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Holocene Environmental Change and Human Impact in Hoya Rincon de Parangueo, Guanajuato, Mexico

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ABSTRACT: This paper presents a paleoenvironmental study on Hoya Rincon de Parangueo, a maar lake in Valle de Santiago in Central Mexican Bajío. Maar lake sediments have been widely used for high-resolution reconstruction of paleoenvironment. Many different paleoenvironmental proxy data such as stable isotopes, pollen, sediment chemistry, and dung fungus spore were produced in this study. The pine-oak ratio, stable isotopes, and sediment chemistry help to reveal paleoenviromental changes throughout the whole period covered by sediment materials from this study site. The evidence I found indicates that during ca. 9,500 ~ ca. 8,300 cal yr B.P. there was dry climate; during ca. 8,300 ~ ca. 6,300 cal yr B.P. it was wetter; during ca. 6,300 ~ ca. 4,000 cal yr B.P. drier and cooler; during ca. 4,000 ~ ca. 1,100 cal yr B.P. milder and wetter. The presence of Chupicuaro culture between ca. 2,500 ~ 1,100 cal yr B.P. is implied by the high frequencies of Amaranthaceae and *Zea mays*. It seems that man left this lake around 1,100 cal yr B.P. due to a dry climate after 1,300 cal yr B.P. Spanish arrival around 400 cal yr B.P. is implied by the fact that *Zea mays* reappears and *Sporormiella* spp. become significant around 120 cm, whereas Poaceae drops sharply.

Key words: Highland Central Mexico, Holocene environmental change, Human impact, Pollen analysis, Sediment chemistry, Stable isotope

INTRODUCTION

Palaeoenvironmental work in highland Central Mexico began in the 1940s (Deevy 1944). Since then a number of studies have produced plenty of paleoenvironmental data, which however are typically difficult to interpret for several reasons. Most paleoenvironmental research in highland Central Mexico has been carried out in major cultural centers such as the Valley of Mexico and the Patzcuaro basin where serious human disturbance after 3,500 B.P. obscures the evidence of climate change (Watts and Bradbury 1982, Lozano García *et al*. 1993, Lozano García and Ortega Guerrero 1994, 1998, Caballero and Ortega Guerrero 1998). More reliable chronology is needed on a number of studies (Brown 1984, Straka and Ohngemach 1989). Many complacent pollen diagrams with the dominance of pine and oak hamper a detailed reconstruction of vegetation change (Lozano Garcia and Xelhauntzi Lopez 1997). Due to these barriers, the results are difficult to bring together to make a comprehensible story as to the nature of Holocene climate changes in highland Central Mexico. Multidisciplinary research is truly necessary to obtain more reliable information that can help detect climate signals. For an understanding of regional climate change, paleoenvironmental data should be produced from as many different sites throughout highland Central Mexico as possible.

This paper presents a paleoenvironmental study on Hoya Rincon de Parangueo, a maar lake in Valle de Santiago in Central Mexican Bajío (Fig. 1). Maar lake sediments have been widely used for high-resolution reconstruction of paleoenvironment. The Valle de Santiago area is currently on the northern limit of agriculture without irrigation. This area might have been occupied and abandoned in association with the level of precipitation so that the paleoenvironmental data from this area could demonstrate the extent of human

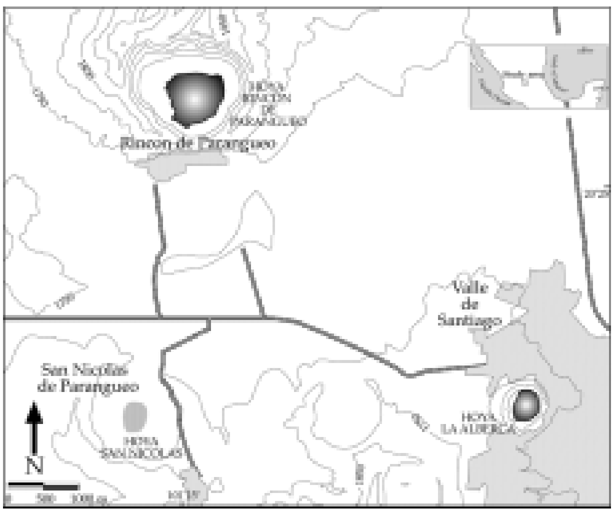

Fig. 1. Map of the study area.

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disturbance that has been related to climate. I could possibly test Armillas' hypothesis that the northern frontier of Mesoamerica was shifted southward due to droughts at the end of the Classic (Armillas 1969).

Brown's work on Hoya San Nicolás (1984) is the only available paleoenvironmental record of this area. Having more data on this area would be helpful towards obtaining a clearer understanding of the paleoenvironment in this area and Central Mexico as well. Hoya Rincon de Parangueo, located about 3 km north of Hoya San Nicolás, is a lake suitable for the comprehensive multi-site research on Valle de Santiago.

One valuable way to reconstruct paleoenvironment is through coupled palynological studies and chemical analyses of lake sediment since the results from these two should produce independent data. This approach could be powerful in separating climatic from anthropogenic signals. In particular, the highland Central Mexico has been severely disturbed by human activities. It is unlikely that pollen records from the area show clear trends of climate change; however, stable isotope or sediment chemistry analyses could suffice. Here, this paper presents many different paleoenvironmental proxy data on Hoya Rincon de Parangueo such as data collected from the study of stable isotopes, pollen, sediment chemistry, and dung fungus spore for a better understanding of paleoenvironmental changes in this area.

