Tepexpan Palaeoindian site, Basin of Mexico: Multi-proxy evidence for environmental change during the Late Pleistocene-Late Holocene

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Abstract

The Tepexpan Palaeoindian skeleton was discovered in 1947 close to the former Lake Texcoco margin, in the Basin of Mexico. The find has been the object of considerable interest and discussion over the last 60 years regarding its real age and archaeological interpretation. Here we report new AMS radiocarbon dates associated with the sedimentary sequence at Tepexpan with ages between 19 110 ± 90 and 612 ± 22 ^{14}C years BP and a new uranium-series date for the skeleton with an age of 4700 ± 200 years BP that indicates a Middle Holocene age. The sedimentary succession was studied in detail using: stable isotopes, diatoms, organic geochemistry and tephrochronology. The multi-proxy evidence suggests large changes around the margins of Lake Texcoco in terms of the balance between aquatic

and terrestrial plants, C_3 and C_4 plants, saline, alkaline and freshwater conditions, volcanic activity, marginal reworking of lake sediments and input from the drainage basin through the Late Pleistocene-Late Holocene. These changes had large impacts on the prehistoric human populations living by the lake shores since the Late Pleistocene in the Basin of Mexico.

Keywords: Basin of Mexico, Lake Texcoco, Tepexpan Man, palaeoclimate, stable isotopes, tephras.

1. Introduction

The aim of this paper is to understand environmental change in the Basin of Mexico over the last 20 000 years at the site of the discovery of the Tepexpan Man (Hombre de Tepexpan) Palaeoindian remains. This near complete human skeleton was found in the eastern margin of the former Lake Texcoco, in marginal lake sands, silts and clays, with diatom and volcanic ash layers (De Terra, 1947; 1949; 1951). Tepexpan is an adult male with an age-at death of 25-30 years. The cranium is meso-to brachicephalic, with a cranial index of 79.4 (Gonzalez et al., 2003). The skeleton was found under a layer of caliche in sediments associated with several mammoth finds nearby (De Terra et al., 1949). At the time of discovery, the human skeleton (assumed to be at least 10 000 years old because it was thought to be in coexistence with the mammoth remains) was regarded as an important Palaeoindian skeleton. Here, a sedimentary succession has been studied 80 m to the east of the original site where the skeleton was found. Since its discovery there has been much discussion about the real age of the human skeleton and its archaeological interpretation, as it marks the beginning of the study of early Americans in Mexico and the use of *science based archaeology* methods (geophysics, radiocarbon dating and forensic reconstruction) in the country. Unless stated otherwise, all dates referred to in the text are uncalibrated radiocarbon years.

The separation of climatic change from volcanic and human-induced changes has been a problem in Mexican palaeoclimatology (Sears, 1951; Sears and Clisby, 1955; Metcalfe, et al. 1991; Caballero Miranda, 1995; Lozano-García and Ortego-Guerrero, 1998; Huddart and Gonzalez, 2006). There has also been much discussion regarding the climatic evidence based on various types of proxy (Brown, 1985; Markgraf, 1993; Buckler et al., 1998; Lounejeva Baturina et al., 2006; Solleiro-Rebolledo et al., 2006) and from various altitudes and locations within Mexico (Metcalfe, 1997; 2006; Metcalfe et al., 2000). There has also been a debate related to Mexico in terms of the timing, route and origin of the first colonization of the Americas (Gonzalez et al., 2006a; Gonzalez et al., 2006b) and at least 27 Palaeoindian remains have been identified in Central Mexico, from excavations and chance finds during the last 60 years. This collection known as the *Preceramic Human collection* is kept at the National Museum of Anthropology in Mexico City and has been radiocarbon dated to Late Pleistocene to Middle Holocene (Gonzalez et al., 2001; 2003). Recently, suggested human footprints from the Valsequillo Basin (east of the Basin of Mexico, south of Puebla) have been dated to at least 40 000 years old (Gonzalez et al., 2006b), although this has resulted in much controversy (Renne et al., 2005; Gonzalez et al., 2006a). Nevertheless, there are increasing suggestions that Mexico played a central role in the origin and dispersal of early Americans since the Late Pleistocene, with ages of at least 10 755 ± 75 years BP (OxA-10 112) for the earliest directly radiocarbon dated humans found in the Basin of Mexico (Gonzalez et al., 2003). Consequently, understanding the role of past climate, volcanism and environmental change in the development of early human groups and their associations with migration and settlement patterns, is particularly significant in this area.

2. Regional Setting

2.1 Characteristics of the Basin of Mexico and Lake Texcoco

The Basin of Mexico is a high altitude (ca. 2240 m. asl), flat-floored basin, surrounded by volcanic mountains (Fig. 1) and has been a closed hydrographic system since ca. 700 ka BP (Vázquez-Sanchez and Jaimes-Palomera, 1989). There are a series of interconnected sub-basins which formerly contained lakes. Prior to artificial drainage, these lakes formed a united lake approximately 1000 km^2 in size (Sanders, 1976), with Lake Texcoco the lowest and most saline of these basins acting as the terminal lake. According to Bradbury (1989), a natural sill at the north end of the basin would have limited the lake's maximum depth to 24 m in the recent geological past. This shallowness, combined with thermal spring inflow and carbonate-rich groundwater, explain Texcoco's high salinity. After draining in the 1900s (Bradbury, 1971), the lake now occupies only a small area to the NE of Mexico City surrounded by salt marshes. Tepexpan lies in a marginal lake position on the northern side of Texcoco town, at an altitude of 2241m. The Río San Juan flows into Lake Texcoco just to the south of the site forming deltaic and lacustrine sedimentary environments (Fig. 1). Hence at Tepexpan, lake environments would have been brackish and marshy, fed by springs emerging from the surrounding volcanic lavas, rather than like the saline central lake. Bradbury (1989) found that the system is currently sodium- and bicarbonate-rich, with the central lake being alkaline (pH > 9), compared to the higher elevation freshwater basins (pH 7.6-8.4).

Basin climate is currently subtropical, with monsoonal rainfall from the western part of the Bermuda high falling predominantly in the warm, summer months between July and

October (500-1000 mm). However, the mountains provide a wide range of precipitation and temperature gradients and as a result the basin seems highly sensitive to climatic change (see Metcalfe et al., 2000 for a review). The Tepexpan site is drier (<600 mm) than the southern basin (Sanders, 1976). Solleiro-Rebolledo et al. (2006) suggest that most of the Teotihuacán valley just to the north of Tepexpan, between 2250 and 2800 m. a.s.l., is semi-arid with a mean annual temperature of 14.9 ^{o}C and annual precipitation of 563.3 mm. It is not clear, however, when either the current monsoonal rainfall patterns, or the differences in rainfall across the basin evolved (Lozano-García and Ortega-Guerrero, 1998). The modern vegetation at Tepexpan is highly disturbed, but along the altitudinal gradient, the natural vegetation comprises: Juniper forests, xerophytic scrubland, pine-oak forests, *Abies* forests, grassland (*Hillaria cenchroides*) and subalpine grassland (Rzedowski and Rzedowski, 1979; 1985). The pre-drained environment would have been one that supported emergent and submergent vegetation. Climatic changes over the last 50 000 years BP have seen fluctuations in the balance between grasslands around the lakes and the mixed pine and oak forests of the upper basin (Lozano-García and Vázquez Selem, 2005).

Human influence in the basin may go back at least as far as 22 000 BP from the evidence suggested at the Tlapacoya Paleoindian site to the SE of the Basin (Fig. 1; Lorenzo and Mirambell, 1986), although most of this very early archaeological evidence is also disputed (Huddart and Gonzalez, 2006; Waters, 1985). There is however, firm evidence for human presence in Tlapacoya back to 10,200 ± 65 years BP (OxA-10 225) by direct radiocarbon dating of a human skull (Gonzalez et al., 2003).

