Short-term climatic change in lake sediments from lake Alchichica, Oriental, Mexico

Margarita Caballero[1], Gloria Vilaclara[2], Alejandro Rodríguez[3] and Diana Juárez[3]
[1] *Institute of Geophysics, UNAM, México, D. F., México*
[2] *FES-Iztacala, UNAM, Los Reyes Iztacala, Tlalnepantla, Edo. de México.*
[3] *Posgrado de Ciencias del Mar y Limnologia, UNAM, México, D. F., México*

Received: September 3, 2000; accepted: July 15, 2001

RESUMEN

En el centro de México el fenómeno de "El Niño" provoca una reducción en la precipitación. Estas variaciones interanuales en el clima pueden modificar el comportamiento de mezcla-estratificación de los lagos, reflejándose a veces en los sedimentos que se acumulan año con año en sus fondos, sobrepuesto a las tendencias de cambio climático de mayor duración. Presentamos datos preliminares de una evaluación del potencial de los sedimentos del lago de Alchichia para registrar cambios climáticos de períodos medio y corto, analizando diatomeas, calcinación y pigmentos totales en un núcleo de 168 cm de longitud (Alchi-III) recuperado de la orilla NE del lago. Dos fechas de 14-C en sedimento total proporcionan un marco cronológico aproximado. La concentración de pigmentos totales resultó ser un indicador paleoambiental pobre, dado que se pierde el contenido de pigmentos en los sedimentos por debajo de 56 cm, indicando que la concentración depende de procesos de degradación. La preservación de diatomeas fue pobre, limitada a los 44 cm superiores. La alta alcalinidad y pH de este lago parece favorecer la disolución del sílice de las diatomeas, limitando el potencial de este lago para estudios paleolimnológicos. El conjunto de diatomeas de los 44 cm superiores indica que el lago ha sido un sistema alcalino-subsalino durante el pasado reciente (últimos ca. 300 años), con una disminución muy reciente del nivel lacustre. No se detectaron evidencias de fluctuaciones climáticas de período corto de tipo El Niño, pero la estratigrafía y los datos de calcinación sugieren que en un pasado reciente (> ca. 300 años ?) el lago tuvo un episodio de aguas más alcalinas y con un nivel lacustre menor que el actual.

PALABRAS CLAVE: Lagos cráter, diatomeas, Cuenca de Oriental.

ABSTRACT

Reduced precipitation in central Mexico is related to ENSO events. These short-term climatic fluctuations can modify mixing-stratification patterns of lake systems, reflected in the sediments deposited at the bottom year after year. Lake sediments can also record longer climatic trends. We present preliminary results of an evaluation of the potential of Lake Alchichica to record short-term fluctuations as well as middle-term climatic variability. Diatom, loss on ignition (LOI) and total pigment analyses were carried out on a 168 cm core from the NE shore of Alchichica. Two 14-C dates on bulk sediment give an approximate chronological frame for the sequence. Total pigment content was a poor palaeoenvironmental proxy in this lake, as pigments were undetected below 56 cm, suggesting that concentration depends on degradation processes. Diatom preservation in the sediments was poor and restricted to the upper 44 cm. High pH and alkalinity in Alchichica favor diatom dissolution, limiting the potential of this lake for palaeolimnologic studies. Diatom assemblages in the upper 44 cm of the sequence suggest that the lake has remained an alkaline-subsaline system during the recent past, probably over the past 300 yr., with a very recent decrease of lake level. There is no record of short-term climatic events such as ENSO. Sediment stratigraphy and LOI data, however, suggest a past event of unknown age (>300 yr. ?), with lower than present lake levels and higher alkalinity.

KEY WORDS: Maar lakes, diatoms, Oriental Basin.

INTRODUCTION

ENSO events, the fluctuations between warm (El Niño) and a cool (La Niña) states of the eastern tropical Pacific ocean, are probably the most important recurrent, inter-annual climatic events on Earth (Latif *et al.*, 1994; Philander, 1990). ENSO is related to important anomalies of the global circulation, both of the oceans and the atmosphere (Ropelewski and Halpert, 1989; Zebiak and Cane, 1987), which induce variations in the climates of several areas of the world (Glantz, 1984). These climatic fluctuations have important economic and social consequences as they severely disrupt terrestrial and aquatic ecosystems (IAI, 1995; Glantz *et al.*, 1991; Barber and Chávez, 1983).

