Late Holocene stratigraphy of the Tetimpa archaeological sites, northeast flank of Popocatépetl volcano, central Mexico

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ABSTRACT

Late Holocene (<2500 yr B.P.) tephras bury a sequence of pre-Hispanic archaeological sites in the Tetimpa area, on the northeast flank of Popocatépetl volcano. From measured stratigraphic sections, 14C dates, and isopach maps, this paper reconstructs the eruptive chronology and the regional extent of deposits associated with the Tetimpa archaeological sites.

A regionally extensive paleosol defines the base of the late Holocene sequence in the Tetimpa area. Deposits from two periods of explosive volcanism unconformably overlie this paleosol. Eruptive sequence I was deposited at ca. 2100 yr B.P. and blanketed Late Holocene sediments. In upland areas, this time period is represented by an unconformity and by Entisols

formed in the top of pumice deposits and lavas from eruptive sequence I. Artifacts, agricultural furrows, and dwellings record human reoccupation of this surface. At the end of this hiatus, several lahars were deposited above the lacustrine sequence and locally above the Entisol in upland positions adjacent to streams.

Between ca. 1350 and ca. 1200 yr B.P., tephras from eruptive sequence II buried these paleosols, occupation sites, lacustrine sediments, and lahars. Andesitic (~62% SiO2) pumice lapilli deposits in the Tetimpa area record three pumice-fall eruptions directed northeast and east of the crater. The first and smallest of these (maximum Tetimpa area thickness = 12 cm; >52 km2 covered by >25 cm) took place at ca. 1350 yr B.P. and was accompanied by pyroclastic surge events preserved in the Tetimpa area by charcoal, sand waves, and cross-stratified sand-sized tephra. At ca. 1200 yr B.P., the products of two Plinian-style eruptions and additional pyroclastic surges reached the Tetimpa area. The largest of these tephra-fall events covered the Tetimpa area with 0.5–1 m of tephra and blanketed an area of >230 km2 with a thickness of >25 cm.

The Tetimpa record confirms two of the four periods of explosive volcanism recognized by studies conducted around Popocatépetl in the past 30 yr. Eruptive sequence I corresponds to the explosive period between 2100 and 2500 yr B.P., and eruptive sequence II corresponds to the period between 900 and 1400 yr B.P. The archaeology and lacustrine stratigraphy of the Tetimpa area help constrain the timing of the Plinian phase of eruptive sequence I to ca. 2100 yr B.P. and suggest that the pumice-fall eruptions of eruptive sequence II took place in at least two intervals between ca. 1350 and ca. 1200 yr B.P.

INTRODUCTION

Popocatépetl volcano, located between the densely populated highland basins of Puebla and Mexico, is one of the most hazardous volcanic centers in the Trans-Mexican volcanic belt (Fig. 1). Small ash eruptions in recent years (GVN, 1994, 1996) have promoted awareness of the volcano’s activity (e.g., CENAPRED, 1995) and prompted studies of the volcano’s Holocene history (Abrams et al., 1995; Macías et al., 1995a, 1995b, 1995c; Siebe et al., 1995a, 1995b, 1995c, 1996). As concerns over modern hazards have grown, so has interest in the effect that the late Holocene eruptions may have had on pre-Hispanic populations (Delgado et al., 1994; Hirth et al., 1995, 1996; Panfil et al., 1995; Plunket and Uruñuela, 1995, 1996a, 1996b; Siebe et al., 1995a, 1995b, 1996) whose regional cultural centers have been located in the basins of Puebla and Mexico for more than 3000 yr (Sanders et al., 1979).

Evidence of the impact of explosive volcanic activity on pre-Hispanic settlements in the Puebla basin comes from excavation of archaeological sites in the Tetimpa area (Plunket and Uruñuela, 1995, 1996a, 1996b). Located 15 km northeast of Popocatépetl’s summit crater, the Tetimpa area surrounds the towns of San Nicolás de los Ranchos and San Buenaventura Nealtican (Fig. 1). At Tetimpa sites, agricultural furrows (Selle, 1973), building foundations, and other artifacts (Plunket and Uruñuela, 1995, 1996a, 1996b) are interbedded with tephra deposits from at least three distinct phases of human settlement spanning the late Holocene (<2500 yr B.P.). The volcanic deposits that separate occupation horizons indicate a sequence of Plinian eruptions on a scale large enough to displace populations and affect regional settlement patterns.

Information about the archaeology of the Tetimpa area augments more than three decades

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The Tetimpa area can be divided into three distinctive landscapes that vary in elevation and depositional environment; these landscapes provide a framework for the Tetimpa stratigraphy. The most distinctive landscape is the Lava Flow Uplands that covers the southwest part of the study area (Fig. 2). Made up of olivine-bearing anodesitic lava flows (von Erffa et al., 1977), the surface is hummocky, and rocky pinnacles protrude between pine and scrub vegetation; the surface is now on average 40–80 m above the modern stream level (inset, Fig. 2). The Tephra Uplands (Fig. 2), a gently rolling surface made up dominantly of tephra deposits from Quaternary volcanic eruptions, are about 20–40 m lower in elevation. The modern town of San Buenaventura Nealtican lies within this area, as do excavated archaeological sites; this landscape is planted extensively for subsistence agriculture. Topographically below these two areas is the third landscape, the Barranca Lowlands (Fig. 2). Streams draining the slopes of Popocatépetl and Iztaccíhuatl formed this landscape by incision into Quaternary tephra and lahar deposits. The towns of San Nicolás de los Ranchos and San Pedro Yancuitlalpan lie within this landscape in a broad valley formed by the junction of the Apol and Alseseca streams. Downstream of this junction, Barranca Nexac becomes narrow and steep sided and follows the northern perimeter of the lava field (Fig. 2).

In the course of quarrying lavas and pumice deposits on the Tephra Uplands, residents of San Buenaventura and San Nicolás have uncovered archaeological sites across much of the Tetimpa area. Agricultural furrows, building foundations, and other artifacts from several pre-Hispanic communities are well preserved beneath the tephra deposits and lava flows (Fig. 2; Seele, 1973; Plunket and Uruñuela, 1995, 1996a, 1996b; Hirth et al., 1996). Volcanic deposits separate occupation horizons and preserve at least three periods of human settlement.

