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Ortega Guerrero, Beatriz; Caballero Miranda, Margarita; Lozano García, Socorro; De la O Villanueva, Margarita

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# Palaeoenvironmental record of the last 70 000 yr in San Felipe Basin, Sonora desert, Mexico: preliminary results

Ortega Guerrero, Beatriz[1], Caballero Miranda, Margarita[2], Lozano García, Socorro[3] and De la O Villanueva, Margarita[4]

[1] *UNAM, Instituto de Geofísica, Estación Regional del Noroeste. Hermosillo, Son., México.*
[2] *UNAM, Instituto de Geofísica, México, D.F., México.*
[3] *UNAM, Instituto de Geología, México, D.F., México.*
[4] *Universidad de Sonora, Depto. de Geología, Hermosillo, Son., México.*

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**RESUMEN**

Con el propósito de documentar los cambios paleoambientales, se lleva a cabo una investigación multidisciplinaria en la Laguna Seca de San Felipe, Baja California. Los resultados preliminares incluyen análisis sedimentológicos de diatomeas y propiedades magnéticas de un núcleo de 9.5 m de longitud. Fechamientos de $^{14}C$ sugieren que la secuencia abarca los últimos 70 000 años. Los resultados de propiedades magnéticas ($\chi$, $\chi_{fd\%}$, MRIS, MRA, parámetros de histéresis y cocientes S), contenido de materia orgánica y tamaño de partículas indican condiciones contrastantes entre el último glacial del Pleistoceno y el glacial tardío-Holoceno. Se infieren condiciones secas entre 70 000 y 45 000 años A.P. El pleniglacial, entre 34 000 y 19 000 años A.P., está caracterizado por condiciones húmedas. A partir de 12 000 años A.P. la tasa de sedimentación y los parámetros magnéticos se incrementan en un factor de 5, cambio interpretado como el aumento en el escurrimiento de aguas superficiales. Entre 7000 y 6000 años A.P. se registra un periodo de aridez, a partir del cual se recuperan las condiciones húmedas. El establecimiento de las actuales condiciones áridas se infiere alrededor de 4000 años A.P.

**PALABRAS CLAVE:** Propiedades magnéticas, sedimentos lacustres, paleoclimas, Cuaternario, Baja California.

**ABSTRACT**

Preliminary results of a palaeoenvironmental research which includes particle size analyses, diatom and rock-magnetic analyses for a 9.5 m long core from Laguna Seca de San Felipe (LSSF), Baja California, are presented. AMS $^{14}C$ dating gives an extrapolated age of ca. 70 kyr for the sequence analysed. Rock-magnetic measurements (including $\chi$, $\chi_{fd\%}$, ARM, SIRM, hysteresis parameters and S ratios), organic content (LOI) and particle size distribution show highly contrasting conditions between glacial and late glacial-Holocene sediments. Dry conditions prevailed between 70 000 and 45 000 yr ago. The full glacial, between 34 000 and 19 000 yr ago, is characterized by moist conditions. The late glacial-Holocene sediments display a five-fold increment in most of the magnetic parameters and in sedimentation rate. This change is interpreted as an increment in runoff waters. At ca. 7000 yr B.P., a dry period is recorded, which probably spans until 6000 yr B.P., when moist conditions return. The onset of the actual arid characteristics occurred around 4000 yr B.P.

**KEY WORDS:** Magnetic properties, lake sediments, Quaternary paleoclimates, Baja California.

## INTRODUCTION

The large North American deserts located in the SW USA and NW Mexico, comprise the Mojave, Sonora and Chihuahua deserts (Figure 1), represent a transition zone of annual rainfall distribution. Precipitation maxima in the Mojave desert occurs in winter, when the westerlies carry humidity from mid-latitudes in the Pacific. The Chihuahua desert features summer rainfall, through the monsoon-type circulation from the Gulf of Mexico and from hurricanes in the tropical Pacific. Rainfall in the Sonoran desert ranges from a biseasonal regime with strong summer monsoon-type precipitation in Sonora and Arizona, to a westerlies winter precipitation regime, on the west coast of Baja California. The higher ranges experience freezing temperatures.

Climatic fluctuations associated to variations in the Earth's orbital parameters during the Late Quaternary have been studied in diverse palaeoenvironmental continental records in North and Central America (e.g. Ruddiman and Wright, 1987; Urrutia *et al*., 1997). Lacustrine sedimentary sequences good stratigraphical resolution for periods older than 10 000 yr ago. Lake-level changes have been inferred from shorelines and from sedimentological and palaeontological data. Most of the palaoenvironmental information from the Mojave, Sonora and Chihuahua deserts was obtained from fossil plant assemblages in packrat middens (e.g. Betancourt *et al*., 1990). The chronology and extent of some of these inferred climatic changes are still being discussed, particularly the transition from late Wisconsin (ca. 12 000 yr B.P.) to mid Holocene (ca. 5000 yr B.P.). Spaulding and Graumlich (1986)


Fig. 1. Distribution of main deserts in NW Mexico and SW USA.

and Spaulding (1990; 1991) infer dry conditions during mid Holocene (ca. 7500 to 4500 yr B.P.), but Van Devender (1990a; 1990b) proposes higher summer precipitation and generally moist conditions between 9000 and 4500 yr B.P.

Palaeoclimate research for the last 18 000 years in these deserts is sparse (e.g., Spaulding, 1991; Thompson *et al.*, 1993; Van Devender *et al.*, 1994; Ortega, 1995; Metcalfe *et al.*, 1997), and there are few studies in earlier records covering Middle Wisconsin (Van Devender, 1990a; Elias and Van Devender, 1990). Research on terrestial records has been particularly scarce in some areas, in Baja California only palaeoclimatic data from pack rat middens is available (Van Devender, 1990b; Peñalba, 1997).

