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MAJOR ELEMENT CHEMISTRY OF THE MARCH-APRIL (1982) CHICHON VOLCANICS

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RESUMEN

El análisis químico de elementos mayores y los estudios petrográficos de los productos eruptivos del volcán Chichón, de marzo-abril, mostraron un alto porcentaje de material juvenil. Las muestras en general, fueron clasificadas como andesitas ricas en álcalis con plagioclasa zoneada, hornblenda, augita y biotita, como minerales principales. Los diagramas K_2O-SiO_2, (MgO-FeO + Fe_2O_3) y AFM sugieren un origen calci-alcalino-shoshonítico que puede estar relacionado con la subducción y que no parece estar ligado a los volcanes de los Tuxtlas. Un alto grado de contaminación por evaporitas es reflejado en el alto porcentaje de álcalis y calcio, xenolitos de carbonatos y cristales de anhidrita en la ceniza. Existe un aumento aparente en el porcentaje de sílice durante cada erupción.

ABSTRACT

Major-oxide chemical analyses and petrographic studies of Chichon volcano's March-April eruptive products showed a high percentage of juvenile material. Samples were generally classified as high-alkali andesites with zoned plagioclase, hornblende, augite and biotite as the main minerals. The K_2O-SiO_2, MgO-(FeO + Fe_2O_3) and AFM diagrams suggest a calcalkaline-shoshonite, probably subduction related origin of the magma, that does not seem to be related to the Tuxtla volcanics. A high degree of evaporite contamination is reflected in the high alkali and calcium percentage as well as in carbonate xenoliths and anhydrite crystals in the ash. There is an apparent silica increase during each eruption.

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INTRODUCTION

Chichon volcano is located in southeastern Mexico (17°22'N latitude, 93°14'W longitude).It lies approximately 350 km from the Middle American Trench, some 150 km above the Benioff zone (Mota, 1979) and is situated between the Mexican and Central American Volcanic Belts (Fig. 1).

After over 100 years of only minor fumarolic activity (Mulleried, 1933; Mooser *et al.,* 1957), Chichon Volcano erupted violently on March 28, 1982. During the following few days, only minor ash emissions were visible, but on April 3 - 4, two large eruptions took place producing extensive airfall products and pyroclastic flows.

The Chichon area is a hilly region dominated by faulted NW trending folds. In this area Tertiary (Oligocene, Eocene and Paleocene) sedimentary and igneous rocks are underlain by a thick Jurassic-Cretaceous shale and carbonate sequence (López, 1975). Evaporites in the area have been reported in the Mesozoic through Tertiary strata. The volcano lies 25 km north of the left-lateral large fault region (e. g. Copainala and Malpaso faults) and immediately south of the oil producing sedimentary basin.

The stratovolcano is a 5 km by 4 km structure with a summit cone. March-April activity took place in the small cone, clearing it of the central dome which had filled its crater earlier. The history of the volcano is poorly documented and the only date available is a 0.207 m. y. K-Ar determination of one of the cone-building phases (Damon and Montesinos, 1978).

In this paper we describe the compositional pattern of the recent Chichon volcanics which may provide insights into the tectonic framework and physical parameters of the volcanic setting.

SAMPLING AND MEASUREMENT

Tephra was sampled continuously during the eruptions at varying distances from the volcano. A series of samples was chosen for chemical analysis so as to reflect the compositional range of the products (Tables 1 and 2; Fig. 1). Chemical analyses were carried out by wet-chemical (Tables 1 and 2) and X-ray fluorescence techniques at the Facultad de Ciencias Químicas, Consejo de Recursos Minerales and Instituto de Geofísica. Estimates of reproducibility (%) are listed in Table 1.

Petrographic studies and CIPW norm calculations were carried out in order to draw inferences on the conditions under which the rocks crystallized.

Table 1

Major Element Chemistry of Chichon Volcanics from March 28 - April 2.

Sample	101 ash	103 lapilli	107 ash	109 pumice	110 lapilli	112 c a.block	112 d pumice	112 e a.block	
Locality	Villahermosa	El Azufre	Tectoapan	Nicapa	Juarez	Col. Volcán	Col.Volcán	Col.Volcán	Reproducibility
SiO_2	58.76	51.94	54.30	51.97	52.65	57.38	55.07	52.00	± 0.15 %
Al_2O_3	19.40	22.44	21.09	18.43	19.81	18.75	18.02	17.43	± 3 %
TiO_2	0.60	0.68	0.60	0.74	0.84	0.58	0.58	0.60	± 15 %
FeO	2.05	2.50	2.39	4.80	5.44	2.75	3.76	3.77	± 15 %
Fe_2O_3	1.50	1.89	1.80	3.62	2.61	2.08	2.83	2.85	± 17 %
MnO	0.17	0.19	0.18	0.14	0.10	0.01	0.20	0.21	± 8 %
MgO	1.52	2.94	1.92	2.77	3.95	3.57	2.32	2.80	± 10 %
CaO	5.50	8.36	7.53	9.02	7.15	5.44	7.83	7.36	± 7 %
Na_2O	5.15	4.40	4.30	4.65	4.42	5.50	5.15	4.78	± 8 %
K_2O	3.60	3.05	4.10	1.92	1.90	2.52	2.70	2.60	± 4 %
P_2O_5	0.37	0.10	0.17	0.30	0.14	0.29	0.28	0.29	± 40 %
SO_3	1.40	0.78	0.66	0.29	1.04	0.37	0.35	2.63	± 40 %
H_2O^-	0.16	0.03	0.07	0.12	-	0.40	0.30	0.18	± 40 %
H_2O^+	0.00	0.70	1.00	0.91	-	0.85	1.20	2.53	± 20 %
Σ	100.18	100.01	100.15	99.69	100.06	100.14	100.33	100.04	

