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GEOLOGY OF XITLE VOLCANO IN SOUTHERN MEXICO CITY—A 2000-YEAR-OLD MONOGENETIC VOLCANO IN AN URBAN AREA

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ABSTRACT

Stratigraphic and geological knowledge of the Basin of Mexico is insufficient for the largest city of the world. This work is a contribution toward the geological framework of the region through detailed mapping of Xitle volcano products and study of the stratigraphy of both explosive and effusive materials. Xitle Formation is defined comprising nine members: one for the explosive products, one for the Xicontle volcano lavas, and seven for the different lava-flow units. Xitle volcano produced 0.12 km^3 of tephra (dense rock) and 0.96 km^3 of lavas for a total of 1.08 km^3 of extruded magma. These magmas yielded a high effusion rate according to the low aspect ratios (10-3-10-4) which also suggests a very low viscosity. The age of the Xitle eruption was determined using geologically well constrained radiometric dates at ~2,000 yr. A statistical analysis of the best available radiometric dates support this age. Xitle volcano lavas are calc-alkaline basalts and basaltic andesites. Each lava flow corresponded to a different batch of magma (7 in total) as indicated by petrographic and chemical analyses of lavas being crystal fractionation the main process affecting Xitle magmas. Eruptive activity of Xitle volcano comprised explosive and effusive phases such as those recognized at other monogenetic volcanoes. However, the explosive events of Xitle volcano produced pyroclastic flows. Ash-flow deposits are important for characterization of eruption explosivity but also for volcanic hazard evaluation at the Basin of Mexico.

Key words: Volcanism, Holocene, Xitle volcano, Mexico City.

RESUMEN

Los conocimientos estratigráficos y geológicos de la Cuenca de México son escasos para la ciudad más grande del mundo. Este trabajo contribuye al entendimiento de la geología de la región a través de cartografía y estratigrafía de los productos eruptivos del volcán Xitle. La Formación Xitle comprende nueve miembros: los productos explosivos, los productos del volcán adventicio Xicontle y siete unidades de flujo de lava. El volcán Xitle produjo 0.12 km^3 de tefras (roca densa), y 0.96 km^3 de lavas para un total de 1.08 km^3 de magma extruído. Estos magmas se caracterizaron por una alta tasa de efusión de acuerdo con las bajas relaciones de aspecto (10-3-10-4), que a su vez sugieren una baja viscosidad del magma. La edad del Xitle se determinó mediante edades radiométricas geológicamente controladas resultando en ~2,000 años AP. Un análisis estadístico de las fechas radiométricas disponibles en la literatura apoyan esta edad. Las lavas producidas por el volcán Xitle son basaltos y andesitas basálticas de afinidad calcialcalina. Cada flujo de lava correspondió a un volumen de magma diferente (siete en total), tal como lo indican los análisis petrográficos y químicos llevados a cabo en las lavas, siendo la cristalización fraccionada el único proceso que afectó a estos magmas. La actividad eruptiva del volcán Xitle comprendió fases explosivas y efusivas similares a las reconocidas en otros volcanes monogenéticos; sin embargo, en el caso del Xitle, los eventos explosivos produjeron flujos piroclásticos. Los depósitos de flujo de cenizas son un aspecto importante no sólo para la caracterización de aspectos vulcanológicos, sino además, para la evaluación de peligros volcánicos en la cuenca de México.

Palabras clave: Vulcanismo, Holoceno, volcán Xitle, ciudad de México.

INTRODUCTION

Xitle Volcano (navel in Náhuatl language) is located in southern Mexico City (Figure 1) in the central part of the Trans-Mexican Volcanic Belt. For a long time, Xitle has been thought to be the youngest volcano of the Chichinautzin volcanic field (CVF), a field of monogenetic volcanoes that formed in the last 0.78 Ma (Herrero-B. and Pal, 1978). The CVF includes shield volcanoes, cinder cones, and lava flows and cones (Martin del Pozzo, 1980, 1982; Lugo-Hubp, 1984).

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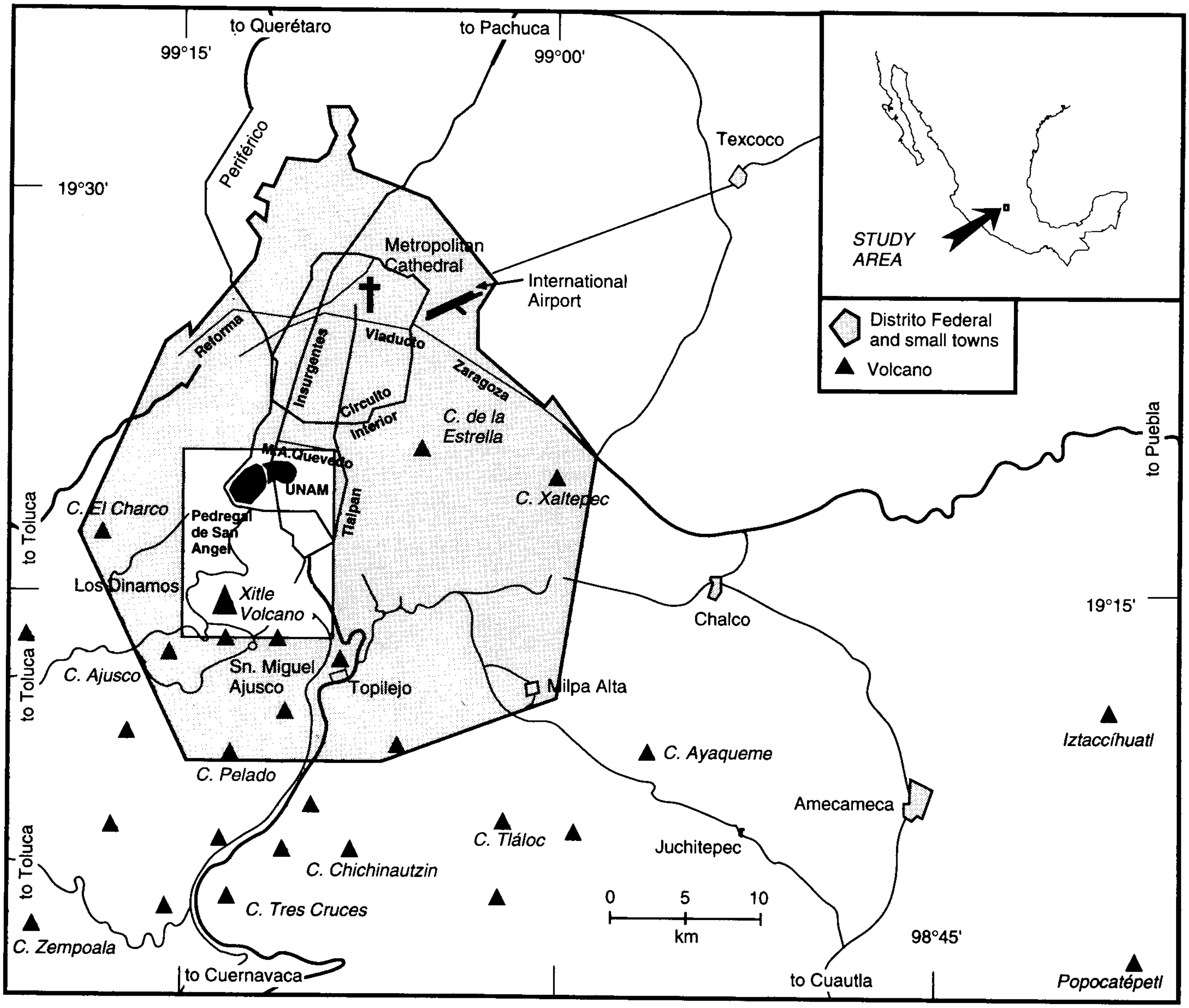

Figure 1. Location of the study area. Mexico City includes an urban part whose boundaries are difficult to define because it currently also includes parts of the State of Mexico. Thus, for better reference we show the boundaries of Distrito Federal (shaded). The inset rectangle represents the studied area.

Xitle volcano is a cinder cone whose associated lavas extend principally to the north of the cone, into the Basin of Mexico.

Mexico City is a densely populated area (nearly 20 million inhabitants), whose southern portion has been built atop the volcanic products of Xitle volcano. Even though the volcanic products are very young and fresh, neither a detailed map of the Xitle volcano deposits, nor a formal stratigraphy have been published, in spite of being one of the latest volcanic events recognized in the most populated city of the world. This volcano, although mostly ignored by geologists, is of great importance for archaeologists (Córdova *et al.,* 1994) because the lavas of Xitle volcano surrounded and buried the pyramids of the Cuicuilco Culture (Schalvezon, 1993), one of the first cultural expressions of the entire country. The eruption of Xitle volcano had a strong impact on the people of the area. In fact, discussion still remains regarding the age of the eruption of Xitle and the time of abandonment of Cuicuilco. The mapping and study of these volcanic products are of the utmost importance for understanding the volcanic evolution, archaeology, and hazard evaluation in the region and for future urban planning.

The main purpose of this study is to report the stratigraphy and geological mapping of Xitle volcano and its products as well as to briefly discuss the timing, origin, and evolution of the eruption, based on new radiometric and geochemical data.

GEOLOGICAL SETTING

Volcanism in the Basin of Mexico

Several authors have studied the geology of the Basin of Mexico and, particularly, Sierra Chichinautzin. The following is an account of the most important work already done.

Fries (1960) described rocks and volcanoes in southern Mexico City and defined the Chichinautzin Group as lava flows, breccias and tuff beds of andesitic-basaltic composition interstratified with clastic material. A regional geological map is included for Morelos, Mexico and Guerrero states.

Mooser (1957, 1963, and 1975) and Mooser *et al.* (1974) described the formation of the Basin of Mexico in terms of seven phases of volcanism. The last two phases represented by the Guadalupe Group and the Chichinautzin Group lasted for a short period (less than 1 Ma), and were dominated by andesitic activity (Gunn and Mooser, 1971). The last volcanic phase produced the closure of the southern outlet of the Basin of Mexico according to Mooser (1975).

