Repeated disasters in Prehispanic time produced by Plinian eruptions at Popocatépetl volcano, Central Mexico: Past key to the future ?

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by

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Abstract

Holocene volcanic activity at Popocatépetl volcano is characterized by recurrent Plinian eruptions of considerable magnitude every 1000 to 2000 years. Among them the last two major eruptions are of particular interest because they destroyed several human settlements. The older major Plinian eruption ocurred between 2500 and 2100 y. B.P. and started with minor ash fall and and ash flows followed by a series of surges produced by hydromagmatic explosions at the crater. Subsequently, the eruption reached its climax with a main Plinian phase and the deposition of a pumice fall with a dispersion axis towards the NE. The eruption culminated with the emplacement of hot ash-flows followed by mudflows. By 822-823 A.D. the area was repopulated and the pattern essentially repeated destroying several settlements, including Cholula, a major ceremonial center which was flooded by lahars. This time the dispersion axis of the Plinian pumice fall was to the east. Reoccurrence of such an eruption today would have disastrous effects and this possibility should be seriously taken into consideration by disaster prevention authorities.

Introduction

On December21, 994 Popocatépetl volcano in central Mexico (Fig. 1) started erupting and forced civil protection authorities to evacuate 50 000 people living on the eastern flank of the volcano. Although so far the activity has been mostly restricted to the periodic emission of fine ash, a major cataclysmic Plinian eruption cannot be ruled out.

Closer inspection of deposits produced by the last two major eruptions 2500 to 2100 y. B.P. and 1255 to 1095 y. B.P. revealed evidence of Popocatépetl´s destructive potential. Both eruptions were quite devastating and followed a similar eruptive pattern. After emission of minor ash fall and ash flows the climactic phases of the eruptions started with hydromagmatic explosions at the summit crater that produced a series of hot *pyroclastic surges*. This activity peaked in a major Plinian eruption whose column reached stratospheric heights and produced thick Plinian pumice fall deposits. The eruptions culminated with the emplacement of ash flows and mudflows radially away from the volcano. In both cases, vast areas were destroyed including Precolumbian settlements, as evidenced by agricultural furrows, pottery sherds, etc. covered or incorporated by the deposits.

Stratigraphic relations

The best outcrops showing the eruptive sequence of the two major Late Holocene Plinian eruptions occur in the northeastern sector of the volcano (Figs. 3 and 4). From more than 130 stratigraphic sections studied in detail, the four most representative arc. shown in Fig. 3. The older Plinian sequence usually rests on top of a dark-grey to brownish ash flow deposit sequence rich in charcoal, whose surface was exposed for a long period of time and was exploited agriculturally by early inhabitants of the Xalitzintla Valley. On this surface well preserved agricultural furrows, abundant pottery sherds and occasional remains of housing structures have been found (1). C-14 dates of charcoal within these deposits yielded ages that range between 2175 + 55/-50 and 2470 ± 70 y. B.P. (Table 1).

The older Plinian eruption started with the emission of minor ash fall ancl ash flows. This activity led to the emplacement of hot, turbulent, diluted surges preserved at proximal areas. "Their deposits consist of up to five thin (2 -10 mm) layers of ochre and grey, silty to sandy ash beds with frequent cross-bedding. After this initial phase of hydromagmatic activity, the main phase of the eruption began producing', a thick and widespread Plinian pumice fall. The deposit is characterized by ochre colored angular pumice clasts of andesitic composition (Table 2) with minor dark grey scoria clasts and occasional light green siltstone clasts. A thickness of 110 cm has has been measured at location 9484 near San Nicolás de 10S Ranchos (Figs. 3 and 4), 20 km from the crater. The principal dispersion axis points towards the NE. Using the methods of (2) to estimate the height of the Plinian eruption column from the thickness, distribution, and clast size, we calculate that the column reached at least 25 km in altitude, well into the stratosphere, where particles and aerosols became globally dispersed.

