K-Ar ages of four mafic lavas from the Central Jalisco Volcanic Lineament: Supporting evidence for a NW migration of volcanism within the Jalisco block, western Mexico

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RESUMEN

Cuatro de las catorce muestras de lavas máficas colectadas a lo largo del lineamiento volcánico central de Jalisco (CJVL) fueron datados por el método de K-Ar para evidenciar un decremento sistemático en la edad del vulcanismo a lo largo del lineamiento como lo indican estudios geológicos y geofísicos previos. Los resultados concuerdan con la progresión en edad propuesta. Específicamente, estos resultados indican que el vulcanismo a lo largo del segmento ubicado más al sureste del CJVL (localizado entre los campos volcánicos de Ayutla y Atenguillo) ocurrió hace cerca de 3.0 Ma, el volcanismo a lo largo del segmento al NW (entre los grábenes de Atenguillo y de Mascota) de 1.8 a 1.9 Ma y entre 0.5 y 0.6 Ma en el Graben de Mascota. La ausencia de vulcanismo a lo largo del segmento ubicado más al noroeste del lineamiento (entre el graben de Mascota y San Sebastián) concuerda con la progresión de la edad propuesta.

Se realizó un análisis geoquímico en las 14 muestras y se determinaron tierras raras en las cuatro muestras datadas. Estos resultados, junto con estudios previos, indican que el vulcanismo ocurrió a lo largo del CJVL y adentro del campo Auytla mostrando una variabilidad composicional similar a la observada en otros campos volcánicos localizados dentro y en el interior del bloque Jalisco.

Además, el afloramineto del cual fue tomada la muestra de Mascota (datada como 0.66 ± 0.038 Ma) es cortado por una falla transcurrente orientada al noroeste (tentativamente identificada según sus estrías rugosas como lateral derecha) indicando que recientemente ocurrió una deformación transcurrente en el graben de Mascota.

PALABRAS CLAVE: Bloque de Jalisco, México, datación K-Ar, geoquímica, tectónica.

ABSTRACT

Four of 14 Plio-Quaternary mafic rock samples collected along the Central Jalisco Volcanic Lineament (CJVL) were dated by the K-Ar method to verify the existence of a systematic decrease in the age of volcanism northwestward along the lineament, as suggested by previous geological and geophysical observations. The results are in agreement with the proposed age progression. Specifically, these results support the contention that the volcanism along the southeastern most segment of the CJVL (located between the Ayutla and Atenguillo volcanic fields) occurred at about 3.0 Ma, volcanism along the segment to the NW (between the Atenguillo and Mascota grabens) at 1.8 to 1.9 Ma, and from 0.5 to 0.06 Ma within the Mascota graben. The lack of observed volcanism along the northwestern most segment of the lineament (between the Mascota graben and San Sebastián) is also consistent with the proposed age progression. A geochemical analysis was performed on all 14 samples and a rare earth element analysis was performed on the four dated samples. These analyses, in conjunction with the results of previous studies, indicate that the volcanism along the CJVL exhibits a varied composition similar to that exhibited by the Plio-Quaternary volcanic rocks located within the main volcanic fields. Additionally, the outcrop from which the Mascota sample (dated as 0.166 ± 0.038 Ma) was obtained is cut by a northwest oriented strike-slip fault (tentatively identified from striation roughness to be right-lateral) indicating that recent strike-slip deformation has occurred in the Mascota graben.

KEY WORDS: Jalisco block, Mexico, K-Ar dating, geochemistry, tectonics.

INTRODUCTION

The Jalisco block, western Mexico, lies southwest of the Tepic-Zacoalco rift (the western part of the Trans Mexican Volcanic Belt which contains the volcanism typically associated with the subduction process) and northwest of the Colima rift (Figure 1). The northeast half of the Jalisco block, between the Trans Mexican Volcanic Belt and the Sierra Cacoma (the granitic coastal mountain range), contains several alkaline volcanic fields located within N-S to NE-SW oriented extensional basins (Wallace and Carmichael, 1989; Lange and Carmichael, 1990; Righter and Carmichael, 1992). These are, from southeast to northwest, the Ayutla, Atenguillo (which extends northeast from Los Volcanes),

