Quaternary pedostratigraphy of the Nevado de Toluca volcano

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ABSTRACT

Paleosol sequences of the Nevado de Toluca volcano (NTV) preserve a detailed record of late Quaternary environmental change. In fact, some studies have been used the NTV paleosols to interpret paleoenvironmental conditions, however some uncertainties still remain concerning their stratigraphic position and correlation. In this paper, we present the results of the NTV pedostratigraphy by using different paleosol units and based on present day tephrostratigraphy. We recognized eight Pleistocene paleosols, labeled PT0–PT7 which cover the 100,000–10,000 yr BP interval. These paleosols are located in four exposures: Arroyo La Ciervita, in the northern flank of the volcano, Zacango, in the northeast, and San Pedro Tlanisco and Barranca Cieneguilla, in the eastern part. The younger five paleosols correspond to different intergrades of Andosols (PT0–PT4) while the older sequence consists of three well developed Luvisols (PT5–PT7). All Andosols have humic horizons allowing radiocarbon dating. PT0 and PT1 were formed at the end of the Pleistocene and correlate with the oxygen isotope stage (OIS) 1 and to the middle-late OIS-2, respectively; the time for PT2 formation corresponds to the end of OIS-3 and the beginning of OIS-2, PT3 to the OIS-3, and PT4 to the OIS-4. PT5–PT7 have not yet been dated, but we correlate them with the OIS-5a and 5b. A more strongly developed paleosol (PT1) was formed during the Last Glacial Maximum (18,000 yr BP) in comparison with other paleosol sequences where weakly developed paleosols were reported or even no soil formation was achieved in this period. We conclude that during late Pleistocene to Holocene, OIS 5 to 1, paleosol sequences of the Nevado de Toluca provide good environmental resolution, similar to or even higher than loess-paleosol sequences, although stratigraphic correlation with other paleoenvironmental records is more difficult because of the heterogeneity of volcanic sediments.

Key words: pedostratigraphy, tephra-paleosol sequences, radiocarbon dating, Quaternary, Nevado de Toluca.

RESUMEN

Las secuencias de paleosuelos del volcán Nevado de Toluca (NTV) conservan un registro detallado de cambio ambiental del Cuaternario tardío. De hecho, algunos estudios han empleado los paleosuelos del NTV para interpretar las condiciones paleoambientales, sin embargo, se tienen dudas sobre su posición y correlación estratigráfica. En este trabajo, presentamos los resultados de la pedoestratigrafía del NTV usando diferentes unidades de paleosuelos, basada en la tefroestratigrafía actual. Reconocimos ocho paleosuelos pleistocénicos (PT0–PT7) que cubren el intervalo 100,000–10,000 años AP. Estos paleosuelos se ubican en cuatro localidades: Arrollo La Ciervita en el flanco norte del volcán, Zacango en el noreste y San Pedro Tlanisco y Barranca Cieneguilla en la parte oriental. Los cinco paleosuelos más jóvenes corresponden a diferentes intergrados de Andosoles (PT0–PT4), mientras que los más *antiguos son Luvisoles bien desarrollados (PT5–PT7). Todos los Andosoles tienen horizontes húmicos permitiendo el fechamiento por radiocarbono. PT0–PT1 fueron formados a fines del Pleistoceno y correlacionan con la etapa isotópica de oxígeno (OIS) 1 y a la mitad tardía de OIS-2, respectivamente. El tiempo de formación de PT2 corresponde al final de OIS-3 y al inicio de OIS-2; PT3 a OIS-3 y PT4 a OIS-4; PT5–PT7 no han sido fechados todavía, pero los correlacionamos con OIS-5a y 5b. Durante el último máximo glacial (18,000 años AP) se formó un paleosuelo de mayor desarrollo (PT1) en comparación con otras secuencias de paleosuelos, donde su desarrollo es débil o no hay formación de suelo durante ese periodo. Concluimos que durante el Pleistoceno tardío – Holoceno (OIS 5–1) las secuencias de paleosuelos del NTV proporcionan una buena resolución paleoambiental, similar o aún mayor que las secuencias loess-paleosuelos. Sin embargo, la correlación estratigráfica es más difícil a causa de la heterogeneidad de los sedimentos volcánicos.*

Palabras claves: pedoestratigrafía, secuencias tefra-paleosuelos, fechamiento con radiocarbono, Cuaternario, Nevado de Toluca.

INTRODUCTION

Several studies regarding tephrostratigraphy of the Nevado de Toluca volcano have been carried out during the last decades (Bloomfield and Valastro, 1974, 1977; Cantagrel *et al.*, 1981; Macías *et al.*, 1997; Newton and Metcalfe, 1999; García-Palomo *et al.*, 2002). These studies have used paleosols as chronostratigraphic markers, as they are a source of carbon in humus, for radiocarbon dating. In fact, ^{14}C dating has incredibly increased the stratigraphic resolution of the volcanic sequence of Nevado de Toluca. However, paleosols should not be regarded as merely fixed time intervals during the Quaternary period, because they include two lapses, the beginning and the end of soil development (Catt, 1991).

