PETROGRAPHY, CHEMISTRY AND SOURCES OF LAJA FROM THE PREHISTORIC SILENCIO CEMETERY, COSTA RICA

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RESUMEN

Se presentan descripciones petrológicas y análisis químicos de lajas de las tumbas del sitio Silencio, así como de dos posibles fuentes de dichas lajas. Uno de los afloramientos se sitúa en Cerro Tovar, en Tilarán, aproximadamente 7 Km al oeste del cementerio y el otro cerca de Casa Blanca, 2 Km más al oeste. Se analizaron 20 muestras de laja del cementerio. El análisis de la mineralogía y la petrografía en secciones delgadas y la fluorescencia de rayos X de rubidio (Rb) estroncio (Sr), zirconio (Zr) y bario (Ba), permitió separarlas en dos grupos principales. Doce muestras corresponden a andesitas máficas de grano fino. Cinco son andesitas de grano grueso. Las tres restantes incluyen: dos basaltos distintos entre ellos y una dacita. El afloramiento de Cerro Tovar presenta andesitas máficas de grano fino, petrológica y químicamente idénticas al tipo que predomina en el cementerio, por lo que podría ser la fuente de estas lajas. De los tipos restantes de laja encontrados en el cementerio, ninguno corresponde a rocas del Cerro Tovar y sus fuentes son aún desconocidas. Las muestras del afloramiento cercano a Casa Blanca, al oeste de Tilarán, no son similares a ninguno de los tipos de laja encontrados en el cementerio.

ABSTRACT

Petrologic descriptions and chemical analysis are presented of both laja (flat stone slabs) used to construct tombs in the prehistoric Silencio cemetery, and also of volcanic rocks from two different potential source outcrops for this laja, one at Cerro Tovar in Tilarán ~7 km west of the cemetery and one near Casa Blanca 2 km further to the southwest. Based upon both their mineralogy and petrography as observed in thin sections, and X-ray fluorescence analysis of the four trace-elements Rubidium (Rb), Strontium (Sr), Zirconium (Zr) and Barium (Ba), 20 samples of laja from the cemetery were found to include two main volcanic rock types. Twelve of these samples are fine-grained mafic andesites and five of the samples are coarse-grained andesites. Three other different rock types, including two distinct basalts and a dacite, also occur as laja, but with only one sample each. The outcrop at Cerro Tovar is fine-grained mafic andesite petrologically and chemically identical to samples of the most common type of laja found in the cemetery and this outcrop may have been the source for this type of laja. None of the other laja types encountered in the cemetery matched the samples from Cerro Tovar, and the sources for these other types of laja have yet to be identified. Samples from the outcrop near Casa Blanca southwest of Tilarán were not similar to any laja found in the cemetery.

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The prehistoric Silencio cemetery is located 3 km south of the southwestern edge of Lake Arenal in the Guanacaste province of Costa Rica (Fig. 1a; Bradley, 1994). Thin stone slabs, called laja, were used to construct tombs in the cemetery (Bradley, 1994). These stones were brought from nearby locations along prehistoric footpaths still visible in satellite imagery (Sever this volume; Weller this volume). The petrology and chemistry were determined for 20 samples of laja collected from the Silencio cemetery, as well as 23 samples of volcanic rocks from two different outcrops in the surrounding region, one at Cerro Tovar at the western edge of Tilarán, ~7 km west of the cemetery, and one from 2 km further to the southwest at Casa Blanca (Fig. 1b). These samples were collected by Payson Sheets during the summers of 2001 and 2002.

The purpose of this study was to identify potential sources for the laja found in the Silencio cemetery. Jorge Barquero (this volume) concluded that the outcrops of volcanic rock at Cerro Tovar in Tilarán are one possible source for this laja. The results presented here confirm this conclusion, but also imply that other sources, which have not yet been located, exist for laja found in the cemetery.

PETROLOGY

Standard petrologic thin sections were prepared from samples of both laja collected from the cemetery and volcanic rocks which outcrop in the vicinity of Tilarán, and these were examined with a polarizing microscope. All of the rocks collected have porphyritic textures, with some large crystals occurring within a groundmass of many smaller mineral grains, and all contain glass (Fig. 2).

