Geochemistry of the Volcanics of Central Mexico *

B. M. GUNN ** and F. MOOSER ***

Abstract

The Tertiary and Recent volcanics of Mexico occur in two provinces. The Cordillera Province is made up of about 1700 m of ignimbrite sheets overlain and intercalated in the upper part by olivine basalt and basaltic andesite. The Rio Lerma Province extends transversely across Mexico and in the Valley of Mexico the lavas consist mainly of andesite and dacite, 68 % of those analysed having 62 ± 4.7 % SiO_2. A total of 108 chemical analyses were made for the major elements, 90 of these including determinations of Cr, Ni, Cu, Zn, Rb, Sr, Ba, Th and Pb for two areas, the Valley of Mexico in the Rio Lerma Province and the Guadalajara region which lies at the intersection of the two provinces. Computer constructions of normative components in the basalt tetrahedron and other projections support an origin of partial melting of tholeiitic to pyrolitic material for the production of andesite. The Guadalajara lavas have consistently higher K/SiO_2 and K/Rb ratios and lower Mg/SiO_2 ratio than the Valley of Mexico rocks suggesting generation at greater depth.

General Geology

Volcanic rocks, mainly of Upper Tertiary and Recent age cover more than a third of the land surface of Mexico and occur in two distinct provinces (Fig. 1).

a) THE CORDILLERA PROVINCE.

This extends along the Sierra Madre Occidental from the Pacific coast inland to the Mesa Central near Torreon, a distance of about

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** Dépt. de Géologie, Université de Montréal.
*** Instituto de Geologia, Universidad de Mexico.

400 km. Volcanic rocks extend continuously in a north-south direction about 2,250 km from southeast of Guadalajara to the United States border, though there is little information as to whether the rocks are of similar type over this distance. Only two access roads, the Mazatlan - Torreon Highway and the Zacatecas - Guadalajara road via Santiago Canyon cross this very large province.

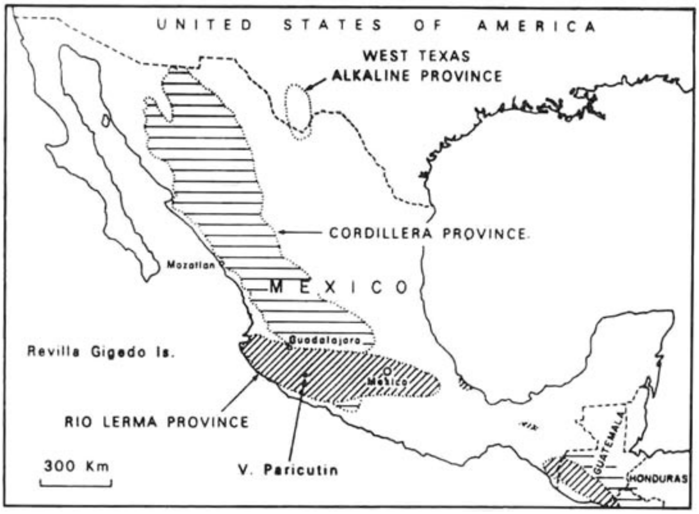


FIG. 1 - Map of the Volcanic Provinces of Mexico.

South and east of Mazatlan, the rocks of the Cordillera Province are predominantly ignimbrite sheets, usually 50-200 ft in thickness, consisting of welded tricuspate glass shards often together with a high percentage of tridymite and sanidine crystals or lithic material, mainly rhyolite. West of Torreon, the ignimbrites are intercalated with, and overlain by, olivine basalt; near Gualadajara, the upper part of the Cordillera ignimbrites, as seen in the Canyon de la Santiago, are intercalated with thin flows of olivine high-alumina basalt and basaltic andesite. Dacitic rocks are absent, the compositional distribution being bimodal. The total thickness of the ignimbrites is estimated to be in the order of 1700 m and they rest mainly on an erosion surface cut in Cretaceous limestone although along the Pacific coast, south of Puerto Vallarta, the basement rocks are mainly Paleozoic metamorphics. Small outcrops of granodiorite, as seen near

Mazatlan, are listed in the Geological Map of Mexico as being of early Tertiary age.

b) THE RIO LERMA PROVINCE.

This province, referred to in the literature by names such as the « Mexican Volcanic Axis » (FOSHAG and GONZALEZ, 1956), the «Mexican Volcanic Belt» (MOOSER and MALDONADO-KOERDELL, 1967), or the « Neo-

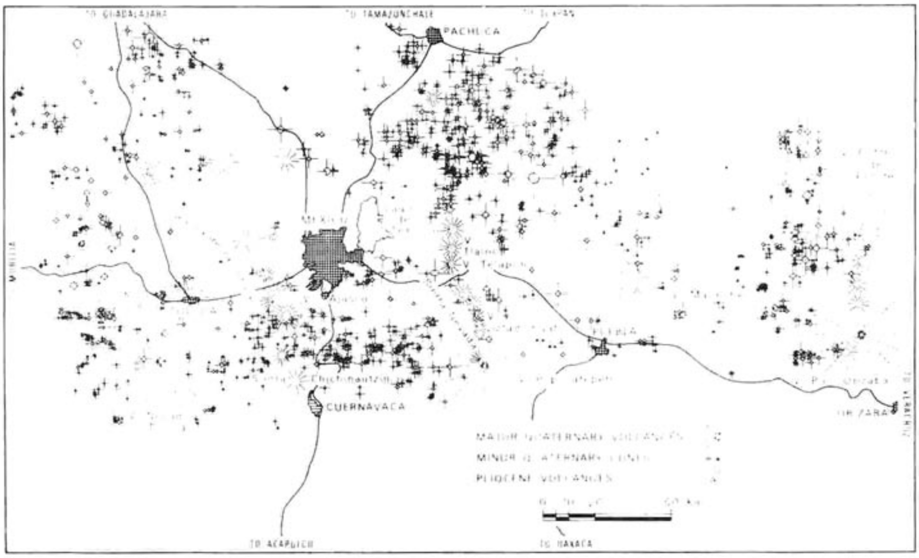
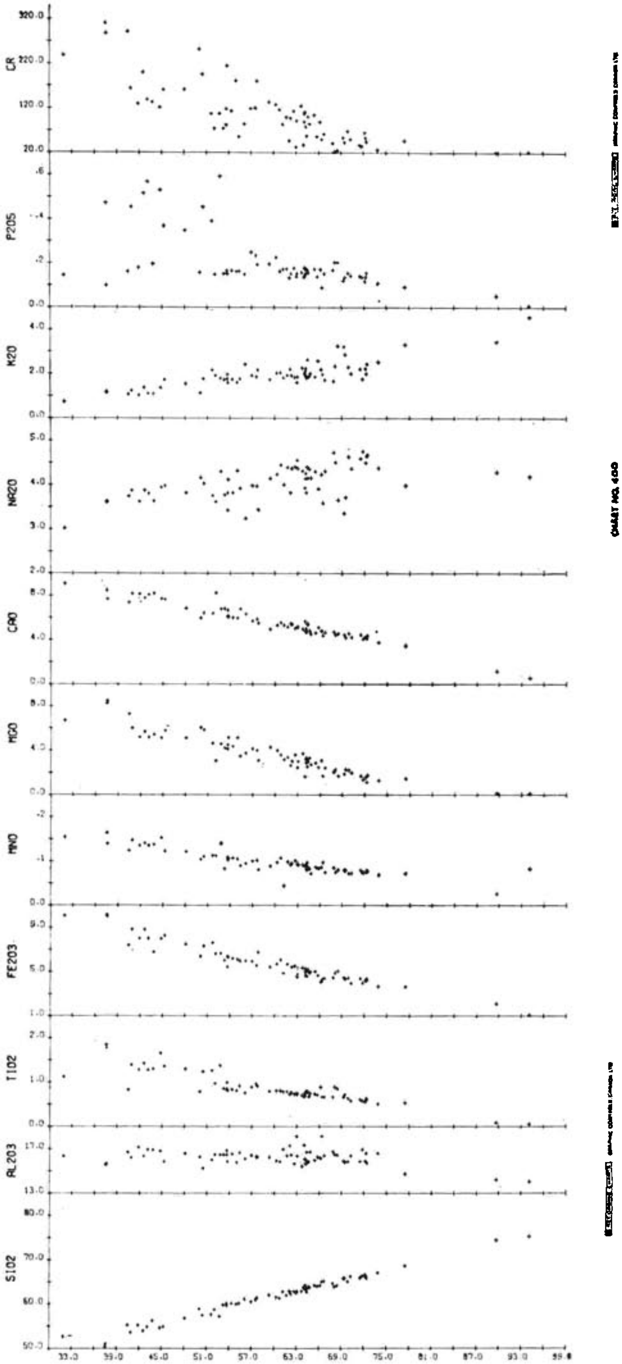


FIG. 2 - Map of Volcanoes in the Mexico City Region.

Volcanic Zone » (WILLIAMS, 1950), consists of an elongated zone of overlapping andesitic strato-volcanoes, scoria cones, lava domes, laharic deposits and obsidian domes extending across Central Mexico between the Pacific and Gulf of Mexico coasts.

The largest of the strato-volcanoes rise to nearly 6000 m above sea level; the total number of cones has never been estimated but is of the order of several thousand. The oldest volcanics of the region are Early Miocene in age with volcanic activity continuing at the present day.

East-west trending faults and block faulted structures parallel the belt. The east and west branches of the Rio Lerma follow a graben



Differentiation Ind.

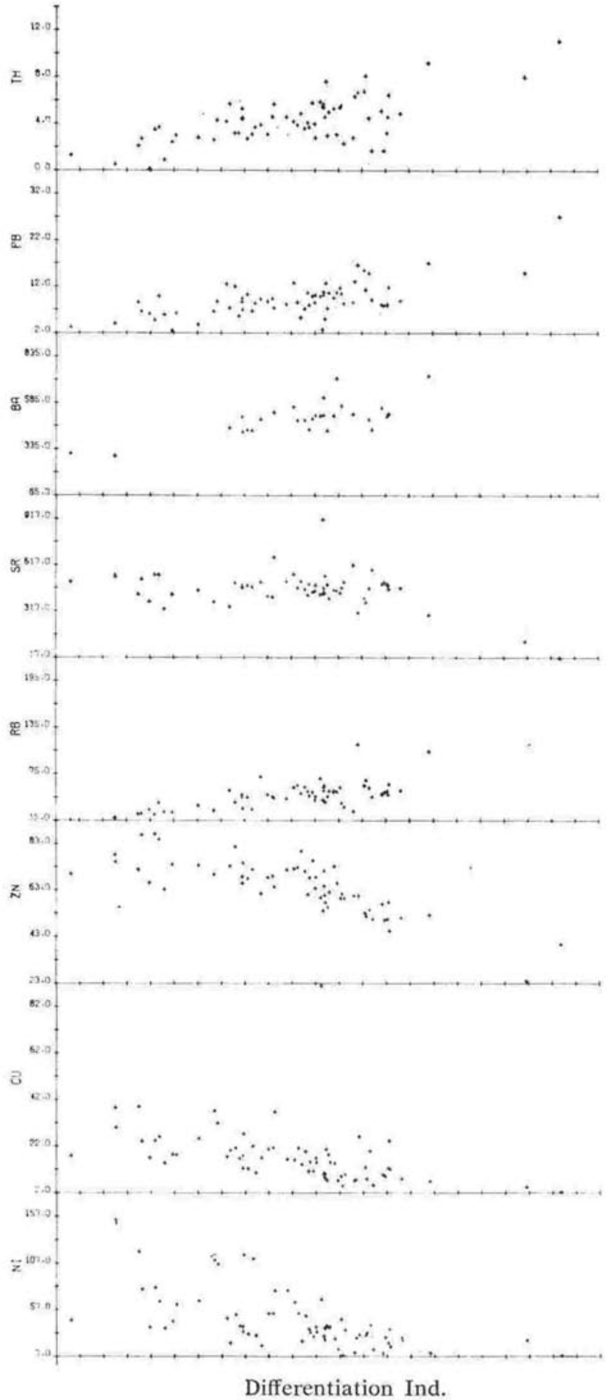


FIG. 3 - Variation Diagrams against the Differentiation Index. Σ (Ab+Or+Leu+Ne+Qz).

along the northern periphery of the belt, and it is from this that the name for the province is derived. The two provinces overlap and interdigitate near the city of Guadalajara.

Statement of Problem

The two distinctive volcanic provinces of Mexico are far from being unique. Similar provinces, partially separated or overlapping

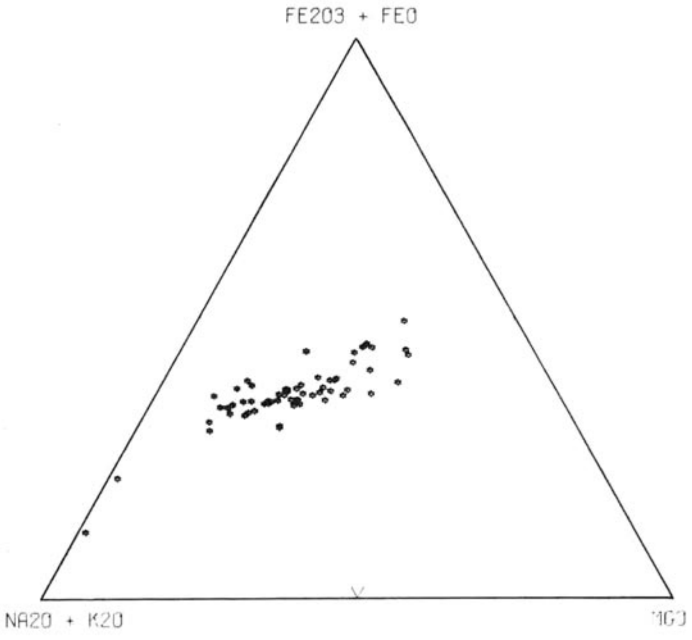


Fig. 4 - FMA Ternary Diagrams for Valley of Mexico Lavas.

in time and space, one consisting of ignimbrite sheets, pumice shower and other varieties of crystal, vitric and lithic tuff, and the other of localised andesite stratovolcanics are known from Oregon, U.S.A.; Guatemala; and New Zealand, to name a few examples. The relationship between the two sub-provinces differs; in Guatemala, the strato-volcanoes lie along a well-defined belt at the edge of the rhyolite plateau. In New Zealand, the andesite volcanoes lie along a fracture zone that extends across an extensive ignimbrite plateau (Healy, 1962). In Mexico, the two provinces lie almost at right angles, overlapping only in the vicinity of Guadalajara.

