PHYSICAL, CHEMICAL, AND MINERALOGICAL CHARACTERIZATION OF VERTISOLS TO DETERMINE THEIR PARENT MATERIAL

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SUMMARY

The response of soils to weathering processes depends upon their parent material. Proper identification of the primary and secondary minerals in Vertisols provides information about the parent material that gives origin to these soils. Thus, the objectives of this study were 1) to determine the physical and chemical properties of Vertisols in order to characterize and classify them; 2) to identify their primary and secondary minerals to ascertain the type of parent material that gave origin to these soils; and 3) to determine the type of rock that produces Vertisols. Two types of Vertisols were studied: one of igneous origin and dark color, and the other of sedimentary origin and pale light color. Soils of igneous origin were classified as Chromic Haplusterts, Typic Haplusterts, and Mollic Ustifluvents. Sedimentary origin soils were classified as Chromic Calciusterts and Typic Calciustolls. Dominant mineralogy of the soils of igneous origin in the sand fraction was comprised of volcanic glass (47%), quartz (31%), and feldspars (22%). Amorphous materials, smectites, vermiculites, illites, and cristobalites dominated the clay fraction. In contrast, in the soils of sedimentary origin the sand fraction was composed of calcite (64%), quartz (34%), and feldspars (2%). Smectites, vermiculites, quartzes, and feldspars composed the clay fraction. The parent material of the igneous soils was rhyolite, while the sedimentary soils were derived from limestone and sediments with high calcium carbonate contents.

Parent material constitutes one of the most important factors in the formation and distribution of Vertisols (Coulombe *et al*., 1996, 2000). Other factors such as climate, time, living organisms and relief are more active and increase the pedogenesis level. The original material (soil at time zero) represents the initial state of the system, which may be a consolidated rock, an unconsolidated deposit, or a pre-existing soil (Porta *et al*., 2003).

Escadafal *et al*. (1989), Coulombe *et al*. (1996) and Demattê and García (1999) indicated that the information provided by the mineralogical composition of a given soil is crucial in order to know its origin and genesis. In the case of Vertisols, the presence of smectites is responsible for their unique morphological properties, such as the clay content (>30%), shrink-swell activities, presence of slickensides, wedge-shaped peds, and *gilgai* microrelief.

Coulombe *et al*. (1996) mentioned that Vertisols of igneous origins can be constituted by basalt, dolerite, ash, tuff and andesite in different regions all over the world. Rhyolites are composed of volcanic glass, quartz crystals, orthoclases, biotites and hornblendes as accessories (Bullock *et al*., 1985). The weathering of volcanic glass

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generates smectites and amorphous siliceous mineral silicates (Gutiérrez *et al.*, 2007). Nevertheless, it is not known how much of those minerals in the Vertisols are developed from rhyolites. In the Mexican Highlands, Vertisols constitute one of the most abundant soils; however, they have been poorly studied. The few research efforts that deal with these soils are mainly related to productivity and management (Ortiz, 1997). In those areas, numerous rock types have been found, mainly of igneous origin, such as acid extrusive and intrusive ones (INEGI, 1988b).

Vertisols in Central Mexico (State of Guanajuato) are derived from basalts, which are abundant in the lowlands (INEGI, 1988b). In another important zone of Vertisols in Mexico, namely the coastal area of the Gulf of Mexico, their origin is sedimentary, mainly from limestone. However, there are no studies on either zone about the morphology, soil properties, mineralogy, and origin of these Vertisols (INEGI, 1988c). Therefore, it is necessary to determine and classify the mineralogy of the soils from these zones in order to know what kind of rocks originated the Vertisols.

In this regard, the objectives of this research were 1) to determine the physical and chemical properties of Vertisols in order to characterize and classify them; 2) to identify their primary and secondary minerals to ascertain the type of parent material that gave origin to these soils; and 3) to determine the type of rock that produces Vertisols.

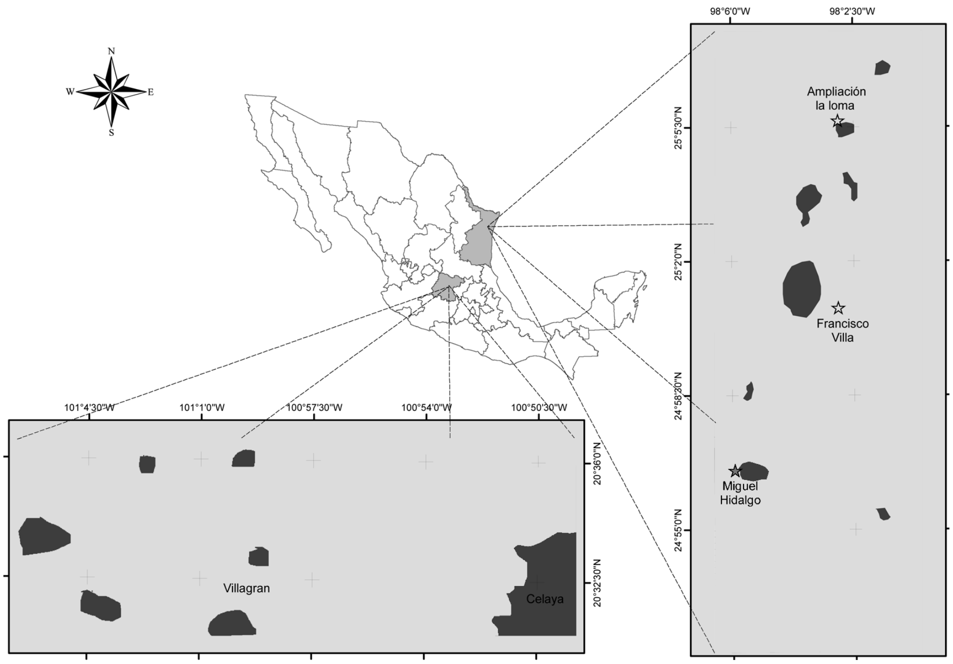

Figure 1. Location of Vertisol study sites in Mexico.