Both porphyritic texture and the presence of glass are common characteristics of volcanic rocks which result from the rapid cooling of magmas when they are erupted from volcanoes. The main minerals in all these samples are plagioclase feldspar, clinopyroxene, orthopyroxene, titanomagnetite, olivine which is often pseudomorphically altered to iddingsite, and amphibole which in some cases is oxidized and dehydrated to basaltic hornblende and/or a dense intergrowth of iron oxides (see Fig. 2a). Alteration of olivine to iddingsite and oxidation of amphibole are also common features of volcanic rocks. None of the rocks studied had vesicles.

SILENCIO CEMETERY

Based on the mineralogy and texture of 20 samples of laja, two main groups of volcanic rocks were identified. The most prominent group, referred to as type SC1 (Tables 1 and 2), are fined-grained plagioclase-rich rocks, commonly with trachytic textures in which plagioclase grains have been oriented by the flow of the magma from which these rocks crystallized (see Fig. 2a). Larger chemically zoned plagioclase phenocrysts also occur in these rocks and in some samples the proportion of plagioclase phenocrysts are greater and trachytic texture is less well developed.

These rocks also contain crystals of clinopyroxene, titanomagnetite and oxidized amphiboles, as well as clear glass. No olivines, orthopyroxenes or fresh amphiboles are present in this group of rocks. Their chemical composition, discussed in the next section, indicates that they are mafic andesites (see Table 2). Twelve of the 20 samples, or 60% of the laja samples collected from the cemetery, are this type of rock.