Building foundations and artifacts belonging to the first period, the Early Tetimpa Occupation, date to ca. 2300–2200 yr B.P. (Plunket and Uruñuela, 1996b). These sites are overlain by agricultural furrows and building structures from a second occupation period, the Late Tetimpa Occupation, dated to ca. 2100–2000 yr B.P. (Plunket and Uruñuela, 1996b). The ceramics found at
these sites correspond to the Late Preclassic archaeological time period (Plunket and Uruñuela, 1995), an initial period of population growth for the pre-Hispanic city of Cholula (Mountjoy and Peterson, 1973; Müller, 1973), 15 km east of the Tetimpa area (Fig. 1).

Preliminary 14C dating of sites from a third occupation period, the Tetimpa Reoccupation, suggests a minimum age of ca. 1300 yr B.P., almost 800 14C yr after the Early and Late Tetimpa Occupations. Fragments of pottery from these sites correspond to the Classic archaeological time period (Hirth et al., 1996), an interval of high population density in the Cholula area (Mountjoy and Peterson, 1973). Cholula may have been an important cultural center at this time, second only in importance in central Mexico to the city of Teotihuacan (Sanders et al., 1979).

LATE HOLOCENE STRATIGRAPHY

Within the context of the Tetimpa archaeology, this paper establishes the chronology of late Holocene eruptions affecting inhabitants of the area. We report on the sedimentary facies, depositional environments, 14C ages, and regional extent of volcanic deposits of the Tetimpa area. To facilitate stratigraphic descriptions, deposits are coded: the first characters correspond to the eruptive sequence (I or II) or eruptive hiatus (EH), subsequent letters to facies designations (A = tephra fall, La = lacustrine deposits, Lf = lava flow, Lr = lahar, S = pyroclastic surge), and Arabic numbers to units within each eruptive sequence. For example, the code II.A1 signifies the first tephra-fall unit deposited in the eruptive sequence II. All 14C dates are reported in yr B.P. (after 13C correction) unless otherwise specified (Table 1).

Basal Paleosol

The oldest surface with cultural remains in the Tetimpa area is a regionally extensive paleosol that serves as the basal horizon for the stratigraphy described in this paper (Fig. 3, A and B). The paleosol is an Inceptisol with slight color and textural changes defining weakly developed A, B, and C soil horizons. The A horizon has a sandy loam texture, is a dark yellowish brown color (10YR 4/2), and contains little organic accumulation. A slight color and textural change indicates the presence of a cambic B horizon (10YR 5/4) with a sandy clay loam texture. Both horizons contain scattered pumice and lithic fragments (<5 cm). In the Tephra Uplands, ca. 5 ka ash-flow tuffs are the parent material for this paleosol (Siebe et al., 1995c). The basal paleosol is found in all three physiographic provinces (Fig. 3, A and B) of the Tetimpa area, and both the Early and Late Tetimpa Occupations took place on this surface (Fig. 3, A and B).

Eruptive Sequence I

Residents of the Late Tetimpa archaeological sites witnessed the first period of late Holocene explosive volcanism. Burying their agricultural fields and dwellings, eruptive sequence I blanketed the Tetimpa area with between 1 and 1.5 m of yellow andesitic (~62% SiO2; Table 2) pumice (unit I.A1; Fig. 3, A and B). The most abundant clast type in the deposit is angular, vesicular to fibrous, pumice lapilli (maximum diameter dmax < 6 cm in the Tetimpa area); angular lithic clasts...
Table 1. Radiocarbon dates determined on samples collected in the Tetimpa area

<table>
<thead>
<tr>
<th>Eruptive sequence II</th>
<th>Conventional 14C age</th>
<th>Measured 14C age</th>
<th>Calibrated calendar age, 95% probability (intercept age)</th>
<th>Stratigraphic context of sample</th>
<th>Excavation or column site (UTM m N/UTM m E)</th>
<th>Sample number and material (lab #)</th>
<th>Analysis method, laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200 ± 70 yr B.P.</td>
<td>1190 ± 70 yr B.P.</td>
<td>a.d. 680 to 1000 (A.D. 875)</td>
<td>Trunk debris in pyroclastic flow above II.A3</td>
<td>95-18 (2109905 m N/542700 m E)</td>
<td>M95-17 charcoal (Beta-83780)</td>
<td>Standard radiometric, Beta Analytic Inc.</td>
<td></td>
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<tr>
<td>1210 ± 60 yr B.P.</td>
<td>1210 ± 60 yr B.P.</td>
<td>a.d. 680 to 980 (A.D. 855)</td>
<td>Beneath II.A2 in San Pedro lacustrine sequence (EH.La2)</td>
<td>94-L4 (Column 4 in Figure 3) (2109050 m N/554700 m E)</td>
<td>94-L4-cs6 charcoal (18802)</td>
<td>AMS, NSF-Arizona AMS Facility</td>
<td></td>
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<tr>
<td>1340 ± 70 yr B.P.</td>
<td>1370 ± 70 yr B.P.</td>
<td>a.d. 605 to 865 (A.D. 675)</td>
<td>Between II.S1 and I.A1 paleosol</td>
<td>94-1 (Column 1 in Figure 3) (2107750 m N/555250 m E) near Operation 5</td>
<td>94-1-cs4a charcoal residue (Beta-86483)</td>
<td>Standard radiometric, Beta Analytic Inc. Standard radiometric, Teledyne</td>
<td></td>
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<tr>
<td>1380 ± 80 yr B.P.</td>
<td>1380 ± 80 yr B.P.</td>
<td>a.d. 550 to 800 (A.D. 660)</td>
<td>Within I.A1 paleosol</td>
<td>94-L6 (2107650 m N/555500 m E)</td>
<td>94-L6-CS3.5c charcoal (Beta-78951)</td>
<td>Standard radiometric, Beta Analytic Inc.</td>
<td></td>
</tr>
<tr>
<td>Late Tetimpa occupation and eruption sequence I</td>
<td>2280 ± 60 yr B.P.</td>
<td>2250 ± 60 yr B.P.</td>
<td>410 to 185 b.c. (375 b.c.)</td>
<td>Base of San Nicolás lacustrine sequence (EH.La1)</td>
<td>94-L6 (2107650 m N/555500 m E)</td>
<td>Standard radiometric, Beta Analytic Inc.</td>
<td></td>
</tr>
<tr>
<td>1930 ± 80 yr B.P.</td>
<td>1930 ± 80 yr B.P.</td>
<td>75 b.c. to a.d. 250 (A.D. 85)</td>
<td>Late Tetimpa site</td>
<td>Operation 5 (2107650 m N/555450 m E)</td>
<td>T94/2-87 charcoal</td>
<td>Standard radiometric, Teledyne</td>
<td></td>
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<tr>
<td>2070 ± 80 yr B.P.</td>
<td>2070 ± 80 yr B.P.</td>
<td>355 to 290 b.c. and 230 b.c. to a.d. 100 (50 b.c.)</td>
<td>Late Tetimpa site</td>
<td>Operation 2 (2106250 m N/555735 m E)</td>
<td>T94/2-29 charcoal</td>
<td>Standard radiometric, Teledyne</td>
<td></td>
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<tr>
<td>2150 ± 80 yr B.P.</td>
<td>2150 ± 80 yr B.P.</td>
<td>385 b.c. to a.d. 25 (180 b.c.)</td>
<td>Late Tetimpa site</td>
<td>Operation 2 (2106250 m N/555735 m E)</td>
<td>T94/2-29 charcoal</td>
<td>Standard radiometric, Teledyne</td>
<td></td>
</tr>
<tr>
<td>Early Tetimpa occupation</td>
<td>2230 ± 80 yr B.P.</td>
<td>2230 ± 80 yr B.P.</td>
<td>405 to 50 b.c. (355, 290, and 230 b.c.)</td>
<td>Early Tetimpa site</td>
<td>Operation 1 (2107750 m N/555250 m E)</td>
<td>T94/1-401 charcoal</td>
<td>Standard radiometric, Teledyne</td>
</tr>
<tr>
<td>2270 ± 80 yr B.P.</td>
<td>2270 ± 80 yr B.P.</td>
<td>485 to 115 b.c. (375 b.c.)</td>
<td>Early Tetimpa site</td>
<td>Operation 1 (2107750 m N/555250 m E)</td>
<td>T94/1-432 charcoal</td>
<td>Standard radiometric, Teledyne</td>
<td></td>
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</tbody>
</table>

