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Rock-magnetic study of Late Pleistocene-Holocene sediments from the Babícora lacustrine basin, Chihuahua, northern Mexico

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RESUMEN

Se reportan los resultados del estudio de propiedades magnéticas y sedimentología en dos perfiles de la secuencia lacustre Cuaternaria de Babícora (29.4° N, 107.7° W; 2,100 m a.s.l.), Estado de Chihuahua, México. Las variaciones de susceptibilidad magnética e intensidades de magnetización remanente natural (NRM) e isotermal (IRM) correlacionan con los contenidos relativos de arenas, arcillas y limos en los sedimentos. Estas relaciones estratigráficas sugieren que los minerales magnéticos son de origen externo y transportados al lago por procesos erosivos. Las curvas de adquisición de IRM y el espectro de coercitividad de campos alternos indican la ocurrencia de titanomagnetitas ricas en hierro, hematitas e hidróxidos de hierro. Las fluctuaciones en el aporte de sedimentos correlacionan con cambios en los procesos de erosión, clima y tectonismo en la cuenca. Cinco fechas de radiocarbono en el rango entre 4,346 y 16,343 años A.P. permiten un control cronológico preliminar. El perfil en el sector sur cubre un periodo mayor que el perfil del sector oeste, que cubre el intervalo entre 11,000 y 6,000 años cuando el lago se extendió en la cuenca. Dos periodos mayores de incremento en la precipitación caracterizados por niveles altos del lago ocurren en el Pleistoceno Tardío y en el Holoceno Temprano. El periodo húmedo del Wisconsin Tardío es seguido por un periodo de aridez gradual hacia los 6,000 años A.P. Entre los 11,000 y los 8,000 años, se tiene otro periodo de incremento en la precipitación de verano. El intervalo árido entre los 3,000 y los 2,000 años es seguido por una etapa de incremento regional en la erosión.

PALABRAS CLAVE: Propiedades magnéticas, sedimentología, Cuaternario, lago de Babícora, Estado de Chihuahua.

ABSTRACT

Rock-magnetic and sedimentological studies of the Quaternary sequence of lake Babícora (29.4°N, 107.7°W; 2,100 m a.s.l.) from Late Wisconsin to Holocene are reported. Two vertical profiles have been studied. Magnetic susceptibilities and natural remanence (NRM) and isothermal remanence (IRM) intensities correlate with sand, silt and clay contents in the sediments, suggesting that magnetic minerals are allogenic. IRM acquisition curves and alternating field coercivity spectra document the occurrence of Ti-poor titanomagnetites, hematites and iron-hydroxides. The fluctuations in the input of sediment correlate with changes in erosional processes, climate and tectonics in the catchment basin. Five radiocarbon dates ranging from 4,346 to 16,343 yr B.P. were obtained. The southern profile covers a longer time span than the western profile, which spans from 11,000 to 6,000 yr B.P., when the lake extended over a larger area. Two major periods of increased rainfall and high lake levels in Late Pleistocene and Early Holocene are recognized. The Late Wisconsin wet period was followed by gradual drying up to around 6,000 yr B.P. Between 11,000 and 8,000 yr B.P. there was another wet period, related to increased summer rainfall. The dry period between 3,000 and 2,000 yr B.P. was followed by widespread erosion.

KEY WORDS: Rock-magnetic properties, sedimentology, Quaternary, lake of Babícora, State of Chihuahua.

INTRODUCTION

Recently paleomagnetic methods have been successfully used in paleoenvironmental and paleoclimatic studies (e.g., Thompson and Oldfield, 1986). Stratigraphic variation in magnetic parameters has been used for lateral correlation and relative dating of sedimentary sequences. Contents of magnetic minerals and magnetic properties of river and lake sediments have become increasingly important for paleoenvironmental studies (Thompson and Oldfield, 1986). Lacustrine basins are mostly material-bounded with closed lake-watershed ecosystems which conveniently provide spatially finite study areas. The lacustrine sedimentary record yields often information concerning the characteristics and processes of the catchment basin such as topography, slope processes, lithology, material flux, vegetation cover, tectonics and erosional processes, and seasonal to long-term climate changes.

Magnetic minerals in lake sediments are usually classified in terms of their origin as authigenic, diagenetic and allogenic. Authigenic minerals are formed in situ by chemical or biogenic processes. Diagenetic minerals result from the transformation of already present minerals. Allogenic minerals originate outside the lake, and may come from nearby or distant sources. Magnetic minerals usually represent a small percentage of lake sediments; yet the study of the magnetic properties of bulk sediments helps investigate the magnetic mineralogy, grain size, sediment source, and diagenetic and authigenic processes (e.g., Dearing *et al.*, 1981; Thompson and Oldfield, 1986; Lozano-García *et al.*, 1993; Snowball, 1993).

In this paper we report some initial results of an interdisciplinary study of Late Pleistocene-Holocene sediments from the Babícora basin, Chihuahua, Mexico (Ortega-Ramírez, 1995a,b). We report a rock-magnetic study of two vertical profiles located in the southern and western sides of the basin (Figure 1).