Though ignimbrites are commonly thought to originate from fissure eruptions in no case does it appear that the fracture zones were common to both the ignimbrite and andesite volcanism. Two such provinces could conceivably be petrogenetically related or be completely unrelated.

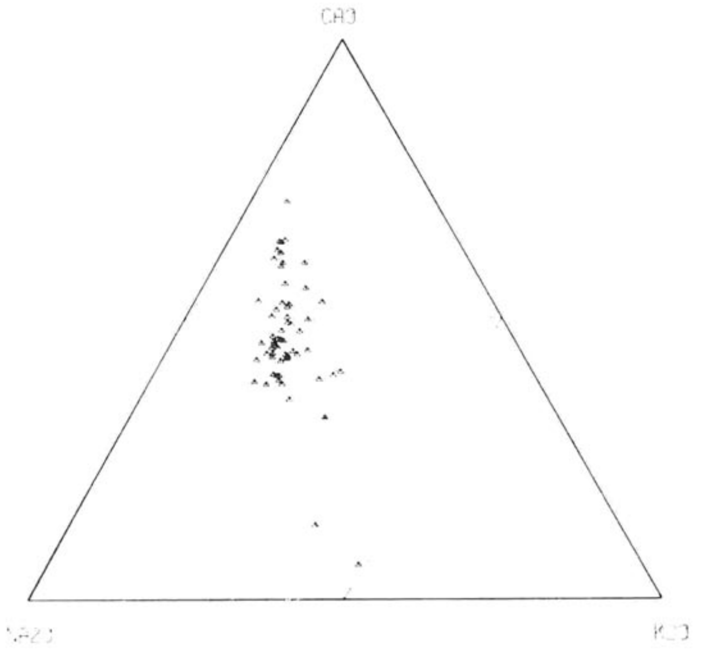


FIG. 5 - Na-Ca-K Ternary Diagram for Valley of Mexico Lavas.

The study of Mexican andesites was undertaken also partly in order to investigate the problem of andesite origin. Though minor olivine basalt and pumiceous rhyolite do occur in the Mexico City region, the great bulk of the rocks are andesites or dacites. All rocks are normatively oversaturated in silica, usually by 10-12 %, the total alkali content in the alkali-silica diagram is intermediate between tholeiitic and alkaline rocks, the mean alumina content is between 16-17 %, and the petrographic textures are almost invariably porphyritic with oscillatory zoned andesine plagioclase and hypersthene being the common phenocryst minerals.

Such an assemblage, characteristic of the circum Pacific orogenic belt contrasts strongly with the lavas of the deep ocean basins where tholeiitic basalts with isolated islands usually of alkali basalt - trachybasalt - trachyte lavas is the rule and with the non-orogenic continental regions where again either tholeiitic flood basalt or alkaline magmatism is the norm. In some way, lavas of andesitic type owe their composition to their association with zones of orogenic activity.

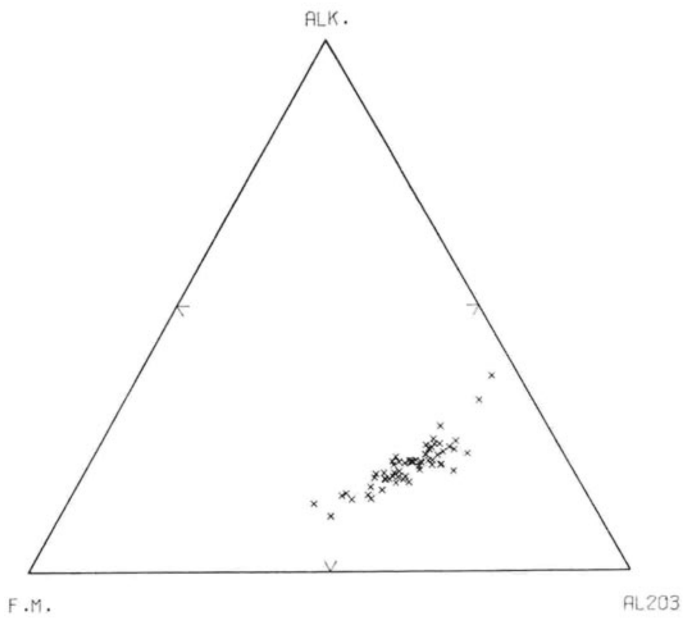


FIG. 6 - Alk-Al_2O_3-Σ Fe^{+++} + MgO Diagram for Valley of Mexico Lavas.

Recent Volcanic Activity

FOSHAG and GONZALEZ (1956) list the most recent activity of the Mexican volcanoes as follows:

San Martin Tuxtla (1793), Orizaba (1687), Popocatepetl (1920-24), Jorullo (1759), Colima (1913), Ceborruco (1870-75), San Juan (1859), and Paricutin (1943-57). Of these, V. Colima, V. Popocatepetl and Pico Orizaba are in a fumarolic quiescent stage and the rest are considered extinct.

In the Cordillera province, the youngest basalts are possibly Post Pleistocene though all activity has now ceased. Potassium argon dates of the uppermost ignimbrite flows near Guadalajara give ages of 9.2 - 4.6 m.y. (WATKINS, pers. comm.).

Previous Work

The calc-alkaline volcanics of Central America have been the subject of surprisingly little study until recent years. WILLIAMS,

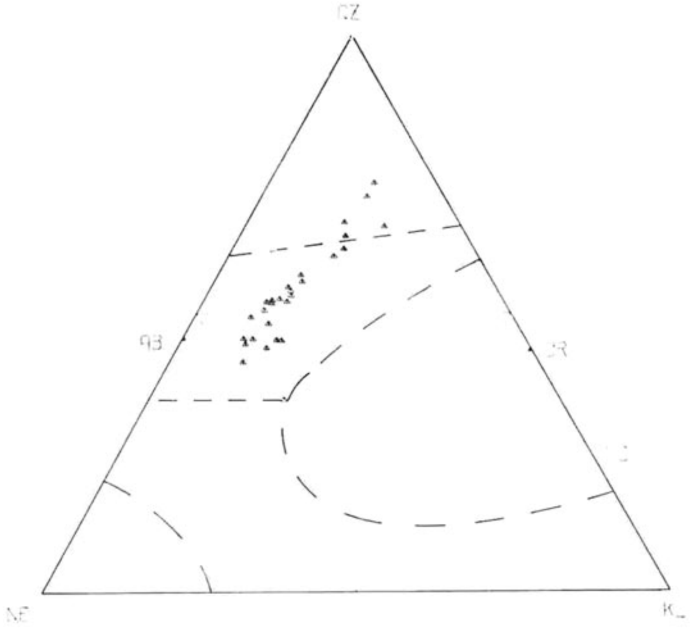


FIG. 7 - Qz-Ne-Kl Ternary Diagram for Guadalajara Region including Alkaline Basalt from Torreon, and 3 ignimbrites.

MCBIRNEY and DENGO (1964) have carried out reconnaissance mapping of Guatemala, MCBIRNEY and WILLIAMS (1965) of Nicaragua, and WILLIAMS and MAYER-ABICH (1955) of San Salvador. The geochemistry of the Guatemala, San Salvador, Costa Rica and Nicaragua Quaternary volcanics has been summarised by MCBIRNEY (1969) and MCBIRNEY has also generously allowed unpublished analyses of these lavas to be used for comparison with the present data.

Reconnaissance mapping of the volcanics of Central Mexico has been carried out by WILLIAMS (1950), MOOSER (1960-67), MAYER (1965), CONSTANTINO (1967), and by the Commission Lerma-Chapala-Santiago in 1960-68.

Comparatively little petrological or geochemical work has been done previously on the volcanic rocks of Mexico. The greatest interest has centered on Volcan Paricutin, 150 km southeast of Guadalajara. This volcano commenced eruption in 1943 and after covering an area of a few square miles with flows of basaltic andesite and building a

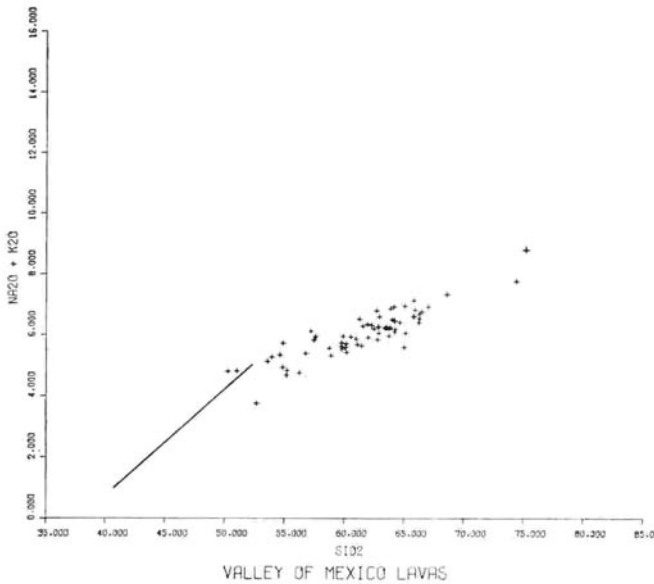


FIG. 8 - Alkalies/SiO_2 Diagram for Valley of Mexico. The diagonal line represents the separation between Hawaiian Alkaline and Tholeiitic Basalts.

composite ash-lava cone about 300 m high, became extinct in 1952. This brief history is undoubtedly typical of the great majority of small cones in Central Mexico. FOSHAG and GONZALEZ (1956) give a description of the complete history of the volcano and include six chemical analyses of the Paricutin lavas. Detailed petrographic descriptions of the andesites and basalts of the Paricutin region were presented by WILLIAMS (1950) together with 18 chemical analyses. These descriptions deal with lavas which appear to be typical of the whole Rio Lerma Province. WILCOX (1954) made a series of 22 analyses of Paricutin lavas and was able to show that a constant change in composition of the magma took place with time from basaltic andesite to andesite (55 to 60 % SiO_2).

The Paricutin lava was also used in melting point studies of continental margin andesites by TILLEY, YODER and SCHAIRER (1966). Barcena Volcano had an even shorter history than Paricutin, beginning eruption on one of the islands of the Revillagigedo group in the

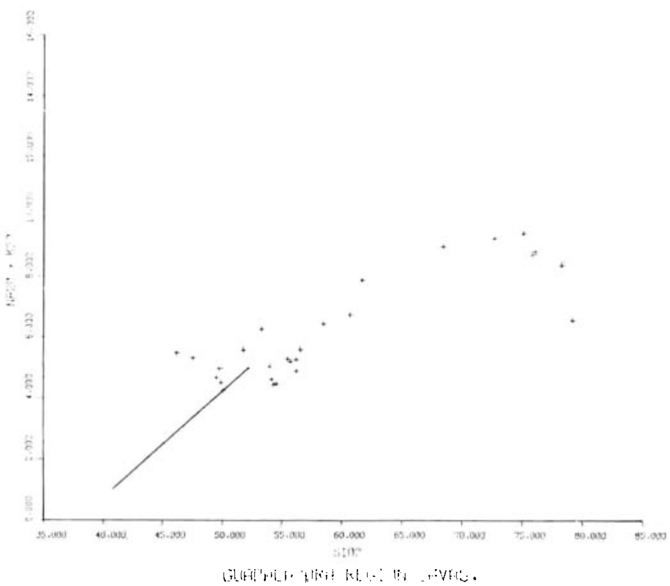


FIG. 9 - Alkalies/SiO_2 Diagram for Guadalajara Region. Note the alkaline character of the Recent Basalts.

Pacific Ocean off the west coast of Mexico in August 1952 and becoming extinct in March 1953 (RICHARDS and DIETZ, 1957).

Volcanology of the Mexico City Region

The geological map of the Mexico City Region (MOOSER, 1957) divides the volcanics in the Valley of Mexico into five groups:

1. *Xochtipec Group*, forming the Oligocene - Miocene basement.

2. *Sierra Nevada Group*, a continuous range of Pliocene age bordering the Valley to the east and surmounted by the Quaternary volcanoes Popocatepetl, Iztaccihuatl, Telapon and Tlaloc. The two

former cones rise more than 17,000 ft and have a permanent snow and ice fields.

3. *Las Cruces Group,* a similar ridge forming the western side of the valley and capped by a similar chain of craters including V. Ajusco.

4. *Chichinautzin Group,* formed of many scores of Quaternary cones which close the southern end of the valley.

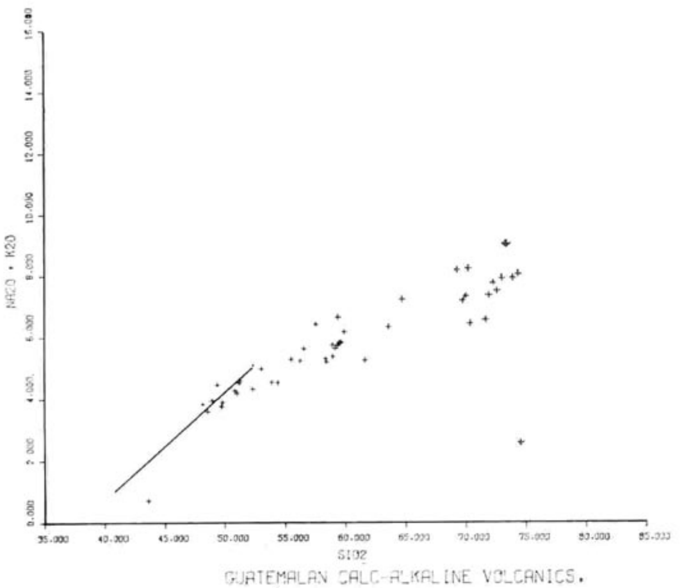


FIG. 10 - Alkalies/SiO_2 Diagram for Guatemala, unpublished data of MCBIRNEY.