METHODS AND MATERIALS

Study Area and Site Description

The Mexican Volcanic Belt (MVB) is an East-West trending continental magnetic region, which stretches across Mexico between latitude 19° and 21° N. It has been developed by the subduction of the Cocos/Rivera plate system. It is about 1,000 km long and 20 to 200 km wide (Negendank *et al*. 1985). The MVB consists of several zones that have specific morphology, structure, or chemical characteristics (Pasquaré *et al*. 1987). There are thousand of volcanic vents within the belt. In particular, maar lakes are scattered in Altiplano areas in the eastern part of the MVB (Negendank *et al*. 1985) and Michoacán-Guanajuato Volcanic Field in the north-central MVB (Ordoñez 1906).

The maars of the Valle de Santiago are located in the Michoacán-Guanajuato Volcanic field, 100 km SW of Queretaro. There are at least 7 maars in the area. Two of the maars hold water while the others have already desiccated. The water level in Hoya Rincon de Parangueo and La Alberca began to drop about 50 years ago. Since lake levels are now 20 m lower, it is easy to gain access to sediments on the lake floor. Hoya San Nicolas has recently dried out, although shallow water is seen in the central part during the wet season.

The Lateglacial of highland Central Mexico was previously cool and dry. In the early Holocene, the climate may have become relatively warmer and wetter. Many records indicate a dry period sometime between 5,000 and 6,000 B.P. and a number of dry intervals during the last 3,000 years (Metcalfe 2000). The study area demonstrates a strong seasonality in terms of precipitation. As the Bermuda high shifts northward and Easterlies move on the Mexican plateau, 80 percent of precipitation falls between May and October. Mean annual precipitation in the area is 650 mm. Mean annual temperature in the area is fairly constant, averaging 19°C and ranging from 14°C in January to 23°C in May (Mosiño Alemán and García 1974).

The dominant types of vegetation in the area before the introduction of modern agriculture were *bosque tropical cadudifolio* (tropical deciduous forest) and *matorral subtropical* (subtropical scrub forest) (Aguilera Gómez 1991, Conserva 2003). *Bosque tropical caductifolio* is mainly composed of members of the Burseraceae and Fabaceae. On the other hand, *matorral subtropical* generally includes *Ipomoea murucoides*, *Acacia pennatula*, *Acacia farnesiana*, *Opuntia* spp., *Lysiloma microphylla* and *Eysenhardtia polystachya*. Currently, valley floors are occupied by various crops including wheat, broccoli, watermelon, and corn. Though some of natural woodlands could survive on the slopes of the volcanic craters, locals use even these for firewood, livestock grazing, wild fruit, and medicinal plants (Aguilera Gómez 1991, Conserva 2003).

The Crater is now occupied by diverse vegetation that Rzedowski (1981) suggested as a relic while the outside is generally dominated by scrubs such as mesquite. As grass was heavily grazed by cattle introduced around A.D. 1550, decreased frequency of fires may have helped woody species like mesquite replace grassland and become dominant in the area. However, vegetation inside the crater could have survived cattle grazing since ranchers likely did not bother bringing cattle in the crater with such high rims and steep slopes. For this reason, relatively diverse vegetation could have survived severe grazing by cattle in colonial times.

Hoya Rincon de Parangueo (20°25' N, 101°14' W) is one of seven major late Pleistocene volcanic craters in Valle de Santiago, Guanajuato (Fig. 1). Walls of the former lake bed are situated at ca. 25 m high. There is no outlet for the lake. Groundwater overexploitation induced by increasing agriculture and overgrazing lowered the lake water level. Its present water depth is very low, and central parts of the lake are covered by shallow green water.

Study Methods

In 2001, a 12.43 m sediment core was recovered with a modified Livingston corer equipped with plastic liners. Coring was done on dry sediment exposed above the level of water because soft sediment prevented reaching lake water. The slugs were split into two halves.

One half was used for description. It was photographed and X-rayed. The remaining half was preserved in a freezer for possible further analyses. In advance of extrusion, cores were scanned at 1 cm intervals for magnetic susceptibility with a Bartington Magnetic Sensor MS2C.

The chronology was established based on seven AMS radiocarbon dates (Table 1) and one historical date for the sediment core. These radiocarbon dates are on charcoal picked from the 125 μm sieved fragments. Calibrated ages were determined using medians calculated by the CALIB 4.4 program written by Stuiver *et al*. (1998).

For pollen analysis, the core sediments were subsampled at 5~45 cm intervals. Pollen was extracted using standard palynological procedures as described by Faegri and Iverson (1989). Two tablets of *Lycopodium* spores were added to each sample to calculate pollen concentration (Stockmarr 1971). The samples were mounted on microscope slides with silicone oil. Pollen counts were made on a Leitz microscope with a 40× planapochromat oil immersion objective at a total magnification of 400×. Pollen identification was aided by the UC Berkeley Department of Geography reference collection and published keys. A minimum of 402 pollen and spores were counted at 61 levels. Maize pollen was identified on the basis of grain diameter. Poaceae pollen with a long axis greater than 60 μm and regularly spaced columellae were identified as *Zea mays* (Irwin and Barghoorn, 1965, Whitehead and Langham, 1965). Pollen concentrations and accumulation rates were calculated with the ratios of *Lycopodium* spores and radiocarbon dates. Pollen diagrams were produced using Calpalyn computer program.

For isotope analysis, we took samples at 1~15 cm intervals from the sediment core. Samples containing about 10 to 100 microgram calcite or aragonite were used for both carbon and oxygen isotope analyses, which were determined using a GV IsoPrime mass spectrometer with Dual-Inlet and MultiCarb systems. Several replicates of two international standards NBS18 and NBS19, and one lab standard HKC-I were measured along with samples for each run. The overall external analytical precision is ±0.04‰ (internal precision: ±0.004‰) for ^{13}C and ±0.07‰ (internal precision: ±0.007‰) for ^{18}O. Isotopic data from more than 210 samples were obtained but they were averaged out at every 10 cm in order to lessen their large variations.