The eruption ended with the emplacement of ash flows distributed radially around the volcano. They were channeled by pre-existing topography and their deposits consist mostly of pumice fragments embedded in a dark grey sandy matrix, rich in charcoal. Afterwards, the erupted material was partially remobilized by lahars that reached localities at considerable distances away from the volcano (e.g. Cuautla and Izúcar).

After this major eruption at least three minor eruptions occured that included the local emplacement of lahars, block-and-ash flows, scoria flows, a minor Plinian pumice fall and related ash flows (see Fig. 3).

The younger major Plinian eruption started again with minor ashfall andflows followed by hydromagmatic activity and emplacement of at least four silly-sandy surge deposits with occasional cross-stratification. C-14 dates of charcoal and pine needles within the ash flow and surge deposits yielded ages that range between 1255 ± 60 and 1095 ± 60 y. B. P. (Table 1). These deposits rest frequently on top of the reworked ochre pumice, with agricultural furrows and abundant pottery shards on top of this reworked surface

Again, after emplacement of the surges, the main phase of the eruption produced a thick pumice fall layer with a dispersion axis towards the ENE. The fall deposit is characterized by pink-grey angular fragments of two-pyroxene andesite pumice almost identical in chemical and mineralogical composition to the ochre pumice (Table 2). This points towards the existence of a large and lon.g-lived magma chamber. The occurrence of minor lithic scoria fragments in both pumice fall deposits suggests repeated injection of more basic magma from greater depths into the silicic shallower chamber during both eruptions. Although at proximal outcrops of the last Plinian eruption only onc fall unit can be recognized, in the Xalitzintla Valley three distinct units are found. Again, using the method of(2), we estimate a height of at least 25 km for the Plinian eruption column. On top of this pumice fall deposit again a sequence of dark grey ash flows and ashfall deposits occurs, which were followed by the emplacement of mudflows.

The above described deposits were previously studied by several investigators (3), who also provided C-14 dates for some of the units. C-14 dates reported by these authors for the upper Plinian eruption range between 880 ± 80 and 965 ± 60 y. B. P., which are consistently younger than our dates. This is in strong disagreement with results of our investigations. It is beyond the scope of this paper to discuss the discrepencies in detail, but we are very confident in our results based on replicate measurements, detailed stratigraphic analyses of more than 130 stratigraphic sections, and relative consistency of our dates obtained at different locations.

Local and globs impact of the eruptions

Due to their favora le geographic location with temperate climate, fertile volcanic soils, and availability of water, the high valleys of Central Mexico provided the means for cultural development of Early Man. Between 1000 and 100 B. C., numerous agricultural settlements and few more important ceremonial centers (e.g. Cuicuilco, Tlatilco, Cholula) had developed in the Valleys of Mexico and Puebla *(4).* The valleys arc divided by the volcanic chain comprising Ixtaccihuatl (5280 m) and Popocatépetl (5452 m) volcanoes (Fig. 3). So far, enough evidence. has been found by us and others (1) supporting a direct impact of the 2500-2100 B.P. eruption on human settlements. in the Xalitzintla Valley (see Fig. 3) agricultural furrrows, housing structures and domestic artifacts were buried by the Plinian fall deposit. Near Paso dc Cortes and Amecameca wc have found pottery sherds embeded in pyroclastic deposits, both, stratigraphically below and above the pumice deposits. Based on the distribution of the deposits the destruction of early settlements must have been very extensive. The timing of this eruption roughly coincides with a major migration within the basin of Mexico. Between 100 B.C. and 100 A.C. archaeologists report that settlements in the southeastern part of the basin at the shores of Chalco lake declined in population, while the Zumpango and Teotihuacán valleys to the north suffered a substantial demographic increase (4).