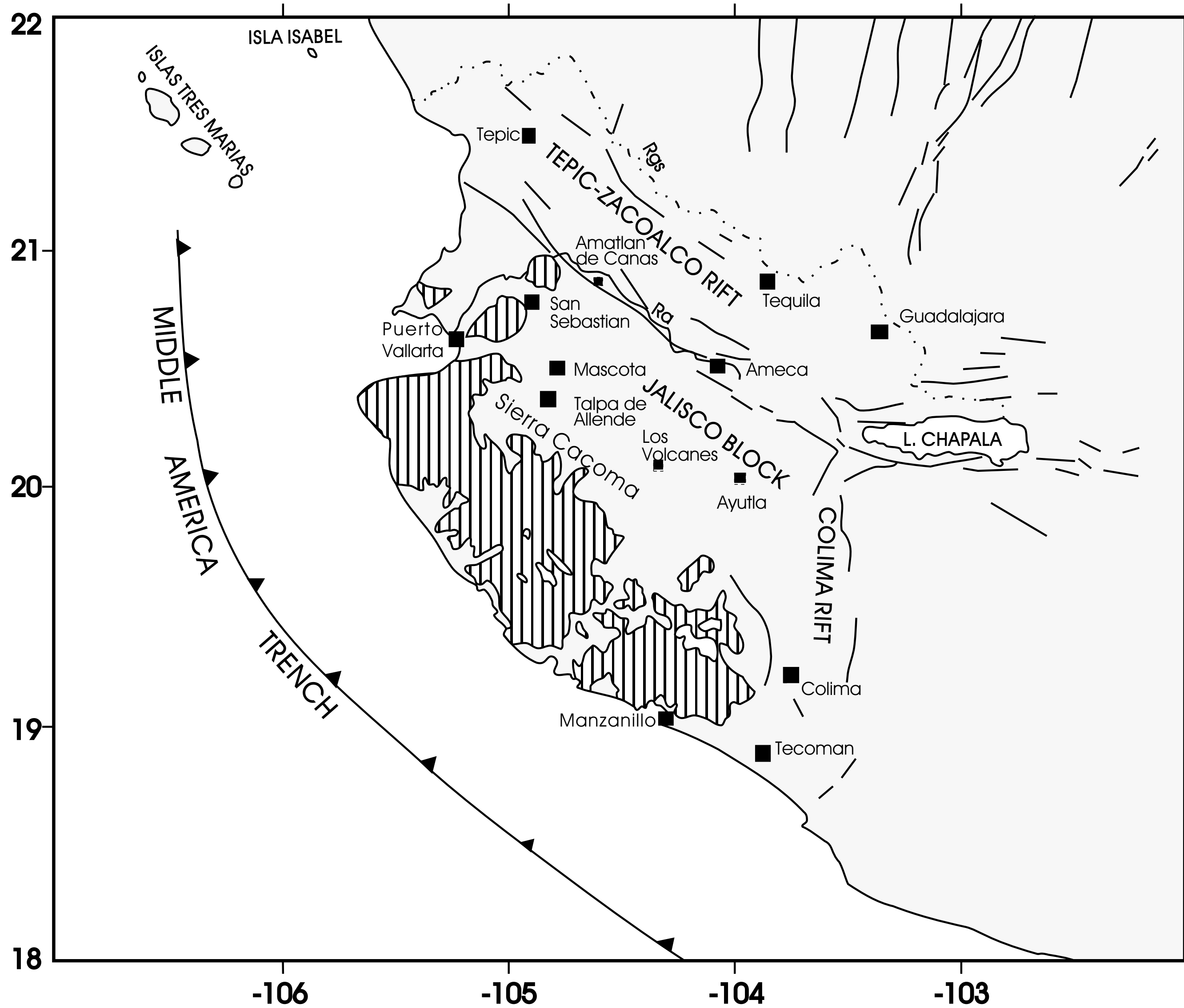

Fig. 1. Location Map. Hatched pattern delineates surface exposures of Cretaceous granitoids (Schaaf and Martínez, 1997). Ra = Río Ameca; Rgs = Río Grande de Santiago.

Mascota, Talpa de Allende, and San Sebastián fields. The southern boundaries of the Ayutla, Atenguillo, and Mascota fields are connected by a narrow, northwest oriented, volcanic lineament (herein termed the ‘Central Jalisco Volcanic Lineament’ or CJVL), whose orientation parallels that of the Tepic-Zacoalco rift. This lineament contains, along almost its entire extent, surface deposits of Plio-Quaternary mafic rocks. This lineament appears to extend from the Mascota field to the San Sebastián field along a prominent normal fault of unknown age; however, surface deposits of Plio-Quaternary igneous rocks are absent along this fault.

The age of volcanism within these fields is variable, however, an overall trend of decreasing ages towards the northwest is indicated from the available radiometric ages (Figure 2). Only one radiometric age (4.6 ± 0.2 Ma) has been reported for the Ayutla field (Righter and Rosas-Elguera, 1999); although its exact location was not presented. The Atenguillo field exhibits the widest range of ages, between 3.4 and 0.6 Ma (Wallace and Carmichael, 1992; Righter *et al.*, 1995); however, the majority of the volcanism within this field dates between 2.5 and 3.5 Ma. Within the Mascota field, radiometric ages range from 61 to 489 ka (Carmichael *et al.*, 1996). Within the Talpa de Allende field, only one radiometric age (1.61 ± 0.02 Ma) has been reported (Lange *et al.*, 1999); although its exact location was not presented. This age is consistent with the reversed polarities reported for of three paleomagnetic samples from the graben (Maillol