The fifth group includes the Pleistocene sedimentary infilling in the enclosed basin.

It is beyond the scope of this communication to describe the more than four hundred large and small cones which litter the flanks of the Sierra and the floor of the Valley (Fig. 2), the purpose being merely to give a background in the geochemistry.

Structure

The main faults and graben of the entire Rio Lerma volcanic belt invariably have an east-west trend, the whole zone being interpreted as being either a continental extension of the Clarion fracture zone, a transform fault intersecting the Mid-Pacific Rise (BULLARD, 1969) or as faulted slices recurving from a southern continuation of the San Andreas fault (MOOSER and MALDONADO-KOERDELL, 1961). Offshore, to the west, the Acapulco Trench extends, parallel to the coastline, from Puerto Vallarta to southern Guatemala. BULLARD (1969) shows a single oceanic plate to be underthrusting southern

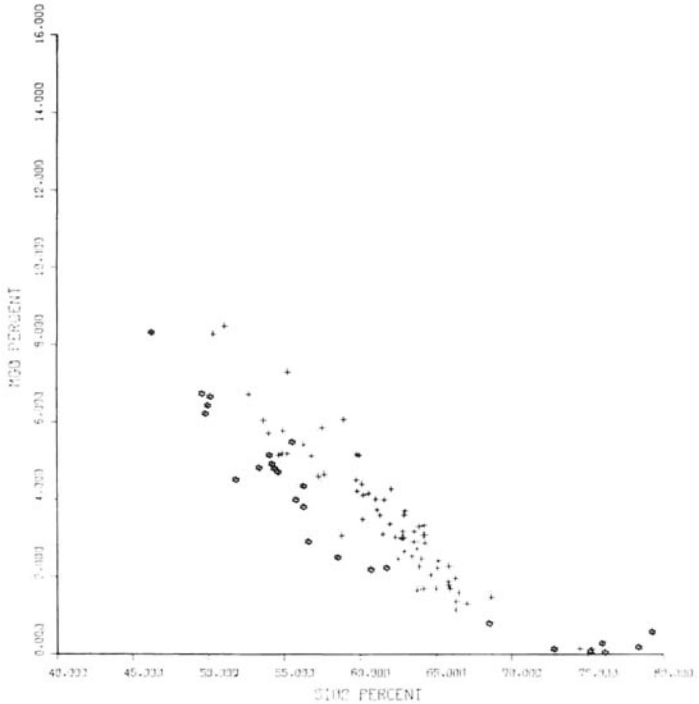


FIG. 11 - MgO/SiO_2 Diagram. Crosses = Valley of Mexico lavas. Stars = Guadalajara volcanics. Note systematic difference between the two regions and the different slope of ignimbrites and rhyolites.

Mexico and Central America in a north-eastly direction along the line of the Acapulco trench.

Within the volcanic belt however, north-south fractures up to 100 km in length appear to exist, the main stratovolcanoes being aligned in north-south chains, as for example, along the Sierra de las Cruces and the Sierra Nevada.

The volcanic islands of the Revillagigedo Group lie in the Pacific

Ocean south of Baja California and form an apparent western extension of the Mexican volcanoes along the Clarion Fracture zone. However, these islands lie west of the Pacific Rise and are alkaline in character, those of Clarion Is. being alkali basalt, trachyandesite and trachyte (BRYAN, 1967) and therefore apparently not related to the Mexican lavas. Socorro Is. at the eastern extremity of the group has more silicic lavas with basalts, soda rhyolite and pantellerite (BRYAN, 1966).

Petrography and Distribution of Rock Types

A short petrographic description is given for each of the samples analysed. A continuous gradation both in chemistry and in petrography is seen between the end members basalt and rhyolite though the intermediate andesites predominate greatly in volume in the Rio Lerma Province. The petrography and distribution of typical samples may be summarised as follows.

BASALTIC ANDESITES AND BASALTS.

True basalts, if defined on the presence of normative labradorite feldspar, do not occur in the Mexico City region though there are a number of olivine-bearing basaltic andesites. Though more than a dozen analysed lavas contain modal olivine only two analyses, both of Volcan Xitle lavas, are olivine normative (MX0001, MX3284). These recent lavas contain up to 15 % olivine, both as phenocrysts and in the groundmass, but the normative feldspar is An_{41} and $x \wedge C$ measurements confirm that the feldspar is a calcic andesine. A single lava has normative feldspar more calcic than An_{50} but this contains vesicular calcite, possibly of secondary origin (MX0011). A dozen other lavas containing modal olivine are quartz normative and may contain 1 mm quartz grains along with the olivine. Both the quartz and olivine are ringed by reaction rims of clinopyroxene. Curiously, quartz xenocrysts or phenocrysts are rarely seen in non-olivine bearing andesites, an exception being seen in the Rio Frio andesites which contain knots of pyroxene possibly formed by reaction of olivine. Olivine is seen in rocks with up to 60 % SiO_2 and is invariably present in those with less than 55 %.

True basalts occur among the flows emanating from small recent cones near Guadalajara, as well as among the Pliocene lavas of Santiago Canyon. They are invariably olivine-bearing, the older basalts having more than 17 % alumina and so being high-alumina basalts. Younger, Pleistocene basalts have 14-15 % alumina and are mildly alkaline in nature. In general, the Guadalajara basalts are not petrographically distinguishable from the basaltic andesites of Mexico City, though constant chemical differences are present.

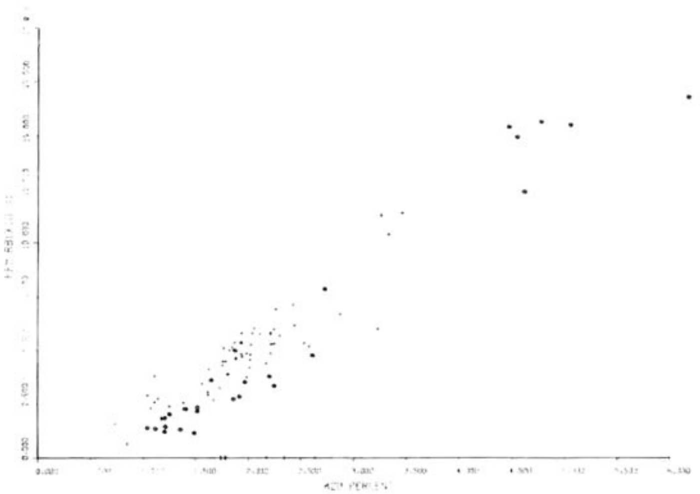


FIG. 12 - K/Rb Diagram of both Valley of Mexico and Guadalajara. The Valley of Mexico Lavas have consistantly lower K and K/Rb ratios.

ANDESITES.

Andesites occur throughout the Rio Lerma Province from V. Ceborruco in the west to Tuxtla in the east. A small area of andesite also occurs in Southern Mexico in the state of Chiapas. True andesites do not appear to occur in the Cordillera Province but due to poor access, insufficient field work has been done as yet to prove this conclusively.

The andesites are usually of the typical porphyritic texture with large phenocrysts of oscillatary-zoned andesine plagioclase, often with a central zone containing altered exsolution blebs of low refractive index and an outer clear zone. Orthopyroxene and clinopyroxene are invariably present together with some olivine in the more basic andesites and brown hornblende in the more silica-rich lavas.

DACITES.

Dacites have the same distribution as the andesites, though the frequency of occurrence is rather less. Coarse phenocrysts of sodic plagioclase, a little ortho- and clinopyroxene and frequently coarse 1 cm crystals of red oxy-hornblende are characteristic. Biotite is found rather rarely and rounded quartz phenocrysts occur in the more siliceous dacites. Some lavas of dacitic texture have a normative feldspar more calcic than An_{30} and have been labelled « dacitic-andesites ».

RHYOLITE.

In the Rio Lerma Province rhyolite and rhyodacite are rare, occurring only as a pumiceous ejecta from Volcan Popocatepetl and Tlaloe.

Near Guadalajara, Recent rhyolite domes occur south of the city but have not been closely investigated. Obsidian is common in the Guadalajara region and appears to be associated in age with the rhyolite and obsidian flows found at the top of the Pliocene Santiago Canyon sequence.

In the Cordillera Province flat-lying ignimbrite sheets are formed of welded tricuspate glass shards together with various amounts of sanidine and tridymite crystals and lithic materials mainly rhyolitic fragments. One sheet in the upper parts of the Santiago Canyon section has a high concentration of coarse sanidine crystals, the composition being unusually potassic. Ignimbrites on the Mazatlan-Durango section are principally of a vitric nature with basalts appearing only at the top of the section. No chemical analyses have yet been made of the ignimbrites of this section.

There appears to be a general trend towards more mafic lavas being produced with time in the Valley of Mexico, basalts and basaltic andesite being common among the small composite cones of Recent age but virtually absent in the Miocene lavas. However, ages can often only be assigned by association with a few horizons dated by K/A and C^{14} methods and the ages of many of the lavas are not precisely known.

Analytical Method

Sample collection was made of as full a range as possible in space, time and rock type in two areas. Firstly, in the region of Guadalajara, Pliocene ignimbrites, rhyolites, obsidians, basaltic andesites and basalts were collected from Santiago Canyon and Pleistocene and Recent olivine basalts and andesites from small basalt cones and andesite stratovolcanoes in the same area, secondly, collection was made of Miocene to Recent lavas from the Valley of Mexico, near Mexico City. About 500 g of each sample was reduced to < 150 mesh powder in a steel percussion grinder. The elements Mg, Al, Si, K, Ca, Ti, Mn, and Fe were analysed in a fused borate glass by X-ray fluorescence, Na by atomic absorption and P by colorimetry. The heavy trace elements Cr, Ni, Cu, Zn, Rb, Sr, Ba, Th, Pb were also determined by X-ray fluorescence using a 3 g pure powder pellet pressed at 8 tons. The intensity data was output on computer cards and all calculation and iterative matrix corrections were made by computer. Each determination was made twice and about 10 % of the samples were also fused in replicate. The accuracy was checked by including standard chemically analysed rocks of similar composition. Four replicate determinations of two samples of the standard andesite AGV-1 are shown (Table 1). A total of 80 analyses were made from the Valley of Mexico for major elements and 62 of these were also analysed for the trace elements given above. A further 28 analyses were made from the Guadalajara region.

TABLE 1 - Four analyses of two samples of the standard Guano Valley Andesite AVG-1 together with the mean of chemical analyses.

	AGV (1)	*AGV (2)*	*AGV (3)*	*AGV (4)*	*CHEM.*
SiO_2	60.45	60.46	60.40	60.46	60.29
Al_2O_2	17.32	17.31	17.39	17.31	17.43
TiO_2	1.07	1.07	1.06	1.06	1.07
ΣFe^{+++}	6.79	6.79	6.83	6.83	6.83
MnO	0.10	0.10	0.10	0.10	0.10
MgO	1.53	1.53	1.49	1.52	1.51
CaO	5.00	5.00	5.00	4.99	5.01
K_2O	2.93	2.93	2.91	2.91	2.93

Three samples were found to lie more than two standard deviations from the common trend on variation diagrams which included Fe as a component. The three rocks were again analysed with identical results but have been excluded from the variation diagrams. All three samples are from the Iztaccihuatl massif but petrographic examination did not reveal any obvious reason for the apparently low iron content. (Table 2).

The corrected results of all analyses were output on computer cards and then were used as follows:

A) As input to statistical programs to determine the mean, mode, median, standard deviation and variance for each element and the coefficient of correlation with every other element.

B) As input to a series of data plotting routines to plot variation diagrams and binary, ternary and three dimensional diagrams of various related components.

As andesitic lavas are dominated by the felsic components, the crystallisation index Σ (Ne + Ab + Qz + SiO_2) was used as an index of fractionation. (Fig. 3).

Comparison with other calc-alkaline provinces has been made both by comparing correlation coefficients and by plotting on similar diagrams. (Figs. 8-12).

The Pearson R correlation coefficient quoted below is a measure of the probability that a given values of X and Y will fall on a least mean square best fit line constructed for all points. A correlation of + 1 and − 1 indicates a perfect correlation of positive or negative slope.

Though the olivine is rarely iddingsitised and other indications of oxidation are absent, the Fe^{+++}/Fe^{++} ratio is variable and shows no correlation with degree of fractionation. The norms were therefore calculated using an assumed constant Fe^{+++} content and all indices include Fe are based on ΣFe^{+++}.

TABLE 2 - Two Mexican lavas analysed in duplicate, of low iron content.

	MX0044	*MX0044*	*MX0047*	*MX0047*
SiO_2	63.03	63.19	59.47	59.66
Al_2O_3	16.44	16.31	16.44	16.44
TiO_2	.95	.94	.92	.91
ΣFe^{+++}	3.92	3.97	5.07	5.10
MnO	.095	.094	.11	.11
MgO	3.85	3.86	5.98	6.08
CaO	5.42	5.35	6.11	6.00
Na_2O	3.89	3.89	4.12	4.12
K_2O	2.24	2.23	1.52	1.52
P_2O_5	.17	.17	.26	.26
Cr	101.	—	217.2	—
Ni	52.	—	112.3	—
Cu	10.	—	25.	—
Zn	56.	—	74.	—
Rb	48.	—	34.	—
Pb	12.	—	8.	—
Th	4.	—	5.1	—

Geochemistry

MEXICO CITY LAVAS.