By 750 to 800 A.D. the ancient cities of Teotihuacán and Cholula had already reached their cultural peak and the Classic Period of Meso-American civilization was near its end. Cholula was one of the most important religious centers in Mesoamerica. In the northern portion of the Mexico Basin, Teotihuacán had achieved utmost importance, with a population estimated as high as 150,000 (4). Archaeological evidence points to a major and abrupt decline in population and cultural activity by 750 A.D. This represents the boundary between the Classic Period and the start of the Postclassic Period (see Fig. 3). Apparently Cholula was temporarily abandoned shortly after this time around 800 A.D. (5). The exact reasons for this major cultural transition are unknown but researchers have speculated that food shortages, soil exhaustion, drought, or invasion by semi-nomadic groups may have been responsible.

Our investigations indicate that a major cataclysmic eruption occured at Popocatepetl at this time and certainly affected a minimum area of ca. 70, 000 km^2. in addition to the volcanic deposits (base surges, pumice falls, ash flows, and lahars) described above, around the city of Cholula we have found evidence for widespread floods that reached the base of the great pyramid of Cholula, where their deposits crop out. The sequence of mudflow and flood deposits contains abundant pumice, pottery sherds, and obsidian artifacts. This implies that the city and surrounding agricultural areas were mostly destroyed, leaving essentially the pyramids sticking out of a muddy wasteland. Whether this event by itself triggered the cultural decline or was only an additional factor cannot be evaluated at this time. In this context it should be mentioned that most of the pyroclastic material produced by this eruption was hot enough to carbonize all organic matter encountered. Large forest fires were associated with the eruption, increasing the potential for devastating floods.

It can not be a coincidence that the rise and fall of Teotihuacán and Cholula, the most important cities in Central Mexico during the Classic Period of Mesoamerican Archaeology are bracketed by Popocatépetl´s last major Plinian eruptions. These eruptions certainly did not only affect smaller settlements in its immediate surroundings, but must also have damaged **man-made** irrigation systems at more distant areas. The repercussions of Cholula´s and Teotihuacan´s fall seem to have been associated with mayor waves of migration felt throughout civilized Mexico and Central America affecting also the Maya centers in Yucatán and Guatemala (4). 1 n this context it is important to mention the cyclic myth of creation and destruction portrayed so profusely in Mesoamerican art and religion, which might have had its origin in the repeated volcanic disasters that rocked central Mexico.

On a global scale, this eruption also had an impact. The younger Plinian eruption column reached stratospheric heights allowing dispersal of S04 -2 rich aerosols and ash around the globe. The hi-yearly S04 record from the GISP2 Greenland ice core (6) shows a major (VEI>4) eruption (7) of unknown origin at A. Il. 822-823. Our C-14 dates (Table 1) for the younger Plinian eruption closely cluster around this date, strongly suggesting that it is the same event. It is further possible that this eruption may have affected global climate, like the 1982 and 1993 Pinatubo eruptions (8). The possibility of pinpointing the date of this eruption with the information from the ice-cores to almost the exact year of its ocurrence is of particular interest and will certainly solve a wealth of stratigraphic problems in the Late Quarternary Geology and Archaeology of the area. Because of the eastward dispersal of the Plinian pumice fall we can speculate that the eruption most probably ocurred during the winter or spring of A.D. 822 or 823, because the winds above 5000 m altidudc have a prevailing eastward direction during that seasons of the year.

Concluding Remarks

In conclusion our investigations reveal that the last two major cataclysmic eruptions of Popocatépetl occurred in historic time and were responsible for natural disasters. The older eruption ocurred between 520 ± 70 and 225 ± 50 B.C. and the younger occurred with great certainty in 822 or 823 A.D. Both eruptions bracket the Classic Period of Mesoamerican Archaeology and the time interval elapsed between both eruptions ranges between 1047 and 1342 years. Assuming periodicity of eruptions and extrapolating into the future another cataclysmic eruption should occur between 1869 and 2164 A.D (see also Fig. 2). This is a very unfavourable conclusion, fortunately based on an uncertain asumption. The crucial question still remains unanswered: 1s the magmatic system ready for another cataclysmic eruption ? Is the present activity with apparently harmless emission of ash only another small *intermezzo in* a long chain reaching back to the days of the Spanish Conquest ? Or are the high S02 emissions recorded during the last months a clear indicator for a Plinian eruption in the near future ? Our present knowledge of the volcano and capability to interpret the data gathered by geophysical monitoring dots not allow us to discard any of the two possibilities.