Analyst: H. Bolaños and A. Obregón.

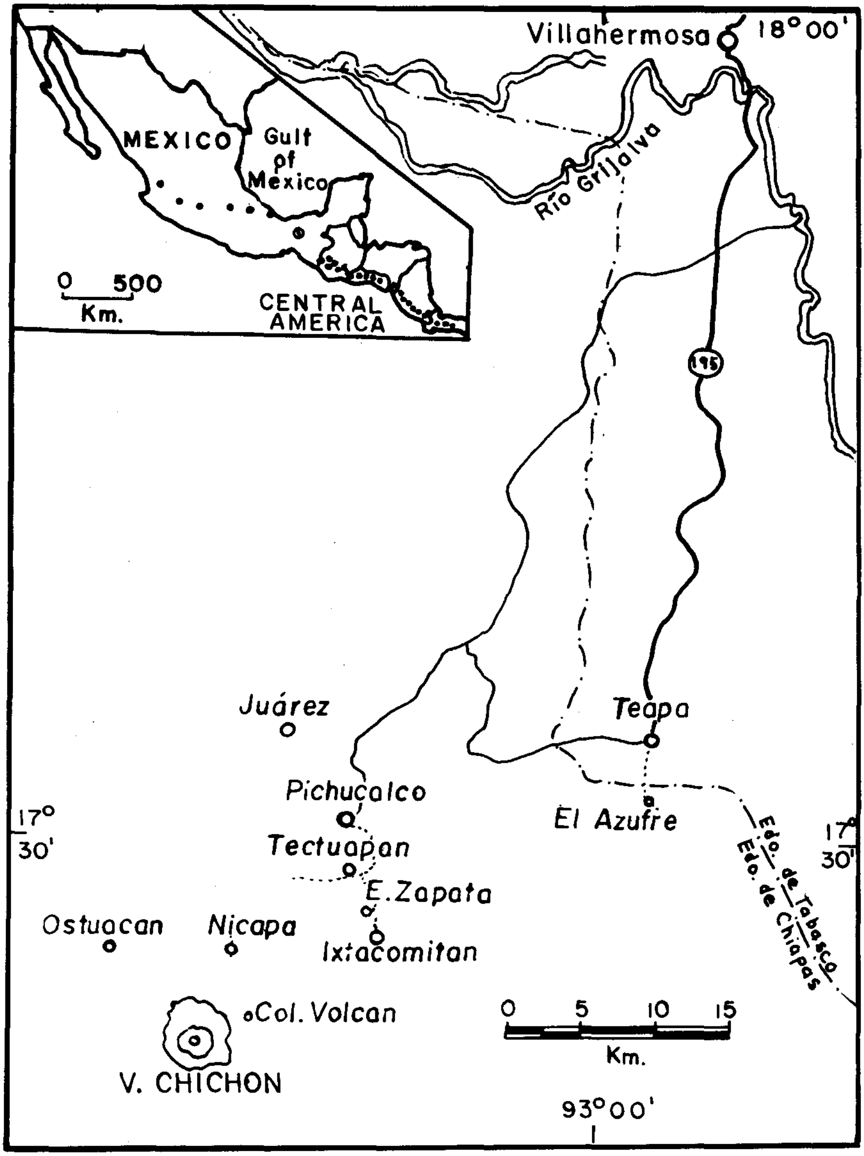


Fig. 1. Index map showing Mexican and Central American Volcanic Belts (circled dot represents Chichon Volcano) and map of Chichon area.

PETROGRAPHY

Samples were subdivided into accidental blocks, pumice fragments and ash and lapilli. Block and pumice samples contained plagioclase and hornblende phenocrysts while the finer ash contained plagioclase and hornblende grains as well as glass fragments. Augite and biotite were present in some samples. The percentage and size of phenocrysts in the accidental blocks varied widely, though many samples clustered around the 50% phenocryst mark. Rock fragments varied from fine grained rocks with small hornblende phenocrysts to much coarser grained rocks with hornblende and plagioclase phenocrysts. Percentage of phenocrysts also varied in pumice fragments, generally from 10-20% for ash fall to over 25% for the pyroclastic flow. Phenocryst size also increased in the flow samples, as did the biotite content.