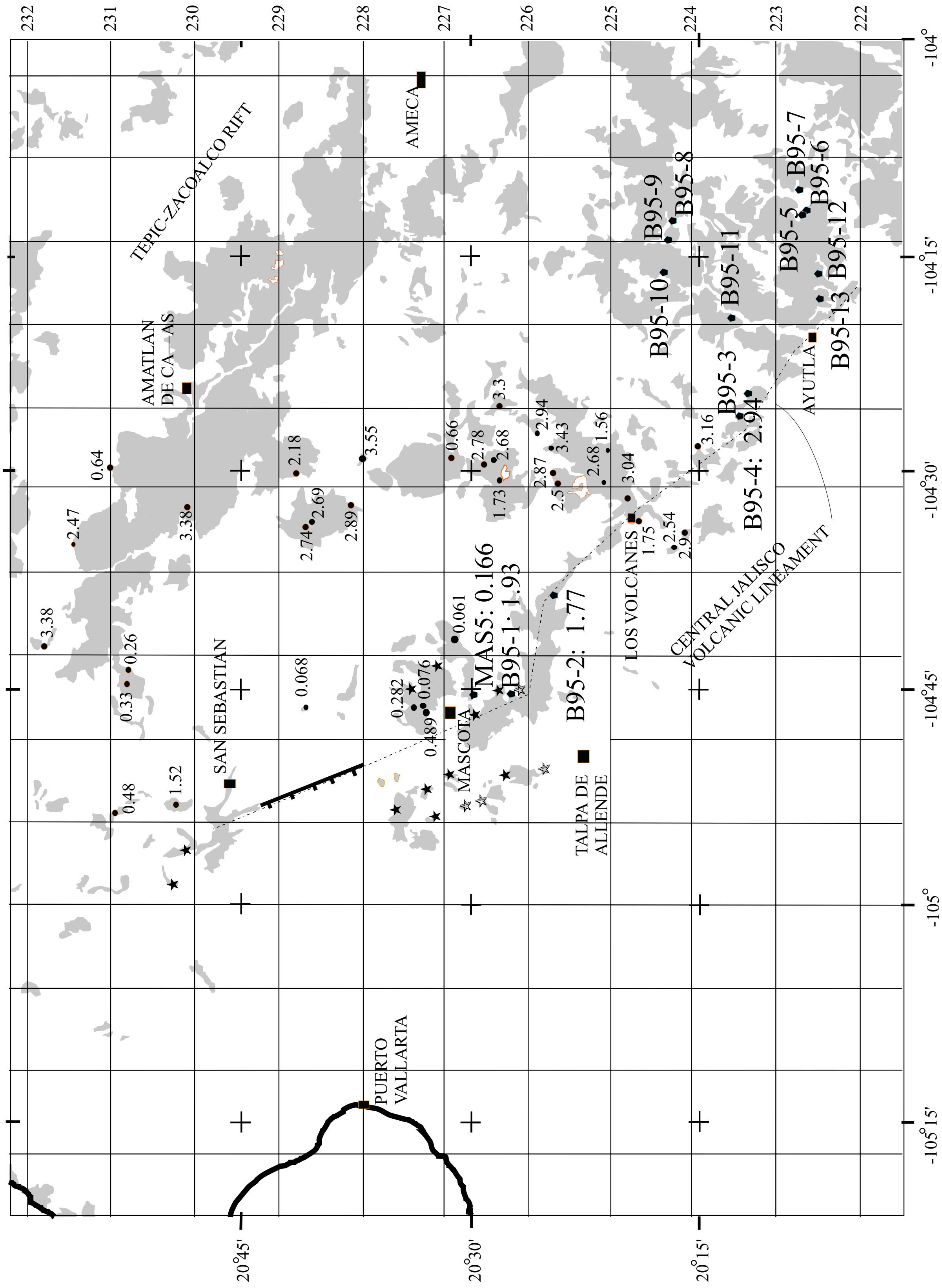

Fig. 2. Distribution and ages of Pliocene-Quaternary volcanism located within the Jalisco block. Also illustrated are the locations (filled pentagons) and ages of the four samples (B95-1, B95-2, B95-4, and MAS-5), and the location of the Central Jalisco Volcanic Lineament (dashed line). See text for the references from which the ages were collected. The paleomagnetic sites of Maillol *et al.* (1997) are marked by open stars (reversed polarity sites) and filled stars (normal polarity sites).

Table 1

Sample Locations

Sample	Rock type	Volcanic Field	Latitude (°N)	Longitude (°W)
MAS-5	Trachyandesite	Mascota	20.51667	104.75833
B95-1	Trachyandesite	CJVL	20.44645	104.75525
B95-2	Trachyandesite	CJVL	20.40975	104.64577
B95-3	Basenite	CJVL	20.21383	104.43060
B95-4	Trachybasaltic Andesite	CJVL	20.19783	104.40767
B95-5	Dacite	Ayutla	20.13762	104.20223
B95-6	Andesite	Ayutla	20.13740	104.19708
B95-7	Basaltic Andesite	Ayutla	20.13930	104.17740
B95-8	Trachyandesite	Ayutla	20.27768	104.20395
B95-9	Andesite	Ayutla	20.28638	104.23202
B95-10	Trachybasaltic Andesite	Ayutla	20.28860	104.26168
B95-11	Basaltic Andesite	Ayutla	20.20400	104.32735
B95-12	Basalt/Trachybasalt	Ayutla	20.11513	104.27382
B95-13	Basaltic Andesite	Ayutla	20.11718	104.30040

and Bandy, 1994; Maillol *et al.*, 1997). Within the San Sebastián field, radiometric dating indicates volcanism occurring between 1.52 to 0.26 Ma (Lange and Carmichael, 1991). Thus, although the ages overlap between the volcanic fields, the ages indicate that volcanism was first initiated in the Ayutla field, followed by the initiation of volcanism within the Atenguillo field, and lastly by the initiation of volcanism within the Mascota, Talpa de Allende, and San Sebastián fields.

Few radiometric ages exist for the Plio-Quaternary igneous outcrops located along the CJVL. However, these few ages also suggest that the volcanism has progressed northwestward along the CJVL (Figure 2). Specifically, the volcanism along the southeastern most part of the CJVL, between the Ayutla and Atenguillo fields, has been dated (one sample) as 3.16 ± 0.12 Ma (± 2σ) (Wallace and Carmichael, 1989); whereas to the northwest, within the Mascota graben, the age of volcanism is between 0.5 and 0.06 Ma (Carmichael *et al.*, 1996). Along the section of the CJVL located between the Atenguillo and Mascota fields, no radiometric ages have been presented in the literature.