Pedostratigraphy allows correlation of Quaternary deposits over a long distance and wide areas and can be used for correlating glacial deposits, river terraces, and for correlation with the oxygen isotope record of deep oceanic sediments by means of different dating methods (Stremme, 1998). Pedostratigraphy is useful to define the soil-forming interval, which is bracketed by the ages of adjacent depositional units. This concept establishes the time of landscape stability (Birkeland, 1984). The basic unit in pedostratigraphy is the geosol, consisting of a traceable, mapable three dimensional body of soil material with one or more differentiated soil horizons (Morrison, 1978; Catt, 1998). In the case of pedocomplexes (soils composed of two or more soils), they are designated as compound geosols and each soil of the pedocomplex is a pedomember. The lateral variations in soil horizons, as the result of modifications in parent material, climate, vegetation, or topography composing different profile types, are designated as pedofacies.

Recently, the Quaternary paleosols buried under the Nevado de Toluca volcanic deposits were recognized as an important alternative record of paleoenvironmental change, as well as good stratigraphic markers (Sedov *et al.*, 2001). They represent a detailed record of late Quaternary environmental change, however some uncertainties still remain concerning their stratigraphic position and correlation.

In the northern and eastern flanks of the Nevado de Toluca volcano (NTV), seven paleosols, labeled as PT1–PT7, have been recognized by Sedov *et al.*(2001). In this study two additional units are recognized (PT0 and PT1a). Although some of these paleosols do not comply with the formal criteria to be regarded as geosols, because they can not be mapped over a broad area, they are soil stratigraphic units.

The objective of this work is to establish the pedostratigraphy of the Nevado de Toluca on the basis of distinguishable paleosol units. The integration of this pedostratigraphic record along with the study of their variability in space and time allow us to infer paleoenvironmental conditions of the region and the effects of volcanic activity in soil formation.

MATERIALS AND METHODS

Temporal-spatial variations in the tephra-paleosol sequence of the NTV were examined in four exposures, located in the northern and eastern flanks of the volcano (Figure 1). The studied sites are Arroyo La Ciervita, Zacango, San Pedro Tlanisco, and Barranca Cieneguilla. In the Arroyo La Ciervita exposure, four paleosol profiles were sampled. In Zacango, two paleosol profiles were included; in each exposure of San Pedro and Barranca Cieneguilla, one profile was examined.

The field reconnaissance and correlation of exposures allowed the construction of a synthetic local pedostratigraphic scheme (Figure 2). Nine different pedostratigraphic units (labeled PT0–PT7) were recognized and at least three of them –PT1, PT2, and PT3– are pedocomplexes (Smolikova, 1967), including more than one

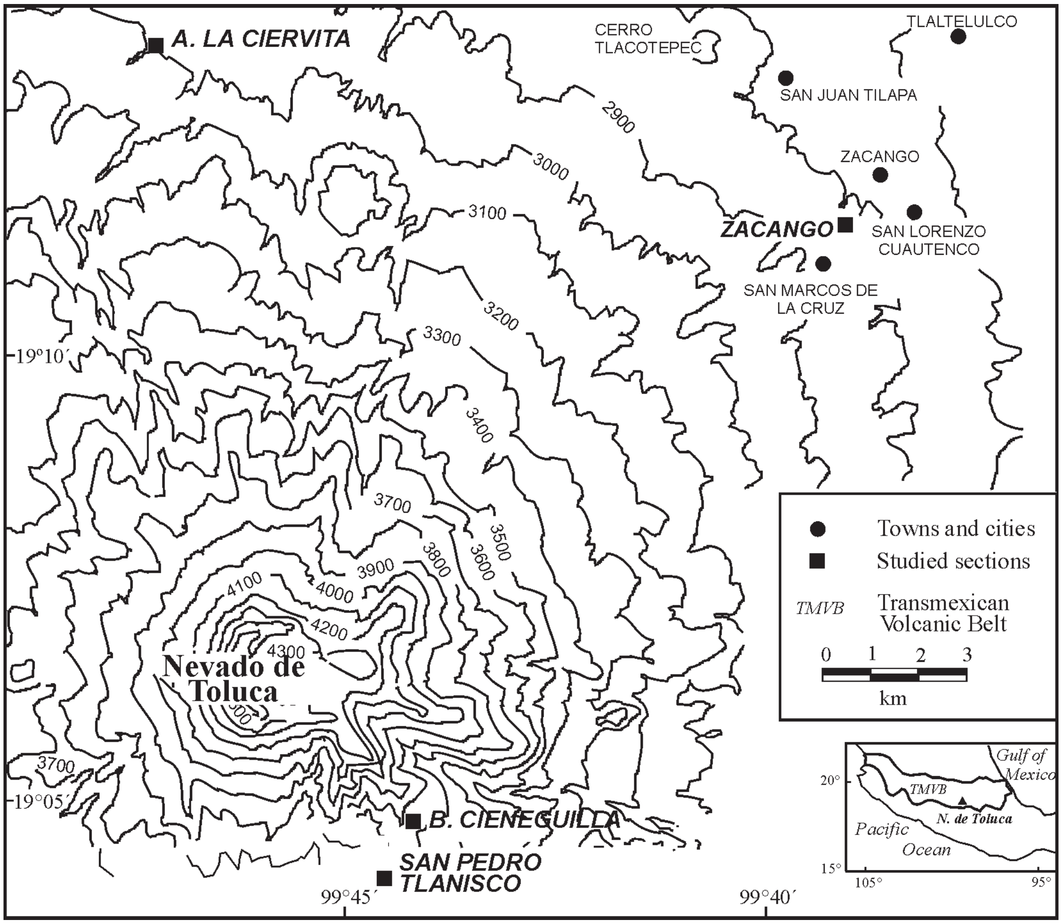

Figure 1. Location of the study area.

event of pedogenesis. Paleosol classification was performed using field criteria and according to FAO (1998).