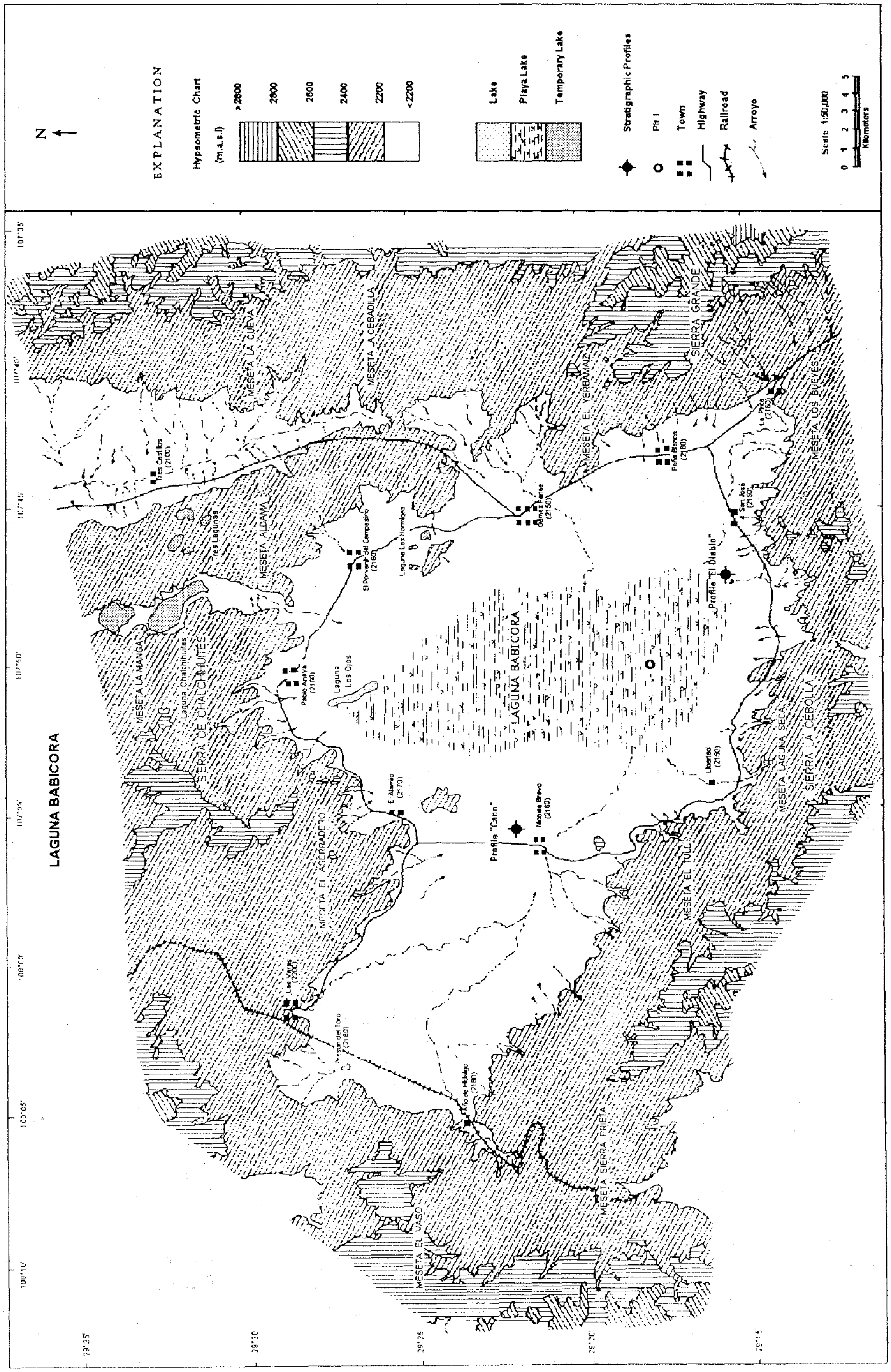

Fig. 1. Location of study sites in the Babícora basin. Vertical profiles sampled are: El Diablo in the southern sector and El Cano in the western sector. Pit I corresponds to the site studied in Metcalfe *et al.* (in press).

GEOLOGIC SETTING

The Babícora basin (29° 15'-29° 30' N, 107° 40'-108° 00' W) is located in western Chihuahua, northern Mexico (Figures 1). The basin was formed by volcanic and tectonic processes during the Tertiary and Quaternary. It lies in the Basin and Range province at the foothills of the Sierra Madre Occidental. Hawley (1969) identifies the high altitude Basin and Range province as the Babícora-Bustillos sector, where basin floors vary between 1,800 and 2,250 m asl and volcanic ranges are higher than 2,700 m asl. The N-S to NNW-SSE oriented narrow volcanic ranges and basins favor internal drainage and the development of ephemeral or permanent lakes. Interior drainage basins take up nearly 50 % of the territory of Chihuahua (Hawley, 1969; Schmidt, 1975). The Babícora basin lies at an altitude of about 2,100 m asl and extends over an area of 1,860 km^2. The volcanic ranges surrounding the basin reach altitudes of 2,500 to 3,000 m and are mainly formed by Miocene-Pliocene rhyolites and some Quaternary basaltic flows. The basin features a lowland marshy area and two permanent shallow lakes in its northern sector. The climate is semi-arid cool steppe with summer rainfall, after the Köeppen-Geiger classification (Schmidt, 1975). Present-day mean annual precipitation is around 550 mm and the maximum mean annual temperature is about 12.5°C, with dry and cold winters and hot and humid summers (Mosiño and García, 1973; Schmidt, 1975). The paleoclimatic and paleoenvironmental evolution of Babícora basin has been the object of two recent studies (Ortega-Ramírez, 1995 a,b; Metcalfe *et al.*, in press).

