Comales of Tzompantepec and paleosols: a case study

Yolanda Ramos-Galicia[1], Claudia Hidalgo-Moreno[2,*], Sergey Sedov[3],
and Thomas Poetsch[4]

[1]Centro Regional del INAH Puebla, Centro Cívico, 5 de Mayo s/n, Los Fuertes, Puebla, Pue., México.
[2]Colegio de Postgraduados, Instituto de Recursos Naturales, 56230 Montecillo, Estado de México, México.
[3]Instituto de Geología, Universidad Autónoma de México, Ciudad Universitaria, 04510 México, D. F., México.
[4]Institut für Geographie, Universität Hamburg, Bundesstrasse 55, D 20146 Hamburg, Germany.
* hidalgo@colpos.mx

ABSTRACT

Use of paleosols as the source of material for industries and handcrafts in past and present is one important aspect of applied paleopedological research. We studied in Tlaxcala State, Mexico, a stratum mined for traditional ceramic production to determine whether it is a paleosol and which properties made it appropriate for this handcraft. Morphological, micromorphological and pedochemical data showed that this stratum has properties of a buried, well developed Luvic Andosol. It has much higher clay content than overlying soils and sediments, due to pedogenetic processes: weathering of primary volcanic minerals (especially volcanic glass) and clay illuviation. We suppose that the suitable ratio between amorphous components and crystalline clay provides the combination of properties desirable for elaboration of ceramic.

Kew words: applied paleopedology, buried paleosol, clay accumulation, weathering, illuviation, ceramic production.

RESUMEN

El uso de paleosuelos como fuente de material para industrias y artesanías en el pasado y en la actualidad es un aspecto importante de la investigación paleopedológica aplicada. Estudiamos en el Estado de Tlaxcala, México, un estrato extraído para producción de cerámica tradicional, con el fin de determinar si es un paleosuelo y cuales propiedades lo hicieron apropiado para la fabricación de esta artesanía. Los datos morfológicos, micromorfológicos y pedoquímicos mostraron que este estrato tiene propiedades de un Andosol lúvico sepultado, bien desarrollado. Tiene un contenido mucho más alto de arcilla que los suelos y sedimentos que sobreyacen debido a procesos pedogenéticos: intemperismo de minerales volcánicos primarios (especialmente vidrio volcánico) e iluviación de arcilla. Suponemos que la proporción adecuada entre componentes de arcilla cristalinos y amorfos ofrece la combinación de propiedades deseable para la producción de la cerámica.

Palabras clave: paleopedología aplicada, paleosol sepultado, acumulación de arcilla, intemperismo, iluviación, producción de cerámica.

INTRODUCTION

Paleopedological research is related mostly to paleoenvironment reconstruction problems, and it has several important practical applications. Among those are the studies of paleosol impacts on hydrology, soil erosion, and land use management. Another interesting aspect is the utilization of paleosols as sources of raw material for industries and handicrafts. Our research focuses on the use of buried soil material for traditional ceramic production in the state of Tlaxcala, central Mexico.

The elaboration of ceramic is one of the most ancient and well-known handicrafts preserved in Tlaxcala; it represents an important part of the material culture of the Tlaxcaltecas. This activity is considered to be a valuable tradition and heritage, and craftsmen families develop great efforts to preserve it (Vega, 1975). Since early times, ceramists have used various kinds of natural raw materials, such as clays and sands from different sites. Some of these materials are related to paleosols.

In this case study we considered the production of red-painted comales (ceramic pans) in San Salvador Tzompantepec, a village located in the north–east of the state, 25 km from the city of Tlaxcala (Figure 1). Most of the nearly 40 family enterprises of pottery makers from this community make comales (Ramos, 1992). This type of production comes from the pre-Columbian period. Comales with polished or smooth surfaces have been found in 600 archaeological sites, within the studies developed by the Puebla–Tlaxcala Archaeological Project (Abascal, 1975).

