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NOTE

Along-arc variation of Sr-isotope composition in volcanic rocks from the Southern Andes (33°S-55°S)

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Strontium isotopic compositions were determined in thirty-two volcanic rock samples collected in thirteen volcanic centers of the 41°30′ – 46°S region of the Southern Volcanic Zone (SVZ) of the Andes. This region is just north of the Chilean triple junction, where the Chile Rise subducts under the South American plate. The along-arc variation of $^{87}Sr/^{86}Sr$ ratios of volcanic rocks from the SVZ (33°S-46°S) is complex and shows a wave-like pattern, which does not correlate either with the age pattern of the subducted Nazca plate or with the thickness of the continental crust. Furthermore, the variation of the Sr-isotope composition in along-arc direction does not seem to correspond to those of other geochemical parameters examined up to now of SVZ rocks. We interpret this Sr-isotopic variation in terms of either locally different crust-magma interactions or heterogeneities in the mantle wedge. Effects of subduction of the Chile Rise on the $^{87}Sr/^{86}Sr$ ratios are not obvious.

INTRODUCTION

Active volcanism occurs parallel to the Peru-Chile Trench in central and southern Chile (33° S-55°S). This volcanic arc consists of two distinct volcanic zones, the Southern Volcanic Zone (SVZ; 33°S-46°S) and Austral Volcanic Zone (AVZ; 49°S-55°S) of the Andes (Stern *et al.*, 1984a). While the SVZ is related to the subduction of the Nazca plate under the South American plate, the AVZ is associated with subduction of the Antarctic plate beneath the South American plate. The Chile Rise, which subducts between latitudes 46°S and 48°S, separates the Nazca and Antarctic plates, forming a triple junction. The plate-tectonic setting off the Chilean coast and the distribution of the Quaternary volcanoes are shown in the inset of Fig. 1.

Along the strike of the SVZ, the thickness of the continental crust under the volcanoes decreases southward from about 50km at latitude 33°S to about 30km at 46°S (Lomnitz, 1962; Cummings and Shiller, 1971). The age of the Nazca plate at the Peru-Chile Trench axis also decreases in the same direction from about 50Ma at 33°S to 0Ma at 46°S (Herron, 1981; Herron *et al.*, 1981). In this context, geochemical studies, particularly Sr-isotope studies, of SVZ lavas are important in evaluating the effects of varying age of the subducted slab and the thickness of the continental crust. The easy access to volcanoes located between 36°S and 41°30′S has determined, in part, that most Sr-isotope studies have been carried out in Quaternary volcanic rocks in this region. Less abundant are data from the region south of 41°30′S, where either access or climatic conditions or both are important handicaps. Recently, Stern *et al.* (1984b) reported Sr-isotope data of some volcanic rocks from three volcanoes located between 45°S and 46°S.

In this paper, we present Sr-isotope compositions of volcanic rocks from volcanoes of the