Materials and Methods

Study area

Two sites with Vertisols of different origins were selected. The first one, with dark soils of igneous origin, is located in Central Mexico (State of Guanajuato), between 20°30'57'' and 20°36'34''N, and between 100°49'20'' and 101°06'40''West (INEGI, 1988a). This site covers 3000km^2 (Figure 1). The dominant geomorphology is mainly volcanoes and valleys (INEGI, 1988b). According to García (2004), the climate is BS1hw(w)(e) g, which is semi-arid semi-warm, with extreme rains in summer. The annual average temperature is 19.6°C, with an annual precipitation of 599.2mm.

The second site has light color Vertisols of sedimentary origin; it covers 2500km^2 and is located in Northeast Mexico, in the coastal plains of the Gulf of Mexico (State of Tamaulipas), between 25°13'22" and 25°29'34"N, and between 98°00'18" and 98°06'23"W st (INEGI, 1988c; Figure 1). The climate is (A) Ca(x') (wo)(e)w", that is, sub-humid temperate with summer rains and presence of an intermediate dry season; the annual average temperature is 23.5°C, with an annual precipitation of 656.7mm (García, 2004).

Field work

The Vertisols in the study sites were delimited on the basis of soil maps prepared by the Mexican National Institute of Statistics and Geography, Scale 1:250000 (INEGI, 1988a). Three representative soil profiles were located and described according to FAO (2006) for each zone, which were located on each type of soil, where Vertisols had two profiles due to them being studied and for covering the largest areaCLARIFY; also, several drillings were made on the surroundings of the profile to verify the soil types and their limits.

Laboratory analysis

The physical and chemical properties of the soil profiles were determined following the procedures of Van Reeuwijk (2006) and the Soil Survey Staff (1998). The physical properties analyzed were moisture content, texture, color, bulk density and real density; the chemical properties studied were organic matter, cation exchange, cation exchange capacity, pH, organic carbon, $CaCO_3$, electrical conductivity, percentage of interchangeable Na, soluble cations, base saturation percentage, P_2O_5, and n-value.

Mineralogy analysis

Mineralogical determinations were carried out in order to characterize the soils, according to the following procedure:

a) *Sand fraction*. This analysis was carried out in order to determine the type of parent materials that originated soils, as well as the presence of lithologic discontinuities. The sand fraction was screened and separated from the silt and clays through a 0.5mm sieve; the carbonates were eliminated using 10% HCl, and the organic matter was removed with 60% H_2O_2. The sand fraction was washed and dried; the sands of the medium fraction (250-500µm) were placed on a slide with unsaturated polyester resin and covered with a slide cover slip. The identification was based on the optic properties according to Gribble and Hall (1992) and electron microscopy was used for identifying the minerals.

b) *Clay fraction*. The clays (fraction <2µm) were separated from the sand and silt by the pipette method (Van Reeuwijk, 2006). The clay was dried through boiling to obtain a dry powder

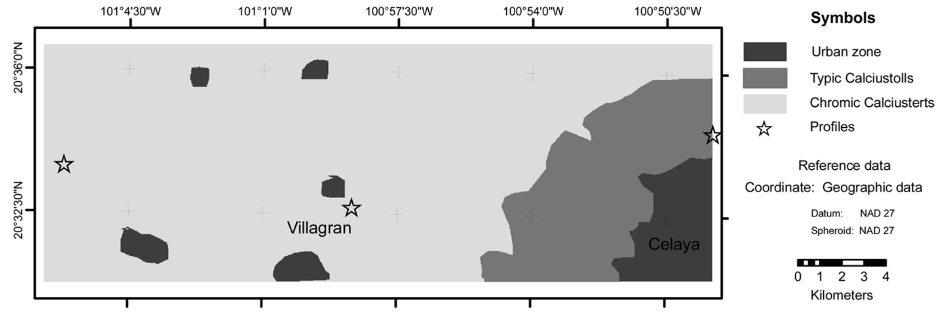

Figure 2. Soils present in Central Mexico and classified by the Soil Taxonomy system.

and then dispersed by ultrasound; some drops were place on a slide for their deposition. Clayey material was identified using an X-ray diffractometer; model MMAGBC, using the Visual Program XRD and Traces (GBC, 2006).

Soil classification

Diagnostic properties, epipedons and subsuperficial horizons of soil profiles were identified in order to analyze and classify pedogenetic processes. The soils were classified according to the Soil Taxonomy System (Soil Survey Staff, 2010).

Results and Discussion

Physical and chemical properties and classification of soils of igneous origin

Profile 1. Clay, organic carbon, and calcium carbonate content varied according to depth, which is characteristic of alluvial deposits. Soil consistency was hard, with 10YR4/1 color (Table I). The formation of a pedogenic structure, slickensides and carbonate accumulation are requirements to define a Bss horizon, which was accomplished in this profile. This profile had both Ochric epipedon and Cambic subsurface horizons. The soil was classified as Chromic Haplusterts (Soil Survey Staff, 2010).

Profile 2. Clay, organic carbon and calcium carbonate had an irregular behavior according to depth. In this soil (Table I), with a high base saturation percentage, the calcium carbonate content was low, it was of neutral color and hard consistency, and showed vertic properties (slickensides and cracks). The irregular behavior of the soil properties show its alluvial origin. This soil had Ochric epipedon and Cambic subsurface horizons. The soil was classified as Typic Haplusterts.