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Table 1: Chemical composition of Popocatépetl Plinian pumice samples

Sample #		9441 Ta +6	9445 Ta-2
material		pink pumice	ochre pumice
Eruption		822-823 A.D.	500-100 B.C.
Si02	%	61,29	61,26
Ti02		0,72	0,72
A1203		16,03	16,22
Fe203		1,23	1,29
FeO		3,67	3,67
Fe203*		5,31	5,37
MnO		0,09	0,09
MgO		3,91	3,83
Cao		5,01	5,13
Na20		4,21	4,27
K20		1,96	1,94
P205		0,21	0,21
LOI		0,88	0,88
Total	%	99,62	99,91
Ba	ppm	476	452
Nb		5	< 5
Rb		57	56
Sr		487	480
Y		23	22
Zr		211	208
Sc		11,2	11,6
Th		5,7	5,7
u		2	2
La		20	20
Ce		41	42
Nd		20	20
Sm		4,6	4,7
Eu		1,3	1,2
Tb		<1	< 1
Yb		2	2
Lu	ppm	0,2	0,2

Table 2: Radiocarbon dates of pyroclastic deposits associated to the last two major Plinian eruptions at Popocatépetl volcano

Sample No.	Eruption	Type of Deposit	Location	Latitude		Altitude	Material dated	Conventional date (y. B.P.)	Calibrated age after (9) (Seattle-Groningen method) cal 1 sigma (68.3 % confidence level)	cal 2 sigma (95 4 % confidence level)	a 13C - PDB (o/oo)
9481	822/823 A.D.	ash-and-pumice flow	Road Paso de Cortés-Xalitzintla	19° 05' 21"	98° 37' 08"	3540 m	charcoal	1095 ± 60	892-924, 936.1008 A D.	790-806, 812.1030 A D	.25,2
9592	822/823 A.D.	blast deposit	Road Paso de Cortés-Xalitzintla	19° 05' 22"	98° 36' 42"	3420 m	charcoal	1130 ± 50	884-980 A D	792-804. 914. ?010 A D	.24,9
9302- B	822/823 A. D	ash-and-pumice flow	Barranca Río Agua Blanca			2320 m	charcoal	1145 ± 100	790-999 A D.	879-1040, 1090-1110, 1140-1150 A.D	.24,1
9440	022/823 A D.	blast deposit	Tlamacaz	19° 03' 25"	98° 38' 08"	3965 m	pine needles	1175 ± 60	790-694, 916-956 A D	712.746, 764-1000 A.D	.2., 8
9686 B L	822/823 A.D.	soil below lahar	Collapsed bridge near San Nicolás	19° 03' 58"	98° 28' 40"	2440 m	charcoal	1255 ± 60	593-820, 840-859 A D.	662-892, 922-941 A D	-21,2
9491	822/823 A.D	ash flow	Road Paso de Cortés-Xalitzintla	19° 04' 57"	98° 35' 48"	3260 m	charcoal log	1255 ± 45	.594.752, 756.978, 644.856 A D	678-880 A D	.23,0
9463	500-100 9 C.	ash-and-pumice flow	Base of Nexpayantla Barranca	19° 04' 31"	98° 42' 21"	2970 m	charcoal	2175 +55/-50	358-288, 252.222, 214..59 140-120 B C	368-64 B C	-24,4
9432	500-100 9 c	ash-and-pumice flow	Road Paso de Cortés-Xalitzintla	19° 05' 20"	98° 37' 00"	3525 m	charcoal	2330 + 195/-190	760-630, 590-570, 560-190 B C	820 B.C. - 70 A.D	-24 5
9443	500-100 B.C.	ash-and-pumice flow	Road Paso de Cortés-Tlamacaz	19° 04' 08"	98° 38' 35"	3805 m		2470 ± 70	762-625, 596-574, 560-488, 444-418 B C	776-406 B C	.244