ROCK-MAGNETIC STUDY

Two vertical profiles have been sampled for the rock-magnetic study (Figures 2 and 3). The El Diablo profile lies in the southwestern sector of the lowland marshy area and the El Cano profile lies in the western sector (Figure 1). The El Diablo profile is 2.5 m thick. Four distinct units have been distinguished from field observations and sedimentology (Figure 2). Unit I is a brown silty sand with abundant organic matter; it is horizontally stratified with a transitional contact at its base. Unit II is a grey brown to grey silty clay which is stratified with a sharp basal contact. Unit III is a grey fine-grained sand with abundant ostracodes and an irregular basal contact. Unit IV is a brown-grey sand and silt. The variation in the relative contents of sand, silt and clay is shown in Figure 2b. Three radiocarbon dates (Figure 4) provide a preliminary chronological control for the profile (Ortega-Ramírez *et al.*, in preparation).

In the El Cano profile, which is about 3 m thick, three composite units have been identified (Figure 3). Unit I is a 1.55 m layer of black to dark grey silts and clays with transitional contacts and abundant organic matter, horizontal stratification, and a sharp basal contact. Unit II is a 1.4 m thick composite sequence of sandy clay, silty clay and fine-grained sand with brown dark grey to yellowish brown color and a transitional basal contact. Unit III, exposed at the base of the profile, is a gravel to sand with subrounded rhyolitic fragments. The contents of sand, silt and clay are shown in Figure 3b. Silt and clay dominate in unit I. Two

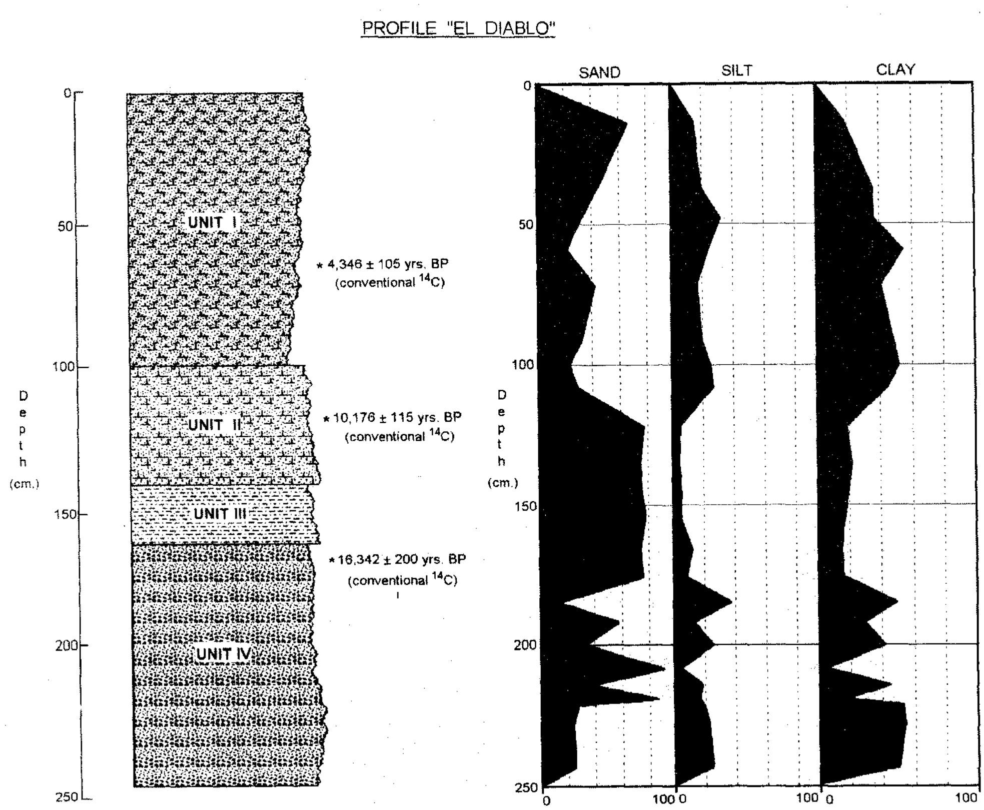

Fig. 2. (a) Stratigraphic column for El Diablo profile. (b) Contents of sand, silt and clay as a function of depth.