Note: All calibrated calendar ages were calculated by Beta-Analytic Inc. using the calibration program of Stuiver and Reimer (1993). UTM—Universal Transverse Mercator.

*Age after measured or estimated 13C/12C correction.

+Conventional 14C ages based on estimated 13C/12C ratios.

+Dates reported by Plunket and Uruñuela (1996b) and, as this paper went to press, Plunkett and Uruñuela, 1998.

...the eruption of the olivine-bearing andesitic lava flows (Fig. 3B, unit I.Lf) followed the Plinian phase of eruptive sequence I. These flows originated from lateral vents on the east side of the volcano (Demant, 1981; von Erffa et al., 1977) and spread over the southwest part of the Tetimpa area, creating the Lava Flow Uplands. Quarries near Nealtican (Fig. 2) show that the lava directly overlies tephra of unit I.A1, the yellow pumice deposit (Fig. 3B). Lava flows have a thickness in the Tetimpa area of 20–40 m, and steep rocky flow fronts reached as far east as San Jerónimo Tecuanipan (Fig. 2). By damming and diverting drainages, the lava flows altered the surface hydrology of the Tetimpa area. Truncated stream valleys and springs at La Leona and along the flow front near San Jerónimo preserve the locations of paleovalleys buried by the lava flows. Near San Nicolás, a thick sequence of laminated silt and clay indicates that the lava flows dammed drainage of the Alseseca and Nexac streams (Fig. 2). Valley walls of the Barranca Lowlands expose these deposits, the San Nicolás lacustrine sequence (EH.La1; Fig. 3C).

Radiocarbon dating of charcoal preserved in the base of this silt and clay sequence provides a minimum age for the eruption of the lavas and the emplacement of the dam. Carbon found in the base of the lacustrine sequence near the dam site (Fig. 2; Panfil, 1996) yielded a date of 2280 ± 60 yr B.P. (Table 1), an age consistent with that of the eruption of unit I.A1, the yellow pumice that buried the Late Tetimpa sites. The lack of soil development or weathering along the contact between the yellow pumice (I.A1) and the andesite (I.Lf; Fig. 3B) is supporting evidence for grouping the yellow pumice and the lava flows in the same eruption sequence: substantial time did not elapse between eruptive events.

**Eruptive Hiatus**

A hiatus in explosive volcanism lasting ~750 14C yr followed eruptive sequence I. In the Barranca Lowlands, this hiatus is recorded by deposition of the San Nicolás lacustrine sequence that crops out south and east of the town (unit EH.La1, Fig. 3C; Fig. 2). Measured sections (Panfil, 1996) indicate that 20 to 25 m of interbedded clay, silt, and sand are uninterrupted by major tephra layers (Fig. 3C). Overall the sequence coarsens upward and can be divided into a lower section (total thickness, 10–20 m; Fig. 3C, 0–5 m marks) consisting mainly of finely laminated silt and clay and an upper section (total thickness, 6–7 m; Fig. 3C, 5–11 m marks) dominated by coarse sand and gravel lenses.

Silt and clay in the lower part of the section sug-
Figure 3. Detailed stratigraphic sections showing deposit characteristics and stratigraphic relationships. Average grain size of clastic deposits indicated by column width. Deposit codes are explained in legend and text. (A) Sequence found near archaeological sites in the Tephra Uplands. (B) Sequence found in the Lava Flow Uplands. (C) San Nicolás lacustrine sequence found along the Aleseca stream in the Barranca Lowlands. The carbon sample found near the dam site at the base of the lacustrine sequence was recovered from a similar stratigraphic section 500 m to the east (Panfil, 1996). (D) San Pedro lacustrine sequence found along the Rio Apol in the Barranca Lowlands. Refer to Figure 2 for column locations.

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**Figure 3. (Continued.)**

C Column 3: Barranca Lowlands (Lake San Nicolás)

D Column 4: Barranca Lowlands (Lake San Nicolás)
paleosols. In the Tephua Uplands, organic accumulations and a sandy matrix define a weakly developed A horizon (10YR 6/3) in the upper 15–40 cm of the yellow pumice, unit IA1 (Fig. 3A). A similar sandy A horizon can be found in pockets on the upper surface of the lava flow (LLf; Fig. 3B). In both areas, the paleosols are Entisols with no B horizon development. Despite the weak development of the soils, it appears that human inhabitants farmed the paleosol surface: ceramics, building structures, and agricultural furrows are found on the IA1 paleosol surface in the Tephua Uplands (Hirth et al., 1996). These artifacts and structures belong to the Tetimpa Reoccupation period (Fig. 3A).