In Central Mexico, ENSO events are related with reduced precipitation, caused probably by a southerly migration of the Intertropical Convergence Zone, as well as a deviation of the hurricane paths away from the continent (Douglas, 1983). It has been well documented that short-term climatic fluctuations of this sort can modify lake systems, particularly their mixing-stratification patterns (Alcocer and Lugo, this volume; Alcocer *et al.*, 2000; Margalef, 1983; Hutchinson, 1957). Such changes in the water column can be reflected in the sediments that are deposited at the bottom year after year. There are several lake basins in central Mexico that could potentially keep a good record of such short-term climatic events as well as of longer climatic change trends (Caballero *et al.*, 1999; Caballero and Ortega 1998; Byrne *et al.*, 1996; Lozano *et al.*, 1993). In particular, there is some evidence that suggests that lakes in Cuenca de Oriental can be sensitive to short-term climatic fluctuations through changes in mixing-stratification patterns. These changes can be related to occasional blooms of cyanobacteria (called lake "sickness" by the local people in Atexcac), or, like in Alchichica, with modifications of the normal annual blooming pattern (Alcocer and Lugo, this volume; Macek *et al.*, 2000, 1994; Alcocer *et al.*, 2000; Lugo *et al.*, 2000 & 1999; Vilaclara *et al.*, 1993). We present preliminary results of a project that aims to study short- and mid-term climatic trends from the sedimentary record of lake Alchichica in Cuenca de Oriental, eastern Mexico.

RESEARCH AREA

Oriental is a closed hydrological basin located in the eastern part of the Trans-Mexican Volcanic Belt (Figure 1). It is bounded by high volcanic structures such as the Sierra Madre Oriental and the Pico de Orizaba, and it has a Cretaceous limestone basement that outcrops within the basin (Reyes, 1979). The central lower lands (2300 m a.s.l.) have two ephemeral lake areas (El Salado or Tepeyahualco and El Carmen or Totolcingo), that nowadays remain dry for most of the year. Oriental also has eleven maars (Casique *et al.*, 1982; Gasca, 1981; Reyes, 1979), six of them containing a water body (locally referred as "axalapazcos"), and the remaining five dry (locally referred as "xalapazcos"). The maar lakes are divided in two geographic groups: i) Quechulac, Alchichica, La Preciosa and Atexcac to the north, with a transition between semiarid and temperate climate (BS to Cw); ii) Aljojuca and Tecuitlapa to the south, with a dominantly sub-humid climate (Cw) (CONABIO-Estadigrafía, 1997a y b; García, 1988). The characteristics of these lakes vary (Table 1), but all of them are alkaline and have relatively high electric conductivity (K_{25}>0.75 mS/cm). Ephemeral lakes are sustained by rainfall, whereas maar lakes are sustained by underground water (Gasca, 1981; Álvarez, 1950). Recharge of the underground water system is provided by rainfall over the nearby hills that capture the moisture of the Trade winds which have crossed over the Gulf of Mexico (Vilaclara *et al.*, 1993; Ramírez-García and Novelo, 1984).

Alchichica is the biggest of the maar lakes (in area and volume) of Cuenca de Oriental and is characterized by alkaline (pH>9), subsaline (8.5 g/l) water. Two main factors are responsible for this chemistry: 1) Incoming waters are rich in sodium from volcanic materials, and in bicarbonates from the Cretaceous limestone; these lakes are known as "sodic lakes" (Margalef, 1983) and are characterized by high alkalinity, high contents of carbonates and sodium, and very low calcium concentration. 2) Due to the sub-arid climate, evaporation is higher than precipitation, and mineral solutes concentrate. Maximum lake depth is 64 m; lake level, however, has been decreasing during the last decades, exposing littoral calcareous stromatolites that are characteristic of this lake (Tavera and Komárek, 1996). It behaves as a warm monomictic lake, oligomesotrophic with a tendency to mesotrophy, with two blooms of primary producers: a diatom bloom during the winter mixing (December-January) and a cyanobacteria bloom at the onset of the stratification period (April-May). The latter bloom appeared to be weakened during the El Niño-La Niña 1997-1998 event (Alcocer *et al.* 2000; Alcocer and Lugo, this volume; Vilaclara *et al.* 1993).

The ephemeral lakes, the xalapazcos and the shallow axalapazcos (Tecuitlapa) present in Cuenca de Oriental are considered to be late phases in the evolution of former, deeper systems (Álvarez, 1950). Nevertheless, very few paleolimnological or paleoenvironmental works have been carried out in this area to confirm this hypothesis or to give information into the evolution of the lakes and the climate of the area. During the 70's, Heine did some geomorphological work on nearby Malinche volcano (Heine, 1988) in relation with glacier advances, establishing three glacial advances within the last ca. 10 000 yr.: MIII by ca. 9000, MIV by ca. 2000 and MV younger than 1000. This sequence, however, has been disputed by White (White *et al.*, 1990; White 1986 y 1962; White and Valastro, 1984) who based their studies on the Iztaccíhuatl and Ajusco volcanoes. Straka and Ohngemach (1989) and Ohngemach and Straka (1983) did some palinological work on two main locations within Cuenca de Oriental: El Carmen (not dated) and the dry maar of Xalapazquillo. The scope of these works was limited by a poor chronology and by overrepresentation of Pinus pollen. Data suggest that during the last ca. 35 000 yr. an important change in the vegetation occurred by ca. 8000 yr. BP, presumably correlating with the Pleistocene/Holocene transition (Straka and Ohngemach, 1989). No paleolimnological information was derived from these studies.