The time frame for the upper part of the sequence (PT0–PT4) was constrained by a set of radiocarbon dates, most of them already published and some new data, performed in the Geological Institute of the Russian Academy of Sciences (RAS). The age of the lower part (PT5–PT7) which is already beyond the detection limit of radiocarbon dating, is only a roughly estimate based on the degree of paleosol development.

RESULTS

Arroyo La Ciervita exposure

This exposure includes four paleosol profiles (A.C.1–A.C.4) in which we recognized three pedocomplexes (PT1–PT3). The modern soil and the three upper pedostratigraphic units are exposed in A.C.1., A.C.2., A.C.3, and A.C.4. sections (Figure 2).

The modern soil (A.C.1.) has been cultivated and it is characterized by a paler color (10 YR 5/3, dry), less developed structure, and lower humus content (2.1%) than modern Andosols under natural-forest vegetation (8.2%) (Sedov *et al.*, 2001). The parent material is a pyroclastic flow deposit dated at 3,200 yr BP (Macías *et al.*, 1997) and younger lahar deposits. The field soil classification corresponds to an Haplic Andosol.

The PT1 unit (A.C.1.) is located below the 3,200 yr BP pyroclastic flow or younger lahars deposits. The buried profile consists of brown-yellow Bw and BC horizons and overlies a thin reworked gray ash layer (Figure 3). In A.C.4., this unit is not well expressed. PT1 has a complex structure because granules of different size are associated with subangular blocks. PT1 was classified in the field as Andic Cambisol. Some charcoal fragments found inside this unit were dated at 13,620±900 yr BP (Aceves, in revision).

The PT2 unit (A.C.1., A.C.2. and A.C.4.) is located directly below the gray ash layer, delimiting the PT1 unit. In these exposures, this unit constitutes a pedocomplex. In A.C.1., it consists in two well developed Ah horizons, underlain by brown AB and Bw horizons (Figure 3). Radiocarbon dates of humus from these horizons are 27,900±500 yr BP and 29,000±1,200 yr BP (Sedov *et al.*, 2001). In A.C.2., a thin discontinuous third Ah horizon

