Composition and Fractionation of Antuco Magma, Southern Chile

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Abstract

Lavas from the Quaternary Antuco volcano in southern Chile are petrographically composed of an olivine basalt to an andesite, and are petrochemically composed of a quartz-normative calc-alkaline rock. The composition of lavas changes toward subsilicic during the volcanic activity. The compositional variation from the andesites of earlier stage through the basaltic andesites of middle stage to the olivine basalts of later stage dues to mainly fractionation of magnesian olivine and calcic plagioclase in a basaltic magma.

Introduction

The calc-alkaline rock series is developed in the Andean continental margin, South America (*e.g.*, HYNDMAN, 1985). The Antuco volcano is a Quaternary stratovolcano located in the Meridional Andes, southern Chile. Petrological studies of the volcano have been reported by VERGARA and KATSUI (1969), DERUELLE (1982), and YAMAMOTO *et al.* (1994). However, there are little petrochemical data of volcanic rocks. In this study, bulk composition of Antuco lavas will be given and fractionation of Antuco magma will be discussed.

Geology

The Antuco volcano is a Quaternary stratovolcano located in the Meridional Andes in southern Chile. A geologic map compiled from the field work and the aerial photographs is shown in Fig. 1. The volcano is composed of some lavas and pyroclastic flows. These volcanic rocks cover the Miocene to Pliocene volcanic and volcani-sedimentary rocks (NISHIDO *et al.*, 1994a) and the Miocene granitic intrusive rocks (NISHIDO *et al.*, 1994b).

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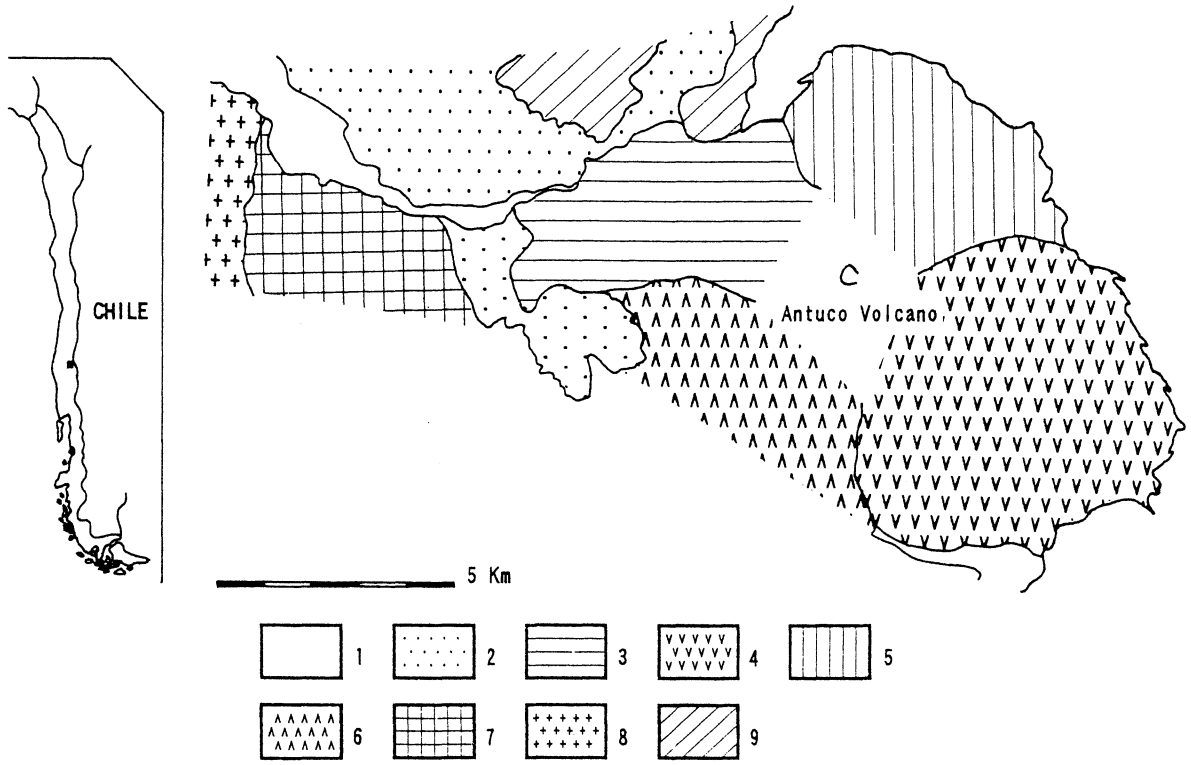

Fig. 1. Index and geologic maps of the Antuco volcano.
Stratigraphic sequences: 1. Alluvial deposits; 2. Pyroclastic flows; 3-7. Antuco lavas (3. Lava-1, 4. Lava-2, 5. Lava-3, 6. Lava-4, 7. Lava-5); 8. Miocene granitic rocks; 9. Neogene volcanics.

