Monogenetic Vulcanism in Sierra Chichinautzin, Mexico

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ABSTRACT

The variation in the activity patterns of the Chichinautzin volcanic rocks is discussed. This sequence of lavas and pyroclastic deposits is located in the central part of the Mexican Volcanic Belt, directly south of Mexico City, and is typical of its Quaternary monogenetic vulcanism.

One-hundred and fourty-six volcanoes and their deposits covering 952 km^2 were mapped. Cone density is 0.15 km^2 with heights ranging from to 315 m and crater diameters from 50 to 750 m. Ratios of cone height/diameter decreased from 0.20 to 0.12 with age. Basal diameters varied from 0.1 km to 2 km.

Lavas are mainly blocky andesites but some dacites and basalts were found. Lengths of flows range from 1.0 to 21.5 km with heights of 0.5 to 300 m and aspect rations of 21.4 to 350.

Three types of volcanic structures are found in the area: scoria cones, lavas cones and thick flows lacking a cone. Pyroclastic deposits are basically Strombolian although some deposits were produced by more violent activity and lava cones seem to have formed by activity transitional to Hawaiian-type vulcanism.

Therre is a dominant E-W trend shown mainly by the orientation of cone clusters.

The Chichinautzin volcanic centers are compared to the monogenetic volcanoes of the Toluca and Paricutin areas which are similar.

INTRODUCTION

Monogenetic volcanisn is a poorly understood subject and the Mexican Volcanic Belt (MVB) is rich in this type of activity. The evolution of the Chichinautzin Formation, a sequence of lavas and tephra located in the central part of the MVB, is typical of Quaternary monogenetic volcanism in the MVB. The purpose of this paper is to contribute to the understanding of the eruptive style through the geometry, products and distribution of cones. Special attention is given to this area because of its proximity to heavily populated areas.

The mapped area covers 952 km^2 directly south of México City (19° 15 N) and north of Cuernavaca (19° N). To the east (99° 00′) and west (99° 20′) Tertiary volcanic rocks limit the Chichinautzin formation.

Volcanic stratigraphy has always been uncertain because different volcanic sequences may be lithologically similar while individual flow units vary considerably within the same flow. Interdigitation of lavas and tephra also pose stratigraphic problems.

However, the use of morphological parameters for the subdivision of volcanic units may provide a rough guide to age. The morphological and radiometric data are listed in Table 1. Characteristic samples of the stratigraphic sequence were analysed petrographically.

Field studies included a detailed description and sampling of cones, lavas and pyroclastic deposits of the different units of the Chichinautzin Formation. Tephra size distribution was obtained through sieving.

Heights, basal and crater diameter and radii (horizontal distance from the rim to the base of cone) for 146 cones were determined (Tables 2, 3, 4, 5 and 6) from the topographic maps and field measurements. The area, volume, and aspect ratio of the lavas were also calculated (Tables 7 and 8).

The Chichinautzin Formation lies unconformably on older Tertiary volvanic rocks. The thickness of the formation was estimated by FRIES (1960) in 1800 m. This should be considered an upper limit, since it was obtained from the difference in elevation between the Valley of Cuer-

TABLE 1 — Geomorphological parameters used the stratigraphy of the area.

Age Unit	Geomorphological parameters	Age (years)*
Hv Holocene Volcanics	-Thin pockets of soil -Uniform cover of short trees and shrubs -All flow structures perfectly preserved -Individual flow-units mappable -Not cultivated ("pedregal").	8,440 ± 70
Plv4 Pleistocene Volcanics 4	-Individual flow-units have marked levees with thin tree cover -Centers of flows have thin soil cover	19,530 ± 160
Plv3 Pleistocene Volcanics 3	-Thin impersistent soil cover -All pressure ridges visible -Outlines of flows very marked -Little erosion of terminal cliffs	21,860 ± 380
Plv2 Pleistocene Volcanics 2	-Very distinct flow margins and terminal cliffs -Surface of flow covered with soil (<2m to 3m) -Rare pressure ridges protrude and indicate flow direction	30,500 ± 1,160
Plv1 Pleistocene Volcanics 1	-Rounded lobate outlines of low margins only -Rounded, eroded and subdued terminal cliffs -No internal flow features -Thick soil cover (<4m) -Intensively cultivated	38,590 ± 3,210

* Based on Bloomfield's C_{14} ages (1975).

TABLE 2 — Geomorphological parameters of the Plv1 cones.

	Name	Unit	Heith H (m)	Radius r (m)	r/H	Diameter of crater rim	Diameter of the base of the cone	H/ Diameter	Crater Diameter/ Basal Diameter
138*	Mezontepec	Plvl	100	300	3.0	100	800	.12	.12
139	Mezontepecito	Plvl	50	100	2.0	200	400	.12	.50
140	Acopiaxco I	Plvl	100	300	3.0	250	800	.12	.31
141	Acopiaxco II	Plvl	200	200	1.0	150	500	.40	.30
142	El Guarda	Plvl	100	200	2.0	350	750	.13	.46
143	Oyameyo	Plvl	250	400	1.6	300	1250	.20	.24
144	Mechatepec	Plvl	50	150	3.0	300	500	.10	.60
145	Quepil I	Plvl	250	500	1.8	250	1250	.20	.20
146	Quepil II	Plvl	300	500	1.8	300	1250	.24	.24

* Number of volcano based on relative age.

TABLE 3 — Geomorphological parameters of the Plv2 cones.