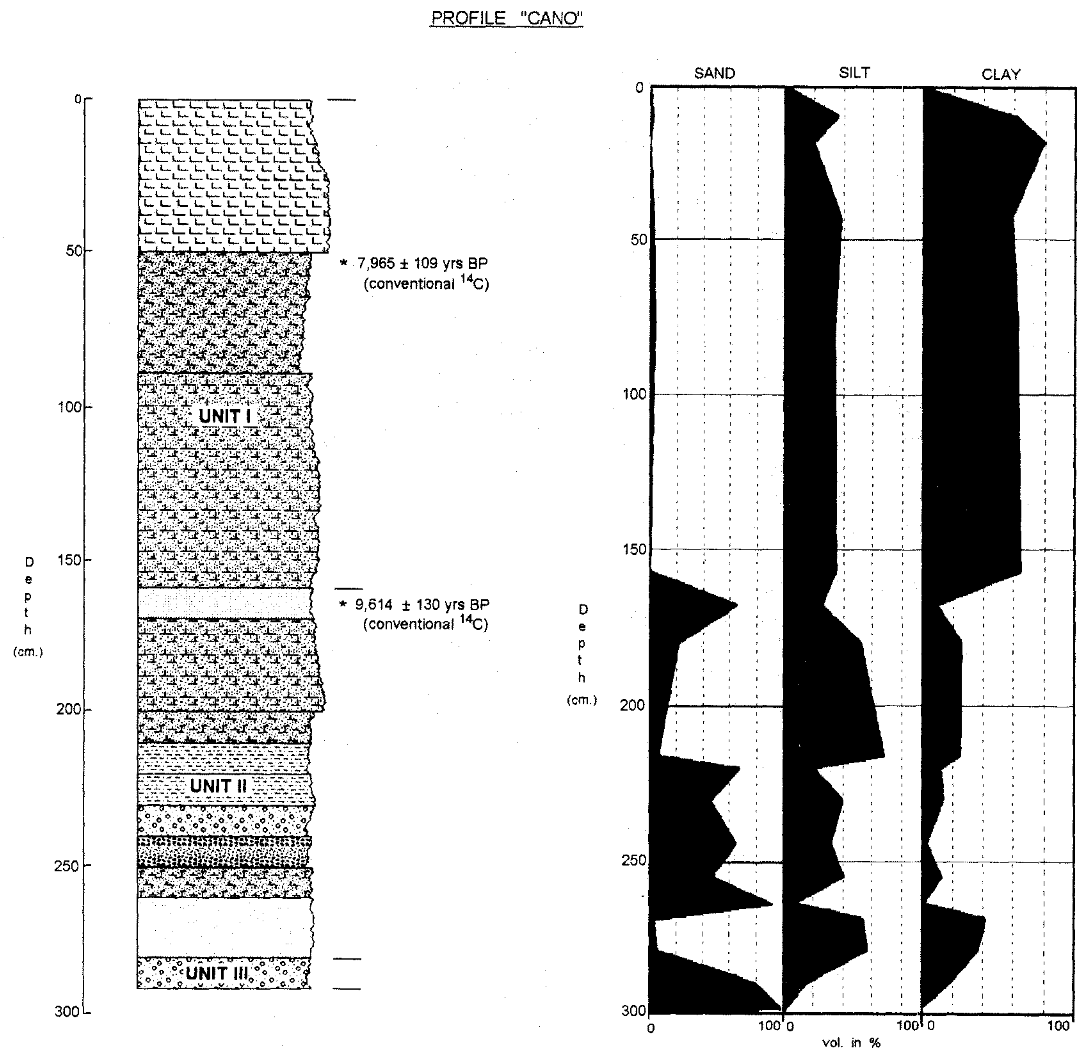

Fig. 3. (a) Stratigraphic column for El Cano profile. (b) Contents of sand, silt and clay plotted as a function of depth.

radiocarbon dates (Figure 4) are available for this profile (Ortega-Ramírez *et al.*, in preparation).

Standard 2.2x2.2x2.2 cm samples were collected within the lacustrine units and subunits at variable spacings. A total of 41 samples (23 in the El Diablo profile and 18 in the El Cano profile) were used.

The low-field magnetic susceptibility was measured with the Bartington system equipped with the laboratory sensor. The susceptibility displays different patterns of variation with depth (Figures 5 and 6). In the El Diablo profile the susceptibility is higher near the surface and decreases around the middle part of unit I. The variations correlate with the relative proportion of sand within all four units (Figure 2). The susceptibility in the El Cano profile shows low values in unit I down to 1.55 cm depth and higher values units II and III (Figure 6). Again the susceptibility correlates closely with sand content (Figure 3). In unit I, the proportion of sand is small in comparison with silt and clay.

The intensity and direction of natural remanent magnetization (NRM) were measured with a Czech spinner JR-5 magnetometer. NRM intensity varies between 46 mA/m to 0.1 mA/m in the El Diablo profile and between 110 mA/m and 0.1 mA/m in the El Cano profile. The pattern of variation with depth is different in both profiles. In the El Diablo profile the higher values are close to the surface and progressively decrease within unit I. The intensity remains small in units II to IV, with some fluctuations (Figure 5). In the El Cano profile, values are small, less than 5 mA/m, within unit I; they increase to around 15 mA/m in unit II and the highest values are found in unit III at the bottom of the profile (Figure 6).

The samples were subjected to a stepwise isothermal remanent magnetization (IRM) by applying a direct magnetic field with a pulse magnetizer. IRM acquisition curves are given for some samples of both profiles in Figure 7. The saturation IRM (or maximum IRM) for every sample was demagnetized by using an alternating field (AF) Schonstedt demagnetizer in steps up to 100 mT. This per–