In this paper, we present the preliminary results of rock-magnetic properties, diatom analyses and sedimentology obtained from a 9.5 m long core collected in the central part of the Laguna Seca de San Felipe (LSSF), Baja California (Figure 2).

Rock-magnetic methods have successfully been used to evaluate a variety of environmental changes in lake

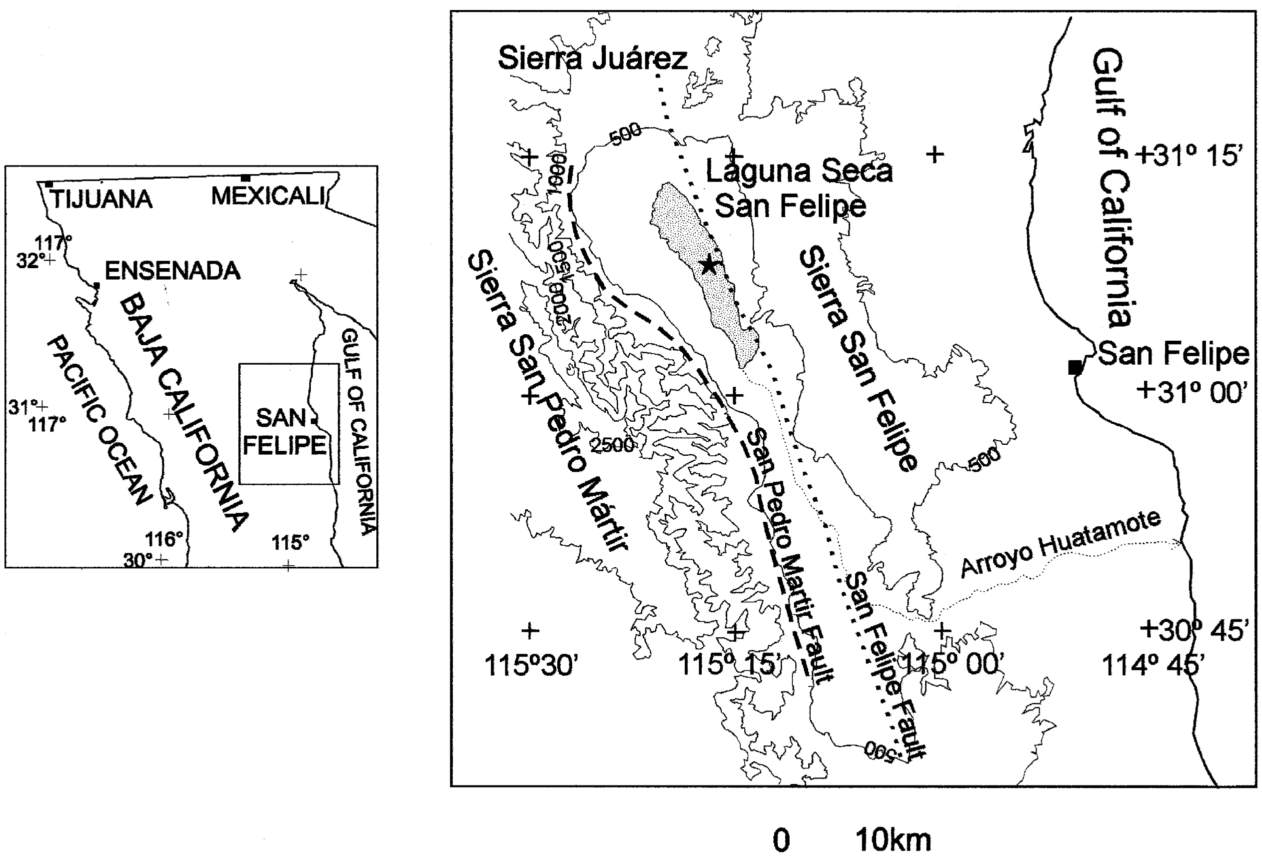


Fig. 2. Localisation map of Laguna Seca de San Felipe (LSSF). Star indicates coring site.

sediment sequences (e.g., Snowball and Thompson, 1992; Thouveny *et al*., 1994). Combined analyses of variations in concentration-dependent magnetic parameters along with mineralogy and size-dependent parameters can provide proxy records of climatic change, as climate affects weathering and sedimentation processes (e.g., Bloemendal and DeMenocal, 1989; Snowball, 1993). Mineral magnetic analyses can enhance the stratigraphic resolution achieved with conventional sedimentological or geochemical procedures.

LSSF (115°15'W, 31°08'N) is located at the westernmost part of the Sonoran desert, in the Gulf Extensional Province, where it occupies a tectonic depression filled with 2.4 km of sediments (Slyker, 1970). Cretaceous granodiorites outcrop in the San Pedro Martir and San Felipe ranges, and Cenozoic volcanic and sedimentary rocks form the Sierra Juárez (Figure 2) (Gastil *et al*., 1975, 1981; Lee *et al*., 1996).

LSSF is 17 km long and 4 km wide, and it drains to the south to the Gulf of California by the Huatamote river. To the east and west of the basin there are NNW elongated eolic accumulations up to 5 m in thickness. Nowadays LSSF is dry, locally covered by patches of salt, and deflation is a common process.

The climate in San Felipe Basin is very dry, temperate, characterized by mean annual temperature of 18-20° C. Mean annual rainfall in San Felipe basin is about 100-200 mm/yr, and up to 300 mm/yr in the mountain ranges. In the upper parts of San Pedro Martir and Juárez ranges the annual average of days with freezing temperatures is 100-140, and diminishes to the lower parts, up to 20 days per year in San Felipe basin (INEGI, 1984).