	Name	Unit	Height H (m)	Radius r (m)	r/H	Diameter of crater rim	Diameter of the base of the cone	H/ Diameter	Crater Diameter/ Basal Diameter
127	Zorillo	Plv2	50	-	-	-	1000	.05	-
128	Malacatepetl I	Plv2	50	250	5.0	200	600	.08	.33
129	Malacatepetl II	Plv2	200	500	2.5	350	1200	.16	.29
130	Muñeco	Plv2	150	550	3.6	200	1500	.10	.13
131	Muñequito	Plv2	100	250	2.5	200	750	.13	.26
132	Malinale	Plv2	100	250	2.5	275	750	.13	.36
133	Malinalito I	Plv2	40	100	2.5	200	500	.08	.40
134	Malinalito II	Plv2	-	75	-	150	300	-	.50
135	Cuauzontle	Plv2	50	100	2.0	250	500	.10	.50
136	Toxtepec	Plv2	20	50	2.5	200	300	.06	.66
137	Cocinas	Plv2	150	-	-	150	600	.25	.25

TABLE 4 — Geomorphological parameters of the Plv3 cones.

	Name	Unit	Height H (m)	Radius r (m)	r/H	Diameter of crater rim	Diameter of the base of the cone	H/ Diameter	Crater Diameter Basal Diameter
82	Yololica	Plv3	150	300	2.0	275	750	.20	.36
83	Yololicita	Plv3	20	50	2.5	125	250	.08	.50
84	Tezontle	Plv3	225	300	1.3	275	1000	.22	.27
85	Raíces I	Plv3	130	300	2.3	300	1000	.13	.30
86	Raíces II	Plv3	100	300	2.0	150	700	.14	.21
87	Raíces III	Plv3	100	300	3.0	200	700	.14	.28
88	Raíces IV	Plv3	150	250	1.6	250	900	.16	.28
89	Cajete	Plv3	140	300	2.1	350	1000	.14	.35
90	Tepeyeyualco I	Plv3	50	-	-	-	650	.08	-
91	Tepeyeyualco II	Plv3	40	100	2.5	400	600	.06	.66
92	Agua Grande	Plv3	50	200	4.0	250	500	.10	.50
93	Tetzalcoatl Grande	Plv3	100	300	3.0	200	800	.12	.25
94	Tetzalcoatl I	Plv3	20	100	5.0	150	300	.06	.50
95	Tetzalcoatl II	Plv3	20	100	5.0	150	400	.05	.37
96	Tetzalcoatl III	Plv3	[illegible]	125	6.3	100	300	.06	.50
97	Tulmiaqui	Plv3	150	350	2.3	350	1100	.14	.32
98	Tulmiaqui II	Plv3	20	100	5.0	350	500	.04	.70
99	Tuxtepec	Plv3	100	150	1.5	300	650	.15	.46
100	Teconzi	Plv3	50	200	4.0	150	600	.08	.25
101	Teconzito	Plv3	50	150	3.0	100	400	.12	.25
102	Pájaros	Plv3	-	-	-	250	-	-	-
103	Pajaritos	Plv3	100	-	-	350	-	-	-
104	Jaras Verdes	Plv3	-	-	-	300	-	-	-
105	Lobos	Plv3	30	100	3.3	100	350	.09	.28
106	Cadenita I	Plv3	50	100	2.0	300	450	.11	.66
107	Cadenita II	Plv3	50	100	2.0	200	450	.11	.44
108	Cadena	Plv3	200	600	4.0	300	1600	.12	.19
109	Tuxtepec	Plv3	100	200	2.0	300	600	.16	.50
110	San Miguel	Plv3	50	150	3.0	150	400	.12	.37
111	Xistune I	Plv3	50	150	3.0	250	600	.08	.42
112	Xistune II	Plv3	75	250	3.3	175	450	.16	.39
113	Xistune III	Plv3	20	50	2.5	200	250	.08	.80
114	Xistune IV	Plv3	10	50	5.0	150	250	.04	.60
115	Tlalocito	Plv3	80	150	1.9	275	500	.16	.55
116	Pajonal	Plv3	100	350	3.5	350	750	.13	.46
117	Panza	Plv3	100	250	2.5	400	1000	.10	.40
118	Pancita	Plv3	40	200	5.0	200	500	.08	.40
119	Cima I	Plv3	40	200	5.0	250	600	.06	.42
120	Cima II	Plv3	30	100	3.3	150	400	.07	.38
121	Cautillo	Plv3	80	150	1.9	600	800	.10	.75
122	Cima III	Plv3	20	50	2.5	150	350	.06	.43
123	Cima IV	Plv3	20	50	2.5	250	400	.05	.62
124	Cima V	Plv3	10	-	-	-	250	-	-
125	Cima VI	Plv3	10	-	-	-	100	.10	-
126	Cima VII	Plv3	30	-	-	-	200	.15	-

navaca and the Chichinautzin volcano and does not consider the irregular underlying topography.

BLOMFIELD (1975) obtained C^{14} ages between 9.4 and 3.5 k.y. for the Chichinautzin Formation west of the area studied. LIBBY (1951) dated the youngest Chichinautzin volcanic rocks, the Xitle flows, at 2,400 years, also using radiocarbon dating. All the rocks showed

TABLE 5 — Geomorphological parameters of the Plv4 cones.