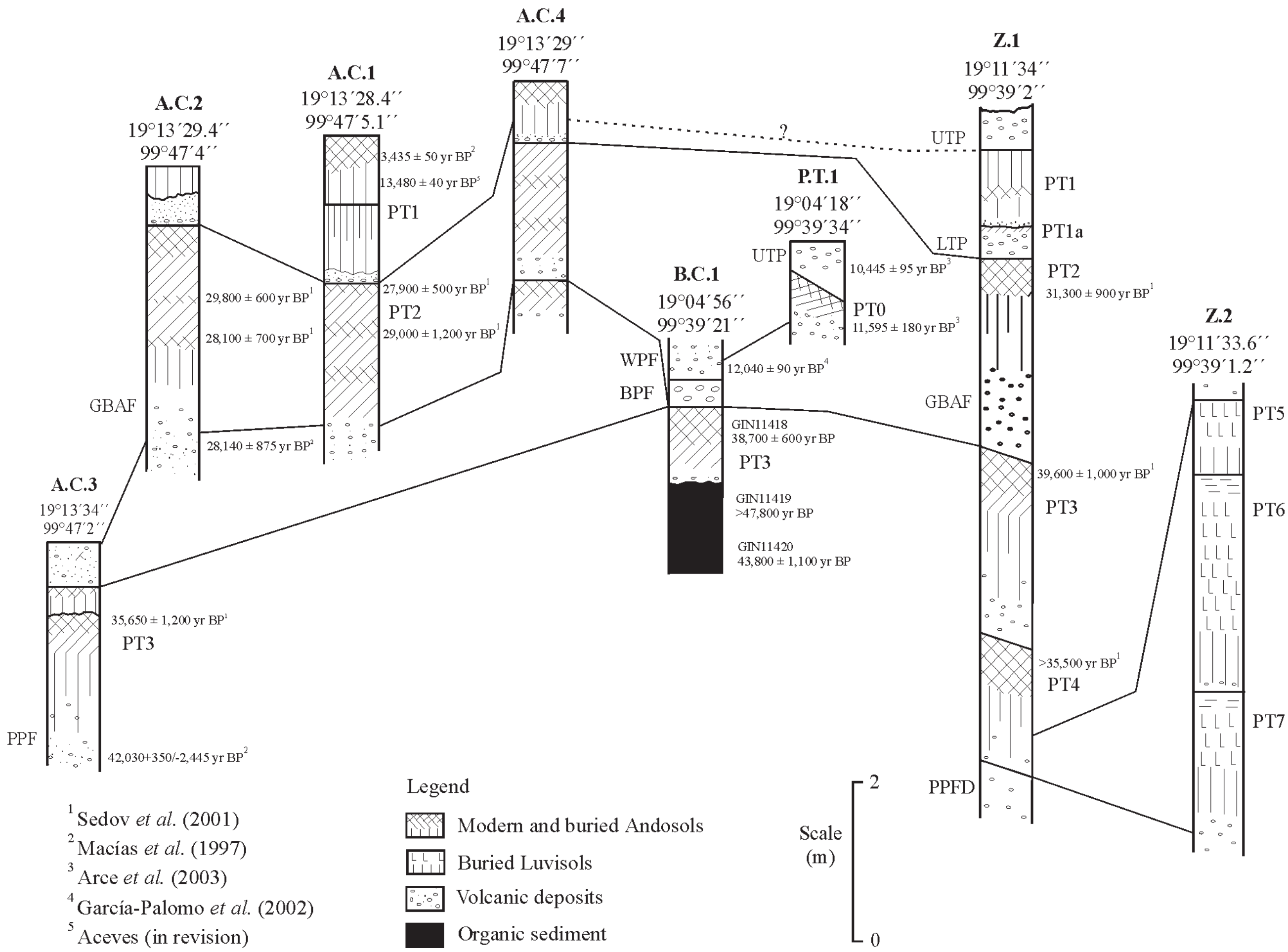

Figure 2. Stratigraphic correlation of buried paleosols (PT0–PT7) in the studied exposures. UTP: Upper Toluca Pumice; A.C.: Arroyo La Ciervita; LTP: Lower Toluca Pumice; B.C.: Barranca Cienegilla; WPF: White Pumice Flow; P.T.: San Pedro Tlanisco; BPF: Brown Pumice Flow; Z.: Zacango; GBAF: Gray Block and Ash Flow; PPF: Pink Pumice Flow; PPFD: Pink Pumice Flow Deposit.

appears in the middle part of the profile. Upper Ah horizons have characteristic coarse subangular blocky-prismatic structures formed by a dense net of fissures. The radiocarbon ages of PT2-humus are 29,800±600 yr BP and 28,100±700 yr BP (Sedov *et al.*, 2001). This unit is underlain by the younger member of a thick gray block and ash flow deposit (GBAF), dated at 28,140 +875/-780 yr BP (Macías *et al.*, 1997). In A.C.4., PT2 has two middle Ah horizons overlain by an AC horizon, so the profile is truncated. PT2 was classified in the field as Mollic Andosol.

The PT3 unit (A.C.3.) is found below the GBAF and over a pink pumice flow (PPF) dated at 42,030 +350/-2445 yr BP (Macías *et al.*, 1997). In most cases it is deeply eroded; in well preserved sections, a pedocomplex, which includes two subprofiles, is observed (Figure 2). In some cases, this unit appears directly under PT2 (A.C.4., Figure 2). The upper paleosol is weakly developed and consists of thin Ah (possibly affected by erosion) and AC horizons. The lower paleosol is thicker, having an Ah-AB-Bw-BCg profile. The characteristic feature of the black Ah horizon is a set of vertical cracks, forming large blocks. In the bottom part of the profile, iron mottles provide evidence of redox processes. The radiocarbon age of humus in the lower Ah is 35,650±1,200 yr BP. In A.C.4., this unit is less developed and directly overlain by PT2. This paleosol was classified in the field as Mollic Andosol.

Zacango exposure

Two sections were described in the Zacango exposure, where we recognized seven paleosol units (PT1–PT7). The PT1 unit (Z.1.) has a very clear stratigraphic position because it is overlain by the Upper Toluca Pumice (UTP) dated at 10,445±95 yr BP (Arce *et al.*, 2003), and underlain by the Lower Toluca Pumice (LTP) dated at 24,260±670 yr BP (Bloomfield and Valastro, 1977). PT1 consists of a brown-yellow, silty loam Bw-horizon relatively compact, with weak subangular blocky structure; a dark brown, silty loam Ah-horizon with weak granular structure, and a brown, silty