Three different materials are used to elaborate comales: a) *black clay* which is the main component, b) *fine sand*, used for molding, and c) *earth of Tepetzil* used to give the red color to comales. According to our preliminary observations, *black clay* could come from a paleosol. We studied some morphological, chemical and mineralogical characteristics of the profile where this material was excavated, and set the following objectives: 1) To define the origin of the mined stratum, using the hypothesis that the unit is a paleosol and that we could describe its genesis and classification; 2) To understand why this material was preferred to the other clay-rich soils and sediments.

We put special emphasis in analysis of clay mineral composition of studied strata, taking into account its importance for the material workability. Up to now, the works on the clay mineral composition of paleosols in Mexican Altiplano are very scarce (Hidalgo, 1991).

MATERIALS AND METHODS

Material

Black clay is dark brown, (10YR 4/3), soft, and is considered to be more easily workable than the local

Figure 1. Location of Tzompantepec in Tlaxcala area.

materials of other colors. This material was obtained in the vicinities of the village, but now the landowners do not want to sell it. So craftsmen families buy it in San Andrés Ahuashuatepec, or they mine *black clay* in the area adjacent to Xala´s creek, about 2 km from Tzompantepec (latitude 19º22' N and longitude 98º05' W). In this site, craftsmen mark a 1x1 m piece of land and then remove the upper clay-poor layer with a spade until they reach the clay stratum. Generally, this stratum is located 1.2 m below the surface and is up to 60 cm thick. The moist black clay is excavated and transported in carriages packed in 60 kg sacks or loaded in trucks.

Morphological studies

We studied the macromorphology of the profile exposed in the quarry, identifying the surface soil and buried paleosol horizons as well as sedimentary layers. In addition, micromorphology observations were conducted. Thin sections were prepared from the blocks with undisturbed structure from the soil genetic horizons and then examined under the petrographic microscope.

Laboratory studies

Some chemical, physical, and mineralogical characteristics useful to understand the genesis of the material and to classify the paleosol were determined. Andic properties were determined because the study area was strongly affected by volcanic activity.

Chemical and physical characteristics

We determined the pH in water, KCl 1M and NaF 1M, P-fixation, as well as Al and Fe extractable with ammonium oxalate (Van Reeuwijk, 1999). Total carbon was

determined with a total carbon analyzer (TOC 5050 A Shimadzu). The pipette method was used for the particle size analysis and Munsell soil color charts for color determination.

Mineralogical characteristics

Primary minerals were determined under the petrographic microscope in the fine sand fractions of immersion specimens. The clay fraction composition (<2 μm) was established by X–ray diffraction, using Cu cathode and Kα radiation. In this case, the clay fraction used was previously cleaned of organic substances (H_2O_2 30%), the oriented clay specimens were prepared after pre-treatments: air-dried (ad), saturated with ethylene-glycol (eg), and heated at 390^0C (c390).

RESULTS AND DISCUSSION

Macromorphology

The morphological study (Figure 2) of the profile showed that the studied material lies below the C horizon of the modern surface soil, clearly reworked by pedogenetic processes. Two buried soil units were defined:

Paleosol 1, located at 94 cm from soil surface, less developed, consisting of a single Bw horizon (31 cm thickness), underlain directly by Paleosol 2 (no C-horizon in between). We suppose that this paleosol was developed on a rather thin sediment and was truncated before burial (for this reason Ah horizon is absent);

Paleosol 2, located at 125 cm from soil surface, mature, consisting of well developed, dark colored, aggregated Ah and AB horizons (80 cm thickness).

Black clay mined by craftsmen, corresponds to the AB and partly Ah horizons of Paleosol 2.

Micromorphology

Field morphological observations as well as a micromorphological study of thin sections showed that both horizons of Paleosol 2 have illuvial clay–humus coatings and infillings (Figure 3a); besides, in Ah horizon some concentrations of bleached sand and silt grains on the ped surfaces (Figure 3b) are present. Both observations demonstrate that incipient *clay* illuviation occurred in this paleosol. On the basis of the morphology, Paleosol 1 is classified as Andic Cambisol and Paleosol 2 as Luvic Andosol.