## METHODS

A 9.5 m long core was drilled, using an Eijelkamp soil sampler, in the central part of the basin (Figure 2). Sampling for fossil content analysis was carried out every five cm in one cm thick slice. 10cm$^3$ material was sampled in non-magnetic acrylic boxes for the magnetic analyses, and the remaining material was used for organic matter content and particle size analyses.

Organic matter content was determined by loss-on-ignition (LOI) at 550°C during two hours, and results presented as percentage of dry weight. Samples for LOI were taken approximately every 10 cm. Particle size determinations were performed in a Microtrac SRA200 laser analyser in 37 samples distributed along the profile. Statistical parameters, mean particle size, standard deviation and skewness, were calculated (Folk and Ward, 1957).

For diatom analyses samples 0.5 g of dry sediment oven dried overnight at 60°C were cleaned by gently boiling with HCl (10%) and NaClO (10%). Samples were rinsed until neutral pH was reached and then taken to a constant volume of 30 µl. For microscope analysis, 200 µl of final solution were mounted in round coverslips using Naphrax as medium. A minimum of 100 valves counts was carried out with an Olympus BH2 microscope at 1 000x magnification.

For rock-magnetic analyses all samples were weighted in order to allow their magnetic properties to be expressed in specific units. The magnetic susceptibility ($\chi$) of all samples was measured with a Bartington MS2 dual frequency susceptibility bridge in 0.465 kHz ($\chi_{lf}$) and 4.65 kHz ($\chi_{hf}$). Frequency dependent susceptibility, $\chi_{fd\%} = [\chi_{lf}-\chi_{hf}]/\chi_{lf}$, is expressed as percentage. Remanences were measured using a Molspin fluxgate magnetometer. A PMag pulse magnetiser was used to induce isothermal magnetisations. A range of forward and backward isothermal remanent magnetisation (IRM) measurements were made in fields between 40 and 1000 mT. The measurement in 1 Tesla was taken as the saturation isothermal remanent magnetisation (SIRM) value. Several ratios and percentages, e.g. SIRM/$\chi$, and F and S ratios, where $F_{+xmT} = 100(IRM_{+x}/SIRM)$ and $S_{-xmT} = 100(SIRM-IRM_{-xmT})/2SIRM$, were calculated to investigate variations in the proportions of different magnetic components. A µMag alternating gradient magnetometer was used to determine the hysteresis parameters of selected samples: coercive force, $(B_o)_C$, coercivity of remanence, $(B_o)_{CR}$, saturation remanence ($M_R$) and saturation of magnetisation ($M_S$).

## RESULTS

### Stratigraphy

The stratigraphy, magnetic susceptibility ($\chi$), loss-on-ignition (LOI), mean particle size ($\phi$) and $^{14}$C AMS dating results are summarized in Figure 3. Sediments are composed essentially of silt size particles, with several intercalations of sand particles. The bottom part of the sequence, between 9.50 and 7.35 m depth, is composed upwards of intercalations of green, white, black and reddish sand. From 7.35 to 4.40 m depth, sediments are dominated by green and black silt. The upper half of the sequence is pale brown silt with some sand content.

A time scale for the column was constructed from six AMS $^{14}$C dates in bulk sediments (Figure 3, Table 1). Linear regression of the dates was applied separately for the four older and the three younger ages. Linear interpolation yields different rates, of 0.09 mm/yr for sediments below 4.35 m depth, and 0.56 mm/yr above this depth. By extrapolation, the estimated age for the bottom and top of the sediment column is of ca. 70 000 yr and 4000 yr, respectively.

LOI results are plotted together with magnetic susceptibility (Figure 3). As estimated from LOI, organic

