Matices Interdisciplinarios en Estudios Fitolíticos y de Otros Microfósiles
M. A. Korstanje y M. del P. Babot, Editoras. BAR International Series S1870, Capítulo 7, pp. 67-76

PHYTOLITHS AS INDICATORS OF PALEOSOLS AND GRASSLAND VEGETATION IN THE TEOTIHUACAN VALLEY, MEXICO

FITOLITOS COMO INDICADORES DE PALEOSUELOS Y VEGETACIÓN DE PASTIZAL DEL VALLE DE TEOTIHUACAN, MÉXICO

McClung de Tapia, Emily[1], Héctor Cabadas-Báez[2], Ernestina Vallejo-Gómez[3], Jorge Gama-Castro[3], Elizabeth Solleiro-Rebolledo[3] y Sergey Sedov[3]
[1]Instituto de Investigaciones Antropológicas, Universidad Nacional Autónoma de México, Cd. Universitaria, 04510 México, D.F., mcclung@servidor.unam.mx
[2]Posgrado en Ciencias de la Tierra, Instituto de Geología, Universidad Nacional Autónoma de México, Cd. Universitaria, 04510 México, D.F.
[3]Instituto de Geología, Universidad Nacional Autónoma de México, Cd. Universitaria, 04510 México, D.F.

ABSTRACT

Phytoliths recovered from pedological profiles in the Teotihuacan Valley, Mexico, as part of a paleoenvironmenal study of the region, are indicators of paleosols as well as fluctuations in the spatial distribution of soils and vegetation through time. In this analysis, grass (Poaceae) phytoliths represented by the subfamilies Pooideae, Panicoideae and Chloridoideae, are considered. A two-stage study included a cross-valley sampling transect undertaken to establish a topographic sequence of soils and to correlate soils in different positions on the landscape: (1) higher elevations; (2) piedmont; (3) alluvial plain; and (4) transition to the lacustrine zone. In the second stage, counts of 1200 phytoliths and mineral grains from these profile were used to calculate the proportion of phytoliths in terms of percentages in each horizon. Twenty-one additional locations were also analyzed to study spatial variability of Holocene soils, with 200 phytoliths counted by horizon in these profiles. Morphotypes in the Pooideae subfamily (C3) include carinate, trapeziform, pyramidal, and crenate forms; in the Panicoideae (C3 and C4), bilobates and crosses; and saddles in the Chloridoideae (C4). Ratios of these types, as well as and an aridity index based on chloridoid abundance, were calculated for samples representing the last 22000 years. Chloridoid phytoliths are predominant from 20000-2000 yrs. BP. A notable decline in the proportion of chloridoid phytoliths, together with an increase in panicoid types, is evident in samples from 2000-1500 yrs BP., and this shift intensifies further between 1500-1000 yrs. BP. Between 1000 yrs. BP and the present, chloridoid phytoliths are once again predominant, with aridity index claculations helping to affirm these trends.

Key Words: *Phytolith analysis, Teotihuacan, Vegetation change, Human impact*

RESUMEN

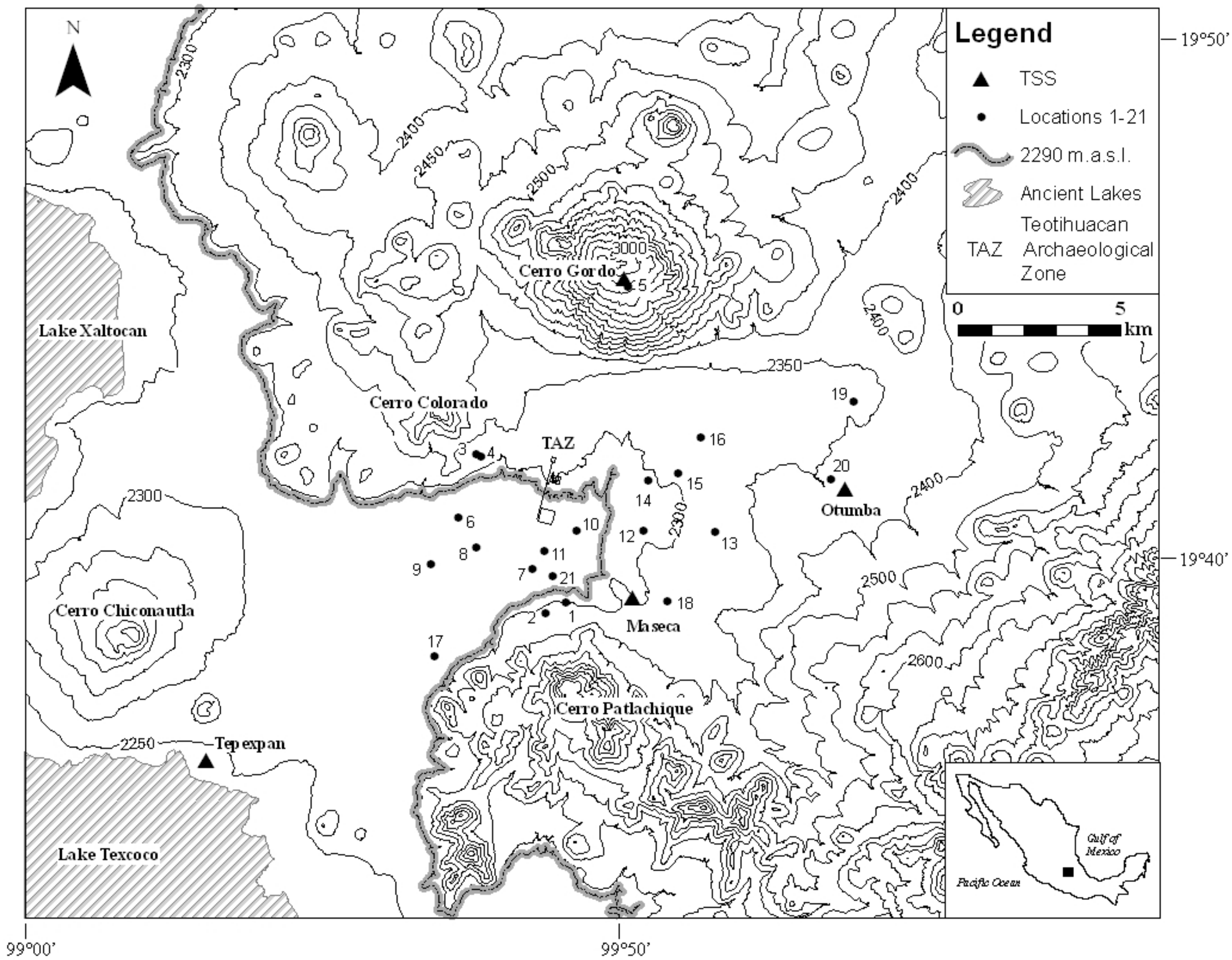
Los fitolitos recuperados de perfiles pedológicos del Valle de Teotihuacan, México conforman parte de un estudio paleoambiental, en el que son considerados como buenos registros de paleosuelos y de la distribución espacial de los suelos y la vegetación a través del tiempo. Este estudio considera el análisis de fitolitos de pastos (Poaceae) representados por las subfamilias Pooideae, Panicoideae y Chloridoideae. El estudio se realizó en dos etapas: la primera incluyó un transecto a través del valle, para establecer la secuencia topográfica de los suelos y realizar correlaciones de acuerdo a la posición que ocupan en el paisaje: (1) zonas elevadas; (2) piedemonte; (3) planicie aluvial; y (4) transición a zonas lacustres. En dichos perfiles, 1200 partículas (fitolitos y granos minerales) fueron contadas para calcular la proporción relativa de fitolitos presentes (en porcentaje) por horizonte de suelo. Fueron analizadas localidades adicionales (21) para estudiar la variabilidad espacial de los suelos del Holoceno; contando en este caso 200 fitolitos por horizonte. Los morfotipos Pooideae (C3) incluyeron carinados, trapeziformes, piramidales, y formas crenadas; en los Panicoideae (C3 y C4), bilobados y en cruces; así como en silla en los Chloridoideae (C4). Las relaciones de los morfotipos presentes y el índice de aridez basado en la abundancia de chloridoides fueron calculados para los últimos 22000 años. Los fitolitos chloridoides fueron predominantes entre los 20000 y 2000 años AP. Una disminución notable en la proporción de chloridoides junto con un incremento en los tipos panicoides es muy evidente entre los 2000 y 1500 años A.P., intensificándose entre los 1500 y 1000 años A.P. En los últimos 1000 años los chloridoides han sido predominantes, el índice de aridez calculado reafirma dicha tendencia.