Profile 3. Clay, organic carbon and calcium carbonate varied according to depth; there was an abrupt textural change and clotted or loose structure that indicated soils buried by alluvial deposits. This soil (Table I) had a slightly hard consistency, granulate structure, clear colors, base saturation percentage >50%, organic carbon content of 0.31-1.01, dark brown color on the surface and clear on the subsurface horizons (10YR3/2). These features are characteristics of a Mollic epipedon; also, a Cambic subsurface horizon was present. The soil was classified as Mollic Ustifluvents.

Profiles 1 and 2 corresponded to Vertisols, as they showed >30% of clay and cracks that open and close in the dry and humid season, respectively; these soils extended through 83% of the study area. The soil from profile 3 was classified as Entisol, which presented a slightly hard consistency in the first three layers, with a clay content <9%; it was a young soil that covered 12% of the area. Other characteristics of this soil were: pH>7.0, organic matter <2.0%, bulk density $1.4 g\cdot cm^{-3}$ and clay >30%. Laird *et al*. (1985) and Oleschko *et al*. (1985) reported similar results to those found in this area. Regarding this study area, 83% was classified as Chromic Haplusterts and Typic Haplusterts, 12% as Mollic Ustifluvents, while the remaining area was urban zone (Figure 2).

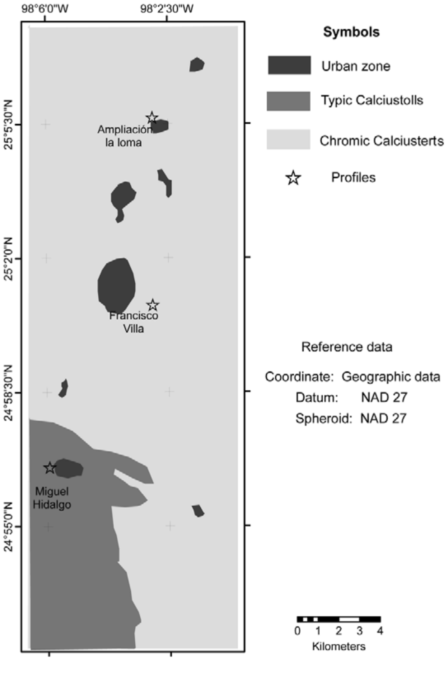

Figure 3. Soils present in Northeastern Mexico and classified by the Soil Taxonomy system.

Physical and chemical properties and classification of soils of sedimentary-origin

Profiles 1 and 2. In general terms, clay and organic carbon had an irregular behavior according to depth; also, the soils evidenced an accumulation of calcium carbonate (Table II), which showed their sedimentary characteristics. The profiles presented Ochric epipedon and Calcic subsurface horizons. The soils were classified as Chromic Calciusterts.

Profile 3. Clay contents exhibited an irregular behavior over depth. Organic carbon diminished, while calcium carbonate increased with depth (Table II). The organic matter originated *in situ* due to prairies and agricultural activities. On the other hand, carbonates increased with depth. This profile presented Mollic epipedon and Calcic subsurface horizons. The soil was classified as Typic Calciustolls.

The results indicated that Chromic Calciusterts cover 79% of this study area and 17% is Typic Calciustolls. The remaining area was urban zone (Figure 3). In Mexico, Vertisols from neutral to alkaline pH are of a calcareous origin and are present in the coastal plains of the Gulf of Mexico (States of Tamaulipas, Veracruz, and Tabasco; Covarrubias, 1985; Palma and Cisneros, 1996). The characteristics of these soils coincide with those of Northeast Mexico and Celaya, which have an alkaline pH. Driese *et al*. (2000) and Nordt *et al*. (2004) reported Vertisols in Texas that presented firm consistency, dark colors on the surface and light colors subsurface, as well as carbonate contents >5%. In addition, Driese *et al*. (2003) concluded that those soils derived from calcite and showed an accumulation of calcium carbonate in their profile, which

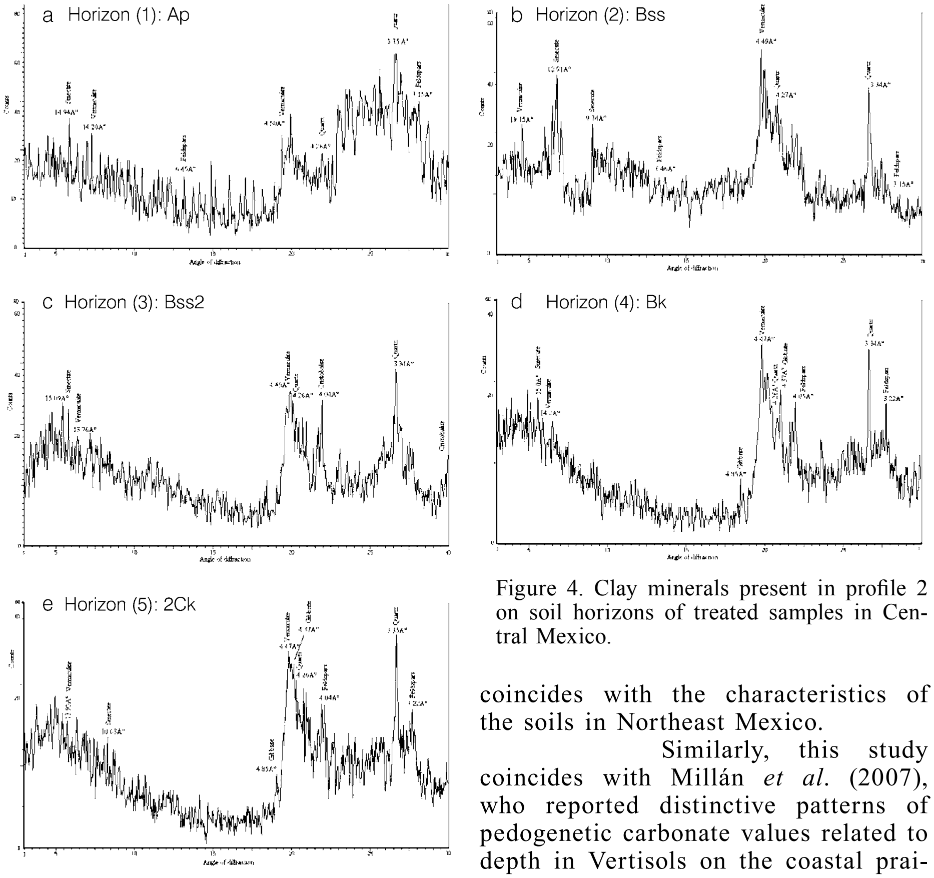

Figure 4. Clay minerals present in profile 2 on soil horizons of treated samples in Central Mexico.

