

Late Pleistocene ignimbrites at Los Azufres Volcanic center, Mexico. Implications for the present magmatic cycle

Evelyne PRADAL⁽¹⁾, Claude ROBIN⁽²⁾

Abstract: *Since Lower Pleistocene, the Los Azufres volcanic center alternates the emission of acidic and basic magmas. Considering this long history, the "cyclic" pattern of the magmatic phases and the recent age of the last ignimbrites (26000 to 38000 years), one can assume that the volcanic activity related to one — or more — voluminous body(ies) of differentiated magma (rhyolite) at shallow depth has not yet ended, especially in the southern area of the complex, where the geothermal field is lying and where more than 200000 persons live in.*

Keywords: Ignimbrites - Late Pleistocene - Magmatic cycles - Caldera - Basic magmas - Volcanic activity - Volcanic hazards.

Résumé : *Les ignimbrites Pléistocène terminal du complexe volcanique de Los Azufres. Implications pour le cycle magmatique actuel.* Depuis le Pléistocène inférieur, le complexe volcanique de Los Azufres alterne l'émission de magmas différenciés — rhyolites et dacites — et basiques. Compte tenu de cette longue histoire, du caractère « cyclique » des phases magmatiques, et de l'âge récent (26000 à 38000 ans) des dernières ignimbrites, on peut penser que l'activité éruptive, liée à un (ou plusieurs) volumineux réservoir(s) de magma différencié à faible profondeur, n'est pas terminée, en particulier au sud du complexe, où se situe le champ géothermique et où vivent plus de 200000 personnes.

Mots-clés : Ignimbrites - Pliocène terminal - Cycles magmatiques - Caldera - Magmas basiques - Activité volcanique - Risques éruptifs.

INTRODUCTION

Located 200 km west of Mexico City, the Los Azufres geothermal field has been extensively studied (CAMACHO y PALACIOS, 1979; AUMENTO y GUTIERREZ, 1980; DE LA CRUZ *et al.*, 1982; DOBSON, 1984; DOBSON and MAHOOD, 1985). This geothermal field lies on the southern part of a volcanic complex (Fig. 1 et 2) interpreted as a large caldera (PRADAL et ROBIN, 1985; PRADAL, 1990). This paper deals with the age of the main volcanic sequences emitted over the whole complex. Since Lower Pleistocene, the volcanic activity alternates mafic (andesites and/or basalts) and differentiated pro-

ducts (rhyolites and/or dacites). New ages from Late Pleistocene ignimbrites suggest that the last period of activity which started about 0.6 Ma ago has probably not ended.

MAIN VOLCANIC UNITS

Basement

Oligocene and Miocene andesite lavas may be observed in the Sierra Mil Cumbres and as inliers within the graben of Cuitzeo. The largest outcrop in the studied area is the Sierra Santa Ines (Fig. 2).

(1) Ecole des Mines, 30319 Alès, France.

(2) Orstom, UR 13, BP A5, Nouméa, New Caledonia.