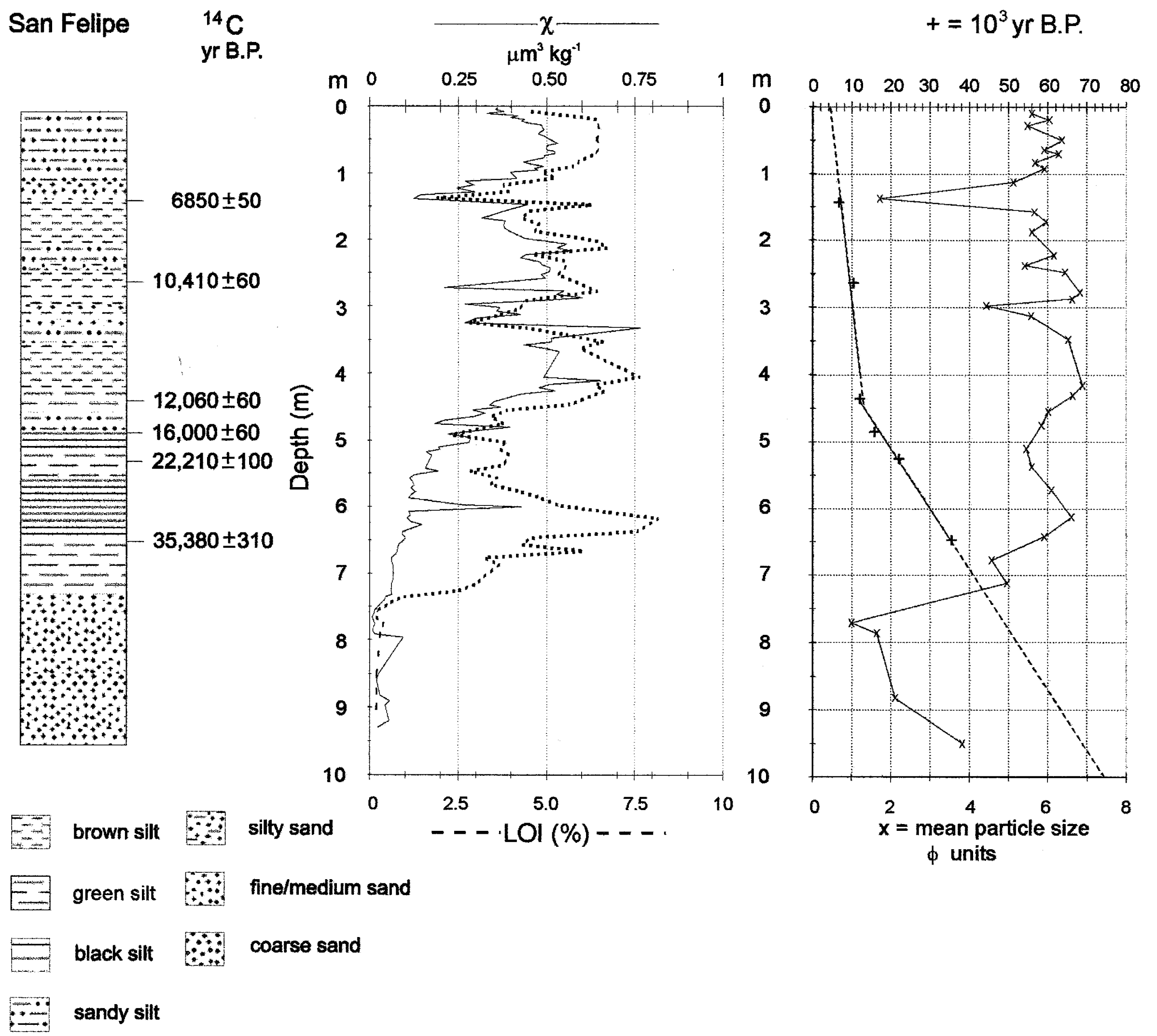


Fig. 3. Stratigraphic column, $^{14}C$ AMS dates, magnetic susceptibility (χ), loss-on-ignition (LOI), mean particle size (ϕ) and sedimentation rate variations according to $^{14}C$ dates linear regression from Laguna Seca de San Felipe core.

**Table 1**

$^{14}C$ AMS dates for Laguna Seca de San Felipe core

| Depth (m) | $^{14}C$ age* (yr B.P.) | $^{13}C/^{14}C$ ratio (‰) | Lab. code |
|---|---|---|---|
| 1.43 | 6850 ± 50 | -30.2 | Beta-106812 |
| 2.63 | 10 410 ± 60 | -24.7 | Beta-106813 |
| 4.35 | 12 060 ± 60 | -23.9 | Beta-102063 |
| 4.84 | 16 000 ± 60 | -26.2 | Beta-102064 |
| 5.27 | 22 210 ± 100 | -25.8 | Beta-102065 |
| 6.5 | 35 380 ± 310 | -26.5 | Beta-102066 |

* conventional radiocarbon dates

matter is more abundant in the silt bearing sediments. The lowest organic content is found in the sand deposits below 7.5 m depth. The organic content in the upper 7.5 m varies between 2.5-8%. Black silts between 5.6-6.4 m depth have the highest organic content.

Particle size is described in Figure 3 and in Table 2. Below 7.71 m depth, the mean particle size of sediments corresponds to medium to coarse sand (ϕ>1). Above this level the particle size corresponds to coarse to medium silt (5.0 to 8.0 ϕ), except for one sample at 1.38 m depth, which corresponds to medium sand. The sediments vary from moderately sorted to very poorly sorted (Folk and Ward, 1957). The skewness is around 65% skewed to coarser sizes, and the remaining 35% to the finer fraction (Table 2). In a Trask (1939) diagram, two clusters are found (Figure 4).

Table 2

Mean particle size (ϕ), standard deviation and skewness statistical parameters for selected samples from LSSF

| Sample depth (m) | Mean (ϕ) | Standard deviation | Skewness |
|---|---|---|---|
| 0.11 | 5.60 | 2.08 | 0.12 |
| 0.20 | 6.04 | 1.60 | 0.18 |
| 0.29 | 5.49 | 1.84 | 0.15 |
| 0.50 | 6.36 | 1.51 | 0.12 |
| 0.65 | 5.91 | 1.63 | 0.08 |
| 0.71 | 6.27 | 1.57 | 0.09 |
| 0.84 | 5.68 | 1.87 | 0.07 |
| 0.93 | 5.92 | 1.79 | 0.10 |
| 1.13 | 5.13 | 2.08 | 0.17 |
| 1.38 | 1.72 | 1.74 | 0.30 |
| 1.58 | 5.67 | 1.97 | 0.11 |
| 1.73 | 5.95 | 1.58 | 0.08 |
| 1.88 | 5.60 | 1.61 | 0.17 |
| 2.23 | 6.16 | 1.45 | 0.04 |
| 2.38 | 5.42 | 1.49 | 1.55 |
| 2.48 | 6.44 | 1.61 | 0.30 |
| 2.78 | 6.82 | 1.31 | 0.33 |
| 2.88 | 6.63 | 1.45 | 0.25 |
| 2.98 | 4.44 | 1.87 | 0.48 |
| 3.13 | 5.58 | 1.47 | 0.29 |
| 3.48 | 6.52 | 1.66 | 0.39 |
| 4.16 | 6.89 | 1.37 | 0.45 |
| 4.31 | 6.64 | 1.51 | 0.41 |
| 4.55 | 6.01 | 2.03 | 0.24 |
| 4.75 | 5.85 | 1.91 | 0.11 |
| 5.10 | 5.46 | 2.09 | 0.04 |
| 5.37 | 5.60 | 2.09 | 0.11 |
| 5.72 | 6.09 | 1.86 | 0.36 |
| 6.12 | 6.61 | 1.66 | 0.50 |
| 6.42 | 5.92 | 2.01 | 0.24 |
| 6.77 | 4.57 | 2.12 | 0.35 |
| 7.11 | 4.97 | 2.17 | 0.18 |
| 7.71 | 1.00 | 1.41 | 0.05 |
| 7.86 | 1.64 | 1.22 | 0.28 |
| 8.82 | 2.11 | 0.99 | 0.35 |
| 9.50 | 3.82 | 1.63 | 0.58 |