The major element data have been displayed in Fig. 3 as variation diagrams plotted against the Differentiation Index. (THORNTON and TUTTLE, 1960), in the ternary diagrams $\Sigma Fe^{+++} - MgO - (Na_2O + K_2O)$,

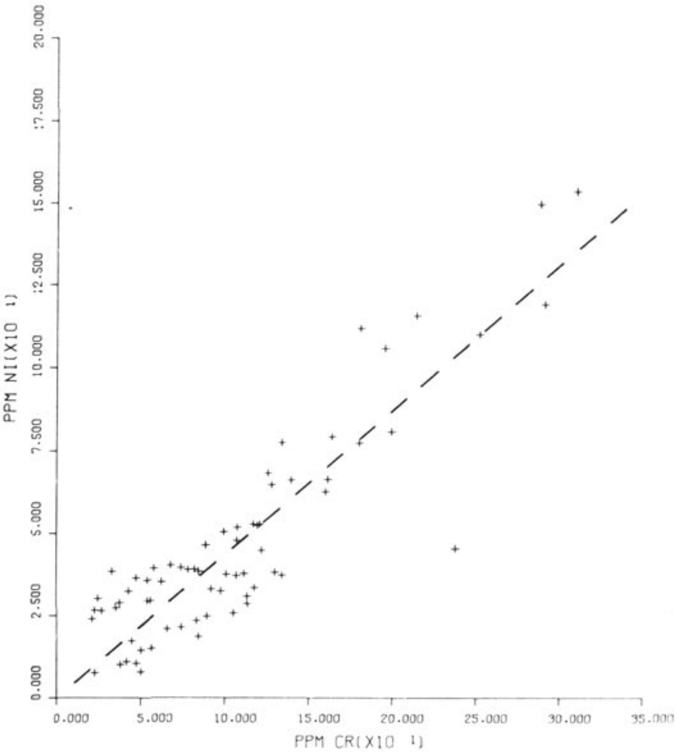


FIG. 13 - Cr/Ni Diagram for Valley of Mexico, together with a line of constant ratio. Note unusual constancy of Cr/Ni ratio (2.3) over a wide range of Cr.

Ca – Na – K, and $Al_2O_3 - \Sigma (Fe^{+++} + MgO) - (Na_2O + K_2O)$. These show the typical pattern for calc-alkaline series lavas. Histograms and frequency diagrams (not shown) show a slightly negatively skewed distribution about a mean of 62 % SiO_2, one standard deviation being equal to 4.7 % SiO_2, while Fe, Mg, Ca, Cr and Ni are positively skewed.

A notable feature is the straight-line nature of the variation diagrams. Unlike most fractionated lava series, here the straight-line relationship holds, though the ratio between any of the elements may change between mafic and felsic members.

Ferromagnesian Elements.

Magnesium shows a linear negative correlation with silica ($R = -.93$ with a least-mean square intercept at 70 % SiO_2). The usual flattening of the MgO/SiO_2 curve at higher silica is absent. Total Fe^{+++}, TiO_2, MnO and CaO also show linear negative correlation with silica with correlation coefficients between $-.92$ to $-.97$. The correlations between the ferromagnesian group elements are all positive with coefficients of 0.88 - 0.92.

The mean $\Sigma\ Fe^{+++}/Ti^{++++}$ ratio of 6.27 compares with 6.4 for 10 basalts and 6.9 for 10 dacites showing that little titania enrichment occurs in the series. Similarly $\Sigma\ Fe^{+++}/Mn^{++}$ has a mean of 55, and extremes of 54 and 60.

$\Sigma\ Fe^{+++}/Mg^{++}$ ratio has a mean 1.6 and extremes of 1.4 and 2.3 and while Mg/Ni and Mg/Cr ratios decrease in the olivine basalts, the relationship is again linear, $R(Mg/Cr) = .93$, $R(Mg/Ni) = .81$, $R(Cr/Ni) = .89$ (Fig. 13). The mean abundances of Cr and Ni are 106 and 46 ppm respectively varying by a factor of 15 over the entire suite of rocks.

Such remarkable constancy in many of the ratios given above suggests that little fractionation of ferromagnesian minerals has occurred.

Alkali Elements.

Rubidium (mean = 50.6 ppm) occurs replacing potassium in micas and feldspars and the ratio K/Rb in many igneous series shows some decrease with increasing K. Here the K/Rb ratio has a mean of 345 with 480 for the basalts and 340 for the dacites. The pumice ejecta are strongly enriched in Rb with K/Rb as low as 170 and these affect the mean and have been excluded. The K/Rb diagram shows what must be regarded as the usual distribution between the K/Rb ratio and contents of plagioclase feldspar and potash feldspar (WATKINS, GUNN and COY-YLL, 1970).

Barium shows little departure from a mean K/Ba = 32, the average Ba content being 487 ppm, and better than .7 correlations are shown with SiO_2, K_2O, Rb and Th.

Thorium (4.3 ppm) is rather low in concentration and the analytical uncertainty at this level is about ± 1 ppm, nevertheless the correlation coefficient of K/Th = .83.

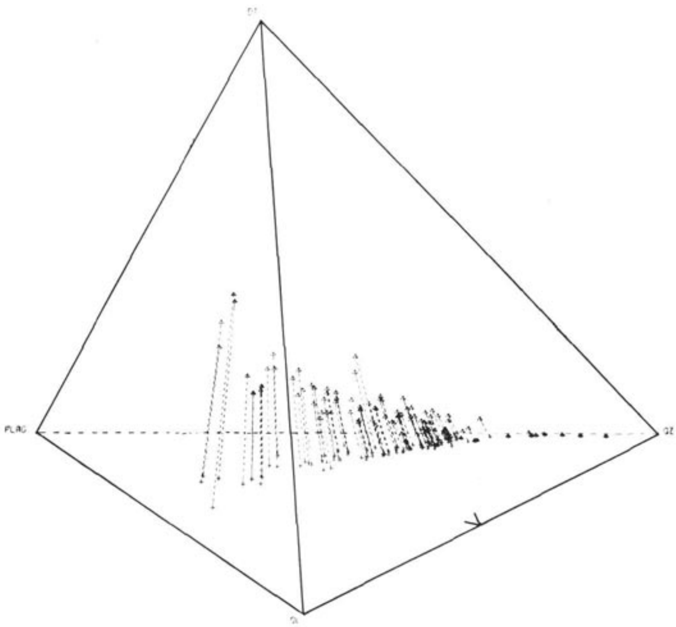


FIG 14 - Basalt Tetrahedron for Valley of Mexico, (Di-Qz-Hy-Ol-Plag). Triangles are actual sample compositions. Crosses are the same points projected onto the basal plane.

Sodium shows a low degree of negative correlation with Ca and no correlation with alumina or potash.

Strontium (460 ppm) correlates poorly with all other elements, the best correlation being with Al_2O_3 (.48), K (−.52).

Chalcophile Elements.

Lead (9.2 ppm) shows high correlations with the potassium group elements, with R (Pb/K) = .83, R (Pb/Rb) = .86, R (Pb/Th) = = .70, R (Pb/Ba) = .75. In the absence of any correlation with Na, this suggests the Pb is camouflaged in the potash feldspar rather than the plagioclase.

Zinc (mean = 64.5 ppm) shows a better than 0.7 correlations with all the ferromagnesian elements.

Copper (mean = 17.8 ppm) is not only present in unusually low concentration but correlates poorly with all other elements.

Comparison of Chemistry of Valley of Mexico and Guadalajara Region

The chemical means of the two areas shows the Guadalajara lavas to be, on the average, more basic. Sampling was more restricted in the Guadalajara area, nevertheless, WILLIAMS (1950) also found the average lava in the nearby Paricutin region to be basaltic andesite, in fact, the most felsic of the 18 lavas analysed by Williams had only 61.3 % SiO_2, less than the average of the Mexico City Lavas. Williams also commented that when plotted against silica, the Paricutin region lavas had more alumina and lower iron than other Mexican lavas.

Not only do basalts and basaltic andesites predominate at the Western end of the Rio Lerma Province compared with andesite-dacite at the Eastern (Mexico City) end, but the Guadalajara lavas have consistantly higher K, Al, Ti and lower Mg relative to silica. The K/Rb ratio is also higher in equivalent rocks in the Guadalajara region, the average K/Rb of 530 being higher than the most basic rocks of the valley of Mexico (K/Rb = 480). The MgO is lower by about 1 % in the basaltic andesites, while the Cr is lower by a factor of 3 (75 ppm cf 224 ppm). (Figs. 11-12-13).

DICKENSON and HATHERTON (1967) have shown that K content of andesites increases in island arcs with distance landward of the offshore trench, and the general more alkaline character of the basalts near Guadalajara suggests generation under higher pressure (GREEN and RINGWOOD, 1968).

Fractionation Trends

The fractionation trends of the region have been shown (Figs. 14-15) using a series of three dimensional tetrahedrons (YODER and TILLEY, 1962). The normative components Diopside - Quartz - Hypersthene - Olivine and Nepheline are plotted within a tetrahedron which is tilted 20° towards the observer and rotated 10° about a vertical axis. The points, plotted as triangles are also projected onto the Ne - Ab - Qz - Hy - Ol base from the Di point.

As none of the lavas from the Valley of Mexico are nepheline normative, they were also plotted on a Plag - Di - Qz - Ol tetrahedron (COOMBS, 1963) and on An - Ab - Or - Qz tetrahedron. The basalt tetrahedron shows the lavas to lie on what appears to be an invariant

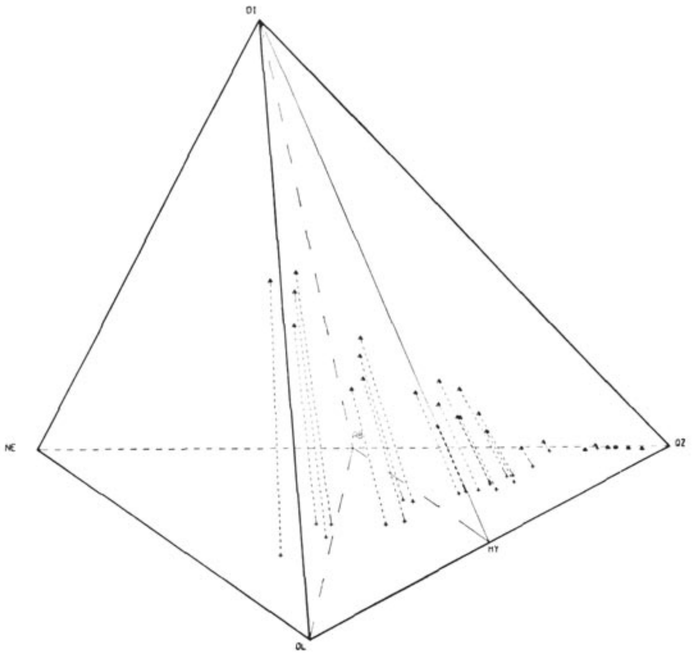


FIG. 15 - Basalt Tetrahedron for Guadalajara region including lavas belonging to both Rio Lerma and Cordillera provinces.

line extending from a point with a composition of approximately equal amounts of Di - Ab - Hy towards a point on the Ab - Qz join at about Qz_{80}, Ab_{20} (Fig. 15).

These diagrams enable us to make some positive comments about the genesis of the lava series as follows:

a) The series follow a trend along an apparent invariant curve common to all calc-alkaline lavas. Similar diagrams of lavas from Guatemala, Costa Rica, San Salvador, Nicaragua, Aleutians Is, Japan and New Zealand showed similar trends.

b) The trend differs from that of continental tholeiitic lava suites which plot much closer to the Hy-Qz join, but overlaps the field of oceanic tholeiites.

c) The trend is unlikely to be the result of crystal fractionation. Such an invariant curve must lie on the intersection of diopside, hypersthene and albite volumes. A liquid could only migrate along the line if approximately equal amounts of plagioclase, clino and orthopyroxene were crystallising simultaneously and being removed from the melt simultaneously.

If one crystal component was removed more rapidly than the other, the residual liquid would curve away from the appropriate point. Recent opinion to the contrary, olivine fractionation alone obviously cannot produce andesite (OSBORN, 1969).

d) Plagioclase has not been added or subtracted from the series, there being remarkable little scatter in the Plag - Hy - Qz plane. Lava series in which plagioclase fractionation has taken place *e.g.* the Steens Basalts of Oregon (GUNN and WATKINS, 1970) show considerable scatter in a direction normal to the plagioclase apex of the tetrahedron.

e) The lack of rhyolites and olivine-rich basalts in the Valley of Mexico suggests a unique origin for andesites.

When the Guadalajara data are plotted on similar diagrams, the same trend is seen, though more of the lavas lie in the Di - Ab - Ol - Hy volume.

Role of Hornblende

Hornblende is a curious mineral in that its composition approximates the bulk composition of many rocks. Hornblende may contain normative nepheline and leucite in alkaline rocks, or may even be quartz normative in diorite pegmatites (DEER, HOWIE and ZUSSMAN, 1963). Some hornblendes and amphibolites therefore project on the Mexican andesite trend. A possible explanation of the andesite trend may be that of fractionation of a silica saturated basalt by removal of large amounts of hornblende under hydrous condition. However, the composition of common hornblendes are too close for most components to basaltic andesite for production of more than small quantities of andesite by fractionation. A hypothesis of partial or virtually total melting of amphibolite to form andesite merely defers the question of the origin of the andesite, to the problem of the origin of the parental amphibolite.

Role of Contamination

The linear nature of the variation diagrams superficially suggests an origin of andesite by contamination with rhyolite material of crustal origin with basalt derived by partial melting of the mantle.

As such mixtures have a predominantly linear trend (GUNN and WATKINS, 1969), we can state with some confidence that andesites could be produced only by contamination with granodiorite of the composition of the Mazatlan granodiorite (MX1050) with varying amounts of basalt. Rhyolite is excluded as a possible parental contaminant because of the low Ba, Si and high Rb, Th and decreasing K/SiO_2 ratio, which occurs in the high silica ignimbrites.