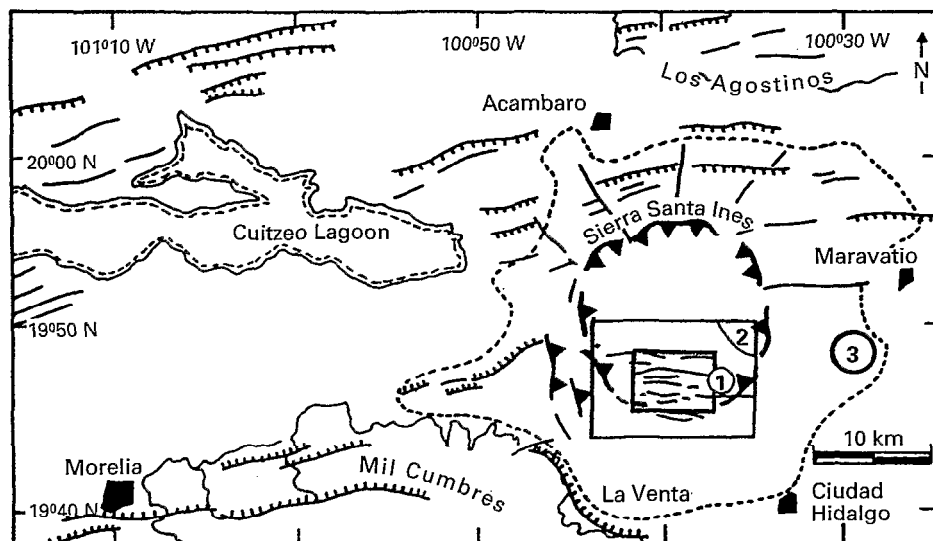


Fig.1. — Schematic structural map from Morelia to Maravatio. 1: Geothermal field; 2: Approximate limits of the Los Azufres Sierra; 3: Extent of the Los Azufres volcanic complex.

Esquisse structurale du secteur Morelia-Maravatio. 1: Champ géothermique; 2: Limites approximatives de la Sierra Los Azufres; 3: Extension du complexe volcanique.

This structure together with the andesites in the Sierra Los Azufres represents the remnants of andesitic series from Miocene to Upper Pliocene. Ages ranging from 13 to 3 m.y. have been obtained on these rocks (AUMENTO y GUTIERREZ, 1980; SILVA-MORA, 1979; PRADAL, 1990).

Ignimbrites

They consist of six rhyolitic sequences, the origin of which is the ring fracture zone (PRADAL, 1990). The Tarandacuaro (TA) and Ucareo (UC) ignimbrites are widely distributed on the eastern, northern and north-western sides of the complex (Fig. 2). They consist of poorly to densely welded tuffs which are locally associated with pumice air-fall and surge deposits. Many domes participate to this rhyolitic phase.

The age of the Ucareo rhyolites (ignimbrites and domes) is well defined between 1.39 ± 0.03 Ma. A problem subsists concerning the age of the earlier TA ignimbrites: two different dates (4.5 ± 0.1 and 3.4 ± 0.1 Ma) have been obtained on the same ignimbrite sampled in two localities (PRADAL, 1990). Such a difference is probably due to the heterogeneity of the samples since they contain

a few percent of andesite xenoliths. Thus, the age is probably less than 3.4 Ma. Considering remains of *Elephas Imperator leidy* within the underlying sediments which refill the graben (GARDUNO, 1987), PRADAL (1990) proposes a Late Pliocene or Lower Pleistocene age for the TA ignimbrite.

The San Pedro Jacuaro (SPJ) sequence of rhyolites crops out mainly on the southern side of Sierra Los Azufres. North of San Pedro Jacuaro, several 10 to 20 m thick ash flow deposits from this sequence are well exposed in quarries. The Pueblo Viejo (PV) sequence, up to 60 m thick, lies on the western part of the complex (Fig. 2). These two series are associated with air fall deposits and domes. Ages from the SPJ and PV rhyolites range from about 1.1 to 0.8 Ma (Tabl. I).

The most important group from the Upper Pleistocene ignimbrites is the Cieneguillas group (CI) which partly filled the eroded PV deposits. Domes extruded near the ring fracture and on the south-western slope of the complex belong to this group. Two of them (Cerros Carpintero and El Bosque) were dated ≈ 0.15 Ma (0.15 ± 0.05 and 0.14 ± 0.02 Ma) by DOBSON (1984). However, our data show that some extrusions -e.g. Cerro