Table 1. Lava samples collected from the Antuco volcano

No.	Sp. No.	Latitude (S)	Longitude (W)	Altitude (m)	Rock	Remarks
				(a) Lava-5		
1	91B2401	37° 22' 57"	71° 23' 03"	1375	Olivine Basalt	
2	91B2402	37° 22' 54"	71° 23' 30"	1255	Olivine Basalt	
3	91B2403	37° 23' 35"	71° 25' 24"	1070	Olivine Basalt	
4	9210604	37° 22' 36"	71° 21' 50"	1410	Olivine Basalt	
5	9210610	37° 22' 37"	71° 22' 28"	1410	Olivine Basalt	
6	9210603	37° 22' 32"	71° 21' 46"	1400	Olivine Basalt	
				(b) Lava-3		
7	9210601	37° 22' 00"	71° 20' 36"	1410	Basaltic Andesite	
8	9210602A	37° 22' 02"	71° 21' 04"	1390	Basaltic Andesite	
9	9210602B	37° 22' 02"	71° 21' 04"	1390	Basaltic Andesite	
				(c) Lava-1		
10	91B2404	37° 23' 34"	71° 27' 02"	940	Andesite	Rich in Xenoliths
11	9210705	37° 23' 34"	71° 27' 14"	940	Andesite	Rich in Xenoliths
12	9210706	37° 23' 34"	71° 27' 14"	940	Andesite	

Twelve lava samples collected from the northwestern mountainside of Antuco volcano are listed in Table 1. They can be stratigraphically included into three groups shown in Fig. 1: Lava-1, Lava-3 and Lava-5 in ascending order. The Lava-1 of earlier stage is distributed in the westernmost of volcano. The Lava-3 of middle stage is distributed in the northern mountainside of volcano. The Lava-5 of later stage is distributed in the northwestern mountainside of volcano.

K-Ar age determination was carried out for two specimens, Nos. 9210705 and 91B2404, in the Lava-1. However, the age could not be obtained in both samples, because the amount of ^{40}Ar was too low.

Petrography

The lava samples from the Antuco volcano were petrographically studied by YAMAMOTO *et al.* (1994).

1. Andesite in the Lava-1

The andesite in the Lava-1 of earlier stage occurs as a dark-colored lava with flow structure. It is composed of a small amount of plagioclase phenocryst, minor amounts of microphenocrysts of olivine, orthopyroxene and clinopyroxene, and a hyalopilitic to intersertal groundmass. Olivine occurs rarely as a pseudomorph. Clinopyroxene exceeds orthopyroxene in amount. A glomeroporphyritic aggregate of plagioclase, clinopyroxene and orthopyroxene grains is rarely found. The groundmass is composed of microlites of plagioclase, clinopyroxene and orthopyroxene and a large amount of slightly devitrified volcanic glass. Large amounts of basalt fragments are included in the specimens Nos. 91B2404 and 9110705.

2. Basaltic Andesite in the Lava-3

The basaltic andesite in the Lava-3 of middle stage occurs as a dark-colored dense lava. It is composed of large amounts of phenocrysts of plagioclase, olivine and clinopyroxene, a small amount of orthopyroxene microphenocryst, and an intersertal to intergranular groundmass. Olivine exceeds commonly clinopyroxene in amount. In the specimen No. 9210602B, olivine is strongly altered to an assemblage of serpentine, chlorite, green mica and iddingsite, and is rimmed by clinopyroxene grains. A glomeroporphyritic aggregate of plagioclase and olivine grains is commonly found, and that of clinopyroxene grains is rarely found. The groundmass is composed of microlites of plagioclase, clinopyroxene and orthopyroxene and a subordinate to relative amount of slightly devitrified volcanic glass.

3. Olivine Basalt in the Lava-5

The olivine basalt in the Lava-5 of later stage occurs as a dark-colored porous block lava.