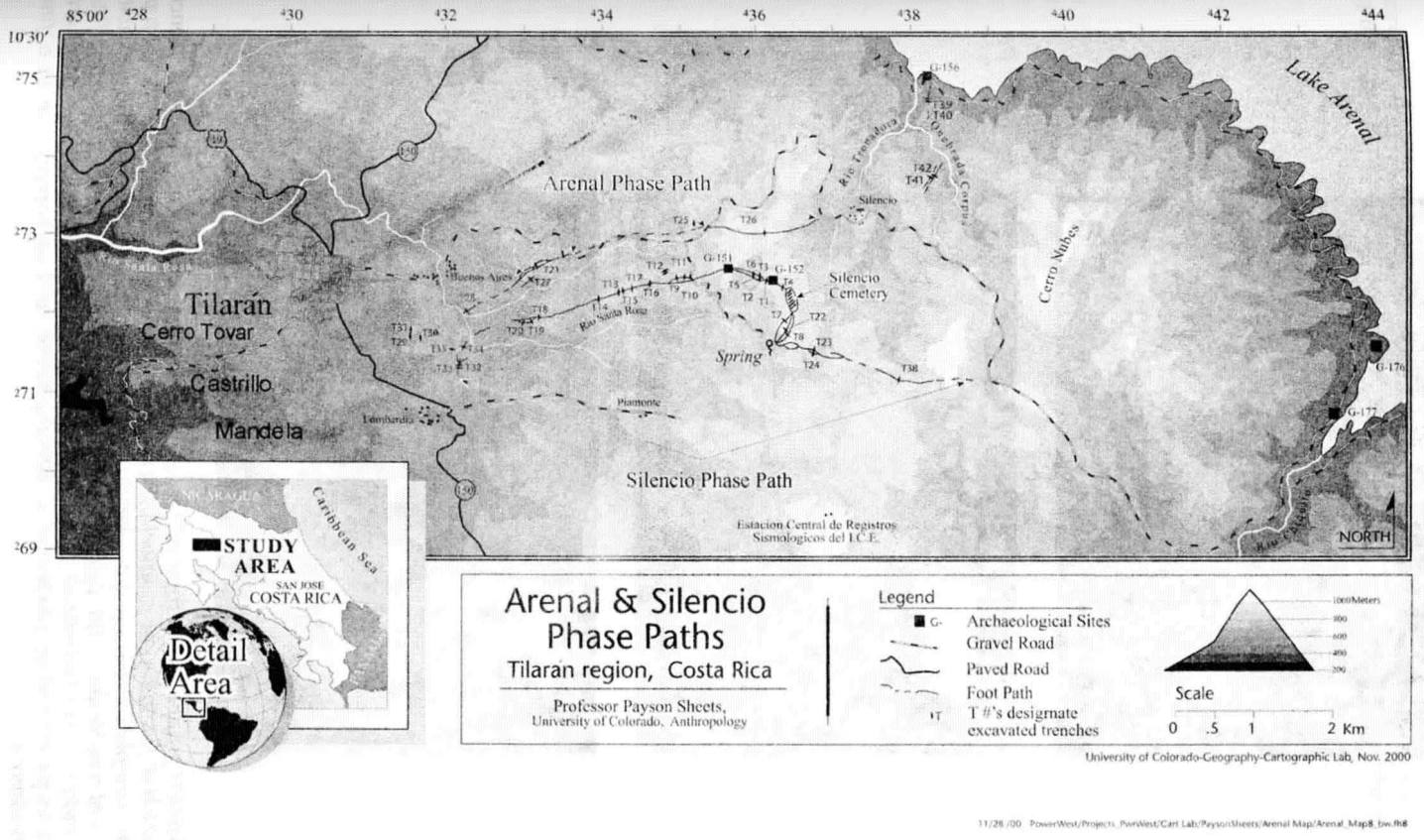

Fig. 1 *Maps showing* ***(a)*** *the location of the Silencio cemetery and the town of Tilarán south of the southwestern edge of Lake Arenal, Costa Rica, and* ***(b)*** *the location of Cerro Tovar and Casa Blanca in relation to the town of Tilarán and the cemetery.*

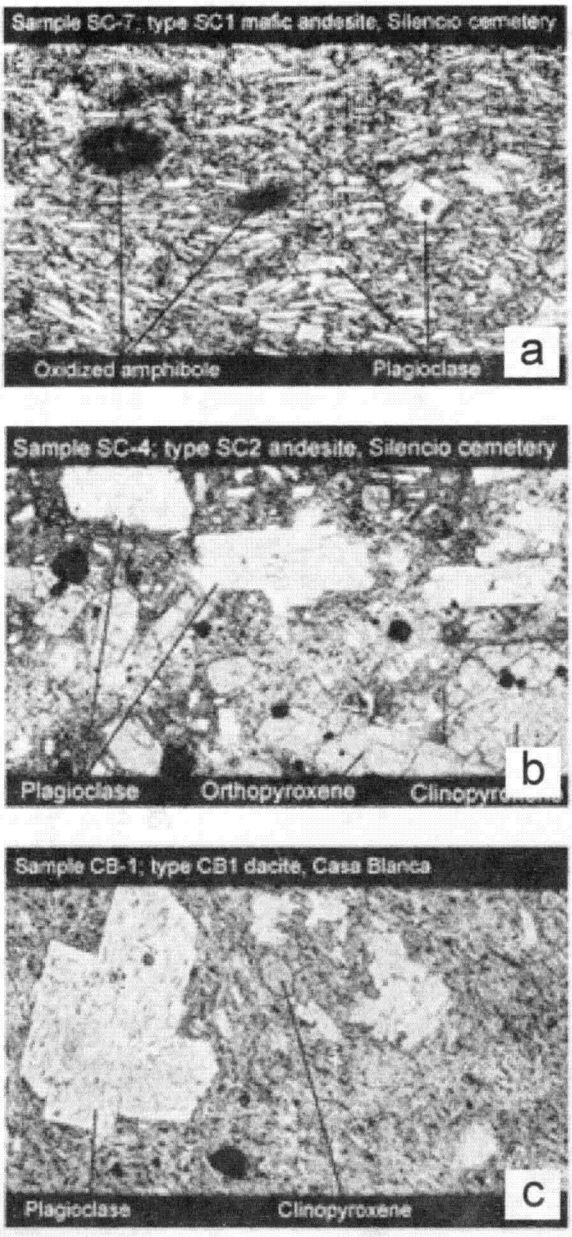

Fig. 2 *Photomicrographs of* ***(a)*** *type SC1 mafic andesite sample SC-7 from the Silencio cemetery, which is fine-grained plagioclase-rich rock with trachytic flow texture;* ***(b)*** *type SC2 andesite sample SC-4 from the Silencio cemetery, which is a porphyritic rock with large crystals of plagioclase, clinopyroxene, orthopyroxene and titanomagnetite in a fine-grained groundmass; and* ***(c)*** *dacite sample CB1 from Casa Blanca, which is a porphyrit - ic rock with large crystal of plagioclase, clinopyroxene and orthopyroxene in a fine-grained groundmass.*