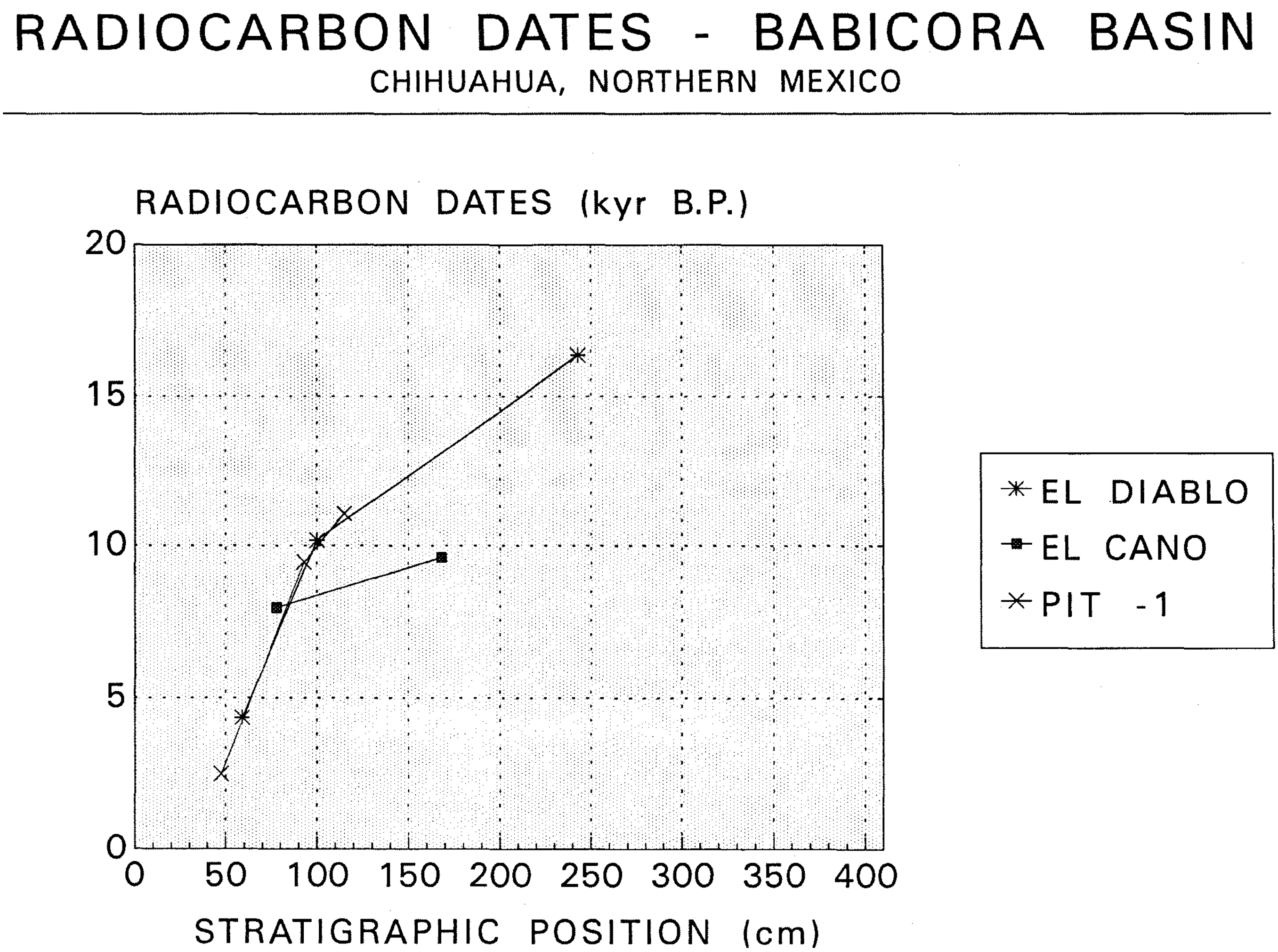

Fig. 4. Radiocarbon dates for El Diablo and El Cano profiles and for Pit I site, plotted as a function of stratigraphic position. Regression curves assume potential functions.

mits investigation of the coercivity spectra. Examples of AF normalized intensity curves are given in Figure 8. Remanence magnetic carriers are mainly Ti-poor titanomagnetites, likely derived from the rhyolitic rocks. The saturation IRM and a partial-IRM are shown for the two profiles in Figures 5 and 6. The IRM shows a similar pattern as that of the NRM, with high values near the surface in the El Diablo profile and at the bottom of the El Cano profile. NRM intensity depends on two major factors: (1) the magnetic mineralogy (carriers of remanence) and the grain size, and (2) the intensity of the ambient geomagnetic field. IRM intensity depends on factor (1), assuming that the laboratory conditions for imparting the remanence are the same for all samples. Comparison of NRM and IRM curves for the El Diablo profile shows differences at about 90-100 cm, 150 cm and 220 cm, which may relate to the geomagnetic field variations. In the El Cano profile, major differences can be observed within unit II, with three peaks in the IRM curve.

The magnetic coercivity spectra for the El Cano profile show a larger percentage of high coercivity than for the El Diablo profile (Figure 8). The low coercivity corresponds to poor-Ti titanomagnetites, which agrees with the inferences from the other magnetic properties such as low-field susceptibility and NRM intensities.The high coercivity fraction observed in the El Cano samples may imply the occurrence of oxidation products such as titanohematites or the presence of iron-hydroxides. The AF demagnetization curves (Figure 8) show that between 30 and 10% of the initial remanence remains after demagnetization up to 60-80 mT.