Particle size distribution

The differences in particle size distribution (Table 1) along the profile are remarkable. Sand fractions dominate

Modern soil

0-28 cm, grayish-brown (10YR 5/2), subangular blocky structure, roots of plants

28-38 cm, light brownish gray (10YR 6/2), less developed

38-94 cm, gray (10YR 6/1) compacted volcanic ash, sand (63-65 %) and silt (27-25 %) prevail in this horizon, (10 % clay)

Paleosol 1

94-125 cm, dark brown, (10YR 4/3) more clayey (20 % clay) than horizon above

Paleosol 2

125-153 cm, dark gray, (10YR 4/1) colored with humus, subangular blocky-granular structure when dry, washed fine, sand-silt particles are visible, (26 % clay)

153-205 cm, dark-gray, (10YR 4/1) darker than horizon above well developed; subangular blocky (with tendency towards prismatic) structure, richer in clay (29 % clay) than above, few thin dark clay-humus coatings are visible on aggregate surfaces

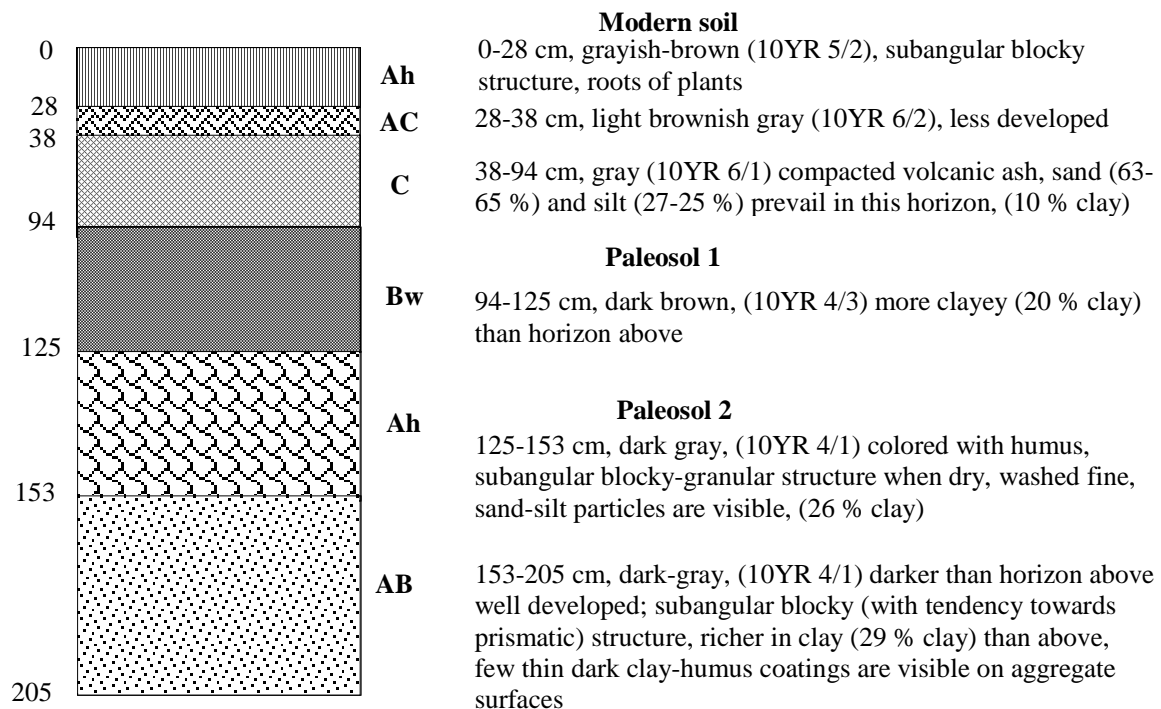| Depth (cm)	Horizon
0	Ah
28	AC
38	C
94	Bw
125	Ah
153	AB
205	