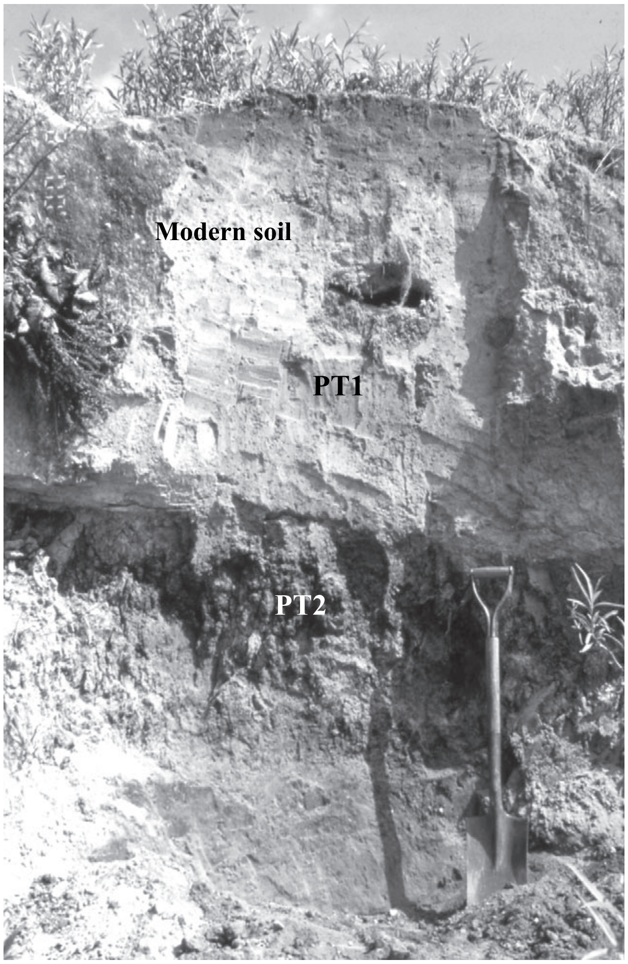

Figure 3. View of a modern Andosol resting over the Bw horizon of PT1. Typical morphology of PT2 with dark-brown Ah horizon and cracks.

loam AC-horizon (Figure 4). Morphologically, the upper B horizon corresponds to an eroded Cambisol, while the lower profile (A-AC) to a Vitric Andosol. PT1 overlies a 5 cm thick gray, weakly stratified layer, composed of medium sand particles of crystals, pumice and lithics. This layer rests on the LTP, where we observed a 6 cm thick paleosol (PT1a), that was considered as an Umbric Leptosol.

Thick profiles of PT2 and PT3 units with similar well-developed Ah horizons with cracks, underlain by brown weathered ABw and Bw horizons were observed in Z.1. (Figures 2 and 4). In contrast to Arroyo La Ciervita, both PT2 and PT3 display a single paleosol profile. Only in the southern part of Z.1. exposure, a second (lower) humus horizon appears in PT2 so that the morphology of this pedocomplex becomes similar to that in Arroyo La Ciervita. The radiocarbon ages of humus of PT2 and PT3 are 31,300±900 yr BP and 39,600±1,000 yr BP, respectively (Sedov *et al.*, 2001). In this case, PT2 overlies the older block and ash flow deposit (GBAF) dated at 37,000±1,125 yr BP (Macías *et al.*, 1997).

The PT4 unit is located below PT3. It also has a profile Ah-Bw-BC, with a dark humus horizon and a brown Bw horizon, similar to PT2 and PT3. One radiocarbon date for this paleosol yielded an age of >35,500 yr BP. PT2, PT3 and PT4 were classified in the field as Mollic Andosols.

The underlying units in this exposure, PT5–PT7 (Z.2., Figure 2), have morphologies that differ completely from the younger ones and from modern soil. Well-developed clay-illuvial (argic) Bt horizons are the most pronounced feature of these paleosols. Their color ranges from yellowish brown PT7 (10YR 5/4 dry; 10YR 4/4 moist) to strong brown in PT6 (10YR 5/4 dry, 7.5YR 4/6 moist). They have an angular blocky-prismatic structure with thick continuous illuvial clay coatings on ped surfaces as well as some Fe–Mn mottles and concretions. Paleosol PT5 is truncated by erosion, so that only the lower part of Bt is preserved, whereas PT6 and PT7 have more complete profiles with pale eluvial EB horizons (very pale brown 10YR 7/4 dry; dark yellowish brown 10YR 4/6 moist) above the set of Bt horizons. No dark humus horizons are present in PT5–PT7 (Figure 5). PT5 and PT7 were classified as Haplic Luvisols and PT6 as Stagnic Luvisol.

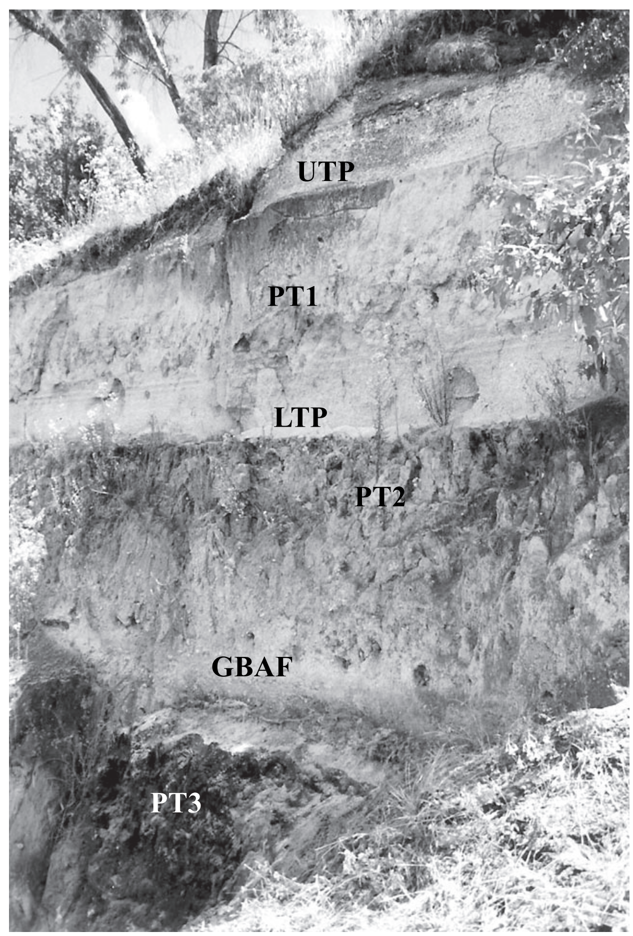

Figure 4. View of soil stratigraphic –PT1, PT2, PT3– and lithostratigraphic –LTP, UTP, GBAF– units in Zacango exposure.