The purpose of the present study is to conduct additional radiometric (K-Ar) dating of the Plio-Quaternary mafic rocks located along the CJVL to verify the apparent age progression. Such an age progression provides an important constraint on theories related to tectonic and magmatic processes occurring within western Mexico. For example, the geometry of the extensional structures located within the northeast half of the Jalisco block is indicative of a right-lateral shear couple acting in this area (Maillol *et al.*, 1997). Thus, the extensional basins and associated mafic volcanism may be the result of either, or both, a northwest movement of the Jalisco block relative to the rest of North America (Luhr *et al.*, 1985) and/or arc-parallel extension produced by a progressive increase in the obliquity of subduction of the Rivera and North American plates northwestward along the Middle America Trench (Kostoglodov and Bandy, 1995). Alternatively, these mafic lavas have been proposed to result from a steepening of the angle of subduction of the Rivera plate beneath the Jalisco block (Pardo and Suárez, 1993, 1995; Ferrari *et al.*, 2001). Verification of the age progression would help to differentiate between the competing proposals.

DATA AND METHODS

Geochemistry

For this study we collected 13 whole-rock samples (Table 1, Figure 2) during a field survey conducted in May, 1995, plus one sample (MAS-5) collected earlier during the paleomagnetic study of Maillol *et al.* (1997). Geochemical analysis of major and some trace elements was performed on all samples by Bondar Clegg, Inchcape Testing Services, Vancouver, B.C., Canada.

Rare earth element (REE) analyses, for four samples (MAS-5, B95-1, B95-2, and B95-4), which were deemed adequate for K-Ar dating, were carried out by inductively coupled plasma mass spectrometry (ICP-MS) at the Instituto de Geofísica, UNAM. For the analysis, 0.2 grams of dried powder rock was digested with a mixture of concentrated acids (10 ml HF and 4 ml $HClO_4$). The solution was evaporated to dryness and dissolved with 4 ml $HClO_4$. After evaporation, the solution was made up to 50 ml with 1% HNO_3.

The ICP mass spectrometer employed was a VG Elemental model PQ3. Detection limits are calculated as the concentration equivalent to three times the standard deviation of five replicates of the blank solution. For all elements, it is better than 50 ppt.

Calibration was performed with a 1, 10, 100, and 200 ppb multi-element standard solution (SPEX-High Purity) and a blank solution of deionized water, all containing HNO_3 at 2%. Matrix effects and instrumental drift can be eliminated by the use of In 115 (10 ppb) as internal standard. The validity of the analytic procedure has been assessed on accuracy and precision tests. These tests were calculated by comparison of measured and reference values of andesite JA-2 (Govindaraju, 1987). All elements have better precision than 3% RSD (relative standard deviation). Data obtained for JA-2 showed good agreement with certified values.

K-Ar Dating

Of the 14 samples collected, only four samples (MAS-5, B95-1, B95-2, and B95-4) were deemed acceptable for whole-rock, K-Ar dating after rigorous petrographic inspection. Because the samples were dated as whole-rocks, it was required that they should be essentially unaltered and holocrystalline. The latter criterion is important because a glass phase would be expected to contain a significant portion of the potassium budget of the rock. Hydration of the glass phase could potentially lead to loss of radiogenic argon from the sample. The ten rejected samples were deemed to have undergone an undesirable amount of alteration based on the presence of brown amphibole phenocrysts (which probably contained significant quantities of potassium) that had been partly to completely altered to a cloudy opaque mass.

K-Ar dating was performed at the University of Texas at Austin. The whole-rock samples were crushed and sieved to obtain a 60-80 mesh fraction, which were not treated further except for washing free of dust. Potassium was determined by flame photometry, using lithium as an internal standard and sodium as a buffer. Standard deviations (1σ) are derived from pooled replicate analyses and are ± 1% for whole rocks.

Radiogenic argon was analyzed by isotope dilution utilizing on-line extraction and purification with a 3" gas-source mass spectrometer operated under computer control. Using RF induction, samples were heated to at least 1500°C. Reproducibilities of radiogenic argon measurements at one standard deviation are 1.7% for whole rocks, based on pooled replicate measurements over an extended period of time. The base uncertainty at 1σ for a whole-rock K-Ar age is therefore ± 2.0%. This analytical uncertainty applies only to sample B95-1. Higher uncertainties apply for analyses in which radiogenic argon is less than 30% of total argon. The