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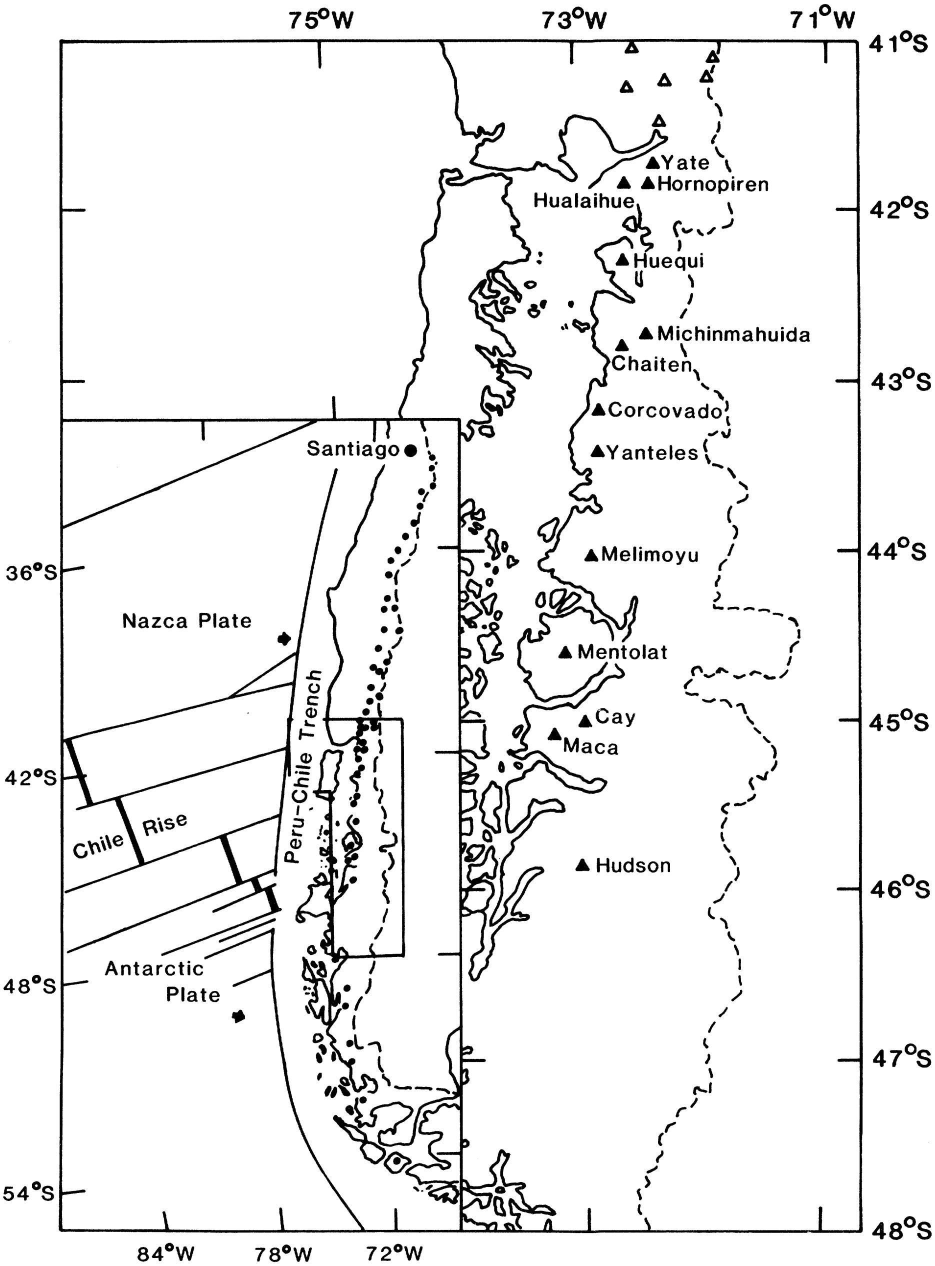

Fig. 1. Map of southern part (41° S-46° S) of the Southern Volcanic Zone (SVZ) of the Andes, showing the major volcanic centers as triangles. Volcanoes investigated in this work are indicated as solid triangles. Inset shows map location, major volcanic centers of the SVZ and AVZ (Austral Volcanic Zone) as solid circles and plate-tectonic settings (after Herron, 1981 and Herron et al., 1981).

41° 30′ S-46° S region. Our aim is to discuss the variation of the $^{87}Sr/^{86}Sr$ ratios of volcanic rocks along the strike of the SVZ of the Andes. We also discuss the effect of the subduction of the Chile Rise by comparing the ratios of volcanic rocks from the AZV with those from the SZV the Andes.

SAMPLES

We collected thirty-two volcanic rock samples from thirteen volcanic centers of the 41°30′S-46°S region using a helicopter, under a program of the Japan-Chile joint expedition on the Southern Andes Volcanic Belt. Locations of volcanic centers investigated in this work are shown in Fig. 1.

EXPERIMENTAL AND RESULTS

We determined $^{87}Sr/^{86}Sr$ ratios of volcanic rock samples using a VG-Micromass MM-30 double collector type mass spectrometer at Chemical Analysis Center of University of Tsukuba. The measured $^{87}Sr/^{86}Sr$ ratio of NBS 987 was 0.71030 ± 0.00003. The uncertainty in the Sr-isotope determinations, estimated from replicated analyses of the same sample, was less than 0.00005. Concentrations of Rb and Sr were obtained by X-ray fluorescence spectrometry. The uncertainties in the Rb and Sr determinations were less than 2ppm and 10ppm, respectively. Details of the analytical procedures are found in Notsu (1983). We also determined SiO_2 contents by conventional wet chemical analysis.

The analytical results are listed in Table 1. The $^{87}Sr/^{86}Sr$ ratios of volcanic rocks analyzed in this work are in the range between 0.70400 and 0.70488, except one rhyolite sample from Chaiten volcano (0.70576). For Cay, Maca and Hudson volcanoes, our new results are consistent with those of Stern *et al.* (1984b).