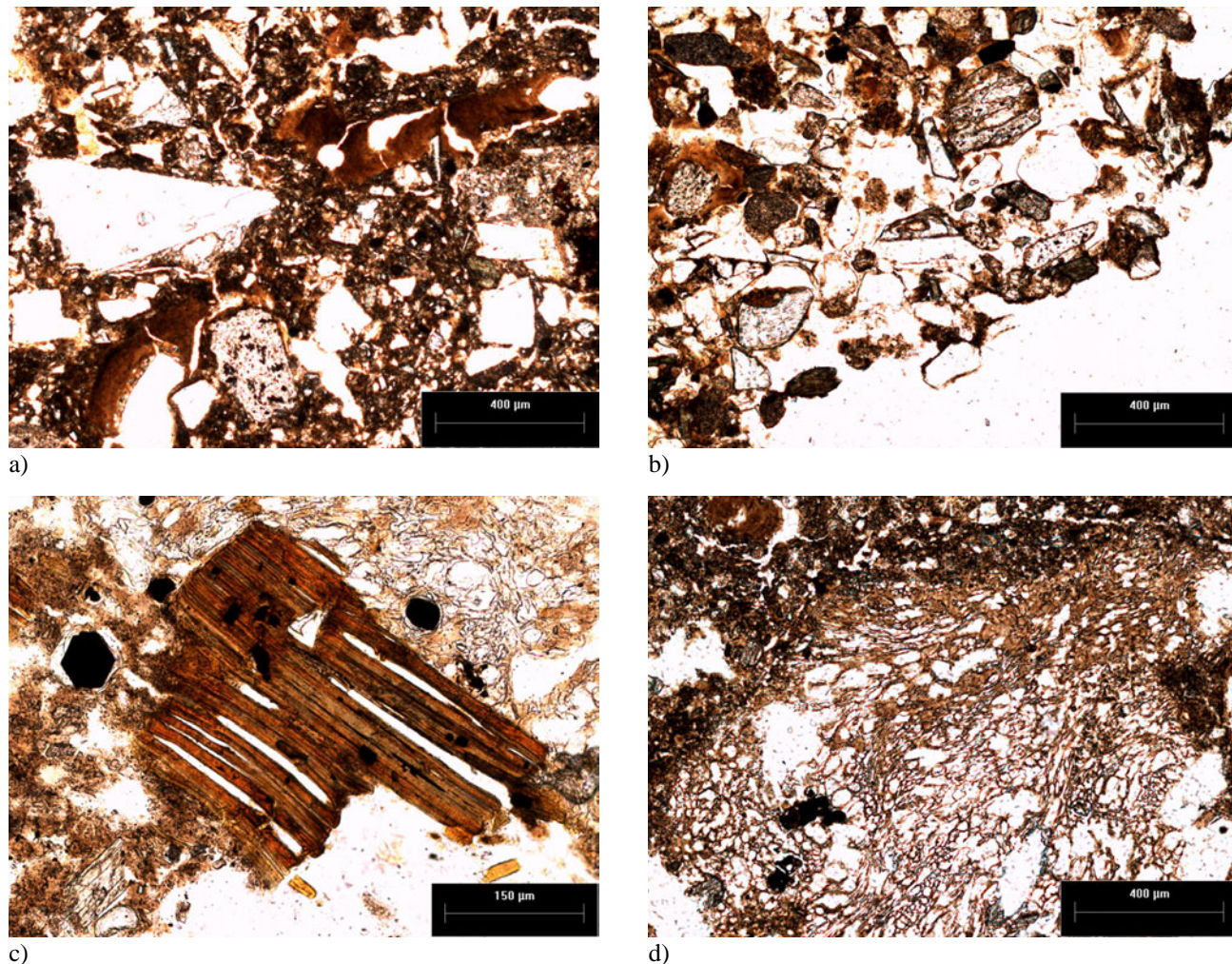Figure 2. Morphological sketch of the Tzompantepec profile.

Figure 3. Micromorphology of the Paleosol 2 Tzompantepec profile, plain polarised light. a) clay-humus coatings in AB horizon; b) concentration of coarse mineral material in the pore, Ah horizon; c) biotite weathering, AB horizon; d) yellow clay infillings in the pores of weathered volcanic glass, AB horizon.

in the modern soil, whereas clay content is rather low (10%, without profile differentiation). In Paleosol 1, the quantity of clay increases up to 20%. Finally, in Paleosol 2 it reaches a maximum of 29% in the AB horizon, nearly 3 times higher than in modern soil; this paleosol has also more silt and much less sand.