Table 2

Major and some trace element analyses

Sample #	SiO2 wt%	TiO2 wt%	Al2O3 wt%	Fe2O3 wt%	MnO wt%	MgO wt%	CaO wt%	Na2O wt%	K2O wt%	P2O5 wt%	LOI wt%	Total wt%	Cr2O3 wt%	FeO wt%	Ba PPM	Cr wt%	Y PPM	Sr PPM	Nb PPM	Zr PPM	Rb PPM
B95-1	56.95	0.06	16.37	5.66	0.09	5.73	6.31	4.77	1.86	0.36	0.41	99.15	0.03	2.25	1115	0.02	18	1407	2	150	15
B95-2	55.02	0.98	15.51	6.52	0.09	5.12	6.97	4.3	3.34	0.77	0.93	99.6	0.04	1.29	1259	0.03	16	>2000	4	290	23
B95-4	51.94	1.57	13.61	6.88	0.1	6.51	7.6	3.4	4.21	1.28	1.07	98.21	0.04	1.35	1855	0.03	19	>2000	9	479	44
B95-5	63.96	0.52	15.64	3.6	0.05	1.89	4.92	3.95	1.08	0.14	3.14	98.88	<0.01	0.64	409	<0.01	17	1349	<1	118	14
B95-9	62.84	0.86	15.51	4.25	0.06	2.09	5.07	3.71	3.23	0.4	1.49	99.52	0.02	0.9	785	0.02	26	1809	<1	315	35
B95-10	55.01	1.36	13.45	6.32	0.09	6.24	7.76	3.53	3.01	0.83	1.04	98.69	0.05	1.29	1056	0.04	18	>2000	4	407	32
B95-13	55.39	0.81	14.78	6.02	0.09	7	6.19	3.69	1.55	0.44	1.09	97.11	0.05	1.8	745	0.04	18	1163	4	211	26
MAS-5	55.68	0.85	16.25	6.19	0.1	5.25	6.84	4.2	2.65	0.57	0.29	98.89	0.02	1.29	1381	0.02	15	1757	3	267	17
B95-3	47.37	2.7	11.62	7.89	0.11	6.24	9.24	2.64	5.46	2.17	2.78	98.24	0.03								
B95-6	57.48	0.73	17.53	6.24	0.09	4.34	6.29	4.06	1.46	0.29	1.15	99.68	0.01								
B95-7	55.33	0.59	15.6	6.47	0.11	8.38	7.55	3.23	1.1	0.18	0.57	99.17	0.07								
B95-8	54.22	1.57	14.66	6.27	0.07	3.82	5.99	3.35	5.45	1.33	1.42	98.18	0.03								
B95-11	53.6	0.61	16.18	6.74	0.11	8.03	7.55	3.87	1.04	0.19	0.78	98.76	0.06								
B95-12	51.03	1.78	16.04	10.34	0.16	4.8	7.37	3.93	1.17	0.61	0.66	97.93	0.03								

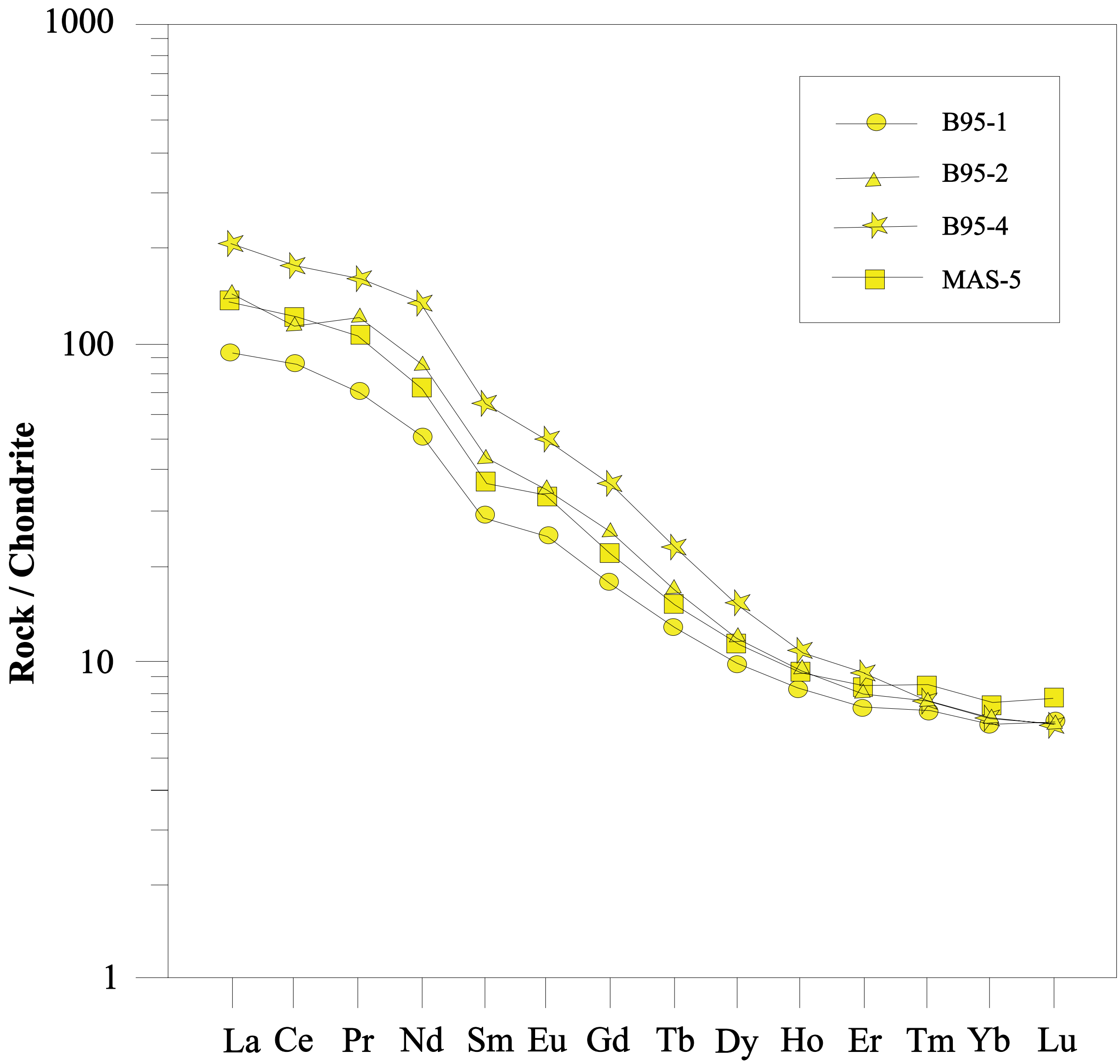

Fig. 3. Rock/ Chondrite REE diagram.

error expansion formulas given by Cox and Dalrymple (1967) and Mahood and Drake (1982) have been used for samples B95-2 and B95-4. Sample MAS-5 showed excessive scatter in repeated analyses, and hence a more conservative precision estimate was derived directly from the data for that sample.