Negendank (1972, 1973a, 1973b) and Richter and Negendank (1976) performed geochemical and petrological studies of the rocks of the Basin of Mexico and proposed that this basin was built during three periods of volcanism ranging from the Oligocene to the Present showing a dacitic to andesitic trend. They proposed a lower crust partial melting origin for the magmas.

Martin del Pozzo (1980) recognized three volcanic features (lava flows, scoria cones, and lava cones) as products of strombolian- and surtseyan-type explosive volcanism with hawaiian-type lava activity. Furthermore, Martin del Pozzo (1980) suggested different magmatic differentiation lines, locating the magma source between the crust and the mantle with at least three different types of contaminating materials.

Verma (1981, 1995) and Verma and Armienta (1985) based on geochemical data, concluded that rocks of the Sierra Chichinautzin belong to the calc-alkaline series, but have strong similarities to Oceanic Island-type volcanic rocks. These authors related the origin of this volcanism to an Oceanic Island Basalt-type source (OIB) with the continental lithosphere subjected to a regional tensile stress regime. They did not associate the origin of these rocks with subduction of the Cocos Plate, in contrast with most authors.

Delgado and Martin del Pozzo (1993) considered that between the late Pliocene and Holocene three different eruptive periods occurred in the southern part of the Basin of Mexico: Las Cruces (late Pliocene to early Pleistocene) characterized by polygenetic volcanic activity producing large stratovolcanoes; Ajusco (middle Pleistocene) characterized by polygenetic volcanic activity producing a relatively small composite volcano, and Chichinautzin (late Pleistocene to Holocene) characterized by monogenetic volcanism predominantly of strombolian type.

Herrero-B. and Pal (1978) established a maximum age for the Sierra Chichinautzin of 0.69 Ma (now corrected to 0.78 Ma) applying paleomagnetic techniques. Scandone (1979) evaluated the volcanic risk in southern Mexico City by estimating the eruption probability as 10-3 eruptions per year via stochastic methods in which the eruption probability depends on the historical eruption record of the zone and the repose time of a volcano.

According to the existing studies regarding the geology of the Basin of Mexico and the Sierra Chichinautzin, five main problems are noted: (a) a lack of detailed geological mapping depicting every stratigraphic unit (not lithological), in spite of the existence of several "reconnaissance"-level geological maps; (b) almost complete ignorance of the stratigraphy of the Basin of Mexico (characterized currently by a proliferation of informal or lithological names), and the processes that gave birth to those stratigraphic units; (c) the lack of a well-defined formal stratigraphy results in a confused chronology of the different events (volcanic and tectonic), and thus, a poor understanding of the geological evolution of the basin; (d) lack of understanding of the structural framework of the basin, timing, and current activity and stress field regime; and (e) poor knowledge of the volcanological features of the region in terms of processes and events; most geochemical work is based on reconnaissance-level studies, and no detailed mapping has been done in order to elucidate the evolution of every single volcano of the active Chichinautzin volcanic field or the Las Cruces volcanic system, etc.

Detailed mapping and stratigraphic work is necessary to better understand the geology of the basin. The purpose of this paper is to report detailed mapping of Xitle volcano and contribute to the stratigraphic knowledge of Chichinautzin Group (through elucidation of Xitle stratigraphy) and hence to the understanding of the Basin of Mexico.

PREVIOUS STUDIES OF XITLE VOLCANO

The studies associated with Xitle volcano started with Felix and Lenk (1890) who reported the chemical analysis of a rock from Pedregal de San Ángel that was classified as a "free hypersthene basalt". Ordóñez (1895) determined the areal extent of Xitle lavas as more than 60 km^2 and briefly described the cone and lavas. Waitz and Wittich (1911) and Wittich (1919) described the lavas of Pedregal de San Ángel and studied minor-scale aspects such as vesicles, explosion pipes, hornitos, and caves. Schmitter (1953) reported petrological studies of the lavas, classifying them as alkaline olivine basalts derived from a gabbro-dioritic magma; he calculated the extent of the lavas as 72 km^2. Schmitter reported the first map of Xitle volcano showing the distribution of the lavas and was the first who attempted to identify individual lava flows and their sequential extrusion.

McGehee (1976) studied the structures, lengths, and types of lava, concluding that the effusive activity followed an explosive phase. Badilla-Cruz (1977) studied the lava structures, noting the vertical distribution of three vesicular zones, and described the lavas as olivine and pyroxene basalts. Enciso de la Vega (1979) mentioned the fissural character of the lavas and the alignment of the Yololica, Magdalena, Cuautzontle, and Xitle volcanoes. This author mentioned that these lavas were the products of an Icelandic-type eruption because of the slow effusion of fluid lava from a fracture more than 7 km long. Walker (1991) described the origin of lava vesicles and types as well as their distribution in the lavas, proposing an evolution model for them. Urrutia-Fucugauchi (1994) performed paleomagnetic studies of the lavas and observed important variations in his measurements. He proposed these variations related to flow and cooling conditions and also to local characteristics at individual sites, like formation of pressure ridges. Córdova *et al.* (1994) presented a map showing different lava flows, but no stratigraphic details were provided.

Despite the numerous reports and articles on the Xitle products, particularly, its lavas, we note the lack of a stratigraphic framework, the eruption evolution, and most importantly, the absence of a detailed map.

GENERAL STRATIGRAPHY

PLIOCENE-PLEISTOCENE

Las Cruces Formation (T_{LC}).

Originally defined by Schlaepfer (1968) as a series of porphyritic dacitic lavas, it crops out in the western half of the study area (Figure 2). In the southwestern part, it consists of microcrystalline dacitic flows underlying the Viborillas basalt. To the northwest, it consists of block and ash pyroclastic-flow deposits, and pumiceous fallout. Delgado and Martin del Pozzo (1993) assigned a Pliocene-early Pleistocene age to this formation.

Ajusco Formation (Q_{Aj}).

Comprises the volcanic products related to the Ajusco volcanic complex (AVC). It includes dacitic and andesitic lava domes and flows, related pyroclastic-flow deposits, and a debris-avalanche deposit (Cervantes *et al.*, 1994; Romero-Terán *et al.*, 1996). This debris-avalanche deposit was produced by the sector collapse of the northeast part of the AVC (a Bandai-type landslide), and reached nearly 16 km from the source (Cervantes *et al.*, 1994). A more detailed description of these deposits and related events will be published elsewhere. Schlaepfer (1968) defined the Ajusco Formation as late Miocene-late Pliocene, but Delgado and Martin del Pozzo (1993) considered this unit as middle Pleistocene based on analysis of the available paleomagnetic data, and discussed a 0.3 Ma age reported by Mora *et al.* (1991) for a basalt from AVC. Recently, Romero-Terán and collaborators (1996) interpreted the evolution of AVC between late Pliocene and middle Pleistocene time.

Vivero Tephras (Q_{TV}).

This is an unusual deposit consisting of near-vent facies of felsic airfall tephra and pyroclastic-flow deposits. The airfall tephra consists of intercalations of coarse pumice (up to 10 cm) and pumiceous ashes. This is a fibrous and vesicular whitish pumice with tiny ferromagnesian crystals. Also present

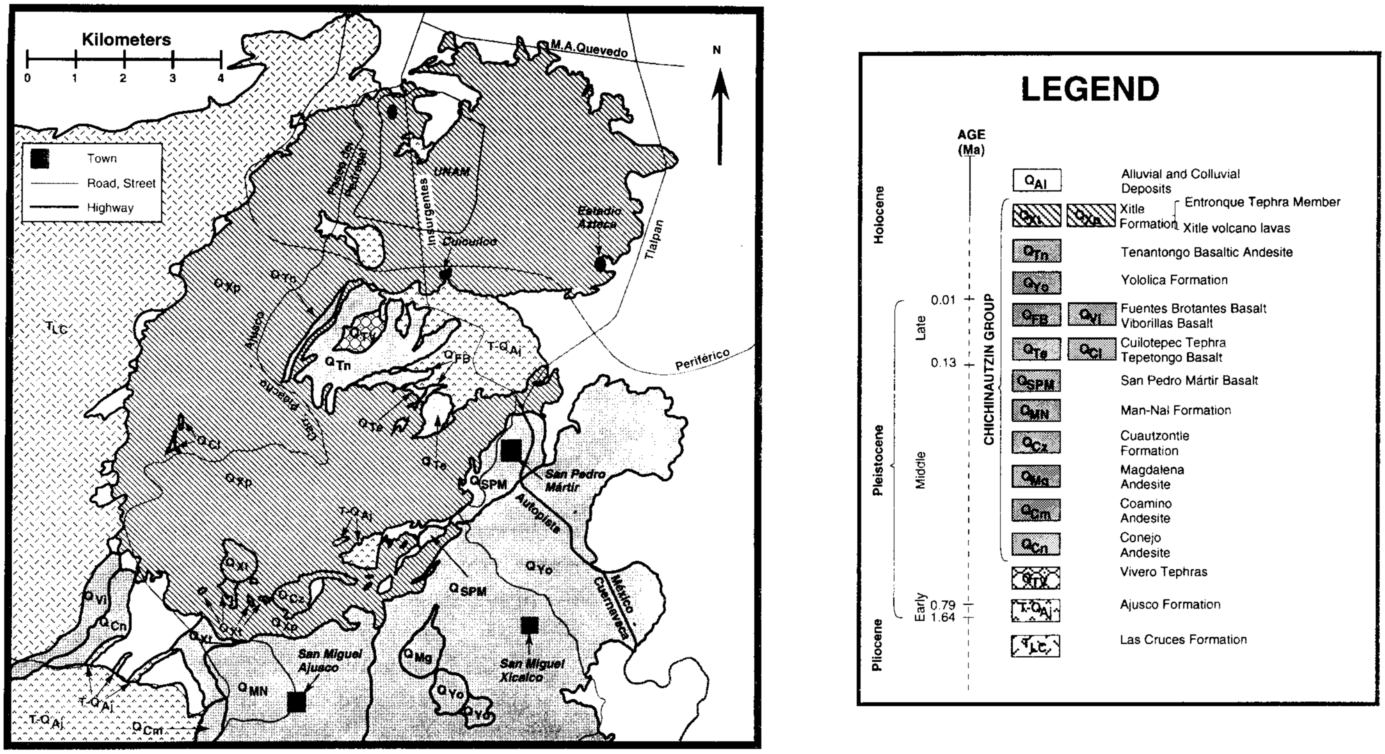

Figure 2. Geological map of Xitle Volcano and its surroundings. The key for each stratigraphic unit appears in the legend and more details on the stratigraphy are in Table 1.

are angular andesitic fragments (less than a centimeter in size) with small vesicles. The source of these deposits is uncertain and has been obscured by later events, but it must be near this site, in Bosques del Pedregal Park. This deposit overlies the debris-avalanche deposit of AVC and underlies the Tenantongo Basaltic Andesite. Its age is probably middle Pleistocene.