All rocks varied from hipocrystalline to hipohialine with porphyritic texture. All plagioclase crystals were zoned (~andesine) and in some cases glass and anhydrite inclusions were present. In a few samples of accidental blocks, the plagioclase fragments were broken and distorted possibly reflecting movement during solidification. Hornblende (which in some samples was altering to biotite), biotite and augite were the principal mafic minerals. Apatite and magnetite were also present in small amounts in the glass matrix.

The bimodal size distribution namely, phenocrysts and glass, clearly demonstrates two different cooling stages for the magma. The crystallization of the phenocrysts probably took place in the magma chamber while glass solidified during eruption. The presence of anhydrite crystals suggests the importance of evaporite contamination. Anhydrite was also observed in intergrowth with plagioclase and other phenocrysts which could indicate shallow crystallization of the magma (Prol *et al.,* 1982).

The high percentage of pumice fragments of all sizes as well as the high percentage of glass in most of the samples of the Chichon volcanics demonstrates the high proportion of "juvenile" or "fresh" magma as compared to accidental material.

The mineral components and textural patterns permit the samples to be classified as andesites.

RESULTS AND DISCUSSION

The petrography suggests the andesitic character of the samples and although some of the silica percentages are low, they generally corroborate this character (Tables 1 and 2). Several hypotheses have been proposed to explain the large volume of andesites in continental orogenic belts. These include differentiation of basaltic magma (Bowen, 1928; Osborn, 1962), contamination and assimilation (Larsen *et al.,*

Table 2

Major Element Chemistry of Chichon Volcanics from April 3 - 6.

	113 lapilli	114 ash	116 ash	117 ash	119 ash	120 ash	121 a. block	126 pumice (flow)	131 ash (flow)
Locality	Pichucalco	Ixtacomitán	5 km S of Villahermosa	Teapa	Pichucalco	Emiliano Zapata	Ostuacán	2 km S of Nicapa	2 km S of Nicapa
SiO_2	52.39	53.33	59.13	58.73	55.65	53.95	52.04	55.93	54.01
Al_2O_3	22.92	20.15	18.25	19.46	20.66	22.56	18.52	18.16	20.23
TiO_2	0.77	0.65	0.90	0.43	0.56	0.69	0.68	0.62	0.66
FeO	4.07	2.93	2.52	2.03	2.33	3.03	4.20	3.36	3.95
Fe_2O_3	0.04	2.11	1.08	1.53	1.763	0.42	3.16	2.53	2.97
MnO	0.26	0.19	0.15	0.18	0.18	0.22	0.05	0.18	0.11
MgO	2.50	2.51	1.70	1.55	1.86	2.38	3.12	2.04	2.17
CaO	8.46	7.79	4.90	5.50	7.17	7.53	7.07	7.46	5.24
Na_2O	4.90	4.50	4.60	5.15	4.10	4.90	4.80	4.65	3.38
K_2O	1.95	1.95	3.00	3.60	4.30	2.35	2.38	2.95	2.37
P_2O_5	0.33	0.38	0.15	0.37	0.18	0.45	0.25	0.22	0.16
SO_3	0.35	0.71	1.71	1.43	0.72	0.99	0.26	0.30	0.06
H_2O^-	0.15	0.04	1.09	0.00	0.08	0.10	0.17	0.20	2.34
H_2O^+	0.66	0.42	0.15	0.16	1.07	0.27	1.70	1.40	2.77
Σ	99.75	100.66	99.33	100.12	100.63	99.84	100.01	99.83	100.43

Analyst: H. Bolaños and A. Obregón.

1938; Tilley, 1950) magma mixing (Sparks *et al.*, 1977; Eichelberger, 1978) and partial melting of subducted ocean crust or of overriding mantle (Green and Ringwood, 1968; Dickinson, 1970). Modern theories generally take into account several of these hypotheses to explain the resulting andesites (O'Hara, 1977). Some authors (Taylor, 1969; Boettcher, 1973; Kushiro, 1973; Moorbath *et al.*, 1978) consider the original source of andesites to be in the mantle that by hydrous partial melting generates a high alumina basalt or an andesitic composition. Water from