Again, such a granodiorite parent would have to be a total, not a partial melt, and the probability of such large volumes of andesite extruded over such a time span being formed by two appropriate melts is very low. DICKENSON and HATHERTON (1967) also conclude that the regularity of K variation across Island arcs excludes the possibility of more than superficial contamination having taken place; TAYLOR and WHITE (1966) do not consider the trace element composition of andesite compatible with contamination of basalt with crustal material.

Partial Melting of Oceanic Tholeiite

Many recent authors would derive andesite by the partial melting of an oceanic tholeiitic crustal plate being underthrust along the continental margins.

The crustal tholeiite on re-entering the mantle is first transformed to eclogite and at a depth depending on the geothermal gradient, undergoes partial melting to give rise to andesitic magmas (RALEIGH and LEE, 1969).

The Rio Lerma Province is seismically active and DICKENSON and HATHERTON (1967) give a depth to the Benioff Zone of 115 km for Volcan Colima and 125 km for V. Paricutin and these lavas may therefore have been generated at pressures of about 40 kb. DICKENSON and HATHERTON show that andesites with an average K content of between 0.7 to 2.5 % K_2O are associated with progressive increase of depths to the Benioff Zone of 90 to 280 km. We may surmise that the rather low K content of the Mexico City region is due to a slightly shallower depth of magma generation. The K contents of the Paricutin region (WILLIAMS, 1950, and this paper) directly overlap with those of the Mexico City region, while those of the Guadalajara region are higher by about 0.75 %. This may be associated with the northward dip of the Benioff zone.

GREEN and RINGWOOD (1969) have found experimentally that at pressures greater than 30 kb a low-temperature trough exists for partial melts of basalt at compositions about 60-65 % silica. This may be the explanation of the frequency distribution for the Mexico City lavas and for the virtual absence of rhyolite. The small change in Fe/Mg ratio found throughout the Mexican volcanics is also predicted by the Green and Ringwood model because of simultaneous melting of garnet and clinopyroxene.

The trend of the Mexican andesite is compatible with a partial-melt hypothesis, but there are some curious anomalies when we come to consider oceanic tholeiite (or the equivalent quartz eclogite) as a possible parent. On an An-Ab-Or diagram, a series of ocean tholeiite lavas (ENGEL, ENGEL and HAVENS, 1965; MUIR and TILLEY, 1964) form a direct continuation of the andesite trend. However, when plotted on the basalt tetrahedron, the oceanic tholeiites show complete overlap with the olivine andesites and basalts.

A basaltic andesite can therefore be generated only from a total melt of oceanic tholeiite for the Ol-Plag-Di-Hy components to which must be added potassium group elements partially melted from a much greater volume of tholeiite. The residiuum would be an oceanic tholeiite strongly depleted in potassium group elements. As such rocks are not found, some doubt is thrown on the possibility of the partial melt hypothesis.

A possibility to be considered is that the andesites alone are partial melting derivatives of oceanic tholeiites while the basaltic andesites and basalts are partial melting products of a pyrolitic mantle underlying the down-thrust oceanic plate. The geochemical continuity of the basalt-andesite-dacite series does not suggest a two separate origins but if the mantle does approximate 3 parts dunite to 1 part basalt (RINGWOOD, 1963) then the mantle underlying andesitic volcanics is merely enriched in the basaltic component derived from the underthrust oceanic basalt. A continuous series of partial melts is therefore possible.

Origin of Ignimbrites

The ignimbrites lie on trends often sharply discordant to the andesites-dacites. That is, trends which are quite linear in the basalt-andesite-dacite series, *e.g.* of increasing Sr, Ba, Na with silica, are reversed in the ignimbrite rhyolite series. The ignimbrites are almost certainly partial melts of the crust and formed above the underthrusting oceanic plate.

McBirney and Weill (1966), on the basis of a combination of melting point experiments and O^{-18} data concluded that the ignimbrites of Honduras and Nicaragua were partial melts of the crustal basement rock. The obsidians of the same area were found to have a Sr isotope composition similar to basalt.

The ignimbrite, rhyolites and obsidians of Guadalajara studied here form a single closely related series for all the elements studied suggesting a common origin which volume consideration alone indicate must be in the crust.

Conclusions

The lavas of the Valley of Mexico which make up part of the Rio Lerma volcanic province are predominantly andesites-dacites. Three dimensional representations of normative components show trends compatible with an origin of partial melting of tholeiitic basalt or its high-pressure equivalent. Both fractional crystallisation and contamination may be virtually excluded as mechanism for the production of andesite. Basaltic andesites overlap with and may be more basic than average ocean tholeiites but have at least four times the content of potassium group elements, suggesting generation from mantle material at greater depth. The volcanics from Guadalajara near the western end of the same volcanic province are mainly basaltic andesite with higher K/SiO_2, K/Rb and lower Mg/SiO_2 ratios when compared with the Mexico City area. These differences may be associated with a greater depth of generation.

The Cordillera province consists mainly of thick ignimbrite sheets overlain by a rather alkaline olivine basalt. High-alumina basalt and basaltic andesite is intercalated with the upper ignimbrite sheets near Guadalajara but are chemically allied to the Rio Lerma province. Rhyolites and obsidians also overlie the ignimbrites but are chemically allied to them and probably have the same source.

Acknowledgements

A. McBirney is thanked for supplying chemical analyses of Guatemala, Nicaragua, San Salvador and Costa Rica for comparison with the data shown here. Field work in the Guadalajara area was supported by Tulane University and the Laboratory and subsequent field work by the Canadian Research Council (Grant A3834). One of the authors (BMG) has been helped extensively by research associates M. Taler, Mona Kerba and Lise Berthiaume.

TABLE 3 - Major + trace elements of 62 lavas from the Valley of Mexico.

	VALLEY OF MEXICO LAVAS.					GUNN AND MOOSER (1970).			CA	
NUMBER	MX0001	MX3284	MX0011	MX0031	MX0030	MX0055	MX0064	MXB060	MX0034	MX0045	NUMBER
SIO2	50.28	51.02	52.66	53.61	53.97	54.64	54.85	54.88	55.19	55.23	SIO2
AL2O3	15.55	15.69	16.34	16.21	16.36	16.83	16.95	15.85	17.17	16.73	AL2O3
TIO2	1.853	1.770	1.124	1.393	1.429	1.654	1.280	1.365	1.289	.837	TIO2
FE2O3	10.165	10.000	10.054	8.848	8.816	7.997	8.033	8.249	8.022	7.431	FE2O3
FEO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	FEO
MNO	.164	.140	.155	.148	.141	.153	.136	.123	.136	.124	MNO
MGO	8.28	8.49	6.72	6.05	5.72	5.15	5.19	5.78	5.19	7.30	MGO
CAO	8.455	7.680	9.056	8.173	7.798	7.724	8.059	7.660	8.157	7.373	CAO
NA2O	3.609	3.630	3.013	3.873	3.876	3.947	3.810	3.979	3.625	3.743	NA2O
K2O	1.176	1.170	.734	1.247	1.382	1.384	1.109	1.734	1.043	1.073	K2O
P2O5	.473	.100	.145	.455	.517	.531	.569	.369	.180	.162	P2O5
H2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	H2O
TOTAL	100.000	99.690	99.999	100.000	100.001	100.001	100.001	100.000	100.000	99.999	TOTAL
CR	310.8	288.7	238.0	164.2	199.7	122.1	139.8	160.5	130.3	291.4	CR
NI	153.7	149.7	45.5	79.4	80.9	44.8	66.4	62.7	38.2	119.2	NI
CU	38.5	30.2	17.8	24.2	24.5	18.5	26.1	18.3	17.1	39.0	CU
ZN	78.3	75.1	69.9	86.8	87.2	74.0	84.9	0.0	66.1	71.8	ZN
RB	17.7	18.9	15.7	24.0	22.7	25.6	37.9	0.0	29.0	23.1	RB
SR	551.6	536.3	506.9	523.8	552.6	424.6	552.3	0.0	379.0	425.6	SR
BA	296.9	0.0	309.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	BA
PB	4.0	0.0	3.2	6.6	4.8	2.5	9.9	6.3	6.1	8.6	PB
TH	.5	0.0	1.3	2.7	3.5	2.4	3.7	3.0	.1	2.1	TH
K/RB	552	514	388	431	505	449	243	R	299	386	K/RB
K/TH	19524	R	4687	3834	3278	4787	2488	4798	86579	4241	K/TH
K/BA	33	R	20	R	R	R	R	R	R	R	K/BA
CA/SR	110	102	128	112	101	130	104	R	154	124	CA/SR
RB/SR	.032	.035	.031	.046	.041	.060	.069	I	.077	.054	RB/SR
MG/CR	161	177	170	222	173	254	224	217	240	151	MG/CR
MG/NI	325	342	891	459	426	693	471	556	820	369	MG/NI
FE/TI	5.5	5.6	8.9	6.4	6.2	4.8	6.3	6.0	6.2	8.9	FE/TI
FE/MN	62	71	65	60	63	52	59	67	59	60	FE/MN
AL/TI	7.41	7.82	12.83	10.27	10.11	8.98	11.69	10.25	11.76	17.64	AL/TI
K/NA	.326	.322	.244	.322	.357	.351	.291	.436	.288	.287	K/NA
CA/NA	2.343	2.116	3.006	2.110	2.012	1.957	2.115	1.925	2.250	1.970	CA/NA

MX0001 BASALT.OLIVINE, VESICULAR, V XITLE FLOW, CUICUITZCO, V.OLIMPICA.19.18/99.
MX3284 BASALT, OL, V. XITLE FLOW, UNIVERSIDAD DE MEXICO, (OL-PLAG-CPX)
MX0011 BASALT, VESICULAR, WITH CALCITE, 10KM N OF TULA PARK, ROAD CUT.
MX0031 ANDESITE, PENON MARQUEZ, NEW COMPLEX, LOWER QUATERNARY 19.22.8/99.01.9
MX0030 ANDESITE, PENON MARQUEZ, OLD COMPLEX, PROBABLY PLIOCENE 19.22.1/99.02.9
MX0055 ANDESITE, BASALTS E OF 54, CO.OLICAN, UPPER QUATERNARY 19.13.9/99.09.7
MX0064 ANDESITE, ON ROAD, S SAN NICOLAS RANGES, UPPER QUATERNARY19.18.2/99.03.0
MXB060 ANDESITE, COCOTITLAN RANGE, LOWER QUATERNARY 19.13.9/99.52.1
MX0034 ANDESITE, NE FOOT OF TEUTLI, UPPER QUATERNARY 19.14.6/99.00.8
MX0045 ANDESITE, PROBLEMATIC ALSO AT BILL HILL BUT LOOSE. 19.08.0/98.39.1

Continued TABLE 3 - Major + trace elements of 62 lavas from the Valley of Mexico.

	VALLEY OF MEXICO LAVAS.					GUNN AND MOOSER (1970).			CA	
NUMBER	MX0066	MX0060	MX0041	MX0059	MX0040	MX0010	MX0048	MX2017	MX0027	MXB039	NUMBER
SIO2	56.27	56.80	57.24	57.50	57.61	58.77	58.90	59.74	59.76	59.80	SIO2
AL2O3	16.93	16.60	16.51	15.26	16.02	16.50	16.30	16.47	15.86	16.50	AL2O3
TIO2	1.297	1.303	1.375	1.242	1.265	.976	.791	.854	.812	.855	TIO2
FE2O3	6.791	7.471	6.646	7.312	7.633	6.643	6.403	6.379	6.324	6.043	FE2O3
FEO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	FEO
MNO	.138	.122	.140	.110	.113	.113	.104	.109	.106	.083	MNO
MGO	5.42	5.13	4.60	5.85	4.64	3.07	6.06	4.51	5.18	4.22	MGO
CAO	8.217	6.855	6.795	6.453	6.393	8.230	5.976	6.166	6.072	6.825	CAO
NA2O	3.636	3.822	4.305	4.030	3.754	3.618	4.158	3.820	4.116	3.774	NA2O
K2O	1.106	1.560	1.805	1.785	2.174	1.927	1.142	1.785	1.614	1.742	K2O
P2O5	.198	.350	.594	.456	.392	.151	.158	.167	.152	.153	P2O5
H2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	H2O
TOTAL	100.000	100.000	100.001	100.001	99.999	99.999	99.999	100.000	100.000	100.000	TOTAL
CR	134.4	161.6	107.8	195.8	107.5	74.3	252.4	118.0	214.5	74.3	CR
NI	37.4	66.5	51.8	105.9	47.9	21.4	110.1	33.5	115.7	39.6	NI
CU	14.8	25.5	21.3	31.9	17.6	20.2	37.3	12.5	27.4	16.8	CU
ZN	63.4	73.7	81.7	0.0	0.0	73.4	69.8	68.8	74.6	0.0	ZN
RB	25.9	34.5	38.6	0.0	0.0	53.7	27.5	44.8	30.6	0.0	RB
SR	330.9	452.7	497.5	0.0	0.0	345.5	375.8	485.4	470.4	0.0	SR
BA	0.0	0.0	0.0	0.0	0.0	447.7	0.0	507.4	425.8	0.0	BA
PB	5.9	3.8	12.0	8.8	12.5	7.4	6.6	8.7	7.0	5.6	PB
TH	.9	2.8	3.2	4.3	4.2	5.7	2.6	4.4	4.5	3.2	TH
K/RB	354	375	388	R	R	298	345	331	438	R	K/RB
K/TH	10201	4625	4682	3446	4297	2806	3646	3368	2977	4519	K/TH
K/BA	R	R	R	R	R	36	R	29	31	R	K/BA
CA/SR	177	108	98	R	R	170	114	91	92	R	CA/SR
RB/SR	.078	.076	.078	I	I	.155	.073	.092	.065	I	RB/SR
MG/CR	243	191	257	180	261	249	145	230	146	343	MG/CR
MG/NI	874	465	535	333	585	866	332	812	270	643	MG/NI
FE/TI	5.2	5.7	4.8	5.9	6.0	6.8	8.1	7.5	7.8	7.1	FE/TI
FE/MN	49	61	47	66	68	59	62	59	60	73	FE/MN
AL/TI	11.52	11.24	10.60	10.85	11.18	14.93	18.19	17.03	17.24	17.04	AL/TI
K/NA	.304	.408	.419	.443	.579	.533	.275	.467	.392	.462	K/NA
CA/NA	2.260	1.794	1.578	1.601	1.703	2.275	1.437	1.614	1.475	1.808	CA/NA

MX0066 ANDESITE. SPRINGS OF SAN LUIS. UPPER QUATERNARY 19.15.3/99.01.9
MX0060 ANDESITE. COCOTITLAN RANGES. LOWER QUATERNARY 19.13.9/99.52.1
MX0041 ANDESITE. (OL). STA. CATERINA. 19.20.2/98.58.9
MX0059 ANDESITE. TENAYO. UPPER QUATERNARY 19.12.8/98.50.0
MX0040 ANDESITE. ESTRELLA RANGE. LOWER QUATERNARY 19.21.0/99.05.3
MX0010 ANDESITE. ROAD N. OF COYOTOPEC. E. OF CERRO PINA BLANCA
MX0048 ANDESITE. IMMEDIATELY N OF ALTZOMONI. MIOCENE 19.07.5/98.38.9
MX2017 ANDESITE. DUPLICATE OF MX0017.
MX0027 ANDESITE. GLASSY.(OL).FLOW OF RECENT CONE. 7 KM S OF AMOMOLUCA. TOLUCA.
MXB039 ANDESITE. DUPLICATE OF MX0039

Continued TABLE 3 - Major + trace elements of 62 lavas from the Valley of Mexico.