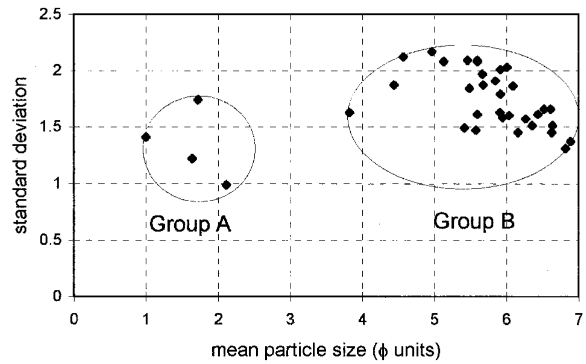


Fig. 4. Biplot of statistical parameters mean particle size (in ϕ units) and standard deviation.

Group A (samples at 1.38, 7.71, 7.86 and 8.82 m) is moderately to poorly sorted sand positively skewed towards the fine particles, suggesting a high energy deposit. Group B, including the remaining 33 samples, is extremely poorly-sorted negatively-skewed silt. Roundness of Group A samples is similar to recent eolic sediments (Figure 5). This suggests that Group A sediments were deposited by wind, rather than by water.

**Diatoms**

Diatom preservation in the core was poor of 35 analyzed samples only 4 were positive, at 4.3, 4.4, 4.5 and 4.75 m. Diatom abundance and species diversity was low and species identification was difficult due to poor preservation of the valves. In the sample at 4.3 m we found 6 x$10^6$ valves/gram of dry sediment, and only 0.5 x$10^6$ valves/gram in the 4.5 m sample. The highest number of taxa was recorded in the 4.3 m sample. A *Nitzschia* similar to *N. bergii* Cleve-Euler (Kramer and Lange Bertalot, 1988) was the most abundant species.

**Magnetic properties**

The upper 4.5 m sediments show a nearly five-fold rise in magnetic concentration ($\chi$ and SIRM) parameters and in $\chi_{fd\%}$ with respect to the lower section. Magnetic susceptibility of the sediments is very low (Figure 6). Lowest values (0.1 $\mu m^3kg^{-1}$) are found in sand horizons; the highest $\chi$ values (up to 0.8 $\mu m^3kg^{-1}$) are in the silty sediments above 4.5 m depth.

Sediments with $\chi$ values lower than 0.1 $\mu m^3kg^{-1}$ are not suitable for $\chi_{fd\%}$ estimations in standard 10 $cm^3$ samples in the Bartington susceptometer (Dearing, 1994). Additional $\chi_{fd\%}$ measurements were performed in 20 $cm^3$ samples from 22 horizons along the profile (Figure 6, dots). Each sample was measured 20 times in both frequencies. Larger proportion of superparamagnetic (SP) grains in the upper 4.5 m sediments is indicated by $\chi_{fd\%}$ higher than 4% in both sample sets.

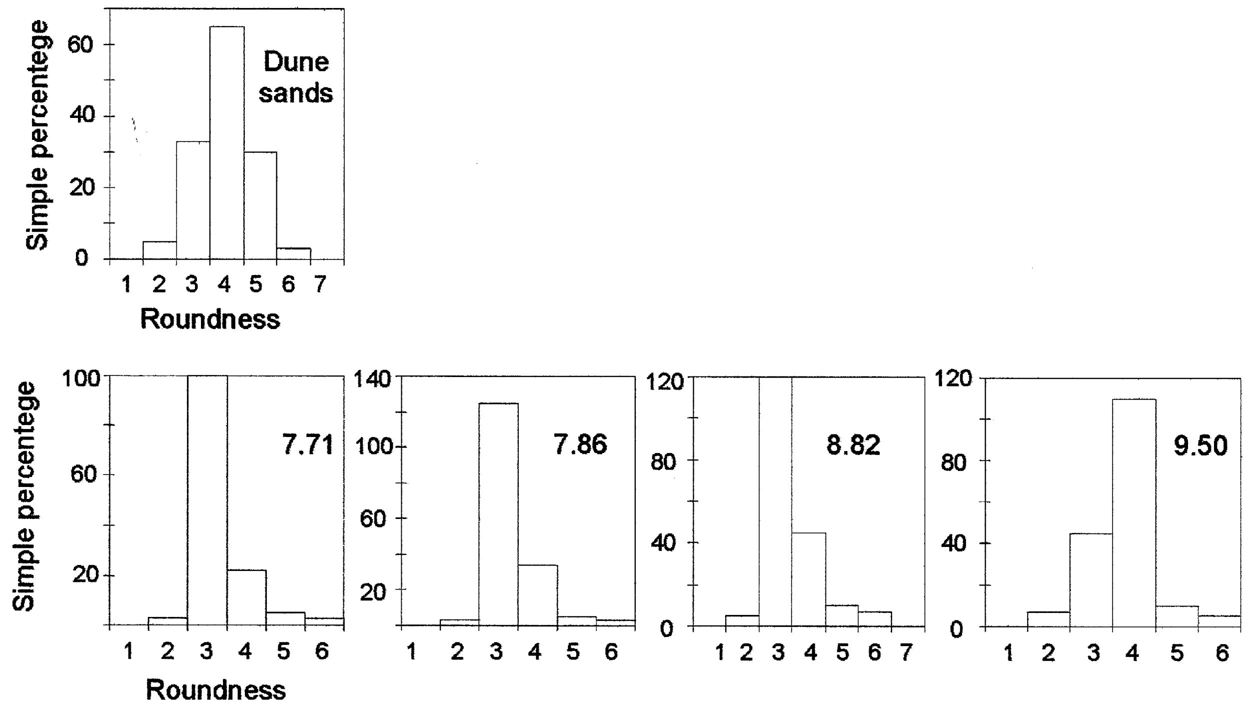


Fig. 5. Roundness of sand size samples from eolic dune sand deposits and samples of 7.71 to 9.5 m depth from Laguna Seca de San Felipe.