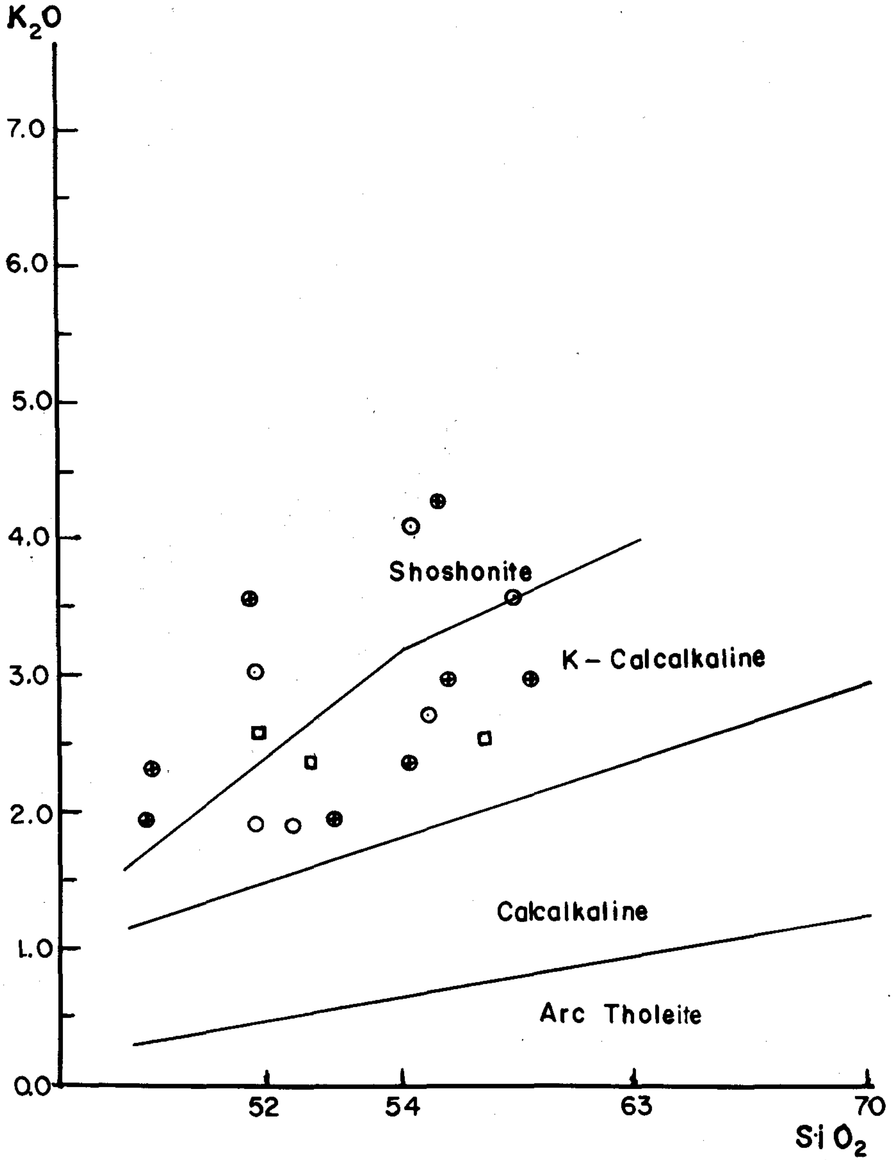


Fig. 2. K_2O-SiO_2 Diagram (after Peccerillo and Taylor, 1976) showing accidental blocks (squares), samples from first eruption (O), and Apr. 3-4 eruption (⊕).