Palabras clave: *Fitolítica, Teotihuacan, Cambio de vegetación, Impacto humano*

INTRODUCTION

Phytoliths were recovered from pedological profiles in the Teotihuacan Valley, Mexico, Central Mexico (Figure 1), as part of a paleoenvironmenal study of the region. In this analysis we focus on phytoliths, particularly from grasses, as indicators of paleosols and of fluctuations in the spatial distribution of vegetation types related to landscape change through time. The study area is located in the northeastern sector of the Basin of Mexico (19º 34' N, 99º 40' W) between 2240-3100 masl, in the Transvolcanic Axis which stretches from west to east across central Mexico. The total area covers approximately 900 km^2. The Teotihuacan area is important because it was the location of the one of the earliest prehispanic cities in the New World and the center of a state that dominated Mesoamerica over at least 500 years, between AD 100-600.

Figure 1. Teotihuacan Valley, Mexico, Central Mexico showing locations of soil profiles.



Basic research on prehistoric environmental conditions in the region is quite recent although archaeological investigation has been going on for over a century.

PHYTOLITHS AS INDICATORS OF PALEOSOLS AND REGIONAL ENVIRONMENTAL CONDITIONS

The recovery and analysis of phytoliths were included in order to detect the presence of paleosols on one hand and the spatial variability of soils and regional vegetation trends on the other. Different methodological approaches were employed in a two-stage study to develop hypotheses for future research in the region.

Gol´yeva (1996, 1997) and Piperno (2006), among others, refer to the concentration of phytoliths in A horizons in pedological profiles as indicators of buried paleosols, based on the assumption that these were exposed surfaces in the past. Evaluation of changes in the proportions of phytoliths and mineral grains in the horizons contributes to an understanding of the formation of soils in a region a well as to the reconstruction of past vegetation (Gol'yeva *et. al.* 1995).

The potential of phytoliths as indicators of environmental conditions is also considered by other authors (e.g., Dinan and Rowlett 1993; Fredlund 1986, 1993; Fredlund and Tieszen 1994, 1997; Piperno 1988, 2006; Twiss 1986, 1992). Pollen is poorly preserved in most of the soils and sediments studied from the Teotihuacan Valley. Phytoliths on the other hand are relatively well represented and permit a general picture of changes in the distributions of grasses through time.

Where plants characterized by C3 and C4 photosynthetic pathways occur together naturally, fluctuations among the proportions of both types are expected to occur with temperature changes and variations in the amount of available atmospheric CO_2 (Gates 1993). Twiss (1992) suggested the use of ratios of "regular grass phytoliths" (corresponding to the subfamilies Pooideae, Panicoideae and Chloridoideae of the Poaceae family) in an assemblage to interpret regional paleoclimatic conditions based on an evaluation of the present worldwide distribution of C3 and

C4 grasses, together with reference to the types of phytoliths generally associated to them. A number of distinctive, short-celled phytoliths, or silica bodies, are generally diagnostic of C3 and C4 grasses, although some exceptions have been noted (Dinan and Rowlett 1993; Fredlund and Tieszen 1994; Piperno 1988, 2006; Twiss 1992).

The subfamily Pooideae is comprised of C3 grasses adapted primarily to high-latitude/high altitude regions, in cool zones with localized moisture. Their presence in subtropical areas is generally restricted to the coolest period of the year. The subfamily Chloridoideae, on the other hand, consists of C4 grass genera, adapted mainly to low/intermediate elevations with relatively low soil humidity and is characteristic of warm, semiarid or arid zones (short grass savanna). The subfamily Panicoideae includes both C3 and C4 grasses as well as by those that share characteristics of both photosynthetic pathways, adapted to warm, humid conditions characteristic of tall-grass savanna (Dinan and Rowlett 1993; Gould and Shaw 1983; Twiss 1992). Although some have adapted to temperate conditions, none occur in mountainous or pollar regions.