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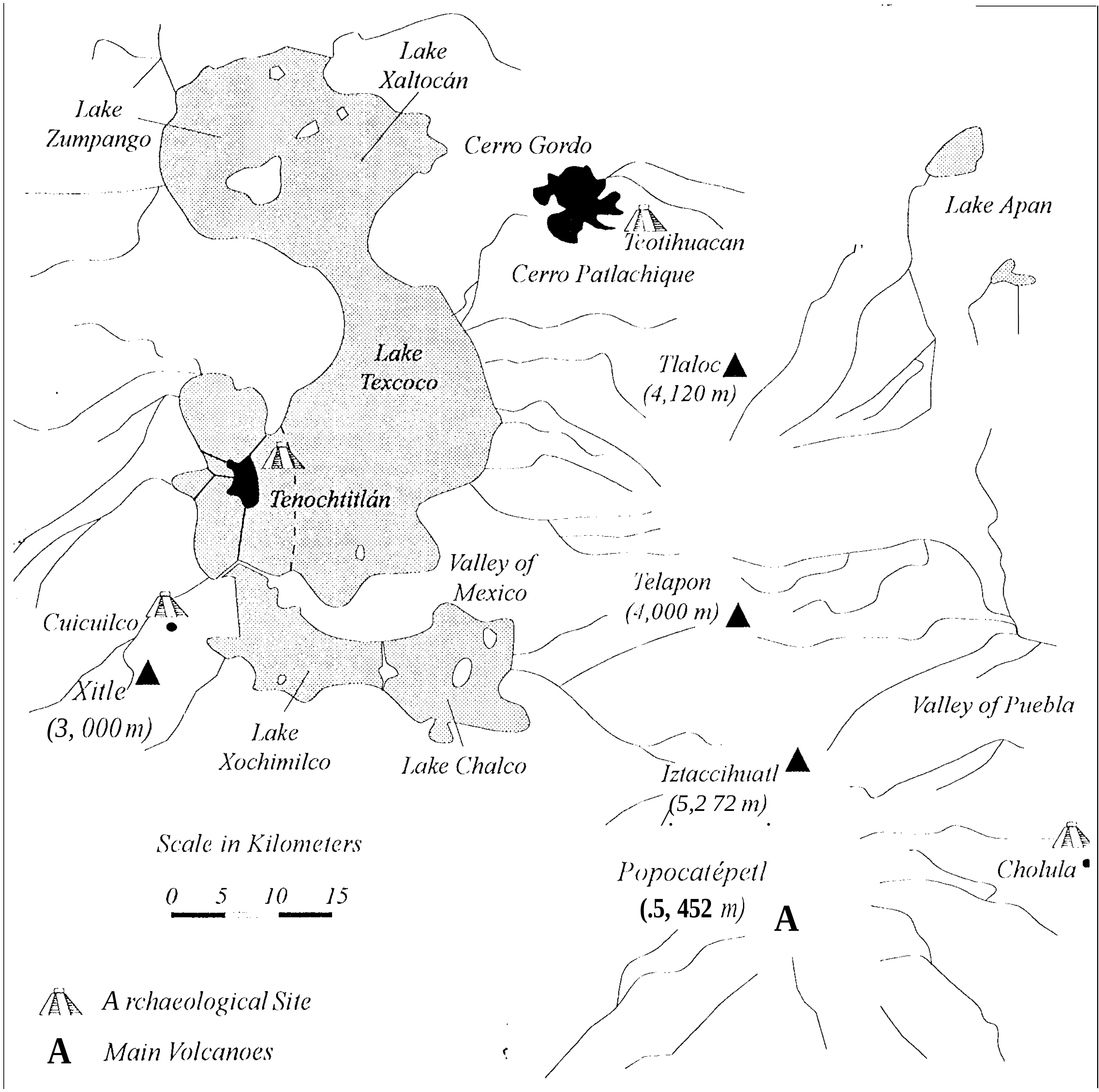