DISCUSSION

Table 1 shows that rocks from a given volcano, independently of their SiO_2 contents, have similar $^{87}Sr/^{86}Sr$ ratios. In the case of Mentolat volcano, for example, five volcanic rock samples with different SiO_2 contents of 53.29 to 63.02% have nearly constant $^{87}Sr/^{86}Sr$ ratios (0.70425-0.70440). The largest difference (0.00033) is observed in the Yanteles volcanic rocks. The result that rocks from a given volcano have relatively similar Sr-isotope compositions has also been obtained further north, between latitudes 36°S and 42°S (Deruelle *et al.*, 1983; Lopez-Escobar, 1984; Hickey *et al.*, 1986), and enables evaluation of regional variations in the whole region of the SVZ of the Andes.

In Fig. 2, our data and other published data (Klerkx *et al.*, 1977; Hildreth *et al.*, 1981; Deruelle *et al.*, 1983; Lopez-Escobar, 1984; Harmon *et al.*, 1984; Stern *et al.*, 1984a, 1984b; Lopez-Escobar *et al.*, 1985; Hickey *et al.*, 1986) are plotted versus the latitude. The detailed behavior of the $^{87}Sr/^{86}Sr$ ratios along the strike of the Andean SVZ is complex. A wave-like pattern with two maximums (at 33-34°S and 42-43°S) and two minimums (at 37°S and 45°S) seems to be observed, although Hualaihue volcano (41°53′S) yields a basalt, whose low $^{87}Sr/^{86}Sr$ ratio is distinctly apart from the wave-like trend of the ratios. South of 45°S, the $^{87}Sr/^{86}Sr$ ratios seem to increase across the volcanic gap at 46°S-49°S, where the Chile Rise intersects the continent, reaching the maximum value at 49°S -50°30′S in the AVZ (0.70495-0.70541; Stern *et al.*, 1984a). In the AVZ, the ratios decrease from north to south and the minimum ratio (0.70268-0.70280) occurs at Cook Islands of 54°S (Stern *et al.*, 1984a). In other wards, effects of the subduction of the Chile Rise on the $^{87}Sr/^{86}Sr$ ratios are not obvious.

Although crustal contamination seems to play an important role in the northernmost part of the SVZ (33°S-36°S) (Hildreth *et al.*, 1984; Lopez-Escobar, 1984; Stern *et al.*, 1984b; Lopez-Escobar *et al.*, 1985), this contribution is small south of 37°S. However, the relatively high $^{87}Sr/^{86}Sr$ ratio of Chaiten rhyolite may reflect a high degree of crustal component in its genesis. It is possible that this rhyolite has been generated by remelting of local crustal material having a relatively high $^{87}Sr/^{86}Sr$ ratio.

Apparently the thickness of the crust decreases steadily southward in the SVZ (Lomnitz, 1962; Cummings and Shiller, 1971; Lowrie and Hey, 1981). The volcanoes on the 33-34°S region where the crust is thickest have lavas with higher $^{87}Sr/^{86}Sr$ ratios than other volcanoes.

Table 1. Analytical results

Volcano (Lat.) Rock type Sample No.	SiO_2 (%)	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Yate (41° 48′ S)					
YAT-001 Andesite	60.81	52	390	0.388	0.70443
Hornopiren (41° 53′ S)					
HOR-001 Basaltic andesite	53.05	20	424	0.137	0.70440
Hualaihue (41° 53′ S)					
HUA-001 Basalt	51.42	8	504	0.046	0.70401
Huequi (42° 23′ S)					
HUE-001 Andesite	58.66	19	422	0.131	0.70488
HUE-002 Andesite	56.33	19	412	0.134	0.70481
Michinmahuida (42° 48′ S)					
MIC-001 Basalt	51.88	30	386	0.226	0.70446
MIC-002 Andesite	60.88	67	317	0.615	0.70444
Chaiten (42° 50′ S)					
CHA-001 Rhyolite	74.44	123	154	2.325	0.70576
Corcovado (43° 11′ S)					
COR-001 Andesite	56.38	33	354	0.271	0.70462
COR-002 Basaltic andesite	52.74	19	422	0.131	0.70436
COR-003 Basalt	51.68	14	415	0.098	0.70446
Yanteles (43° 28′ S)					
YAN-001 Andesite	57.46	27	376	0.209	0.70461
YAN-002 Basaltic andesite	54.57	15	424	0.103	0.70428
Melimoyu (44° 04′ S)					
MEL-001 Andesite	56.84	48	417	0.335	0.70426
MEL-002 Basaltic andesite	53.29	35	494	0.206	0.70423
MEL-003 Basaltic andesite	53.44	40	488	0.239	0.70430
Mentolat (44° 42′ S)					
MEN-001 Andesite	59.16	25	380	0.192	0.70437
MEN-002 Andesite	59.78	19	421	0.131	0.70440
MEN-003 Basaltic andesite	53.29	11	451	0.071	0.70425
MEN-004 Dacite	63.02	27	392	0.201	0.70437
MEN-005 Andesite	60.55	19	419	0.132	0.70426
Cay (45° 04′ S)					
CAY-001 Basalt	49.71	12	611	0.057	0.70409
CAY-002 Basalt	50.47	15	604	0.072	0.70408
CAY-003 Basalt	51.23	14	610	0.067	0.70401
CAY-004 Basalt	48.96	11	603	0.053	0.70400
CAY-005 Basalt	50.77	9	578	0.045	0.70422
Maca (45° 06′ S)					
MAC-001 Basaltic andesite	54.72	28	491	0.166	0.70414
MAC-002 Basaltic andesite	53.50	30	440	0.198	0.70428
MAC-003 Basaltic andesite	55.32	32	429	0.217	0.70437
MAC-004 Basalt	50.36	11	591	0.054	0.70423
Hudson (45° 55′ S)					
HUD-001 Basalt	51.90	23	547	0.122	0.70430
HUD-003 Basalt	50.82	26	498	0.152	0.70424