Table 1

Concentration in ppm (parts-per-million), as determined by X-ray fluorescence analysis, of the trace-elements Rb, Sr, Zr and Ba in samples of laja from the Silencio cemetery and nearby outcrops of volcanic rocks.

Trace elements	Rb	Sr	Zr	Ba	Type
Silencio Cemetery Laja					
Samples of 2001 (8)					
SC-A1	37	818	68	730	SC1
SC-A2	30	800	76	731	SC1
SC-A3	38	812	69	749	SC1
SC-A6	--	--	--	--	SC1
SC-B1	37	869	62	779	SC1
SC-C1	49	536	169	1154	??
SC-D1	44	750	127	952	SC2
SC-E1	20	580	65	659	??
Samples of 2002 (12)					
SC-01	44	712	95	835	SC2
SC-02	38	894	33	718	SC1
SC-03	44	879	52	692	SC1
SC-04	54	747	166	976	SC2
SC-05	--	954	25	723	SC1
SC-06	68	774	139	978	SC2
SC-07	37	855	72	857	SC1
SC-08	43	842	74	828	SC1
SC-09	41	749	132	1041	SC1
SC-10	42	796	103	935	SC1
SC-11	122	1312	340	1562	??
SC-12	--	724	124	1104	SC2
Potential Source Areas					
Tovar					
Samples of 2001 (5)					
CA1	36	835	69	723	SC1
CA2	37	860	67	792	SC1
CA3	38	881	70	654	SC1
CA4	36	923	65	732	SC1
CA5	35	845	75	808	SC1
Samples of 2002 (4)					
T01	34	881	96	720	SC1
T02	41	870	107	791	SC1
T03	37	882	54	716	SC1
T04	41	751	106	1296	SC1
Casa Blanca					
Samples of 2001 (6)					
CB1	38	464	104	1327	CB1
CB2	35	450	98	1497	CB1
CB3	35	466	98	1315	CB1
CB4	36	470	96	1506	CB1

Table 1 *(cont's)*

Trace elements	Rb	Sr	Zr	Ba	Type
Potential Source Areas					
CB5	30	446	102	1373	CB1
CB6	34	429	100	1523	CB1
Samples of 2002 (8)					
CB01	40	434	103	1395	CB1
CB02	42	449	123	1588	CB1
CB03	40	454	113	1613	CB1
CB04	38	457	103	1534	CB1
CB05	35	460	45	1287	CB1
CBW01	29	503	118	1211	CB1
CBW02	38	494	83	1498	CB1
CBW03	45	503	101	1522	CB1

The next most prominent group, referred to as type SC2 (see Tables 1 and 2), are coarser grained (see Fig. 2B) than type SC1 mafic andesites, with a greater proportion of large crystals of chemically zoned plagioclase, clinopyroxene, orthopyroxene, titanomagnetite, and occasional olivine often altered to iddingsite. These minerals occur in a fine-grained groundmass formed by small crystal of plagioclase and pyroxene and both clear and brown glass. Flow textures are less well developed in these rocks compared to the SC1 mafic andesites. These rocks also clearly differ from type SC1 mafic andesites with respect to the presence of olivine and orthopyroxene, the absence of basaltic hornblende, as well as their coarser texture. A chemical analysis, discussed below, indicates that these rocks are andesites (see Table 2). Five of the 20 samples, or 25% of the laja samples collected from the cemetery, are this type of rock.