3. Previous palaeoenvironmental work in the Basin of Mexico

Lacustrine studies in the basin have focussed predominantly on Lake Chalco to the south of Texcoco (Sears, 1952; Bradbury, 1971; 1989; Watts and Bradbury, 1982; González Quintero, 1986; Lozano-García et al. 1993; Lozano-García and Ortega-Guerrero, 1994; Caballero, 1997; Caballero and Ortega-Guerrero, 1998; Ortega-Guerrero et al., 2000) and Tecocomulco in the north of the Basin (Caballero et al., 1999). There has also been a pollen study of a core from the centre of Lake Texcoco (Lozano-García and Ortega-Guerrero, 1998) and diatom and pollen work on sections from across the basin, including several sites around Texcoco (see Bradbury, 1971; 1989). Here diatoms were used to reconstruct past environments over the last 30 000 years BP, although diatom preservation and dating control were poor (Table 1). Texcoco varied between a saline lake, saline marsh, alkaline lake and alkaline marsh, depending on effective moisture in the basin. During drier periods, the level of Texcoco would drop, forming algal-rich, concentrated pools and creating large areas of river and spring-fed freshwater marshes around the margins of the lake. This is because there is very little change in altitude between the base of Texcoco and the upper basins. During humid periods, and possibly on a seasonal basis, Texcoco would rise and flood the surrounding freshwater marshes with saline water (Bradbury, 1971).

The lakes in the Basin of Mexico are some of the most intensely studied in the Neotropics yet an array of problems have hindered a consensus on general patterns of environmental change (Lozano-García et al., 1993; Metcalfe, 1997; Metcalfe et al., 2000; Sedov et al., 2001; Huddart and Gonzalez, 2006; See Table 1). Finding continuous sedimentary successions, particularly back to 20 000 years is difficult because of numerous late Pleistocene volcanic events that have led to sediment discontinuities and multiple ash layers that render the stratigraphy difficult to analyse and interpret. The Holocene period, which is better represented in many sedimentary successions, has also been difficult to interpret due to low microfossil preservation and intense human activity from ~3500 BP onwards (Metcalfe et al., 1991). Adding to these problems, many sedimentary successions suffer from poor chronological control, largely due to a lack of available organic material to be dated.

Despite these problems, some patterns of basin palaeoclimate are emerging. Most lacustrine records point to the Last Glacial Maximum (LGM) (ca. 23-15 ka BP) being cool and relatively dry; involving the expansion of grasslands around the lake basins (Lozano-García et al., 1993; Lozano-García and Ortega-Guerrero, 1994; Ortega-Guerrero et al., 2000). However, in the highlands, open forest communities, demonstrated by high arboreal pollen levels (e.g. Lozano-García and Ortega-Guerrero, 1998), suggest more variable conditions than first envisaged (Bradbury, 1997; Metcalfe et al., 2000; Sedov et al., 2001) and a more recent study of palaeosols from the Teotihuacán Valley suggest more humid conditions at the LGM (Solleiro-Rebolledo et al., 2006). The late glacial period is less well understood, partly due to frequent volcanic events, which have widely obscured the lacustrine, sedimentary record (Ortega-Guerrero et al., 2000). There is increasing evidence for dry, possibly very dry, conditions in the basin at this time, but local conditions are variable with arguments both for a relatively moist period (15-10 ka BP) (Lozano-García et al., 1993; Caballero and Ortega-Guerrero, 1998) and increased aridity (Bradbury, 1989; Caballero et al. 1999), with Lake Texcoco becoming saline and the marsh areas expanding. In the south of the basin increased freshwater input from the catchment may have been caused by reduced catchment vegetation due to the intense volcanism (Caballero and Ortega-Guerrero, 1998). The combined results of drying and volcanism have been used to explain why many records suggest a hiatus in sedimentation around Texcoco from ca.14 500-6000 BP (Bradbury, 1989; Lozano-García and Ortega-Guerrero, 1998; Sedov et al., 2001).

Most studies suggest an arid period from 9000-6000 BP in the basin (e.g., Lozano-García et al., 1993; Caballero et al., 1999). The main lake was saline and may have occasionally dried out (Bradbury 1989; Lozano-García and Ortega-Guerrero 1998). The pollen record from Texcoco however, suggests that the aridity was not as intense as the late glacial. In the nearby Lerma Basin initially the Holocene was cool, indicated by glacial advances (10 000-9000 BP), followed by climatic amelioration, which was strongest from 8000-3700 BP and correlates to the expansion of *Abies* pollen in the Basin of Mexico. Brief wet periods are evident at 6800 and 5100 BP, followed by widespread deforestation from 3500-1200 BP. Many inferences about the nature and timing of arid intervals since the late Pleistocene are at variance from the rest of Central Mexico (Metcalfe et al., 2000; Table 1). This variance may be due to the complications referred to, but also the fact that Mexico lies between Tropical and Temperate climate regimes.

$\delta^{18}O$ applications have been shown to provide good evidence for past moisture availability in Mexico (Davies, 1995; Bridgwater et al., 1999), but the number of studies has been restricted by a lack of carbonates in volcanic terrain lakes. Here, we present a range of geochemical analyses of a late Pleistocene sedimentary succession excavated at Tepexpan that has the potential to provide detailed records of palaeoclimate. This will allow further understanding of the Central Mexican palaeoenvironment and its influence on human populations and migration patterns. This information, combined with an improved geochronological framework for key early human sites will aid an understanding of Mexican Palaeoindian geoarchaeology during the Late Pleistocene-Early Holocene.

4. Methods, Results and Interpretations

4.1 Lithology

The new sedimentary succession reported here is situated close to the eastern margin of the former Texcoco lake (Fig. 1) and is located at 19º36’52”N, 98º56’47”W at an altitude of 2255 m a.s.l., approximately 80 m from the discovery of Tepexpan Man. Organic and carbonate contents of the sediment were estimated from weight loss-on-ignition at 550°C and 950°C respectively, along with % water content. XRD analysis on 18 samples spaced through the section was carried out using a Philips model PW 1730 X-ray generator, with a PW 1716 diffractometer and PW 1050/25 detector in order to check carbonate species present.

4.2 Lithology Results

The studied sedimentary succession comprises 4 m of fine sands, silts and clays with volcanic ash, calcrete and ostracod layers (Fig. 2). The lithology can be split into 6 distinct units. ***Unit 1*** (400-360 cm) is variable consisting of 12-20 cm interbeds of brown silty clay and approximately 3-8 cm fine sand units, with included ostracods, diatoms and ash. ***Unit 2*** (360-310 cm) is more uniform, consisting predominantly of ash-rich, brown, laminated fine sand, with a band of silt to fine sand at 321-326 cm. There is a colour change to a pale brown fine sand in ***Unit 3*** (310-235 cm), with occasional calcareous and diatom-rich laminations and ripples. ***Unit 4*** (235-138 cm) is volcanic ash dominated and calcareous. The dominant grain size is silty-sand and the upper part of the unit (138-180 cm) is fine sand, with fine ash laminations. In ***Unit 5*** (138-124 cm) there is a band of dark brown silt with carbonate nodules. ***Unit 6*** has an indurated, calcareous, brown silt (124-30 cm) and a caliche (calcrete) layer at 62-62.5 cm. Top soil forms the top 30 cm of the section. The % water content of the sediments varies widely from 5 to 60% (Fig. 2). % carbonate and % organic matter follow similar trends; they are lowest in the ash-rich, Unit 4 and high in Units 1 to 3 (Fig. 2). XRD analyses indicated the samples contained calcite, except one sample of aragonite at 256 cm.

The sedimentary succession described here was also studied by Lounejeva Baturina et al. (2006) and Solleiro-Rebolledo et al. (2006) and it is pertinent to discuss the differences in the current work with these previous studies. The lowest part of our Unit 4 they consider to be a syn-sedimentary formed Fluvisol which has no clear pedogenic horizons but has silica infillings of root channels. We consider this to be largely a tephra fall into the lake and not of pedogenic origin. Our Units 5 and 6 they consider to be dry-land palaeosols separated by pyroclastic sediment (Lounejeva Baturina et al., 2006), partly redeposited by fluvial processes. The lowest of the three upper palaeosols is classified as a Fluvial Cambisol, the middle has a large, hard, carbonate rich ACk horizon and dark brown-black root infillings, whilst the upper palaeosol is thinner with dark-brown Ah horizons and abundant powdery, neoformed calcite. The upper two palaeosols are classified as Calcaric Fluvisols. We also noted a set of deep, narrow fissures beginning in their middle paleosol into the lacustrine sedimentary succession below.