RESULTS

Geochemistry

The results of the geochemical and REE analyses are presented in Tables 2 and 3, respectively. The REE values presented in Table 3 are normalized to recommended chondrite values of Evensen *et al.* (1978). Chondrite normalized REE diagram pattern of the analyzed samples are shown in Figure 3. All analyzed rocks exhibit similar REE normalized diagram patterns. These REE patterns are similar to those exhibited by other lamprophyres of the Jalisco block (Luhr, 1997).

A graph of %SiO_2 versus $Na_2O + K_2O$ for the 14 samples is shown in Figure 4. The samples both from the CJVL and from the Ayutla volcanic field exhibit a compositional variability similar to that observed in the other volcanic fields located within the Jalisco block (Luhr, 1997).

Table 3

REE concentrations (in ppm) for the CJVL

	BA5-2	BA95-1	B95-4	MAS5
La	142.07	93.42	206.62	136.92
Ce	72.17	66.28	11.77	101.55
Pr	120.06	70.25	190.31	103.77
Nd	83.88	50.17	130.75	71.89
Sm	43.05	28.64	64.03	36.36
Eu	33.61	24.82	49.47	32.92
Gd	25.01	17.67	35.83	21.83
Tb	16.56	12.82	22.70	14.95
Dy	11.57	9.68	15.23	11.22
Ho	8.99	8.11	10.58	9.17
Er	7.59	7.05	8.86	8.13
Tm	7.42	7.03	7.42	8.20
Yb	6.42	6.30	6.60	7.21
Lu	6.30	6.30	6.30	7.48

K-Ar Dating

The results of the K-Ar dating are presented in Table 4. Sample B95-4, located between the Ayutla and Atenguillo fields, yielded an age of 2.94 ± 0.06 Ma. Samples B95-1 and B95-2 located between the Atenguillo and Mascota fields, yielded ages of 1.93 ± 0.10 Ma and 1.77 ± 0.12 Ma, respectively. Sample MAS-5, located within the Mascota field, yielded an age of 0.166 ± 0.038 Ma, consistent with the normal polarity of this site determined in the paleomagnetic study of Maillol *et al.* (1997).

DISCUSSION

The results of the radiometric dating of the four samples collected along the CJVL provide further support for a northwest younging of volcanism along the CJVL, as suggested by the results of previous studies. Further, these results suggest that volcanism along any given segment of the lineament has not been continuous, but has instead occurred during short (narrow time spans) episodes of volcanism. The age of sample B95-4 (2.94 Ma) is consistent at the 2σ-uncertainty level with the only other, previously published, dated sample (3.16 Ma) from that part of the CJVL located between the Ayutla and Atenguillo fields. Thus, it appears that a single pulse of volcanism occurred along this section of the CJVL at about 3.0 Ma, and that no further volcanism has occurred along this segment of the CJVL since that time. Similarly, the ages of samples B95-1 and B95-2 (1.93 ± 0.10 Ma and 1.77 ± 0.12 Ma, respectively) suggest that, although volcanism within the Mascota and Atenguillo fields overlap in time, volcanism along the segment of the CJVL located between these two fields occurred during a single pulse of volcanism at about 1.85 Ma, and that no further volcanism has occurred along this segment of the CJVL since that time.

The results of the present study and those of previous studies indicate the following chronology for the volcanism occurring within the Jalisco block of western Mexico. At about 4.5 Ma, volcanism within the Jalisco block was confined to the Ayutla volcanic field, located in the NE corner of the Jalisco block adjacent to the Tepic-Zacoalco and Colima rifts. This time corresponds roughly to the time (4.6 to 3.9 Ma) of a widespread pulse of alkaline volcanism, which occurred both within the Colima rift and within the Tepic-Zacoalco rift, previously proposed (Allan *et al.*, 1991) to mark the initiation of the separation of the Jalisco block from the North American plate. Consequently, volcanism within the Ayutla field may be related to the initial formation of the Jalisco block.

If volcanism within the Ayutla field is a part of the abovementioned volcanic pulse, then by analogy, volcanism within this field ceased at about 3.9 Ma. However, more dating is needed to determine the exact time at which volcanism ceased. At 3.5 Ma volcanism within the Jalisco block relocated to the Atenguillo field. At this time, no volcanism was occurring along the CJVL. At about 3.0 Ma, a short pulse of trachyandesite/basanite volcanism occurred along the segment of the CJVL located between the then inactive Ayutla field and the newly initiated Atenguillo field. This pulse of volcanism was short lived, as no volcanism younger than about 3.0 Ma is observed.