In the Barranca Lowlands, most of the San Nicolás lacustrine sequence (EHLa1) is capped by as much as 6.5 m of massive lahar deposits (EH.Lr1, 2, and 3; Fig. 3C). Sieved samples of the purplish-gray matrix have a composition of 16% sand, 76% silt, and 8% clay (Galster, 1996). Supported in the matrix are clasts of mixed volcanic lithologies as much as 2 m in diameter (Fig. 3C). Locally, clasts are concentrated in bands at the top of distinct flow units, indicating deposition by a laminar flow. These clast-rich layers and interbedded sand beds (Fig. 3D; 0–2 m mark) separate three flow units and indicate at least three lahar-emplacement events.

Lahars traveled through the Alseseca stream valley, bypassed the San Nicolás lake dam, and continued downstream in Barranca Nexac at least as far east as San Jerónimo Tecuanipan (Fig. 2). Lahars also flowed across upland surfaces adjacent to the barranca and may have jumped a narrow drainage divide into Barranca Torres (Fig. 2). In these upland areas, the thin, purplish, well-indurated lahars crop out above the paleosol developed in the IA1 yellow pumice deposit (Fig. 3A; EHLr 0.8 m mark). From stratigraphic evidence in the Tetimpa area, it is unclear what triggered the lahars. It is possible that they were associated with an early eruption phase of eruptive sequence II; however, the lacustrine sequences immediately below and above the lahar deposits do not preserve tephra layers (Fig. 3, C and D). Lacking this evidence, we group the lahars within the eruptive hiatus (EH.Lr 1, 2, and 3; Fig. 3C). Three were deposited as fallout tephra.

Of these beds, unit IA1 is the thinnest in the Tetimpa area and has the smallest regional extent (Fig. 5A). Near archaeological sites, it has a maximum thickness of 12 cm (Fig. 5B, Table 3), is well sorted (Mdθ = 1.8 after Inman [1952]), and contains andesitic (~62% SiO₂; Table 2) pumice lapilli with d₉₅ < 2 cm. The deposit has an overall pinkish-gray color (5YR 3/1) and locally contains inverse symmetric grading or vertical size-sorted laminae. The ellipsoid-shaped area covered by the deposit (Fig. 5A) indicates deposition by winds blowing from the southwest, and the minimum bulk volume is estimated at 0.3 km³ (Table 3).

Units IA2 and IA3 have similar components, suggesting that they represent different phases of one eruption (Table 2). Both deposits are well sorted (IIA2: Mdθ = 1.4; IIA3: Mdθ = 1.7) and made dominantly of andesitic (~62% SiO₂; Table 2) pumice lapilli (IIA2: d₉₅ < 3.6 cm; IIA3: d₉₅ < 3.6 cm). The lahar deposits are found at the base of eruptive sequence II and are separated from the first tephras by 30 cm of laminated clays and silts (Fig. 3D; EH.La2, 2.0–2.3 m mark). The duration of the eruptive hiatus is constrained by 14C dates from the lacustrine sequences and from the paleosol developed in the yellow pumice (IA1) of eruptive sequence I. Carbon from the base of the San Nicolás lacustrine sequence dates the beginning of sedimentation behind the lava-flow dam and the cessation of eruptive sequence I to ca. 2100 yr B.P. During lacustrine sedimentation in the Barranca Lowlands, paleosols developed in upland areas, and the Tetimpa Reoccupation period of human settlement took place (Fig. 3A). Carbon from the paleosol surface in the Tephua Uplands yielded a date of 1340 ± 70 yr B.P. (Fig. 3A; Table 1), indicating that the eruptive hiatus persisted for ~750 14C yr. This time period is consistent with the age estimated for the Tetimpa Reoccupation sites from ceramic chronologies (Hirth et al., 1996).

Near the end of this eruptive hiatus, lahars (EH.Lr 1, 2, and 3) traveled through the Tetimpa area, capping most of the San Nicolás lake deposits (EH.La1; Fig. 3C) and extending up onto the paleosol surface developed in the yellow pumice (IA1; Fig. 3A). Sedimentation continued only in the north end of the San Nicolás lake (EH.La2; Fig. 3D) where the lahars appear to have draineddamaged from the Apol stream. The San Pedro lacustrine sequence (Fig. 3D) indicates that deposits from a second series of explosive eruptions, eruptive sequence II, reached the Tetimpa area soon after lahar deposition. During this eruptive period, a series of tephra falls blanketed the landscape developed during the eruptive hiatus and buried settlements of the Tetimpa Reoccupation. The tephras record two types of eruptive events: subaerial fallout that suggest Plinian eruption phases and pyroclastic surges.

All three landscapes of the Tetimpa area preserve a sequence of andesitic pumice deposits (units IA1, IA2, IA3; Fig. 3, A–D). Similar to the IA1 pumice unit from eruptive sequence I, these deposits are well sorted and dominantly composed of angular pumice lapilli with minor lithic lapilli and crystal-rich ash. Values for mean diameter and sorting (graphical standard deviation) are consistent with those predicted for pyroclastic-fall deposits by Wohletz and Heiken (1992). This observation and the deposits’ regionally uniform distribution suggest that all three were deposited as fallout tephras.

Though limited in extent, these younger lacustrine deposits contain tephra layers associated with the second period of explosive volcanism and are critical for constraining the timing of lahar events and the beginning of eruptive sequence II (Fig. 3D). The lahar deposits are found at the base of eruptive sequence II and are separated from the first tephras by 30 cm of laminated clays and silts (Fig. 3D; EH.La2, 2.0–2.3 m mark).

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### Eruptive Sequence II

The San Pedro lacustrine sequence (Fig. 3D) indicates that deposits from a second series of explosive eruptions, eruptive sequence II, reached the Tetimpa area soon after lahar deposition. During this eruptive period, a series of tephra falls blanketed the landscape developed during the eruptive hiatus and buried settlements of the Tetimpa Reoccupation. The tephras record two types of eruptive events: subaerial fallout that suggest Plinian eruption phases and pyroclastic surges.

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Isopach data points (thicknesses in cm):
paleosol + clean pumice/clean pumice only

Figure 4. Isopach and isopleth maps for deposit I.A1. The regional isopach map (A) should be considered an estimate of the minimum extent of the deposit; isopach lines are drawn for the outcrop thickness of clean, unmixed tephra and exclude the fraction of the deposit incorporated into the overlying paleosol (see Fig. 3A). For comparison, isopach data points (in A and B) show both the thickness of the clean, unmixed tephra deposit and the thickness of the sum of the tephra and the overlying paleosol. In some cases, the original deposit thickness may have been 20–40 cm greater than the measured clean, unmixed tephra thickness. The local isopach map (B) demonstrates local variations in tephra thickness in the Tetimpa area (inset in A) where pumice-mining operations created an extremely high outcrop density. Isopleths are for the distribution of the maximum diameters of the five largest pumice (C) and lithic (D) clasts found in 1 m² outcrop exposures (Panfil, 1996). Refer to Figures 1 and 2 for town names and latitude and longitude. Deposit I.A1 correlates with unit LCPPF in Siebe et al. (1996).