Commonly, the olivine basalt is composed of large amounts of phenocrysts of

plagioclase and olivine, a small amount of orthopyroxene microphenocryst, and an intersertal groundmass. Phenocrystic clinopyroxene can be scarcely found in almost all samples, but is rarely found in the specimen No. 9210604 as a microphenocryst. Plagioclase phenocrysts consist of both fresh grains and sieve textured ones. The groundmass is composed of microlites of plagioclase, clinopyroxene and orthopyroxene and a subordinate to relative amount of slightly devitrified volcanic glass.

Only the olivine basalt of specimen No. 9210603 is composed of small amounts of phenocrysts of plagioclase and olivine and of microphenocrysts of orthopyroxene and clinopyroxene, and a hyalopilitic groundmass. Cloudy plagioclase phenocryst is rarely found. The groundmass is composed of microlites of plagioclase, clinopyroxene and orthopyroxene and a large amount of slightly devitrified volcanic glass.

Bulk Composition

The lava samples from the Antuco volcano were chemically analyzed by the XRF method. Chemical compositions and CIPW norms are listed in Table 1, and the variation diagram is shown in Fig. 2.

The SiO_2 content of rocks from the Lava-1 of earlier stage ranges from 55 wt.% to 60 wt.%, and they are compositionally basaltic andesitic to andesitic. The SiO_2 content of rocks from the Lava-3 of middle stage ranges from 52 wt.% to 55 wt.%, and they are compositionally basaltic andesitic. The SiO_2 content of rocks from the Lava-5 of later stage ranges from 50 wt.% to 53 wt.%, and they are compositionally basaltic to basaltic andesitic. As mentioned above, the SiO_2 content of analyzed lavas decreases during the volcanic activity.

In the norms, almost all analyzed lavas are of quartz normative, but only the olivine basalt No. 91B2401 having the most subsilicic composition is of hypersthene normative. Normative C is not calculated in all analyzed lavas, and they are of metaluminous.

In Fig. 2, the amounts of MnO, Na_2O, K_2O and P_2O_5 vary regularly, but those of TiO_2, Al_2O_3, total FeO, MgO and CaO vary irregularly. Especially, compositional gaps in Al_2O_3, total FeO, MgO and CaO can be seen around 53 wt.% in SiO_2.

Figure 3 shows the FAM diagram of lavas from the Antuco volcano. In Fig. 3, a solid line represents the boundary curve between calc-alkaline and tholeiitic series reported by IRVINE and BARAGAR (1971). The analyzed lavas are plotted in the field of calc-alkaline suite.

Figure 4 shows also the relation between SiO_2 and Na_2O+K_2O of lavas from the Antuco volcano. In Fig. 4, solid lines represent the boundary curves between alkali olivine basalt, high-alumina basalt and tholeiitic series reported by KUNO (1966). The analyzed lavas are plotted in the field of high-alumina basalt.