The relative abundance of different types of grasses can be estimated by taking the ratio of the total of each type with respect to the sum of phytoliths associated with the subfamilies Pooideae (F), Panicoideae (P) and Chloridoideae (C) in a given assemblage (total “regular grass phytoliths”, indicated throughout as “FPC”). Accordingly, Twiss (1992) argued that high values of the ratio for relative abundance of pooid (C3) grasses indicate cool climatic conditions appropriate to high latitudes or high altitudes in zones where C3 grasses prevail. In contrast, low values suggest warm, humid to arid climatic conditions associated with lower latitudes and elevations. High values of the ratio for relative abundance of chloridoid grasses (C4) suggest the predominance of semi-arid conditions. Fredlund and Tieszen (1994, 1997) and Trombold and Israde-Alcantara (2005) among others have shown that the general Pooideae-Panicoideae-Chloridoideae subfamily typology of phytolith types can provide a useful framework for broad characterization of regional grassland composition through time and can be employed as the base for outlining hypothetical changes in vegetation, temperature and environmental humidity.

Environment of the Teotihuacan Region

The principal geological features of the region include Miocene geoforms (Cerros Patlachique, Malinalco and Colorado) surrounded by soils derived from the weathering of volcanic tuff and pumice from Plio-Pleistocene ash flows; Cerro Gordo and Cerro Chiconautla are Late Pliocene-Early Pleistocene structures (Departamento del Distrito Federal 1975; Mooser 1968). Most of the remaining area is comprised of Quaternary alluvial deposits, lavas and basalts, stratovolcanos and cineritic cones.

The region is located in the transition zone between semi-arid (BS) and subhumid (C) climatic conditions (García 1968, 1974). Average annual temperatures fall between 12 ^{o} and 18 ^{o}C below 2800 masl and 5-12 ^{o}C for the surrounding slopes between 2800-3100 masl Total annual precipitation in the region today falls between 500-600 mm (García 1968), reaching 700 mm on the summit of Cerro Gordo and 800 mm in the Sierra Patlachique (Castilla-Hernández and Tejero-Diez 1983; Evans 1980). 80-94% of the annual precipitation occurs between May and October.

Phaeozems (48%), Vertisols (16%), Cambisols (13%) and Lithosols (13.5%) comprise the main soil types in the region today (Secretaría de Programación y Presupuesto 1982a, 1982b). With the exception of Lithosols (now called Leptosols, WRB 2006), all are potentially fertile soils, suitable for agriculture. Vertisols in the southwestern sector of the Teotihuacan region are probably related to lacustrine and alluvial deposits and a considerable part of this area is irrigated today. Cambisols may have supported pine-oak forests in the region, whereas Phaeozems are more likely to have been covered with diverse communities including oak scrub, xerophytic vegetation and grassland (FitzPatrick 1980). Modern irrigation includes small areas of Phaeozems and Cambisols but these soils are mainly utilized for rainfall-dependent crops and, especially the cultivation of "nopal" (*Opuntia* spp.), barley (*Hordeum* spp.) and to a lesser extent, "maguey" (*Agave* spp.). Because of the importance of soils in prehistoric economies as well as a source of climatic information, field research was directed towards a detailed study of soil formation and geomorphological processes in the region (Cabadas 2004; McClung de Tapia *et. al.* 2003, 2005).

Patches of primary vegetation are scarce in the region today (Castilla-Hernández and Tejero-Diez 1983; Rzedowski *et al.* 1964), including a small stand of oak forest (*Quercus* spp.) on the upper north slope of Cerro Gordo (3050 masl). Pine forest is no longer present. Most of the higher slopes, 2800-3000 masl, are populated with oak scrub (*Q. frutex;* Castilla-Hernández and Tejero-Diez 1983), considered as an indicator of human intervention (Departamento del Distrito Federal 1975). Other communities represented in the region include xerophytic scrub (*Opuntia, Zaluzania and Mimosa*) up to about 2750 masl and small extensions of grasslands between 2400-3050 masl. Poaceae in the region are represented by the subfamilies Pooideae, Panicoideae and Chloridoideae (Castilla-Hernández and Tejero-Diez 1983; Gould and Shaw 1983).

Prehispanic land use

Early sedentary communities in the Teotihuacan region mainly occupied the piedmont rather than the deep soil alluvium in the central part of the valley where the risk of frosts is an important limiting factor. Steeper ground is less affected by frosts because of greater evaporation in addition to runoff of both surface humidity and soil water, and is thus more suitable for rainfall based cultivation. However, cultivation of slopes requires some kind of protection against soil gravity transport and gully and sheet erosion during torrential seasonal showers as well as wind erosion in the dry season. The use of techniques for the conservation of soil and humidity such as channeling of runoff was probably carried out from an early period on slopes to enhance humidity concentrations for rainfall dependent cultivars; however, available evidence for such techniques is difficult to date, mainly because of the mixture of cultural and sedimentary materials contained in channels. The earliest indications of such techniques are dated to the Terminal Formative period (Tzacualli-Miccaotli phases, approximately AD 100-250; Charlton 1990; Nichols and Frederick 1993), associated with the development of the prehispanic urban center of Teotihuacan. The construction of terraces may be as late as AD 1300-1500, corresponding to the Aztec occupation of the region, although evidence for this period would mask earlier deposits.

METHODOLOGY

A regional approach was adopted for the selection of soil profile (pedon) locations in which cross-valley transects represented the major topographic features, to establish a topographic sequence of soils and to correlate soils in different positions in the landscape (Figure 1): (1) higher elevations of volcanos (Cerro Gordo, 2948 masl, 19° 44’ 55“ N; 98° 49’ 24’’ W); (2) piedmont (Maseca, 2320 masl, 19° 39’ 55’’ N; 98° 49’ 16.07’ ’W); (3) alluvial plain (Otumba, 2314 masl, 19° 41’ 32’’ N; 98° 45’ 49’’ W); and (4) transition to the lacustrine zone (Tepexpan, 2255 masl, 19^o 36’ 52” N; 98^o 56’ 47” W). In these profiles, phytoliths were recorded as percentages per horizon.

Soil characteristics that are not affected by burial were evaluated (such as texture, microstructure, etc.), and phytoliths were recovered from the silt fraction. Silt was separated from the total soil by gravity sedimentation following the destruction of cementing agents: carbonates (HCl 3N), organic matter (H_2O_2 10%) and iron oxides (dithionate-citrate-bicarbonate extraction) based on Mehra and Jackson (1960).

The silt fraction of each horizon of these profiles was observed under a petrographic microscope and described; 1200 phytoliths and mineral grains were counted in order to calculate their relative proportions (Gol´yeva 1997). Glycerin was employed as an immersion medium because its refractive index (1.48) is intermediate between phytoliths (1.41-1.45) and volcanic glass (1.48-1.61), thus facilitating differentiation between the two.