MATERIALS AND METHODS

Short-term climatic events in the area of study can be reflected as modifications on the phytoplankton composition and on its normal pattern of annual blooms. It is our

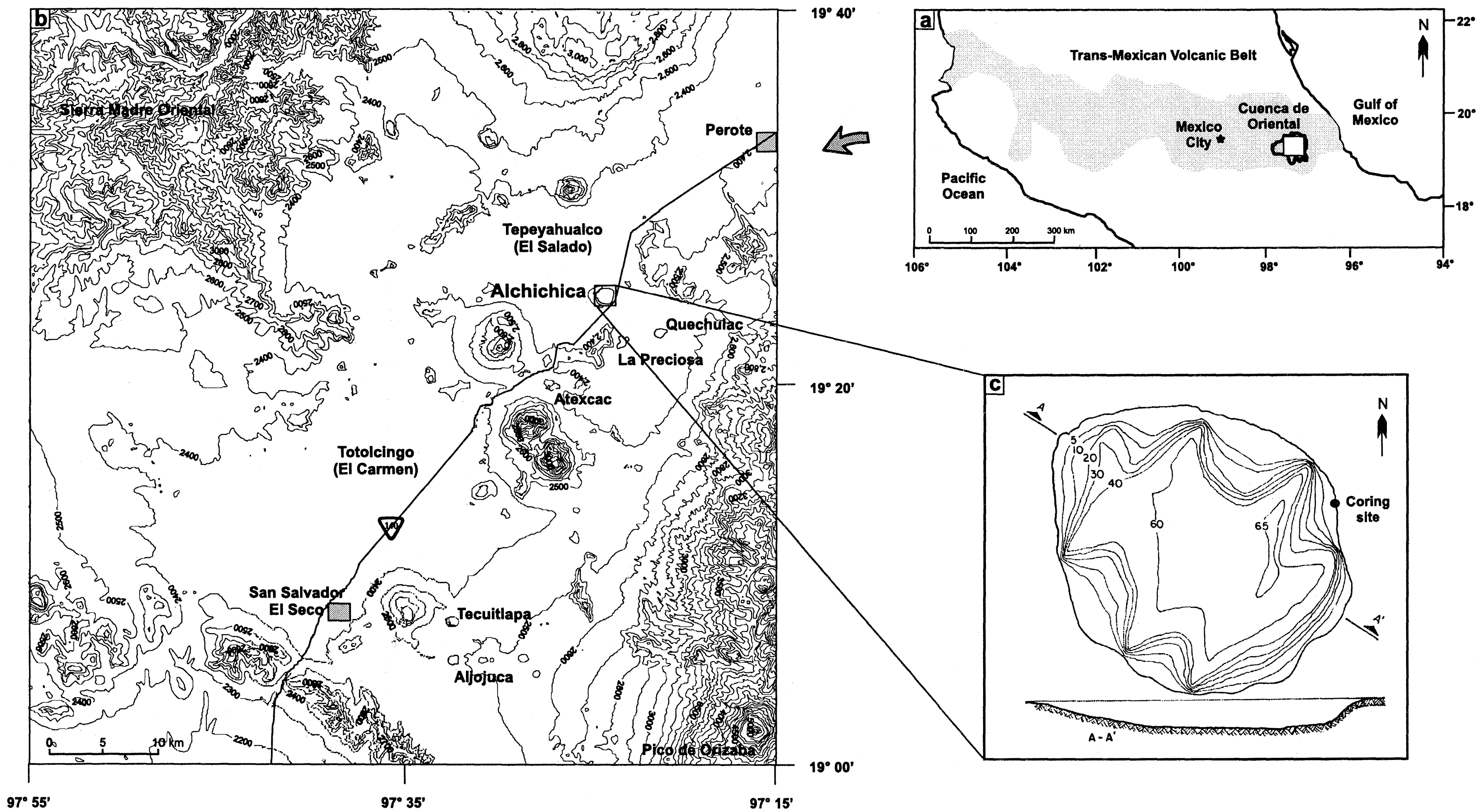

Fig. 1. Location map: a) Trans-Mexican Volcanic Belt, b) Cuenca de Oriental c) Lake Alchichica (taken from Vilaclara *et al.,* 1993, modified from Arredondo *et al.,* 1983) with location of coring site.