	Name	Unit	Height H (m)	Radius r (m)	r/H	Diameter of cater rim	Diamter of the base of the cone	H/Diameter	Crater Diameter/Basal Diameter
51	Tres Cumbres I	Plv4	250	400	1.6	175	1500	.16	.12
52	Tres Cumbres II	Plv4	250	500	2.0	500	1250	.20	.40
53	Oclayuca	Plv4	120	850	7.0	100	1600	.07	.06
54	El Hoyo	Plv4	50	100	2.0	300	500	.10	.60
55	Tepetl III	Plv4	50	300	6.0	200	400	.12	.50
56	Quimixtepec	Plv4	65	300	4.6	275	600	.11	.41 a .50
57	Los Otates I	Plv4	100	250	2.5	275	600	.16	.45
58	Los Otates II	Plv4	50	250	5	250	600	.08	.42
59	Los Otates III	Plv4	-	100	-	100	600	-	.16
60	Yecahuazac	Plv4	100	300	3	375	800	.12	.47
61	Cuiloyo	Plv4	100	-	-	-	500	.20	-
62	Cuiloyito	Plv4	80	250	3.1	175	400	.20	.44
63	Ocotecatl I	Plv4	150	300	2.0	350	1000	.15	.35
64	Ocotecatl II	Plv4	70	200	2.8	500	800	.09	.62
65	Piripitillo	Plv4	40	125	3.1	300	500	.08	.60
66	Chinguiriteria I	Plv4	50	250	5.0	125	500	.10	.25
67	Chinguiriteria II	Plv4	60	200	3.3	200	500	.12	.40
68	San Bartolo	Plv4	70	200	2.8	200	750	.90	.26
69	San Bartolito	Plv4	50	250	5.0	250	1000	.20	.25
70	La Comalera I	Plv4	170	375	2.2	300	1500	.11	.20
71	La Comalera II	Plv4	20	-	-	200	250	.08	.80
72	La Comalera III	Plv4	70	-	-	250	500	.14	.50
73	Cuautzin I	Plv4	250	500	2.0	750	2000	.12	.37
74	Cuautzin II	Plv4	100	400	4.0	300	1250	.08	.24
75	Cuautzin III	Plv4	70	150	2.1	100	400	.17	.25
76	Cuautzin IV	Plv4	50	-	-	200	500	.10	.40
77	Tesoyo	Plv4	150	300	2.0	350	1000	.15	.35
78	Tesoyito	Plv4	20	100	5.0	250	300	.06	.83
79	Teuctli I	Plv4	100	200	2.0	250	750	.13	.33
80	Teuctli II	Plv4	50	100	2.0	200	250	.20	.80
81	Teuctli III	Plv4	15	100	6.6	100	300	.05	.33

TABLE 6 — Geomorphological parameters of the Hv cones.

	N a m e	Unit	Height H (m)	Radius r (m)	r/H	Diameter of crater rim	Diameter of the base of the cone	H/ Diameter	Crater Diameter Basal Diameter
1	Xitle	Hv	100	250	2.5	350	750	.13	.46
2	Xicontle	Hv	70	200	2.8	150	500	.14	.30
3	Chichinautzin	Hv	100	225	2.2	250	750	.13	.33
4	Chichinautzin II	Hv	15	75	5.0	250	400	.10	.62
5	Palomito	Hv	100	200	2.0	350	700	.14	.50
6	Palomito II	Hv	30	75	2.5	100	250	.12	.40
7	Caballito	Hv	125	200	1.6	300	750	.16	.40
8	Caballito II	Hv	50	150	3.0	125	400	.12	.31
9	Mantoca	Hv	80	175	2.2	150	500	.16	.30
10	Jumentos	Hv	150	250	2.0	300	750	.20	.40
11	Los Cardos I	Hv	150	250	1.6	150	600	.25	.25
12	Los Cardos II	Hv	60	150	2.5	150	650	.09	.23
13	Los Cardos III	Hv	150	200	1.3	150	-	-	-
14	Los Cardos IV	Hv	60	150	2.5	150	500	.12	.30
15	Los Cardos V	Hv	100	200	2.0	150	500	.20	.30
16	Tabaquillo	Hv	200	sin	cono	-	1500	.13	-
17	Huilotito	Hv	125	200	1.6	300	750	.16	.40
18	Huilote	Hv	250	400	1.6	250	1000	.25	.25
19	Chalchihuites	Hv	315	700	2.2	350	1500	.21	.23
20	Capulín	Hv	150	200	1.3	250	650	.23	.38
21	Xicomulco	Hv	125	sin	cono	-	1200	.10	-
22	Tetequillo	Hv	200	sin	cono	-	1250	.16	-
23	Tioca	Hv	90	100,150	2	250	750	.12	.33
24	Tzompoli	Hv	65	150	1.8	250	600	.10	.416
25	Tepetlapan	Hv	40	100	2.5	300	500	.08	.60
26	Tlamacasco	Hv	100	sin cráter		-	1100	.09	-
27	Tioquitas I	Hv	50	100	2.0	250	400	.12	.62
28	Tioquitas II	Hv	50	100	2.0	250	400	.12	.62
29	Tlacualleli I	Hv	40	100	2.5	200	400	.10	.50
30	Tlacualleli II	Hv	30	100	3.3	125	250	.12	.50
31	Pelado	Hv	150	300	2.0	425	1100	.14	.62
32	Xoxocol	Hv	40	75	1.9	250	400	.10	.38
33	Cerro del Agua II	Hv	~40	-	-	300	1000	.04	.30
34	Tlaloc I	Hv	150	300	2.0	~ 350	1000	.15	.35
35	Tlaloc II	Hv	80	250	3.1	250	750	.11	.33
36	Tlaloc III	Hv	-	40	-	250	-	-	-
37	Tlaloc IV	Hv	-	-	-	250	-	-	-
38	Tlaloc V	Hv	15	50	5.0	50	250	.06	.20
39	Tlaloc VI	Hv	40	100	2.5	150	750	.05	.20
40	Cerro del Agua I	Hv	100	150	1.5	300	750	.13	.40
41	Ocusacayo I	Hv	50	100	2.0	125	500	.10	.25
42	Ocusacayo II	Hv	50	150	3.0	125	400	.12	.31
43	Ocusacayo III	Hv	50	150	3.0	150	500	.10	.30
44	Ocusacayo IV	Hv	20	100	5.0	100	400	.05	.25
45	Suchioc Grande	Hv	150	400	2.6	450	750	.20	.60
46	Suchioc Chico	Hv	30	200	6.6	250	500	.06	.50
47	Ololica	Hv	120	350	2.9	350	1000	.12	.35
48	Cadenita III	Hv	30	100	5.0	300	~ 500	.06	.60
49	Tepetl I	Hv	30	100	3.3	250	500	.06	.50
50	Tepetl II	Hv	80	150	1.9	250	550	.12	.50

TABLE 7 — Dimensions and volumes of the Plv1, Plv2, Plv3 and Plv4 lavas.