4.3 Stable isotopes

4.3.1 Modern samples

Water samples were collected for $^{18}O/^{16}O$ analysis from the remnant lake and surrounding basin springs to characterise the modern hydrology and were analysed using the equilibration method for oxygen (Epstein and Mayeda, 1953). Analytical precision is typically ±0.05‰ for $\delta^{18}O$ (1σ). Isotope values are reported as per mil (‰) deviations of the isotopic ratio ($^{18}O/^{16}O$) from standard mean oceanic water (V-SMOW).

4.3.2 Modern isotope hydrology results and interpretation

The present, highly evaporated, Lake Texcoco has a $\delta^{18}O$ value of –3.3‰ (in 2003). Spring water has a mean $\delta^{18}O$ value of -11.7±0.2 ‰ (n=3) and is likely to represent the $\delta^{18}O$ composition of precipitation in the basin. As described above, the hydrology of Lake Texcoco is unusual as during drier periods freshwater may become more influential giving rise to low marginal lake $\delta^{18}O$ values, approaching –12‰ or lower. During humid periods the lake level rises introducing saline, evaporated and thus isotopically heavy water to the surrounding freshwater marshes (Bradbury, 1971).

4.3.3 Carbonate $\delta^{18}O$ and $\delta^{13}C$ Methods

Sediment samples were treated with 5% sodium hypochlorite solution for 24 hours to oxidise reactive organic material, washed three times in distilled water and sieved at 85µm. The <85µm fraction was filtered through quartz microfibre filter paper, dried at 40°C and ground in agate. The isolated material was reacted with anhydrous phosphoric acid *in vacuo* overnight at a constant 25°C. The CO_2 thus liberated was separated from water vapour and collected for analysis on a VG Optima mass spectrometer. Overall analytical reproducibility for this type of sample is normally around 0.2‰ for $\delta^{13}C$ and $\delta^{18}O$ (2σ). Isotope values ($\delta^{13}C$ and $\delta^{18}O$) are reported as per mil (‰) deviations of the isotopic ratios ($^{13}C/^{12}C$ and $^{18}O/^{16}O$) from the standard V-PDB.

4.3.4 $\delta^{13}C_{organics}$ and C/N Methods

Percentage carbon and nitrogen, used to calculate C/N, were measured on sediments treated with 5% HCl to remove carbonates using a Carlo Erba elemental analyser, calibrated through an internal acetanilide standard. Replicate analysis of samples gave a precision of + <0.1 (1σ). $^{13}C/^{12}C$ analyses were performed by combustion using a Carlo Erba 1500 on-line to a VG Triple Trap and Optima dual-inlet mass spectrometer. $\delta^{13}C_{organic}$ values were calculated to the V-PDB scale using a within-run laboratory standard (cellulose, Sigma Chemical prod. no. C-6413) calibrated against NBS-19 and NBS-22. Replicate analysis gave a precision of $\pm$ <0.1‰ (1σ).

4.3.5 Carbonate $\delta^{18}O$ and $\delta^{13}C$ Results and Interpretation

The carbonate $\delta^{18}O$ and $\delta^{13}C$ show good correspondence suggesting that they are responding to changes in climatically-induced, moisture variations (variations in P-E) (See Fig. 3). Units 1- 3 show similar trends where the values start relatively low and increase through the unit. $\delta^{18}O_{calcite}$ in Units 1 and 2 increases from –3 to –4‰ to +7‰ and similarly in Unit 3, increases from –2‰ to over +7‰, before progressively decreasing at the top of the unit to –2‰. $\delta^{13}C_{calcite}$ shows similar patterns in units 1-2, increasing from around 0‰ to +6‰ and similarly in Unit 3 it increases from –2 to +6‰ but unlike $\delta^{18}O_{calcite}$, does not decrease at the top of the unit. In the ash-rich Unit 4, values for carbon and oxygen are variable, beginning low (<–10‰ and <–6‰ respectively) and then stabilising for $\delta^{13}C_{calcite}$ at around –1 to +1‰; but remaining variable for $\delta^{18}O_{calcite}$ at –7 to +2‰. $\delta^{18}O$ and $\delta^{13}C$ values are relatively stable in units 5 and 6, around –5 to –3‰ and 0 to +2‰ respectively. The top 3 values have lower $\delta^{18}O$ and $\delta^{13}C$ values coinciding with lower C/N values and higher % water content (Fig. 3).

4.3.6 $\delta^{13}C_{organics}$ and C/N Results and Interpretation

$\delta^{13}C_{organics}$ and C/N ratios are usually measured together as $\delta^{13}C_{organics}$ can be difficult to interpret without knowing the source of the organic material reaching the lake (Figs 2 and 4). C/N ratios can distinguish between aquatic vegetation (C/N ratios of 4-10) and terrestrial, vascular plants (ratios > 20) (Talbot and Lærdal, 2000). Normally, lacustrine sedimentary C/N ratios of between 10 and 20 represent a mixture of aquatic and higher plant material

(Meyers, 1994). Plankton has average C/N ratios of between 5 and 8 (Tyson, 1995) but freshwater macrophytes are more varied and record ratios of between 12 and 30. Phytoplankton and macrophytes will utilise dissolved CO_2 in the lake in the same way as C_3 plants and thus will have a similar range of $\delta^{13}C$ values (−17‰ to –9‰; Degens et al., 1968). If dissolved CO_2 becomes depleted in a lake due to elevated pH, or increased productivity, HCO_3^- will be utilised instead, which has a higher $\delta^{13}C$ ratio, thus increasing aquatic plant $\delta^{13}C$ values to C_4 ranges (Laws et al., 1995). If C/N ratios indicate terrestrial sources of plant material, C_4 grasses (−17‰ to –9‰; Deines, 1980) can be distinguished from C_3 plants (−33‰ to –23‰) O'Leary et al. (1992). Common C_4 plants, with high $\delta^{13}C$ values, include *Poaceae*, *Chenopodiaceae* (Cerling *et al*., 1988) and *Cyperaceae* (sedge family; Tyson, 1995), whereas most other plants (temperate grasses, shrubs, trees and some forbs) have lower $\delta^{13}C$ values and are C_3 category. There is an intermediary group of plants (CAM), including most succulents, that have intermediary $\delta^{13}C$ ratios of −11‰ to −28‰ (Schleser, 1995).

%C closely follows trends in % water content, with peaks in both occurring concurrently in Units 1 and 2 at 389, 365 and 323 cm. In Unit 3, %C begins at around 4% but drops off rapidly through the unit to <1% that is maintained through Unit 4, before it increases gradually to a few % through the upper 2 units (Fig. 3). Neither %C, %N, or C/N decrease systematically down the section, suggesting that diagenetic processes have not severely affected the sediments (Fig. 3). %C and %N positively correlate (r^2 = 0.91, n=151) suggesting that they are both organically bound (cf. Talbot and Johannessen 1992). C/N ratios vary between units (Figs 3 and 4); in Units 1 and 3, values are predominantly greater than 15, suggesting a dominance of terrestrial or vascular plants. In Unit 6 C/N is intermediate, around 10-15 and suggests a mixed environment. In Units 2 and 5, C/N values range from 3 to 13 indicating that aquatic plants dominate. Low % TOC values in unit 4 mean that C/N interpretations are unreliable and are thus not shown or discussed. C/N ratios begin high at the section base (c. 20) and fall progressively through units 1 and 2 (to < 5) before returning to high values (15-20) in unit 3. Values are again low in unit 5 (c. 5) and then increase to around 15 in the upper unit.

$\delta^{13}C_{organics}$ is relatively stable in Units 1 to 3 ranging from –18‰ to –21‰. There is a peak of heavier values around –18‰ at 331-345 cm, coinciding with C/N values of <5. In Units 5 and 6, $\delta^{13}C_{organics}$ values are considerably higher, ranging from –16.4 to –14.7‰ and are approaching C_4 values (Figures 3 and 4).