PLEISTOCENE-HOLOCENE

Chichinautzin Group

The stratigraphic rank of this formational group has been changed twice since its original definition (Fries, 1960; Bloomfield, 1975; Martin del Pozzo, 1982; Vázquez-Sánchez and Jaimes-Palomera, 1989). We consider the nomenclature proposed by Delgado and Martin del Pozzo (1993) appropriate after following our detailed work to define the lower rank units within this group. In the study area, the Chichinautzin Group comprises ten Pleistocene units and three Holocene units (Table 1).

Two late volcanic events were recognized in this area: one is represented by the Tenantongo Basaltic Andesite which crops out sparingly (Q_{Tn} in Figure 2) and are covered by the effusive products from the other events of the eruption of Xitle volcano. The Tenantongo Basaltic Andesite presents young morphologies suggesting a recent age. They are very similar to the morphology of the younger Xitle lavas but the main physical difference concerns vegetation, which is denser at Tenantongo Basaltic Andesite.

STRATIGRAPHY OF XITLE VOLCANO

XITLE FORMATION (Q_X)

This formation comprises all the volcanic products related to the eruption of Xitle volcano. It consists of a unit made of the airfall products, a unit representing an entire lava cone, and seven lava flows. Xitle volcano has been thought to be the youngest volcano in Sierra Chichinautzin; however, Delgado, Arana and collaborators (1997) report even younger volcanic activity at Pelado volcano.

Entronque Tephra Member (Q_{Xt})

This unit is made of the airfall products from Xitle volcano, ranging in size from fine ash to blocks, and includes the cinder of the Xitle volcano edifice. The type section is in a quarry near the Ajusco Circuit road (500 meters from the intersection of the circuit and about 1.5 km south of the cone). This deposit is subdivided into three fall sequences, each one characterized by a coarse basal lapilli layer (Figure 3).

The lowermost sequence consists of basaltic scoria, basaltic lithic fragments, and glass. The scoria is highly vesicular, angular, and dark greenish-gray in color. The lithics are smaller and less vesicular than the scoria, angular, and dark gray. The glass is dark brown in color, angular, and also has a basaltic character. This sequence is less than 40 cm in thickness and shows intercalations of ash and lapilli with sizes up to 1 cm. The basal layer consists of a 20 cm intercalation of fine to coarse ash (≤ 2 mm) at the bottom, followed by 9 cm of

Table 1. Information about stratigraphic units present in the study area.

UNIT	SYMBOL	TYPE	LITHOLOGY	AGE	STRATIGRAPHIC RELATIONS
HOLOCENE					
Xitle Formation	Q_X	Scoria cone and lava flows	Olivine basalt	Holocene	Overlies Las Cruces and Ajusco Formations, Conejo and Coamino Andesites, Magdalena Andesite, Man-Nal and Cuautzontle Formations and San Pedro Mártir, Tepetongo, Fuentes Brotantes and Viborillas Basalts and Cuilotepec Tephra
Tenantongo Basaltic-Andesite	Q_{Tn}	Lava flow	Olivine basaltic-andesite	Holocene	Overlies Ajusco Formation, Vivero Tephras, Fuentes Brotantes Basalt. Underlies Xitle Formation
Yololica Formation	Q_{Yo}	Scoria cone and lava flows	Olivine basalt	Holocene	Overlies Magdalena Andesite, Man-Nal Formation and San Pedro Mártir Basalt. Underlies Xitle Formation
PLEISTOCENE					
Viborillas Basalt	Q_{Vi}	Lava flow	Porphyritic olivine basalt	Late Pleistocene	Overlies Las Cruces Formation, Ajusco Formation and Conejo Andesite. Underlies Xitle Formation
Fuentes Brotantes Basalt	Q_{FB}	Lava flow	Clinopyroxene basalt	Late Pleistocene	Overlies Ajusco Formation. Underlies Tenantongo Basalt and Xitle Formation
Cuilotepec Tephra	Q_{CI}	Scoria cone	Basaltic scoria	Late Pleistocene	Underlies Xitle Formation
Tepetongo Basalt	Q_{Te}	Lava flow	Olivine basalt	Late Pleistocene	Underlies Xitle Formation and overlies Ajusco Formation
San Pedro Mártir Basalt	Q_{SPM}	Lava flow	Basalt	Middle Pleistocene	Underlies Yololica and Xitle Formations
Man-Nal Formation	Q_{MN}	Scoria cone and lava flows	Olivine basalt	Middle Pleistocene	Overlies Coamino Andesite. Underlies Yololica and Xitle Formations
Cuatzontle Formation	Q_{Cz}	Lava cone	Aphanitic biotite andesite	Middle Pleistocene	Underlies Xitle Formation
Magdalena Andesite	Q_{Mg}	Lava cone	Porphyritic pyroxene andesite	Middle Pleistocene	Underlies Yololica Formation
Coamino Andesite	Q_{Cm}	Lava flow	Porphyritic andesite	Middle Pleistocene	Underlies Man-Nal and Xitle Formations
Conejo Andesite	Q_{Cn}	Lava flow	Porphyritic andesite	Middle Pleistocene	Underlies Xitle Formation and Viborillas Basalt

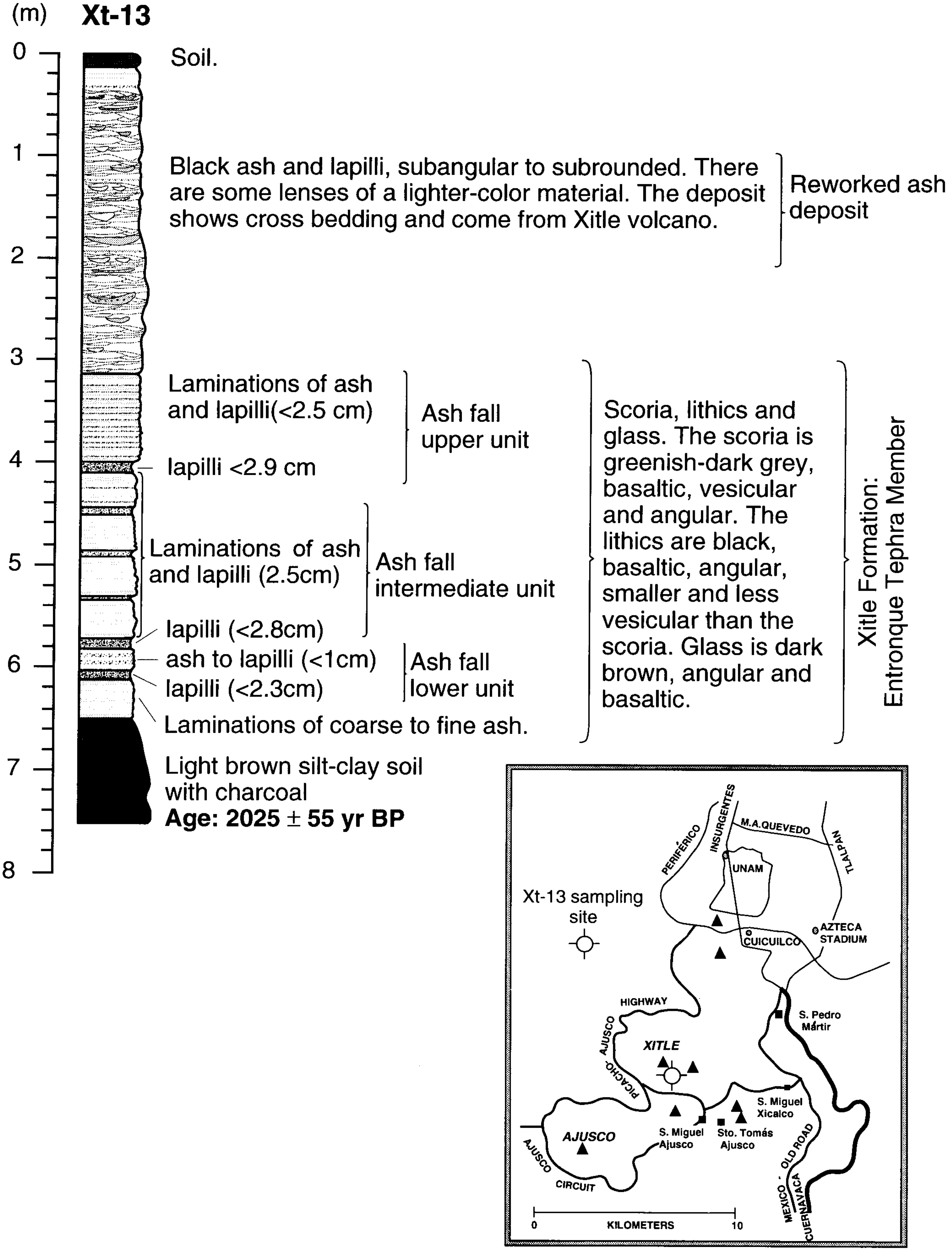

Figure 3. Stratigraphic column at site Xt-13 showing the type section of the Entronque Tephra Member of Xitle Formation. Locality is shown at the inset.

angular and highly vesicular scoriaceous lapilli and ash (< 2.3 cm).