	VALLEY OF MEXICO LAVAS.					GUNN AND MOOSER (1970).			CA		
NUMBER	MX0026	MX0017	MX0042	MX0039	MX0033	MX0038	MX0028	MX0005	MX0014	MX0004	NUMBER
SIO2	59.92	60.13	60.17	60.19	60.58	61.03	61.13	61.32	61.50	61.60	SIO2
AL2O3	15.78	16.55	16.70	16.87	16.44	16.32	16.12	15.85	16.30	15.94	AL2O3
TIO2	.809	.843	.921	.998	.895	.969	.758	.808	.913	.811	TIO2
FE2O3	6.149	6.218	5.972	5.470	5.950	5.595	6.004	6.083	6.747	5.713	FE2O3
FEO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	FEO
MNO	.105	.107	.090	.102	.100	.102	.095	.107	.081	.097	MNO
MGO	5.14	4.40	3.49	4.12	4.16	4.01	3.74	3.60	3.11	4.00	MGO
CAO	5.996	6.020	6.792	6.683	5.716	5.885	6.332	5.561	5.537	5.324	CAO
NA2O	4.320	3.820	3.920	3.426	3.987	3.973	3.243	4.448	3.439	4.242	NA2O
K2O	1.616	1.754	1.776	1.983	1.929	1.879	2.429	2.058	2.175	2.039	K2O
P2O5	.163	.167	.166	.156	.251	.237	.151	.165	.195	.228	P2O5
H2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	H2O
TOTAL	100.001	100.000	100.001	100.001	100.000	100.001	100.000	99.998	100.000	100.000	TOTAL
CR	181.1	13.7	55.9	82.2	119.6	121.0	84.5	117.2	180.5	128.3	CR
NI	111.8	30.9	29.3	39.1	52.5	52.8	18.5	52.9	77.5	64.9	NI
CU	22.1	12.4	10.6	18.0	20.7	21.4	17.0	21.1	36.7	16.1	CU
ZN	71.8	67.9	0.0	66.0	68.4	69.1	61.5	72.7	64.5	72.3	ZN
RB	29.2	44.6	0.0	48.3	48.1	45.7	71.2	60.1	43.9	57.7	RB
SR	474.0	481.4	0.0	470.3	412.8	407.2	503.6	465.6	665.8	555.4	SR
BA	434.0	436.4	0.0	0.0	0.0	0.0	494.0	489.7	531.5	562.6	BA
PB	6.7	10.3	8.4	9.4	8.8	9.4	9.3	8.6	7.4	12.8	PB
TH	3.1	2.7	3.7	5.3	3.1	4.6	3.9	3.9	5.7	4.2	TH
K/RB	459	326	R	341	333	341	283	284	411	293	K/RB
K/TH	4327	5393	3984	3106	5165	3391	5170	4380	3167	4030	K/TH
K/BA	31	33	R	R	R	R	41	35	34	30	K/BA
CA/SR	90	89	R	102	99	103	90	85	59	69	CA/SR
RB/SR	.062	.093	I	.103	.117	.112	.141	.129	.066	.104	RB/SR
MG/CR	171	233	377	302	210	200	267	185	104	188	MG/CR
MG/NI	277	858	718	636	477	458	1219	411	242	372	MG/NI
FE/TI	7.6	7.4	6.5	5.5	6.6	5.8	7.9	7.5	7.4	7.0	FE/TI
FE/MN	59	58	66	54	59	55	63	57	83	59	FE/MN
AL/TI	17.22	17.33	16.01	14.93	16.22	14.87	18.78	17.31	15.76	17.35	AL/TI
K/NA	.374	.459	.453	.579	.484	.473	.749	.463	.632	.481	K/NA
CA/NA	1.388	1.576	1.733	1.951	1.434	1.481	1.953	1.250	1.610	1.255	CA/NA

MX0026 ANDESITE.(OL) 3 MI S. OF TOLUCA RD AT FOOT OF SIERRA. RECENT CONE.
MX0017 ANDESITE. IZTACCIHUATL.EASTERN RIM LLANO GRANDE. EL ALTO 19.13.2/98.40.8
MX0042 ANDESITE. STA. ISABEL (LAREDO ROAD). MID.MIOCENE 19.30.0/99.06.3
MX0039 ANDESITE. N OF MX0038. BASE OF CO.PATLACATE. MID MIOCENE.
MX0033 ANDESITE. N PART CHIMALHUACAN RANGES. LOWER QUATERNARY 19.25.1/98.57.5
MX0038 ANDESITE. (OPX-CPX). RIO FRIO. UP.QUAT. 19.19.3/98.43.3
MX0028 ANDESITE. (PLAG-CPX-OPX-HBDE). DISSECTED CONE 0.5 KM N OF TOLUCA.
MX0005 ANDESITE. (PLAG-CPX-OPX-OL). FLOW S OF TIN HUT. V.POPOCATEPETL.
MX0014 ANDESITE ON TOP OF M13 COMPLEX 19.25.1/99.21.6
MX0004 ANDESITE. (PLAG-CPX-OPX-OL). RECENT FLOW. LAS CRUCES. V.POPOCATEPETL.

Continued TABLE 3 - Major + trace elements of 62 lavas from the Valley of Mexico.

	VALLEY OF MEXICO LAVAS.					GUNN AND MOOSER (1970).			CA	
NUMBER	MX0006	MX0050	MX2008	MX0046	MXB044	MX0051	MX0008	MX0029	MX0063	MX0007	NUMBER
SIO2	61.98	62.04	62.32	62.51	62.74	62.82	62.87	62.88	62.91	62.96	SIO2
AL2O3	16.40	16.27	16.48	18.14	15.81	16.98	16.38	15.66	17.32	15.43	AL2O3
TIO2	.789	.801	.773	.724	.785	.792	.754	.736	.726	.705	TIO2
FE2O3	5.681	5.446	5.433	4.580	5.234	4.875	5.304	5.545	4.636	5.350	FE2O3
FEO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	FEO
MNO	.098	.089	.095	.094	.085	.044	.091	.101	.092	.092	MNO
MGO	3.36	4.28	3.03	2.46	2.98	3.17	3.02	3.60	2.66	3.72	MGO
CAO	5.180	4.977	5.413	5.163	5.401	5.321	5.185	5.044	5.485	5.001	CAO
NA2O	4.397	4.142	4.364	4.560	4.157	4.002	4.364	4.408	3.826	4.319	NA2O
K2O	1.937	1.755	1.941	1.626	2.632	1.822	1.880	1.848	2.216	2.268	K2O
P2O5	.175	.198	.155	.141	.172	.174	.155	.179	.135	.158	P2O5
H2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	H2O
TOTAL	99.998	100.000	100.001	100.001	100.001	100.000	100.000	100.000	100.001	100.000	TOTAL
CR	99.6	134.3	97.9	33.0	58.0	83.3	92.3	113.7	47.4	126.0	CR
NI	50.5	77.6	32.5	38.5	39.4	23.3	33.1	28.6	36.5	68.3	NI
CU	19.7	16.3	15.2	17.0	7.4	14.1	14.9	11.3	11.2	91.0	CU
ZN	71.1	71.7	68.4	63.8	0.0	79.8	68.5	75.8	61.2	59.8	ZN
RB	57.9	42.9	46.9	41.0	0.0	49.8	46.3	51.4	52.6	69.0	RB
SR	457.1	508.8	491.3	447.1	0.0	509.3	484.4	440.0	420.6	423.2	SR
BA	490.1	0.0	440.2	0.0	0.0	0.0	516.5	497.0	0.0	513.7	BA
PB	7.2	8.2	8.0	8.5	12.7	5.3	10.2	9.9	10.6	9.9	PB
TH	3.6	4.6	3.7	4.0	7.6	4.9	2.8	5.8	4.1	5.9	TH
K/RB	278	340	344	329	R	304	337	298	350	273	K/RB
K/TH	4466	3167	4355	3374	2875	3087	5574	2645	4487	3191	K/TH
K/BA	33	R	37	R	R	R	30	31	R	37	K/BA
CA/SR	81	70	79	83	R	75	77	82	93	84	CA/SR
RB/SR	.127	.084	.095	.092	T	.098	.096	.117	.125	.163	RB/SR
MG/CR	204	192	187	449	310	230	197	191	338	178	MG/CR
MG/NI	402	333	563	385	457	822	550	758	439	328	MG/NI
FE/TI	7.2	6.8	7.0	6.3	6.7	6.2	7.0	7.5	6.4	7.6	FE/TI
FE/MN	58	61	57	49	62	111	58	55	50	58	FE/MN
AL/TI	18.35	17.93	18.82	22.12	17.78	18.92	19.18	18.78	21.06	19.32	AL/TI
K/NA	.441	.424	.445	.357	.633	.455	.431	.419	.579	.525	K/NA
CA/NA	1.178	1.202	1.240	1.132	1.299	1.330	1.188	1.144	1.434	1.158	CA/NA

MX0006 ANDESITE. (PLAG-CPX-OPX). RECENT FLOW. S OF TIN HUT. V.POPOCATEPETL.
MX0050 DACITE. BASALT 1KM N CORTEZ PASS. UPPER QUATERNARY 19.05.7/98.38.9
MX2008 ANDESITE. BASALTIC. DUPLICATE OF MX0008.
MX0046 DACITE. CORTEZ PASS ROAD. YOLOXOCHITL CURVE. MID. MIOCENE19.05.2/98.40.8
MXB044 DACITE. PRAF TELAPON E OF FRIO RIVER. PLIOCENE 19.21.3/98.37.7
MX0051 DACITE. ALTZOMONI (CHIMNEY). MIOCENE 19.07.0/98.39.4
MX0008 ANDESITE. BASALTIC. BOULDER IN STREAM BED. NE OF HUT. V.POPOCATEPETL.
MX0029 DACITE. 500M E STA CRUZ ACALPIXCA. UPPER QUATERNARY 19.15.0/99.09.0
MX0063 DACITE. BASALTS BELOW 24. PLIO-PLIESTOCENE 19.30.0/98.47.5
MX0007 DACITE. (PLAG-OPX-CPX-HBDE). N.E. OF TIN HUT. VOLCAN POPOCATEPETL.

Continued TABLE 3 - Major + trace elements of 62 lavas from the Valley of Mexico.