Table 1

Main characteristics of the maar lakes in Cuenca Oriental (modified from Vilaclara *et al.* 1993, CONABIO-Estadigrafía, 1997a y b & García, 1988)

MAAR LAKES	Position	Altitud. m a.s.l.	Z_M m	Climate	Precip. mm/yr	K_{25} mS/cm	pH	Ionic dominance meq./l
ALJOJUCA	19°05'N 97°32'W	2340	45		< 600	1.22	8.4	$HCO_3^- > CO_3^= > Cl^- > SO_4^=$ $Na^+ > Mg^{++} > Ca^{++} > K^+$
TECUITLAPA	19°08'N 97°33'W	2380	4.5		600	1.65	8.5	$HCO_3^- > CO_3^= > Cl^- > SO_4^=$ $Na^+ > Mg^{++} > K^+ > Ca^{++}$
ATEXCAC	19°20'N 97°27'W	2340	35	C(w")(w)(i')g	500	11.0	8.4	$Cl^- > CO_3^= > HCO_3^- > SO_4^=$ $Na^+ > Mg^{++} > K^+ > Ca^{++}$
QUECHULAC	19°22'N 97°21'W	2350	35	temperate	<500	0.75	8.4	$HCO_3^- > Cl^- > CO_3^= > SO_4^=$ $Mg^{++} > Na^+ > Ca^{++} > K^+$
LA PRECIOSA	19°22'N 97°23'W	2330	45		<500	2.15	8.7	$Cl^- > HCO_3^- > CO_3^= > SO_4^=$ $Mg^{++} > Na^+ > Ca^{++} > K^{++}$
ALCHICHICA	19°25'N 97°24'W	2320	64	Bskw"(w)(i') subarid	<400	13.0	8.9	$Cl^- > CO_3^= > SO_4^= > HCO_3^-$ $Na^+ > Mg^{++} > K^+ > Ca^{++}$

hypothesis that by measuring the content of pigments preserved in the sediments and contrasting this with the diatom record it might be possible to detect such short-term climatic events. Diatoms, together with loss on ignition, are well-established tools in the study of longer-term limnological and climatic trends (e.g. Bradbury, 1991; Caballero and Ortega, 1998).

Field Work.- Three littoral cores (Alchi-I: 60, Alchi-II: 70 and Alchi-III: 168 cm) were taken from lake Alchichica to evaluate the potential of its sediments as records of limnological and climatic conditions. Cores were taken with an Eijelkamp soil sampler, which consists of a stainless steel casing with an inner plastic tube where the sample is collected. The casing and plastic sampling tube are introduced in the sediment by manual pressure or using a motor hammer and recovered by a lever system. The three cores were taken from the NE shores, in a pool formed just behind some stromatolites. According to field data, this littoral area was permanently covered by water before 1979, thus registering older changes in the entire lake. Such zones are the best choice for paleolimnological studies in Alchichica because the bottom of the lake was disturbed by strong explosions in 1974, detonated as part of seismological survey across Central Mexico (J. Urrutia, pers. com.).

Sampling.- All cores were sampled by extracting one-centimeter slices every five centimeters, preserved by cooling until analyzed.

Dating.- Two 14-C dates (AMS) on bulk sediment are available for the Alchi-III core, reported ages are conventional radicarbon dates in years before present (yr. BP). Bulk sediment dates in this area can nonetheless have a systematic error due to the input to the lake of old carbon from the calcareous Cretaceous basement. The presence of old carbon in the system dilutes the amount of radiocarbon, giving older ages than the true age of the sediment; the magnitude of this effect in the area has not been quantified. Determinations were made in the AMS Radiocarbon Research Laboratory of the University of Colorado, as part of a collaborative program for palaeoenvironmental research between USA and Latin America.

Loss on Ignition (LOI).- LOI was determined by burning a known weight of dry sediment at 550°C for two hours and at 950°C for another two hours. Weight differences are expressed as a percentage of the initial dry weight. The loss at 550°C is proportional to the organic matter content in the sample, the loss at 950°C correlates with carbonate content.

Pigments.- Total pigments were determined by the Bengtsson and Enell (1986) method, which consists of an extraction with acetone at low temperature in the absence of light. Pigment content was measured by spectrometry and expressed as spectrometric units per gram of organic matter (or Pigment Units, P.U.).

Diatoms.- Samples were cleaned with HCl (10%) and concentrated H_2O_2. The remaining sediment was neutralized by successive rinsing and taken to a constant volume (30 ml). Microscope slides were made by mounting 200 ml of cleaned material with Naphrax. A minimum of 400 valves was counted using an Olympus BH-2 microscope. Data are expressed as relative (% of total count) and total (valves/gram of dry sediment) abundance.

RESULTS AND DISCUSSION

The Alchi-III core is considered to be the most representative and its sediments were used to test the total pigment extraction methodology and to perform LOI and diatom analyses (Figure 2). Although the literature states the usefulness of pigment determination in sediments for paleoenvironmental studies (Leavitt, 1993, Leavitt *et al.*, 1997), the results suggest that the bulk concentration of pigments in the sediments of Alchichica is determined mainly by degradation processes: High levels are present in the near surface sediments (from 2,375 P.U. at 6 cm to 150 P.U. at 56 cm) and levels below the detection limits occur at grater depths. Sediment stratigraphy, LOI and diatom data nonetheless suggest that the Alchichica record can be divided into four stages:

i) The base of the sequence (165 – 125 cm) is formed mainly by precipitated carbonates ($CaCO_3$ ca. 50%). There is no further data for palaeolimnological reconstruction during this phase, but given the nature of this lake and the location of the core, it might be part of an old stromatolite-like structure.