	Name	Maximum height of Flow (m)	Average thickness (m)	Maximum length (Km)	Aspect. ratio Length/width	Width	Area (Km^2)	Volume (Km^3)	Unit
1	Xitle	-	40	13.5	337.5		75-80	3.2	Hv
3	Chichinautzin	100	50 varía		220				
5 6 7 8	Palomito Palomito II Caballito Caballito II conjunto	40	40	14	350		25	1.0	Hv
9	Manteca	-	-	1.0	-		1.0	-	Hv
10	Jumento	50	50	2.75	55		3.0	.15	Hv
16	Tabaquillo	200	80	6.0	75'	1.5	9.0	.72	Hv
17	La Gloria	250	100	21.5	215	1.5	32	3.2	Hv
17	Builotito	150	80	2.0	25	1.0	1.5	.12	Hv
11 12 13 14 15	Cardos I Cardos II Cardos III conjunto Cardos IV Cardos V		50	6.0	120	2.5	15	.75	Hv
21	Xicomulco		75	4.5,1.0	60	4.5+1.5	6	.45	Hv
22	Tetequillo	300	100	3.5	35	5.25		.52	Hv
23	Tioca	70	70	1.5	21.4	3.0		.21	Hv
24	Tzempoli		20	2.0	100	1.5		.03	Hv
25	Tepetlapan		20	2.0	100	1.5		.03	Hv
29	Tlacualleli	50	50	1.75	35	3.0		.15	Hv
	Zona Xicomulco conjunto		70			30		2.1	Hv
31	Pelado		30	6.5	216	63.5		1.9	Hv
33 34 35 36 37 38	Tlaloc I Tlaloc II Tlaloc III conjunto Tlaloc IV Tlaloc V Tlaloc VI		40	7.0	175	96		4.8	Hv
41 42 43 44	Ocusacayo I Ocusacayo II conjunto Ocusacayo III Ocusacayo IV		35	7.0	200	14		.49	Hv
45	Suchioc Grande		20	4.5	225	14		.28	Hv
47	Ololica		20	2.0	100	3.0		.06	Hv
49	Tepetl I		30	3.0	100	3.0		.09	Hv
50	Tepetl II		50	1.5	30	3.0		.075	Hv

normal magnetic polarity (MOOSER *et al.*, 1974), which places a lower limit of 700,000 on the Chichinautzin Formation.

The lavas and pyroclastic deposits are composed of oxihornblende andesites and dacites, hyperstene andesites and olivine-augite basaltic andesites and basalts.

PREVIOUS STUDIES

The first geological study in the area was carried out by HUMBOLDT (1826). In 1890, FELIX and LENK published chemical analysis of some of these volcanic rocks. Further research was reported by

ORDOÑEZ (1890, 1895); WITTICH and WAITZ (1910), WITTICH (1917), LIBBY (1951), SCHMITTER (1953), and RZEDOWSKI (1954).

FRIES (1960) named the Quaternary volcanic rocks Chichinautzin Group after rocks he studied south of México City. It should be pointed out that according to article 9 of the Stratigraphic Code, Fries' Chichinautzin Group should be classified as a Formation since it has not been formally subdivided. SCHLAEPFER'S studies (1968) in the same region resulted in a map of region on a scale (1:100.000).

LUGO (1970) made detailed petrologic and geomorphological studies of the northwestern part of the area. BLOOMFIELD (1973, 1975) carried out petrographic, geochemical and stratigraphic studies over an area of 700 km^2 which included the outcrops of the Chichinautzin Formation to the west of Mexico City in the Valley of Toluca.

GUNN and MOOSER (1971), NEGENDANK (1972, 1976) and RICHTER and NEGENDANK (1976) examined the chemical

TABLE 8 — Dimensions and volumes of the Hv lavas.

#	Name		Maximum height of flow (m)	Average thickness (m)	Maximum length (km)	Aspect ratio length/width	Width	Area (km^2)	Volume (km^3)	Unit
51	Tres Cumbres	conjunto		50	10	200		50	2.5	Plv4
52	Tres Cumbritas									
53	Oclayuca			50	35	70		70	.35	Plv4
56	Quimixtepec									
57	Los Otates I									
58	Los Otates II	conjunto		50	10	200		60	3	Plv4
59	Los Otates III									
73	Cuautzin I									
74	Cuautzin II									
75	Cuautzin III	conjunto		80	5	625		40	3.2	Plv4
76	Cuautzin IV									
77	Tesoyo			-	1.2	-		-	3.75	Plv4
79	Teuctli I			-	4	-		-	36	Plv4
80	Teuctli II			40	2	50		2	.08	Plv4
82	Yololica		50	50	10	200		25	1.25	Plv3
92	Agua Grande		80	30	6	200	1.15	6.9	.207	Plv3
93	Tetzacoatl Grande		-	10	1.5	150		3	.03	Plv3
100	Teconzi			10	1.5	150		2	.02	Plv3
103	Pájaros II		-	-	1.0	-		1.5	-	Plv3
104	Jaras Verdes		-	-	3.0	-		6.25	-	Plv3
108	Cadena		-	-	2.5	-		2	-	Plv3
127	Zorrillo		50	40	2.75	68.7	2	4	.16	Plv2
129	Malacatepetl II		-	-	2.0	-		5.5	-	Plv2
132	Malinale		-	-	-	-		1.5	-	Plv2
138	Mezontepec		-	-	3.5	-		12.25	-	Plv1
140	Acopiaxco I	conjunto	-	-	8	-		21.0	-	Plv1
141	Acopiaxco II									
143	Oyameyo		-	-	2.5	-		17.5	-	Plv1