SIRM measurements display similar fluctuations in $\chi$ and $\chi_{fd\%}$ (Figure 6). Low SIRM values (< 1 $mAm^2kg^{-1}$) dominate the lower part of the core, whereas higher values (2 to 4 $mAm^2kg^{-1}$) are present in the upper half. The SIRM/$\chi$ ratio fluctuations are also similar (Figure 6).

F and S ratios show downcore differences. Sediments below 4.5 m display larger variations in S ratio (e.g. $S_{-200}$ ranges from 65 to 100%), while sediments above 4.5 m, which display constant $F_{300}$ and $S_{-200}$ ratios near 95%. Magnetic-hysteresis measurements summarized in a biplot (Figure 7), reveal that most samples fall into the pseudo-single domain (PSD) range. Samples below 4.5 m depth are clustered in two groups.

From the IRM acquisition measurements (F and S ratios), we infer that the main carriers of magnetisations corresponds to ferrimagnetic phase minerals, presumably some spinels or pure magnetites, in accordance with the igneous rocks that outcrop in the catchment, and they are not indicative of significative content of antiferrimagnetic (hematite/goethite) phases. Main magnetic variations in the sequence are related to changes in grain size and concentration.

## DISCUSSION

Preliminary results show a high contrast between glacial and late glacial-Holocene sediments. From $^{14}C$ dating, an abrupt shift in sedimentation occurred around 12 000 yr B.P. or 4.5 m depth (Figure 3). The average sedimentation rate between 35 380 and 12 060 yr B.P. was 0.09 mm/yr, increasing five-fold to 0.56 mm/yr between 12 060 and 6850 yr B.P. A similar variation is observed in the LOI, the particle size and the rock-magnetic records.

Finer particle size concentrations correspond to higher organic content, except for the sands at the bottom of the core, where the increase in fines is not matched by a rise in LOI. The variation pattern of $\chi$ and LOI is similar along the core, except between 4.5 and 7.0 m depth, where the pattern is reversed (Figure 3).

Rock-magnetic parameters show important fluctuations in magnetic grain size along the core. Samples below 7.9 m depth have a stable magnetisation (high SIRM/$\chi$) and they plot towards SD in the PSD field (Figure 7). However, the high $S_{-200}$ ratio corresponds to soft magnetisation, as for large MD grains. The variations in $(B_O)_{CR}/(B_O)_C$ and $M_R/M_S$ ratios are mostly caused by changes in $(B_O)_C$ and $M_S$, which may indicate the presence of a slightly more coercive phase. The magnetic carriers of these sediments could be explained as a mixture of large multidomain (MD) and single domain (SD) grains.

Samples between 7.9 and 6.4 m plot in the PSD field, close to the boundary of the MD area (Figure 7). Low SIRM/