coincides with the characteristics of the soils in Northeast Mexico.

Similarly, this study coincides with Millán *et al.* (2007), who reported distinctive patterns of pedogenetic carbonate values related to depth in Vertisols on the coastal prairies of Texas and established that climate is a determining factor for Vertisol formation in the Texas Gulf Coast, evidence that is in keeping with the features of the Vertisols of the present study. For Mollisol formation in the study area, prairie vegetation is responsible for organic matter accumulation; which favors the development of texture in these soils (Soil Survey Staff, 2010).

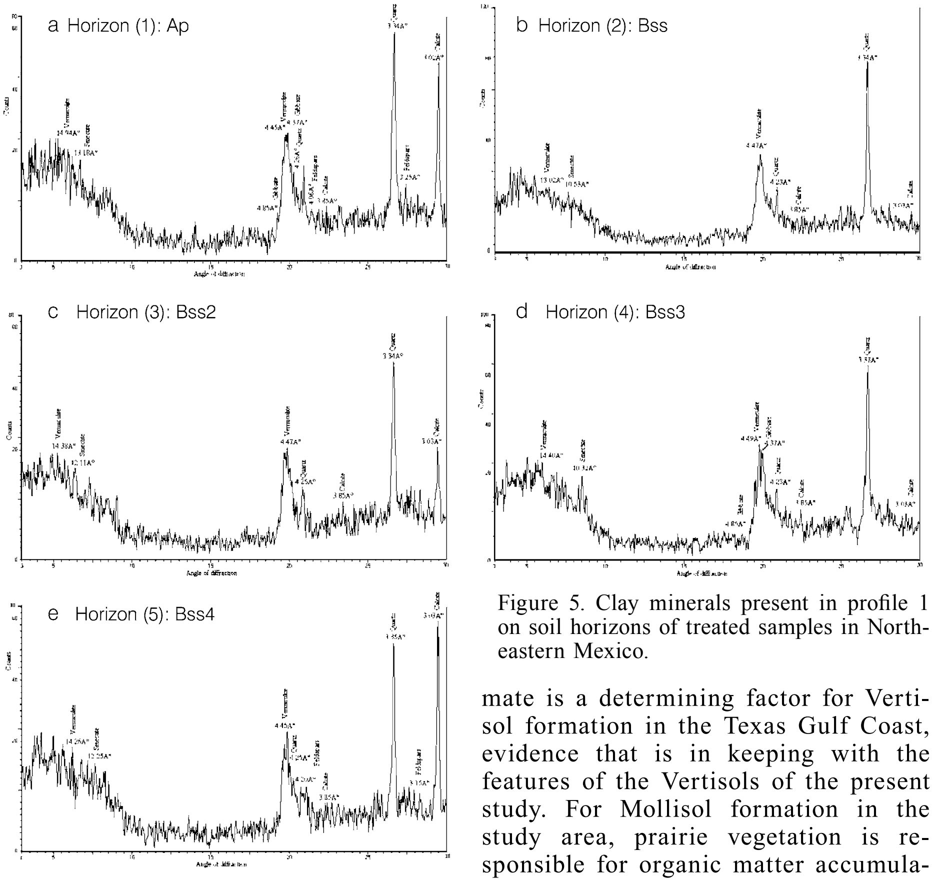

Figure 5. Clay minerals present in profile 1 on soil horizons of treated samples in Northeastern Mexico.

Regarding the classification of these soils, several factors have to be considered. Brady and Weil (1999) stated that geological processes bring several parent materials to the surface, from which the soils are formed. Besides, the nature of the parent material has a significant influence on soil characteristics. For example, texture controls water percolation through the soil profile and affects the translocation of fine particles. Lastly, Coulombe *et al.* (2000) and Stiles *et al.* (2003) concluded that Vertisols start developing when the geomorphic surface and minerals are exposed to climate; also, Vertisols are typically present in low areas and foothills; these coincide with the Vertisols presently studied, which were found on slopes <1%.

Mineralogy of soils of igneous-origin

Profile 1. The mineralogical composition of the sand fraction of soil was volcanic glass (47%), quartz (40%) and feldspar (orthoclase; 13%). Regarding the secondary minerals found in the diffractograms, a wide and diffuse band (general treatment) were of amorphous material such as smectite, vermiculite, cristobalite, quartz, feldspar and goethite (Figure 4).

Profile 2. The mineralogical composition of the sand fraction was volcanic glass (47%), quartz (31%) and feldspar (22%). Regarding the clay fraction, it was composed of smectite, mica, kaolinite, quartz, feldspar and goethite (Figure 4).

Profile 3. The mineralogical composition of its sand fraction was quartz (47%), volcanic glass (39%) and feldspar (14%). The clay fraction was composed of smectite, quartz, and feldspar (Figure 4).