Table 2. Chemical analyses and CIPW norms of lavas from the Antuco volcano

No.	1	2	3	4	5	6	7	8	9	10	11	12
Sp. No.	91B2401	91B2402	91B2403	9210604	9210610	9210603	9210601	9210602A	9210602B	91B2404	9210705	9210706
SiO_2	50.84	52.19	51.81	52.08	52.55	51.99	52.96	54.76	54.15	55.56	59.61	55.52
TiO_2	1.00	1.06	1.01	1.07	1.07	1.01	1.13	1.48	1.46	1.57	1.36	1.58
Al_2O_3	16.75	18.58	18.25	17.92	18.76	17.20	19.15	16.43	16.74	16.11	15.75	16.21
Fe_2O_3	3.60	3.68	3.69	3.56	3.39	3.67	3.28	4.09	3.82	4.48	2.11	2.91
FeO	5.92	4.50	4.62	4.90	4.68	4.99	4.78	5.75	5.90	5.36	5.85	6.82
MnO	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.17	0.17	0.17	0.16	0.17
MgO	8.65	5.18	5.94	5.50	4.96	7.07	3.61	3.70	3.74	3.18	2.15	3.24
CaO	8.61	9.75	9.59	9.76	9.56	8.87	9.30	7.59	7.87	6.96	5.35	7.03
Na_2O	3.17	3.41	3.34	3.39	3.60	3.27	3.71	4.08	4.15	4.37	4.80	4.42
K_2O	0.68	0.74	0.71	0.74	0.74	0.83	0.76	1.00	0.97	1.21	1.73	1.20
H_2O^+	0.18	0.24	0.25	0.19	0.21	0.22	0.36	0.13	0.12	0.13	0.33	0.14
H_2O^-	0.09	0.07	0.07	0.07	0.05	0.09	0.13	0.09	0.09	0.07	0.07	0.08
P_2O_5	0.18	0.19	0.18	0.18	0.20	0.18	0.18	0.24	0.23	0.29	0.35	0.29
Total	99.82	99.73	99.60	99.50	99.91	99.53	99.49	99.51	99.41	99.46	99.62	99.61
Q	–	2.75	1.89	2.25	2.37	1.41	4.14	6.50	4.85	7.47	9.89	5.20
Or	4.02	4.37	4.20	4.37	4.37	4.91	4.49	5.91	5.73	7.15	10.22	7.09
Ab	26.82	28.86	28.26	28.69	30.46	27.67	31.39	34.53	35.12	36.98	40.62	37.40
An	29.47	33.21	32.71	31.50	32.85	29.80	33.36	23.56	24.19	20.77	16.32	20.85
Di	9.65	11.12	10.92	12.63	10.65	10.39	9.40	10.17	10.87	9.59	6.62	10.03
Wo	5.04	5.81	5.72	6.58	5.54	5.44	4.85	5.23	5.58	4.95	3.31	5.07
En	3.54	4.12	4.09	4.54	3.79	3.90	3.04	3.19	3.31	3.12	1.43	2.52
Fs	1.07	1.19	1.11	1.51	1.32	1.05	1.51	1.75	1.98	1.52	1.88	2.44
Hy	18.49	11.32	13.61	12.20	11.53	17.39	8.90	9.33	9.61	7.14	9.09	10.93
En	14.19	8.78	10.70	9.16	8.56	13.71	5.95	6.03	6.01	4.80	3.92	5.55
Fs	4.30	2.54	2.91	3.04	2.97	3.68	2.95	3.30	3.60	2.34	5.17	5.38
Ol	3.56	–	–	–	–	–	–	–	–	–	–	–
Fo	2.67	–	–	–	–	–	–	–	–	–	–	–
Fa	0.89	–	–	–	–	–	–	–	–	–	–	–
Il	1.90	2.01	1.92	2.03	2.03	1.92	2.15	2.81	2.77	2.98	2.58	3.00
Mt	5.22	5.34	5.35	5.16	4.92	5.32	4.76	5.93	5.54	6.50	3.06	4.22
Ap	0.42	0.44	0.42	0.42	0.46	0.42	0.42	0.56	0.53	0.67	0.81	0.67