Complementary locations for pedological profiles were selected to evaluate spatial variability in soils and study changes in vegetation during the Holocene (Locations 1-21, Figure 1). In this case, the extraction technique described by Pearsall (2000) and Piperno (1988, 2006) was employed for the recovery of phytoliths, including the use of $ZnBr_2$ as a heavy liquid. Glycerin was also used as a mounting medium and 200 phytoliths were counted by horizon. Phase contrast was employed to enhance visibility using traditional light microscopy at magnifications of 100-400X.

The taxonomy of phytoliths in Mexican Poaceae and the taphonomy of assemblages from soils has received little attention (for a preliminary attempt, see Zurita 1987). Consequently, phytolith determinations in this study were based largely on published results (Gallego and Distel 2004; Fredlund and Tieszen 1994; Pearsall 2000; Piperno 1988, 2006; Piperno and Pearsall 1998; Prychid *et al.* 2004). Principal morphotypes recognized in the Pooideae (C3) include carinate, trapeziform, pyramidal, and crenate forms; in the Panicoideae (C3 and C4), bilobates and crosses; and saddles in the Chloridoideae (C4) (Figure 2). These morphotypes are combined in the categories “F” (Pooid), “P” (Panicoid) and “C” (Chloridoid). Ratios of “Regular Grass Phytoliths” (Pooid [F/FPC] Panicoid [P/FPC], and Chloridoid [C/FPC] types) and an aridity index based on Chloridoid abundance ([C/PC], Twiss 1992) were calculated for each period between 22000 BP – present in the Teotihuacan Valley (Table 1). In this analysis, only phytoliths from radiocarbon-dated horizons are considered, with the exception of the period 500 BP-present in which all superficial horizons are included.

Phytoliths were not dated directly; total humates from organic sediment were subjected to conventional radiocarbon dating owing to the absence of charcoal in the profiles and dates are interpreted in this paper to indicate mean residence times. A detailed description of the pedological profiles and dating results is available elsewhere (McClung de Tapia *et. al.* 2005).

RESULTS

The topographic sequence of soils (TSS, Figure 1) in the Teotihuacan Valley (Cabadas 2004) indicates Pleistocene argid paleosols with ages of 22000 yrs BP and 18000 yrs BP (Chromic Luvisols, according to WRB, 2006) at high elevations (Cerro Gordo). In the piedmont (Maseca) a paleosol with an age of approximately 11000 yrs BP was observed (Stagnic Luvisols according to WRB 2006). Soils in the alluvial plain (Otumba and Tepexpan) are more recent and are generally poorly developed (Mollic Fluvisols, WRB 2006). At the edge of the former Lake Texcoco (Tepexpan), the sequence includes a pedosediment developed in a swamp environment overlain by three paleosols (Fluvisols, and soils with fluvic material, WRB 2006). The sequence from approximately 5000 BP to the present is the most complete as well as being the most relevant from the perspective of human occupation in the Teotihuacan region. Varying degrees of soil formation is evident depending upon location (McClung de Tapia *et. al.* 2003, 2005).

In the Cerro Gordo profile, the percentage of phytoliths varies between 4.90% and 5.20% in the Ap and Ah horizons respectively, with 14.68% in the AB horizon and falling to 8.22% in AB. Few phytoliths were recovered from 2A (1.55%), 2B/E (0.66%) and 2Bt (1.69%). 3Bt registered 19.57% while 3BtC 0.25%. C4 grasses predominate in all horizons (Figure 2A) with the exception of 3Bt where C3 slightly outnumber C4.

In the Maseca profile, the surface Ap horizon contains 13.62% phytoliths, Bk (3.96%), C (2.26 %), 2 Btg1 (6.74%), 2Btg2 (9.77%) and 2C (4.52%). C4 grasses represented by saddle-shaped phytoliths (Chlorideae) predominate in all horizons (Figure 2B).

In Otumba, preservation was improved and the Ap horizon contained 14.23% phytoliths, AB (19.52%), 2Ah (19.31%), 2AB (13.31%), and 2C (4.05%). In all cases, C4 grasses were predominant, represented by saddle-shaped phytoliths (Figure 2E).

A preliminary view of the Tepexpan sequence indicates that diatoms and sponge spicules are more abundant than phytoliths (1-5%). Diagnostic phytoliths were not observed.

The ratios of grass phytoliths from the radiocarbon-dated horizons Locations 1-21 indicate changes over time in the predominance of grasses pertaining to the subfamilies Pooideae, Panicoideae and Chloridoideae. In Table 1 the total phytoliths recovered from horizons dating to each period are indicated, followed by the total of "Regular Grass Phytoliths" (FPC) as described previously. An aridity index was also calculated based on the proportion of phytoliths corresponding to grasses of the Chloridoideae subfamily with respect to the sum of Panicoideae and Chloridoideae (Twiss 1992). The period designated as 500 yrs. BP-present refers to modern conditions (2 radiocarbon-dated surface horizons were dated to ca. 300 BP while others were clearly modern (McClung de Tapia *et. al.* 2005). Finally, the complementary pedological profiles (Locations 1-21) with horizons corresponding to these periods are indicated in the last column of Table 1.

Chloridoid phytoliths are predominant in the period between approximately 20000-5000 yrs. BP (50.52%). Between 5000-3500 BP a slight increase in chloridoids is apparent (53.19%), declining again to 50.51% during 3500-3000 BP. A slight decline follows between 3000-2500 BP (49.68%), returning to 51.87% between 2500-2000 BP. During the period between 2000-1500 yrs BP a notable decline is seen in the proportion of Chloridoid phytoliths (36.74%) together with a slight increase in Panicoid types (44.87%). This trend is intensified in the following period, between 1500-1000 yrs. BP, during which time panicoid-type phytoliths are at their peak (67.90) as compared to 17.49% for chloridoids. Finally, between 1000-500 yrs. BP chloridoid phytoliths are once again predominant (50.36%) while the proportions of pooid and panicoid types decline. From the Colonial period to the present (500 BP-present) chloridoid phytoliths continue to predominate in the record (47.10%) although panicoid types comprise 32.83%. Throughout the sequence, fluctuations in the relative proportions of Pooideae and Panicoideae are evident, suggesting to us that subregional variation should be considered in the characterization of the region. Pooideae ratios range from a high of 24.91% (22000-5000 BP) to a low of 5.96% (2500-2000 BP) and considerable variability is evident in Table 1. Panicoideae on the other hand are consistently more abundant than Pooideae and fluctuate between a maximum of 67.90% (1500-1000 BP) and a minimum of 30.36% (5000-3500 BP).