4.4 Organic geochemistry

4.4.1 Methods

For lipid extraction, four samples characteristic of different lithologies from the Tepexpan section were freeze-dried and powdered to pass a 63 μm sieve. Accurately weighed sediment portions were spiked with a known amount of hexatriacontane (*n*-C_{36} alkane) dissolved in dichloromethane (DCM). The sediments were mixed with an equal amount of anhydrous sodium sulphate and extracted with DCM:methanol (9:1 v/v) in an accelerated solvent extraction system ASE 200 (Dionex). The solvent was reduced under a stream of dry nitrogen gas to a volume of 5 ml. The total lipid extracts were split into acid and neutral fractions by solid phase extraction using normal phase C18 cartridges (Aminopropyl Bond Elute) pre-washed with DCM:isopropanol, 2:1 v/v. The neutral fraction was recovered with 10 ml DCM:isopropanol, 2:1 v/v and separated into hydrocarbon, alcohol and polar portions using thin layer chromatography (TLC) (silica 60 G, 0.25 mm thick). The plates were developed using 1% acetic acid in hexane: ethylacetate 7:2 v/v) and the aliphatic and alcohol fractions collected. Combined gas chromatography-mass spectrometry (GC-MS) was performed using a Fisons 8000 GC directly coupled to a Fisons 800 MD single-quadrupole mass spectrometer. Sample application (1 µl) was by on-column injection. The GC oven was temperature-programmed from 40˚C (1 min. isothermal) to 310˚C at 4˚C / min. and held isothermally at 310˚C for 5 min. Peak areas of the products and internal standard were measured using the total ion current (TIC) on the GC-MS. For Elemental Analysis and Rock-Eval Pyrolysis concentrations of total organic carbon (TOC) were determined on the carbonate free samples using an Elementar C, N, S analyser operated in C mode. Kerogen typing was conducted using a Rock-Eval II instrument (precision of measurement for HI, OI; ±5%. Hydrogen Indices (HI=S2×100/TOC) and Oxygen Indices (OI=S3×100/TOC) were measured using TOC values.

4.4.2 Results and Interpretation

The *n*-alkane distributions of the sediment samples from selected palaeoenvironments (Units 1, 3, 4 and 6) are shown in Fig. 5. Similar *n*-alkane distributions in the range of nC_{13}-nC_{33} and maximal *n*-alkane at nC_{31} were observed in samples from the lowest part of the section (389cm, Unit 1 and 304cm, Unit 3) (Table 2). The range and relative abundance of *n*-alkanes are consistent with a dominant input from land plant, epicuticular waxes (Meyers, 1997; 2003). Freshwater microalgae, such as *Botryococcus braunii,* also yield odd numbered long chain *n*-alkanes in the range $nC_{25\text{-}35}$; however, sediments rich in *B. braunii* also contain significant concentrations of macrocyclic-alkanes in the range C_{15}-C_{24} (Audino et al., 2001). The absence of macrocyclic-alkanes here confirmed that the odd carbon numbered high molecular weight *n*-alkanes are mainly sourced from terrestrial plant waxes. This notion is supported in part by the high terrigenous/aquatic ratio (TAR) values of 6.6 and 6.9 which indicates elevated terrestrial sources of lipids relative to aquatic sources, such as algae (Meyers, 1997) (Table 2). The odd to even carbon preference values of ~4 for both samples show a strong odd *n*-alkane preponderance which is consistent with terrigenous input from either grasses, or deciduous trees, or both, and low thermal maturity (Scalan and Smith, 1970) (Table 2).

Ficken et al. (2000) have shown in four surface lake sediments and 23 plant species from Kenya that submerged and floating leaved aquatic plants yield enhanced abundances of C_{23} and C_{25} *n*-alkanes as compared to emergent and fully terrestrial plants which are dominated by C_{29}, C_{31} and C_{33} homologues. This was formulated into the proxy, *P*aq for submerged/ floating aquatic plants *versus* emergent terrestrial plant sources. At Tepexpan samples at 304 and 389 cm give intermediate values of 0.4 corresponding to emergent macrophytes, or possibly a mixture of terrestrial, emergent and submerged vegetation (Table 2). The sample at 199 cm (Unit 4) with *P*aq value of 0.7 corresponds with *n*-alkanes derived mainly from submerged/floating species. Evidence that this section of the lake represents a changed palaeoenvironment from that above (118 cm, unit 6), or below (389 cm, Unit 1 and 304 cm, unit 3) is supported by the high relative abundance of low molecular weight homologues, even *n*-alkane preponderance, as well as TAR value of 0.4 which suggest increased sources of aquatic sources of *n*-alkanes (Table 2). The moderate OEP value of 0.7 could be caused by thermal maturation due to volcanism since carbon number preference is known to diminish with thermal maturity/marine input.

The uppermost section (118 cm, Unit 6) probably represents a mixture of different terrestrial and aquatic sources as evidenced by the high abundance of odd carbon numbered high molecular weight homologues (nC_{31}- nC_{33}). However, a significant contribution from lower molecular weight *n*-alkanes, as well as *P*aq of 0.4 (emergent macrophytes), and moderate TAR of 0.4, possibly indicates mainly terrestrial watershed sources (Meyers, 1997). The input of C_3 and C_4 plants into agricultural soils can be delineated on the basis that the former are slightly depleted in nC_{33} as compared to their C_4 vegetation (Wiesenberg et al., 2004). The high proportion of nC_{33} relative to nC_{29} and nC_{31} in sample 118 cm may therefore indicate an increase in C_4 plant input (Fig. 6).

The Rock-Eval pyrolysis data presented in Fig. 7 can be used to characterise bulk organic matter; the hydrogen and oxygen indices provide proxy information for algal or land plant derived organic matter (Meyers, 2003; Holtvoeth et al., 2001). Samples 118 cm, 304 cm and 389 cm all have HI values above 50 mg (HC/g TOC) but lower than 200 mg (HC/g TOC). With variable OI values, this suggests that the hydrocarbons are probably derived from a Type III kerogen, which is predominantly composed of organic matter sourced from land plants. In contrast, Type II kerogens originate from bacterial, phytoplankton and or zooplankton sources, or from type II/III mixed marine/terrigenous inputs, which yield HI values of 300-600 mg and 200-300 mg (HC/g TOC) respectively. Type IV kerogens are generally classified as having HI values of <50 mg. However, previous studies of HI indices from Late Quaternary sediments from Lakes Victoria and Rukwa have suggested that HI values of <200 possibly indicate either a mixed source of organic matter, or a significant coal or charcoal component as well as possible reworking and oxidation (Talbot and Livingstone, 1989).

The HI/OI indices of Sample 199 cm (Unit 4) cannot be readily explained in terms of kerogen type, or sources of organic matter since HI values of >1000 have not been previously described even in algal Type I source rocks, which are derived in the main from reworked algal debris deposited in lacustrine or marine settings. One plausible explanation for this spurious data point maybe that the very low TOC value is not reliable, or that the mineral matrix contributes to CO_2 production, thus elevating S3 (mg CO_2/g rock) and OI indices.

4.5 Diatom ecology

4.5.1 Methods, Results and Interpretation

Here we present preliminary results from 17 samples through the section between 401 and 40cm in depth. Samples were prepared using a standard method to remove carbonate and organic matter (Battarbee, 1986). Diatoms were identified under 1000 x magnification using standard floras and interpreted using both published information and personal data on the ecology of modern Mexican diatoms (e.g. Davies et al., 2002). Diatom abundance and preservation through the section is variable from few to relatively abundant. The flora indicates shallow water, but of varying degrees of salinity/alkalinity, with some signs of changes between $NaCO_3$ and NaCl chemistry (Fig. 8). In Unit 1, the diatoms indicate variable conditions. Shallow water is indicated with small *Nitzschia* spp. or *Fragilaria* spp. dominating. The species suggest mostly freshwater conditions with occasional increases in alkalinity and water chemistry varying between HCO_3^-, CO_3 and Cl. Diatoms are abundant and well preserved and indicate vegetation nearby in some places (388-390 cm), but are sparse and poorly preserved, with signs of mechanical damage and corrosion in others (378-380 cm). At 378-380 cm very alkaline conditions are suggested by thinly silicified *Nitzchia* spp. and the lake appears shallower and more evaporated than the base of the unit. Between 364-366 cm more abundant diatoms indicate slightly fresher conditions again and a shallow, vegetated, fairly alkaline lake. In Unit 2 the diatoms change to being predominantly thinly silicified and generally preservation is poor. This is likely to be due to increasing alkalinity through this unit. Where species can be identified confidently, they comprise epiphytic and benthic species, indicating moderately alkaline and shallow, HCO_3^-/CO_3 water (338-334 cm), apart from at 323-324 cm where slightly deeper and fresher conditions are indicated. Unit 3 also has poor preservation to begin with, improving up through the unit, with the species present suggesting fluctuating conditions, shallow water and indications of NaCl chemistry (*C. clypeus*). The presence of vegetation is still evident. Unit 4 is rich in silica debris but has few diatoms. Those which are present indicate shallow, NaCl and CO_3 waters, at the edge of a lake, with some vegetation. Again there is very poor preservation in Unit 5 but there are indications of a mixed alkaline (NaCl-CO_3), shallow water flora and there is less sign of epiphytic taxa. At the top of the section (40 cm) only very small fragments of diatom can be seen again, possibly because the lake was too alkaline to preserve the frustules well. Generally the diatoms indicate shallow water, with moderate to high alkalinity, with only the sample from 388-390 cm suggesting fresher water. There is more evidence for NaCl waters in the middle part of the core (e.g. 300-250 cm), with increasing loss of preservation in the upper section. This suggests that an already shallow system became unsuitable for diatom preservation and no longer supported many aquatic macrophytes.