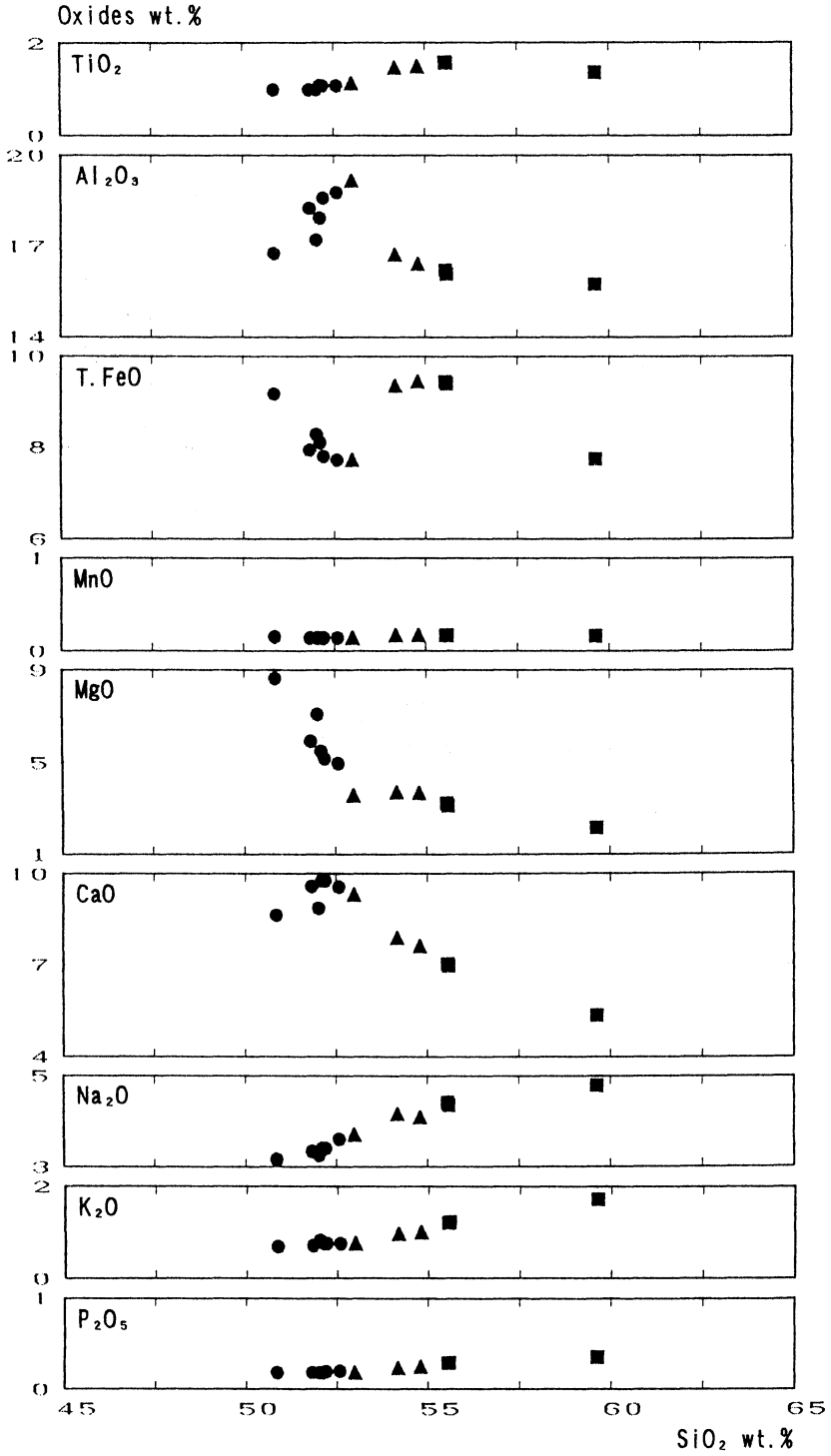

Fig. 2. Variation diagram of lavas from the Antuco volcano. Squares: Lava-1, Triangles: Lava-3, Circles: Lava-5.

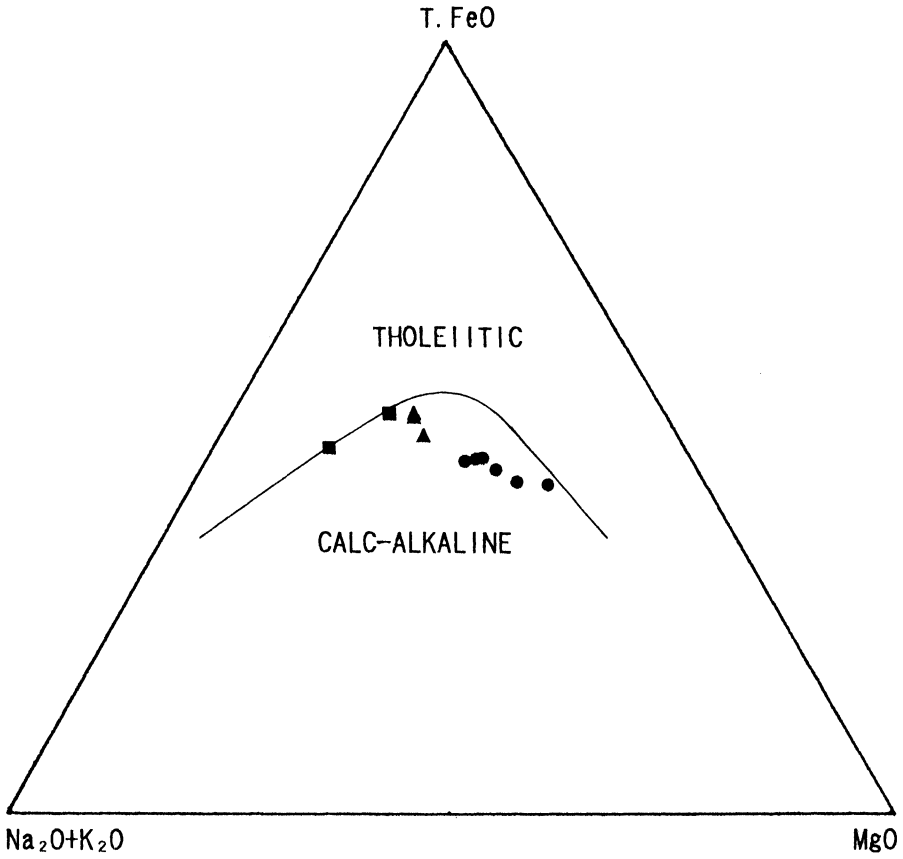

Fig. 3. FAM diagram of lavas from the Antuco volcano.
The symbols are the same as in Fig. 2.