Because of the minerals present in the soils of this area, it can be concluded that the parent material is rhyolite, but there are no reports of Vertisols derived from rhyolites. Rhyolites are composed of volcanic glass, quartz crystals, orthoclases, biotites and hornbledes as accessories (Bullock *et al.*, 1985; INEGI, 1988b). This coincides with the report by Gutiérrez *et al.* (2007), who stated that the weathering of volcanic glass generates smectites and amorphous siliceous mineral silicates, and with that of Segura *et al.* (2000),

TABLE I

PHYSICAL AND CHEMICAL SOIL PROPERTIES OF THREE PROFILES FOR CLASSIFYING IN CENTRAL MEXICO

Horizon and profile	Depth (cm)	Geographic location	Color		WRD %	BD g·cm^{-1}	pH	EC dS.M^{-1}	OM	OC	$CaCO_3$	Sand	Silt	Clay	Textural class name
			dry	moist						%			%		
Ap	0-20	20°33’46” N	10YR6/1	10YR4/1	6.09	1.55	8.2	0.67	1.28	0.74	0.28	19.49	16.98	63.53	clay
Bss	20-41	101°06’13” W	10YR5/1	10YR4/1	18.34	1.66	8.9	0.56	0.54	0.31	0.83	14.77	23.77	61.45	clay
Bss2	41-70		10YR5/1	10YR2/2	25.52	1.62	9.2	2.31	0.40	0.23	0.90	17.25	28.02	54.74	clay
Bk	70-82		10YR6/1	10YR5/2	19.19	1.51	9.4	2.06	0.27	0.16	1.66	29.35	21.57	49.08	clay
2Ck	82-107		10YR7/1	10YR5/3	12.09	1.52	9.3	2.42	2.15	1.25	0.90	43.68	23.05	33.27	clay loam
Ap	0-15	20°32’47” N	10YR4/1	10YR2/1	17.24	1.79	7.1	0.69	1.34	0.78	0.194	20.21	14.16	65.63	clay
Bss	15-49	100°58’43” W	10YR5/1	10YR3/1	36.98	1.88	7.5	0.38	0.87	0.51	0.215	16.48	20.08	63.44	clay
Bss2	49-69		10YR5/1	10YR4/1	23.54	1.69	8.0	0.48	0.40	0.23	0.201	17.50	18.95	63.55	clay
Bw	69-84		10YR6/1	10YR5/2	23.37	1.66	7.7	0.53	0.47	0.27	0.298	15.42	21.08	63.50	clay
Bw2	84-105		10YR5/1	10YR5/2	23.3	1.69	7.5	0.47	0.40	0.23	0.547	18.41	23.62	57.97	clay
Ap	0-15	20°34’41” N	10YR3/2	10YR3/2	12.77	1.46	7.1	0.55	1.75	1.01	0.23	52.90	37.74	9.36	sandy loam
C	15-36	100°49’19” W	10YR5/2	10YR3/2	10.07	1.45	7.3	0.36	1.55	0.90	0.36	53.58	38.21	8.21	sandy loam
C2	36-53		10YR4/2	10YR2/2	10.68	1.54	7.8	0.26	0.74	0.43	0.32	55.16	36.59	8.25	sandy loam
Ck	53-80		10YR5/2	10YR5/3	13.03	1.34	8.0	0.33	0.54	0.31	0.77	49.93	46.06	4.01	sandy loam
2C	80-107		10YR5/3	10YR4/3	5.67	1.35	7.7	0.17	0.54	0.31	0.26	88.03	8.39	3.58	sand
3C	107-142		10YR5/2	10YR5/2	17.12	1.28	8.0	0.32	0.54	0.31	0.39	42.07	44.84	13.09	loam
3C2	142-X		10YR6/1	10YR5/2	27.23	1.26	8.1	0.33	0.87	0.51	0.53	11.35	57.66	30.99	silty clay loam

Continuation…

Horizon and profile	Structure	Soil consistency	Bases extracted (cmol$_c$. kg^{-1})				P_2O_5 ppm	Bases extracted* (mmol. L^{-1})				CEC cmol$_c$·kg^{-1}	BS %	n value
			Ca	Mg	Na	K		Na	K	Mg	Ca			
Ap	subangular blocks	hard	14.22	1.86	8.12	9.81	16.96	14.08	0.03	0.00	0.37	89.15	38.15	0.04
Bss	subangular blocks	hard	9.83	1.72	6.76	23.43	7.81	12.24	0.02	0.11	0.31	74.15	56.28	0.22
Bss2	subangular blocks	hard	9.29	2.16	10.84	18.55	7.24	39.63	0.02	0.00	0.25	61.71	66.19	0.36
Bk	subangular blocks	hard	6.31	1.78	17.18	16.36	10.10	58.83	0.02	0.00	0.21	57.43	72.50	0.30
2Ck	massive	hard	6.56	1.74	7.01	15.02	10.10	39.63	0.02	0.00	0.15	71.50	42.40	0.19
Ap	subangular blocks	very hard	10.95	3.83	5.38	33.00	26.11	0.97	0.10	0.11	0.45	54.26	97.95	0.21
Bss	subangular blocks	hard	13.54	6.11	6.74	31.90	15.82	0.58	0.03	0.05	0.20	61.81	94.29	0.50
Bss2	subangular blocks	hard	13.78	3.75	10.14	26.78	7.81	0.77	0.06	0.00	0.30	42.84	98.02	0.30
Bw	massive	hard	12.84	5.92	10.14	26.05	12.96	0.78	0.04	0.04	0.32	46.72	98.65	0.30
Bw2	massive	hard	13.63	6.08	6.08	29.71	19.25	0.68	0.06	0.03	0.28	44.98	99.13	0.31
Ap	granular	slightly hard	11.83	3.17	0.47	0.97	27.83	0.45	0.41	0.38	1.07	39.88	49.38	0.36
C	subangular blocks	slightly hard	12.05	3.34	1.25	0.77	28.97	0.40	0.28	0.22	0.71	72.11	26.67	0.19
C2	subangular blocks	slightly hard	12.19	2.80	1.30	0.74	19.25	0.37	0.22	0.15	tr	17.14	97.75	0.32
Ck	crumb	friable	12.58	2.70	1.75	0.56	8.39	0.49	0.20	0.15	tr	23.26	82.23	0.68
2C	crumb	friable	6.37	1.86	0.15	2.82	12.39	0.35	0.10	0.09	tr	39.27	61.34	0.77
3C	crumb	friable	13.86	4.19	3.08	0.46	8.96	0.51	0.13	0.26	tr	73.13	31.19	0.55
3C2	subangular blocks	slightly hard	14.22	4.56	4.23	0.51	8.39	0.47	0.13	0.22	0.41	42.64	55.57	0.47