Loss on ignition analyses were carried out to determine sediment composition as follows: oven drying at 100°C for 24 hours for water content and heating at 550°C for 1 hour for organic content. Residue of sediment samples was then analyzed with a Philips PW 2400 X-Ray Florescence scanner (XRF) to determine chemical composition.

RESULTS

Stratigraphy and Chronology

The sediment stratigraphy for the 2001 core is shown in Fig. 2. The top is overlaid by the slump that was deposited probably during a major earthquake. As shown, there are two varve sections between 40~120 and 210~300 cm coring depth. At the top of the first varve is a unique green layer, which is assumed to be the end of genuine sediments. The laminated cuplets, which are generally 1 mm thick, consist mainly of authigenic carbonate and organic matter. The first change in sedimentation takes place at around 125 cm, where finely laminated sediments are replaced by partly laminated sediments. A thick white carbonate layer is situated at the transition, of which

Table 1. Radiocarbon dates from Hoya Rincon de Parangueo

Core	Depth (m)	Material dated	Laboratory number[a]	$\delta^{13}C$	Age (^{14}C yr B.P.)	Two sigma age range (cal yr B.P.)[b]	Median (cal yr B.P.)[b]	Corrected median (cal yr B.P.)[c]
RP-1	2.08	charcoal	OS 46514	−16	1530 +/− 60	1310~1533	1426	1166
RP-1	2.87	charcoal	OS 47526	−16	2340 +/− 55	2158~2694	2372	2112
RP-1	3.69	charcoal	CAMS−102236	−16	2460 +/− 60	2357~2714	2540	2280
RP-1	4.80	charcoal	OS 47523	−16	3150 +/− 70	3209~3556	3374	3114
RP-1	6.97	charcoal	CAMS−102237	−16	4320 +/− 90	4619~5283	4919	4659
RP-1	10.03	charcoal	CAMS−102238	−16	6640 +/− 45	7439~7581	7524	7264
RP-1	11.99	charcoal	CAMS−94183	−16	8500 +/− 45	9452~9543	9505	9245

[a] The CAMS and OS numbers are AMS (Accelerator Mass Spectrometer) dates.
[b] All dates were calibrated with the intcal98.14c data set (Stuiver *et al*. 1998).
[c] 260 years were subtracted from all dates. (varve counting correction).

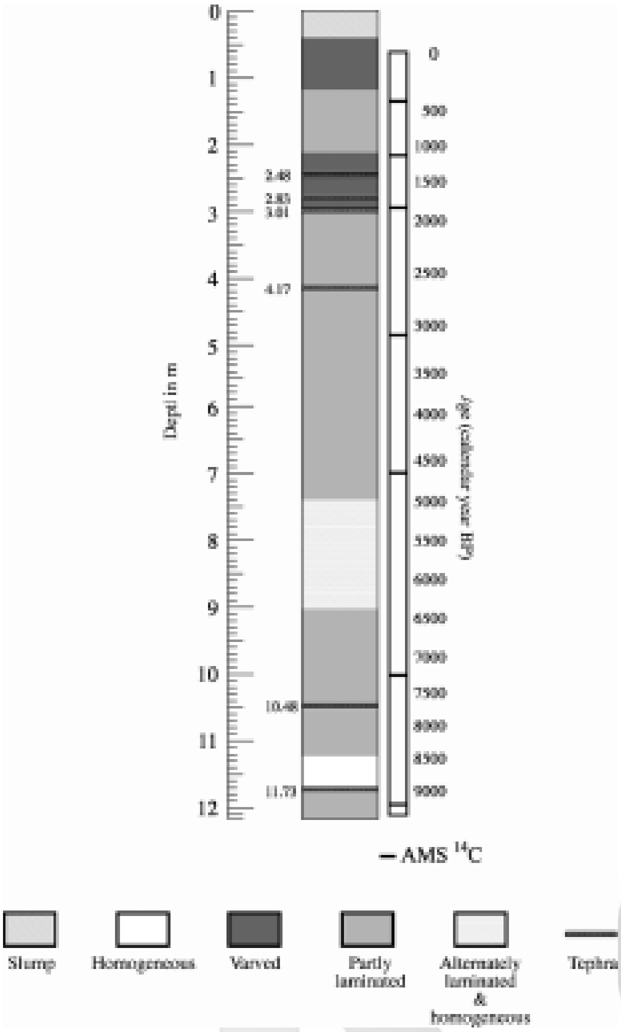

Fig. 2. Hoya Rincon de Parangueo stratigraphy.

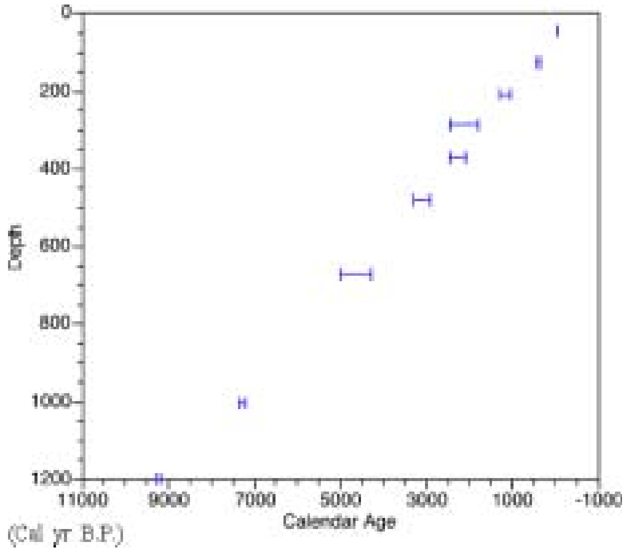

Fig. 3. Hoya Rincon de Parangueo age-depth profile.

estimated age is about A.D. 1500. In the second varve between 210~300 cm, cuplets are interrupted by 3 tephra horizons (248, 283, and 301 cm). The partly laminated section takes the place of the well laminated section at the 301 cm tephra layer. Below 301 cm, this core is mainly composed of partly laminated sediments though an alternate laminated section (740~900 cm) and a homogeneous section (1,120~1,170 cm) intervene. In total, 6 tephra layers are seen throughout the core, but there could possibly be more. With the exception of the top part of the core, deeper sediments typically show brighter tones probably due to higher percentages of carbonate.