ii) The interval between 125 and 49 cm is dominated by silt deposition with variable content of calcareous concretions (ca. 5-30% of carbonate) that are bigger (gravel size) and more abundant at the base of the section and show a general decreasing trend towards the top (Figure 2). No

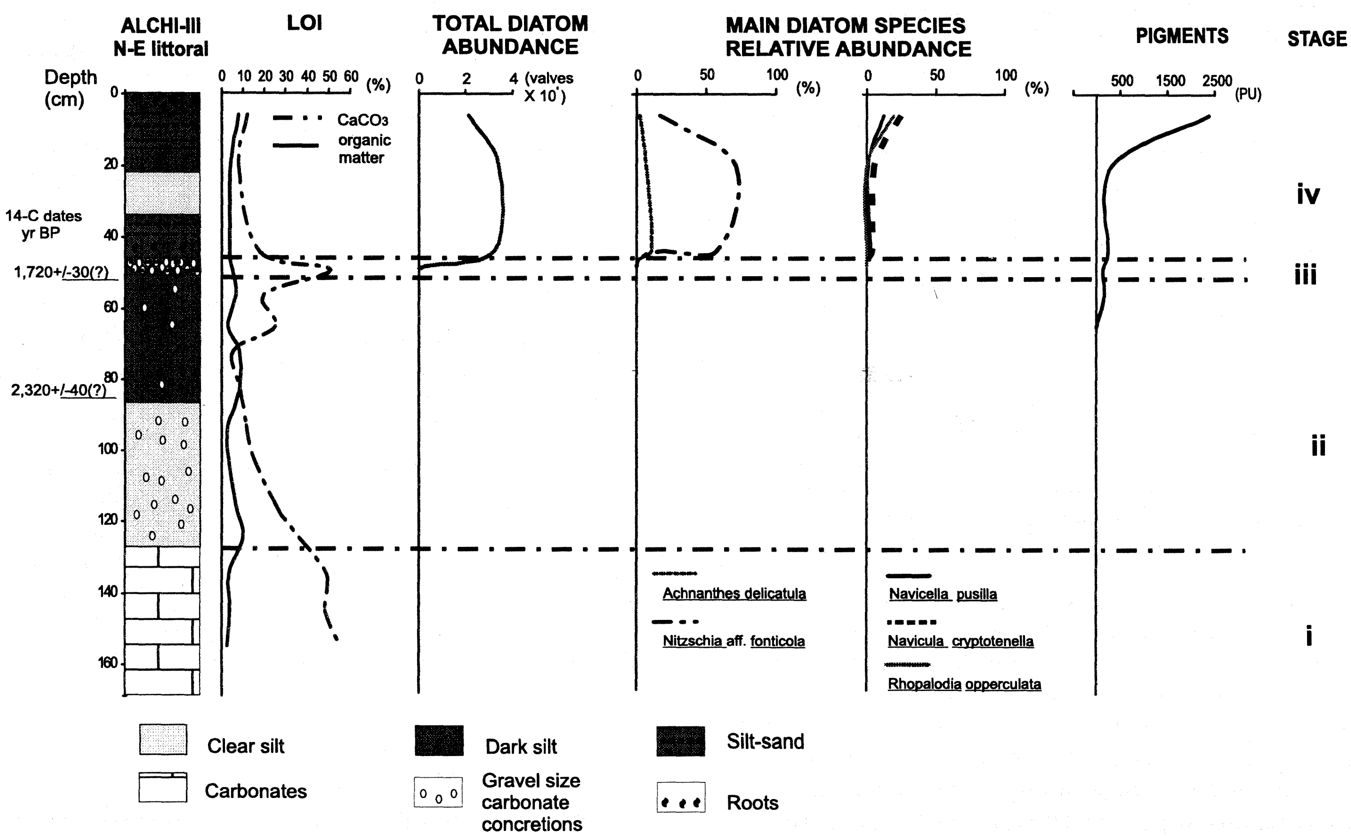

Fig. 2. Sediment sequence, Loss on Ignition (LOI), diatom and pigment stratigraphy from core ALCHI-III, recovered from the northeastern shores of Lake Alchichica, Cuenca de Oriental, Central Mexico.

diatoms are preserved, so paleolimnological interpretation is limited. It is considered that this phase represents a lacustrine episode similar to present.

iii) The interval between 49 and 44 cm is a carbonate-rich horizon with abundant coarse sand to gravel size calcareous concretions (ca. 50% of carbonate). It is possible that this interval corresponds with a period of higher water alkalinity associated with higher evaporation and lower lake level. The presence of roots at the top of the unit supports the interpretation of a lower lake level phase.