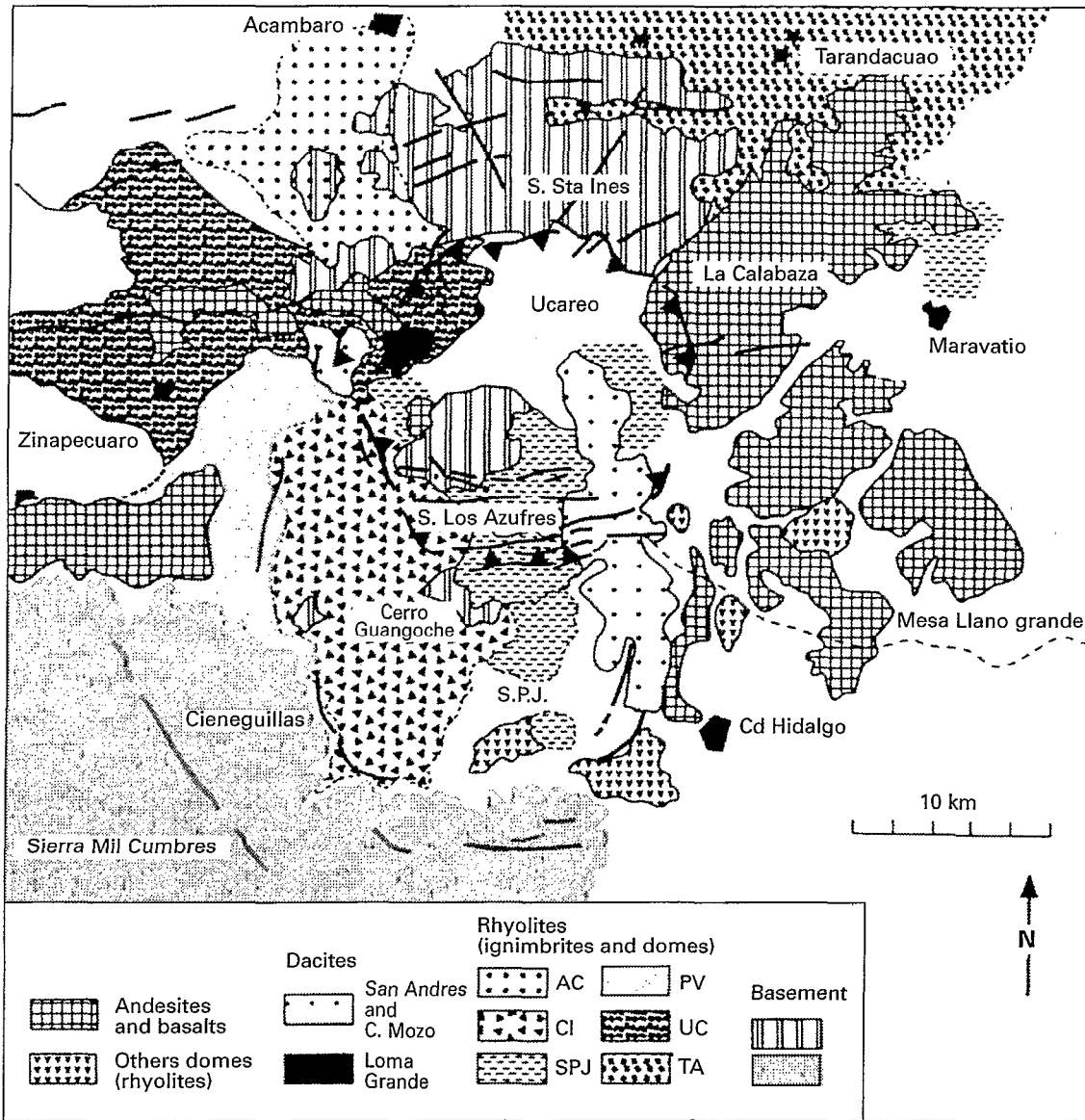


Fig.2. — Geological sketch map of the Los Azufres volcanic complex. For clarity, domes belonging to the UC, SPJ, PV and CI sequences have not been represented.

TA: Tarandacuao; UC: Ucaréo; SPJ: San Pedro Jacuaro; PV: Pueblo Viejo; CA: Acambaro; CI: Cieneguillas.
 Carte géologique simplifiée du complexe volcanique de Los Azufres. Par souci de clarté, les dômes des formations UC, SPJ, PV et CI n'ont pas été représentés.