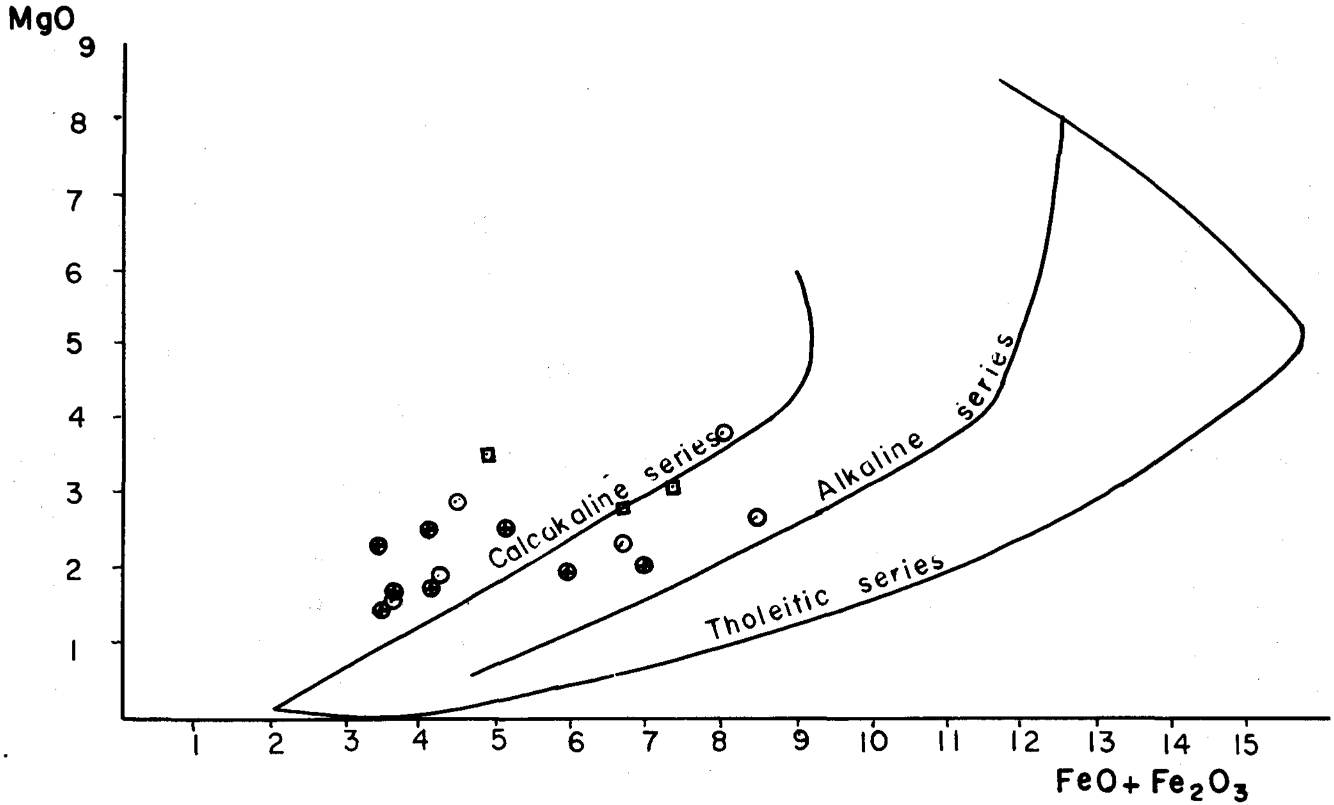


Fig. 3. MgO–(FeO + Fe_2O_3) (after Tilley and Muir, 1967) diagram showing accidental blocks (squares), samples from first eruption (O), and Apr. 3-4 eruption (⊕).

the subducted ocean crust probably decreases melting temperatures and causes partial melting without extra heat input (McBirney, 1969). The magmas then undergo fractional crystallization at depths where amphibole and plagioclase are stable, between 5 and 10 Kb (Green *et al.*, 1967) which corresponds to between 15 and 50 km. Additional crystallization probably occurs in shallow magma chambers between 2 and 5 km. Abundance of phenocrysts suggests considerable crystallization at low pressures (O'Hara, 1968). The common occurrence of summit calderas is also consistent with the existence of shallow chambers, as in the case of Chichon's 2 km summit caldera. Seismic data for Chichon also support this conclusion, since earthquakes were found to cluster at 2-5 km and 15-25 km (Servicio Sismológico Nacional, personal communication, 1982).

The results of the chemical analyses of the Chichon volcanics were plotted on several diagrams in order to characterize the compositional pattern. In the K_2O-SiO_2, diagram (Fig. 2), samples fall in the high-K calc-alkaline and shoshonitic fields. The MgO-($FeO+Fe_2O_3$) diagram (Fig. 3) shows rocks to be calc-alkaline although some samples tend towards the alkaline series. Orogenic or subduction areas have been related to the calc-alkaline series (Jakes and White, 1972) and shoshonitic rocks are subduction related rocks with high alkali values and probably generated deeper than their calc-alkaline associates (Jakes and White, 1972; Barberi *et al.*, 1974).

Similar results are observed in the AFM diagram (Fig. 4) where samples are basically calc-alkaline trending towards shoshonitic. Fig. 4 shows the data on the AFM diagram where the compositional trends of the Central American andesites (McBirney, 1969), the Mexican Volcanic Belt (MVB) and the Tuxtla volcanics of eastern Mexico are plotted against the Chichon volcanics. As can be seen in Fig. 4, the Tuxtla field does not coincide with the Chichon samples. These varying chemical patterns are also reflected in the more alkaline and mafic nature of the Tuxtla volcanics; picrite-basanite-alkali basalt and hawaiite. Thorpe (1977) argues that the Tuxtla area is distinct from the volcanics of the MVB and regards it as linked to fracturing and extension associated to this belt, while Robin (1976) relates the magma genesis of the Tuxtlas to the tectonics of the Gulf of Mexico. The Chichon volcanics do overlap with the Central American volcanic field and with the rocks from the western MVB on the AFM diagram (Fig. 4). No iron enrichment is evident for the Chichon samples. The intermediate, andesitic character of these samples is also characteristic of orogenic areas (calc-alkaline continental margin type associations). Titanium values are low and aluminum values high for alkaline rocks and are typical of calc-alkaline associations (Wedepohl, 1969). High alkali and calcium values may result from the evaporite contamination and are probably responsible for the mildly-alkaline or shoshonitic character.