<table>
<thead>
<tr>
<th>Tephra-fall unit</th>
<th>Maximum deposit thickness in Tetimpa area (cm)</th>
<th>Dispersal axis orientation</th>
<th>Minimum area covered by &gt;25 cm of tephra (km²)</th>
<th>Minimum bulk deposit volume* (km³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.A1 Yellow Pumice</td>
<td>~100–150†</td>
<td>East</td>
<td>240</td>
<td>3.2</td>
</tr>
<tr>
<td>II.A1 Pink Pumice</td>
<td>12</td>
<td>Northeast</td>
<td>52</td>
<td>0.27</td>
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<tr>
<td>II.A2 Lower White Pumice</td>
<td>20</td>
<td>Northeast</td>
<td>180</td>
<td>0.42</td>
</tr>
<tr>
<td>II.A3 Upper White Pumice</td>
<td>50–60†</td>
<td>East</td>
<td>230</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*Estimates of minimum bulk deposit volumes were made from isopach data and the method of Pyle (1989). Estimates are uncorrected for deposit and pumice porosity.
†Thickness excludes portion of deposit incorporated into overlying paleosol or soil.
$d_{\text{max}} < 4.1$ cm near archaeological sites. Pumice fragments are generally less dense and more fibrous than those from unit I.A1. The deposits have an overall white to light yellow color (2.5YR 7/4 to 10YR 8/2) and also contain lithic lapilli (I.A2: $d_{\text{max}} < 1.0$ cm; I.A3: $d_{\text{max}} < 1.2$ cm near archaeological sites) and crystal-rich ash.

The dispersal axis for the I.A2 deposit (Fig. 6A; Table 3) is northeast, indicating southwesterly winds during the eruption. During deposition of unit I.A3, the wind shifted, and the dispersal axis for this deposit is oriented to the east (Fig. 7A; Table 3). Estimates based on the isopleth data (Figs. 6, C and D; 7, C and D) and the method of Carey and Sparks (1986) suggest column heights of between 20 and 30 km for both eruption plumes and wind speeds of between 20 and 30 m/s at the tropopause (Panfil, 1996). As with the yellow pumice from eruptive sequence I (unit I.A1), the extensive nature of the deposits and their composition suggest Plinian eruption phases.

At least three 1–13-cm-thick bands of coarse sand-sized, subangular crystal and lithic ash are locally interbedded with tephra-fall deposits of eruptive sequence II (Figs. 3A-D). Given their grain size and composition, these deposits can be interpreted as either fine-grained tephra-fall layers or pyroclastic surge deposits.

The strongest evidence supporting a surge origin is charcoal at the base of the I.S1 deposit (Fig. 3A) and sedimentary structures that indicate deposition by a moving current (Fig. 8). Charcoal is preserved at the contact between the I.S1 unit and the paleosol developed in the I.A1 deposit; a hot surge would have charred vegetation on this surface leaving behind a carbon lag. The millimeter- to centimeter-scale cross-laminations found in units I.S1, I.S2, and I.S3 are further evidence suggesting deposition by a turbulent flow (Figs. 3A and 8). Unit I.S3 also contains sand waves, dunelike structures (Fig. 8) typical of surge deposits (Allen, 1984; Carey, 1991). These structures have a wavelength of 1–2 m and an amplitude of ~30 cm. A nonvolcanic depositional mechanism such as stream flow seems unlikely for these structures since the orientation of cross-bedding within them indicates current flow in an upslope direction. Sand waves found in unit I.S3 match Allen’s (1984) description of type A2 progressive bedforms, suggesting deposition by a relatively dry and/or hot surge.

The strongest evidence supporting deposition as tephra fall is the regionally extensive nature of the deposits (Fig. 5, B and C). The units are not confined to areas proximal to the crater, but instead are found as far as 20 km east of the volcano. In addition, unlike many surge deposits formed as the lower-density differentiates of pyroclastic flows (Carey, 1991), the Tetipama area pyroclastic surge units are not found in association with pyroclastic flow deposits. However, pyroclastic flow deposits are exposed 6 km upslope of the archaeological sites (Panfil, 1996), and other pyroclastic flow deposits have been previously reported within eruptive sequence II (Boudal and Robin, 1989; Siebe et al., 1995c, 1996). It is also possible that the surges were emplaced independently of pyroclastic flows by a phreatomagmatic mechanism (J. L. Macías, 1997, personal commun.) similar to that described for deposits at El Chichón volcano in Mexico (Macías et al., 1997).

Some of the strongest evidence supporting the
surge origin—the sand waves—has only been described within the Tetimpa area. This restriction may be a consequence of the excellent exposures created by the pumice-mining operations near San Buenaventura. However, it is also possible that the surge events occurred at the same time as tephra-fall events with more regional distribution. The II.S1, II.A1, II.S2, and II.S3 deposits may include material from both tephra-fall and pyroclastic surge events. The gradation between II.S1, II.A1, and II.S2 and between II.S3 and II.A3 (Fig. 8) supports this interpretation, as it suggests that the surges incorporated tephra-fall material that was deposited at the same time.

Concurrent deposition of II.S1 and II.S2 with II.A1 may also explain the laminations and size sorting noted locally in unit II.A1 (Fig. 8).

Superposition relationships, 14C dating, and the San Nicolás lacustrine sequence (EH.La2) constrain the timing of events in eruptive sequence II. In most areas, eruptive sequence II deposits crop out as a stacked sequence above the paleosols and lahar deposits of the eruptive hiatus (Fig. 3, A–C). However, 14C dating and the EH.La2 sequence (Fig. 3D) show that the eruptive sequence II events took place in two phases, perhaps separated in time by as much as ~150 14C yr.

The thin, pinkish, tephra-fall unit (II.A1) and its associated surges (II.S1, II.S2) took place during the earlier of these two phases. Pyroclastic surge II.S1 produced the carbon residue noted along the upper contact of the paleosols developed in the deposits from eruptive sequence I (Fig. 3, A and B). Charcoal from this scorched surface dates these eruption events to 1340 ± 70 yr B.P. (Table 1; Fig. 3A). The three deposits directly overlain one another and in some cases merge (Fig. 8), suggesting that they were produced either concurrently or by events that occurred in close succession.