This shows that Paleosol 2 reached a higher degree of weathering and secondary mineral accumulation than the modern soil and Paleosol 1. Although the morphological evidences of clay translocation are already visible in

Table 1. Particle size distribution in Tzompantepec soil.

Horizon	Size of particle (mm)						Sand (%)	Silt (%)	Clay (%)	Texture
	>1	1.0-0.5	0.5-0.25	0.25-0.05	0.05-0.002	<0.002				
Ah	0.23	3	15	47	25	10	65	25	10	Sandy loam
AC	0.34	4	15	47	24	10	66	24	10	Sandy loam
C	0.40	2	12	48	27	10	63	27	10	Sandy loam
Bw	0.33	2	10	40	28	20	52	28	20	Loam
Ah	0.16	2	7	18	46	26	28	46	26	Loam
AB	0.44	2	8	16	43	29	28	43	29	Clay loam

Note: Sand: 1.0–0.05 mm; silt: 0.05–0.002 mm; clay: <0.002 mm.

Table 2. Chemical and Andic properties of Tzompantec soil.

| Horizon | Total C (%) | pH | | | ΔpH* | P_fixed (%) | Al_o (%) | Fe_o (%) | Al + ½Fe_o |
		H₂O	KCl	NaF (60 min)					
Ah	0.6	6.1	5.1	8.7	1.0	10	0.06	0.12	0.12
AC	0.3	6.6	5.3	8.9	1.3	5	0.05	0.10	0.10
C	0.2	6.5	5.0	8.8	1.4	7	0.05	0.07	0.08
Bw	0.3	6.7	5.4	9.3	1.3	15	0.09	0.09	0.13
Ah	0.5	6.9	5.7	9.3	1.3	16	0.11	0.19	0.20
AB	0.5	7.0	5.8	9.4	1.2	17	0.12	0.11	0.17

Note: ΔpH: pH in H_2O minus pH in KCl IM; NaF (60 min): pH in NaF measured 60 minutes after stirring; P_{fixed}: phosphorous fixation; Al_o: aluminum extractable with ammonium oxalate; Fe_o: iron extractable with ammonium oxalate.

Table 3. Primary minerals of the Tzompantec profile.

| Horizon | Plagioclase | Biotite | Amphiboles | Pyroxenes | Volcanic glass | Fine Matrix | | Opaline bioliths | Ore Minerals (Magnetite and others) |
						Mostly clays	Volcanic rock fragments		
Ah	xx	(x)	x	x	x	NF	xx	NF	NF
AC	xxx	(x)	xx	xx	x	NF	x	(x)	(x)
C	x	NF	x	x	x	NF	x	(x)	(x)
Bw	x	(x)	x	x	x	NF	x	x	(x)
Ah	x	NF	(x)	(x)	x	NF	x	xxx	NF
AB	xx	NF	xx	xx	x	NF	xx	(x)	(x)

Note: xxx = much, xx = moderate, x = few, (x) = traces, NF = not found
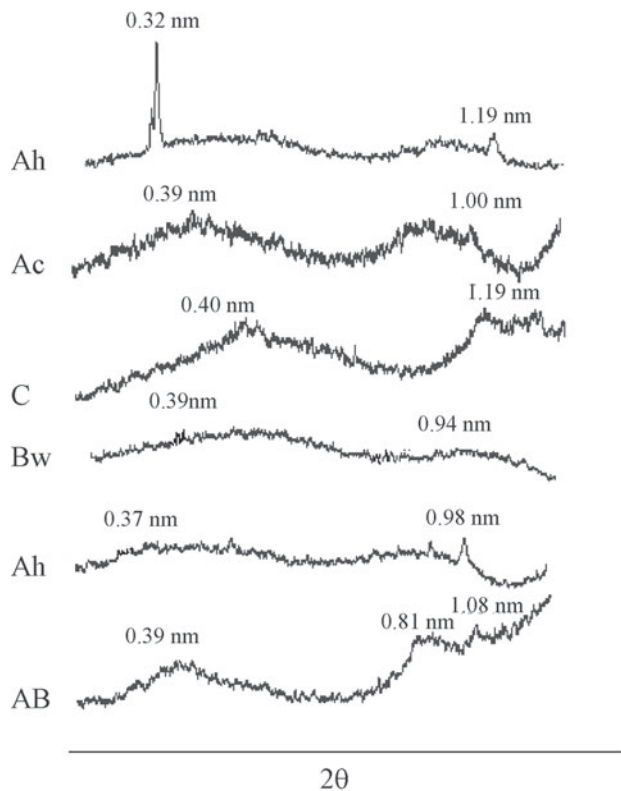