Magmatic assimilation or contamination by carbonates and evaporites has been reported at Vesuvius (Rittman, 1933; Ayrton, 1974) Nevada (Wells *et al.*, 1971;

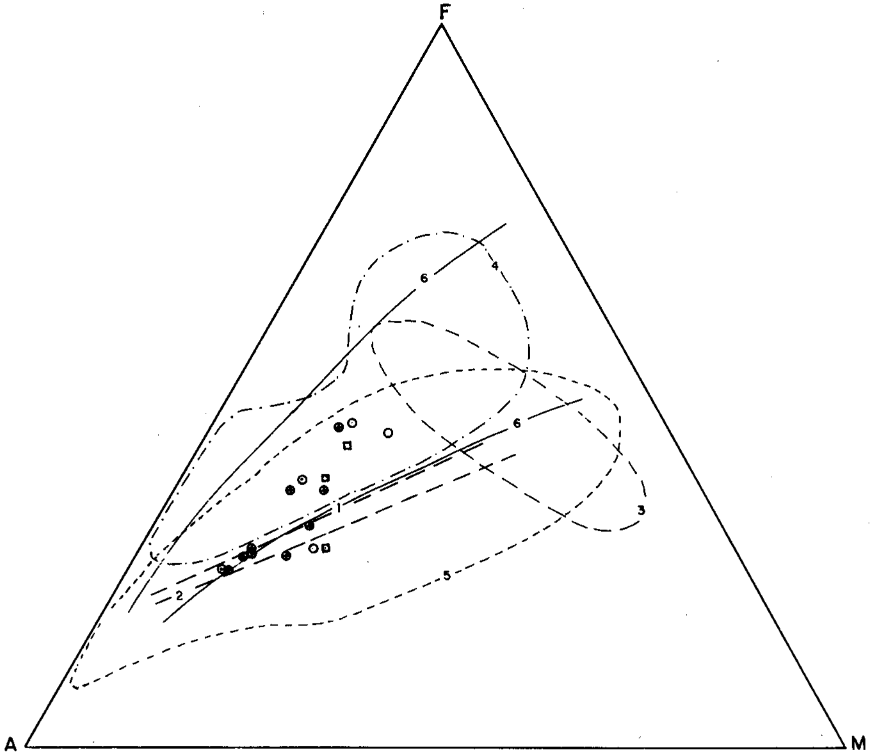
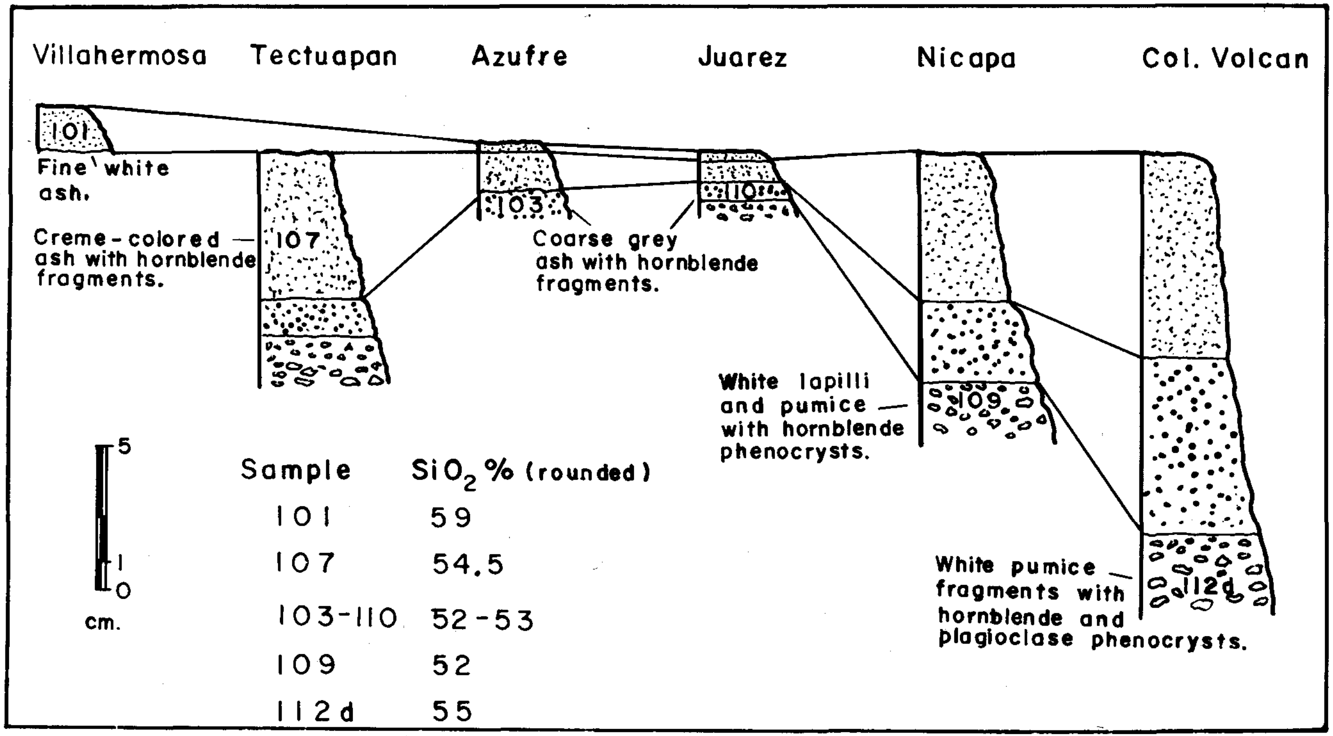


Fig. 4. AFM Diagram showing Chichon samples and curves for 1: Calcalkaline continental margin Crater Lake series (Williams, 1942); 2: Shoshonitic series; 3: Tuxtla Alkaline series (Thorpe, 1977); 4: Northeastern Mexican Volcanic Belt series (Pal *et al.*, 1978); 5: Western Mexican Volcanic Belt series (Pal *et al.*, 1978) and 6: Central American andesitic series (McBirney, 1969).