I obtained seven radiocarbon dates from concentrated charcoal samples (Table 1). A striking peak of dung fungus spore (*Sporormiella*) at 126 cm was used as a historical date on the basis of the fact that the Spanish introduced livestock to this area ca. A.D. 1550. Additionally, I adjusted radiocarbon dates with the counts of annual layers (varve): 260 years was subtracted from each original radiocarbon date. In total, eight dates are generally well ordered (Fig. 3) but radiocarbon data of 369 cm sample, which was taken from the portion disturbed during coring, was not used for the chronology.

Paleoenvironmental Data

Selected results of pollen, XRF, isotope, and LOI analyses are presented in Fig. 4~7. Based on multi-proxy data, diagrams are divided into 5 units for discussion purposes.

Unit 5 (1,250~1,100 cm, ca. 9,500~8,300 cal yr B.P.) is marked by very high values of δ^{18}O. Na_2O and Cl percentages are also extremely high but decrease dramatically at the unit 5/4 boundary. The δ^{13}C values remain relatively low in the bottom levels but increase rapidly at the top of the unit. Isotopic values (3 point running mean) of this unit are between 3.5 and 5 ‰ for δ^{18}O and 12 to 17 ‰ for 13C while chemical percentages are between 4.5 and 11 % for Na_2O and 0.35 to 1.5 % for Cl. Organic content is very high at the bottom but progressively declines toward the top of the unit. Pollen records do not show much variation. *Pinus* percentage slightly decreases. Pine oak ratio is relatively high. Amaranthaceae and high spine Asteraceae pollen are present at low levels (< 5%). Pollen accumulation rate is relatively high at the bottom (10,000 cm^{-2} year^{-1}). But it drops to < 7,000 cm^{-2} year^{-1} around 1,170 cm and maintains this value up to the top of the unit.

Unit 4 (1,100~890 cm, ca. 8,300~ca. 6,300 cal yr B.P.) is characterized by a steady decrease of δ^{18}O. δ^{18}O decreases from 5 to 2 ‰ in the unit. Na_2O and Cl percentages also show steady decreases (Fig. 6). The δ^{13}C attains its highest value in lower parts of the unit. Around 1,050 cm, it dramatically drops to <10 ‰ and does not change much in the rest of the unit. Isotopic values (3 point running mean) of this unit are between 2 and 5 ‰ for δ^{18}O and 8 to 18

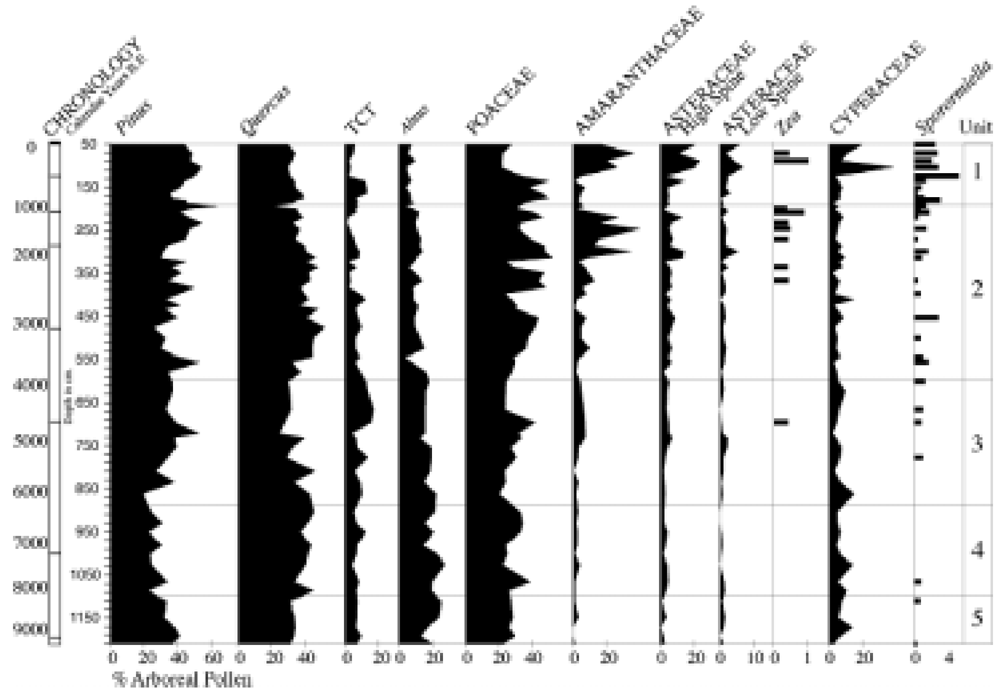

Fig. 4. Hoya Rincon de Parangueo pollen diagram.