One sample each of three other types of laja were collected in the cemetery. Sample SC-11 is a fine-grained plagioclase and clinopyroxene rock, with many large phenocrysts of clinopyroxene. This rock has well developed trachytic flow texture and also contains titanomagnetite, basaltic hornblende, and occasional olivine in a groundmass of clear glass. A chemical analysis indicates that this rock is a basalt (see Table 2). Sample SC-E1 is a texturally and mineralogically distinct basalt with a fine-grained subophitic texture consisting of plagioclase intergrown with clinopyroxene, along with titanomagnetite and phenocrysts of olivine generally altered to iddingsite. This basalt does not contain amphibole. Sample SC-C1 consists of a relatively small proportion of crystals of plagioclase and fresh hornblende in a very fine-grained glassy groundmass with trachytic flow texture. The glassy nature of this sample and the absence of both pyroxenes and olivine suggest that this rock is a dacite.

CERRO TOVAR

Nine samples from outcrops at Cerro Tovar on the western edge of Tilarán, ~7 km west of the Silencio cemetery, have identical textures and mineralogy to the twelve samples of type SC1 mafic andesite laja from the cemetery. Chemical analyses discussed below confirm their similarity (see Tables 1 and 2). These rocks are clearly the same as each other and these outcrops certainly may have been the source for this type of laja, which is the most common type in the cemetery. No samples from the outcrops at Cerro Tovar resemble the other types of laja found in the cemetery.

Table 2

Concentrations of major-elements (in oxide percents) and trace-elements (in ppm) of selected samples of the most important rock types from the Silencio cemetery and near - by outcrops of volcanic rocks.

location type sample #	Silencio SC1 SC-02	Silencio SC1 SC-03	Silencio SC2 SC-06	Silencio ?? SC-11	Casa Blanca CB1 CB-02	Cerro Tovar SC1 T-02
Si02	55,12	55,72	57,57	49,73	62,06	55,38
Ti02	0,61	0,65	0,73	1,31	0,67	0,66
A1203	18,15	18,63	17,44	15,82	16,29	18,59
Fe203*	7,69	8	7,36	9,6	5,95	8,09
MnO	0,14	0,14	0,1	0,13	0,09	0,14
MgO	3,97	4,09	3,33	4,76	1,34	4
CaO	7,47	7,47	7,05	9,47	3,96	7,28
Na2O	3,28	3,11	3,14	2,61	3,22	2,99
K2O	1,24	1,22	2,11	3,17	1,66	1,2
P2O5	0,24	0,24	0,24	0,73	0,18	0,23
LOI**	0,79	0,85	1,31	1,21	3,22	1,53
Total	**98,7**	**100,12**	**100,38**	**98,55**	**98,65**	**100,09**
Cs	0,6	0,7	0,7	0,4	0,6	0,6
Rb	23	24	53	98	32	23
Sr	1000	1010	871	1470	443	972
Ba	777	798	1140	1480	1460	853
Th	3,9	3,9	6,1	15,1	2,9	3,9
U	1,2	1,2	2,1	5,9	1,2	1,2
Nb	6	5	7	16	5	5
Ta	1,9	1,5	1,4	1,8	0,7	1,3
Zr	73	77	141	339	119	78
Hf	1,9	1,9	3,2	8,3	2,9	1,9
Y	25	30	18	24	19	18
La	40	39,7	33,1	74,5	17,7	29,2
Ce	50,6	49,4	60,1	146,9	29,3	43,7
Nd	37,2	32,9	27,3	69,8	17,2	25,6
Sm	7,24	6,11	5,1	12,1	3,87	5,03
Eu	2,28	2,03	1,31	3,37	1,11	1,53
Tb	0,86	0,82	0,6	1,1	0,61	0,61
Yb	2,03	2,09	1,65	1,79	1,8	1,58
Lu	0,33	0,35	0,27	0,27	0,3	0,26
V	163	170	170	239	114	169
Cr	27	28	29	92	--	28
Co	31	29	27	34	13	29
Ni	26	26	24	79	--	27
Cu	88	67	81	100	25	84
Zn	85	88	85	128	68	91