			VALLEY OF MEXICO LAVAS.				GUNN AND MOOSER (1970).		CA		
NUMBER	MX0053	MX0002	MX0018	MX0032	MX0061	MX0036	MX0022	MX0015	MX0037	MX0043	NUMBER
SIO2	63.42	63.55	63.57	63.76	63.76	63.88	63.90	64.01	64.18	64.19	SIO2
AL2O3	16.74	16.02	16.12	16.76	17.35	16.52	15.87	16.29	16.46	16.21	AL2O3
TIO2	.806	.761	.751	.746	.676	.896	.680	.716	.851	.894	TIO2
FE2O3	4.611	5.296	5.077	5.007	4.713	4.869	4.906	4.663	5.051	4.071	FE2O3
FEO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	FEO
MNO	.097	.091	.088	.072	.088	.075	.083	.083	.080	.086	MNO
MGO	2.54	2.91	3.18	2.72	1.65	2.27	3.31	2.47	1.69	3.09	MGO
CAO	5.429	5.001	4.789	4.529	5.677	4.437	4.841	5.134	4.564	4.842	CAO
NA2O	4.400	4.257	4.136	4.156	3.938	4.508	4.357	3.909	3.654	4.233	NA2O
K2O	1.806	1.937	2.114	2.028	2.013	2.341	1.883	2.583	3.264	2.220	K2O
P2O5	.156	.176	.183	.220	.138	.205	.159	.140	.204	.172	P2O5
H2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	H2O
TOTAL	100.000	99.999	100.000	100.000	100.000	99.999	100.000	99.999	100.000	100.000	TOTAL
CR	78.5	89.4	107.2	84.6	37.8	22.5	101.2	56.5	24.7	88.9	CR
NI	39.0	24.7	37.2	38.5	28.8	26.6	37.6	14.8	30.2	46.5	NI
CU	20.7	8.6	10.1	15.1	10.1	7.5	18.4	7.3	26.1	9.1	CU
ZN	57.8	71.3	64.7	62.1	54.2	0.0	55.7	66.0	60.6	59.6	ZN
RB	38.9	53.2	57.6	52.5	41.7	0.0	45.7	51.7	112.7	57.7	RB
SR	543.5	466.3	430.4	398.5	909.9	0.0	487.1	448.2	306.4	433.6	SR
BA	0.0	518.0	612.4	0.0	0.0	0.0	434.5	715.9	0.0	0.0	BA
PB	5.0	10.1	10.8	10.6	2.7	13.1	7.3	10.7	16.6	11.7	PB
TH	4.6	5.4	5.7	5.0	5.5	6.4	3.0	3.1	6.7	5.4	TH
CE	-0.0	-0.0	-0.0	-0.0	-0.0	0.0	-0.0	1000.0	-0.0	-0.0	CE
K/RB	385	302	305	321	401	R	342	415	240	319	K/RB
K/TH	3259	2978	3079	3367	3038	3036	5210	6917	4044	3413	K/TH
K/BA	R	31	29	R	R	R	36	30	R	R	K/BA
CA/SR	71	77	80	81	45	R	71	82	106	80	CA/SR
RB/SR	.072	.114	.134	.132	.046	T	.094	.115	.368	.133	RB/SR
MG/CR	195	196	179	194	263	608	197	264	413	209	MG/CR
MG/NI	393	710	516	427	345	514	531	1007	338	400	MG/NI
FE/TI	5.7	7.0	6.8	6.7	7.0	5.4	7.2	6.5	5.9	4.6	FE/TI
FE/MN	48	58	58	70	54	65	59	56	63	47	FE/MN
AL/TI	18.33	18.58	18.94	19.84	22.66	16.27	20.61	20.08	17.07	16.01	AL/TI
K/NA	.410	.455	.511	.488	.511	.519	.432	.661	.893	.574	K/NA
CA/NA	1.234	1.175	1.158	1.090	1.442	.984	1.111	1.313	1.249	1.144	CA/NA

MX0053	DACITE. (PLAG-HBDE-OPX-CPX). ZACATEPEC. MIOCENE AGE.	19.18.4/99.11.9
MX0002	ANDESITE. (PLAG-CPX-OPX). SUMMIT. VOLCAN POPOCATEPETL.	19.01.4/98.37.8
MX0018	ANDESITE. RIO FRIO. SOUTH OF PUEBLA HIGHWAY.	19.19.3/98.49.4
MX0032	DACITE. PINO RANGES. LOWER QUATERNARY	19.22.8/98.56.1
MX0061	DACITE. OLDER PART NW BARRIENTOS. MIDDLE MIOCENE	
MX0036	DACITE. LAVA SE OF TEXCOCO. ABANICOS FLANK	19.26.7/98.51.0
MX0022	ANDESITE. LA MARQUEZA. HIGHWAY TO TOLUCA.	19.18.5/99.21.9
MX0015	ANDESITE. EASTERNMOST DOME OF PINO RANGE. L.QUATERNARY.	19.21.6/98.53.6
MX0037	DACITE. (PLAG-OPX-CPX). PENON DE LOS BANOS. MID MIOCENE	19.26.4/99.09.9
MX0043	DACITE. PROBLEMATIC FRIO RIVER. UPPER QUATERNARY	19.20.0/98.42.5

Continued TABLE 3 - Major + trace elements of 62 lavas from the Valley of Mexico.

	VALLEY OF MEXICO LAVAS.					GUNN AND MOOSER (1970).			CA	
NUMBER	MXR043	MXC043	MX0003	MX0021	MX0009	MX0024	MX0057	MX0035	MX0062	MX0025	NUMBER
SIO2	64.23	64.23	64.26	64.66	65.02	65.09	65.14	65.82	65.83	65.84	SIO2
AL2O3	16.18	16.18	16.00	16.77	18.14	15.86	16.42	15.90	15.79	15.75	AL2O3
TIO2	.884	.884	.737	.670	.670	.639	.669	.663	.721	.621	TIO2
FE2O3	4.124	4.124	5.043	4.473	4.337	4.456	4.412	4.482	4.357	4.274	FE2O3
FEO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	FEO
MNO	.086	.086	.087	.085	.097	.072	.075	.079	.079	.077	MNO
MGO	3.09	3.09	2.88	2.05	1.68	2.23	2.42	1.88	2.28	1.78	MGO
CAO	4.789	4.789	4.643	4.726	4.385	4.556	4.669	4.458	4.209	4.385	CAO
NA2O	4.233	4.233	4.300	4.729	3.589	4.636	4.312	3.358	3.720	4.675	NA2O
K2O	2.212	2.212	1.870	1.671	1.988	2.302	1.729	3.231	2.878	2.442	K2O
P2O5	.172	.172	.175	.170	.091	.156	.153	.122	.137	.157	P2O5
H2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	H2O
TOTAL	100.000	100.000	100.000	100.000	100.000	100.000	100.001	100.000	100.001	100.000	TOTAL
CR	88.9	88.9	105.1	41.6	50.3	67.9	62.5	54.2	43.0	44.6	CR
NI	46.5	46.5	25.7	10.9	7.7	40.3	35.3	29.5	32.5	17.2	NI
CU	9.1	9.1	14.7	7.2	5.0	19.9	9.8	12.9	7.9	12.0	CU
ZN	59.6	59.6	73.3	60.6	61.5	54.5	59.4	53.3	51.8	45.5	ZN
RB	57.7	57.7	53.4	26.6	37.4	56.7	32.4	59.9	66.7	61.5	RB
SR	433.6	433.6	453.5	614.8	468.5	464.8	504.8	401.8	372.1	458.2	SR
BA	0.0	0.0	515.4	523.1	566.6	494.8	0.0	0.0	0.0	524.6	BA
PB	11.7	11.7	9.6	8.6	10.5	14.8	8.3	15.5	11.3	11.8	PB
TH	5.4	5.4	5.3	2.8	5.6	4.5	2.3	6.8	8.1	6.5	TH
K/RB	318	318	291	521	441	337	443	448	358	330	K/RB
K/TH	3400	3400	2929	4954	2947	4246	6240	3944	2949	3119	K/TH
K/BA	R	R	30	27	29	39	R	R	R	39	K/BA
CA/SR	79	79	73	55	67	70	66	79	81	68	CA/SR
RB/SR	.133	.133	.118	.043	.080	.122	.064	.149	.179	.134	RB/SR
MG/CR	209	209	165	297	202	198	234	209	320	241	MG/CR
MG/NI	400	400	676	1133	1318	334	414	385	423	625	MG/NI
FE/TI	4.7	4.7	6.8	6.7	6.5	7.0	6.6	6.8	6.0	5.9	FE/TI
FE/MN	48	48	58	53	45	62	59	57	55	56	FE/MN
AL/TI	16.16	16.16	19.16	22.09	23.90	21.91	21.66	21.17	19.33	22.38	AL/TI
K/NA	.523	.523	.435	.353	.554	.497	.401	.962	.774	.522	K/NA
CA/NA	1.131	1.131	1.080	.999	1.222	.983	1.083	1.328	1.131	.938	CA/NA

MXR043 DACITE. DUPLICATE MAJOR ELEMENT ANALYSIS.
MXC043 DACITE. DUPLICATE MAJOR ELEMENT ANALYSIS.
MX0003 ANDESITE. (PLAG-OPX-CPX). SUMMIT. VOLCAN POPOCATEPETL. 19.01.4/98.37.8
MX0021 DACITE. BIOTITE. AJUSCO. MAIN CONE ABOVE V.XITLE. CAM. MONTE ALEGRO.L.PL
MX0009 DACITE. (PLAG-HBDE-BIOT-QTZ). DISSECTED CONES 30KM N OF MEX. GUADY RD.
MX0024 DACITE. HNBDE. BOULDER IN LAHAR. ROAD CUT W. OF SALAZAR. TOLUCA RD.
MX0057 DACITE. (HBDE-PLAG). CO.TLAPACOYA. PUEBLA RD. UP.MIOC. 19.17.1/98.54.9
MX0035 DACITE. SAN ANDRES DE LA CANADA. AFLORAM. S SIERRA GUADALUPE MID MIOCENE
MX0062 DACITE. TLALOC LAST ERUPTION. NE TEXCOCO. PLIOPLIESTOCENE19.30.0/98.47.5
MX0025 DACITE. WEATHERED. ROAD CUT. SIERRA DE LAS CRUCES. 1/4MI W OF MX24

Continued TABLE 3 - Major + trace elements of 62 lavas from the Valley of Mexico.

VALLEY OF MEXICO LAVAS. GUNN AND MOOSER (1970).

NUMBER	MX0012	MX0016	MX0052	MX0058	MX0013	MX0054	MX3275	MX0019	MX0056	MX0020	NUMBER
SIO2	65.93	66.26	66.31	66.31	66.53	67.03	64.25	68.66	74.46	75.26	SIO2
AL2O3	15.87	16.40	16.62	16.94	15.91	16.61	15.65	14.74	14.21	14.04	AL2O3
TIO2	.611	.580	.628	.583	.560	.515	.750	.541	.088	.056	TIO2
FE2O3	4.388	3.953	4.317	3.979	4.197	3.685	5.023	3.652	2.112	1.104	FE2O3
FEO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	FEO
MNO	.079	.073	.078	.073	.076	.069	.080	.072	.026	.082	MNO
MGO	1.70	1.97	1.14	1.35	1.58	1.30	3.35	1.47	.14	.12	MGO
CAO	4.462	4.233	4.104	4.091	4.279	3.776	4.670	3.466	1.164	.558	CAO
NA2O	4.596	4.364	4.648	4.757	4.499	4.378	3.830	3.984	4.287	4.189	NA2O
K2O	2.214	2.020	2.020	1.768	2.250	2.531	2.250	3.332	3.461	4.587	K2O
P2O5	.143	.144	.139	.137	.119	.109	.150	.094	.053	.008	P2O5
H2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	H2O
TOTAL	99.999	99.995	100.000	100.000	100.001	100.000	100.003	100.001	100.000	99.999	TOTAL
CR	37.9	50.1	54.1	35.2	65.6	26.7	111.7	47.4	21.0	22.7	CR
NI	10.0	14.3	35.7	27.3	20.8	26.5	37.8	10.3	24.0	7.5	NI
CU	9.7	5.2	24.3	9.0	12.5	7.9	9.8	6.9	4.4	2.2	CU
ZN	57.0	50.5	57.7	50.2	50.5	51.0	60.8	52.3	24.0	39.7	ZN
RB	48.3	45.3	47.9	50.8	53.1	53.3	59.7	103.7	113.8	224.0	RB
SR	488.7	584.6	482.5	501.7	489.3	466.7	435.8	291.4	121.1	17.2	SR
BA	555.3	439.2	0.0	0.0	510.3	0.0	0.0	730.7	0.0	85.5	BA
PB	8.1	9.1	8.1	7.8	8.1	8.9	0.0	17.0	15.0	27.2	PB
TH	5.1	1.7	4.6	1.7	3.2	4.9	0.0	9.2	8.0	11.1	TH
CE	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	1000.0	-0.0	-0.0	CE
K/RB	381	370	350	289	352	394	313	267	252	170	K/RB
K/TH	3604	9864	3645	8633	5837	4288	R	3006	3591	3430	K/TH
K/BA	33	38	R	R	37	R	R	38	R	445	K/BA
CA/SR	65	52	61	58	63	58	77	85	69	232	CA/SR
RB/SR	.099	.077	.099	.101	.109	.114	.137	.356	.940	13.023	RB/SR
MG/CR	270	237	127	232	146	293	181	187	41	31	MG/CR
MG/NI	1025	832	193	299	459	296	535	859	36	95	MG/NI
FE/TI	7.2	6.8	6.9	6.8	7.5	7.2	6.7	6.8	24.0	19.7	FE/TI
FE/MN	56	54	55	55	55	53	63	51	81	13	FE/MN
AL/TI	22.93	24.96	23.36	25.66	25.07	28.47	18.42	24.05	142.51	221.24	AL/TI
K/NA	.482	.463	.435	.372	.500	.578	.587	.836	.807	1.095	K/NA
CA/NA	.971	.970	.883	.860	.951	.862	1.219	.870	.272	.133	CA/NA

MX0012 DACITE. LAHAR BOULDER. SAN MIGUEL SAND MINE.STA.FE. TOLUCA RD.
MX0016 ANDESITE.SAND MINES. STA FE. BELOW BLUE SANDS. L.PLIOCENE19.23.2/99.15.0
MX0052 DACITE. MIRADOR. MIOCENE 19.13.0/99.09.2
MX0058 DACITE . PULPITO DEL DIABLO. MIDDLE MIOCENE 19.10.1/98.46.2
MX0013 DACITE. SAN FRANCISCO CHIMALPA 19.26.6/99.20.7
MX0054 DACITE. PETLACALCO DOME. MIOCENE 19.13.9/99.11.1
MX3275 DACITE. PUEBLA TOLL RD. VOLCAN IXTACIHUATTL. MEXICO.
MX0019 RHYODACITE.NEW TELAPON. N. PUEBLA HIGHWAY. U.PLIOCENE 19.20.1/98.42.9
MX0056 RHYOLITE. RIOLITE DE LA LUMBR 9. MIDDLE MIOCENE
MX0020 RHYOLITE. RIOT.(PUMICE).TLALOC CONE. NUEE ARDENTE. RIO FRIO.19.20/98.40.

TABLE 4 - Major + trace elements of 28 lavas and ignimbrites from the Guadalajara Region.