The aridity index reaffirms the trends described previously. Maximum aridity is indicated between 20000-5000 BP (67.28%) followed by a gradual decline through time. Between 5000-3500 BP a slight decline (63.66%) is evident, which is maintained between 3500-3000 BP (63.57%). Ratios decline to 57.93% between 3000-2500 BP, 55.16% between 2500-2000 BP, 45.02% between 2000-1500 BP, reaching a low of 20.48% between 1500-1000 BP. Between 1000-500 BP the index increases to 57.17%, reaching 58.93% which describes modern conditions.

In either case, it is clear that a reduction in chloridoid phytoliths (from 36.74% to 17.49% of "total regular phytoliths") together with an increase in panicoid types (from 44.87% to 67.90%) characterizes the region between 2000-1000 BP. In the subsequent period, however, between 1000-500 BP, both groups return to their prior ratios.

DISCUSSION

Regional trends

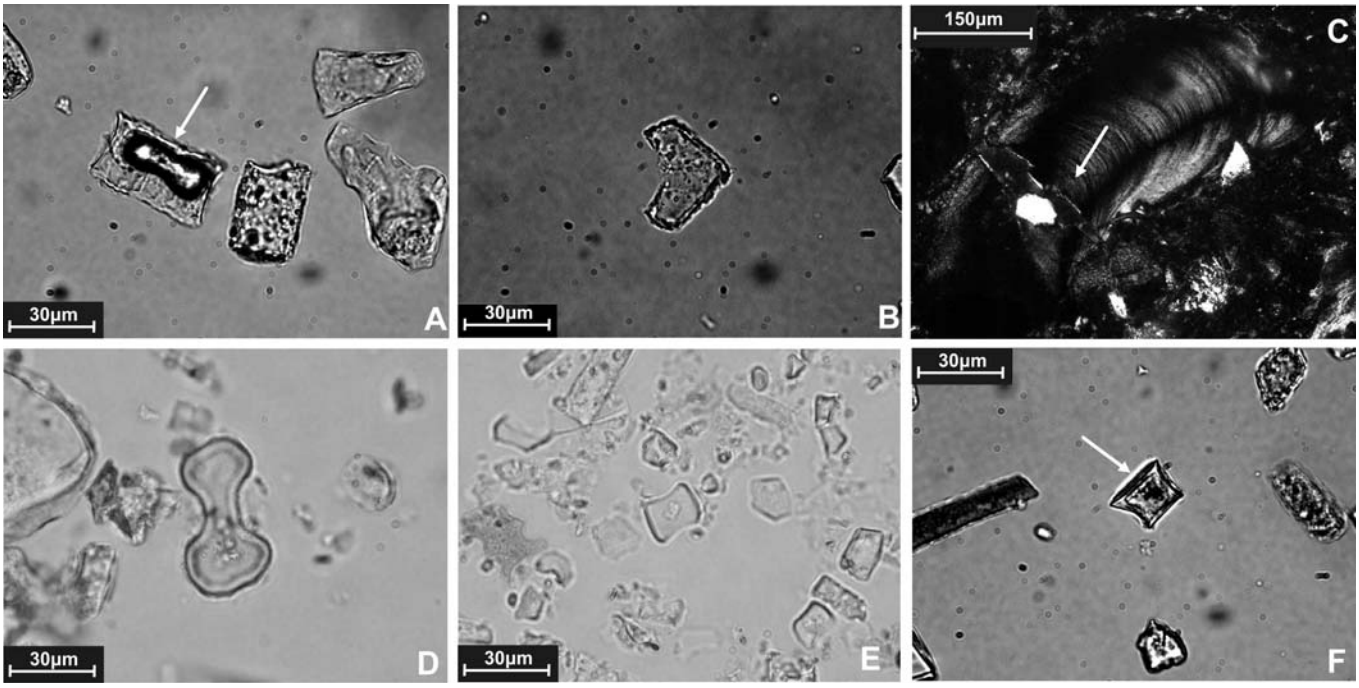
The earliest paleosols (22000 yrs BP) were formed in relatively humid conditions, as suggested by the presence of phytoliths from C3 plants (mainly pyramidal, trapeziform and carinate forms) together with the presence of kaolinite clay minerals, although the predominance of chloridoid phytoliths in another profile on Cerro Gordo (Location 5) at a slightly lower elevation reflects semi-arid conditions at this time. Towards 18000 yrs. BP conditions became less humid based on the increased frequency of C4 plants. In the Maseca profile, the paleosols corresponding to about 11670 yrs BP show discontinuous infillings of calcium carbonate, indicating changes in the evapotranspiration rate. This site shows evidence for polygenesis based on other indicators for more humid conditions (clay cutans) prior to the onset of drier conditions (Figure 2C).

The most recent period of soil formation, during the Holocene, is represented by the profiles at Otumba in the alluvial plain and Tepexpan at the edge of the lakeshore, both of which are characterized by relatively dry conditions. Tepexpan in particular, shows evidence for a lacustrine zone in transition.

Based on the relative abundance of phytolith types in the samples studied from the perspective of spatial and temporal variability during the Holocene (Locations 1-21), changes are evident in grasses through time on a regional scale. A general trend from semi-arid conditions between *ca.* 5000-3500 BP (based on the predominance of chloridoid phytoliths) towards increased humidity and cooler conditions between *ca.* 3500-3000 BP (based on a slightly greater proportion of pooid and panicoid types together) is apparent. A return to warmer temperature and, perhaps, slightly wetter conditions appears to have been underway around the time when the region was first settled by sedentary farming communities, between 3000 BP and 2500 BP. Between 2500 and 2000 BP increased humidity with slightly warmer temperatures is indicated. Higher humidity but probably somewhat lower temperatures characterized the period between 2000 and 1500 BP. Increased humidity and warmer conditions prevailed during the period between 1500-1000 BP. A return to essentially semi-arid conditions began around 1000 BP, with a slight increase in humidity accompanied by possibly cooler temperature after about 500 BP.