4.6 Tephra

4.6.1 Methods

Selected samples from the Tepexpan sedimentary succession were analysed for major element geochemistry of the tephras (volcanic glass) using a Cameca SX100 Electron Probe Microanalyser at 10 kV beam voltage (Appendix). Total iron is expressed as FeO and analyses of pure glass with totals above 95% were normally present. Carbon coated slide samples were analysed using the wavelength dispersive method, with an accelerating voltage of 10 kV. Homogeneous Lipari glass and an andradite (garnet) were analysed at regular intervals to establish the probe stability.

4.6.2 Tephrachronology results and interpretation

The results presented are the first study of the tephra glass geochemistry at this archaeological site, although Gonzalez and Huddart (2007) presented data from the nearby

Tocuila Mammoths site, whilst Ortega-Guerrero and Newton (1998) studied tephra geochemistry from mainly the southern part of the Basin of Mexico. Prior work in the basin by Mooser (1967), Lambert (1986) and Bradbury (1989) used tephras as stratigraphic markers using mainly subjective criteria (colour and grain size of the layers). The tephra geochemistry is given in the Appendix. A summary of the results is as follows:

a) There are a range of basaltic, basaltic-andesite and rhyolitic ash contributions to the sediments, with strong evidence of reworking. The only real tephra layer *in situ* is the 20 cm basaltic-andesite tephra in samples TX59 and TX55. This means that there are several characteristic tephra markers from the Basin of Mexico that are missing in the Tepexpan sedimentary succession, based on the ^{14}C dates obtained for this section (see the results reported in Mooser (1967) and Lozano-Garcia and Ortega-Guerrero (1998) and the discussion in Gonzalez and Huddart (2007)).

b) In the lowest part of the succession between 370-404 cm, dated to between 16 730 ± 75 and 19 110 ± 90 BP, there is a component of rhyolitic tephra (72-75% SiO_2) in the silty fine sand, although there are a few grains at 64% SiO_2 (TX151, TX142). However there is no obvious rhyolitic tephra marker reported previously in the basin at this time period (which could have been reworked), except for the rhyolitic component in the pyroclastic flows and ash on the piedmont fringe to the East. It has been suggested by Huddart and Gonzalez (2006) that these pyroclastic flows and associated rhyolitic ash were active as late as ca.37 000 BP from one of the rhyolitic domes found around the Quetzaltepec Sierra (Volcan Telapon). This is much later than had formerly been suggested, as these volcanoes were always thought to be Tertiary in age (Mooser (1975). It is clear that the relationships between these deposits, and their dating, is poorly understood because the dacitic lavas and pyroclasts with large quantities of pumice that together form the Tlaloc Formation were thought by Vasquez-Sanchez and Jaimes-Palomera (1989) to be between 0.6-0.7 Ma, while the piedmont fringe sequences of pyroclastic deposits, lava flows and fluvial sediments were considered to be mainly Pleistocene in age (Mooser et al., 1996).

c) In the succession between 340-370 cm there is a mixed tephra component with rhyolitic (73-75% SiO_2) and basaltic-andesitic (64-65% SiO_2) grains. This suggests that the reworking of the rhyolitic ash from the upper basin catchment still continued, along with the complete reworking of the Pomez con Andesita (Pumice-With-Andesite ash) (c.14 500-14 000 BP). This ash has not been recognised *in situ* at Tepexpan, although it has been noted at many other locations throughout the basin, such as Tlapacoya, Tocuila and pockets of this ash have been found in lacustrine clay as 'ash balls' at the nearby Santa Isabel Iztapan II Mammoth site (Huddart and Gonzalez, 2006). Bradbury (1971) proposed that Tepexpan Man was as old as the Pumice with Andesite ash, because he found pumice clasts from this ash in the sediments immediately below the caliche layer, where the skeleton was found (Fig. 2). This illustrates that there has been significant reworking of this ash at Tepexpan and many other sites in the basin, such as at Tlapacoya from the slopes above the hill (Huddart and Gonzalez, 2006) and at Tocuila from the flanks of lahar channels (Gonzalez and Huddart, 2007). From these examples it is clear that the reworking process is very common and must be recognised in the sections, to avoid confusion and to be able to construct a correct and accurate tephrachronology.

d) The only tephra found *in situ* in the section is a 20 cm basaltic-andesitic to andesitic tephra found between c.200-220 cm, with SiO_2 contents between 54-59% (Appendix). It cannot be the Gran Ceniza Basaltica because of its age and it may be the Chimalpa tephra dated to 14,015± 130 BP (Ortega-Guerrero and Newton, 1998), and although this had similar % of SiO_2 (54-58%) it was only 5 cm thick in the southern Chalco basin. The likely source of this tephra may be one of the monogenetic cinder cones close to Tepexpan such as Cerro Chiconautla, Cerro Tlahuilco or Cerro Santiago.

e) Between 200-130 cm the buff fine sand has a major component of volcanic ash, although with no obvious tephra horizons *in situ*. For example, in samples TX29, TX14 and TX6 there is a mixed tephra population including basaltic, basaltic-andesite and rhyolitic grains. There is no evidence of the 10 500 BP, Upper Toluca Pumice *in situ* which produced a medium to fine sand pumice layer up to 50cm thick in the Basin of Mexico (Arce et al., 2003), which is present at the Tocuila Mammoths site (Gonzalez et al., 2001;Gonzalez and Huddart, 2007). The rhyolitic component from the upper drainage basin may also have contributions from the rhyolitic tephras (76-78% SiO_2) dated to around 13 450± 40 BP from Tequexquinahuac in the upper part of the piedmont slope to the south-east of Tepexpan (Huddart and Gonzalez, 2006). This could be equivalent to the San Martin tephra (67-73% SiO_2), described by Ortega-Guerrero and Newton (1998) from a location in the southern Lake Chalco basin, which was dated to 13 990± 100 BP However, it seems more likely that there are two different rhyolitic eruptions in this period. At the Tocuila Mammoths site there is a beige, sandy silt, with pumice clasts just above a white rhyolitic ash (73-74% Si). It included gastropods which have been dated by AMS to 10 016± 39 BP (OxA-15840). Whilst it is possible that this ash is a phase of the Upper Toluca Pumice, the silica content from that tephra is between 69-73% (Newton and Metcalfe, 1999) and hence lower than this ash found in Tocuila. The other components to this part of the Tepexpan sedimentary succession must come from the basaltic and basaltic andesite ash, lower in the sedimentary succession, the Pumice-with-Andesite and Upper Toluca Pumice, reworked from the lake margins and from all these sediments from the drainage basin to the north-east. This reworking can be also seen in sample TX6 where there are incorporated mud balls with volcanic ash grains in the centre.

f) Below the caliche layer, the pale white, $CaCO_3$-rich silt has a mixed tephra population with components from the PWA, UTP and a basaltic ash (TX4) at 70 cm and again evidence for reworking with the presence of muddy balls. Gastropods from this layer at 88.5 cm have been dated to 6333± 30 BP whilst sample TX2 at 50 cm above the caliche again shows a mixed population and muddy balls and has been dated to 612± 22 BP However, there is another rhyolitic tephra from core E at Chalco (the Huitzilzingo tephra) dated to 2645± 55 BP (Ortega-Guerrero and Newton 1998) but this is not apparent at Tepexpan. Whilst there is no obvious source for the rhyolitic tephras in the Basin of Mexico apart from the Tlaloc-Telapon massif volcanic system, this has implications for the region as the associated dating suggests that perhaps these rhyolitic, explosive eruptions have been periodic throughout the time period from 37 000 to 2645 BP in the basin of Mexico.