A short hiatus followed the eruption of these units (II.S1, II.A1, and II.S2). The EH.La2 lacustrine deposits (Fig. 3D, 2.4–3.7 m interval) include 1.3 m of laminated clay, silt, and sand above the pinkish pumice of unit II.A1. Carbon from the top of this interval dates to 1210 ± 60 yr B.P., suggesting that these deposits may record a time interval of years to decades before the next explosive eruption phase began. Locally, deposits II.S1, II.A1, and II.S2 are found in lenses mixed into the paleosol developed in unit I.A1. The disturbed deposits are further evidence of a time gap between the first and second phases of eruptive sequence II.

The second explosive eruption phase deposited tephra-fall units II.A2 and II.A3, a third pyroclastic surge deposit II.S3, and possibly a fourth, II.S4. The white pumice of unit II.A2 preserves the first Plinian phase of these events to reach the Tetimpa area (Fig. 3, A–C). Defining the upper contact of this unit is the fine-grained deposit of II.S3, which locally contains sand waves and cross-beds and records a surge event in the Tetimpa area. Another Plinian eruption phase occurred with or followed deposition of II.S3 and deposited the white pumice of unit II.A3 (Fig. 3, A–D). Locally, fine-grained deposits of II.S4, possibly a fourth surge, are exposed above this unit (Fig. 3D). Because units II.A2, II.S3, II.A3, and II.S4 are not separated by lacustrine sediments in the San Pedro lacustrine sequence (Fig. 3D), it is likely that they occurred without as long a time gap as noted between II.S2 and II.A2. A 14C date of 1190 ± 70 B.P. (Table 1) from deposits lying stratigraphically above unit
ILA3 near the Paso de Cortez (Fig. 1) supports this conclusion by providing a minimum age for these Plinian eruptions.

Deposits of eruptive sequence II preserve a complex sequence of eruptive events that reached the Tetimpa area in two phases at ca. 1350 and ca. 1200 yr B.P. These events included pyroclastic surges and tephra falls that buried the Tetimpa Reoccupation sites and blanketed much of the northeastern and eastern slopes of Popocatépetl. The modern surface Entisol, defined in the Tetimpa area by a 30–120-cm-thick A horizon (10YR 3/1), extends into deposits from eruptive sequence II (Fig. 3, A–C). The soil indicates either that major tephra eruptions have not affected the Tetimpa area since ca. 1200 yr B.P. or that the geologic record for these events is not preserved in the Tetimpa area.

CONCLUSIONS

Correlation across Tetimpa Landscapes

Deposits in the Tetimpa area record two periods of explosive volcanism within the past 2500 yr — eruptive sequence I and eruptive sequence II — separated by a hiatus of ~750 14C yr. During both periods, pre-Hispanic occupation sites in the Tetimpa area were buried by Plinian eruptions of proportions large enough to displace populations and affect regional settlement patterns.

Figure 9 illustrates the stratigraphic correlations across the three landscapes of the Tetimpa area, the Lava Flow Uplands, the Barranca Lowlands, and the Tephras Uplands. At the base of the sequence is the regionally extensive paleosol surface exposed before the late Holocene eruptions. Both the Early and Late Tetimpa occupations took place on this paleosol (Fig. 9, column C). In ca. 2100 yr B.P., residents of the Late Tetimpa sites abandoned the area as eruptive sequence I blanketed this surface with yellow andesitic pumice (I.A1; Fig. 9; all columns) and olivine-bearing andesitic lava flows (ILL; Fig. 9, column A). Isopach maps show that the eruption was large enough to have regional human consequences: pumice lapilli deposits >25 cm thick cover an area of at least 240 km². With the dispersal axis of the deposit oriented to the east, it is likely that tephra reached as far as Cholula during a period when the city's population was rising (Mountjoy and Peterson, 1973).

In addition to burying settlements and agricultural fields, lava flows (ILL) of eruptive sequence I buried stream valleys, dammed drainages, and caused the deposition of a lacustrine sequence in the Barranca Lowlands (Fig. 9, column B). The San Nicolás lacustrine sequence (EH.Lal) records a hiatus in volcanic activity experienced by the Tetimpa area between ca. 2100 and ca. 1350 yr

Figure 7. Isopach and isopleth maps for deposit II.A3. (A) The regional isopach map should be considered an estimate of the minimum extent of the deposit; isopach lines are drawn for the outcrop thickness of clean, unmixed tephra and exclude the fraction of the deposit incorporated into the overlying soil (see Fig. 3A). For comparison, isopach data points (in A and B) show both the thickness of the clean, unmixed tephra deposit and the thickness of the sum of the tephra and the overlying soil. The local isopach map (B) demonstrates local variations in tephra and soil thickness in the Tetimpa area (inset in A). Isopleths are for the distribution of the maximum diameters of the five largest pumice (C) and lithic (D) clasts found in 1 m² outcrop exposures (Panfil, 1996). Parentheses indicate sites lacking units II.S3 and II.A3 to provide stratigraphic context for the conclusion by providing a minimum age for these Plinian eruptions.

Deposit II.A3 correlates with unit UCPPF3 in Siebe et al. (1996). Parentheses indicate sites lacking units II.S3 and II.A3 to provide stratigraphic context for the identification of this pumice unit. Refer to Figures 1 and 2 for town names and latitude and longitude. Deposit II.A3 correlates with unit UCPPF3 in Siebe et al. (1996).
B.P. During this time, Entisols developed in the pumice (I.A1) and lava (I.Lf) deposits covering the upland areas (Fig. 9, columns A and C), and residents of the Tetimpa Reoccupation returned to farm the Tephra Uplands (Fig. 9, column C). At the end of the eruptive hiatus, a series of lahars (EH.Lr1, 2, and 3) flowed through the Tetimpa area, capping most of the San Nicolás lacustrine sequence (Fig. 9, column B). Lahars flowed as far east as San Jerónimo and caused ponding and additional lacustrine sedimentation in a small area of the Barranca Lowlands (EH.La2; Fig. 9, column B).