However, the wave-like Sr-isotope variation of volcanic rocks along the strike of the SVZ does not match the monotonous decreasing trend of the crustal thickness. Therefore, if the continental crust affects the $^{87}Sr/^{86}Sr$ ratios of the SVZ magmas, either its thickness should have points of maximum and minimum, not detected yet by the scarce gravimetric studies, or there exist areas where crust-magma interaction is more intense, favoring the enrichment of sub-crustal derived magma in radiogenic strontium.

As arc magmas involve slab-derived components through fluids released from the slab (Arculus and Powell, 1986), the differences in slab-mantle wedge interaction shall cause chemical and isotopic variation in arc magmas. However, the Sr-isotope pattern of volcanic rocks from the Andean SVZ does not match the age pattern of the subducted Nazca plate (Herron, 1981, Herron *et al.*, 1981). This

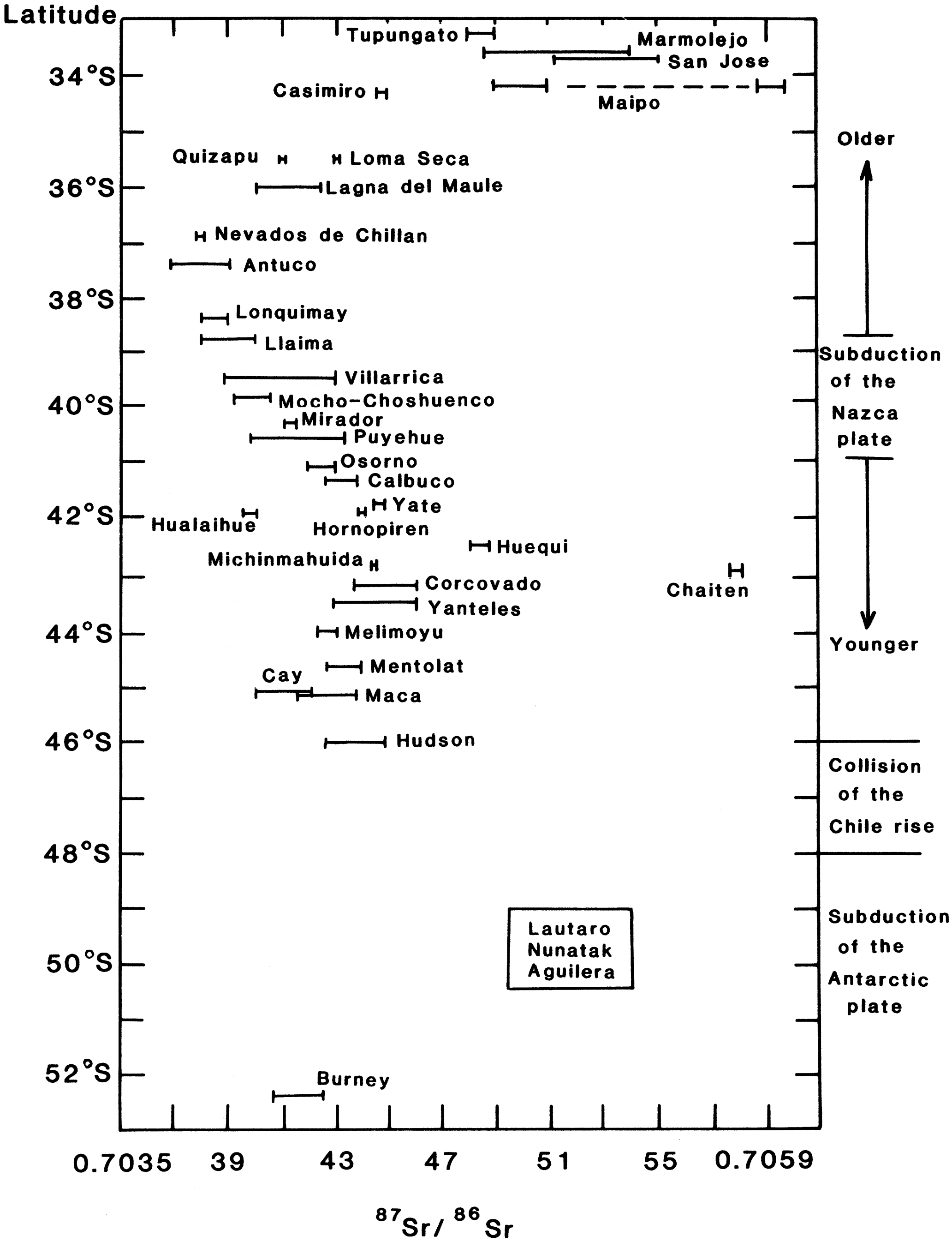

Fig. 2. Along-arc variarion of $^{87}Sr/^{86}Sr$ ratios in volcanic rocks from the Southern Volcanic Zone (SVZ) and Austral Volcanic Zone (AVZ) of the Andes. Data sources are shown in the text.

suggests that either the aging effect of the subducted plate or the duration of slab-mantle wedge interaction does not play a key role in controlling the Sr-isotope characteristics of the SVZ magmas.

Geochemical variations in volcanic rocks from the SVZ, primarily north of 42°S, have already been summarized by Deruelle *et al.*

(1983), Lopez-Escobar (1984), Hickey *et al.* (1984, 1986), Stern *et al.* (1984b), Harmon *et al.* (1984) and Onuma and Lopez-Escobar (1987). Hickey *et al.* (1986) grouped the SVZ volcanoes (34°S-41°S) into two types based on geochemical difference of volcanic rocks and showed that $^{87}Sr/^{86}Sr$ ratios of the two types of volcanic rocks overlap extensively. No elemental parameter of volcanic rocks exhibits the wave-like variation similar to Sr-isotope composition along the strike of the SVZ. The $^{143}Nd/^{144}Nd$ ratios of volcanic rocks from 34-36°S region (0.51269-0.51278) are distinctly lower than those from 37-41°S (0.51281-0.51289) (Hickey *et al.