Phytolith evidence from horizons corresponding to 1500-1000 BP indicates *relatively high humidity* throughout the study region during this interval. However, some investigators have argued for notably drier conditions between *ca.* 1500-900 BP in the lake basins of the Transvolcanic Belt that stretches across central Mexico (Arnauld *et al.* 1994; García 1974; Metcalfe 1994; Metcalfe and O'Hara 1992; Metcalfe *et al.* 1989; O'Hara *et al.* 1993, etc.), while others suggest that conditions may have been more humid in some parts of central Mexico during at least part of the same period (Cordova 1997; Frederick 1997; Heine 1987).

Figure 2. Phytoliths from the Teotihuacan Valley: A. and B. Phytoliths saddle type from Cerro Gordo and Maseca; C. Micromorphological evidence for more humid conditions (clay cutans) in Cerro Gordo; D. Panicoideae type; E. Chloridoideae (saddle) type; F. Rondel type.



^{14}C Years BP	FPC	Total phytoliths	F/FPC	P/FPC	C/FPC	C/PC	Profile Locations
22000-5000	574	1245	24.91	24.56	50.52	67.28	5,12, 13
5000-3500	517	1298	16.44	30.36	53.19	63.66	1,12,9
3500-3000	677	1382	20.53	28.95	50.51	63.57	2,16,9
3000-2500	316	686	14.24	36.07	49.68	57.93	2,16,6,15
2500-2000	453	1072	5.96	42.16	51.87	55.16	2,1,4,8,16,6
2000-1500	332	706	18.37	44.87	36.74	45.02	11,16, 7
1500-1000	726	1332	14.60	67.90	17.49	20.48	13,2,6,10,11,8, 14
1000-500	554	911	11.91	37.72	50.36	57.17	16,13,12,15,7
500-present	2193	4180	20.06	32.83	47.10	58.93	1-21

Table 1. Ratios of Regular Grass Phytoliths (Pooid [F/FPC] Panicoid [P/FPC], and Chloridoid [C/FPC] types) and an aridity index based on Chloridoid abundance [C/PC] for the period 22000 BP – present in the Teotihuacan Valley (Locations 1-21). Phytoliths from radiocarbon-dated horizons are considered in all periods with the exception of 500 BP-present in which all superficial horizons are included.

Subregional diversity

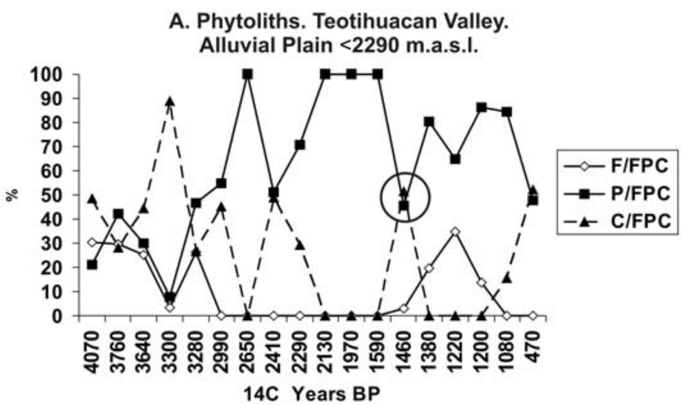
The analysis of spatial variability, subregional similarities in the soil characteristics, environmental humidity regimes and paleoethnobotanical evidence among profiles permitted a further subdivision of the alluvial plain into two sectors, above and below 2290 masl (Figure 1).

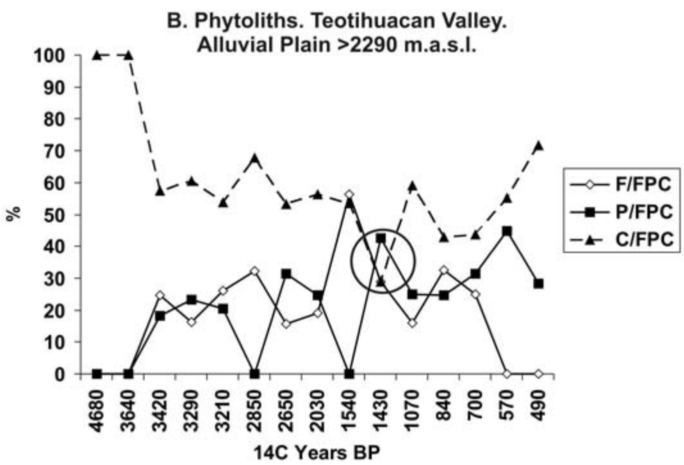
Analyses of the distribution of phytolith types in the horizons associated with each period based on ^{14}C dates suggests that the regional trends evident in Table 1 mask subregional diversity. In almost all cases higher soil humidity represented by panicoid and, to some extent, pooid phytoliths, is associated with horizons from profiles located below 2290 masl or in the Cerro Patlachique area (Figure 1).

On the other hand, most of the horizons from profiles above this contour are characterized by predominantly chloridoid phytoliths, generally indicative of grasses adapted to semi-arid conditions.

In the lower sector of the alluvual plain (≤ 2290 masl), the natural high humidity associated with springs and a high water-table is clearly reflected in the predominance of panicoid phytoliths. On the other hand, in the sector above 2290 masl more semi-arid conditions are confirmed by the high relative abundance of chloridoid grasses.

Figure 3. A. Relative abundance of "Regular Grass Phytoliths" (FPC) from ^{14}C dated horizons in the alluvial plain (<2290 masl, Locations 6, 7, 8, 9, 10) of the Teotihuacan Valley. B. Relative abundance of "Regular Grass Phytoliths" (FPC) from ^{14}C dated horizons in the alluvial plain (>2290 masl, Locations 12, 13, 14, 15, 16) of the Teotihuacan Valley. Circles indicate reversal of trends evident around 1400 years BP. Radiocarbon dates from McClung de Tapia *et. al.* 2005.





The phytolith evidence for local vegetation at different periods does not indicate that increased drought affected the Teotihuacan region between ca. 1500-900 BP (cf. McClung de Tapia *et al.* 2003). However, around 1400 yrs. BP, a simultaneous and proportional decline in panicoid grasses with respect to chloridoid grasses in the lower sector of the alluvial plain (≤ 2290 m), concurrent with an increase in panicoid grasses at the expense of chloridoid grasses in the upper sector (2290 masl), points to a dramatic change in the landscape of the Teotihuacan Valley (Figure 3). This may be related to the abandonment of the systematic practice of drainage and canalization associated with the permanent irrigation system in the lower sector during the prehispanic period. A generalized increase in soil humidity in this zone may also have affected the lower reaches of the sector above 2290 m, as a result of uncontrolled seasonal flow from higher slopes that were no longer maintained as part of the piedmont agricultural system. Another hypothesis is that erosion related to torrential precipitation events was responsible for the redeposition of phytoliths corresponding to earlier, more humid conditions in higher slopes. More precise dating would be required in order to relate either process with specific prehispanic occupations.