DISCUSSION

The stratigraphic variation of magnetic properties in two profiles of the Babícora basin correlates with lithology (composition, texture, colour, grain size, and nature of unit contacts), and particularly with the relative proportions of sand. In the El Cano profile, this correlation is particularly marked because of the absence of sand in the first shallow unit. Susceptibility, NRM intensity and IRM intensity display similar patterns characterized by low values for unit I and higher values and higher within-unit variability for

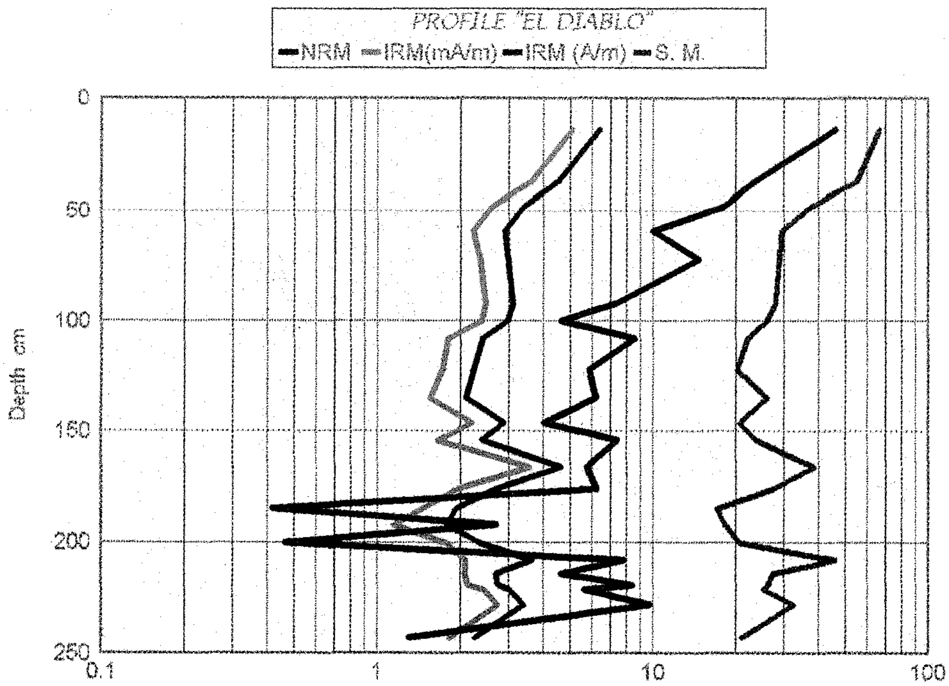

Fig. 5. Summary of rock-magnetic properties observed in El Diablo profile plotted as a function of stratigraphic position.

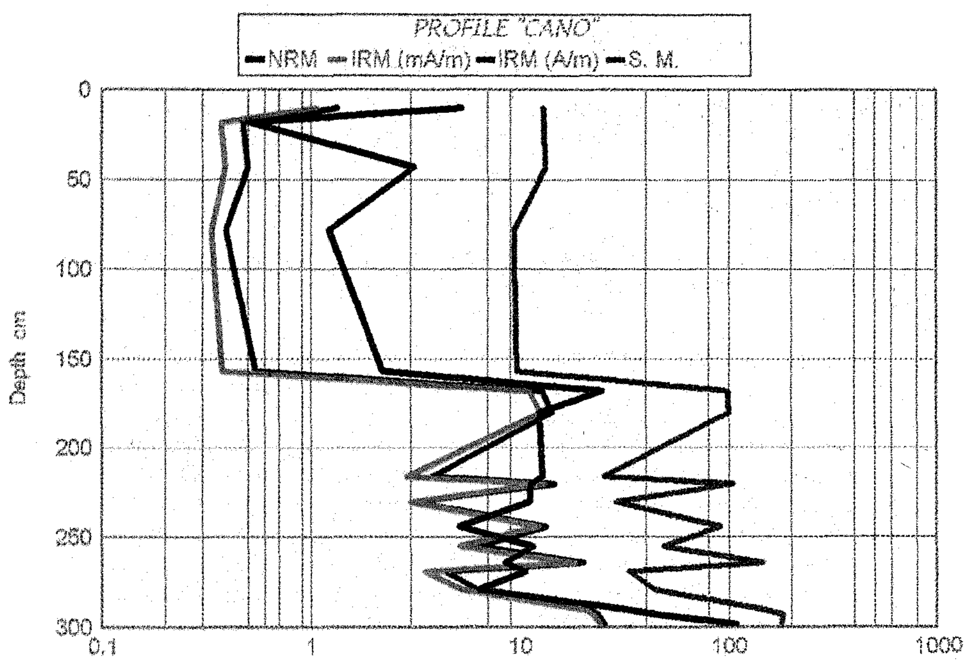

Fig. 6. Summary of rock-magnetic properties observed in El Cano profile plotted as a function of stratigraphic position.

units II and III. The variation in susceptibility and IRM intensity within unit II correlates with the relative content of sand in the unit. These results suggest that the magnetic minerals are likely allogenic. The iron-titanium oxides came from the surrounding rocks in the catchment basin and were transported to the lake. The oxides are mainly Ti-poor titanomagnetites and magnetites derived from the surrounding rhyolitic rocks. A smaller percentage of high coercivity minerals observed in the AF demagnetization curves is also present in samples from both profiles. Their significance and origin are to be established by future rock-magnetic experiments.