Gilluly and Masursky, 1965) and other areas, but none has been as extreme as in Chichon's case. Halite in stratospheric clouds (Sean, 1982), carbonate xenoliths and anhydrite crystals in the ash reflect contamination by underlying evaporites.

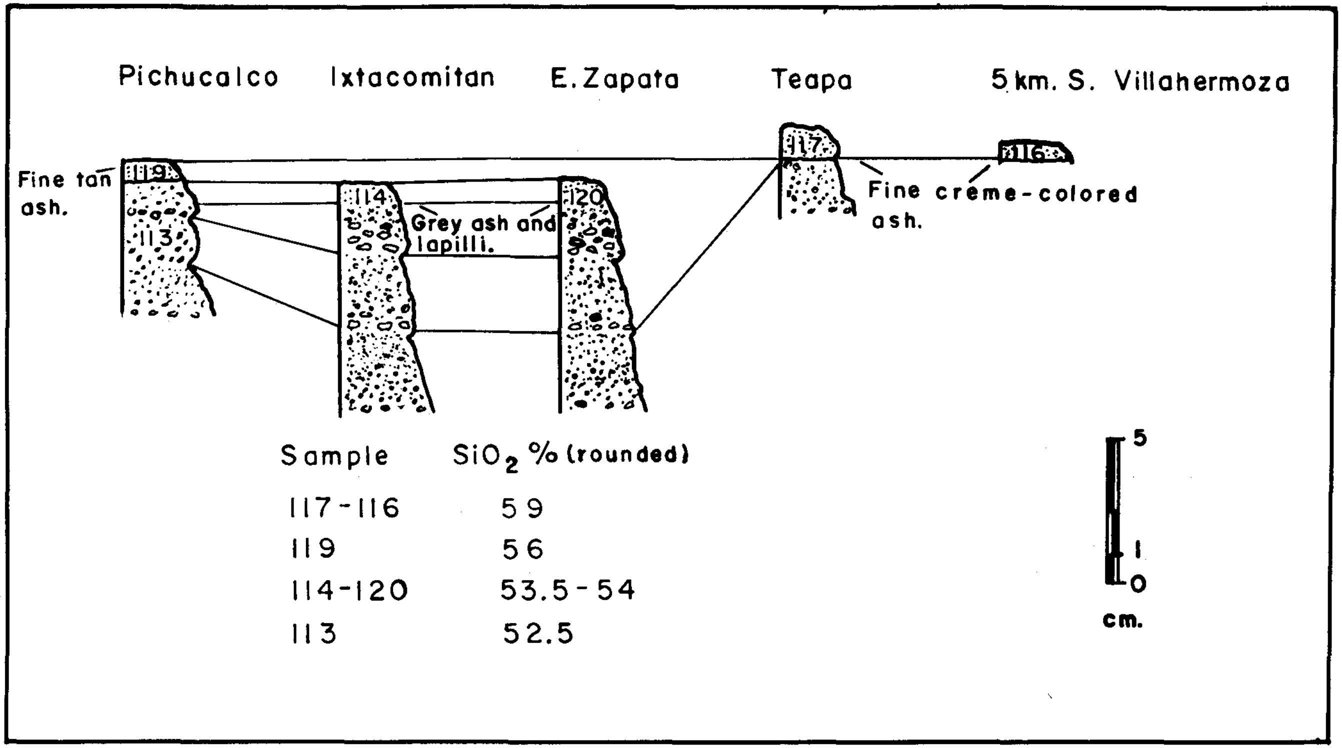
The presence of hydroxyl minerals, such as hornblende and biotite and of zoned plagioclase phenocrysts is characteristic of calc-alkaline volcanics. The hydrous nature of the Chichon volcanics is also reflected in the extensive pyroclastic flows which issued on April 3rd, and abundance of hornblende and biotite. The presence of water and alkalies also increases hornblende stability (Kushiro, 1974). The influx of water may have a triggering effect on explosive eruptions (Sparks *et al.*, 1977).

The tephra sequence of the first eruption seems to show an increase in silica from the first more hornblende-rich ejecta to the finer light colored ash (Fig. 5).



Sample	SiO_2 % (rounded)
101	59
107	54.5
103-110	52-53
109	52
112d	55

Fig. 5. Tephra sections for March 31-Apr. 2 showing SiO_2%.