5. Tepexpan Chronology

One of the main problems for the study of the Tepexpan Palaeoindian site has been the lack of a well constrained chronology. This is because the only directly dated material was the Tepexpan human skeleton itself, with lots of problems of contamination with younger material added to the specimen at the time of discovery during the 1940’s, to try to consolidate it. This situation gave as a result an erroneous young (contaminated) radiocarbon date of around 2000 years BP (Lorenzo, 1989; Stafford et al., 1991; Gonzalez et al., 2003). We report in here a new Uranium-series date of 4700 ± 200 years BP (Fig. 9) that has been obtained directly from the skeleton, which is more or less in agreement with an AMS radiocarbon date of 5600 ± 40 years BP (Beta 205077) obtained by Solleiro et al. (2006) for humus associated with the layer where the skeleton was found. Also, an independent chronology for the new sediment section was obtained here using a combination of AMS radiocarbon dating on ostracods, gastropods and detailed tephrochronology studies. The different methods used are explained below.

5.1.1 Uranium series dating of the Tepexpan human skeleton

Direct dating of bone by U-series presents a particular challenge because bone remains an open system for uranium, and any attempt to calculate a date from U-series measurements requires a model of uranium uptake. Here we employ the method of Pike et al. (2002) who have shown that the U uptake regime for a bone is reflected in the distribution of U and U-series isotopes across a bone section. Analyses were made on a section of bone from the Tepexpan human skeleton, from the outer (periosteal) to inner (endosteal) surfaces using laser ablation plasma mass spectrometry according to the method of Eggins et al. (2005). The U distribution is ∪-shaped while the dates are relatively uniform towards the outer surface getting older towards the centre (Fig. 9, Table 3). However, the low $^{230}Th/^{232}Th$ indicates significant contamination by detrital ^{232}Th, presumable from sediment, for many of the samples. Detritus brings with it ^{230}Th, and in most cases will lead to older apparent ages. In this case, all of the older dates towards the centre of the bone are heavily contaminated. Rejecting any dates with $^{230}Th/^{232}Th$ >10 leaves a relatively uniform distribution of dates with a mean of 4700 ± 200 years. A uniform distribution of U-series dates, with a ∪-shaped uranium concentration profile is indicative of the early cessation of uranium uptake by the bone (Pike et al., 2002), so we have taken the mean of the closed system dates to be out best estimate of the age of the bone. There could, of course, have been a delay before the onset of uranium uptake, so this should be taken as a minimum age and therefore not inconsistent with the radiocarbon date in humus in the layer where Tepexpan Man was found, of 5600 ± 40 years BP reported by Solleiro et al. (1996).

5.1.2 Radiocarbon dating

Two gastropod shell samples for AMS radiocarbon dating were extracted from a section adjacent to the Tepexpan Man section described here and correlated to the section whilst in the field (equivalent depths of 46 cm and 88.5 cm respectively). The whole and broken shells were pre-treated using an acid wash procedure to remove the external shell layer in case of any post-depositional change and crushed before acid hydrolysis treatment, CO_2 collection, graphitization and AMS dating. Two additional samples for dating were taken from ostracod-rich layers at 365 cm and 400 cm. Ostracods were separated by treating with 5% sodium hypochlorite, sieved at >180 μm, then screened under a microscope where juveniles, broken shells, any with carbonate overgrowths were removed, along with other contaminants. Between 10-20 mg of ostracods were selected and checked for the presence of aragonite with Fiegl's solution. As the staining indicated only calcite, ostracods were lightly crushed and rinsed in water, before being AMS dated using direct combustion. The dates are reported as uncalibrated radiocarbon years BP after correction for isotopic fractionation (Table 4).

5.1.3 Sediment Sequence Dates

The four AMS radiocarbon dates range from 19 110 ± 90 years at the base of the section to 612 ± 22 years at 46 cm from the surface (Table 4). Assuming continuous sedimentation, the rate of accumulation ranges from ~0.15 $mm.y^{-}$ (19 110 ± 90 to 16 730 ± 75), ~0.27 $mm.y^{-}$ (16 730 ± 75 to 6334 ± 30) and ~0.07 $mm.y^{-}$ (6334 ± 30 to 612 ± 22). Rates of 0.15 $mm.y^{-}$ and 0.27 $mm.y^{-}$ are fairly slow, but not uncommon for lake environments, however given the marginal location of the Tepexpan site in relation to the lake basin, with a river nearby, some sediment erosion events are to be expected. The very slow accumulation rate from the period between 6334 to 612 yrs BP almost certainly does indicate a discontinuity. There are suggestions that the sedimentary record of the Holocene in Mexico is commonly incomplete due to human disturbance of the environment and also due to intense drying in some locations and this may be reflected here too. In the Late

Pleistocene the large accumulation of ash in Unit 4 was deposited quickly as a series of instantaneous ashfalls and hence the accumulation rate between 16 730 ± 75 and 6334 ± 30 BP may overestimate the true lake sedimentation rate.

Based on the tephra studies it seems likely that there are important gaps in the sedimentary succession during the Late Pleistocene-Early Holocene related to volcanic events and subsequent reworking as the ones already found in the lahar channels and discontinuities in the Tocuila Mammoths sedimentary succession (Gonzalez and Huddart, 2007) and those proposed from ca. 14 000 years BP onwards (Bradbury, 1989; Lozano-García and Ortega-Guerrero, 1998). The significant shift in the geochemical proxies occurring at 310 cm at the lithological boundary between the ash-rich fine sand of Unit 2 to the more calcareous, paler fine sand of Unit 3 (see below) might indicate a discontinuity. Bradbury (1989) suggested that when the margins of Lake Texcoco were exposed, or covered by shallow water, the sediments would accumulate very slowly and thus creating a reliable detailed chronology at Tepexpan maybe difficult. Hence the chronology in here is only a guide to the timing of the inferred climate changes.

6. Overall Interpretation of Lake Conditions

Bradbury's (1989) diatom ecology reflects the fluctuating influence of the Rio San Juan that feeds into the Texcoco Lake via the Teotihuacan Valley. Deeper water periods associated with clays and planktonic species also indicate saline water; whereas freshwater and alkaline water diatoms occur during the regression of Lake Texcoco, when the river water influence becomes relatively strong. The multiproxy study discussed here also suggests large changes in the nature of Lake Texcoco at its margins in terms of the balance between aquatic and terrestrial plants, C_3 and C_4 plants, saline, alkaline and freshwater conditions and volcanic activity. The overall profile represents a volcano-lacustrine, regressive sequence.

Unit 1 The presence of clays and silts suggest relatively deeper water. The water content of the sediment is high, and Bradbury (1989) suggested this may be due to high clay content in the sediment caused by in-wash of weathered ash from the catchment. Other proxies also suggest high in-wash from the catchment, the main peaks in water content corresponds to peaks in %C which may indicate increased nutrient and plant inflow to the margins. The organic geochemistry sample at 389 cm suggests organic material dominated by terrestrial plant waxes and that these are likely to be a mix of terrestrial plants from the catchment and emergent macrophytes. This is also suggested by the C/N and $\delta^{13}C_{organic}$ data which points to terrestrial plant material of C_3 type. The fact that carbonate $\delta^{18}O$ and $\delta^{13}C$ values are high to begin with (around 0‰) and increase through the unit, suggest that the lake water was fairly saline and was progressively evaporating through the unit, possibly as climate became drier. The variability in the unit is emphasized by the changing diatom ecology, which fluctuates between periods of freshwater and very alkaline conditions in a marginal lake setting. Thus overall the proxies point to high river inflow into the margins of a saline lake, indicating a variable climate, possibly becoming drier through the unit.