The stratigraphic variations in susceptibility and IRM intensity within sedimentary units are likely reflecting fluctuations in the input of sediment into the lake. These

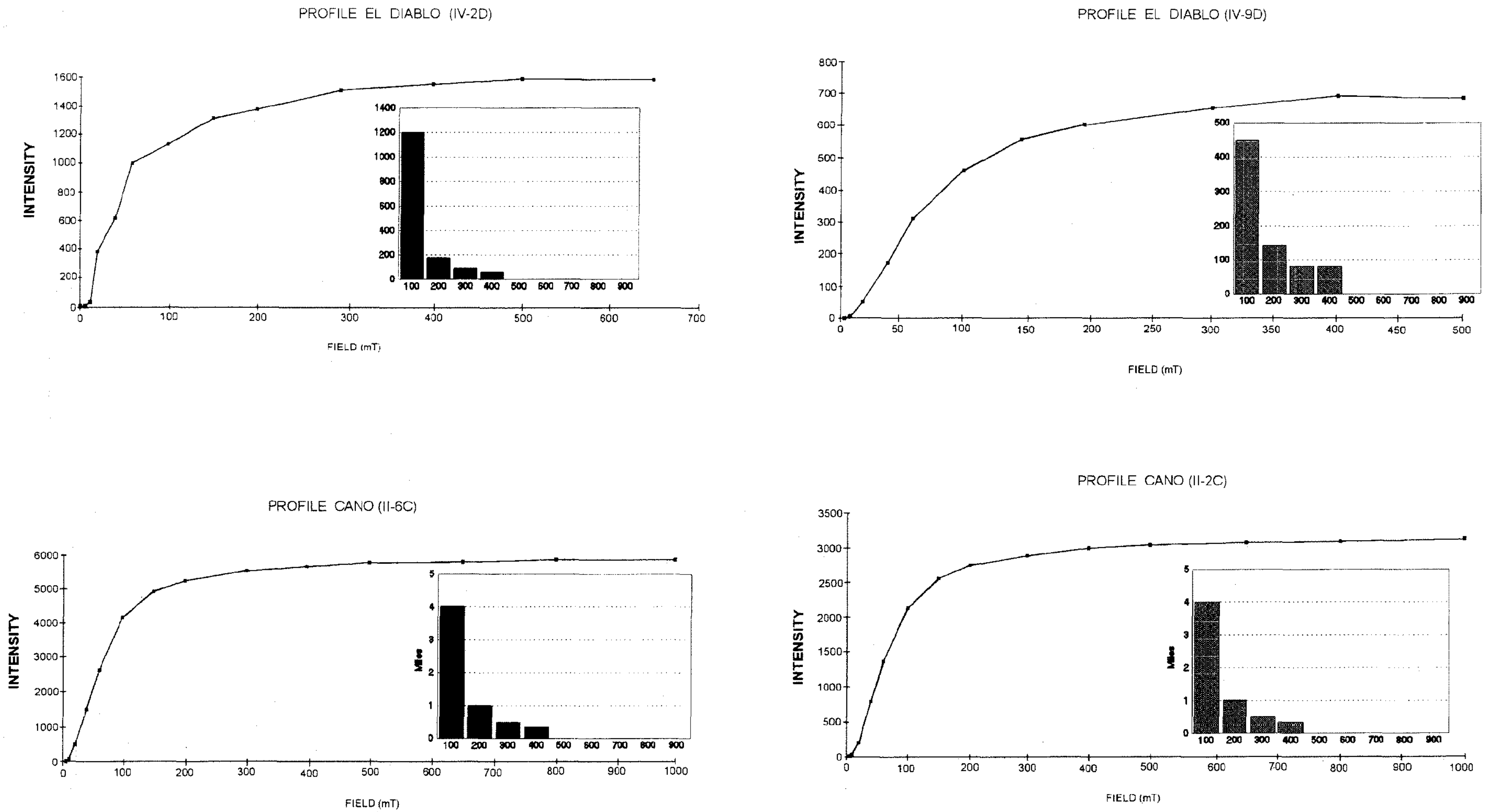

Fig. 7. Examples of isothermal remanent magnetization (IRM) acquisition curves for samples from El Diablo and El Cano profiles. The coercivity spectra are given in form of histograms. Note that most of the magnetization is acquired below 100 mT.