The intermediate sequence is made of similar materials with laminations of ash and lapilli, clast sizes less than 2.5 cm, and a total thickness of 1.65 m. The basal layer (10 cm in thickness) made of lapilli (up to 2.8 cm) and ash-lapilli at the middle part.

The upper sequence is composed of the same materials and has a thickness of 1.10 m. It is characterized by laminations of ash to lapilli (less than 2.5 cm). The sequence shows normal grading. The basal layer is made of lapilli-size material (less than 2.9 cm) with a thickness of 12 cm.

The total thickness of the member is 3.4 m; reworked ash deposits and a light brown soil overlie it. The member overlies a light brown clay-silty soil that contains charcoal fragments that were dated at 2,025 ± 55 years.

The deposit has a lobate shape directed southward. The thickness profile shows a wedge shape along the dispersion axis, whilst perpendicularly to the dispersion axis, it shows a lenticular shape. The calculated volume of the deposit is 0.35 km^3 or 0.12 km^3 of dense rock (volume of airfall tephra was calculated from isopach maps according to Pyle (1989) and from the cone volume according to Hasenaka and Carmichael (1985). The height of the cone is around 100 m. To the south, the deposit overlies the Man-Nal Formation, to the east the Cuautzontle Formation and to the southwest the deposits from Ajusco Volcanic Complex. It is intercalated with the lavas from Xitle volcano.

LAVAS FROM XITLE VOLCANO (Q_{Xp})

The lavas from Xitle comprise all the effusive products of Xitle volcano identified as different basaltic lava flows and a lava cone (Figure 4). Xitle volcano, Xicontle volcano, and the source areas of all Xitle volcano lava flows define an ENE fissure. In spite of an apparent NW-SE lineation of Xitle, Cuatzontle, Magdalena, and Yololica volcanoes, the ENE fissure defined by Xitle lavas and volcanic cones seems to have been the main path for the magma.

Each of the seven discrete lava flows is considered as a member unit of the Xitle Formation, and is in fact, composed by several minor flows whose source area and flow direction was the same. These are very fresh lava flows where it is still possible to observe features like pahoehoe structures (but at proximal facies they are mostly aa-type lavas like at Héroes de 1910 Basaltic Lava Member or San Buenaventura Basaltic Lava Member), levees, pressure ridges, tumulis, hornitos, explosion pipes, lava tubes, etc. The maximum thickness of the unit is 35 meters, but it shows high variability in thickness depending on the underlying topography, which consists of hummocks of the debris-avalanche deposit from the Ajusco Volcano Complex and other older lava flows. The Xitle volcano lava flows have a total area of 70.2 km^2 and a total volume of extruded lava of 0.96 km^3. To the south, the lavas are limited by the Man-Nal Formation, to the east by the Yololica Formation, and to the west by the Las Cruces Formation. The morphology of the seven flows is described in Table 2.

Xicontle Basaltic Lava Member

This parasitic lava cone west of Xitle volcano is 70 meters high and is formed by porphyritic basalt (sample Xi-6) with plagioclase and olivine phenocrysts. Occasionally, mica phenocrysts (phlogopite?) are observed.

Agua Escondida Basaltic Lava Member (BAE)(Flow I in the petrographic descriptions)

This was the first lava flow extruded from Xitle volcano, and was probably associated with the formation of Xicontle cone, from which it flowed to the northwest (Figure 4) and traveled along the foothills of Sierra de las Cruces for 5.7 km (Table 2). It is the fifth largest flow of this member and is made of olivine basalt (sample Xi-7).

Héroes de 1910 Basaltic Lava Member (BH) (Flow II)

This is located southwest of Xitle volcano, and flowed from the Xicontle cone to the southeast and southwest. It consists of olivine basalt (sample Xi-4) and represents the smallest lava-flow member with area of 1.3 km^2 (Table 2). The average thickness of this unit is approximately 2 meters.

Seminario Basaltic Lava Member (BS) (Flow III)

This flow extends to the northeast of Xitle volcano reaching the area of the current Tlalpan Avenue. It has a total extent of 10.6 km^2, a maximum range of 7.7 km, and an average thickness of 7 meters. It is a basalt with olivine, plagioclase, and clinopyroxene phenocrysts in an aphanitic groundmass.

Miguel Hidalgo Basaltic Lava Member (BMH) (Flow IV)

This unit flowed to the NNE of Xitle volcano and covered an area of 4.5 km^2. It is an olivine basalt (sample Xi-9) with an average thickness of 8 m and a maximum flow distance of 6.4 km.

Ciudad Universitaria Basaltic Lava Member (BCU) (Flow V)

This unit spilled out from the southern part of Xitle volcano, flowed first to the south and then to the northeast, covering the zone where the main campus of the Universidad Nacional Autónoma de México currently lies. The BCU member is formed by several minor flow units of olivine basalt (samples Xi-14 to 19), and represents the most widespread unit (25.2 km^2), with the greatest maximum extent (12.5 km) and thickness (average 25 m); this means that BCU represents the

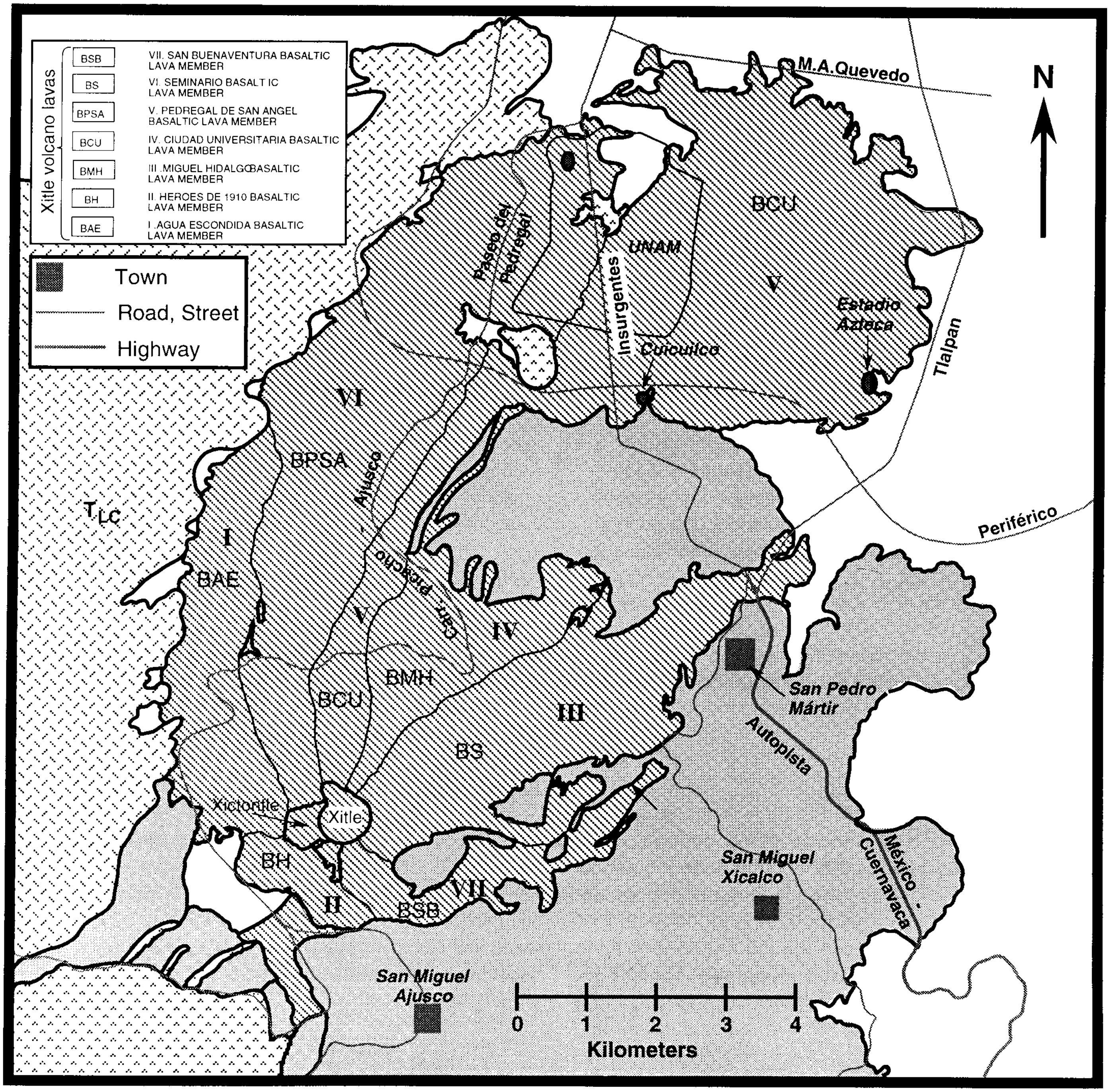

Figure 4. Geological map of Xitle Volcano showing distribution of lavas. Roman numerals indicate the extrusion sequence of the lava flows. Nomenclature of the different lava flow members is shown in the inset.

paroxysmal phase of the eruption and had the lowest viscosity and largest effusion rate. These lavas show the best-preserved pahoehoe structures. Even though BCU is quite narrow in the proximal and intermediate facies (Figure 4), the lava flows ponded into a small basin where currently the thickest section can be observed (up to 40 m). This flow surrounded and covered the Cuicuilco archeological site where many radiocarbon datings have been reported (Arnold and Libby, 1951; Libby, 1955; Fergusson and Libby, 1963; Deevey, 1959; Córdova *et al.*, 1994). These lavas flowed along pre-existing stream channels and over marshy areas and thus, explosion pipes are well exposed in this unit (good examples can be seen at the university campus). An outstanding feature of these lavas is that in the vicinity of the pyramid of Cuicuilco, part of the flow reached what was probably an artificial pond fed by a spring (which still exists) and a stream. As the lavas entered the water, pillow lavas were formed (Figure 5). The resulting pillows are characterized by their lobate shapes, concentric exfo-

Table 2. Morphologic data of Xitle lavas.