Unit 2 by contrast is less variable and has a generally coarser grain size, suggesting shallower water. Carbonate $\delta^{18}O$ and $\delta^{13}C$ data suggest further evaporation and concentration of lake water indicating the continued aridification of climate and lower lake levels. C/N and $\delta^{13}C$ begin and end with higher values typical of terrestrial plants, but in the centre of the unit (at 331-345 cm) fall to below 5 and this is concurrent with higher $\delta^{13}C$ values that approach –18‰. This would suggest a period of increased phytoplankton numbers, indicating algal-rich pools utilising bicarbonate rather than CO_2. The diatom preservation is generally poor in this unit and is likely to be due to increasing alkalinity which is supported by some epiphytic and benthic species which indicate moderately alkaline and shallow, HCO_3^-/CO_3 water (338-334 cm). A brief wet phase indicated by a band of silt to fine sand at 321-326 cm and diatoms at 323-324 cm indicate slightly deeper and fresher conditions. Thus the lake margins at this point appear to have become relatively shallow and stagnant, with less river inflow and the development of alkaline pools, although conditions remain variable with interruptions from brief wetter periods.

Unit 3 is much like Unit 1 and the organic geochemistry suggests a change back to the dominance of terrestrial or emergent plants rather than aquatics. C/N ratios >15 concur with this indicating a higher plant dominance. Very high %C at the beginning of the unit, followed by a rapid but progressive decline, suggests in-wash is high and climate is humid at the start, then drying through the unit supported by high and increasing $\delta^{18}O$ and $\delta^{13}C$ carbonates. Diatom preservation improves through the unit and suggests fluctuating shallow water, including indications of NaCl chemistry, with the presence of vegetation.

Unit 4 The dominance of volcanic ash makes interpretations of the palaeoclimate difficult as little organic material is preserved. What is there suggests a submerged or floating aquatics source for organics from the organic geochemistry and limited C/N data. $\delta^{18}O$ and $\delta^{13}C$ from preserved carbonates are lower and variable particularly to begin with and initially $\delta^{18}O$ and $\delta^{13}C$ carbonates fall suggesting an increase in freshwater inflow. The few diatoms preserved in this environment suggest shallow, NaCl and CO_3 waters at the edge of a lake with some vegetation. Thus the limited evidence points to shallow, freshwater re-established in a highly variable, volcanically-disturbed horizon. Solleiro-Rebolledo et al. (2006) suggest that their syn-sedimentary Fluvisol developed in a transitional environment at the periphery of a drying lake with sedimentation hampering the soil profile, although they recognised weak humus accumulation, silica neoformation and a restricted and late calcite precipitation (potentially indicating a hiatus?).

Unit 5 Following this volcanically-disturbed period, the lake changes character dramatically to one of initially aquatic vegetation in concentrated alkaline pools (low C/N ratios and high $\delta^{13}C_{organic}$), with increased evaporation, suggested by the carbonate isotopes and diatom species indicative of increasingly alkaline conditions At the top of the section (***Unit 6***), the organic geochemistry suggests a mix of aquatic and terrestrial plants and higher $\delta^{13}C_{organics}$ for the terrestrial plants may relate to an increase in C4 *Cyperaceae* and thus possibly spring flow. However, increasing human influence in the region, in the form of cereal growing, is a more likely reason for the increase in C4 plants. The consistently high $\delta^{13}C_{organic}$ values also suggest that the aquatic portion of the organics were utilising HCO_3^-, thus lake conditions are likely to have been very alkaline. The diatom flora suggest less aquatic vegetation and a mixed alkaline ($NaCl-CO_3$), shallow water flora. Solleiro-Rebolledo et al. (2006) recognised palaeosols in this part of the succession which had characteristics related to hydromorphic conditions which resulted from high groundwater levels indicated by Fe-Mn (with humus) hypercoatings in the voids. They also had characteristics related to a dry environment, such as deep fissures, indicating intense desiccation and secondary carbonate precipitation, the latter especially in the uppermost palaeosol and modern soil. There are also impure clay coatings in the strongly calcified palaeosols and the presence of lithogenic calcite suggests that they were never carbonate-free. They attribute this particle translocation to infiltration of flood waters, saturated with suspended sediment and so conditions suitable for illuvial pedofeatures were possible even in the carbonate-rich soils of an arid environment.

Generally, the evidence indicates periods of high inflow at the base of the sedimentary succession that fluctuated with periods of marginal flooding by saline water and periods of enhanced evaporation. In the middle of the sedimentary succession, volcanic events disturb the proxy evidence but lower lake levels and some freshwater input is suggested. Following this, increasing loss of diatom preservation, increase in C_4 vegetation and lower $\delta^{18}O$ and $\delta^{13}C$ carbonates in the upper section suggest the lake was drying out and the spring and river water was feeding more marginal parts.

7. Discussion

Although the chronology of the sedimentary succession is limited, general comparisons with existing palaeoclimate reconstructions in the basin can be made as follows:

7.1 Last Glacial Maximum (19 000-16 500 yrs BP)

Unit 1 captures the later part of the LGM (c.19-16.5 ka BP) although there maybe some hiatuses present. The geochemical and diatom interpretation here points to high sediment in-wash from the catchment into a relatively saline lake. This suggests that the climate may have been generally dry in the basin (increasingly so), tying in with widespread evidence for the expansion of grasslands at this time (Lozano-García et al., 1993; Lozano-García and Ortega-Guerrero, 1994; Ortega-Guerrero et al., 2000). The interruption of this aridity, with evidence for high river inflow from the catchment suggests a more variable picture though, supporting other evidence for some increased humidity (Bradbury, 1997; Lozano-García and Ortega-Guerrero, 1998; Metcalfe et al., 2000; Sedov et al., 2001; Solleiro-Rebolledo et al., 2006). Indeed Bradbury (1989) infers extended open water environments at 19-18 ka BP and increases in winter precipitation, however the chronology is uncertain. There is some evidence in northern Mexico for the cessation of the summer monsoon regime, wetter conditions (Metcalfe et al., 2002; Castiglia and Fawcett, 2006) and for the southward displacement of the mid-latitude Westerlies (Bruner, 1982) due to the expansion of the Laurentide ice sheet to the north and the effects may have reached as far south as central Mexico (Gonzáles Quintero and Fuentes Mata, 1980; Van Devender and Burgess, 1985; Bradbury, 1997). Metcalfe et al. (2000) suggest that the LGM was probably cool and humid due to decreases in evaporation rather than increased precipitation. An alternative explanation for enhanced periods of river inflow is increases in meltwater flow from mountain glaciers in the basin. Lozano-García et al. (1993) postulate that Popocatépetl volcanism may have increased meltwater runoff to Lake Chalco in the LGM, however this was most prevalent from 22.5-19 ka BP (Bradbury, 1989; Caballero and Ortega-Guerrero, 1998). Fluctuations between acid and neutral water at Chalco between 19 ka and 15 ka BP may also have been due to volcanism affecting the mountain ice fields above the lake, or the direct consequence of ashfall on lake chemistry (Caballero, 1997). The Teotihuacán Valley could have also received increased meltwater associated with enhanced volcanism at this time which found its way into the river input at Tepexpan. Alternatively, the enhanced inflow into Lake Chalco is thought to have been high enough to allow it to overflow into Lake Texcoco, increasing the freshwater input further north (Caballero, 1997).