*, 1986), and there seems no wave-like variation of $^{143}Nd/^{144}Nd$ ratios of volcanic rocks from 34°S to 41°S. As to $\delta^{18}O$ values of volcanic rocks (Deruelle *et al.*, 1983; Stern *et al.*, 1984b), the wave-like variation corresponding to the Sr-isotope variation does not seem to be observed. Recently, Onuma and Lopez-Escobar (1987) showed the regular variation of the degree of partial melting to generate primary magmas, based on the Sr/Ca-Ba/Ca systematics of volcanic rocks, in the along-arc direction between 33°S and 46°S. However, there seems no correlation between the $^{87}Sr/^{86}Sr$ ratios of volcanic rocks and the degrees of partial melting of their primary magmas. These elemental and isotopic features imply that locally different processes that take place in the upper mantle or crust are responsible for the along-arc variation of Sr-isotope composition in volcanic rocks. In addition, isotopic heterogeneity in the mantle wedge may, in part, superimpose these processes to form the complicated Sr-isotope pattern.

Conclusion

The behavior of the $^{87}Sr/^{86}Sr$ ratio in volcanic rocks along the SVZ of the Andes (33°S -46°S) is complex. The overall along-arc variation of this ratio seems to exhibit a wave-like pattern with maximums at 33-34°S and 42 -43°S, minimums at 37°S and 45°S. No discontinuous variation is observed across the 46°S -49°S region, where the Chile Rise intersects the continent. This Sr-isotope pattern does not match either the age pattern of the subducted Nazca plate nor the thickness pattern of the continental crust. The along-arc variation of Sr-isotope composition does not seem to correspond to those of other geochemical parameters of volcanic rocks of the SVZ. We interpret this in terms of either locally different nature of crust-magma interaction or heterogeneous nature of the mantle wedge beneath the SVZ of the Andes.

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