Between 3.0 and 1.9 Ma, volcanism within the Jalisco block was confined to the Atenguillo field. At 1.9 Ma, volcanism extended to the NW along the CJVL from the Atenguillo field to the then nonexistent Mascota field. Shortly after this volcanic pulse, volcanism commenced in the Talpa de Allende and the small San Sebastián field (between 1.6 and 1.5 Ma). However, volcanism ceased along the CJVL between the Atenguillo and Talpa de Allende fields. By 0.6 Ma, volcanism apparently ceased in the Talpa de Allende field and Atenguillo (youngest reported age within this field is 0.66 Ma) fields and shifted to the Mascota field. Volcanism continued within the San Sebastián field. At present, volcanism appears to be active only within the Mascota field, where volcanism as young as 0.06 Ma has been dated, and perhaps the San Sebastián field, where volcanism as young as 0.26 Ma has been reported.

Presently, two proposals exist to explain the presence of volcanism within the Jalisco block. The first proposal is

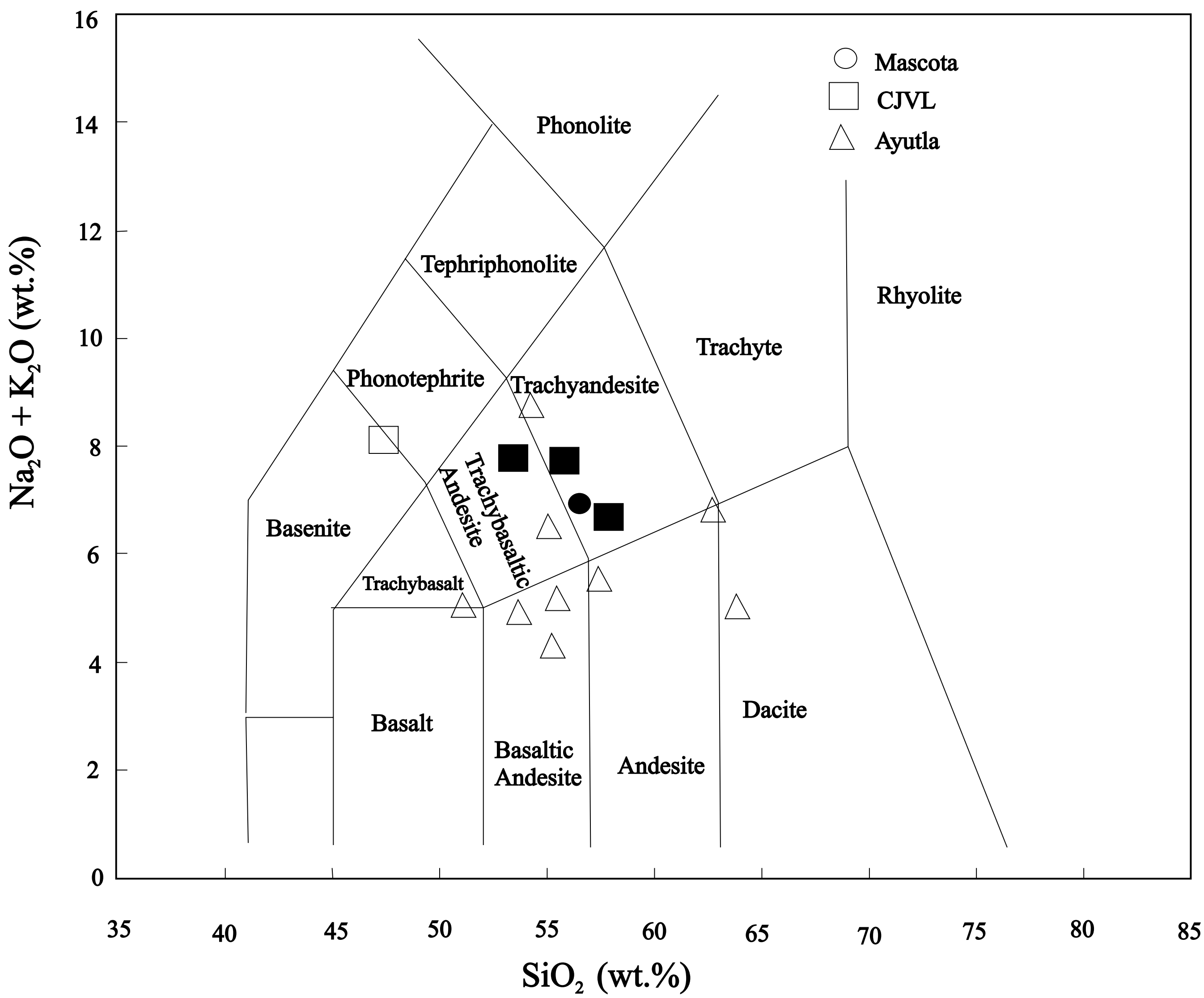

Fig. 4. System of classification based on silica versus total alkalies, illustrating the compositional variation of the 14 samples analyzed in the present study. The filled symbols represent the four samples dated in this study. The reader is referred to Luhr (1997) for a detailed presentation of the diversity exhibited within the rest of the main volcanic fields of the Jalsico block.