CONCLUSION

Anthropic disturbance may affect the preservation of phytoliths in modern agricultural soils. Micromorphological characteristics such as the mixing of microstructures, re-worked clay films, and "dirty" clay cutans characteristic of agricultural horizons, together with remains of ceramics on the surface indicate that this is an ongoing process. Potential infiltration of microbotanical remains will have to be evaluated systematically and detailed phytolith counts from all horizons are available even though only radiocarbon-dated horizons have been considered here; therefore, it will be possible to consider this problem in future stages of the research. The tendency for phytoliths to be clearly concentrated in A horizons suggests that translocation is not a significant problem for interpretation at the regional and temporal scale employed at this stage of the research.

Chronological control is insufficient at present to permit a conclusive evaluation of specific changes in vegetation through time. Further soil analyses and radiocarbon assays are necessary to provide a better understanding of geomorphic processes and human impact in the region (McClung de Tapia *et al.* 2003), and to situate this information within a chronological framework. Finally, future analyses of phytoliths in securely dated cultural contexts will be fundamental in order to test the hypotheses presented here.

ACKNOWLEDGMENTS

Financial support for this research has been provided by CONACYT (Consejo Nacional de Ciencia y Tecnología, Mexico), DGAPA-PAPIIT (Dirección General de Asuntos del Personal Académico, UNAM), the Instituto de Investigacions Antropológicas, UNAM and the Instituto de Geología, UNAM. Physical-chemical analyses of soils were coordinated by Ernestina Vallejo-Gómez (Laboratorio de Edafología, Instituto de Geología, UNAM) and Irma Domínguez-Rubio (Laboratorio de Fertilidad de Suelos, Colegio de Posgraduados, Chapingo and the Departamento del Hombre y su Ambiente, Universidad Autónoma Metropolitana-Xochimilco). Conventional and AMS radiocarbon dates were obtained from Beta Analytic, Inc. Analyses of botanical materials were carried out in the Laboratorio de Paleoetnobotánica y Paleoambiente, Instituto de Investigaciones Antropológicas, UNAM. Phytoliths were identified by Judith Zurita-Noguera, Concepción Herrera-Escobar and Hector Cabadas-Báez; pollen was identified by Emilio Ibarra-Morales and Mónica Moguel-Bernal. Rodrigo Tapia prepared Figure 1.

BIBLIOGRAPHY

Arnauld, C., P. Carot y M. F. Fauvet-Berthelot
1994 8000 Años de la Cuenca de Zacapu: Evolución de los Paisajes y Primeros Desmontes In: *Cuadernos de Estudios Michoacanos* Vol. 6, editado por P. Pétrequin, pp 9-28. Centre d'Études Mexicaines et Centraméricaines, México.

Cabadas-Báez, H.
2004 *Paleosuelos como indicadores de cambio ambiental en el Cuaternario Superior: El caso del Valle de Teotihuacan.* Unpublished Undergraduate Thesis in Geology, Facultad de Ingenieria, Universidad Nacional Autónoma de México, México.

Castilla-Hernández, M. E. y J. D. Tejero-Díez
1983 *Estudio Florístico del Cerro Gordo (Próximo a San Juan Teotihuacan) y Regiones Aledañas.* Unpublished Undergraduate Thesis, Escuela Nacional de Estudios Profesionales-Iztacala, Universidad Nacional Autónoma de México, México.

Charlton, T.
1990 Operation 12, Field 20, Irrigation System Excavations. In: *Preliminary Report on Recent Research in the Otumba City-State.* Volume 1, edited by T. H. Charlton and D. L. Nichols. Research Report Number 3, Mesoamerican Research Colloquium, Department of Anthropology, The University of Iowa, Iowa City, Iowa, pp 201-212.

Cordova, C.
1997 *Landscape transformation in Aztec and Spanish Colonial Texcoco, Mexico.* Unpublished PhD. Dissertation, University of Texas, Austin.

Departamento del Distrito Federal
1975 *Memoria de las obras del sistema de drenaje profundo del Distrito Federal*, Tomo I. Departamento del Distrito Federal, México.

Dinan, E. H. and R. M. Rowlett
1993 Vegetational changes at the Shriver Paleo-Indian site, N.W. Missouri: Phytolith analysis as an aid to environmental reconstruction. In: *Current research in phytolith analysis: applications in archaeology and paleoecology*, edited by D. M. Pearsall y D. R. Piperno. MASCA Research Papers in Science and Archaeology, Vol. 10, University Museum of Archaeology and Anthropology. Philadelphia, University of Pennsylvania, pp 73-82.

Evans, S. T.
1980 *A settlement system analysis of the Teotihuacan region, Mexico, A.D. 1350-1520.* Unpublished Ph.D. Dissertation, Pennsylvania State University.

FitzPatrick, E. A.
1980 *Soils: Their Formation, Classification and Distribution.* Longman, London and New York.

Frederick, C.
1997 Landscape change and human settlement in the Southeastern Basin of Mexico. Department of Archaeology and Prehistory, University of Sheffield, Sheffield, United Kingdom.

Fredlund, G. G.
1986 A 620,000 year opal phytolith record from Central Nebraskan loess. In: *Plant opal phytolith analysis in archaeology and paleoecology. Proceedings of the 1984 Phytolith Research Workshop, North Carolina State University, Raleigh, North Carolina*, edited by I. Rovner. Occasional Papers No. 1 of The Phytolitharien, pp 12-21.
1993 Paleoenvironmental interpretations of stable carbon, hydrogen and oxygen isotopes from opal phytoliths, Eustis Ash Pit, Nebraska. In: *Current research in phytolith analysis: applications in archaeology and paleoecology*, D. M. Pearsall and D. R. Piperno. MASCA Research Papers in Science and Archaeology, Vol. 10, University Museum of Archaeology and Anthropology. University of Pennsylvania, Philadelphia, pp 37-46

Fredlund, G. G. and L. T. Tziesen
1994 Modern phytolith assemblages from the North American Great Plains. *Journal of Biogeography* 21: 321-335.
1997 Calibrating grass phytolith assemblages in climatic terms: application to late Pleistocene assemblages from Kansas and Nebraska. *Palaeogeography, Palaeoclimatology, Palaeoecology* 136: 199-211.