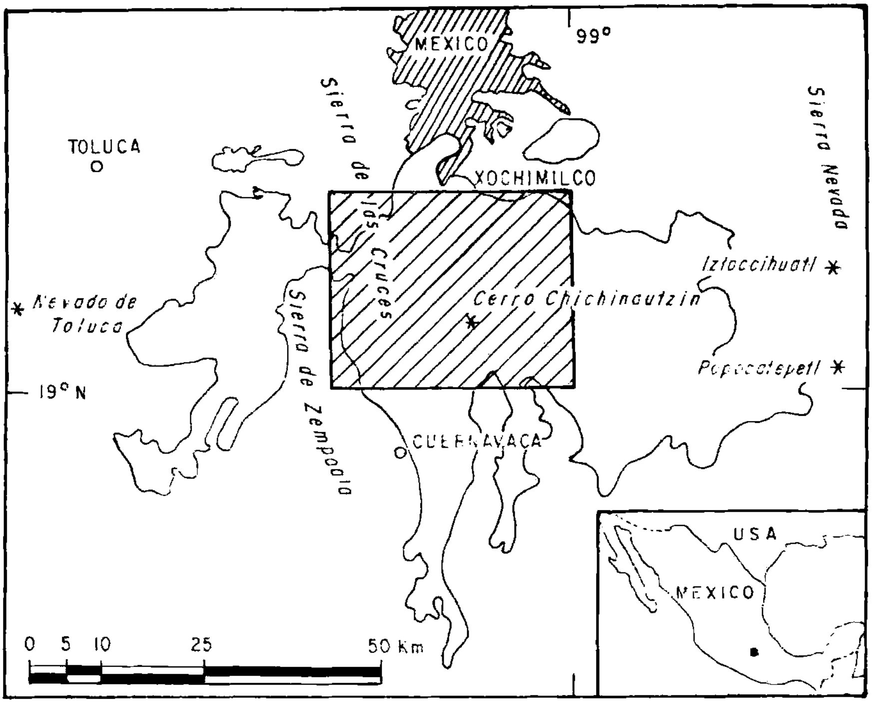

FIG. 1 - Generalised map showing the area studied.

composition of the rocks in the Valley of Mexico and MOOSER *et al.* (1974) reported paleomagnetic studies in the same region.

The origin and structure of the MVB has been discusssed by MOOSER (1957, 1961, 1963, 1975), and DEMANT (1976, 1978) considered the area in a regional context. A more detailed study has recently been carried out by MARTIN-DEL POZZO (1980).

CHARACTERISTICS OF THE VOLCANIC ACTIVITY

The morphological factors are usually good indicators of the age of cones. Nevertheless, since some cones overlap and others are partly covered by other volcanic deposits, their morphology shows some variation. The average values of the morphological parameters for each unit are given in Table 9. Theoretically, the ratio of crater to basal diameter should increase with age but the values for Plv1 and Plv2 units are lower than expected (Tables 2, 3 and 9). This is probably due to the fact that some cones are partly covered and others have a high percentage of lavas. A decrease in the ratio of height to diameter with age (from 0.20 to 0.11) proved to be very useful in the separation of units (Tables 2, 3, 4, 5, 6 and 9). This is consistent with WOOD's findings (1980 *b*).

Basal diameters (Tables 2 to 6) varied from 0.1 km to 2 km. According to FEDOTOV (1976), MCGRECHEN and SETTLE (1975) and WOOD (1980 *a*), this would correspond to nominal volumes of between, 0.04 km^3 with effusion rates of close to 30 m^3/sec, and 0.6 km^3 with effusion rates of 400 m^3/sec; this would imply magma reservoirs at dephts between 3

TABLE 9 — Average values of the geomorphological parameters of the volcanoes in the Chichinautzin Formation.

Unit	Radius/Height	Height/Basal diameter	Crater diameter/ Basal diameter
		.20 corrected value	
Hv	2.2	.14 average	.35
Hv-Plv4	2.9	.15	.42
Plv4	3.4	.15	.40
Plv3	3.0	.12	.50 corrected value
			.30 average
Plv2	2.9	.11	.48
Plv1	2.0	.11	.40

km for the smaller cones and from 35 to 40 km for the larger. Corrections must be made for the larger volumes of Mexican monogenetic volcanoes (Tables 7 and 8).

Chichinautzin's earliest acitivty began in Pleistocene times with the andesitic volcanism that produced the rocks in unit Plvl. Cinder and lava cones (Table 2) covered the central part of the area (Fig. 2). The proportion of lavas to pyroclastics, defined as the explosive index, seems to have been intermediate, owing to the predominance of Strombolian activity. The vertical and lateral extent of this unit is not clearly known, since it is obscured by younger volcanic rockes (Table 7).

The volcanoes in unit Plv2 (Table 3, 7 and Fig. 2) are concentrated in the northwestern part of the area. Volcanism varied from andesitic to basaltic and though more mafic than the earlier Plvl unit its explosive index and morphology are similar.

Rocks in unit Plv3 have the same andesitic to basaltic character and explosive index, but their distribution is widespread (Table 4,7 and FIg. 2).

The cones in unit Plv4 are concentrated in the southern part of the area with the exception of Cuautzin Volcano which is located in the central part (Table 5 and Fig. 2). This unit is made up primarily of andesitic and basaltic lava flows which extend over large areas. The explosive index is lower than in the earlier units, owing to a higher proportion of lavas.