Unfortunately, no ages are available for this part of the sequence, as they have no possibility for radiocarbon dating. It is likely that PT5–PT7 formed in the 100,000–50,000 yr BP interval (for details see Sedov *et al.*, 2001). These paleosols rests over a thick light-pink pyroclastic flow deposit (PPFD).

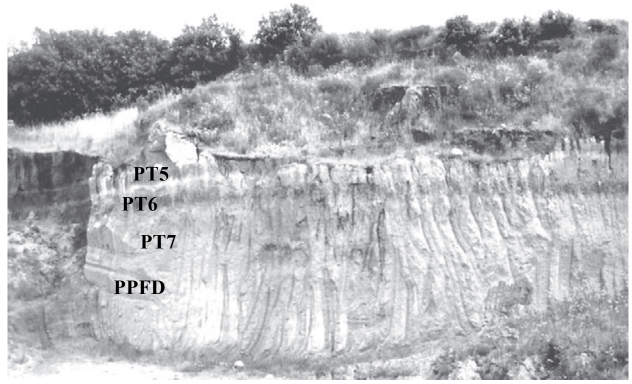

Figure 5. View of soil stratigraphic units –PT5, PT6, PT7– over the PPFD in Zacango exposure.

Arroyo San Pedro Tlanixco exposure

In this exposure, we sampled a poorly developed paleosol, labeled as PT0. It exhibits a 30 cm-profile with a black Ah horizon, 7 cm thick, rich in humus, that was classified in the field as lithic Andosol. It was formed on a steep slope (30°). Its radiocarbon age is 11,595±180 yr BP (Arce *et al.*, 2003). This paleosol rests on top of the White Pumice Flow deposit (WPF) dated at 12,040±90 yr BP (García-Palomo *et al.*, 2002) and underlies the UTP.

Barranca Cieneguilla exposure

In this section we only found a 35 cm thick, weakly developed paleosol, with a thin (11–19 cm), dark Ah horizon that has a wavy contact with an AC horizon, and is covered by a fallout layer of the WPF (Cervantes-de la Cruz, 2001) and a thick brown pyroclastic flow (BPF). The paleosol rests over a thick black organic deposit (>120 cm). The radiocarbon dating of paleosol humus gave an age of 38,700±600 yr BP, therefore this unit is correlative to PT3. Two samples from the organic sediment yielded ages of >47,800 and 43,800 ±1100 yr BP (Figure 2).

DISCUSSION AND CONCLUSIONS

Pedostratigraphy of the Toluca volcano and paleosol correlation

The paleosol stratigraphy extracted from the four studied exposures, allows the construction of a composite pedostratigraphic column (Figure 6). The lower part of the sequence is constituted by three very well expressed paleosols (PT5–PT7). Although so far they have not being dated, they were probably formed during the 100,000–50,000 yr BP interval (Sedov *et al.*, 2001), and represent a long time interval of landscape and volcanic stability (Jasso-Castañeda *et al.*, 2002). Field observations suggest that these units are widespread on the eastern flank of the volcano and thus are geosols. However, at the present time they are not yet studied in detail.

The younger paleosols can be correlated on the basis of their radiocarbon ages and stratigraphic position. The best exposure of PT4 is found in Zacango, instead of in Barranca Cieneguilla, where a thick organic sediment appears at the same stratigraphic level (Figure 2). Recent field observations in the Barranca Tepehuisco indicate that this organic sediment (70-cm thick) overlies paleosol PT4, which rests directly on the PPFD observed in Zacango under PT7.

PT3 is a paleosol formed from different parent materials, which can be found in some exposures. In the Arroyo La Ciervita, its parent material is the PPF dated at 42,000 yr BP, while the soil age is 35,000 yr BP and can be correlated with lacustrine deposits of 35,160±960 yr BP (Caballero *et al.*, 2001); in Zacango and Barranca Cieneguilla, it was formed from a different volcanic deposit. At the latter site, PT3 (38,700 years old) lies over thick organic sediments. This difference between PT3 dates can be explained as a function of differences in sediment accumulation rates. In Arroyo La Ciervita, no evidence of the 37,000 yr-GBAF was found, and in Zacango and Barranca Cieneguilla, the PPF is absent because of its localized distribution. However, this paleosol unit is very common in the NTV, as we can deduce from some works related to tephrostratigraphy (Cantagrel *et al.*, 1981; Macías *et al.*, 1997). These authors dated some volcanic deposits by using buried paleosol ages around 38,000 yr BP (Table 1) that are similar to PT3.