WRD: water retention difference, BD: bulk density, EC: electrical conductivity, OM: organic matter, OC: organic carbon.
* Form saturated paste, CEC: cation exchange capacity, BS: base saturation.

who noted the presence of amorphous materials derived from acidic tuffs of andesite in Vertisols of the former Texcoco Lake, east of Mexico City. Also, Porta *et al.* (2003) claimed that rhyolites produce clay soils; if there is a well-defined dry season, smectite clays are produced.

The latter disagrees with reports by Coulombe *et al.* (1996; 2000) and Dixon and Schulze (2002), who mentioned that Vertisols of igneous origin can be derived from basalt, augite, dolerite, ash, tuff and andesite in different regions around the world. Hence, the findings of our study are relevant since this is the first time that a different origin of Vertisols is reported. Brimhal *et al.* (1991) and Ashley and Driese (2000) had stated that soil systems are generally dynamic and open to influxes of new materials due to geological processes such as the introduction of volcanic and volcaniclastic inputs. In terms of mineralogical composition, the studied Vertisols were derived from the same kind of sediment of crystalline deposits, considering their volcanic glass content.

Regarding secondary minerals, they are dominated by smectite, illite, cristobalite and goethite, which are expandable minerals; in addition, these soils present prominent sliding surfaces on the faces of the prisms or surrounding the rocks. Another explanation for this behavior of expandable minerals can be found in the work of Tessier (1984), who indicated that when a microstructure is composed mainly of quartz crystals, Ca^{2+} in the exchange sites, then an alkaline electrolyte concentration leads the shrink-swell potential, characteristic that occurs in the studied soils.

Rasmussen *et al.* (2010) established that parent material influences temperature and moisture regimes, which benefit from the formation of smectite in the soil. This coincides with what was found in our study area, where the soil moisture regime is udic and the soil temperature regime is thermic, which favor the formation of smectite and, consequently, Vertisols. Lastly, a comparison between the mineralogical composition of

TABLE II
PHYSICAL AND CHEMICAL SOIL PROPERTIES OF THREE PROFILES FOR CLASSIFYING IN NORTHEASTERN MEXICO

Horizon and profile	Depth (cm)	Geographic location	Color		WRD %	BD g·cm^{-1}	pH	CE dS·m^{-1}	OM	OC	$CaCO_3$	Sand	Silt	Clay	Textural class name
			dry	moist						%			%		
Ap	0-11	25°05'40" N	10YR5/2	10YR5/2	9.7	1.60	8.1	0.61	1.75	1.01	20.0	15.59	21.78	62.63	clay
Bss	11-45	98°02'57" W	10YR5/1	10YR3/2	11.5	1.80	7.9	0.47	2.29	1.33	23.4	15.37	22.40	62.23	clay
Bss2	45-77		10YR6/1	10YR5/2	11.8	1.78	8.4	0.37	2.15	1.25	24.7	13.95	22.13	63.92	clay
Bss3	77-103		10YR7/1	10YR6/2	14.0	1.98	8.5	0.44	1.75	1.01	24.0	11.56	20.21	68.22	clay
Bss4	103-133		10YR7/1	10YR6/2	14.0	1.97	8.6	0.92	1.95	1.13	24.8	10.22	19.95	69.83	clay
2Ck	133-X		10YR8/2	10YR7/3	10.1	1.80	7.9	4.11	1.75	1.01	14.8	16.14	76.24	7.62	silt loam
Ap	0-20	25°00'48" N	10YR5/1	10YR5/1	3.3	1.59	8.0	0.73	2.15	1.25	15.1	10.60	29.11	60.29	clay
Bss	20-50	98°02'58" W	10YR6/1	10YR5/2	11.0	1.86	8.4	0.49	2.22	1.29	15.8	13.85	16.30	69.85	clay
Bss2	50-72		10YR6/1	10YR5/1	13.1	1.98	8.7	0.64	1.88	1.09	15.5	13.31	16.86	69.84	clay
Bk	72-90		10YR5/1	10YR5/1	14.3	1.99	8.4	2.26	1.75	1.01	14.2	12.43	16.57	71.01	clay
2Ck	90-118		10YR5/2	10YR7/1	12.7	1.73	8.0	3.68	1.82	1.05	15.1	16.08	79.25	4.66	silt loam
2Ck2	118-X		10YR7/2	10YR8/3	12.3	1.72	8.0	5.00	2.02	1.17	19.0	16.03	79.30	4.66	silt loam
Ap	0-14	24°56'33" N	10YR5/3	10YR2/1	8.7	0.00	8.2	0.56	3.03	1.76	25.3	46.39	24.87	28.74	loam
Bk	14-46	98°05'57" W	10YR6/2	10YR2/1	4.1	1.48	8.2	0.36	2.76	1.60	25.3	36.14	25.54	38.31	clay loam
Bk2	46-79		10YR5/2	10YR4/1	2.7	1.17	7.8	0.49	2.76	1.60	30.5	34.59	31.50	33.92	clay loam
Bk3	79-101		10YR6/2	10YR5/1	6.8	0.00	8.0	0.38	2.42	1.40	30.5	30.08	33.76	36.17	clay loam
Ck	101-135		10YR8/2	10YR5/3	8.8	0.00	8.0	0.65	2.08	1.21	34.9	39.71	34.08	26.21	loam
Ck2	135-X		10YR7/2	10YR6/4	4.1	0.00	7.7	7.57	2.0171	1.17	35.9	36.16	34.38	29.47	clay loam

Continuation...