that this volcanism is related to a steepening of the subducted Rivera plate beneath the Jalisco block and a consequent SW migration of the volcanic front (Pardo and Suárez, 1993, 1995; Ferrari *et al.*, 1994; Ferrari *et al.*, 2001). The second proposal is that it is the result crustal extension within the forearc region (Wallace *et al.*, 1992; Righter *et al.*, 1995), perhaps related to a separation of the Jalisco block from the rest of the North American plate (Luhr *et al.*, 1985). Consistent with the proposal of Luhr *et al.* (1985), Kostoglodov and Bandy (1995) proposed that the Jalisco block was undergoing a NW-SE oriented stretching (or arc-parallel extension), the stretching being the result of a progressive increase, northwestward along the Middle America Trench, of the obliquity of subduction of the Rivera plate relative to the North American plate. Analogous situations have been observed at other subduction zones where a progressive increase in the obliquity of subduction along the trench is occurring, such as the Aleutian Arc (Avé Lallemant, 1996), and the Sumatra trench (McCaffrey, 1992). This stretching appears, from Landsat imagery, to involve a right-lateral shear couple acting within the northern part of the Jalisco block (Maillol *et al.*, 1997) between the Sierra Cacoma and the Tepic-Zacoalco rift.

The NW migration of volcanism, the predominantly alkaline nature of volcanism within the Jalisco block as compared to the rest of the Trans Mexican Volcanic belt, and the cessation of volcanism within the Ayutla and Atenguillo

Table 4

K-Ar analyses

Sample	Mineral Type	%K	$\%^{40}Ar$	$^{40}Ar \times 10^{-6}$ scc/gr	Age (Ma)	± 1σ
MAS-5	Whole Rock	2.179	3.9	0.0144	0.166	0.038
		2.167	3.6	0.0136		
B95-1	Whole Rock	1.356	20.1	0.0973	1.93	0.10
		1.346	21.0	0.1049		
B95-2	Whole Rock	2.820	29.1	0.1858	1.77	0.12
		2.832	46.3	0.2035		
B95-4	Whole Rock	3.733	58.7	0.4234	2.94	0.06
		3.686	56.4	0.4237		

fields (and along the CJVL), is hard to reconcile with the first proposal. If volcanism is due to a steepening of the subduction angle of the Rivera Plate, then (1) why should there be a predominance of alkaline volcanism which is typically associated with areas of crustal extension?, (2) why is there a lack of present-day volcanism in the SW part of the Jalisco block?, and (3) why is the volcanism migrating to the NW? Further, the Atenguillo graben contains several shield volcanoes consisting of hawaiite and alkali-olivine basalts, which are "unusual for a continental-arc setting" (Righter and Carmichael, 1992).

These questions are more easily explained by the second proposal. Alkaline volcanism is commonly observed in areas where the forearc region is undergoing extension (Righter and Carmichael, 1992). Further, the lack of present-day volcanism at the SE end of the Jalisco block and the NW migration of volcanism within the Jalisco block can be easily explained; specifically, that part of the Jalisco block which accommodates the arc parallel extension has migrated NW, and is presently located in the NW part of the Jalisco block (i.e., within the San Sebastián and the Mascota fields, and perhaps within the tectonically active Puerto Vallarta Graben (Núñez-Cornú *et al.*, 2000). Also, one of the reviewers of this paper pointed out in support of the second proposal that "these alkaline lavas are very small in volume and simply don't reflect an arc volcanic front in the way that most would consider the front of the principle arc volcanism. Instead, they appear to represent very small amounts of partial melting, associated with minor mantle upwelling in the region of pull-apart basins."

The parallel orientations of the CJVL and the Tepic-Zacoalco rift suggest that the CJVL may have accommodated part of the right-lateral motion occurring across the shear-couple noted by Maillol *et al.* (1997), as the CJVL lies within the proposed shear couple. Evidence for recent right-lateral strike-slip motion exists within the shear couple. Sample MAS-5 was observed to be cut by a NW oriented strike slip fault, the motion along which was tentatively identified as right-lateral (Maillol and Bandy, 1994; Maillol *et al.*, 1997). This indicates that strike-slip motion has occurred in this area since the emplacement of this flow (0.166 ± 0.038 Ma). Further, Lange and Carmichael (1990) observed that, within the Talpa de Allende graben, "a minette flow that is exposed extensively on both banks [of the Río Talpa] is visibly displaced right-laterally."

CONCLUSIONS

We conclude from the results of this study the following.

(1) The K-Ar dates are consistent with a NW younging of volcanism along the CJVL located within the center of the Jalisco block; sample B95-4, located at the SE end of the CJVL between the Ayutla and Atenguillo fields, yielded an age of 2.94 ± 0.06 Ma; samples B95-1 and B95-2, located along the center of the lineament between the Atenguillo and Mascota fields, yielded ages of 1.93 ± 0.10 Ma and 1.77 ± 0.12 Ma, respectively; and sample MAS-5, located at the NW part of the lineament within the Mascota field, yielded an age of 0.166 ± 0.038 Ma.

(2) The geochemical composition of the volcanic rocks located along the CJVL and within the Ayutla field show a compositional variability similar to that exhibited by those of the other main volcanic fields of the Jalisco block.

(3) The age distribution of recent volcanic rocks within the Jalisco block, the orientation of the grabens containing the main volcanic fields located within the Jalisco block (and the Puerto Vallarta graben), and the presence of alkaline volcanics within the interior of the Jalisco block are most easily explained by a NW-SE oriented stretching of the Jalisco block, the stretching being the result of a NW progressive increase in the obliquity of subduction of the Rivera Plate relative to the North American Plate along the Middle America Trench off the coast of Jalisco. The area of the Jalisco block where the extension has been accommodated has migrated to the NW, and presently lies within the Mascota and San Sebastián fields, and within the Puerto Vallarta graben.

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