Holocene volcanic activity was located in three different parts of the area (Table 6 and 8, and Fig. 2). Thick blocky lava flows of hypersthene and olivine andesites were erupted in the northeastern part (Tetequillo-Xicomulco zone) with individual flow units of up to 300 m. No cone is associated to these northward flowing lavas, and flow ridges show that they covered their vents as they flowed.

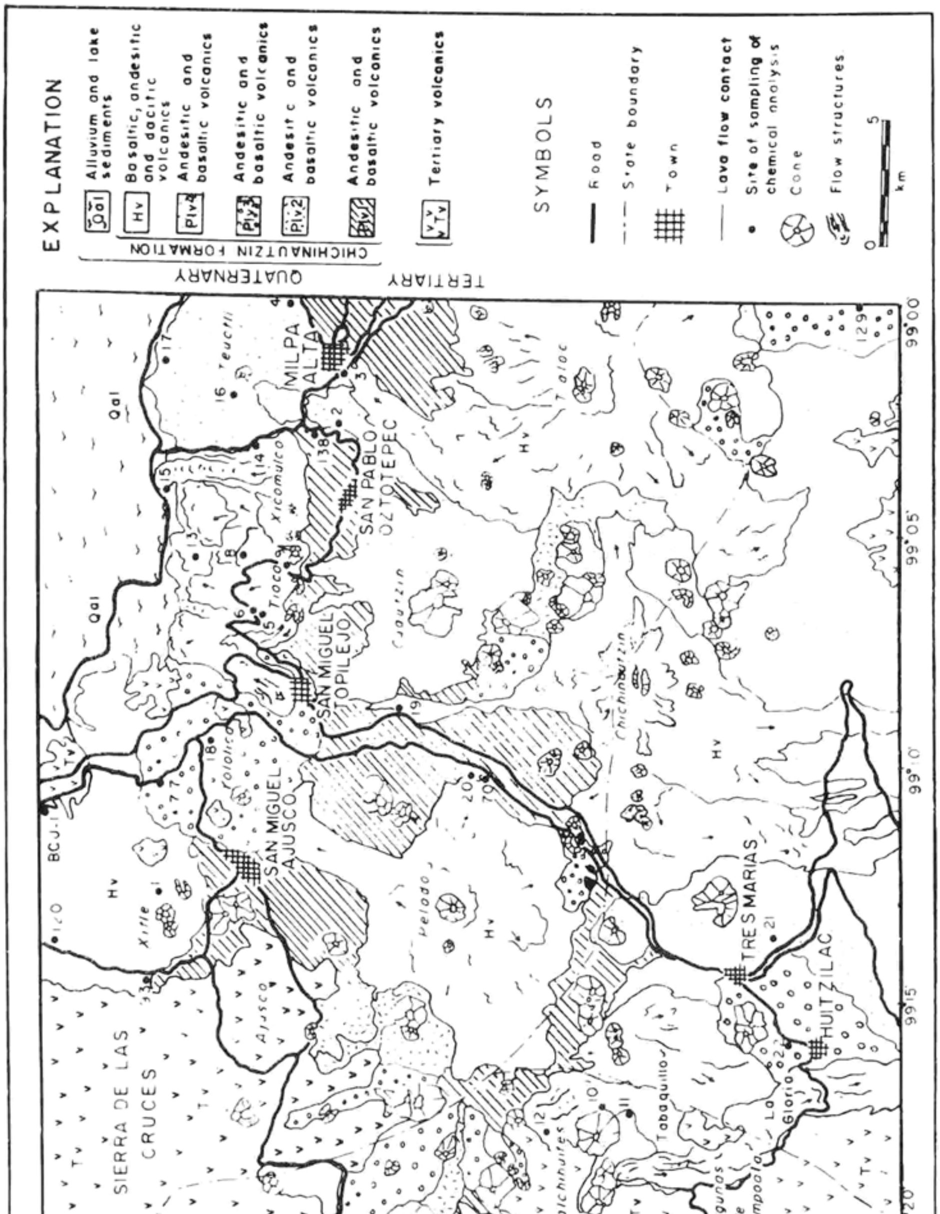

FIG. 2 – Map of the monogenetic volcanoes and associated lavas and tephra.

Volcanic activity must have been of a quiet type with slow viscous flows with associated very little pyroclastic material. The hornblende dacite flows in the region of Laguna de Zempoala are very similar to these andesites except that thay flowed southward and show more contamination (SÀNCHEZ-RUBIO and MARTIN-DEL POZZO, in praparation). Basaltic (and andesitic basalt) vulcanism during this time was widespread with thin flows covering most of the area. Though some of the volcanoes have scoria cones, the lava proportion is much higher than that of pyroclastic deposits. The morphology suggests rapid fluid flow.

As can be seen in Fig. 3 the types of volcanic structures in the area can be devided into three basic groups:

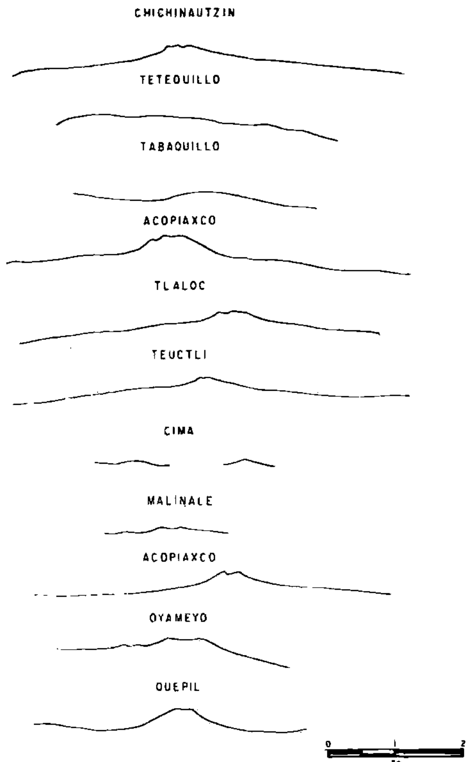

FIG. 3 – Diagram showing variation of volcanic profiles.