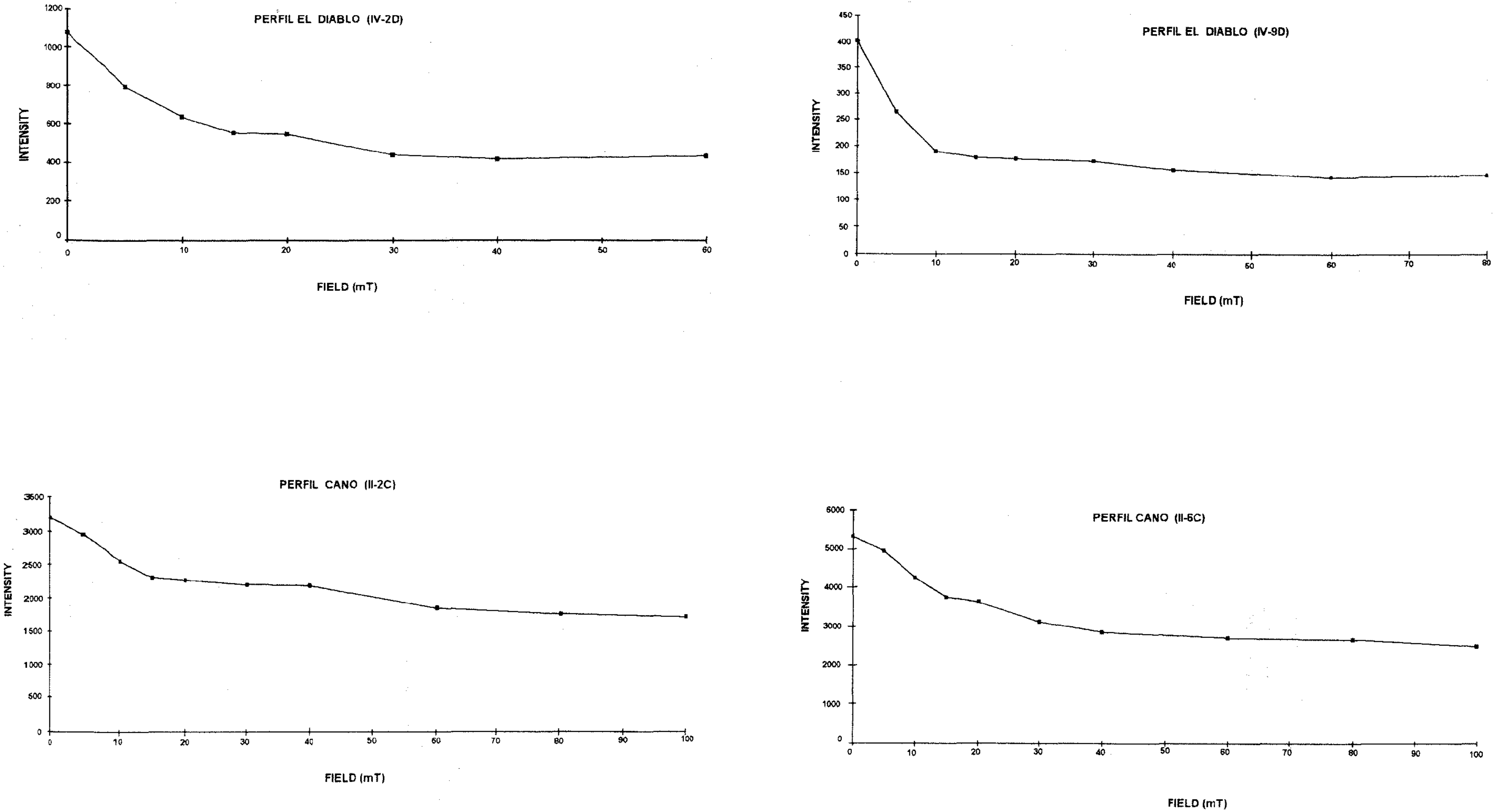

Fig. 8. Examples of alternating field demagnetization curves for samples of El Diablo and El Cano profiles. Normalized intensity changes are plotted as a function of apllied field.

fluctuations are in turn related to changes in erosional processes, climate, and tectonics. Results from other lacustrine basins with various environments also suggest that the magnetic minerals are mostly hallogenic (e.g., Dearing *et al.*, 1981; Thompson and Oldfield, 1986; Snowball and Thompson, 1992). Thus input of magnetic minerals estimated from the stratigraphic patterns of susceptibility and other magnetic parameters may be used as a measure of erosion and depositional processes. Changes in climate and vegetation cover in the catchment area can also be inferred from the magnetic measurements (Peck *et al.*, 1994).

The variation of rock magnetic properties with stratigraphic position is different in the two profiles (compare patterns in Figures 5 and 6). Units in the two profiles cannot be laterally correlated. The radiocarbon dates for the El Cano profile suggest that this profile represents a shorter time interval than that covered in the El Diablo profile. Extrapolation of the curve fitted to the radiocarbon dates tentatively suggests that units I and II span a period from 11,000 to 6,000 yr B.P. Unit III, which is formed by gravel and sand with subrounded rhyolitic clasts, dates from the end of the glacial period and represents an interval of increased erosion and transport into the lake. The next interval, up to 8,000 yr B.P., may have also been a wet period with the lake extending over a large area. Lacustrine sediments were deposited in the western El Cano profile, represented by unit II and part of unit III. The stratigraphic changes in unit II may reflect changing conditions in the extension and water level of the lake in response to climatic conditions. Depositional conditions in the southern El Diablo profile were probably less affected by changes in water level and extension of the lake. The area was probably under water most of the time, which is reflected by the sediments of unit II.

Metcalfe *et al.* (in press) have studied a section located about halfway between the El Diablo and El Cano profiles (Figure 1). This profile, labelled Pit 1, is 140 cm long and is composed of fine layered dark grey/black clays from the surface down to 55 cm underlain by hard brown clays from 90 cm to 140 cm. The middle unit is formed by dark grey/brown and light grey silty clays with white concretions. Low field susceptibility increases irregularly from the surface to the bottom with peaks at about 60, 105 and 130 cm. Sediment input was higher below 100 cm. Three radiocarbon dates of 2,470 ± 60, 9,470 ± 60 and 11,060 ± 390 yr B.P. are available for depths 47, 94, and 115 cm, respectively. This chronology correlates well with the El Diablo profile (Figure 4).

In summary, we find two major periods of increased humidity during the late Pleistocene and early Holocene characterized by high lake levels and extensive lake surface. The early Holocene wet period was followed by gradual drying, with arid conditions at about 6,000 yr B.P. The extent of the lake shrank and the western region was probably exposed to erosion. This was followed by another wet period and changes in lake level and extension. A dry phase followed from around 3,000 to 2,000 yr B.P. This arid phase is marked by a widespread 2,000 yr old erosion surface (Ortega-Ramírez, 1995a,b).

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