Unit	Flow Number	Area [km^2]	Thickness [m]	Volume [km^3]	Maximum distance [km]	D [km]	Aspect Ratio
Agua Escondida Basaltic Lava Member	I	5.9	3.0	0.018	5.7	2.7	0.0011
Héroes de 1910 Basaltic Lava Member	II	1.3	2.0	0.003	1.7	1.3	0.0015
Seminario Basaltic Lava Member	III	10.6	7.0	0.074	7.7	2.6	0.0027
Miguel Hidalgo Basaltic Lava Member	IV	5.5	8.0	0.044	6.4	5.7	0.0014
Ciudad Universitaria Basaltic Lava Member	V	25.2	25.0	0.630	12.5	4.9	0.0051
Pedregal de San Ángel Basaltic Lava Member	VI	18.8	10.0	0.188	10.5	3.7	0.0027
San Buenaventura Basaltic Lava Member	VII	2.8	2.5	0.007	4.6	1.9	0.0013

liation of glassy crusts, and their overall glassy nature, especially at the core of the pillows.

Pedregal de San Ángel Basaltic Lava Member (BPSA)(Flow VI)

This lava flow extends from the northern flank of the Xicontle cone to the north for more than 10 km covering an area of 18.8 km^2 with an average thickness of 10 m. A sample of carbonized wood from site CU-1 in the vicinity of the university campus was analyzed in this study and yielded an age of 1,945 ± 55 yr. At this site, a soil sample was also dated at 1,785 +55/-50 yr. A discussion on these ages is given below.

San Buenaventura Basaltic Lava Member (BSB) (Flow VII)

This was the last lava flow erupted. It flowed to the south and southeast, and then, to the east and northeast. It is a basalt with very altered phenocrysts of olivine and plagioclase. It has a thickness of 2.5 meters, flowed for 4.6 km, and has an area of 2.8 km^2. The BSB lavas had the highest viscosity of all the Xitle volcano lava flows as reflected in the predominant aa textures. Granitic xenoliths were found in these lavas.

OTHER PRODUCTS FROM XITLE VOLCANO

Other volcanic products have been identified at Xitle volcano, including small pyroclastic-flow deposits, beneath the lava flows. However, those deposits do not crop out extensively and could not be mapped. These pyroclastic-flow deposits are matrix supported and dominated by basaltic ash (subrounded basaltic lithic fragments commonly between 0.1 and 2.0 mm in size). These massive deposits contain charcoal fragments (1.0 to 3.0 mm) disseminated through the matrix.

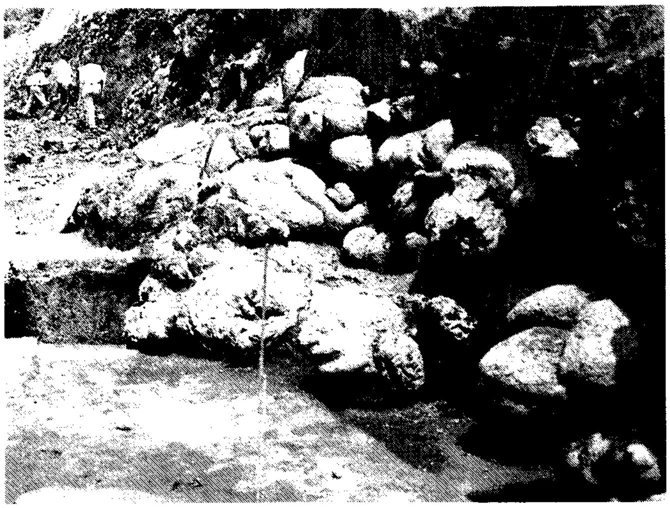

Figure 5. Pillow lavas crop out 100 m southeast of the Cuicuilco pyramid. Notice the lobulate shapes of the pillows.

AGE

Arellano (1946) was the first to assign an age to the eruption of Xitle as >10,000 yr based on soil development criteria. Schmitter (1953) estimated an age between 2,500 and 5,000 years for the Xitle volcano lavas, based on the age of the Totolzingo Formation and the sedimentation rhythm after the Xitle eruption. Maldonado-Koerdell (1954) estimated Xitle volcano's age between 2,000 or 3,000 yr based on morphological observations.

The activity of Xitle volcano was one of the first volcanic activities determined using radiocarbon data. Arnold and Libby (1951) and Libby (1955) dated carbonized material and organic matter obtained from a soil found beneath the lavas as 2,422 ± 250 and 2,400 ± 100 years BP, respectively. This age was a very important one because it was considered to represent the age of the activity of Xitle and, at the same time, the age of the destruction of the Cuicuilco ceremonial site under the lava flows.

Fergusson and Libby (1963) obtained younger ages of 1,536 ± 65 and 1,790 ± 75 yr from carbonized wood found directly below the lavas. After archeological findings reporting cultural remains that supported the younger age (Müller, 1968), Heizer and Bennyhoff (1972) concluded that those findings represented reoccupations by people returning to the site. The age of destruction of Cuicuilco and hence the activity of Xitle volcano became a theme of debate.

Crane and Griffin (1958), Deevey *et al.* (1959) and White *et al.* (1990) reported additional ages obtained from organic material buried by the lavas, clustering around 2,000 yr (2,040 ± 200; 1,975 ± 60; and 1,960 ± 70 yr, respectively) coinciding with cultural evidences, according to Heizer and Bennyhoff (1972). Problems related to most of the early reported ages included lack of appropriate stratigraphic control and correction/calibration of radiocarbon dates.

Ortega-Guerrero *et al.* (1993) dated a burnt wood fragment found beneath the lava flow as 1,960 ± 65 yr. Córdova *et al.* (1994) reported two $\delta^{13}C$ corrected ages (2,030 ± 60; and

2,090 ± 70 yr), but in spite of their nearly 2,000 yr data, they assumed the younger age of Fergusson and Libby (1963) to be more reliable.

Urrutia-Fucugauchi (1996) made a comprehensive review of the available radiometric dates observing that data clustered around three ages: 2,000; 2,375; and 4,000 yr. He favored the 2,000 yr age.

During this study four new ages were obtained (Table 3), three of them for charcoal and one on a soil sample. All the dates are stratigraphically controlled (*i.e.*, Figures 3 and 6) and $\delta^{13}C$ corrected. Site Xt-13 (Figure 3) is nearly 1 km from the vent and shows a sequence of airfall ejecta from Xitle volcano. The dated charcoal was obtained from the top of the soil layer. The ashes burned this charcoal as they fell during the eruption. At site CU-1 charcoal was obtained just below a lava sequence corresponding to Pedregal de San Ángel Basaltic Lava Member (Flow VI). Sample from CU-1B section was a fragment of carbonized wood, whereas the sample from CU-1A section was wet charcoal due to percolating and circulating water through the lava pile. We think that CU-1A sample was contaminated by groundwater and chemically enriched in ^{14}C making it younger (Hedges, 1992).

Table 3. Available radiometric ages for Xitle lavas or related materials.

Data	Age	Std. dev.	Reference
1	1430	200	Crane and Griffin, 1958
2	1536	65	Fergusson and Libby, 1963
3	1785	55	This study
4	1790	75	Fergusson and Libby, 1963
5	1925	60	Deevey *et al* ., 1959
6	1945	55	This study
7	1950	80	Fergusson and Libby, 1963
8	1960	70	White *et al* ., 1990
9	1960	65	Urrutia, 1996
	1975	60	Deevey *et al* ., 1959
10	2025	65	This study
11	2030	60	Córdova *et al.* , 1994
12	2040	200	Crane and Griffin, 1958
13	2090	70	Córdova *et al.*, 1994
14	2100	75	Fergusson and Libby, 1963
15	2190	80	Fergusson and Libby, 1963
16	2230	80	Fergusson and Libby, 1963
17	2300	70	Fergusson and Libby, 1963
18	2422	250	Arnold and Libby, 1951
19	2450	250	Crane and Griffin, 1958
20	2490	100	Fergusson and Libby, 1964
21	2560	100	Fergusson and Libby, 1964
22	2560	80	Fergusson and Libby, 1964
23	2600	70	Fergusson and Libby, 1963
24	2965	85	This study
25	3320	100	Fergusson and Libby, 1964
26	3850	200	Fergusson and Libby, 1963
27	3820	100	Fergusson and Libby, 1963
28	3930	100	Fergusson and Libby, 1963
29	3980	60	Fergusson and Libby, 1963
30	4050	75	Fergusson and Libby, 1963
31	4110	120	Fergusson and Libby, 1963
32	4690	70	Córdova *et al.*, 1994

CU-1A age (1,785 +55/-50 yr) is not much different from CU-1B (1,945 ± 55 yr), and furthermore, CU-1B is consistent with the age of Xt-13 (2,025 ± 55 yr). The fourth age was obtained from a carbon rich soil (sample XI-94-15) beneath the ash sequence and thus, it is older (2,965 ± 85 yr).

With these results, we conclude that the kind of sample and sampling site may influence the apparent age for the eruption of Xitle volcano. In the case of the soil sample, no large fragments of charcoal were obtained, and no evidence was found that the ashes burned organic material. Thus, the organic material contained in the soil reveals an age older than the eruption age representing the maximum age of the volcanic activity (2,965 ± 85 yr).

Good stratigraphic control allows better constraint to Xitle volcano's age of activity. The ages from stratigraphically well controlled samples and without contamination should represent the average age of the eruption because one of them was obtained beneath the explosive products of Xitle volcano, and the other was sampled beneath the effusive products. Their similarity is remarkable taking into account the different processes that carbonized the organic material.

Nevertheless, another age obtained beneath the lavas is younger. As an extreme case CU-1A sample illustrates the influence of contaminating underground waters (percolating and circulating below the lava flows) on charcoal and the effect on a stratigraphically controlled sample.

These new ages together with that of Ortega-Guerrero and collaborators (1993), all of them stratigraphically well constrained, allow us to date the eruption of Xitle volcano at the average date of 1,977 ± 43 yr.