iv) A final period (44 – 0 cm) is dominated by silt deposition, with low carbonate content (ca. 10%) present as fine sand carbonate concretions. This last episode is the only one with diatom preservation (Figure 2), even though valves are badly corroded which gives evidence of diatom dissolution, well documented in high pH, carbonate rich environments such as Alchichica (Straub, 1993, Flower, 1993). This process explains the absence of diatoms in deeper sediments. Diatom assemblage is dominated by *Nitzschia aff. fonticola*, with *Achnanthes delicatula, Navicella pusilla, Navicula cryptotenella and Rhopalodia opperculata.* All these species are characteristic of alkaline, saline conditions similar to present ones, so this phase is interpreted as a lacustrine episode with lower alkalinity and higher water level than the previous interval. The last sample, however, has a slightly different assemblage, with lower abundance of *N.* aff. *fonticola* and *A. delicatula*, but higher numbers of *N. cryptotenella, N. pusilla* and *R. opperculata*; this change in diatoms is associated with the presence of abundant roots in the sediment. This change in diatom assemblage is not easy to explain, as all species have a similar ecology. The increase in *R. opperculata*, a species with a typical bentonic habitat and the abundance of roots in the sediment, suggest that it is related with a lower water level trend, documented by recent photographs taken during fieldwork in 1979, which clearly show a higher than present lake level that fully covered the stromatolites exposed today (Tavera and Komárek, 1996).

Two AMS 14-C dates are available for the Alchi-III sequence: NSRL-10406, 1720+/-30 (50-53cm) and NSRL-10407, 2320+/-40 (83-88 cm). The true age of the sediments, however, is difficult to estimate as dates might have a systematic error induced by the old carbon entering the system from the Cretaceous calcareous rocks that outcrop in the area (Reyes 1979). In an effort to estimate the true age of the sediments, and assuming that the entrance of old carbon to the system is more or less uniform, the average sedimentation rate between 83 and 53 cm (the two dated horizons) is calculated as ca. 0.6 mm/yr. This sedimentation rate is consistent with that expected in an oligotrophic lake such as Alchichica (0.3-1mm/yr., Bradbury, 1991; Longmore, 1986; Saarnisto, 1986). Taking into account this rate of sedimentation, we can estimate that the sediments from stage ii (125 – 49 cm) were deposited in a lapse of ca. 600 yr., and maybe the sediments from stage i (of similar nature to those between 83 and 53 cm) were deposited in a lapse of ca. 300 yr. With this approximate time frame in mind, we can suggest that the shallow water stage (stage ii) ended ca. 300 yr. ago. The sedimentation rate of this horizon must have been nonetheless different from that of stages ii and i, whereby the duration of this phase cannot be calculated with the available data.

CONCLUSIONS

1. The total pigment content of littoral sediments is not a good palaeoenvironmental proxy in lake Alchichica because its concentration is affected by degradation processes.

2. The high pH and alkalinity of Alchichica favors diatom dissolution in the sediments, limiting the potential of this lake as a palaeoenvironmental and palaeolimnological research site.

3. The diatoms preserved in the upper 44 cm of the sequence indicate that the lake has remained as an alkaline-subsaline, high pH system during the recent past (probably the last ca. 300 yr.).

4. A recent trend to lower lake level is observed in the last 5 cm of the sediment sequence; this trend is further documented by recent photographic evidence and by the exposition to air of the stromatolites. The lake, however, has not significantly changed its nature and, at least in the studied cores, shows no evidence of shorter-term climatic events such as ENSO.

5. In a longer time scale, a possible interval of lower-than-present lake level and higher alkalinity is detected as a carbonate rich horizon (49 to 44 cm). The age and duration of this event is unknown, but it might be older than ca. 300 years. This dry episode was preceded by a lacustrine phase (similar to present) that might have spanned for ca. 600 yr.

ACKNOWLEDGEMENTS

To CONACyT for financial support though project 075PÑ-1297. To Rodolfo Robledo, Teodoro Hernández, Susana Sosa, Ana Ma. Soler, Cecilia Caballero and Martha Gaytan for field work and technical assistance. To the National Science Foundation (NSF) grant ATM-9809285 to the University of Colorado INSTAAR - Laboratory for AMS Radiocarbon Preparation and Research.

BIBLIOGRAPHY

ALCOCER, J., A. LUGO, E. ESCOBAR, M. R. SÁNCHEZ and G. VILACLARA, 2000. Water column stratification and its implications in the tropical warm monomictic lake Alchichica, Puebla, Mexico. *Verh. Int. Ver. Limnologie 27*, in press.

ALCOCER, J. and A. LUGO, 2003. Is the limnological dynamics of tropical lake Alchichica affected by El Niño Southern Oscillation. *Geofís. Int., this volume.*

ÁLVAREZ, J., 1950. Contribución al conocimiento de los peces de la región de los Llanos, Estado de Puebla (México). *An. Esc. Nal. de Cienc. Biol. VI,* 81-107.

ARREDONDO J. L., L. E. BORREGO, R. M. CASTILLO and M. A. VALLADOLID, 1983. Batimetría y morfometría de los lagos maars de la Cuenca de Oriental, Puebla, México. *Biótica 8(1),* 37-47.