Sample	SiO_2 % (rounded)
117-116	59
119	56
114-120	53.5-54
113	52.5

Fig. 6. Tephra sections for Apr. 3-6 showing SiO_2%.

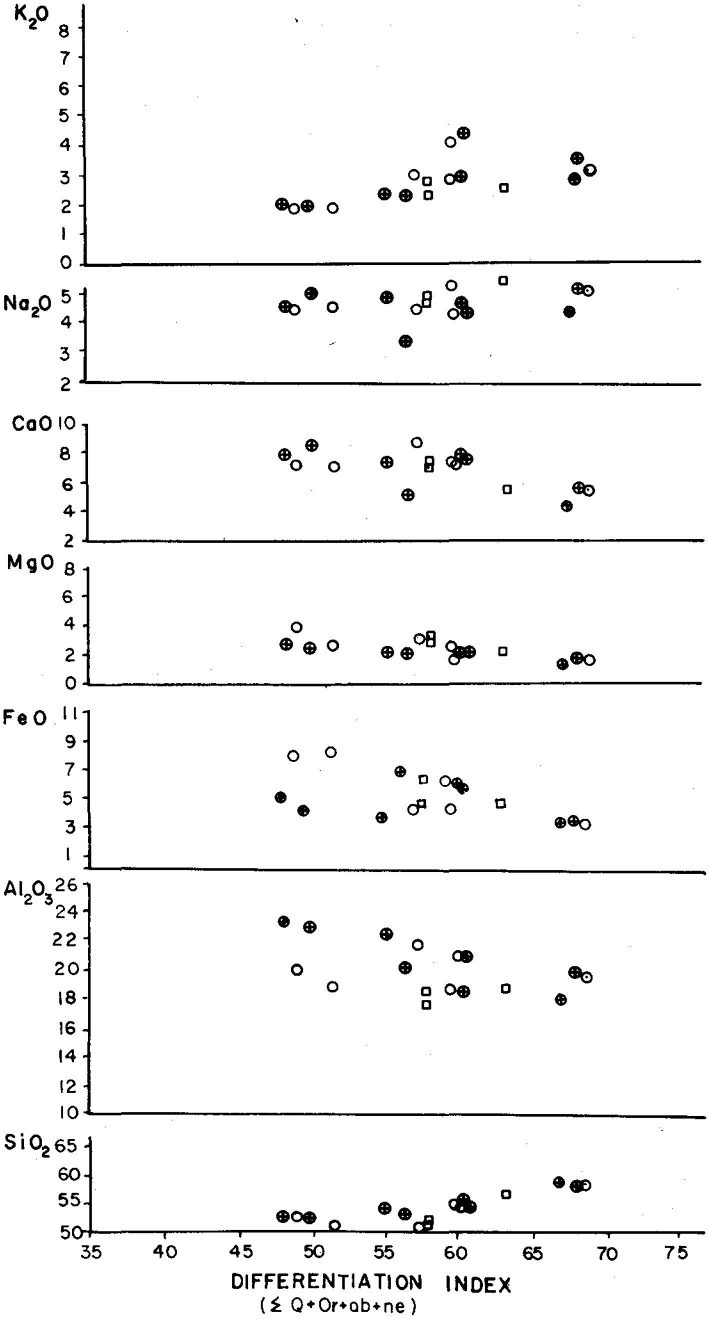


Fig. 7. Plots of several oxides against the differentiation index.

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The same appears to occur with the April 3-4 eruptions (Fig. 6), although no clear chemical distinction can be drawn between the April 3 and 4 eruptions. This is consistent with the differentiation diagram (Fig. 7) where linear regression coefficients were low when all of the samples were included, but were above 0.7 when the samples from the first eruption, the second-third eruption, and the accidental blocks were treated separately. On April 2, the eruptive cloud which issued from the volcano was observed to be divided into two columns, one dark grey (probably more hornblende-rich) and another tan colored. This could reflect the observed variations in the products. It could also be due to the injection of more basic magma from deeper levels before the first and second large eruptions which could also have triggered the explosive activity. This is consistent with the deeper earthquakes between eruptions and shallow seismic activity leading up to them (Servicio Sismológico Nacional, personal communication, 1982). However, further evidence is needed to support this conclusion.

CONCLUSIONS

Petrographic studies as well as major element chemical analyses suggest that the Chichon volcanics are high-alkali andesites. A general calcalkaline to shoshonite tendency can be noticed in the K_2O-SiO_2, MgO-(FeO+Fe_2O_3) and AFM diagrams. There does not seem to be any genetic link with volcanics from the Tuxtla area. High alkali and calcium values probably reflect the high degree of contamination as do microscopic observations and diagrams. An increase in silica was also observed during each eruption.

We wish to mention that further geochemical studies involving trace element and isotopic analyses, should be undertaken in order to obtain further geochemical constraints on the petrogenesis of this area.

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