Figure 4. XDR patterns of the air-dried oriented clay fraction of Tzompantepec soil profile: Ah, AC, C, Bw, Ah, AB are the horizons.

Paleosol 2, the eluvial–illuvial differentiation of clay content within the profile is moderate: only a 3% difference between the Ah and AB horizon; this confirms that the clay illuviation process had only reached the initial stages.

Chemical and Andic properties

The chemical and Andic (Soil Survey Staff, 1995) properties of the studied profile are presented in Table 2. pH_{H_2O} is slightly acid to neutral, increasing with depth; pH_{KCl} is 1–1.5 units lower than pH_{H_2O}. Obviously, pH values in the buried paleosols do not represent the original soil characteristics, as this property is rather dynamic and changes rapidly after burial.

However, pH in the NaF solution, which depends on the reaction of amorphous compounds, increases considerably in the buried paleosols (up to 9.3–9.4); this value is closer to the accepted level for diagnosing Andic properties. Phosphorus fixation also increases in buried Paleosols, however, values are too low to fit into the criteria for Andic properties. Fe and Al, extractable by ammonium oxalate, also increase in Paleosol 2, however the values are surprisingly low: $Al_o + ½ Fe_o$ range between 0.13 to 0.20, definitely below the diagnostic level for soils with Andic properties. These results indicate to us that "active
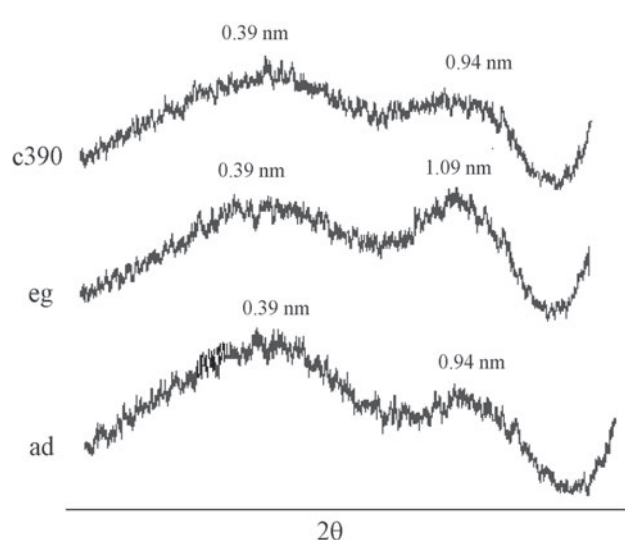
Figure 5. XDR patterns of Bw horizon: air-dried (ad), saturated with ethylene-glycol (eg) and heated at 390⁰C (c390).
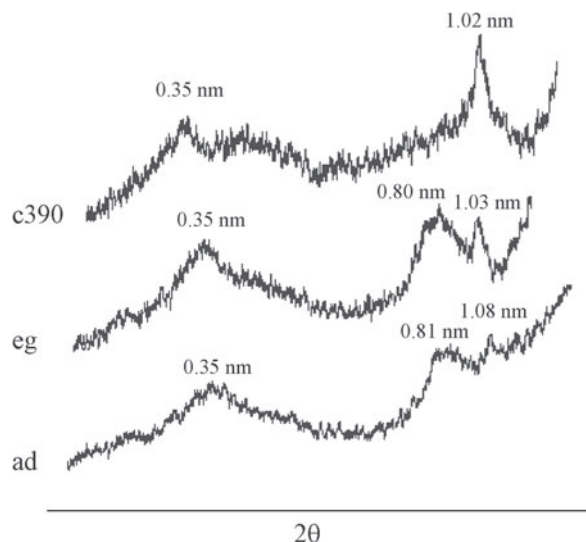