* Total Fe

** LOI= Loss -on-ignition (H20 and C02)

CASA BLANCA

Volcanic rock samples from two outcrops at Casa Blanca, 2 and 3 km further to the southwest of Cerro Tovar, are coarse grained, with large phenocrysts of plagioclase, clinopyroxene and orthopyroxene. They are texturally somewhat similar to type SC2 laja from the Silencio cemetery (see Fig. 2C), but the samples from Casa Blanca have fewer phenocrysts and more fine-grained groundmass than type SC2 laja, and also lack olivine. The groundmass of these rocks is plagioclase-rich and has flow structures. Glass does not occur in the groundmass of these rocks, which have apparently undergone hydrothermal alteration. As discussed below, their chemical composition also differs from SC2 laja and indicates that they are altered dacites (see Tables 1 and 2). The rocks from Casa Blanca are not similar to any laja samples from the cemetery.

CHEMISTRY

Each rock sample was ground into a fine powder for chemical analysis by energy dispersive X-ray fluorescence (XRF) to determine their Rubidium (Rb), Strontium (Sr), Zirconium (Zr) and Barium (Ba) contents in parts-per-million (ppm) (see Table 1). Selected samples were also analyzed by ion-coupled-plasma mass-spectrometer (ICP-MS) to determine a more complete major and trace elements chemical composition (Table 2). These data were used to compare the chemistry of the laja from Silencio cemetery with the samples collected from the potential source outcrops at Cerro Tovar and Casa Blanca.

The laja samples from the cemetery could be separated into two groups of similar trace element contents and ratios based solely on the concentrations of the four trace elements Rb, Sr, Zr and Ba (types SC1 and SC2; see Fig. 3a and Table 1). These two main groups are exactly equivalent to the petrologic groupings described above. The most common type of laja, group SC1 mafic andesites, have Rb that varies between 30 and 44 ppm, Sr between 796 and 954 ppm, Zr between 25 and 103 ppm, and Ba between 692 and 1041 ppm. In contrast, the next most common type, group SC2 andesites, have higher Rb between 44 and 68 ppm, lower Sr between 712 and 750 ppm, higher Zr between 95 and 166 ppm, and generally higher Ba between 835 and 1104 ppm. These differences are illustrated in the triangular diagram plotting relative proportions of Sr, Zr and Ba (see Fig. 3a). The three individual samples of laja of different petrology described above, dacite SC-C1 and basalts SC-E1 and SC-11, also have different concentrations of these four trace elements both compared to each other and to the two most important types of laja in the cemetery (see Table 1).

The nine samples from the outcrops at Cerro Tovar are chemically identical to the type SC1 laja from the cemetery (see Table 1 and Fig. 3b), which confirms that Cerro Tovar is the probable source for this type of laja. The chemistry of the samples from Cerro Tovar did not match the chemistry of either the second of the two main groups of laja, group SC2, nor the three other laja types found in the cemetery. The sources for these other types of laja are still yet to be identified. The samples from the other potential source area at Casa Blanca differ chemically from any laja found in the cemetery, having significantly lower Sr and higher Ba (see Table 1 and Fig. 3b).

To better characterize chemically the main laja types from the cemetery and the volcanic rocks collected at Cerro Tovar and Casa Blanca, six samples were chosen for more complete ICP-MS analysis (see Table 2). Three samples typical of group SC1 laja, two from the cemetery (SC-02 and SC-03) and one from Cerro Tovar (T-02), have major-element compositions equivalent to mafic andesites. The analysis of a sample of type SC2 laja from the cemetery (SC-06) indicates that these rocks are andesites. One of the single samples of petrologically and chemically distinct laja (SC-11) has the com-