	GUADALAJARA REGION LAVAS.					GUNN AND MOOSER, (1970).			CA	
NUMBER	MX1040	MX1035	MX1041	MX1029	MX1030	MX1031	MX1038	MX1039	MX1057	MX1056	NUMBER
SIO2	49.90	54.57	50.06	55.73	56.25	56.23	56.57	60.70	58.49	61.71	SIO2
AL2O3	16.75	18.49	16.97	18.44	17.73	17.95	16.73	16.65	18.17	16.89	AL2O3
TIO2	1.902	.992	1.862	1.008	1.158	1.160	1.819	1.310	1.139	.769	TIO2
FE2O3	11.865	7.316	10.997	7.664	7.977	7.260	9.470	7.480	6.428	5.726	FE2O3
FEO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	FEO
MNO	.151	.102	.131	.110	.109	.093	.151	.138	.103	.127	MNO
MGO	6.41	4.70	6.64	3.98	4.34	3.80	2.90	2.16	2.48	2.22	MGO
CAO	8.329	9.166	8.909	7.669	7.361	8.054	6.574	4.631	6.561	4.497	CAO
NA2O	3.460	3.260	3.120	3.680	3.230	3.380	3.620	4.120	4.570	5.140	NA2O
K2O	1.036	1.201	1.115	1.511	1.648	1.872	1.964	2.609	1.854	2.726	K2O
P2O5	.200	.200	.200	.200	.200	.200	.200	.200	.200	.200	P2O5
H2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	H2O
TOTAL	100.000	99.999	100.001	100.001	99.999	99.999	99.998	99.999	99.999	100.000	TOTAL
CR	56.2	99.4	132.3	62.8	71.1	90.6	28.8	22.6	64.5	38.7	CR
NI	61.2	76.9	105.5	37.8	59.2	67.2	5.3	4.5	0.0	0.0	NI
CU	32.8	33.9	37.8	59.7	40.4	43.0	23.0	6.8	23.1	2.6	CU
ZN	95.2	62.5	84.1	72.8	71.2	75.2	91.6	85.8	68.3	99.9	ZN
RB	13.7	18.3	13.4	21.5	35.8	49.6	35.0	47.4	27.1	78.2	RB
SR	498.0	689.8	670.3	9[illegible]5.1	611.3	625.8	531.8	461.3	654.9	257.5	SR
BA	361.2	538.7	388.1	473.6	603.3	698.7	701.9	865.0	840.4	1062.9	BA
K/RB	628	545	691	583	382	313	466	457	568	289	K/RB
K/BA	24	19	24	26	23	22	23	25	18	21	K/BA
CA/SR	120	95	95	59	86	92	88	72	72	125	CA/SR
RB/SR	.028	.027	.020	.023	.059	.079	.066	.103	.041	.304	RB/SR
MG/CR	688	285	303	382	368	253	607	578	232	345	MG/CR
MG/NI	632	369	380	635	442	341	3297	2901	R	R	MG/NI
FE/TI	6.2	7.4	5.9	7.6	6.9	6.3	5.2	5.7	5.6	7.4	FE/TI
FE/MN	79	72	84	70	73	78	63	54	62	45	FE/MN
AL/TI	7.77	16.46	8.04	16.15	13.51	13.66	8.12	11.22	14.08	19.38	AL/TI
K/NA	.299	.368	.357	.411	.510	.554	.543	.633	.406	.530	K/NA
CA/NA	2.407	2.812	2.855	2.084	2.279	2.383	1.816	1.124	1.436	.875	CA/NA

MX1040 ANDESITE,BASALTIC. AA TYPE, (PLAG-OL-CPX). SANTIAGO CANYON. ALT 3660FT.
MX1035 BASALT,HIGH AL. (PLAG-CPX-ID). TOP OF SANTIAGO CANYON.
MX1041 BASALT,HIGH AL. (PLAG-CPX-CHL-OL). SANTIAGO CANYON. PLIOCENE.
MX1029 ANDESITE,BASALTIC. (PLAG). MICROPHENOCRYSTS. GUADALAJARA QUARRY.
MX1030 BASALT,HIGH AL. (PLAG-CPX). OUSKIRTS OF GUADALAJARA, SANTIAGO CAN. RD.
MX1031 ANDESITE,BASALTIC. (PLAG-OPX-CPX). ROAD CUT, 3 MI. ON SANTIAGO CANYON RD
MX1038 ANDESITE,BASALTIC. (PLAG-CPX-CHL). SANTIAGO CANYON RD. PARALLEL GRAN.TEX
MX1039 ANDESITE, SANTIAGO CANYON, 3900FT., MICRO-CRYSTALLINE, PARALLEL GRAN.
MX1057 ANDESITE. (PLAG-OPX-CPX). CERORRUCO LAVA BEDS. PORPHYRITIC TEXTURE.
MX1056 TUFFACEOUS BRECCIA, BETWEEN MAGDALENE AND IXTLAN DEL RIO.

Continued TABLE 4 - Major + trace elements of 28 lavas and ignimbrites from the Guadalajara Region.

	GUADALAJARA REGION LAVAS.					GUNN AND MOOSER, (1970).			CA	
NUMBER	MX1059	MX1045	MX1054	MX1046	MX1049	MX1047	MX1051	MX1053	MX1052	MX1050	NUMBER
SIO2	46.18	47.56	49.52	49.73	51.78	53.33	53.98	54.16	54.33	55.50	SIO2
AL2O3	14.58	16.73	6.28	13.87	15.33	16.15	17.95	18.25	18.20	17.40	AL2O3
TIO2	3.128	2.975	1.319	2.509	2.628	2.052	1.122	1.106	1.111	1.054	TIO2
FE2O3	12.730	14.352	11.035	13.111	12.135	9.985	8.324	8.187	8.467	8.001	FE2O3
FEO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	FEO
MNO	.163	.186	.153	.186	.184	.153	-0.000	.122	.123	.121	MNO
MGO	8.31	4.16	6.72	6.21	4.50	4.81	5.14	4.91	4.79	5.48	MGO
CAO	9.233	8.536	10.109	9.224	7.687	7.068	8.261	8.452	8.364	6.964	CAO
NA2O	3.280	3.960	3.180	3.760	3.650	4.010	3.510	3.360	3.020	4.070	NA2O
K2O	2.201	1.351	1.484	1.202	1.913	2.246	1.514	1.250	1.404	1.209	K2O
P2O5	.200	.200	.200	.200	.200	.200	.200	.200	.200	.200	P2O5
H2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	H2O
TOTAL	100.000	99.999	100.000	100.000	100.000	100.002	99.999	99.999	100.000	100.001	TOTAL
CR	147.8	49.1	177.2	67.1	78.8	60.0	79.2	81.1	76.9	149.5	CR
NI	0.0	47.9	0.0	36.4	0.0	0.0	0.0	0.0	0.0	0.0	NI
CU	63.0	44.2	69.2	52.4	42.1	34.7	48.2	42.4	45.3	35.6	CU
ZN	92.9	119.9	77.5	86.7	90.1	80.1	73.7	69.7	75.4	81.6	ZN
RB	37.6	13.0	11.4	12.0	28.2	33.2	23.3	20.1	22.6	14.4	RB
SR	860.5	568.8	326.6	525.1	537.5	505.8	671.5	731.3	682.2	585.4	SR
BA	632.5	820.2	215.6	365.2	697.5	829.4	508.4	485.1	532.8	415.3	BA
K/RB	486	863	1081	831	563	562	539	516	516	697	K/RB
K/BA	29	14	57	27	23	22	25	21	22	24	K/BA
CA/SR	77	107	221	126	102	100	88	83	88	85	CA/SR
RB/SR	.044	.023	.035	.023	.052	.066	.035	.027	.033	.025	RB/SR
MG/CR	339	521	229	558	344	483	391	365	376	221	MG/CR
MG/NI	R	523	R	1029	R	R	R	R	R	R	MG/NI
FE/TI	4.1	4.8	8.4	5.2	4.6	4.9	7.4	7.4	7.6	7.6	FE/TI
FE/MN	78	77	72	70	66	65	R	67	69	66	FE/MN
AL/TI	4.11	4.96	10.89	4.88	5.15	6.95	14.12	14.57	14.46	14.58	AL/TI
K/NA	.671	.341	.467	.320	.524	.560	.431	.372	.465	.297	K/NA
CA/NA	2.815	2.156	3.179	2.453	2.106	1.763	2.354	2.515	2.770	1.711	CA/NA

MX1059 BASALT.PICRITIC. (OL-PLAG-CPX). RECENT FLOW 35 MI E OF DURANGO. MEXICO.
MX1045 BASALT.PICRITIC. (PLAG-OL). SCORIA CONE. 12 MI FROM GUADY. NOGALES RD.
MX1054 BASALT.PICRITIC. (PLAG-OL-CPX). OLD FLOW. 5MI E OF ZAPOTLANE.
MX1046 BASALT.PICRITIC. (PLAG-OL-OPX). OLD FLOW. 22 MI S. OF TEQUILA.
MX1049 ANDESITE.BASALTIC. (PLAG-OL-CPX). 3 MI E OF IXTLAN DEL RIO.
MX1047 BASALT.APHYRIC. (PLAG-OL-CPX). 5 MI W. OF MAGDALENA.
MX1051 ANDESITE.BASALTIC. AT FOOT OF TUFF CONE. 6MI OUT ON GUANAJATO RD.
MX1053 BASALT.HIGH AL. (PLAG-OL-CPX). COMPOSITE CONE 8 MI. ON GUANAJATO RD.
MX1052 BASALT.HIGH AL. (PLAG-OL-CPX). FOOT OF TUFF CONE. 6 MI. ON GUANAJATO RD.
MX1050 ANDESITE.BASALTIC. (OL-PLAG-GLASS). V. PARICUTIN. NEAR SAN JUAN CHURCH.

Continued TABLE 4 - Major + trace elements of 28 lavas and ignimbrites from the Guadalajara Region.

	GUADALAJARA REGION LAVAS.				GUNN AND MOOSER, (1970).				CA		
NUMBER	MX1058	MX1048	MX1037	MX1034	MX1032	MX1238	MX1042				NUMBER
SIO2	68.50	75.15	72.74	75.92	76.13	78.31	79.21	0.00	0.00	0.00	SIO2
AL2O3	15.20	13.01	14.46	12.99	12.91	11.39	11.14	0.00	0.00	0.00	AL2O3
TIO2	.569	.127	.137	.105	.143	.184	.230	0.000	0.000	0.000	TIO2
FE2O3	4.092	1.648	2.391	1.313	1.277	1.277	1.605	0.000	0.000	0.000	FE2O3
FEO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	FEO
MNO	.083	.047	.053	.041	.043	.046	.013	0.000	0.000	0.000	MNO
MGO	.77	.07	.12	.27	.03	.17	.56	0.00	0.00	0.00	MGO
CAO	1.711	.455	.759	.569	.572	.190	.600	0.000	0.000	0.000	CAO
NA2O	5.580	4.339	4.620	2.522	4.017	3.862	1.986	0.000	0.000	0.000	NA2O
K2O	3.391	5.059	4.621	6.180	4.782	4.476	4.555	0.000	0.000	0.000	K2O
P2O5	.100	.100	.100	.100	.100	.100	.100	0.000	0.000	0.000	P2O5
H2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	H2O
TOTAL	99.999	99.999	100.000	100.001	100.000	99.999	100.001	0.000	0.000	0.000	TOTAL
CR	24.6	32.3	5.2	7.5	11.6	10.7	20.2	0.0	0.0	0.0	CR
NI	0.0	6.0	7.2	4.0	4.3	8.1	6.5	0.0	0.0	0.0	NI
CU	7.2	3.0	1.7	2.5	1.9	1.2	4.3	0.0	0.0	0.0	CU
ZN	51.2	62.8	25.1	32.1	34.7	47.6	19.1	0.0	0.0	0.0	ZN
RB	63.5	155.1	123.8	168.2	156.4	154.0	149.2	0.0	0.0	0.0	RB
SR	253.8	8.1	96.6	34.0	32.3	20.7	104.7	0.0	0.0	0.0	SR
BA	1485.5	110.2	564.8	348.5	350.2	200.5	809.0	0.0	0.0	0.0	BA
K/RB	443	271	310	305	254	241	253	0	0	0	K/RB
K/BA	19	381	68	147	113	185	47	0	0	0	K/BA
CA/SR	46	401	56	120	127	66	41	0	0	0	CA/SR
RB/SR	.250	19.148	1.282	4.947	4.842	7.440	1.425	0.000	0.000	0.000	RB/SR
MG/CR	190	13	140	217	16	95	168	0	0	0	MG/CR
MG/NI	8	70	101	407	43	126	522	0	0	0	MG/NI
FE/TI	7.2	13.0	17.5	12.5	8.9	6.9	7.0	0.0	0.0	0.0	FE/TI
FE/MN	49	35	45	32	30	28	123	0	0	0	FE/MN
AL/TI	23.58	90.41	93.17	109.16	79.68	54.62	42.76	0.00	0.00	0.00	AL/TI
K/NA	.608	1.166	1.000	2.450	1.190	1.159	2.294	0.000	0.000	0.000	K/NA
CA/NA	.307	.105	.164	.226	.142	.049	.302	0.000	0.000	0.000	CA/NA

MX1058 GRANODIORITE.MICRO. BASE OF SCARP OF SIERRA MADRE OCCIDENTAL, MAZATLAN.
MX1048 OBSIDIAN. IXTLAN DEL RIO. . CONTAINS PARALLEL MICROLITES.
MX1037 IGNIMBRITE.CRYSTAL. (SAN-BIOT-QTZFEES). TOP OF SANTIAGO CANYON.
MX1034 RHYOLITE. QUARRY ABOVE SANTIAGO CANYON. PUMICE.
MX1032 OBSIDIAN. TOP OF SANTIAGO CANYON.
MX1238 IGNIMBRITE.RHYOLITIC. (SAN-TRID-). 30FT LAYER. SANTIAGO CANYON.
MX1042 RHYOLITIC TUFF. BOTTOM SANTIAGO CANYON.
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