Figure 6. Representative XDR patterns of an horizon (Ah) with illite. The air-dried (ad) oriented clay fraction was saturated with ethylene-glycol (eg) and heated at 390⁰C (c390).

aluminum" associated to allophane and imogolite is present in low quantities (Wada, 1980; Parfitt, 1984). The ferri-hydrite content calculated according to Childs *et al.* (1991) as Fe_o x 1.7 also reaches its maximum level in Paleosol 2 (0.32% in Ah horizon).

Mineralogy

The main components of the fine sand fraction (Table 3) in all horizons of the profile are plagioclase, pyroxene, amphibol, volcanic glass and volcanic rock fragments. These materials are typical of the Trans-Mexican Volcanic Belt soils, and are derived from volcanic parent material (Sedov *et al.*, 2001). Biotite is present in small quantities.

Micromorphological observations showed that primary minerals, particularly the porous volcanic glass and biotite (Figure3c), have some clear weathering features. Vesicular pores are partly filled with yellow material (anisotropic under crossed polarizers), supposedly neoformed clay (Figure 3d). These features are better expressed in paleosols, especially in Paleosol 2. It also should be taken into account that the Ah horizon of this paleosol is enriched with phytoliths, confirming that it was exposed on the paleoland surface and populated by plants for a relatively long time.

Clay Mineralogy

Figure 4 shows the diffractograms from oriented samples of clay fraction (<2 μm), air-dried (ad) and without organic matter. Very broad reflections, centered at 0.39 nm

and 1.00 nm, indicate the predominance of amorphous minerals. These components are more abundant in the Bw horizon of Paleosol 1, which is also supported by the X–ray diffraction data from the samples treated with ethylene-glycol (eg) and those heated at 390 ⁰C (c390) (Figure 5).

In some diffractograms, a broad peak area centered at ~1.0 nm (which varies between 1.19 nm and 0.98 nm for different horizons) is observed, which indicates the existence of 2:1 crystalline silicate clay minerals. This component is present mainly in the AB and Ah horizons of Paleosol 2. Since this broad peak remained unchanged after the ethylene glycol (eg) pretreatment and heating up to 390⁰C (c390) (Figure 6), we conclude that it belongs to the illite group. Although the X–ray diffraction analysis did not allow us to identify the exact types of clay components, the difference between pH_{H_2O} and pH_{KCl} by more than one unit confirms the presence of a clay component with a high permanent charge.

CONCLUSIONS

We conclude that the *black clay* used for ceramic production comes from Paleosol 2 which has a typical profile morphology of Luvic Andosol. The rather small P-fixation index leads us to assume that the quantities of amorphous components, similar to allophane or imogolite, are rather low. However, the X–ray diffraction analysis shows the presence of amorphous components together with some crystalline clay minerals similar to the illite group.

This Paleosol has a much higher degree of development (80 cm in thickness of the Ah and AB horizons and clay accumulation), than the modern surface soil (94

cm in thickness). Incipient clay illuviation was detected here, which indicates that the evolution process towards the profile with eluvial–illuvial clay differentiation had begun prior to burial. This combination of properties is similar to that of buried Pleistocene Andosols from the Nevado de Toluca tephra–paleosol sequence, studied by Sedov *et al.* (2001). Similar to the Nevado de Toluca profiles, we can apply the concept of "Intergraded Andisols" which are defined as presenting "an advanced degree of evolution and weathering towards soils with a much lesser content of amorphous materials" (Fernández-Caldas *et al.*, 1985).

The relatively high content of amorphous components in the fine fraction of Paleosol 2 makes this material appropriate for use as a raw material for the elaboration of pottery. This characteristic could be the reason for the plasticity of *black clay*. A similar situation was reported by McNabb (1979) in western Oregon soils. In addition, the crystalline clay minerals of the illite group will favor good firing properties.

ACKNOWLEDGEMENTS

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