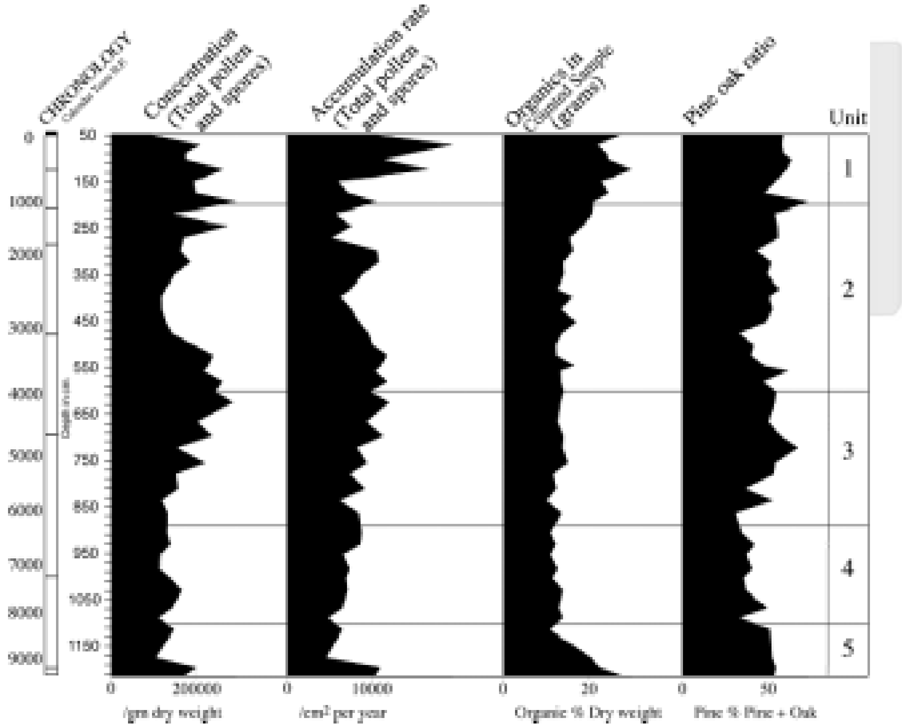

Fig. 5. Hoya Rincon de Parangueo pollen concentration, pollen accumulation rate, organic matter, and pine oak ratio.

‰ for $\delta^{13}C$ while chemical percentages are between 3 and 5 % for Na_2O and 0.3 to 0.7 % for Cl. Organic content constantly constitutes about 15 % of the sediment throughout the unit. *Quercus* is a dominant pollen type. *Pinus* percentage and pine oak ratio gradually decrease. Amaranthaceae and high spine Asteraceae pollen frequencies are still very low. Pollen accumulation rates do not show much change from around 7,000 cm^{-2} $year^{-1}$, which is the same rate as the previous unit.

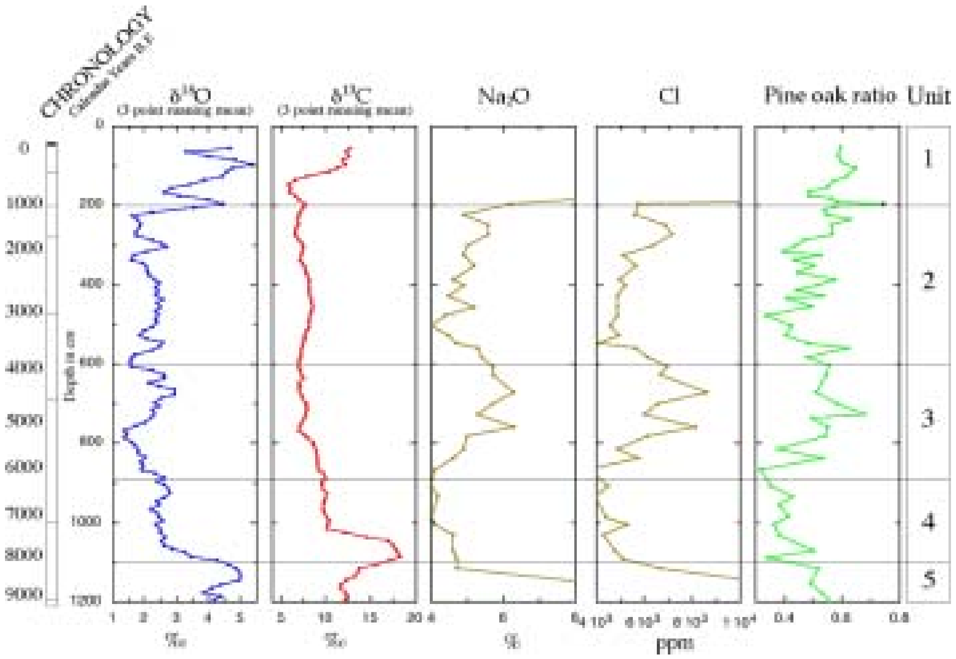

Fig. 6. Hoya Rincon de Parangueo isotopic data (3-point running mean, V-PDB (‰) = Vienna Peedee belemnite), sediment chemistry (Na_2O and Cl), and pine oak ratio.

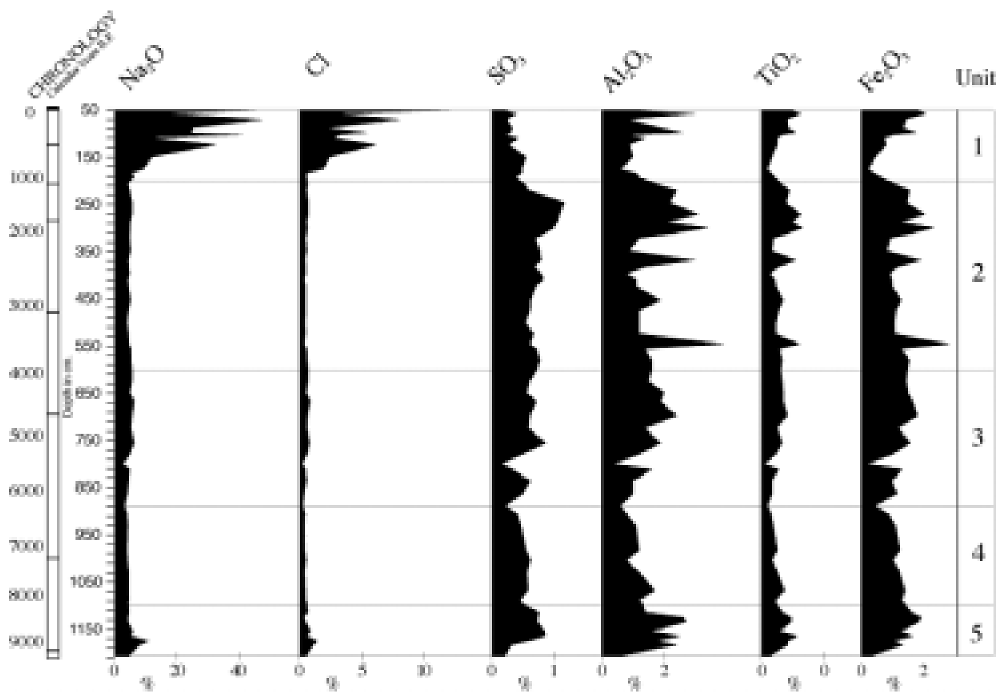

Fig. 7. Hoya Rincon de Parangueo sediment chemistry.