1. - Flows with heights of 70 to 300 m of andesitic composition without a cone. Tetequillo, Xicomulco and Tabaquillo belong to these kind of structures (Figs. 2 and 3).

2. - Scoria cones with outward dips of 30°, such as the Panza Volcano or the Xitle and Pelado cones (Fig. 2).

3. - Lava cones. These volcanoes are of two types: (a) shield type, such as the bases of the Teutli and Pelado volcanoes and (b) the conical type with steeper slopes, such as the Chichinautzin volcano (Fig. 2). No basic petrographic difference was found between these types possibly because their viscosities were similar and probably a higher effusion rate for the shield volcanoes should account for the morphological variations. WALKER (1973) has found the same effect in other volcanoes.

In general, the explosive index seems to have been intermediate. Tephra sections and distribution for three characteristic volcanoes are showed in Fig. 4. Fine grained particles, clasts (crystals and fragments) with angular faces, and beds less that 1 cm thick showing little oxidation are considered typical of Surtseyan-type volcanism (WALKER, 1971); coarser grained and more exidized deposits are characteristic of Strombolian activity; in the area the deposits are intermediate between both classes. The median diameter of the particles (MD ø) for the Strombolian type varies from + 1 ø to − 4 ø (0.5 to 5 mm) and for the Surtseyan type from + 3 ø to − 1 ø (0.12 to 2 mm) (WALKER, 1971). The Md ø of the samples studied ranged from 2 ø to 0 ø (0.25 to 1 mm) (Fig. 5) while the standard deviation (σ ø) was 0.5 or Strombolian, since 1.5 is the limit between these types. Cone aspect ratios are also Strombolian (Tables 2, 3, 4, 5 and 6).

Some volcanoes, such as Chichinautzin, could have had activity similar to the Hawaiian volcanoes, since they have a high lava proportion and some have lava cones as well. There are both blocky lava cones and spatter cones.

All of the cones are monogenetic; many have overlapping adventive cones. They have an E-W alignement, although there are also other older less conspicuous alignments trending NE and NW.

The lavas of the Hv unit cover the largest portion of the area (Fig. 2) with an extent and volume estimated at 413.75 km^2 and 20.325 km^3 respectively. Most lavas are blocky, but a few are of the *aa* and even pahoehoe types. It seems that the velocity and volume of the emissions, as well as topography determined the length of the flows. Some flows of similar composition have a wide range of lengths (2 to 21.5 km). This is the case of the La Gloria and El Huilotito flows (Table 8 and Fig. 2).

Chichinautzin's volcanic activity is very similar to that of Michoacan's monogenetic cones. Paricutin's lavas varied from olivine basaltic andesites to orthopyroxene andesites (WILCOX, 1954); morphology, explosive index, and lava type (*aa* to blocky) are also alike. Paricutin's lavas flowed from 6 to 15 m per minute to 100 m a day (WILLIAMS, 1950), at an average temperature of 1, 100° (EGGLER, 1971); the conditions seemed to have been similar in some of the volcanoes of the area studied.

VOLCANIC HAZARD

Monogenetic activity in the Sierra Chichinautzin has continued through historical times. The lavas of Xitlè volcano, on which the University of Mexico and large residential areas are

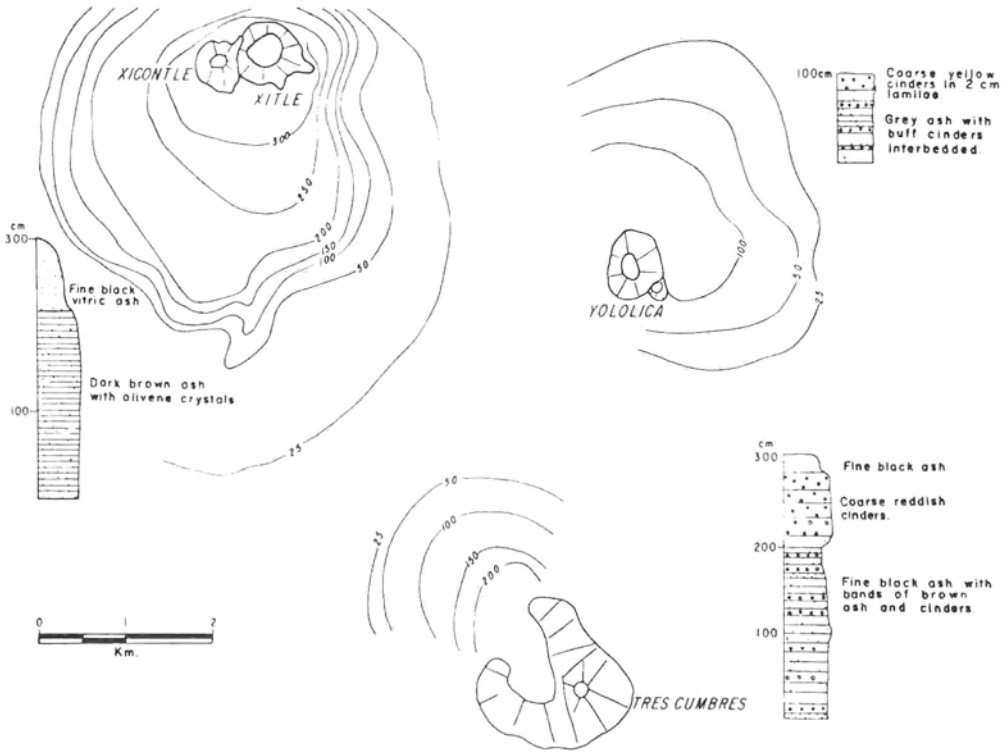

FIG. 4 – Isopach map showing characteristic sequences of tephra for three volcanoes.