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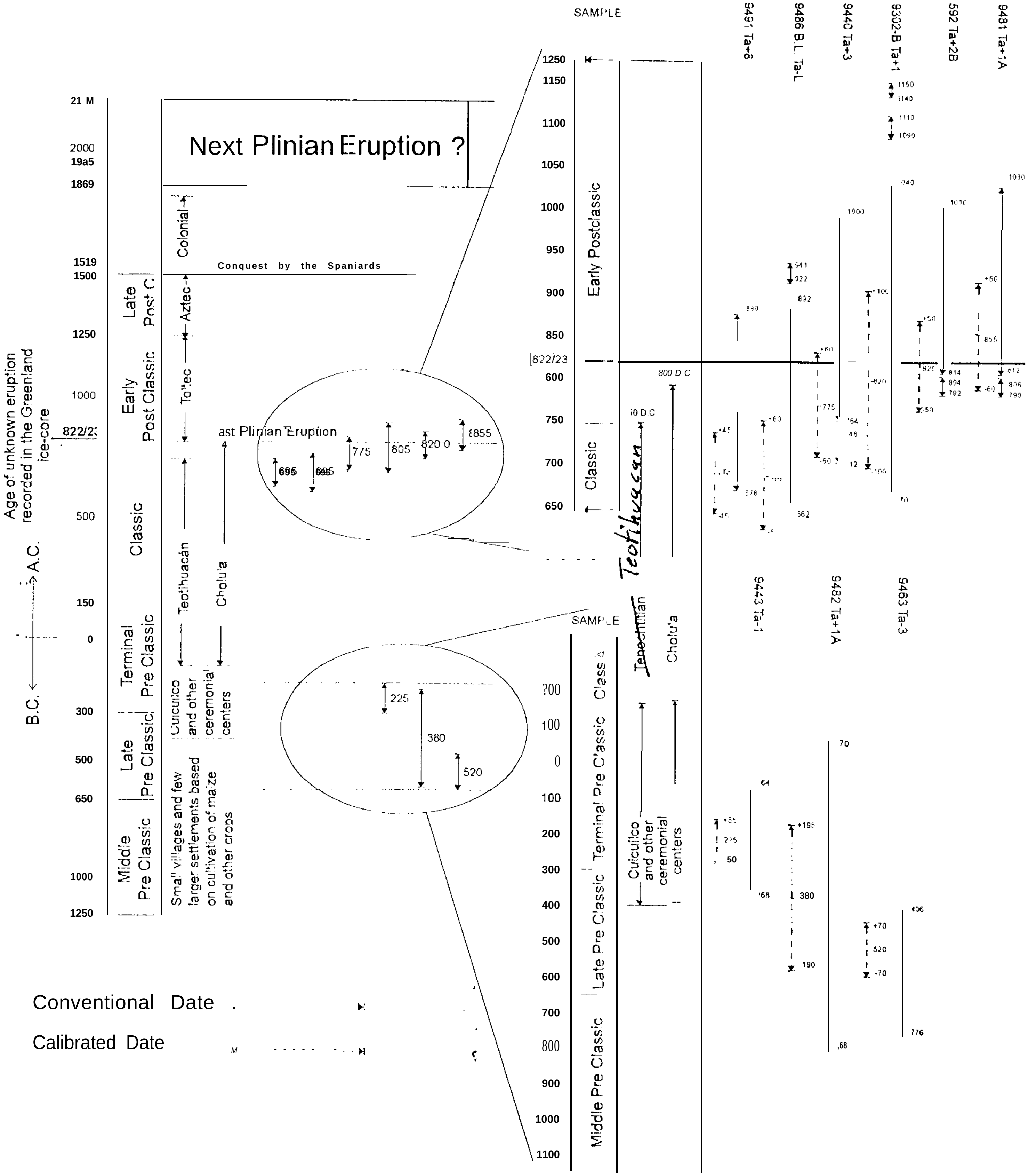