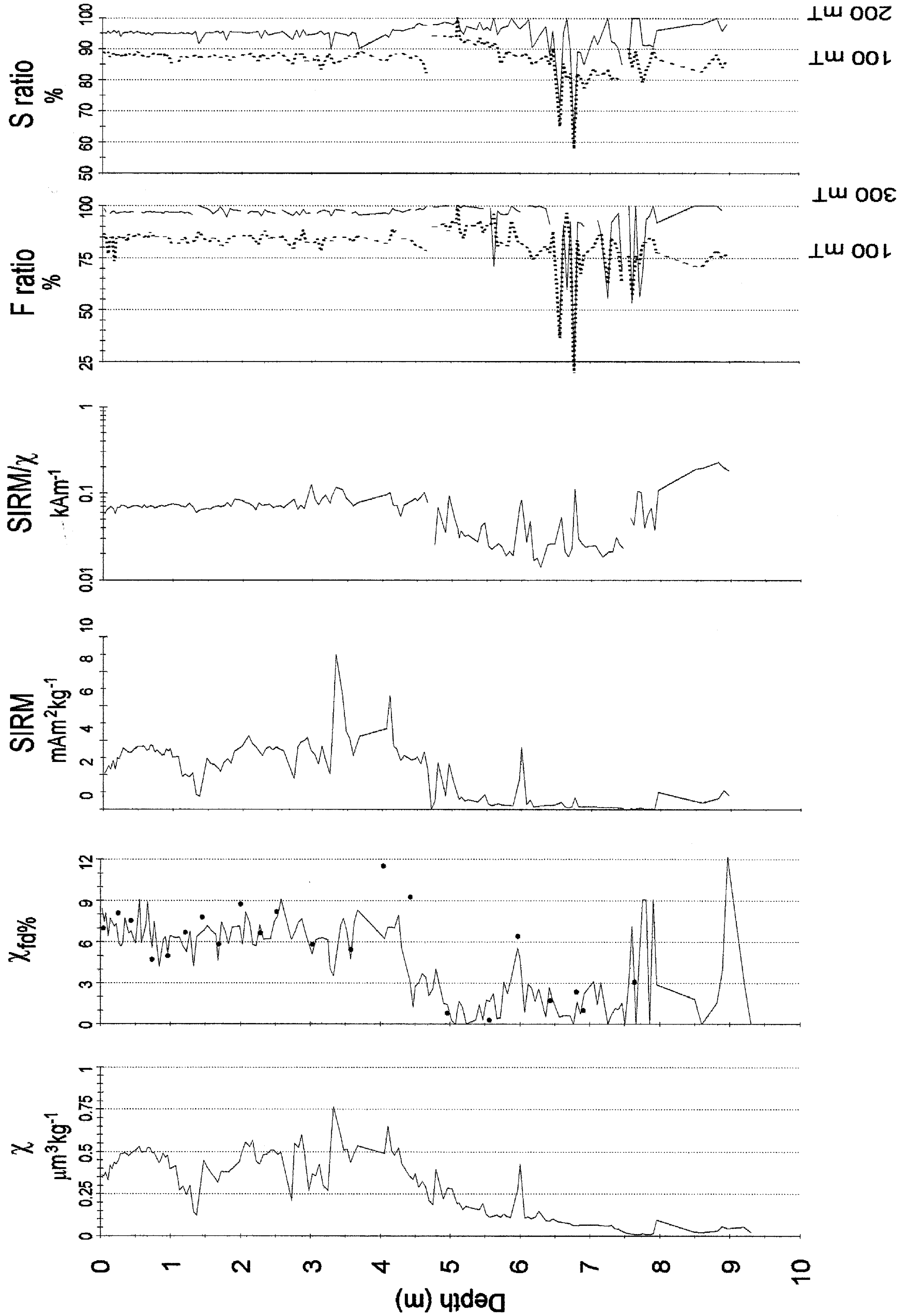


Fig. 6. Values of magnetic specific susceptibility ($\chi$), frequency dependent susceptibility ($\chi_{fd\%}$), saturation remanence of magnetisation (SIRM), F and S ratios. Dots on $\chi_{fd\%}$ profile correspond to large volume (20 $cm^3$) additional samples.

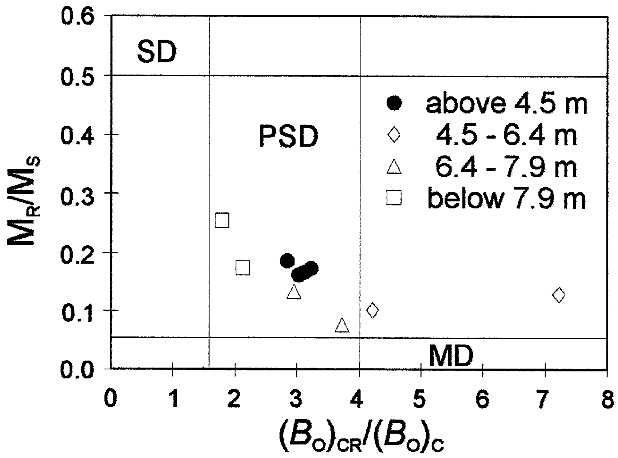


Fig. 7. Biplot of $(B_O)_{CR}/(B_O)_C$ versus $M_R/M_S$ (Day *et al.*, 1977) for samples from various stratigraphic levels in LSSF (SD = single domain, PSD = pseudo single domain, MD = multi domain).

$\chi$ and low $\chi_{fd\%}$ indicate respectively soft MD grains and the absence of SPM grains. However, F and S ratios indicate magnetically harder material than previous, and peaks of $S_{-200}$ below 70% indicate even harder horizons of higher stability. Under the microscope, quartz grains are found to be coated by a reddish layer, possibly haematite or goethite, which could account for the magnetic hardness. Black silt between 6.4 and 4.5 m is characterized by MD assemblages, as inferred from low SIRM/$\chi$, high F and S ratios, and coercivity parameters (Figure 7).

Sediments above 4.5 m show less variation in downcore magnetic parameters. Magnetic minerals plot in the PSD field, and a relatively high abundance of SP grains is indicated by $\chi_{fd\%}$ values. Relatively high SIRM/$\chi$ values indicate higher stability minerals. The $S_{-200}$ ratio (95%) points to intermediate magnetisation. Magnetic minerals in this section may be a mixture of grains in the MD-SD threshold (or PSD), and SPM. Short-term fluctuations towards lower magnetic concentration are coincident with sand horizons at 1.35 and 3.25 m depth.

Dissolution of iron oxides by reductive conditions is unlikely to be an important factor in the downcore variations of magnetic concentration and grain size parameters. Reductive dissolution of iron oxides tends to decrease magnetic content and to reduce magnetic grain sizes (Karlin and Levi, 1983; Alexander *et al.*, 1993). Reductive dissolution could be present between 7.35 - 6.25 m, where organic matter is relatively high and magnetic grains could have been reduced in size from MD to SD. Elsewhere larger MD grains are present and organic content is low. Fluctuations of magnetic properties along the column are more likely to be associated to variations in the input rate and to different sources of sediments.

## ENVIRONMENTAL IMPLICATIONS

Sediments from the early Middle Wisconsin substage, between ca. 70 000 yr (?) and ca. 45 000 yr (9.5 - 7.35 m), are eolic sands, suggesting dry conditions and no lake in the basin. The relatively coarse-grained (MD) magnetite component may have been eroded from the catchment area. After ca. 45 000 yr the silt fraction in sediments suggests a fluvial transport, with moister conditions and a higher precipitation/evaporation ratio. Partial dissolution of iron oxides in the relatively organic rich sediments may account for the low magnetic concentration. However, a slight but steady increase in the magnetic concentration parameters and in the organic content can be detected. Because of relatively humid environment, the magnetically hard component is likely to be goethite, which would agree with oxidising conditions. We conclude that a water body existed in the basin after 45 000 yr. Data from pack rat middens in the Chihuahua and Sonora deserts (Van Devender, 1990a; 1990b) indicates that the Middle Wisconsin was drier than the late Wisconsin.