Regarding the stratigraphic position of PT2, its lower limit is well defined. In the Arroyo La Ciervita exposures, it is formed from the GBAF (28,000 yr BP), which is in agreement with its radiocarbon ages (27,900±500 yr BP, and 29,000±1,200 yr BP). In Zacango, PT2 is 31,000 years old, and rests over the 37,000 yr BP deposit. The PT2 upper limit in Zacango is the LTP, so its pedogenesis ended at 24,000 yr BP. The large time variation for soil formation in both exposures is likely due to variable rates and spatial patterns of volcanic sedimentation. In the Arroyo La Ciervita, PT2 is a pedocomplex, with two Ah horizons (A.C.2.) that change laterally into three Ah horizons (A.C.1. and A.C.3., Figure 2), indicating that it was affected by different periods of ash deposition or reworking. In contrast, in Zacango it has a single profile, evidencing a longer period of landscape stability.

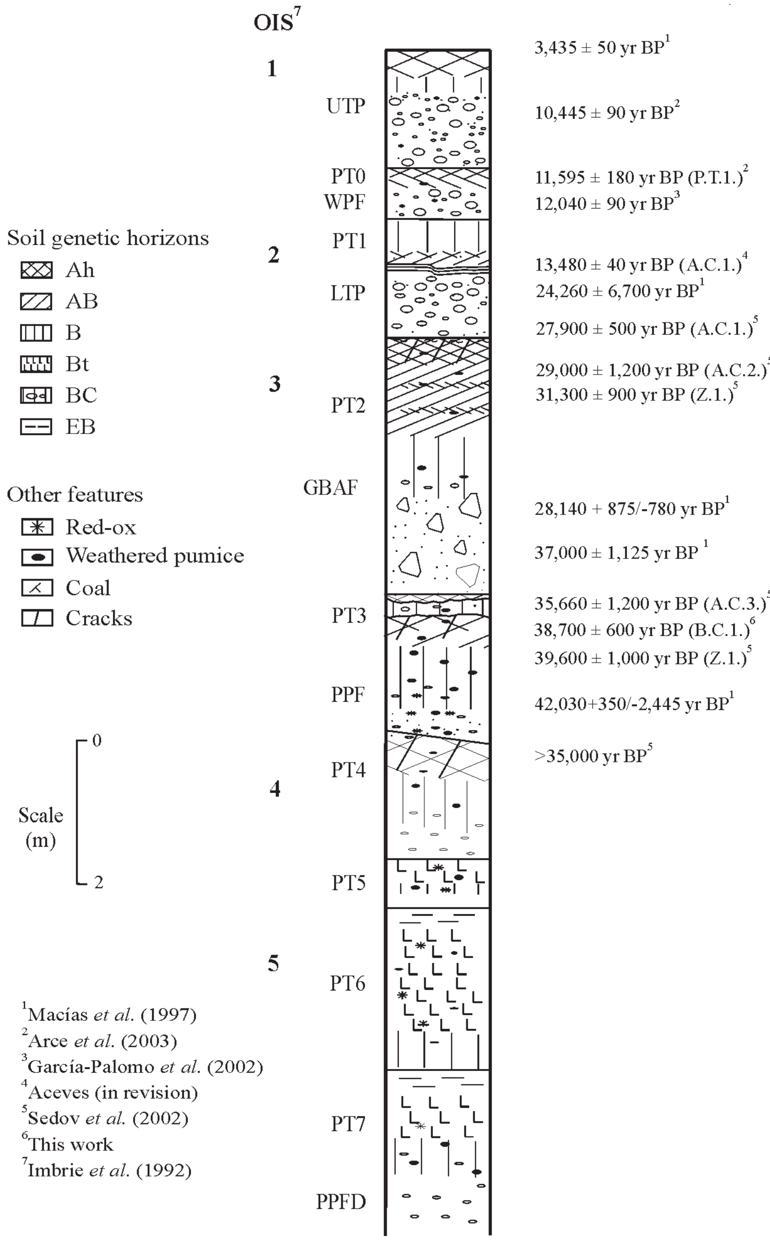

Figure 6. Pedostratigraphy of the Nevado de Toluca volcano (composite section) and correlation with the marine oxygen isotope stages (OIS).

Although at the present time no other exposures were studied, some works (Bloomfield and Valastro, 1974, 1977; Macías *et al.*, 1997) report the presence of a paleosol with a similar age (Table 1) that is very common in the northern and eastern flank of the volcano.

Nevertheless, some uncertainty is still left about the age of the unit PT1 (A.C.1) and its relationship with the pedocomplex PT1 in Zacango (Z.1.). In Arroyo La Ciervita, where PT1 was described for the first time, its age is 13,480 yr BP and it is limited by a 3,435 yr BP pyroclastic flow deposit and by the upper member of PT2 (27,900 yr BP). In Zacango, this soil is bracketed by deposits with ages of 24,000 (LTP) and 10,500 yr BP (UTP), respectively. Recent field observations at El Refugio quarry show that this unit exhibits a better developed profile, 60 cm thick, with an Ah horizon, rich in humus, dated at 13,500 yr BP (García-Palomo *et al.*, 2002). On the basis of radiocarbon dating, we can correlate PT1 with other soils in different exposures (Table 1).