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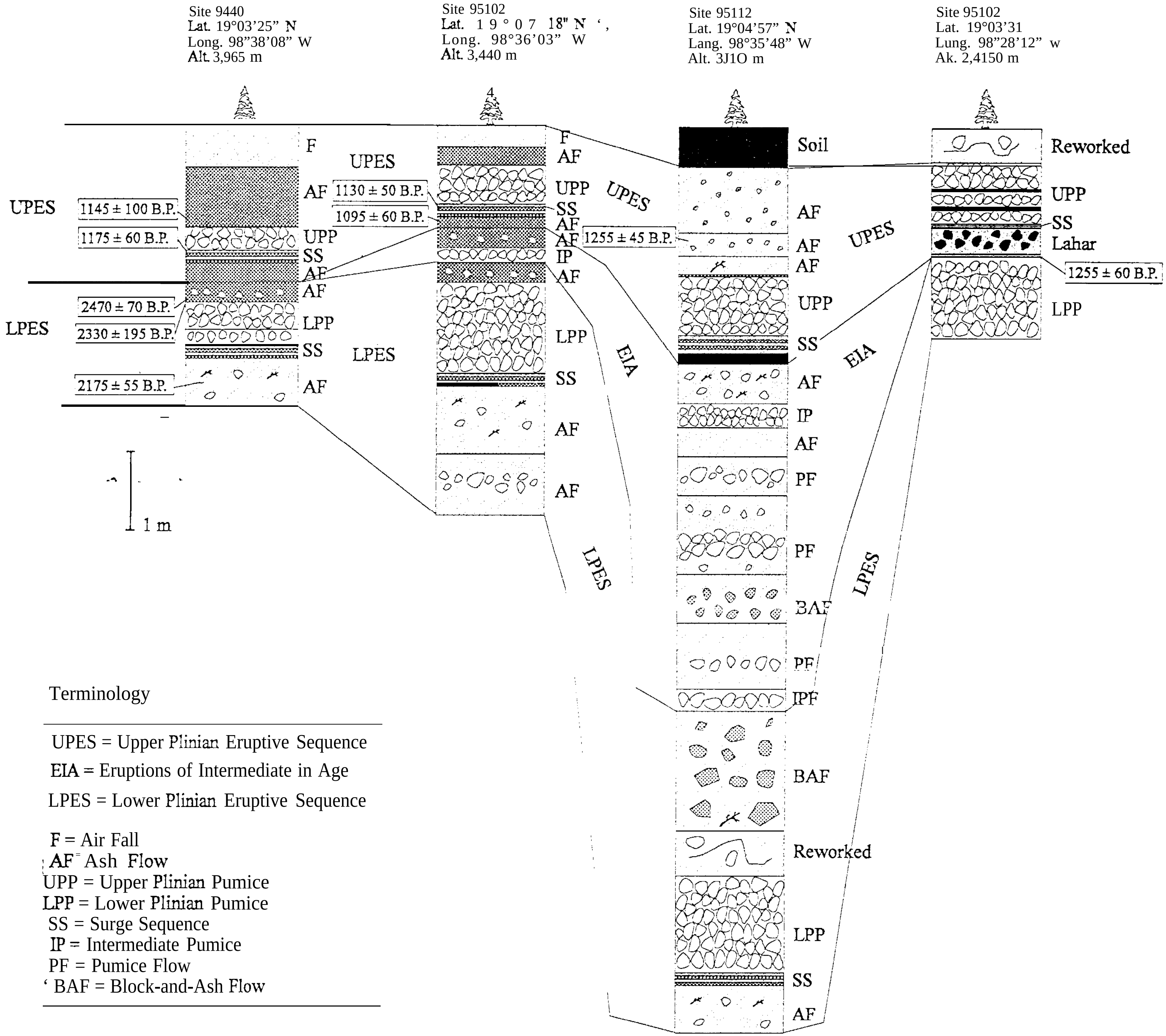