Guangoche (Fig. 2) and their pyroclastic products are much more recent (26.000 to 29.000 years; Tabl. II). This supposes that the CI group corresponds to a long phase of rhyolitic magmatism which is still going on. The volume of the CI rhyolites is estimated at 10 12 km³.

South of Acambaro, the AC ash and pumice flow deposit covers at least 20 km². It reaches 25 m in thickness. Obsidian-rich levels in the deposits indicate that they were emplaced as several flows. This ignimbrite is 36 000 ± 1400 years old (Tabl. II). The AC deposits can be followed from the

TABLE I

Summary of K-Ar dates. Sources of data.
1: SILVA MORA (1979); 2: AUMENTO Y GUTIEREZ (1980); 3: DOBSON and MAHOOD (1985); 4: PRADAL (1990).
Datations K-Ar. Origine des données.

Sample and locality	Coordinates	Material	K %	Ar 40* ng/g	Ar Atm %	Age (My)
CIENEGUILLAS						
Rhyolite	Mesa El carpintero	100°43'15 - 19°48'05	glass	3.92 - 3.93	81.7	0.14 +/- 0.02 (3)
Rhyolite	Mesa El Bosque	100°42'27 - 19°47'41	biotite	5.51	98.5	0.15 +/- 0.05 (3)
Rhyolite	Cerro El Rosario	100°42'52 - 19°45'32	biotite	5.69 - 6.03	96.8	0.30 +/- 0.07 (3)
DACITIC DOMES						
	Cerro San Andres	100°37'30 - 19°46'38	plagiocl.	1.5 - 1.55	95.5	0.33 +/- 0.07 (3)
	Cerro Mozo	100°43'55 - 19°51'25	WR	1.46	0.050	0.50 +/- 0.10 (4)
LA CALABAZA						
	Andesite AZ 130	100°35'50 - 19°52'	WR	1.14	0.047	0.60 +/- 0.05 (4)
ZAPOTE ALTO						
	Basic Andesite AZ 124	100°44'50 - 19°50'30	WR	1.87	0.103	0.79 +/- 0.06 (4)
	Basic Andesite AZ 74	100°48'45 - 19°48'25	WR	1.71	0.096	0.81 +/- 0.08 (4)
PUEBLO VIEJO - SAN PEDRO JUACUARO						
Rhyolite AZ 157	Agua Fria	100°39'30 - 19°47'20	WR	3.82	0.201	0.76 +/- 0.06 (4)
Rhyolite	Geothermal field	100°40'22 - 19°48'46	glass	3.87 - 3.90	49.7	0.84 +/- 0.02 (3)
Rhyolite	Geothermal field	100°39'46 - 19°46'58	WR	3.73 - 3.87	87.0	0.93 +/- 0.04 (3)
Rhyolite	Geothermal field	100°39'26 - 19°56'21	glass	3.88 - 3.91	47.1	1.03 +/- 0.02 (3)
Obsidian 122	San Pedro Jucuaro	100°39'30 - 19°44'00	WR	3.95	0.285	1.04 +/- 0.06 (4)
LOMA GRANDE						
	Dacite AZ 128	100°43'30 - 19°52'30	WR	1.94	0.165	1.22 +/- 0.09 (4)
Ucareo						
Rhyolite AZ 121	Zinapecuaro	100°50'50 - 19°51'30	WR	3.84	0.347	1.30 +/- 0.03 (4)
Rhyolite AZ 11	Ucareo	100°41'55 - 19°53'25	WR	3.97	0.360	1.31 +/- 0.04 (4)
Rhyolite AZ 82	Cerro Cuate	100°45'25 - 19°50'30	WR	3.57	0.343	1.39 +/- 0.05 (4)

(4) Analyses realized at the K-Ar laboratory of Clermont Ferrand University by C. JAMOND, using new decay constants.

Acambaro plain up a zone marked by large obsidian veins and small rhyolitic extrusions close to the southern edge of the Sierra Santa Ines.