Alternatively, a statistical analysis of all the available ages is presented below. The 32 available ages cluster at 2,000 and 4,000 yr (Figure 7). Taking into account these clusters we define ranges where most data occur. The first cluster of data shows a wide range (including standard deviations, Figure 8) and thus, an age of 2,161± 261 is obtained with 21 dates. However, the best average is obtained from the 10 dates that cluster better, resulting an age of 2,003 ± 62 yr. This statistical approach supports the age obtained with good geological controls.

The second cluster yields an average of 3,957 ± 113 yr. In this case, we suspect it represents the age of a different volcanic event. Tenantongo Basaltic Andesite is geomorphologically very similar to Xitle volcano lavas and hence very easy to confuse. Petrographic and chemical differences give clues to distinguish them, but they can easily be confused in the field. We speculate the ages of the ~4,000 yr cluster may represent the age of Tenantongo Basaltic Andesite, although there is no stratigraphic control of those ages to support this suggestion. Additional field work on Tenantongo Basaltic Andesite may throw light on this.

We conclude therefore, that Xitle volcano erupted 1,977 ± 43 yr based on geologically well controlled dates, or 2,003 ± 62 yr based on a statistical analysis of the best ages reported to

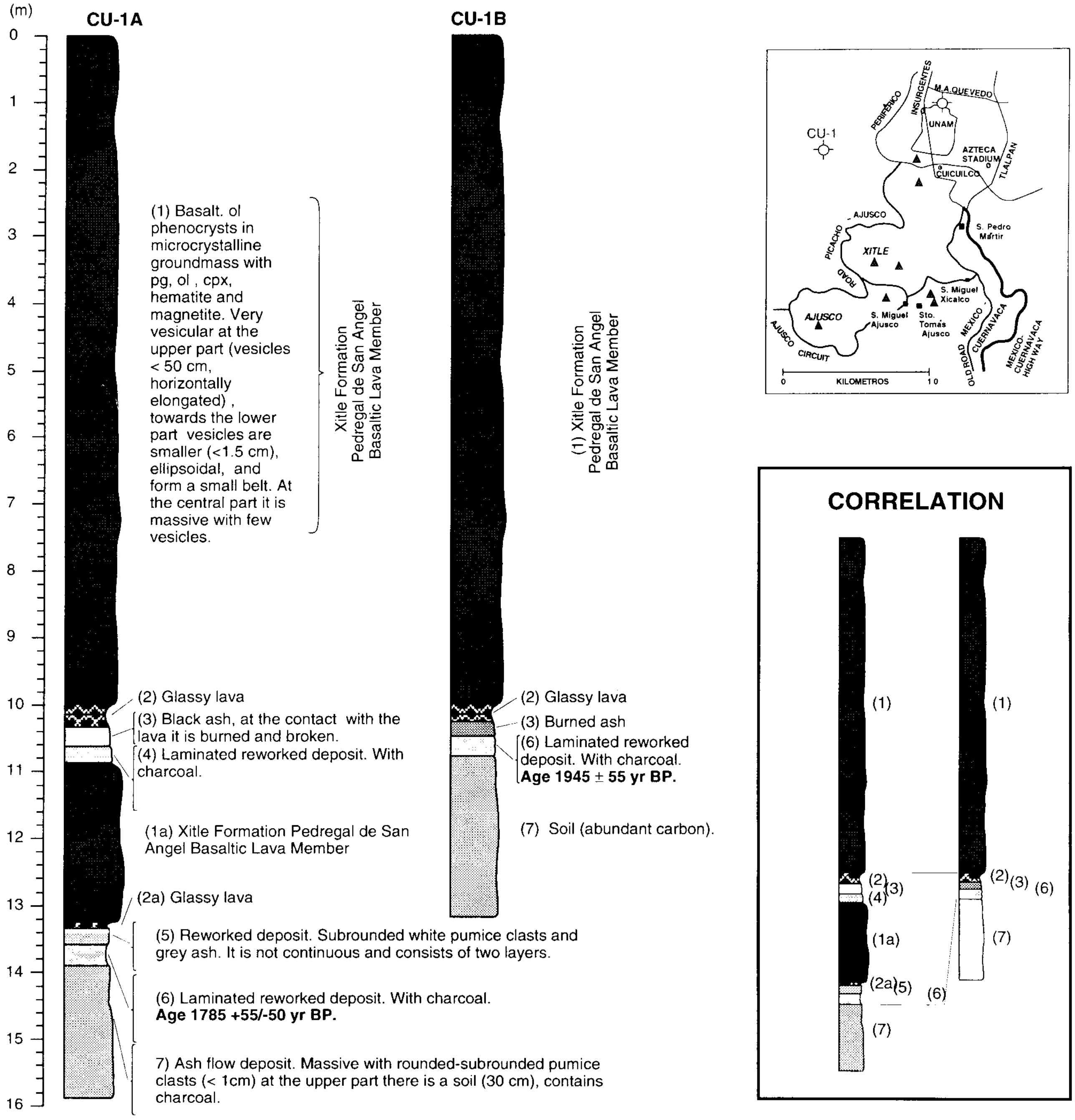

Figure 6. Stratigraphic columns and correlation of site CU-1 showing Xitle lavas overlying Las Cruces deposits. CU-1 and CU-2 are 5 m apart from each other. Locality is shown at the inset.

date. As a corollary, we state the time for the destruction of the Cuicuilco ceremonial site at about 2,000 yr.

These ages have no resolution to indicate the duration of the entire eruption of Xitle. Nevertheless, the eruptive activity possibly did not last more than 50 years since no soils are present between lava flows, within the airfall ejecta, or at the contact between lavas and pyroclastic products. Records on the duration of monogenetic volcanoes' eruptions such as those of Jorullo (1759–1774; Gadow, 1930), and Parícutin (1943–1952; Luhr and Simkin, 1993) in Michoacán (Mexico) support this.

PETROGRAPHIC AND GEOCHEMICAL FEATURES

Each lava flow was sampled in order to understand the evolution of the eruption and characterize the magmatism that gave birth to Xitle volcano. After reconnaissance of the stratigraphic sequence the petrographic features and geochemical signatures of the lavas were determined. Sampling included proximal and distal facies of the lava flows as well as a vertical section in the Ciudad Universitaria Basaltic Lava Member.

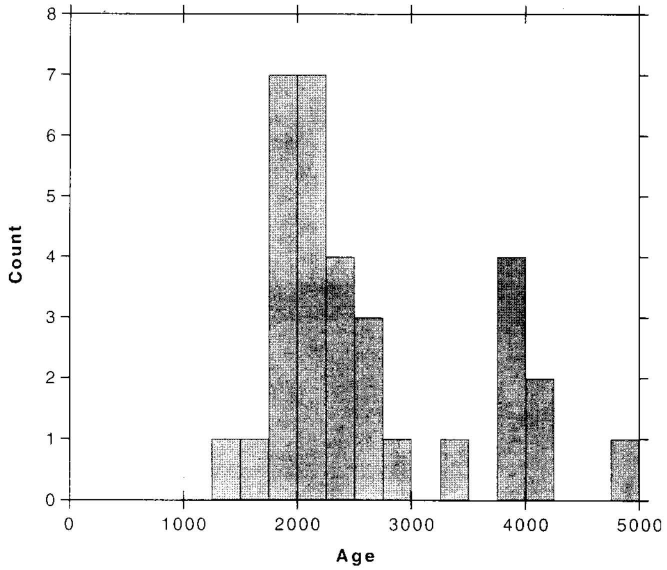

Figure 7. Histogram made with all the available radiometric ages. Clusters are evident at 2,000 and 4,000 yr. Data from Table 3.

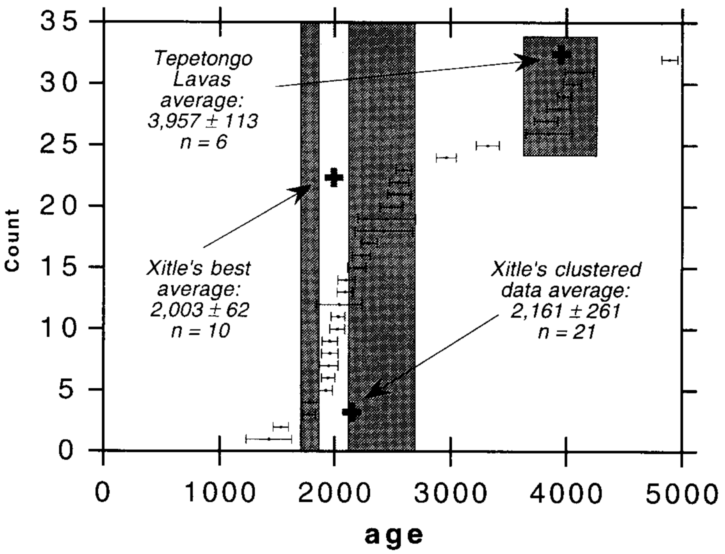

Figure 8. Diagram showing radiometric dates and their standard deviations showing clustering of data and best averages.

Modal analyses were carried out counting 1,000 points in every thin section. Plagioclase and olivine phenocrysts were defined at > 0.3 mm whereas pyroxene phenocrysts were > 0.1 mm. Plagioclase and olivine, and pyroxene groundmass was defined in sizes < 0.03 mm and < 0.01 mm, respectively. For chemical analyses, the samples were cleaned up and broken into small pieces using a hammer, then crushed to a fine powder using a tungsten carbide mill. Alternatively, an agate mortar was used to crush some samples. Thereafter, the samples were analyzed for major and some trace elements in a sequential XRF spectrometer (Siemens SRS 3000 at the Laboratorio Universitario de Geoquímica Isotópica) using calibration curves constructed with 40 geochemical reference samples. Major elements were determined on fused glass disks. These were prepared by mixing thoroughly 0.8 g of sample powder with 7.2 g of LiB_4O_7-$LiBO_2$ flux mixture (50:50 wt %, Claisse Inc). Two drops of LiBr solution in water (250 g/L) were used as non-wetting agent. The mixture was poured into a crucible made of 95% Pt-5% Au, and heated to 950°C in a furnace (Fluxy by Corporation Scientifique Claisse) equipped with three crucibles for simultaneous preparation of glass disks. FeO was determined colorimetrically by acid decomposition and titration with 0.1 N solution of $K_2Cr_2O_7$.

