water bodies instead of the present Lake Mar Chiquita.

B_3 is a very thin laminated subunit mainly formed by fine-grained calcium carbonate and gypsum to a lesser extend, alternating with olive gray organic matter-rich sediments (2.1% TOC). The reconstructed lake record curve indicates a transitional phase from a high to a low stand period coinciding with the deposition of this subunit that corresponds to 1891 AD (level 58 cm in Fig. 3a).

DISCUSSION AND CONCLUSIONS

The combined historical, instrumental and sedimentological data presented here indicate that this closed basin is sensitive to intra-annual to decadal variations in the E/P balance for this region of South America. Lamination is most probably produced by variations in the organic matter content as a result of seasonal changes in the productivity of the lake. Moreover, the observed clustering of laminas is a response to changes in the organic matter production that is in turn most probably related to long-term lake level fluctuations.

Sedimentary and mineralogical changes combined with a reliable chronology and compared with historical data, provide a unique archive of recent fluctuation in the water balance. Lower sedimentation rates, high percentages of TOC and diatoms and low contents of calcium carbonate characterize high lake level intervals. Conversely, low lake levels are recorded as evaporite-rich and organic matter-poor sediments as well as higher sedimentation rate values.

Long dry intervals during the first 3/4 of the XX century and a recent upward trend in streamflows have been reported in the Rio de la Plata basin (Genta et al., 1998, Depetris et al., in press, etc). The observed variations in the hydrological balance in Lake Mar Chiquita are synchronic with these river changes suggesting the same triggering mechanism and point towards the potential of this lacustrine basin to reconstruct lake level changes in prehistorical times. The sedimentary record will then provide a unique archive of long-term trends in the climate system at this latitude.

REFERENCES

BEHL, R.J. and KENNET, J.P. (1996) – Brief interstadial events in the Santa Barbara basin, NE Pacific, during the past 60 ky. *Nature*, 379, pp. 243-246.

DEPETRIS, P., PIOVANO, E.L., PASQUINI, A. and PROBST, J.L. (in press) – The signal of ENSO-triggered hydrological anomalies in the Paraná upper drainage basin.

GENTA, J.L., PEREZ IRIBARREN, G. and MECHOSO, C. (1998) – A recent increasing trend in the streamflow of rivers in Southeastern South America. *Journal of Climate*, 11, pp, 2858-2862.

KRÖLING, D. and IRIONDO, M. (1999) – Upper Quaternary palaeoclimates of the Mar Chiquita area, North Pampa, Argentina. *Quaternary International*, 57/58, pp. 149-163.

MARTINEZ, D., GOMEZ PERAL, M. and MAGGI, J. (1994) – Caracterización geoquímica y sedimentológica de los fangos de la laguna Mar Chiquita, Provincia de Córdoba: aplicación del análisis multivariante. *Revista de la Asociación Geológica Argentina*, 49, pp. 26-38.

NOLLER, J. S. (2000) – Lead-210 Geochronology. In Quaternary Geochronology: Methods and Applications. Jay Strattron Noller, Janet M. Sowers & William R. Lettis, *Editors,* pp 115-120. American Geophysical Union, Washington, DC.

VÖRÖSMARTY, C.J., FEKETE, B.M., MAYBECK, M. (1998) – Global Simulated 30 Minute Topological Network, Complex Systems Research Center, University of New Hampshire, Collaborative effort among the University of New Hampshire, UNESCO International Hydrological Programme, IGBP Core Project: Biospheric Aspects of the Hydrological Cycle. Funding provided by UNESCO, US Committee on Scientific Hydrology, NASA, University of New Hampshire.