Gallego, L. and R. A. Distel
2004 Phytolith assemblages in grasses native to central Argentina. *Annals of Botany* 94: 865-874.

García, E.
1968 Clima actual de Teotihuacan. In: *Materiales para la Arqueología de Teotihuacan,* edited by J. L. Lorenzo. Instituto Nacional de Antropología e Historia, México, pp 11-28.
1974 Situciones climáticas durante el auge y la caída de la cultura teotihuacana. *Boletín del Instituto de Geografía UNAM* 5: 35-69.

Gates, D. M.
1993 *Climate change and its biological consequences.* Sinauer Associates, New York.

Gol'yeva, A. A.
1996 Experience in using phytolith analysis in soil science. Eurasian Soil Science 28: 248-256.
1997 Biomorph analysis as a component of the genetic and morphological study of soil. Eurasian Soil Science 30: 927-936.

Gol'yeva, A. A., A. L. Aleksandrovskiy and L. K. Tselishcheva
1995 Phytolithic analysis of Holocene Paleosols. *Eurasian Soil Science* 27: 46-56.

Gould, F. W. and R. B. Shaw
1983 *Grass Systematics*. Second Edition. Texas A&M University Press, College Station.

Heine, K.
1987 Anthropogenic sedimentological changes during the Holocene in Mexico and Central America. *Striae* 26: 51-63.

McClung de Tapia, E., E. Solleiro-Rebolledo, J. Gama-Castro, J. L. Villalpando and S. Sedov
2003 Paleosols in the Teotihuacan Valley, México: evidence for paleoenvironment and human impact. *Revista Mexicana de Ciencias Geológicas* 20: 270-282.

McClung de Tapia, E., I. Domínguez-Rubio, E. Solleiro-Rebolledo, J. Gama-Castro and S. Sedov
2005 Radiocarbon dates from soil profiles in the Teotihuacan Valley, Mexico: indicators of goemorphological processes. *Radiocarbon* 47(1): 159-175.

Mehra, O. P. and M. L. Jackson.
1960 Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. *Clay and Clay Minerals* 7: 317-327.

Metcalfe, S. E.
1994 *Changing environments of the Zacapu Basin, Central Mexico: a diatom-based history spanning the last 30,000 years.* Research Paper 48, School of Geography, University of Oxford, Oxford.

Metcalfe, S. E. y S. L. O'Hara
1992 Sensibilidad de los lagos mexicanos a alteraciones en el medio ambiente: ejemplos del Eje Neovolcánico. *Ingeniería Hidráulica en México* Mayo-Diciembre: 107-121.

Metcalfe S. E., F. A. Street-Perrott, R. B. Brown, P. E. Hales, R. A. Perrott and F. M. Steininger
1989 Late Holocene human impact on the lake basins in Central Mexico. *Geoarchaeology* 4: 119-141.

Mooser, F.
1968 Geología, naturaleza y desarrollo del valle de Teotihuacan. In: *Materiales para la Arqueología de Teotihuacan*, edited by J. L. Lorenzo. Instituto Nacional de Antropología e Historia, México, pp 31-37.

Nichols, D. L. and C. D. Frederick
1993 Irrigation canals and chinampas: recent research in the northern Basin of Mexico. *Research in Economic Anthropology*, 7 Suppl.: 123-150.

O'Hara S. L., F. A. Street-Perrott and T. P. Burt
1993 Accelerated soil erosion around a Mexican highland lake caused by prehispanic agriculture. *Nature* 362: 48-51.

Pearsall, D. M.
2000 *Paleoethnobotany: a Handbook of Procedures*. Academic Press, San Diego.

Piperno, D. R.
1988 *Phytolith Analysis: an archaeological and geological perspective*. Academic Press, San Diego.
2006 *Phytoliths: A comprehensive guide for archaeologists and paleoecologists*. Altamira Press, Lanham.

Piperno, D. R. and D. M. Pearsall
1998 The silica bodies of tropical American grasses: morphology, taxonomy and implications for grass systematics and fossil phytolith identification. *Smithsonian Contributions to Botany* 85: 1-40.

Prychid, C. J., P. J. Rudall and M. Gregory
2004 Systematics and biology of silica bodies in Monocotyledons. *The Botanical Review* 69(4): 377-440.

Rzedowski, J., G. Guzmán, A. Hernández and C. Muñiz
1964 Cartografía de la vegetación de la parte norte del valle de México. *Anales de la Escuela Nacional de Ciencias Biológicas* 13: 31-57.

Sanders, W. T.
1976 The agricultural history of the Basin of Mexico, In: *The Valley of Mexico*, edited by E. R. Wolf. University of New Mexico Press, Albuquerque, pp. 101-159.

Secretaría de Programación y Presupuesto
1982a *Carta edafológica (E14B21, Texcoco) 1: 50000*. Secretaría de Programación y Presupuesto, Coordinación General de los Servicios Nacionales de Estadística, Geografía e Informática, México.
1982b *Carta edafológica (E14B11, Tizayuca) 1: 50000.* Secretaría de Programación y Presupuesto, Coordinación General de los Servicios Nacionales de Estadística, Geografía e Informática, México.

Trombold, C. D. and I. Israde-Alcantara
2005 Paleoenvironment and plant cultivation on terraces at La Quemada, Zacatecas, Mexico: the pollen, phytolith and diatom evidence. *Journal of Archaeological Science* 32: 341-353.

Twiss, P. C.
1986 Morphology of opal phytoliths in C_3 and C_4 grasses. In: *Plant opal phytolith analysis in archaeology and paleoecology: Proceedings of the 1984 Phytolith Research Workshop, North Carolina State University, Raleigh, North Carolina*, edited by I. Rovner. Occasional Papers No. 1 of The Phytolitharien, pp 4-8.
1992 Predicted world distribution of C3 and C4 grass phytoliths. In: *Phytolith Systematics: emerging issues*, edited by G. Jr. Rapp and S. C. Mulholland. Plenum Press, New York, pp. 113-128.

WRB, IUSS Working Group
2006 *World reference base for soil resources*. 2nd Edition. World Soil Resources Report No. 103. FAO, Roma.

Zurita-Noguera, J.

1987 *Análisis de fitolitos de Guachimonton, Teuchitlan, Jalisco.* Unpublished Undergraduate Thesis in Archaeology, Escuela Nacional de Antropología e Historia, México.