In Unit 3 (890~600 cm, ca. 6,300~ca. 4,000 cal yr B.P.), Na_2O and Cl percentages rise simultaneously in the lower part. They both exhibit comparatively high values. Relatively high $\delta^{18}O$ values are shown in this unit, although they are not prominent. On the other hand, $\delta^{13}C$ consistently maintains its relatively low values. Isotopic values (3 point running mean) of this unit are between 1.5 and 3 ‰ for $\delta^{18}O$ and 6.5 to 8 ‰ for $\delta^{13}C$ while chemical percentages are between 2.5 and 6.5 % for Na_2O and 0.2 to 0.8 % for Cl. Organic content throughout the unit is not much different from that of the previous unit. *Pinus* becomes more important than *Quercus* and pine oak ratio is noticeably high. *Quercus* percentages progressively decline in the unit. *Zea mays* occurs at 667 cm where Poaceae has a peak. Pollen accumulation rates suddenly increase at 7 cm reaching >12,000 cm^{-2} $year^{-1}$ and maintain this number up to the top of the unit.

Unit 2 (600~200 cm, ca. 4,000~ca. 1,100 cal yr B.P.) is marked by a considerable variation of pollen records. Amaranthaceae percentages rise dramatically from <5 to >30% around 320 cm and drop sharply to <5% at the top of the unit. High spine Asteraceae has a similar trend with Amaranthaceae. *Zea mays* reappears at 369 cm and is continuously present throughout the unit. Dominant pollen types are *Quercus* and Poaceae. Poaceae values remain high although they vary within a wide range (25~40 %). Na_2O and Cl percentages gradually increase. Isotopic values remain relatively low without any significant change. $\delta^{18}O$ values of this unit are generally between 1.5 and 2.5 ‰ whereas $\delta^{13}C$ values are between 6.5 and 8 ‰. Al_2O_3, TiO_2 and Fe_2O_3 percentages, which do not change much in the previous units, show noticeable increases and drops that match a significant change of Amaranthaceae frequencies. Pine oak ratio and pollen accumulation rates begin to decrease around 500 cm. Pollen accumulation rates generally maintain their low values except between 350~310 cm.

In Unit 1 (200~44 cm, ca. 1,100 B.P. - Present), all the proxy data exhibit marked changes. Amaranthaceae pollen almost disappears at the bottom of the unit and is rare throughout the lower half of the unit. It suddenly increases from about 120cm and regains importance in the upper half. In the upper half, high spine Asteraceae pollen also shows some increase and *Zea mays* pollen starts to be seen again; however, Poaceae pollen declines abruptly from 40 to < 20 %. Fossil spores of the dung fungus *Sporormiella* spp. display a conspicuous spike at 126 cm. On the other hand, $\delta^{18}O$ values begin to increase at the bottom and rise dramatically toward the top. Unlike $\delta^{18}O$, $\delta^{13}C$ maintains low values in the lower half and thereafter show a drastic increase corresponding to Amaranthaceae. $\delta^{18}O$ values of this unit are generally between 1 and 6 ‰ whereas $\delta^{13}C$ values are between 6 and 13 ‰. Al_2O_3, TiO_2 and Fe_2O_3 show almost the same variations as Amaranthaceae. Na_2O and Cl percentages increase continuously and attain their highest values throughout the core at the top. Organic content progressively rises and reach 30 % near the top. Pollen accumulation rates are very high between 120 cm - top with > 20,000 cm^{-2} $year^{-1}$ as a maximum.

DISCUSSION

The majority of pollen records from Central Mexico are very complicated to interpret since percentages of important taxa such as *Pinus* and *Quercus* do not change significantly (Lozano-García and Xelhuantzi-López 1997). Pollen records from the study site, Hoya Rincon de Parangueo, seem to be complacent to climate change like other previous pollen records, although evidence of human disturbance is clearly shown in the uppermost sediments. I need to point out here that the natural pine and oak stands are obviously located far from the study site, which means that pine and oak frequencies in pollen records depend on long distance dispersal from an extensive area. Since paleoenvironmentally meaningful signals are dampened by long distance dispersal of main taxa from a wide region, pollen records do not provide reliable evidence for climate changes. However, paleoclimatic histories in the study area could be reconstructed through other paleoenvironmental records, such as isotopic data and sediment chemistry, which are independent from palynological evidence.

Unit 5 (1,250~1,100 cm, ca. 9,500~ca. 8,300 cal yr B.P.)

Dry conditions are generally indicated by high Na_2O and Cl percentages and high values of $\delta^{18}O$. Interestingly, $\delta^{13}C$ values start to increase dramatically at the top of the unit after remaining low in nearly the entire unit, whereas $\delta^{18}O$ shows a marked decrease at the top. A typical high correlation between these two stable isotopes does not apply to this case. This difference may indicate that at the end of this period, wet climate became dominant resulting in relatively heavy erosion in the crater where only sparse vegetation may have remained due to earlier dry conditions. Increased input of nutrients from slopes may have proliferated the lake plankton population and led to high photosynthesis rates in the lake. As isotopically lighter carbon (^{12}C) was preferred for consumption by the lake plankton, an isotopic ratio of dissolved inorganic carbon in lake water probably increased as shown in Fig. 6. A significant transition from a dry phase to a wet phase possibly took place around 8,300 cal yr B.P. in the area. This interpretation is also supported by a dramatic decrease in Na_2O and Cl percentages at the unit 5/4 boundary. The transition is indicated in studies on La Piscina de Yuriria and Chignahuapan as well (Caballero *et al*. 2002) (Fig. 8).