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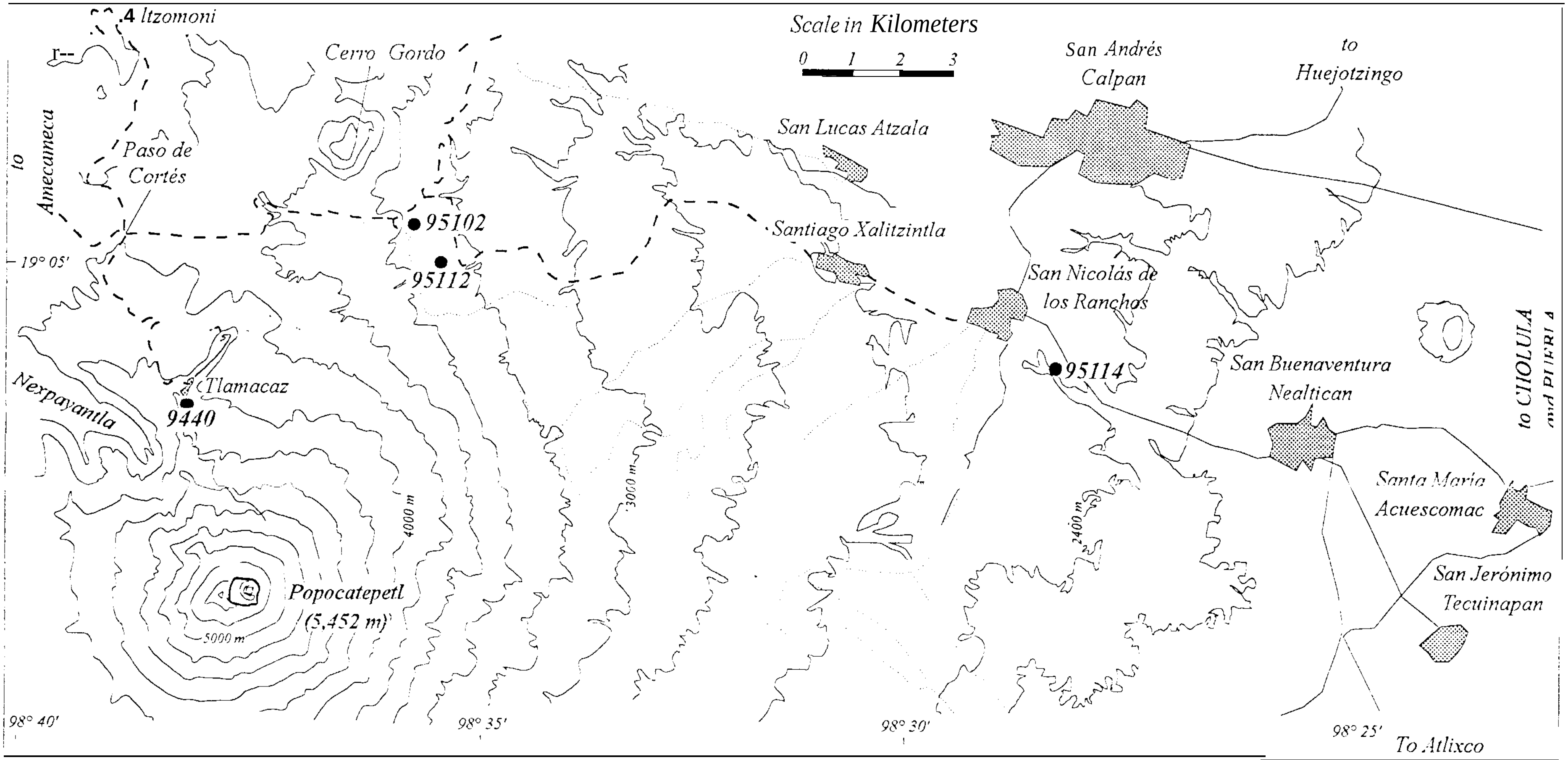

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