The early full glacial period, between ca. 34 000 to ca. 19 000 yr, has the largest organic content in the record. The highest productivity in the lake is recorded from ca. 34 000 yr to 28 000 yr B.P., where LOI has maximum values (5 - 8%). Higher magnetic concentrations may be related to a higher water input, which have deposited the medium silt-size particles. The diatoms preserved in the sediments are *Cheatoceros* sp., a planktonic species common in saline lakes, and *Amphora* sp., which indicates littoral vegetation. These relatively moist conditions persist until ca. 12 000 yr B.P. (4.5 m). In paleoclimatic records from the SW United States, higher lake levels and expansion of woodlands have been reported for the last glacial maximum, ca. 18 000 yr B.P., until ca. 13 000 yr B.P. (Smith and Street-Perrot, 1983; Thompson *et al.*, 1993).

The absence of diatoms in the early and the late sediments may be due to an increase in salinity and/or alkalinity and to the establishment of an intermittent flooding regime in the lake (Flower, 1993).

Late glacial conditions produced a sudden increment in most parameters around 12 000 yr B.P. This pattern is nearly constant through the early Holocene until ca. 7000 yr B.P.

One alternative explanation for a major variation at 12 000 yr B.P. is tectonic activity on the San Pedro Martir fault. The rise in sedimentation rate and magnetic concentration may be associated to uplift and increasing erosion. However, the increment is mostly in smaller particle sizes and in SP + SD magnetic grains. We conclude that the shift must be related to late glacial climatic change.

The magnetic SP grains bearing in the upper LSSF sediments may reflect a sustained development and erosion of soils, resulting in the formation of ultrafine (SP) magnetite grains (Maher, 1986). The presence of large PSD+SD grains indicates that not all magnetic material was soil-derived but that some was contributed by the bedrock. This requires relatively moist conditions during most of the 12 000 - 7000 yr B.P. period, leading to increased runoff and sediment accumulation. The water level in the basin was relatively constant. Plant macrofossils in the Sonora and Chihuahua deserts agree with a greater rainfall, mostly in the winter, and cooler summers for the Late Wisconsin (Van Devender, 1990a; 1990b).

The sediments at ca. 11 000 yr B.P. have lower organic content, lower magnetic concentration and minor SP grain content. This could reflect drier conditions corresponding to the Younger Dryas event. At ca. 7000 yr B.P. there is a sharp decline in magnetic concentration and in LOI, and an increment in particle size. No decline is found in $\chi_{fd\%}$ and SIRM/$\chi$. This change is interpreted as a shift to drier conditions, during which the lake may have disappeared, and eolic accumulations took place. No $^{14}$C dates are available for the upper part of the column; but extremely dry conditions may have lasted through 6000 yr B.P.

After this period to higher magnetic concentration and LOI values, and finer particle size sediments, similar to conditions prevailing in the early Holocene, are found. The upper part of the sequence shows a trend towards decreasing magnetic concentration and organic content, along with an enhancement in SP minerals. The onset of modern dry conditions is highly speculative but might be located at ca. 5000 yr B.P.

## CONCLUSIONS

Sediments from San Felipe, Baja California, collected in a 9.5 m length core span roughly the last 70 000 years. The age of the youngest deposits is unknown, as the last 4000 yr may have been eroded. Downcore variations of particle size, organic content and rock-magnetic parameters are indicative of changes in the environmental and climatic conditions from Middle Wisconsin to mid Holocene. Magnetic grain sizes are particular useful, as they are found to reflect changes in the source of sediments eroded from the catchment.

Dry conditions during early Middle Wisconsin (70 000-45 000 yr) are inferred. Sediments from this period are characterized by eolic sands. The nature of the magnetic carriers remains unclear, as SIRM/$\chi$ and hysteresis measurements point to stable SD component, but the high $S_{-200}$ indicates soft MD grains.

After 45 000 yr B.P. there is a trend of increasing humidity and a lake begins to develop in the basin. The full glacial period, between 34 000 and 19 000 yr B.P., is characterized by moist conditions. Highest productivity is recorded between ca. 34 000 and ca. 28 000 yr B.P. Relatively moist conditions continued through 12 000 yr B.P.

Rock-magnetic characteristics suggest that sediments younger than 12 000 years are derived from the bedrock and eroded soils around the basin.

Late glacial and Holocene climatic changes inferred in LSSF resemble the interpretations of Spaulding and Graumlich from SW North America (Spaulding and Graumlich, 1986; Spaulding, 1990, 1991). Wetter and probably warmer conditions in LSSF appeared since ca. 12 000 yr B.P., and lasted until ca. 7000 yr B.P. Dry mid-Holocene conditions lasted apparently less in SW North America, between ca. 7000 and 6000 yr B.P. The return to moister conditions may have persisted until ca. 5000 yr B.P., when the present-day dry climate was established.

A dry period during the late glacial-Holocene climate amelioration is dated around 11 000 yr B.P., which may correspond to the Younger Dryas climatic deterioration.

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Ortega Guerrero, Beatriz[1], Caballero Miranda, Margarita[2], Lozano García, Socorro[3] and De la O Villanueva, Margarita[4]

[1] *UNAM, Instituto de Geofísica, Estación Regional del Noroeste. A.Postal 1039 Hermosillo, Sonora, México. bortega@tonatiuh.igeofcu.unam.mx*

[2] *UNAM, Instituto de Geofísica, Cd. Universitaria, México, D.F., México. Email: maga@tonatiuh.igeofcu.unam.mx*

[3] *UNAM, Instituto de Geología, Cd. Universitaria, México, D.F., México. Email: mslozano@servidor.unam.mx*

[4] *Universidad de Sonora, Depto. de Geología, Hermosillo, Son., México.*