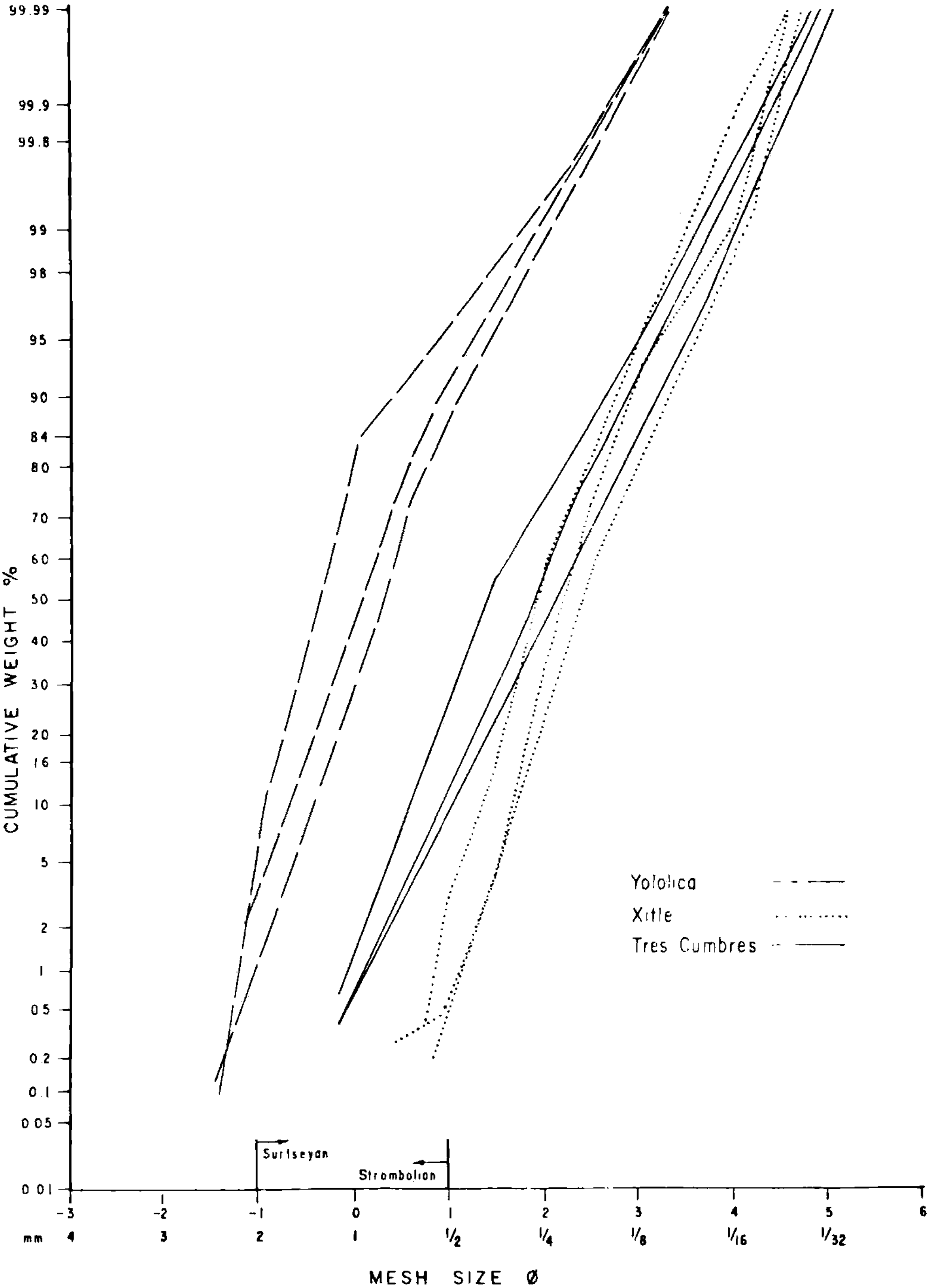

FIG. 5 – Cumulative curves for tephra from three volcanoes.

built, covered part of the Cuiculco pyramid, 2,400 years ago. The eruption of Chichinautzin volcano itself (Burning Lord in the Indian language) was also witnessed by early inhabitants. By observing the tephra distribution on the isopach map (Fig. 3) and the length of the lava flows (Tables 7 and 8) one might conclude that if new activity were to take place, it would most likely affect Mexico City.

CONCLUSIONS

The Chichinautzin Formation owes its origin to monogenetic vulcanism with volcanoes of a short lifespan and intermediate explosive index for most of them. Pyroclastic deposits are basically Strombolian although a few have several characteristics of Surtseyan-type eruptions. The activity that produced the lava cones may be transitional to Hawaiian-type vulcanism.

The lavas are predominantly blocky andesites with aspect ratios between 21.4 and 350. The lenghts of the flows range between 1 and 21.5 km with thicknesses between 0.5 m and 300 m. Cone heights range from 10 to 315 m and diameters from 50 to 750 m (Tabels 2 to 6). Cone density is 0.15 km^2.

Basal diameters ranging from 0.1 km to 2 km could imply magma reservoir depths between 3 km for the smaller cones and 35-40 km for the larger ones, although larger volumes in Mexican monogenetic volcanoes would probably offset these calculations.

These values resemble those reported by BLOOMFIELD (1975) for the Southern Valley of Toluca and the petrological characterization of the two areas are also similar, but Bloomfield's statement that the longest flows are more differentiated does not seem to be justified. The Paricutin region in Michoacan is also similar in its monogenetic volcanism morphology, and in the composition of its rocks.

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