Horizon and profile	Structure	Soil consistency	Extracted bases (cmol$_c$. kg^{-1})				P_2O_5 ppm	Extractable bases* (mmol·l^{-1})				CEC cmol$_c$. kg^{-1}	BS %	n value
			Ca	Mg	Na	K		Na	K	Mg	Ca			
Ap	crumb	hard	34.55	3.51	1.54	3.20	8.5	2.41	0.44	0.45	1.54	9.38	99.87	0.03
Bss	subangular blocks	hard	33.29	3.74	1.70	2.12	9.7	2.08	0.21	0.46	1.02	31.72	98.52	0.06
Bss2	subangular blocks	hard	25.67	4.27	3.24	1.19	6.2	2.74	0.12	0.00	1.76	26.11	99.12	0.07
Bss3	subangular blocks	hard	16.38	3.86	4.33	1.00	7.4	3.62	0.10	0.00	2.87	32.33	79.08	0.10
Bss4	subangular blocks	hard	18.67	4.82	9.04	1.38	7.4	7.03	0.18	0.67	0.59	27.44	98.94	0.11
2Ck	crumb	hard	35.66	4.73	12.90	1.59	4.5	19.99	0.23	6.71	5.43	26.93	99.45	0.00
Ap	crumb	slightly hard	31.35	3.08	3.28	1.32	3.9	3.51	0.18	0.00	1.30	25.30	98.78	0.00
Bss	subangular blocks	firm	24.87	4.31	7.23	1.16	6.2	3.73	0.09	0.33	1.83	35.70	99.95	0.06
Bss2	subangular blocks	hard	17.73	3.72	10.46	1.20	5.7	4.83	0.14	0.60	0.47	34.07	97.17	0.09
Bk	crumb	very hard	17.97	3.65	17.11	1.32	6.8	14.72	0.17	1.43	3.17	15.30	99.53	0.11
2Ck	crumb	hard	30.58	4.72	19.39	1.59	5.1	20.21	0.39	3.67	8.76	30.60	99.86	0.00
2Ck2	crumb	hard	43.87	5.75	25.40	2.03	6.2	0.48	0.22	7.74	9.03	15.61	97.98	0.00
Ap	subangular blocks	friable	17.61	1.66	0.86	4.66	13.7	0.41	2.05	0.34	1.08	15.10	99.65	0.00
Bk	subangular blocks	friable	21.23	1.30	0.82	2.33	25.2	0.61	0.77	0.28	0.93	13.46	99.76	0.00
Bk2	subangular blocks	friable	22.70	1.12	0.92	0.81	34.3	0.83	0.10	0.29	1.81	16.42	98.32	0.00
Bk3	subangular blocks	friable	20.26	1.00	1.01	0.64	37.2	0.86	0.08	0.35	1.99	16.12	97.98	0.00
Ck	granular	friable	16.04	1.08	1.15	0.52	34.3	1.97	0.05	0.55	2.92	13.26	97.65	0.00
Ck2	granular	loose	15.27	2.17	2.44	0.83	33.2	12.74	0.52	10.44	7.16	16.52	97.43	0.00

WRD: water retention difference, BD: bulk density, EC: electrical conductivity, OM: organic matter, OC: organic carbon.
* Form saturated paste, CEC: cation exchange capacity, BS: base saturation.

parent material and of a horizon formed by weathering reveals that their differences are due to a loss of solubility and the occurrence of new minerals as smectite and illite (Porta *et al.*, 2003).

Mineralogy of soils of sedimentary origin

Profile 1. The mineralogical composition of the sand fraction was calcite (64%), quartz (34%) and feldspar (2%), while the clay fraction was composed of smectite, quartz, calcite and feldspar (Figure 5).

Profile 2. The mineralogical composition of the sand fraction was calcite (56%), quartz (40%) and feldspar (4%); the clay fraction was composed of smectite, vermiculite, quartz, feldspar, dolomite and calcite (Figure 5).

Profile 3. The mineralogical composition of the sand fraction was calcite (88%), quartz (10%) and feldspar (2%); the clay fraction consisted of smectite, vermiculite, quartz, feldspar and dolomite (Figure 5).

The origin of the Vertisols in the Northeast Mexico site is limestone, which is formed of sediment with a high calcium carbonate content. This coincides with a study by Coulombe *et al.* (1996), who reported for the coastal zone of Texas that Vertisols originated from this material. Doner and Lynn (1989) stated that the sediment was formed from sedimentary rocks related to the presence of dolomite, a product of physical weathering, and that carbonates are common minerals in neutral and alkaline Vertisols. Driese *et al.* (2003) also concluded that Vertisols from Texas contain carbonate and dolomite. Mermut and Dasog (1986) pointed out that the presence of calcite ($CaCO_3$), Ca-Mg carbonates (calcite and dolomite) and Na carbonates, undifferentiated and polymorphic forms of a calcite called dragonite, is common in soils of calcareous origin, which coincides with the minerals found in the soils of the study area. The results coincide with Kalbande *et al.* (1992) and Coulombe *et al.* (2000), who found the presence of smectite, vermiculite and dolomite in Vertisols in India and the USA.