Between ca. 1350 and ca. 1200 yr B.P., tephras from eruptive sequence II buried paleosols, occupation sites, and lowland deposits of the eruptive hiatus. Lacustrine deposits (EH.La2) between these tephra layers near San Pedro Yancuitlalten demonstrate that eruption events took place in two phases (Fig. 9, column B). The first phase occurred at ca. 1350 yr B.P. when pyroclastic surges (ILS1, ILS2) and a small tephra fall (I.A1) reached the Tetimpa area (Fig. 9; all columns). Lacustrine deposits (EH.La2) crop out above unit I.AI in the Barranca Lowlands and mark the brief hiatus that followed (Fig. 9, column B). The second explosive phase of eruptive sequence II occurred at ca. 1200 yr B.P. and deposited Plinian pumice falls (II.A2, II.A3) and additional pyroclastic surges (ILS3, ILS4) across the Tetimpa area (Fig. 9; all columns). As with eruptive sequence I, the Plinian events were of substantial proportions: deposit II.A2 covered an area of at least 180 km² with >25 cm of pumice whereas deposit II.A3 covered an even larger area, blanketing at least 230 km² with >25 cm of pumice. Tephra was first distributed to the northeast and later to the east, suggesting that tephra from both of these Plinian events reached Cholula, a regional population center around the time of this eruption.

Regional Integration

To establish an integrated eruptive chronology for Popocatépetl, we summarize published dates for Holocene eruptions and make correlations with the Tetimpa stratigraphy. Table 4 compiles the dates and deposits reported for explosive eruptions at Popocatépetl between ca. 5100 and 450 yr B.P.

The first studies to provide ¹⁴C dates for explosive Holocene eruptions were conducted during the 1970s (Heine and Heide-Weise, 1973; Heine, 1978; Lambert and Valastro, 1976). These studies reported dates of ca. 900 yr B.P. for pumice deposits on the northeast slope near the Tetimpa area.

In the 1980s, geologists conducted more comprehensive stratigraphic studies—e.g., Boudal and Robin (1989), Cantagrel et al. (1984), Robin (1981), and Robin and Boudal (1987). These authors presented additional ¹⁴C dates and made correlations with those reported by the earlier studies. They concluded that Popocatépetl had undergone two periods of explosive volcanism within the past 5000 yr (Robin and Boudal, 1987). Their dates for these eruptive periods cluster between 900 and 1200 yr B.P. and between 4000 and 5000 yr B.P. (Table 4, column 4). Of the tephras they described, these authors reported pumice deposits on the northeast flank near the Tetimpa area.

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During the 1990s, more detailed stratigraphic studies and extensive ¹⁴C dating were carried out (Abrams et al., 1995; Siebe et al., 1995a, 1995c, 1996). These studies redefined the eruptive chronology developed in the 1980s and sketched the regional distribution of major tephra-fall deposits (Siebe et al., 1996). The geologists determined that in addition to the explosive periods...
dated in the 1980s, two additional explosive periods occurred within the past 5000 yr. The eruptive chronology was revised into four explosive periods: 4600–5100, 2100–2500, 1600–1900, and 900–1400 yr B.P. (Table 4, column 3). In addition, Siebe et al. (1996) established that the youngest pumice deposits on the northeast side of the volcano distinguish three eruptive periods instead of the one period identified by Robin and Boudal (1987).

The Tetimpa stratigraphy supports this revised eruption chronology. Ages and distributions of pumice deposits from eruptive sequence I and eruptive sequence II generally correspond to those identified by Siebe et al. (1996) (Table 4, columns 2 and 3). In addition, the archaeology and lacustrine stratigraphy of the Tetimpa area help constrain the timing of specific eruption events within these eruptive sequences. Correlations between the study by Siebe et al. (1996) and the Tetimpa stratigraphy help summarize our current understanding of two of the most recent eruptive periods of Popocatépetl volcano.

Eruptive sequence I of the Tetimpa area corresponds to the Lower Ceramic Plinian eruptive sequence described by Siebe et al. (1996) and to the eruptive period between 2100–2500 yr B.P. (Table 4). There is good agreement between isopach maps for the Plinian deposit from this eruptive sequence; unit I.A1 corresponds to the Lower Ceramic Plinian pumice fall of Siebe et al. (1996). Excavation of the Late Tetimpa sites further constrains the age of the Plinian phase of this eruption to ca. 2100 yr B.P. (Plunket and Uruñuela, 1996b; Table 1) since it appears that the eruption caused the abandonment of Late Tetimpa dwellings.

Eruptive sequence II of the Tetimpa area corresponds to the Upper Ceramic Plinian eruptive sequence of Siebe et al. (1996) and to the eruptive period between 900 and 1400 yr B.P. (Table 4). Both the study by Siebe et al. (1996) and our study mapped three pumice deposits from this eruptive period on the east and northeast side of the volcano. However, the interpreted ages and dispersal-axis orientations of some deposits vary.

Although these discrepancies are currently unresolved, our comparison of 14C dates, composite sections, and dispersal-axis orientations suggest that the three units described in each study may actually represent four pumice eruptions. The pink pumice of the Tetimpa area, unit II.A1, is the oldest and smallest pumice unit. It was deposited toward the northeast and was associated with pyroclastic surges. On the basis of 14C dates in the composite sections of Siebe et al. (1996), it may correlate with the first tephra-fall (AF) unit identified in the Upper Ceramic Plinian eruptive sequence, which was not presented in an isopach map by Siebe et al. (1996). This eruption was followed by two or three Plinian eruption phases. The first, unit UCPPF1 in Siebe et al. (1996), had a dispersal axis toward the north-northeast and was not mapped in our study. The second, unit UCPPF2, was directed toward the northeast and corresponds to unit II.A2 of the Tetimpa area; the third, unit UCPPF3, was directed toward the east and corresponds to unit II.A3.

Lacustrine deposits (EH.La2) in the Tetimpa area demonstrate that the tephra-fall events of eruptive sequence II did not occur in rapid succession, but instead occurred in two intervals that were separated by perhaps years to decades. Radiocarbon dates from our study and from Siebe et al. (1996) date the beginning of this eruptive sequence to ca. 1350 yr B.P. (ca. A.D. 670). In the Tetimpa area, the first events recorded in the stratigraphy are pyroclastic surges and tephra
eruption II.A1. Lacustrine deposits (EH.La2) overlie unit II.A1 and indicate a time gap before the Plinian eruption events. Radiocarbon dates in the Tetimpa area suggest that these Plinian eruption phases occurred at ca. 1200 yr B.P. (ca. A.D. 860). This result is in good agreement with the date of A.D. 822 or 823 suggested by Siebe et al. (1996) from correlation with the sulfate record from the Greenland Ice Sheet Program 2 core (Zielinski et al., 1994). Ongoing excavations of the Tetimpa Reoccupation sites buried during this eruptive period may further constrain the timing of eruption events within this sequence.