BARBER, R. T. and F. P. CHÁVEZ, 1983. Biological consequences of El Niño. *Science 222,* 1203-1210.

BENGTSSON, L. and M. ENELL, 1986. Chemical analysis. *In:* B.E. Berglund (Ed.), Handbook of Holocene Palaeoecology and Palaeohydrology. John Wiley & Sons, Chichester, p. 423-448.

BRADBURY, J. P., 1991. The late Cenozoic diatom stratigraphy and paleolimnology of Tule Lake, Siskiyou Co. California. *J. Paleolimnol., 6,* 205-255.

BYRNE, R., D. ALLEN, E. EDLUND and C. POLANSKY, 1996. Can lake sediments provide a record of tropical storms? The case of Laguna de Juanacatlán, Jalisco, Mexico. *In:* C.M. Isaacs and V.L. Tharp (Eds.), Proceedings of the Twelfth Annual Pacific Climate (PACLIM) Workshop, p. 159. Interagency Ecological Program for the Sacramento-San Joaquín Estuary, Technical Report 46.

CABALLERO, M. and B. ORTEGA, 1998. Lake levels since about 40 000 years ago at Lake Chalco, near Mexico City. *Quatern. Res., 50,* 69-79.

CABALLERO, M., S. LOZANO, B. ORTEGA, J. URRUTIA and J. L. MACÍAS, 1999. Environmental characteristics of Lake Tecocomulco, northern basin of Mexico, for the last 50 000 years. *J. Paleolimnol., 22,* 399-411.

CASIQUE, V. J., D. S. GARCÍA, G. C. YÁÑEZ, H. L. H. PALACIOS and V. H. GARCÍA, 1982. Resultados de las exploraciones realizadas por C. F. E. en el proyecto geotérmico Los Humeros-Derrumbadas, Estados de Puebla y Veracruz. Anales del Instituto de Geofísica, UNAM, 27-28: 9-61.

CONABIO-ESTADIGRAFÍA, 1997a. Carta de Climas de México, 1:1,000,000. CONABIO, México.

CONABIO-ESTADIGRAFÍA, 1997b. Carta de Precipitación Total anual de México, 1:1,000,000. CONABIO, México.

DOUGLAS, A. V., 1983. The Mexican summer monsoon of 1982. Proc. 7th Ann. Clim. Diag. Work. NOAA, 70-79.

FLOWER, R. J., 1983.Diatom preservation: experiments and observations on dissolution and breakage in modern and fossil material. *Hydrobiología, 269/270,* 473-484.

GARCÍA, M. E., 1988. Modificaciones al sistema de clasificación climática de Köppen para adaptarlo a las condiciones de México. Ed. por M.E. García, México. 217 pp.

GASCA, D. A., 1981. Algunas notas de la génesis de los lagos-cráter de la Cuenca Oriental. INAH, Colección Científica, 98, México.

GLANTZ, M. H. 1984. Floods, fires, and famine: Is El Niño to blame? *Oceanus 27,* 14-20.

GLANTZ, M. H., R. W. KATZ and N. NICHOLLS, (Eds.). 1991. Teleconnections linking worldwide climate anomalies. Cambridge University Press, Cambridge, UK.

HEINE, K., 1988. Late Quaternary glacial chronology of the Mexican volcanoes. *Die Geowissenchaften 6,* 197-205.

HUTCHINSON, G. E., 1957. A treatise on Limnology, Vol. I. John Wiley & Sons, N.Y.

IAI. 1995. El Niño-Southen Oscillation and Interannual Climate Variability. Workshop Report. Inter-American Institute for Global Change Research.

LATIF, M., T. P. BARNETT, M. A. CANE, M. FLÜGEL, N. E. GRAHAM, H. VON STORCH, J.-S. XU and S. E. ZEBIAK, 1994. A review of ENSO prediction studies. *Climate Dynamics 9,* 167-179.

LEAVITT, P. R., 1993. A review of factors that regulate carotenoid and chlorophyll deposition and fossil pigment abundace. *J. Paleolimnol., 9,* 109 – 127.

LEAVITT, P. R., R. D. VINEBROOKE, D. B. DONALD, J. P. SMOL and D. W. SCHINDLER, 1997. Past ultraviolet radiation environments in lakes derived from fossil pigments. *Nature, 388*, 457-459.

LONGMORE, M. E., 1986. Modern and ancient sediment-data base for management of aquatic ecosystems and their catchments. pp. 509-522. *In:* P. De Deckker and W.D. Williams: Limnology in Australia. Dr. W. Junk Publishers, Dordrecht, 671 pp.

LOZANO, S., B. ORTEGA, M. CABALLERO and J. URRUTIA, 1993. Late Pleistocene and Holocene palaeoenvironments of Chalco lake, Central México. *Quaternary Res., 40,* 332-342.

LUGO, A., M. E. GONZÁLEZ, M. R. SÁNCHEZ and J. ALCOCER, 1999. Distribution of *Leptodiaptomus novamexicanus* (Copepoda: Calanoidea) in a Mexican hyposaline lake. *Rev. Biol. Trop. 17*, 145-152.