Dacitic domes

They are less numerous than the rhyolitic domes. A large dacitic extrusion in the north-western part of the complex was dated 1.22 ± 0.09 Ma (Loma Grande, Tabl. I) and seems to follow the Ucareo series of ignimbrites and domes. The major dacitic phase belongs to the emplacement of Cerros Mozo and San Andres, from 0.6 to 0.3 Ma.

Mafic lava flows

Basaltic volcanism occurred between the eruption of the lower ignimbrites (TA and UC) and the intermediate rhyolite sequences (PV and SPJ ignimbrites) as indicated by small volume of lava flows in the western part of the complex and scoria reworked by the PV ignimbrites.

Three additional series of basalts and andesites occurred during the Pleistocene development:

(i) - in the west, olivine basalts and andesite lava flows with a total thickness of 100 to 120 m

form a plateau of about 70 km², south of Zinapecuaro (Fig.2). Two samples have been dated at ≈ 0.8 - 0.75 Ma.

(ii) - about 0.6 my ago, andesites and basalts from cerro La Calabaza partly covered the eastern edge of the complex and spread out over 120 km² with a maximum thickness of about 300 m.

TABLE II

C14 ages of ignimbrite deposits from the Cieneguillas and Acambaro sequences. ¹⁴C analyses by the centre des faibles radioactivités (CFR). Gif-sur-Yvette, France.

Datations au carbone 14 des coulées cendro-ponçueuses de Cieneguillas et Acambaro. Analyses réalisées au centre des Faibles Radioactivités de Gif-sur-Yvette (France).

Volcanic sequence	Locality	Age (years B.P.)
CIENEGUILLAS		
AZ 88	100°45'20 W - 19°45'50 N	28,000 +/- 650
AZ 120	100°45' W - 19°42'40 N	26,800 +/- 900
AZ 136	100°43'45W - 19°41'55 N	26,700 +/- 450
ACAMBARO		
AZ 126	100°44'30W - 19°59'20 N	36,300 +/- 400

(iii) - on the south-east slopes, the Mesa Lano Grande (100 km²) consists of a pile of basaltic flows which commonly reaches 150 m in thickness. Its age is inferred the same age as the La Calabaza series.

Numerous undated — almost presumably recent — scoria cones occur outside the complex. Some of them are scattered above the basalt sequences and the andesites of La Calabaza.

VOLCANIC HAZARDS

The previous data suggest that volcanic risks remain threat, specially to the northwestern and southern area. On the north-western part of the complex, Acambaro city (about 80 000 inhabitants) is built on the Acambaro ash and pumice flow deposits and more than 200 000 people live in the southern part of the complex, where the recent rhyolitic domes and ash flows tuffs (Cieneguillas unit) deposits lie on (Fig. 2). According to this, it seems that a detailed mapping of the volcanic hazards should be realized in a next field work.

CONCLUSION

Since ≈ 1.4 my, the Los Azufres volcanic complex alternated acidic and mafic volcanisms. As an example of "magmatic cycle", dacitic lavas (Loma Grande) and then basalts followed the Ucareo

rhyolites. Another cycle took place between ≈ 1 and 0.75, 0.8 Ma.; it began with the emission of the SPJ and PV ignimbrites and ended with the basaltic andesites on the western side (Zapote Alto, Tabl. I).

A period of quiescence from ≈ 0.75 Ma to ≈ 0.6 Ma preceeded the voluminous series of mafic lava flows which gave rise to the La Calabaza and Llano Grande sequences. During a long lasting phase of nearly continuous activity, this mafic volcanism grades into dacites (cerro San Andres and cerro Mozo, 0.5 to 0.3 Ma) and then rhyolites (ignimbrites and domes of the CI and AC groups). Considering the volume of the CI and AC rhyolites (10-12 km³ and 1-2 km³ respectively) and the recent age of the last ignimbrites, one can assume that the Upper Pleistocene volcanic activity corresponds to progressive differentiation in one, or more, voluminous body(ies) of magma which evolution has not yet ended. Consequently, volcanic hazards remain permanent threat to the complex area, specially to the southern part, where more than 200 000 persons live in.

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