PETROGRAPHY

Modal analyses by flow unit for proximal and distal facies are listed in Table 4. In order of abundance, the Xitle volcano lavas contain plagioclase (plag), olivine (ol) and clinopyroxene (cpx). Other minerals include magnetite, ilmenite, titanomagnetite and hematite. At Xicontle volcano mica flakes were observed in the groundmass and thought to be phlogopite. Unfortunately, we were not able to study them due to their size and scarcity.

The modal compositions of the lavas are different from proximal to distal facies. Plagioclase phenocrysts are slightly more abundant at the proximal facies compared to the distal facies (Figure 9A). However, plagioclase is more abundant in the groundmass at distal facies along the eruption. This might indicate that for proximal facies, the magma resided longer in the crust, so as to permit growth of more plagioclase, whereas the distal facies represent the first portions from each batch of magma erupted. The highest content of plagioclase coincided with the paroxysmal phase of the eruption (Flow V) as can be seen in the total content of plagioclase in both proximal and distal facies (Figure 9B).

The proximal facies of Flow I shows a high content of olivine phenocrysts, as does the distal facies of Flow V. The olivine phenocryst abundance for distal facies peaked during the paroxysmal phase (Flow V) with a gradual decrease thereafter (Figure 9A). The patterns of the groundmass olivine contents at proximal and distal facies show negative correlations. The paroxysmal phase marked saw groundmass olivine reach a maximum for proximal facies and a minimum for distal facies. The total amount of ol is higher at distal facies (Figure 9B). A well-defined pattern of increasing total olivine with time is seen in the distal facies during the pre-paroxysmal phase of the eruption, reaching a maximum during the extrusion of Flow V, and a decrease in the overall content of ol after this phase.

Cpx phenocrysts are almost completely absent at both facies. The content of cpx in the groundmass at the proximal facies is higher during the first phase of the eruption (Flow I) and lower in the latest phase (Figure 9A). An overall depletion in cpx mark the paroxysmal phase.

Even though well-defined patterns cannot be identified, the peaks in the overall content in plagioclase and olivine combined with depletion in clinopyroxene during the emission of Flow V confirm it as the paroxysmal phase and suggest the highest effusion rate.

Table 4. Modal analyses data for thin sections from Xitle lavas according to their facies.

PROXIMAL FACIES

Flow number	Plagioclase		Olivine		Clinopyroxene groundmass	Magnetite	Vesicles	Total		
	Phenocrysts	Groundmass	Phenocrysts	Groundmass				pg	ol	cpx
I		38.9	12.2	12.7	21.0	0.8	14.3	38.9	24.9	21.0
II	1.0	33.2	4.4	9.0	9.8	2.0	40.6	34.2	13.4	9.8
III	8.9	40.1	3.5	8.4	11.4		25.7	49.0	11.9	11.4
IV	4.8	35.7	8.1	15.5	18.0	0.4	17.5	40.5	23.6	18.0
V		56.3	5.8	15.5	9.8		12.6	56.3	21.3	9.8
VI	1.4	50.4	4.0	9.4	13.8	2.0	19.0	51.8	13.4	13.8
VII	20.6	29.3	6.7	6.0	8.9	0.7	27.8	49.9	12.7	8.9

DISTAL FACIES

Flow number	Plagioclase		Olivine		Clinopyroxene groundmass	Magnetite	Vesicles	Total		
	Phenocrysts	Groundmass	Phenocrysts	Groundmass				pg	ol	cpx
I	2.1	48.5	5.3	13.3	15.9	3.7	12.2	50.6	18.6	15.9
II	3.0	44.0	5.0	14.8	17.2	0.4	15.6	47.0	19.8	17.2
III	1.3	49.8	4.1	14.2	11.6	0.6	18.4	51.1	18.3	11.6
IV	3.2	37.6	7.0	13.4	10.4	1.2	27.2	40.8	20.4	10.4
V		53.6	13.6	13.5	7.3	0.4	11.6	53.6	27.1	7.3
VI		42.6	8.7	16.4	14.5	1.2	16.6	42.6	25.1	14.5
VII	2.2	44.0	2.2	18.6	14.8	1.4	16.8	46.2	20.8	14.8

CHEMISTRY

Chemical analyses of Xitle lavas are summarized in Table 5. The results are discussed according to their stratigraphic position in the sequence of flows.

Xitle volcano lavas are basalts and basaltic andesites according to their total alkali-silica content with a SiO_2 range between ~50 % and ~53 % (Figure 10A). These are mostly medium-K lavas, except Flow I lavas (the first effusive event), which plot in the high-K field (Figure 10B). Xitle lavas were high-K basalts in the beginning but as the eruption evolved through Flow II, III, and IV medium-K basaltic andesites were emitted. During the paroxysmal phase of the eruption (Flow V) the extruded lavas were more mafic, and classify as basaltic. This condition is also true for Flow VI although the MgO content at Flow V was the highest (Figure 11A). By the end of the eruption of Xitle volcano (Flow VII), all products were basaltic andesites and the MgO content was the lowest. The Tenantongo Basaltic Andesite is shown for comparison. In general, Xitle volcano lavas are primitive rocks (MgO = 7–9.5 wt %).

TiO_2 shows a fractionation trend for ilmenite (Figure 11B), although TiO_2 trends combined with total iron reflect crystallization of titanomagnetite (Figure 11C) (Böhnel *et al.*, 1997).

ORIGIN, EVOLUTION AND ERUPTION OF XITLE VOLCANO

ORIGIN

Verma and Armienta (1985) suggested a mantle source for Sierra Chichinautzin (including Xitle volcano lavas) based on $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotopic ratios, and ^{10}Be data. Further, Verma (in press) states that rocks of Sierra Chichinautzin cannot be generated by slab melting or fluid

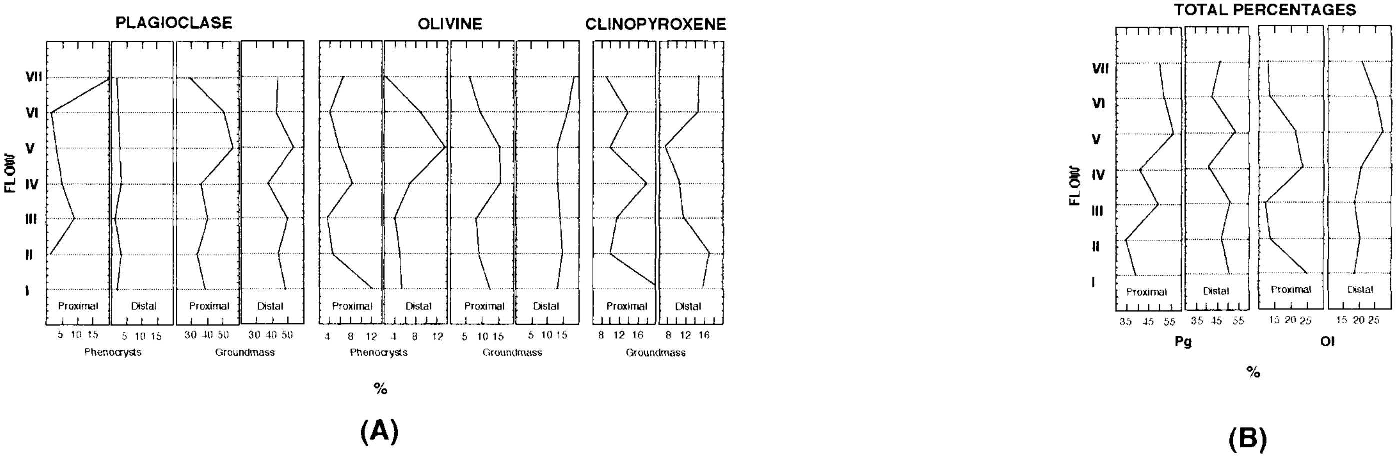

Figure 9. Modal analyses diagrams showing the abundance of plag, ol, and cpx as the eruption evolved. (A) Modal content of plag, ol and cpx phenocrysts and groundmass according to facies. (B) Total content of plag and ol according to facies. Data from Table 4.

Table 5. Chemical analyses of Xitle lavas (raw data).

	Flow I	**Flow II**	**Flow III**	**Flow IV**	**Flow V**	**Flow VI**	**Flow VII**	**Xicontle**	**Tenantongo**
Sample	**X7**	**X23**	**X13**	**X24**	**X14**	**X11**	**X25**	**X6a**	**X12a**
SiO_2	51.64	52.52	52.62	52.34	50.83	51.07	52.35	52.27	55.68
TiO_2	1.74	1.76	1.73	1.68	1.80	1.86	1.69	1.77	1.10
Al_2O_3	15.91	15.89	15.50	16.00	15.99	16.07	16.08	15.67	16.12
Fe_2O_3	1.99	1.68	1.87	2.14	2.30	2.56	3.01	2.33	1.83
FeO	6.87	6.96	7.15	6.67	7.01	6.72	5.83	6.58	5.44
MnO	0.15	0.15	0.15	0.15	0.16	0.16	0.15	0.15	0.13
MgO	8.00	8.10	8.10	8.07	8.69	8.06	7.77	7.93	7.43
CaO	7.85	7.33	7.13	7.67	8.09	7.94	7.59	7.22	7.36
Na_2O	3.31	3.63	3.39	3.57	3.33	3.43	3.57	3.37	3.33
K_2O	1.56	1.29	1.30	1.20	1.02	1.16	1.24	1.51	1.24
P_2O_5	0.51	0.57	0.60	0.51	0.48	0.52	0.53	0.60	0.27
Total	99.53	99.87	99.55	99.99	99.69	99.55	99.81	99.42	99.93

transport associated with subduction of the Cocos plate, suggesting that Sierra Chichinautzin lavas were probably generated by a rifting process from partial melting of the underlying mantle. The magmas then, were extruded through monogenetic volcanoes facilitated by crustal weakening caused by tensional stress in the area.