Unit 4 (1,100~890 cm, ca. 8,300~ca. 6,300 cal yr B.P.)

Low $\delta^{18}O$ values and low percentages of Na_2O and Cl indicate that wet conditions were prevalent during this period. High values of $\delta^{13}C$ in a basal part may indicate that erosion continuously occurred until 7,800 cal yr B.P. As the climate became wetter and vegetation coverage expanded in the crater, there may not have been a serious erosion any longer, resulting in low values of $\delta^{13}C$ in the rest of the period. Decreasing pine oak ratio may have been an indication that the climate regionally became warmer and wetter. Metcalfe *et al*. (2000) summarized the central Mexican paleoenvi-

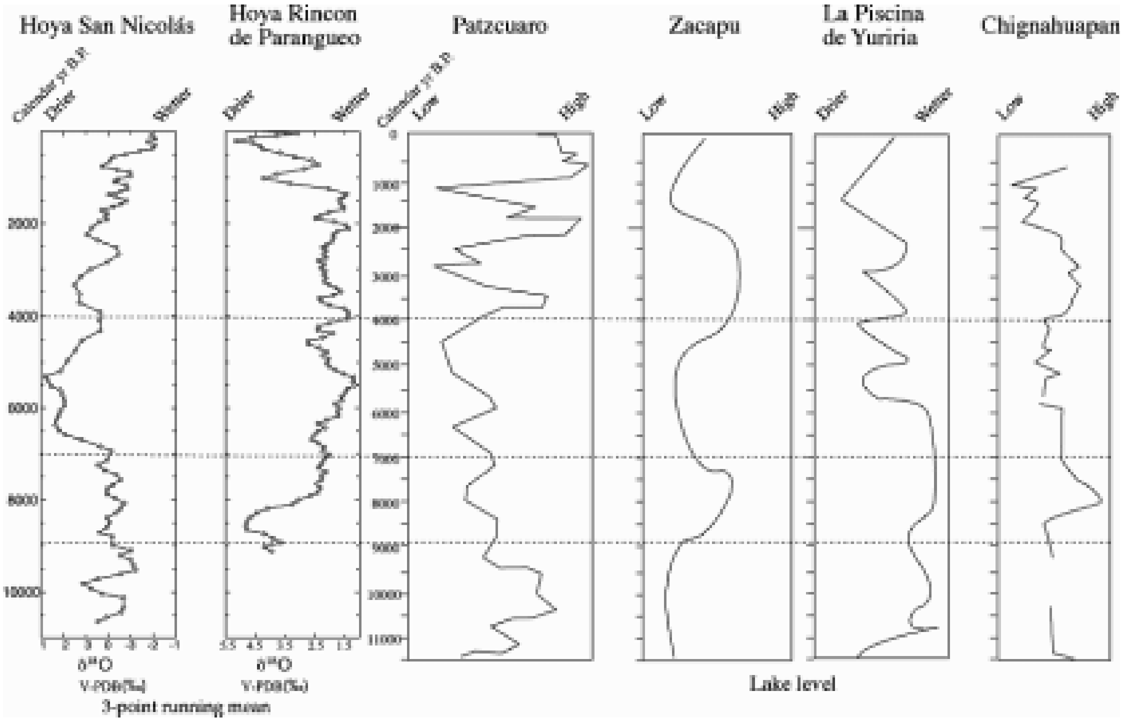

Fig. 8. The evidence of long term climate trends from sites in Central Mexico: Hoya San Nicolás (Park, in prep.), Hoya Rincon de Parangueo (This study) and Patzcuaro, Zacapu, La Piscina de Yuriria, and Chignahuapan (Caballero *et al*. 2002).

ronmental records and suggested that in the early Holocene, conditions seemed to have become warmer and wetter.

Unit 3 (890~600 cm, ca. 6,300~ca. 4,000 cal yr B.P.)

High percentages of Na_2O and Cl and relatively high values of $\delta^{18}O$ between 800~600 cm may be an indication of dry conditions during this period. Also, considering that pines are generally adapted to cold and dry climate in Central Mexico, high pine oak ratio indicates that "regional" climate was colder and drier than in the previous period. Pine and oak frequencies in pollen records are related to long distance dispersal from an extensive area since natural pine and oak stands are located far from the study site (Conserva *et al*. 2003). However, an indistinct variation of $\delta^{18}O$ values does not fully confirm the presence of these dry conditions in the area. The fact that even *Zea mays* was found around 4,600 cal yr B.P. moreover undermines my interpretation, which is mainly based on sediment chemistry (Na_2O and Cl concentrations) and pine oak ratio. But there are certainly a fair number of prior pollen records and lake level reconstructions that support my suggestion. For example, $\delta^{18}O$ values from Hoya San Nicolás, another coring site in the same study area, are very low between 7,000~4,000 cal yr B.P., indicating dry conditions (Park, in prep). Arnauld *et al*. (1997) suggested that Zacapu lake in Michoacán reached the lowest water level ca. 6,000 through 4,000 B.P. Paleolimnological records from Central Mexico indicate low lake levels in between approximately 4,400~6,100 cal yr B.P. (Fritz *et al*. 2001). Metcalfe *et al*. (2000) pointed out that a large number of data from central Mexico indicate a dry period sometime between 5,000~6,000 yr B.P. Lake level curves produced from Patzcuaro, La Piscina de Yuriria, and Chignahuapan all exhibit low lake levels between 5,500~4,000 cal yr B.P., which nicely corresponds to high values of $\delta^{18}O$ during the same period in this study (Caballero *et al*. 2002) (Fig. 8).