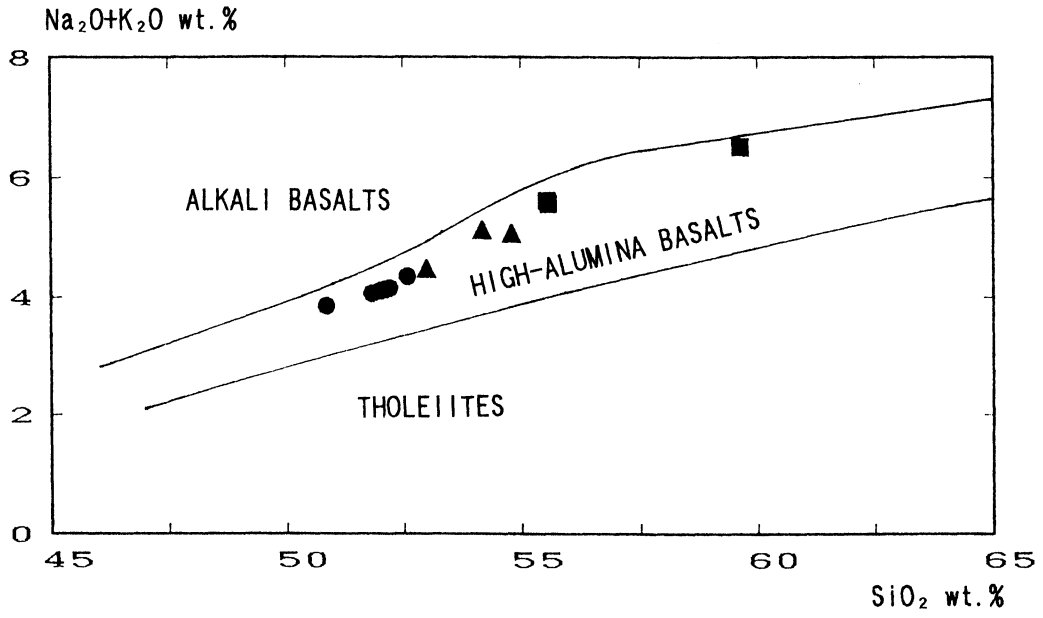

Fig. 4. Relation between SiO_2 and Na_2O+K_2O of lavas from the Antuco volcano.
The symbols are the same as in Fig. 2.

Fractionation of Antuco Magma

The olivine basalts in the Lava-5 of later stage are different in composition from the MORB (SCHILLING *et al.*, 1983) and the average basalt of Andes (EWART, 1982). They can be chemically divided into two types: one is a rock rich in MgO and total FeO and the other is a rock rich in CaO and Al_2O_3 (Fig. 2). They contain commonly large amounts of olivine and plagioclase and small amounts of pyroxenes. This mode of occurrence indicates that the rock rich in MgO and total FeO is a rock rich in olivine and the rock rich in CaO and Al_2O_3 is a rock rich in calcic plagioclase.

The compositional gaps in Al_2O_3, total FeO, MgO and CaO can be seen between the olivine basalts in the Lava-5 of later stage and the basaltic andesites in the Lava-3 of middle stage (Fig. 2). The olivine basalts are rich in MgO, CaO and Al_2O_3 and poor in total FeO, as compared to the basaltic andesites. These compositional gaps indicate that the olivine basalts were formed by fractionation of both magnesian olivine and calcic plagioclase in a basaltic magma.

The basaltic andesites in the Lava-3 of middle stage contain large amounts of phenocrysts of plagioclase, olivine and clinopyroxene. On the other hand, the andesites in the Lava-1 of earlier stage contain a small amount of plagioclase phenocryst. The amounts of phenocryst and microphenocryst decrease from the basaltic andesites to the andesites. Such modes of occurrence suggest that the andesites rich in SiO_2 may be of a residual liquid after fractionation.

Some andesites in the Lava-1 of earlier stage contain a large amount of basalt xenolith. However, they are similar in composition to the basaltic andesites. These facts indicate that the basalt xenolith is a cognate, and suggest that mixing did not take place between a basaltic magma and a residual liquid.

There is no evidence for contamination by crustal materials in all lavas from the Antuco volcano.

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