LUGO, A., J. ALCOCER, M. R. SÁNCHEZ, E. ESCOBAR and M. MACEK, (in press). Temporal and spatial variation of bacterioplankton abundance in a tropical, warm monomictic, saline lake: Alchichica, Puebla, Mexico. *Verh. Int. Ver. Limnologie 27.*

MACEK, M., G. VILACLARA and A. LUGO, 1994. Changes in protozoan assemblage structure and activity in a stratified tropical lake. *Marine Microbial Food Webs 8 (1-2)*, 235-249.

MACEK, M., A. LUGO and G. VILACLARA, 2000. Pelagic cilliate assemblages of the high altitude lake Atexcac (Puebla, Mexico). Chapter *In:* M. Munawar; S.G. Lawrence; I.F. Munawar & D.S. Malley (Eds.): Aquatic Ecosystems of Mexico: Status and scope. Backhueys Scientific, 435 pp.

MARGALEF, R., 1983. Limnología. Omega, Barcelona, 1010 pp.

OHNGEMACH, D. and H. STRAKA 1983. Resumen en español del trabajo en Puebla de la comunidad alemana. *In:* W. Lauer (Ed.), Das Mexiko-Projekt der Deutschen Forschungsgemeinschaft 18: Beiträge zur Vegetation- und Klimageschichte im Gebiet von Puebla-Tlaxcala. S. Steiner, Wiesbaden, pp. 143-161.

PHILANDER, S. G., 1990. El Niño, La Niña, and the Southern Oscillation. Academic Press, San Diego.

RAMÍREZ-GARCÍA, P. and A. NOVELO. 1984. Vegetación acuática vascular de seis lagos crater en el estado de Puebla, México. *Bol. Soc. Bot. Mexico 46,* 75-88.

REYES, C. M., 1979. Geología de la Cuenca Oriental. Estados de Puebla, Veracruz y Tlaxcala. Inst. Nal. Antrop. Hist. De México. 62 pp.

ROPELEWSKI, C. F. and M. S. HALPERT, 1989. Precipitation patterns associated with the high index phase of the Southern Oscillation. *J. Climate 2,* 268-284.

SAARNISTO, M., 1986. Annually laminated lake sediments. pp 343-370. *In:* B.E. Berglund (Ed.): Handbook of Holocene Palaeoecology and Palaeohydrology. John Wiley & Sons, Ltd., Chichester, 869 pp.

STRAKA, H. and D. OHNGEMACH, 1989. Late Quaternary vegetation history of the Mexican highland. *Plant Systematics and Evolution 162*, 115-132.

STRAUB, F., 1993. Diatoms and their preservation in the sediments of Lake Neuchâtel (Switzerland) as evidence of past hydrological changes. *Hydrobiología 269/270,* 167-178.

TAVERA, R. and J. KOMÁREK, 1996. Cyanoprokaryotes in the volcanic lake of Alchichica, Puebla State, Mexico. *Algological Studies 83,* 511-538.

VILACLARA, G., M. CHÁVEZ, A. LUGO, H. GONZÁLEZ and M. GAYTÁN, 1993. Comparative description of crater-lakes basic chemistry in Puebla State, México. *Verh. Internat. Verein. Limnol. 25 (1),* 435-440.

WHITE, S. E., 1962. Late Pleistocene glacial sequence for the west side of Iztaccíhuatl, México. *Geol. Soc. Am. Bull., 73,* 935-958.

WHITE, S. E., 1986. Quaternary glacial stratigraphy and chronology of Mexico. *Quat. Sci. Rev., 5,* 201-205.

WHITE, S. E. and S. VALASTRO, Jr. 1984. Pleistocene glaciation of volcano Ajusco, Central Mexico, and comparison with the standard Mexican glacial sequence. *Quatern. Res., 21,* 21-35.

WHITE, S. E., M. REYES C., J. ORTEGA R. and S. VALASTRO Jr. 1990. El Ajusco: Geomorfología volcánica y acontecimientos glaciares durante el Pleistoceno superior y comparación con las series glaciales mexicanas y las de las Montañas Rocallosas. Colección Científica, INAH, México.

ZEBIAK, S. E. and M. A. CANE, 1987. A model of El Niño-Southern Oscillation. *Month. Weath. Rev., 115,* 2262-2278.

Margarita Caballero[1], Gloria Vilaclara[2], Alejandro Rodríguez[3] and Diana Juárez[3]

[1] *Institute of Geophysics, UNAM, Ciudad Universitaria, Coyoacán, 04510 México, D. F., México.*
Email: maga@geofisica.unam.mx

[2] *FES-Iztacala, UNAM, Los Reyes Iztacala, 54090 Tlalnepantla, Edo. de México.*

[3] *Posgrado de Ciencias del Mar y Limnología, UNAM, 04510 Ciudad Universitaria, México, D. F., México.*