The stratigraphy and archaeology of the Tetimpa area vividly demonstrate the human consequence of late Holocene eruptions of Popocatépetl volcano. Two explosive periods within the past 2500 yr buried occupation sites and forced human abandonment of the area. Both of these eruptive periods included Plinian pumice falls on scales large enough to have regional consequences. The potential recurrence of these events underscores the need to support ongoing hazards mitigation and monitoring efforts.

ACKNOWLEDGMENTS

We especially thank the Mesoamerican Research Foundation, which provided the principal funding for this study. The National Science Foundation Graduate Fellowships Program and the GSA Graduate Research Grants Program also supported this research.

### Table 4. Compilation of Eruption Dates Reported for the Period from Ca. 5100 to Ca. 450 yr B.P. for Popocatépetl

<table>
<thead>
<tr>
<th>Eruptive period (yrs B.P.)</th>
<th>Tetimpa area</th>
<th>Studies in the 1990s [This study; Plunket and Urufiela, 1996a]</th>
<th>Studies in the 1980s [Siebe et al., 1995a; Abrams et al., 1995a; Siebe et al., 1995b; Siebe et al., 1995c]</th>
<th>Studies in the 1970s [Cantagrel et al., 1984; Robin 1981; Robin and Boudal, 1987]</th>
</tr>
</thead>
<tbody>
<tr>
<td>400–800</td>
<td></td>
<td>450 (n/a)&lt;sup&gt;7&lt;/sup&gt;</td>
<td>About 430–450 (n/a)&lt;sup&gt;11&lt;/sup&gt; pyroclastic flows</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>450 to 800 (T)&lt;sup&gt;8&lt;/sup&gt;</td>
<td>pumice, sand</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>880 ± 80 (C)&lt;sup&gt;9&lt;/sup&gt;</td>
<td>880–960 (n/a)&lt;sup&gt;12&lt;/sup&gt; “Eruption”</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>800 ± 65 (C)&lt;sup&gt;9&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>950 ± 50 (T)&lt;sup&gt;10&lt;/sup&gt;</td>
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<tr>
<td></td>
<td></td>
<td>1000 ± 60 (C)&lt;sup&gt;11&lt;/sup&gt;</td>
<td>965 ± 60 (C)&lt;sup&gt;11&lt;/sup&gt;Layer of yellow pumice on northeast side</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;4 pyroclastic flows on north slope above “superior” gray pumice layers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1220 ± 60 (C)&lt;sup&gt;12&lt;/sup&gt;</td>
<td>&lt;1626 ± 34 (C)&lt;sup&gt;13&lt;/sup&gt;Medium to dark gray ash</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1230 ± 90 (C)&lt;sup&gt;13&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>900–1400 eruptive sequence II</td>
<td>1250 to 1150 (C)&lt;sup&gt;14&lt;/sup&gt;</td>
<td>1255 to 1095 (C)&lt;sup&gt;14&lt;/sup&gt;</td>
<td>1275 ± 60 to 855 ± 155 (C)&lt;sup&gt;14&lt;/sup&gt; pyroclastic surges, lahars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;1190 ± 70 (C)&lt;sup&gt;15&lt;/sup&gt;</td>
<td>&lt;1210 ± 60 (C)&lt;sup&gt;1&lt;/sup&gt; White pumice fall to the northeast and east—II.A2, II.A3 and pyroclastic surges—II.S3, II.S4</td>
<td>880 ± 60 (C)&lt;sup&gt;15&lt;/sup&gt; “Eruption”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;1340 ± 70 (C)&lt;sup&gt;16&lt;/sup&gt;</td>
<td>&lt;1380 ± 80 yr B.P. (C)&lt;sup&gt;12&lt;/sup&gt;</td>
<td>900 ± 65 (C)&lt;sup&gt;9&lt;/sup&gt; Pumice fall to the northeast and east, pyroclastic surges, lahars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pyroclastic surges—II.S1, II.S2, pink pumice fall to the northeast—II.A1</td>
<td>1275 ± 60 (C)&lt;sup&gt;17&lt;/sup&gt;</td>
<td>950 ± 50 (T)&lt;sup&gt;10&lt;/sup&gt; Pumice fall to the northeast and east, pyroclastic surges, lahars</td>
<td></td>
</tr>
<tr>
<td>1600–1900</td>
<td>1695 ± 100 to 1825 ± 175 (C)&lt;sup&gt;18&lt;/sup&gt;</td>
<td>1700 ± 100 to 1825 ± 175 (C)&lt;sup&gt;18&lt;/sup&gt;Lavas, lahars, pumice fall, and ash flows</td>
<td>1626 ± 34 (C)&lt;sup&gt;13&lt;/sup&gt;White, pale yellow ash</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1626 ± 34 (C)&lt;sup&gt;13&lt;/sup&gt; Lava, pumice, sand</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2100–2500 eruptive sequence I</td>
<td>2450 to 2050 (C)&lt;sup&gt;19&lt;/sup&gt;</td>
<td>2500 to 2100 (C)&lt;sup&gt;19&lt;/sup&gt;</td>
<td>2750 ±135 to 2165 ± 65 (C)&lt;sup&gt;19&lt;/sup&gt; pyroclastic surges, lahars</td>
<td></td>
</tr>
<tr>
<td>2750 ±135 to 2165 ± 65 (C)&lt;sup&gt;19&lt;/sup&gt;</td>
<td></td>
<td></td>
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<tr>
<td>3800</td>
<td>3840 ± 70 (C)&lt;sup&gt;20&lt;/sup&gt; Pyroclastic flows, ashes, pumice</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4300</td>
<td>4320 ± 70 (C)&lt;sup&gt;20&lt;/sup&gt; Ash and scoria flows, bombs</td>
<td></td>
<td></td>
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<tr>
<td>4600–5100</td>
<td>4645 ± 60 (C)&lt;sup&gt;21&lt;/sup&gt; Basal horizon</td>
<td>5145 ± 75 to 4780 ± 65 (C)&lt;sup&gt;21&lt;/sup&gt; Pumice fall to the northeast, pyroclastic flows, and possible blast deposits</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4980 ± 50 (C)&lt;sup&gt;21&lt;/sup&gt;</td>
<td>4805 ±60 (C)&lt;sup&gt;12&lt;/sup&gt; “Eruption”</td>
<td>5075 ±45 Piuprice, yellow pumice lapilli</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5081 ± 45 (C)&lt;sup&gt;13&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Dating methods are indicated in parentheses: C—14C (uncorrected for 13C), C13—14C (corrected for 13C), T—tephrachronology, n/a—unspecified. Numbered footnotes in table refer to references in header for each column.

*Dates reported by the authors in calendar years (age in yr B.P. approximated by subtracting or adding from 1950).