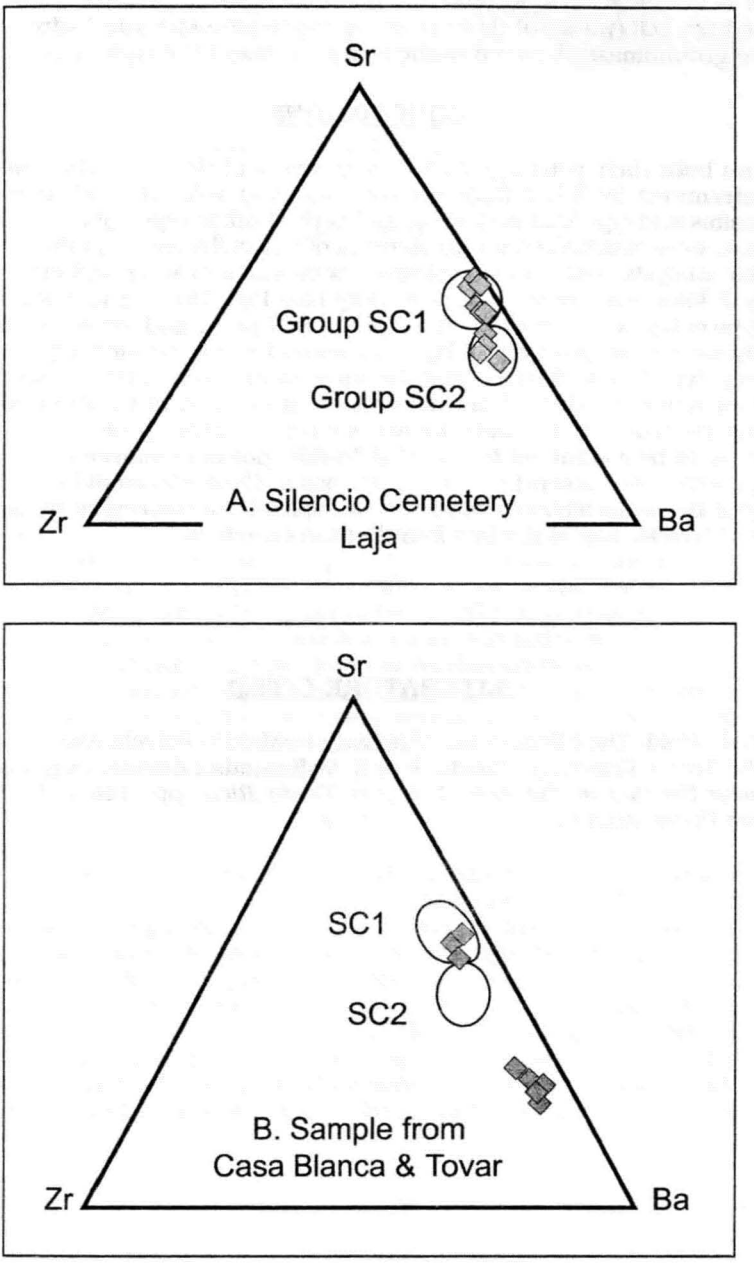

Fig. 3 *Triangular plots of the proportions of Sr, Zr and Ba in* ***(a)*** *samples of group SC1 mafic andesite and group SC2 andesite laja from the Silencio cemetery; and* ***(b)*** *samples of volcanic rocks from Tovar and Casa Blanca compared to the field for types SC1 and SC2 laja from the cemetery.*

position of a basalt. A sample from Casa Blanca (CB-02) has the composition of a dacite. The high LOI (water) of this sample is consistent with the hydrothermal alteration of the groundmass observed in the thin sections of the rocks from this locality.

CONCLUSIONS

Based on both their petrology and their contents of the trace-elements Rb, Sr, Zr and Ba determined by X-ray fluorescence, two main volcanic rock types, type SC1 mafic andesites and type SC2 andesites, and several other types of rocks with only one sample each, were established for 20 samples of laja collected from the Silencio cemetery. Similar analysis confirm that volcanic rocks which outcrop at Cerro Tovar, located roughly 7 kilometers west of the cemetery (see Fig. 1b), are identical to the most common type of laja within the cemetery, group SC1 mafic andesites, and that this site is the likely source for this type of laja. The second most common type of laja within the cemetery, type SC2 andesites, and the three other types of laja found in the cemetery in minor amounts, differ from the rocks that outcrop at Cerro Tovar, and these types of laja currently do not have known sources. Further geologic fieldwork in the area will have to be conducted in order to find the possible source outcrops for these laja. Samples from two potential source outcrops at Casa Blanca did not match, either chemically or petrologically, any of the laja samples from the cemetery and this is not a possible source for any of the laja found in the cemetery.

LITERATURE CITED

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