7.2 Late Glacial (15 000-10 000 yrs BP)

The lack of dates from this part of the sedimentary succession makes pinpointing the late glacial problematic, although the tephras indicate that it is likely to fall across *Units 2 to 4*. There are certainly volcanically-disturbed and reworked sediments and the suggestion of hiatuses in the Tepexpan sedimentary succession at this point indicate it may fall during this time period. Many studies from Lake Chalco suggest a moist Late Glacial (Lozano-García et al., 1993; Caballero and Ortega-Guerrero, 1997). However, much inter-basin variability is apparent and a pollen study from Lake Texcoco and Lake Chalco comparing the period sees evidence for drying conditions in the Late Glacial, with Lake Texcoco becoming saline and the freshwater marsh areas expanding, possibly due to reduced catchment vegetation due to the intense volcanism (Caballero and Ortega-Guerreo, 1997). In the north of the basin, deposition apparently ceased at Tecocomulco indicating very dry conditions (Caballero et al., 1999). The conditions in the central part of the Tepexpan sedimentary succession are certainly variable with the lake initially being shallow and quite stagnant, with reduced inflow (Unit 2), changing to more humid conditions and deeper water at the beginning of Unit 3, before indications of P/E declining, with some suggestions of brief periods of spring or river inflow. Deposition of volcanic ash in Unit 4 obscures many of the proxy indicators, however the carbonate $\delta^{18}O$ and $\delta^{13}C$ suggest P/E remained low during the volcanism. This period in the basin is unlikely to be fully resolved until sedimentary successions less affected by volcanism can be located, although this may be impossible because of the major ash thicknesses for the Pumice-with-Andesite and Upper Toluca Pumice that fell in this basin (Huddart and Gonzalez, 2006). In their paleosol study at Tepexpan, Solleiro-Rebolledo et al. (2006) measured a relatively low $\delta^{13}C$ (soil organic matter) value on humus (-25‰), equivalent to the lower part of Unit 4 in this study, suggesting a lowering of lake level and the development of a swamp ecosystem, although still with relatively humid climatic conditions.

7.3 Early-Mid Holocene (10 000-6000 yrs BP)

As the period of intense volcanism is dated as ending around the onset of the Holocene, Unit 5 and the bottom part of Unit 6 are likely to represent the early-mid Holocene period. Although difficult to age, Unit 5 indicates alkaline, very shallow conditions in the lake and stagnant pools of water with aquatic plants. The carbonate data suggest that these pools were spring or river fed and that the lake was reduced in size at this point, indicating arid conditions. The base of Unit 6, where Tepexpan Man Was found also suggests aridity in terms of the carbonate data, but higher C/N ratios suggest more terrestrial plants, perhaps from the expansion of C_4 plants and/or agriculture. Despite some parts of central Mexico being wet in the early Holocene (Metcalfe, 2006), the Basin of Mexico has several reconstructions that point to very arid conditions (e.g., Lozano-García et al., 1993; Bradbury, 1989 et al., 1993; Lozano-García and Xehuantzi Lopez 1997; Caballero et al., 1999; Solleiro-Rebolledo et al., 2006). Bradbury (1989) describes a shallow, fairly saline lake with periods of desiccation and Lozano-García and Ortega-Guerrero (1998) find increased numbers of *Ruppia maritima* which indicates increased salinity. Lozano-García and Ortega-Guerrero (1998) argue that the pollen record from Texcoco shows arid conditions, but less so than the Late Glacial period, with more water in the basin in the early Holocene. Lake Chalco had low lake levels and alkaline/saline waters at this time (Caballero, 1995). However, the glaciations of Mexican volcanoes indicate greater moisture in the period 10 000 to 8200 BP (Heine, 1984, 1988) as ice advances occurred in this period and between 8000 and 6000 BP (Vázquez Selem and Heine, 2004). Buckler et al. (1998) and Lozano-García and Vázquez-Selem (2005) suggest generally wetter conditions with occasional arid intervals (6000-5000 BP). Solleiro-Rebolledo et al. (2006) suggest that the sharp increase of pedogenic $\delta^{13}C$ (SOM) values accompanied by carbonate precipitation in their upper palaeosols marks a change towards drier environmental conditions. However, they noted that this was a gradual transition, based on some evidence related to periodic flooding. In the Lerma Basin, to the west of this basin, the period from 8000-3700 BP is warm and dry with some brief wet periods at 6800 and 5100 BP (Caballero et al., 2002; Lozano-García et al., 2005). There is no evidence for such wet periods from this sedimentary succession, apart from the hydromorphic conditions and flooding evidence provided by Solleiro-Rebolledo et al. (2006).

7.4 Mid-Late Holocene (5000 yrs BP-present)

There is almost certainly a hiatus between the two upper radiocarbon dates from the sedimentary succession in the late Holocene, caused by periods when the lake dried out resulting in erosion at the site. From 6300 BP, the organic geochemistry and C/N data suggest an increase in terrestrial plants and expansion of C_4 plants. Increases in C_4 *Cyperaceae,* and thus possibly spring flow, may be one part of this expansion, but arid C_4 grasses and the expansion of agriculture are likely. The diatom flora also indicate less aquatic vegetation and a mixed alkaline ($NaCl$-CO_3), shallow water lake. The indurated nature of the sediment additionally signifies intense drying through the late Holocene.

Many Mexican records are highly disturbed in the late Holocene resulting in poor understanding of climatic fluctuations. There is, however, widespread evidence for drying in the mid-Holocene, which seems to have increased in severity from south to north across present day Mexico and up in the USA. Typical of many Mexican records, widespread deforestation and human disturbance is evident from 3500-1200 BP. Buckler et al. (1998) suggest drier conditions beginning at 6500 BP and by 5000 BP the region was more xeric than today. Solleiro-Rebolledo et al. (2006) argue that the later cultural and agricultural development of the Teotihuacan civilization appeared to develop in an arid environment, backed up by the archaeological evidence for water management and irrigation (Nichols et al., 1991; McClung de Tapia, 2000). For the last 2000 years though the climate appears not to have changed drastically (Lounejeva Baturina et al., 2006), although evidence for this period from the Basin of Mexico is extremely sparse due to shrinkage and deflation of the most recent sediments following drainage of the basin.

8. Conclusions

There are several general conclusions which can be made with regard to the Tepexpan Palaeoindian site specifically and the general palaeoclimatic reconstructions for the Basin of Mexico during the last 20 000 years BP:

1) The multi-proxy evidence suggests large changes around the margins of Lake Texcoco in terms of the balance between aquatic and terrestrial plants, C_3 and C_4 plants, saline, alkaline and freshwater conditions, volcanic activity and marginal reworking of lake sediments and input from the drainage basin through Units 1-6 (Late Pleistocene-Late Holocene). These changes will have had a large impact on the prehistoric populations living by the lake shore.

2) Overall correlations between the multiproxy evidence and climate conditions is thought to be good for the last 20 000 BP from the Tepexpan site despite problems caused by persistent volcanic activity. However, a more detailed multi-proxy analysis is needed in a deeper water location in Texcoco Lake to unravel climatic changes that were complicated in the marginal lake environment of this site.

3) Many of the main marker tephras found in the Basin of Mexico (Pumice with Andesite, Upper Toluca Pumice, etc) are eroded and reworked in the marginal environments of Tepexpan, where river, deltaic and laharic (volcanic mudflow) events were common. Only one tephra was found *in situ* (between 200 to 220 cm depth) and that is likely to have had a local source from a monogenetic cinder cone. It may well be equivalent to the Chimalpa tephra of Ortega-Guerrero and Newton (1998). It is suggested also that rhyolitic tephras have been an important input into the lake from 37 000 to 2645 BP which is much younger than previously suggested.

4) The Tepexpan Man Palaeoindian skeleton has been assigned a minimum date of 4700 ± 200 years BP (Middle Holocene) by U-Series dating in this study and 5700-5900 years BP from an AMS date on humus in the layer where the skeleton was found (Solleiro et al., 2006). Younger ^{14}C dates of around 2000 years reported before for the skeleton (Lorenzo, 1989; Staffordd et al., 1991, Gonzalez et al., 2003) are interpreted here as being contaminated by younger preservatives used on the skeleton during conservation, according to the values of C/N obtained for the skeleton, and should be discarded from interpretations. Despite the middle Holocene age obtained for the Tepexpan skeleton and associated sediments it remains a very important piece of evidence for Palaeoindian populations in the Basin of Mexico that requires consideration by the archaeologists interested in the study of the early peopling of the Americas.

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10. Appendix

Geochemical analysis from tephra shards from selected samples at Tepexpan.

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Table 3 - U-series measurements on the Tepexpan human skeleton. Low $^{230}Th/^{232}Th$ indicates contamination with detrital thorium, and dates with $^{230}Th/^{232}Th < 10$ have been rejected. The mean of the uncontaminated dates is 4700 ± 200 years.

Table 4 - New AMS radiocarbon ages on marginal lake shells and ostracods from Lake Texcoco at the Tepexpan Man sedimentary sequence.