The less developed paleosol PT0 was found in two gullies, under the UTP yielding an age of 11,595±180 yr BP at San Pedro Tlanixco and Barranca Tepehuisco. We consider that it is correlative to the paleosol dated by Bloomfield and Valastro (1974) which provided the age of the UTP for many years. The duration of soil formation for PT0 was around 1,000 years.

Correlation of paleosol units and the deep-ocean isotopic records

The correlation of Quaternary sediments with the oxygen isotopic stages (OIS) has been widely used and it is considered as a extraordinary model for correlation at the regional scale (Walker *et al.*, 1999).

The Quaternary paleosol units of the Nevado de Toluca can be correlated with the OIS (Figure 6). Although, PT5–PT7 have not been dated yet, we correlate them to the OIS-5a and 5b, while PT4 was formed during the OIS-4. Development of PT3 occurred during the OIS-3, while PT2 was formed at the end of OIS-3 and the beginning of OIS-2. The formation of PT1 corresponds to the middle-late OIS-2, that includes the Last Glacial Maximum (LGM) that occurred 18,000±3,000 yr BP (Williams *et al.*, 1998). In central Mexico, the minimum temperature of the LGM occurred around 17,000–16,000 yr BP (Heine, 1994). Bloomfield (1975) reported the presence of a paleosol whose age coincides with the LGM (Table 1), but we are not sure if it is the same as PT1. PT0 was formed at the beginning of the OIS-1.

Table 1. ^{14}C ages reported in the literature for different paleosol units correlative to PT0-PT4.

Paleosol unit	^{14}C age (yr BP)	Location
PT0	11,050±130[1]	19°09’N; 99°49’W
	11,595±180[2]	19°04’18’’N; 99°39’34’’W
PT1	13,620±150[3]	19°04’N; 99°22’W
	13,870±180[3]	19°10’N; 99°39’W
	13,480 +/- 40[4]	19°13’28.4’’N; 99°47’5’’W
PT2	27,900±500[5]	19°13’28.4’’N; 99°47’5’’W
	28,100±700[5]	19°13’28’’N; 99°47’5’’
	29,000±1,200[5]	19°13’28’’N; 99°47’5’’
		19°13’28’’N; 99°47’5’’
	29,800±600[5]	19°11’34’’N; 99°32.2’W
	31,300±900[5]	19°05’N; 99°51’W
	27,590±650[3]	19°03’N; 99°52’30’’W
	24,260±670[1]	19°05’N; 99°51’W
	25,275+1,210/-150[6]	19°02’54’’N; 99°39’’W
PT3	35,650±1,200[5]	19°13’31’’N; 99°47’2’’
	39,600±1,000[5]	19°11’34’’N; 99°32.2’W
	38,000[7]	Barranca del Jaral
	39,355+1385/-1180[8]	
	36.780+3325/-2345[8]	
	38,700±600[9]	19°04’55.8’’N; 99°39’20.9’’W
PT4	>35,500[5]	19°11’34’’N; 99°32.2’W
PT?	17,090±220[2]	19°10’N; 99°39’W
	18,560±210[10]	19°09.5’N; 99°31’W
	19,630±240[10]	19°09.5’N; 99°31’W
	19,720±240[10]	19°09.5’N; 99°31’W
	20,210±520[10]	19°09.5’N; 99°31’W

[1]Bloomfield and Valastro (1974); [2]Arce *et al.* (2003); [3]Bloomfield and Valastro (1977); [4]Aceves (in revision); [5]Sedov *et al.* (2001); [6]Macías *et al.* (1997); [7]Cantagrel *et al.* (1981); [8]García-Palomo *et al.* (2002); [9]this work; [10]Bloomfield (1975).

Definition of pedostratigraphic units

Not all paleosols exposed in the Nevado de Toluca volcano comply the formal requirements to be considered as soil stratigraphic units –geosols– which are not soils or paleosols, “but rather a whole soilscape that can be recognized as a laterally extensive stratigraphic horizon” (Retallack, 1990). However, they are good stratigraphic markers and they follow the Vreeken´s concept of “time transgresive chronosequences without historical overlap” (Vreeken, 1975), in which different profiles began forming at different times and successive periods of burial ended their development at different times. So, the studied paleosols were developed and buried at distinct periods and every one has a specific pedogenic history that does not overlap in time.

Although, paleosols PT2 and PT3 are diachronous, they do not exactly represent the same period of time throughout their geographical extent. This is because of the great variability resulting from spatial variations of climate, flora, fauna, parent material deposition, geomorphic position and history of the land surface (Catt, 1991).

Concerning the parent material, volcanic sediments represent an additional source of soil variability, because deposits cannot be traced for long distances and they are thicker in gullies and in sites close to the eruptive center. In the loess-paleosol sequences, parent material is more homogeneous and covers larger areas, so correlation from one site to the other can be achieved (Bronger and Heinkele, 1989; Stremme, 1998). However, pedostratigraphic units found in the Nevado de Toluca can be traced in different flanks of the volcano, and represent a valuable tool for reconstruction of ancient climates, relief, and time span when volcanic activity ceased or diminished.

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