Xitle volcano lavas show calc-alkaline affinity characteristic of subduction-related environments (Figure 12). Tenantongo lavas show also calc-alkaline signature.

The data presented in this paper do not support Verma's suggestion for a rifting process to explain the origin of Xitle volcano basalts due to their calc-alkaline affinity. However, additional studies must be done to better define the origin of Sierra Chichinautzin magmas.

EVOLUTION

The lavas ascended from depth through the crust along fractures produced under an extensional regime present in the region since the Pliocene (Delgado *et al.*, 1993; Lermo-Samaniego *et al.*, 1995; Delgado, Nieto-Obregón *et al.*, 1995). Magma ascent was fast due to high effusion rates and temperatures as suggested by the high Xitle volcano lava outflow distances and maximum ranges and aspect ratios of 10-3-10-4 (Walker, 1973).

Mainly crystal fractionation processes affected the Xitle volcano lavas. Geochemical data suggests differentiation trends, also supported by the petrographic features of the rocks according to their facies (*i.e.*, distal facies containing abundant plag in the groundmass while proximal facies lavas contain plag phenocrysts preferentially). These crystallization patterns also support a fast ascent of the magmas and little interaction with the crustal rocks.

ERUPTION OF XITLE VOLCANO

The eruption of Xitle volcano started 2,000 years ago with explosive and concomitant effusive activity. The explosive activity gave birth to the Xitle cone itself and the effusive activity perhaps started later as in the case of Parícutin in Michoacán (Foshag and González-Reyna, 1956). The explosive activity produced typical eruptive columns perhaps of no more than 8,000 m high. This assumption is based on the distribution patterns of ash-fall tephra, which was preferentially dispersed towards the south. This distribution pattern reflects the lower atmospheric wind regimes (below ~6,000 m a.s.l.) and also reflects in part the distribution patterns of the higher atmospheric winds (up to 8,000 m a.s.l. for Xitle volcano; Delgado, Carrasco *et al.*, 1995; Cervantes and Molinero, 1995). Such altitudes are typical for strombolian explosive activity. During the paroxysmal phase of the eruption (perhaps at the beginning of it) the explosive activity was very intense and produced a few ash-flow deposits that were eventually buried by Flow V lavas. Ashes are also present on the northern flank of Xitle volcano, but most of them are reworked by water as can be seen at Cuicuilco ceremonial center and several other sites in the university campus.

The effusive activity first produced the formation of the satellitic Xicontle cone. Thereafter, Flow I appeared at the flank of Xicontle and formed mainly aa-type lava flows. Flow II also formed these kind of lavas and was distributed towards the south, where it was partially buried by ash falls. Flow III and IV used the easiest ways available to flow but the areas for the next lavas to flow were progressively more restricted. The previous morphology at the northern flank of Xitle volcano was dominated by steep slopes and mounds (hummocks), relicts of the sector collapse of the northern flank of Ajusco volcano in the middle Pleistocene (Cervantes *et al.*, 1994; Delgado, Romero-Terán *et al.*, 1997). This morphology controlled strongly the movement of Flows I, III, IV, V, and VI. Flow V followed a very well defined stream channel reaching a marshy area (near UNAM campus) where it ponded and piled up a very thick sequence. Cuicuilco ceremonial center was nested between two streams and close to a water reservoir (presumably artificial since a rustic dike contained the water), which was fed by the stream itself and by a spring. Flow V fol-

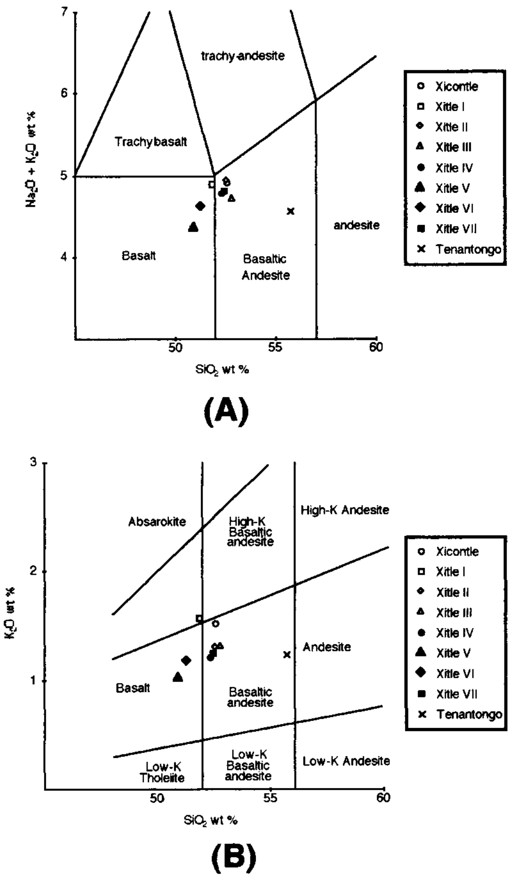

Figure 10. Total alkali-silica diagrams and silica-K_2O diagram for Xitle volcano lavas. (A) TAS (Le Bas *et al.*, 1986) for the different lava flows including Xicontle and Tenantongo lavas. (B) Silica vs. K_2O diagram for Xitle lavas (boundaries according to Peccerillo and Taylor, 1976). Data from Table 5 recalculated to 100 %.

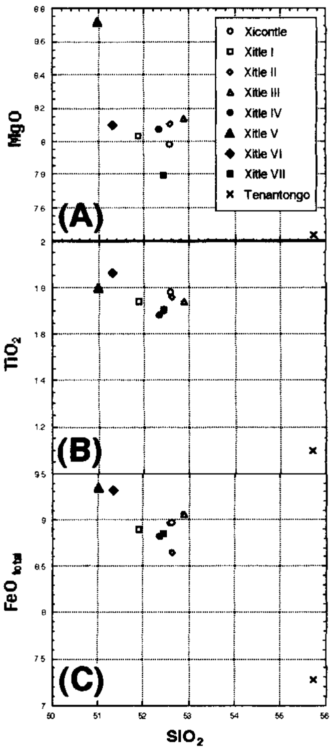

Figure 11. Harker diagrams for Xitle volcano, Xicontle and Tenantongo lavas. Data from Table 5 recalculated to 100 %.

lowed several stream channels in that direction finally buried the flanks of the pyramid and flow around it and entered into the water at the artificial dam. The edges of the lava flow that entered into the water body (5 to 10 meters deep; Alejandro Pastrana, personal communication) were chilled immediately and pillows were formed. Flow V is perhaps the most interesting lava flow because several unusual structures were formed in this lava. For instance, explosion pipes were formed as the flow was passing over marshy areas where steam explosions were produced by the lava's heat. Most of the lava tubes and the longest ones were developed in Flow V. Flow VI was also a large lava flow representing the end of the paroxysmal phase of the eruption and the initiation of the end of the entire event associated with Flow VII as indicated by stratigraphy, areal extent, range, thickness, volume, petrography and chemistry of the lavas. The total amount of extruded magma is estimated to be 1.08 km^3, an amount comparable with the magma volumes extruded by Paricutin volcano between 1943 and 1952 (1.32 km^3; McBirney *et al.*, 1987), and by Jorullo volcano in 1759-1774 (~2 km^3; Luhr and Carmichael, 1985).

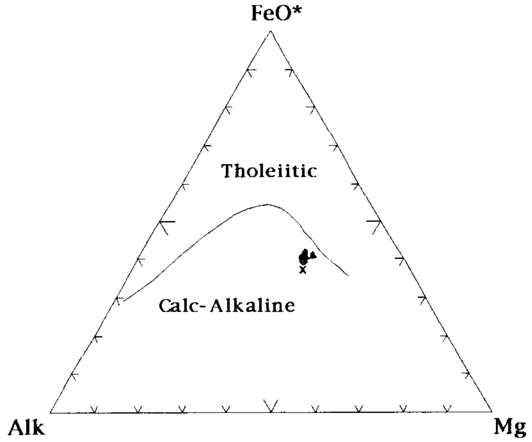

Figure 12. AFM diagram for Xitle volcano lavas (boundaries according to Irvine and Baragar, 1971).

CONCLUSIONS

Xitle volcano is a young volcano located within the largest city of the world and thus, deserves thorough study. Knowledge of its geological framework is of importance not only for understanding of the geological evolution, general stratigraphy, and volcanological background of the Basin of Mexico, but also for understanding of the human settlements of the region. The paucity of detailed geological studies at Xitle volcano is notable in spite of the numerous published titles.

Stratigraphic studies defined precisely the nine units of Xitle Formation and the stratigraphic relationships among them and the previous rocks. This study allowed the recognition of important features such as the amount of magma emitted.

Unusual features were identified such as the pillow lavas developed at Flow V unit. They might be considered as "man-made" pillow lavas, even though the influence of man was incidental.

The age of Xitle volcano was established at ~2,000 yr according to geologically well controlled radiometric ages (1,977 ± 43 yr), and statistically analyzed data using the available radiometric dates (2,003 ± 62 yr). The Xitle volcano eruption date cannot be older than 3,000 yr or younger than 1,800 yr). This ages constrain also the date for the destruction of Cuicuilco ceremonial site.

The magmas extruded at Xitle volcano were calc-alkaline basalts and basaltic andesites. Crystal fractionation was the main process affecting these magmas. Presence of phlogopite traces may indicate a particularly hydrous nature of the involved melts. However, more detailed studies need to be done.

Evolution of Xitle volcano has some similarities with other well-studied volcanoes such as Parícutin and Jorullo in terms of extruded volumes. Nonetheless, even though Xitle volcano erupted explosively and effusively as several other monogenetic volcanoes, development of pyroclastic flows is a very important issue not only to evaluate the explosivity of this kind of volcanism but also to evaluate the volcanic hazards in the Basin of Mexico.

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