Unit 2 (600~200 cm, ca. 4,000 ~ ca. 1,100 cal yr B.P.)

From this period, evidence of human disturbance starts to appear in the pollen record. The climate seems to have been mild and wet. The presence of Chupicuaro culture between 1,100~2,500 cal yr B.P. is implied by high frequencies of Amaranthaceae and the emergence of *Zea mays*. Al_2O_3, TiO_2 and Fe_2O_3, indicators of erosion, show that substantial erosion took place due to agricultural activities between 1,100~2,500 cal yr B.P. Relatively wet climate is implied by the fact that $\delta^{18}O$ values constantly remain low. Low percentages of Na_2O and Cl indicate that climate was wetter than the previous period. Also, low pollen accumulation rates reflect that a regional climate in this period may have been relatively warm and wet because total pollen accumulation rates in the pollen record are mainly determined by accumulation rates of pine pollen. Arnauld *et al*. (1997) suggested that the marsh in the Zacapu lake basin expanded again around 4,000 B.P. Also, the water level of the Chalco lake in Central Mexico rose after 3,000 yr B.P., (Lozano-Garcia *et al*. 1993, Fritz *et al*. 2001). What's significant is that the isotope data suggest that an abrupt transition to a dry climate occurred around 1,400~1,300 cal yr B.P. Nevertheless, agricultural activities seem to have continued later on and stopped around 1,100 cal yr B.P. as shown in pollen record. Some archeologists suggest that this dramatic climate change destroyed Teotihuacan.

Unit 1 (200~44 cm, ca. 1,100 cal yr B.P. - present)

The alternation between human occupancy and abandonment is evident during this period. Disappearance of *Zea mays* and low frequencies of Amaranthaceae and Asteraceae in the first half of the unit indicate that human kind abandoned the lake between ca. 1,100~650 cal yr B.P. The reason they left the lake could be explained by dramatic increases of $\delta^{18}O$, Na_2O and Cl values around 220 cm reflecting that climate became hostile between 1,400~1,300 cal yr B.P. Spanish arrival around 400 cal yr B.P. is indicated by the fact that *Zea mays* reappears and the presence of Amaranthaceae and Asteraceae, agricultural weedy types, become significant again around 120 cm, whereas Poaceae drops sharply. Sheep, cattle and goats introduced by the Spanish consumed grasses rapidly enough to demonstrate abrupt declines of Poaceae frequency in the pollen diagram. These changes of pollen frequencies reflect the introduction of Spanish farming practices about four hundred years ago. The arrival of the Spaniards and their cattle raising at this time are also indicated by a prominent spike of *Sporormiella* which emerges with an increase in Amaranthaceae frequencies and fine lamination of sediments. Fossil spores of the dung fungus *Sporormiella* spp. have been used as reliable proxy data for livestock introduction (Davis 1987) and megafauna extinction (Burney *et al*. 2003). Fine lamination seems to have developed due to a depletion of oxygen in the lake that resulted from increased input of nutrients by raising livestock. An increase in the importance of Amaranthaceae indicates that they raised livestock and cultivated *Zea mays* with the introduction of Spanish agrosystems. Erosion is implied by high percentages of Al_2O_3, TiO_2 and Fe_2O_3 corresponding to Amaranthaceae frequencies. Elevation of $\delta^{13}C$ values around 400 cal yr B.P. was related to a high influx of livestock waste that caused lake plankton to flourish. Consequent high photosynthesis rates must have raised isotopic ratios of dissolved inorganic carbon in lake water.

CONCLUSION

Pollen records of this study are complacent like other prior pollen records produced in Central Mexico. However, they clearly show human disturbance since ca. 2,500 cal yr B.P. and interestingly, the pine oak ratio indicates some important climate changes in the area. Other proxy, such as isotope and sediment chemistry, reveal paleoenvironmental changes throughout the whole period covered by the sediment materials. In summary, based on the paleolimnological evidence of this study, the findings of climate change in the study area are:

1) In Unit 5 (1,250~1,100 cm, ca. 9,500 ~ ca. 8,300 cal yr B.P.), dry conditions are generally indicated by high Na_2O and Cl percentages and great values of $\delta^{18}O$.

2) In Unit 4 (1,100~890 cm, ca. 8,300 ~ ca. 6,300 cal yr B.P.), low $\delta^{18}O$ values and low percentages of Na_2O and Cl indicate that wet conditions were prevalent during this period.

3) In Unit 3 (890~600 cm, ca. 6,300 ~ ca. 4,000 cal yr B.P.), high percentages of Na_2O and Cl and high pine oak ratios may be an indication of dry and cool conditions during this period.

4) In Unit 2 (600~200 cm, ca. 4,000 ~ ca. 1,100 cal yr B.P.), evidence of human disturbance begins to appear in the pollen records. The climate seems to have been mild and wet. The presence of Chupicuaro culture between 1,100~2,500 cal yr B.P. is implied by the high frequencies of Amaranthaceae and *Zea mays*.

5) In Unit 1 (200~44 cm, ca. 1,100 cal yr B.P.- present), the alternation of human occupancy and abandonment is evidently shown. The reason man left this lake around 1,100 cal yr B.P. could be explained by the dramatic increase of $\delta^{18}O$ around 220 cm reflecting that climate became hostile after 1,300 cal yr B.P. Spanish arrival around 400 cal yr B.P. is implied by the fact that *Zea mays* reappears and Amaranthaceae, Asteraceae and *Sporormiella* spp. become significant around 120 cm, whereas Poaceae drops sharply.

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