Dixon and Schulze (2002) and Porta *et al.* (2003) stated that the calcite in a wet moisture regime produces soils rich in clay, whereas in a dry regime it produces smectite clay. He *et al.* (2008) concluded that in relatively young soils, illites are the first to be formed, followed by smectites and vermiculite. In our study area, the soil temperature regime is hyperthermic and the soil moisture regime is ustic, which favor formation of smectite in these soils. Also, high temperatures and prolonged dry seasons favor the formation of Vertisols. Lastly, the dominant Vertisols in this area are a product of the weathering of limestone and residual materials like clays and oxides. This process generates soils abundant in clay (>30%) that are of a light color, or reddish when Fe oxides are dominant. Vertisols are dominant in the study area and are present in the lowest parts, in flood and deposit areas.

Finally, the parent material that originated these soils are rhyolites for the central part and limestone for the northeastern part: The resulting Vertisols in both areas are soils rich in clay, organic matter, Ca, Mg and K; they also present high cation exchange capacity and base saturation (Tables I and II), which gives them high fertility. Coulombe *et al.* (1996) reported that Vertisols around the world are originated from basalt, granite, andesite, biotte, augite, olivine, limestone and dolomite; parent material that gives high fertility to those soils originated from them, and therefore crops are good.

Conclusions

The dominant mineralogy of Vertisols of igneous origin in the sand fraction was comprised of volcanic glass (47%), quartz (31%) and feldspars (22%). The clay fraction was made up of smectite, amorphous material, cristobalite and goethite, which contribute to the intense shrink-swell processes of these soils. These were classified as Chromic Haplusterts and Typic Haplusterts. The parent material that formed the Vertisols of Central Mexico was rhyolites, which are acid igneous rocks.

Vertisols of sedimentary origin were composed of calcite (64%), quartz (34%) and feldspars (2%) in the sand fraction, while the clay fraction was dominated by smectites, vermiculites, quartzes, calcites and feldspars. The soils were classified as Chromic Calciusterts and Typic Calciustolls. These soils were formed of limestone and alluvial deposits of sedimentary rocks.

Thus, it can be concluded that in this study rhyolites were identified as the type of rock from which Vertisols are derived in the central zone of Mexico when their minerals weather. We consider this to be relevant due to the fact that there are no prior studies reporting Vertisols as having originated from rhyolites.

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CARACTERIZACIÓN FÍSICA, QUÍMICA Y MINERALÓGICA DE VERTISOLES PARA DETERMINAR SU MATERIAL PARENTAL

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RESUMEN

La respuesta de los suelos a los procesos de intemperismo depende del material parental que los origina. La identificación de los minerales primarios y secundarios en Vertisoles permite conocer el material parental que da origen a estos suelos. Por ello, los objetivos de este estudio fueron: 1) determinar las propiedades físicas y químicas en Vertisoles para su caracterización y clasificación; 2) identificar los minerales primarios y secundarios para determinar el tipo de material que da origen a estos suelos; y 3) determinar el tipo de roca que origina los Vertisoles de las zonas de estudio. Dos tipos de Vertisoles fueron estudiados: uno de origen ígneo y color obscuro, y el otro de origen sedimentario y color claro. Los suelos de origen ígneo fueron clasificados como: Chromic Haplusterts, Typic Haplusterts, y Mollic Ustifluvents. Los de origen sedimentario fueron clasificados como Chromic Calciusterts y Typic Calciustolls. La mineralogía dominante en los suelos de origen ígneo en la fracción arenosa está compuesta por vidrio volcánico (47%), cuarzo (31%) y feldespato (22%). La fracción arcillosa está compuesta por materiales amorfos, esmectitas, vermiculitas, ilitas y cristobalitas. En contraste, en los suelos de origen sedimentario la fracción arenosa está compuesta por calcita (64%), cuarzo (34%) y feldespato (2%). Esmectitas, vermiculitas, cuarzo y feldespato componen la fracción arcillosa. El material parental que originó los Vertisoles de origen ígneo fue la riolita, mientras los de origen sedimentario se originaron de caliza y de sedimentos con altos contenidos de carbonato de calcio.

CARACTERIZAÇÃO FÍSICA, QUÍMICA E MINERALÓGICA DE VERTISOIS PARA DETERMINAR SEU MATERIAL PARENTAL

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RESUMO

A resposta dos solos aos processos de intemperismo depende do material parental que os origina. A identificação dos minerais primários e secundários em Vertisois permite conhecer o material parental que da origem a estes solos. Por isto, os objetivos deste estudo foram: 1) determinar as propriedades físicas e químicas em Vertisois para sua caracterização e classificação; 2) identificar os minerais primários e secundários para determinar o tipo de material que da origem a estes solos; e 3) determinar o tipo de rocha que origina os Vertisois das zonas de estudo. Dois tipos de Vertisois foram estudados: um de origem ígneo e cor escura, e o outro de origenm sedimentário e cor clara. Os solos de origem ígnea foram classificados como: Chromic Haplusterts, Typic Haplusterts, e Mollic Ustifluvents. Os de origem sedimentário foram classificados como Chromic Calciusterts e Typic Calciustolls. A mineralogia dominante nos solos de origem ígnea na fração arenosa está composta por vidro vulcânico (47%), quartzo (31%) e feldespato (22%). A fração argilosa está composta por materiais amorfos, esmectitas, vermiculitas, ilitas y cristobalitas. Em contraste, nos solos de origem sedimentário a fração arenosa está composta por calcita (64%), quartzo (34%) e feldespato (2%). Esmectitas, vermiculitas, quartzo e feldespato compõe a fração argilosa. O material parental que originou os Vertisois de origem ígnea foi a riolita, enquanto que os de origem sedimentário se originaram de caliza e de sedimentos com altos conteúdos de carbonato de cálcio.