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Evolution of Neogene Volcano-Plutonism in Antuco, Southern Chile

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Abstract

Volcanic and granitic rocks of Neogene age are developed in Antuco, southern Chile. The volcanic rocks are composed of an olivine basalt to an andesite. The granitic rock is composed of an I-type granodiorite. The volcanic rocks of pre-granite contain tholeiites in composition, and the K-Ar age indicates that they were formed during the Middle Miocene time (12.2±3.9 Ma). The whole rock K-Ar age indicates that the granitic rock was emplaced in the epizone during Late Miocene time (11.4 ±0.8 Ma). The volcanic rocks of post-granite contain mainly calc-alkaline rocks, and the K-Ar age indicates that they were formed during mainly Pliocene time (6.6± 0.5 Ma to 4.0 ± 0.4 Ma). The calc-alkaline basaltic rocks of post-granite are compositionally similar to the Recent Antuco lavas.

Introduction

Volcanic and volcani-sedimentary sequences of Neogene age are widely developed and granitic intrusive bodies of Neogene age are zonally distributed in the coastal area of western side of Andes in Chile (*e.g.*, AGUIRRE, 1983). Studies on these rocks are important to know historical evolution of volcanic and plutonic activities in Andes ranging in age from Tertiary to Recent. The present paper presents the results of petrographical, petrochemical and K-Ar dating studies of volcanic and granitic rock samples collected from outcrops in the Antuco area, southern Chile.

Geology

Volcanic and granitic rocks of Neogene age are widely distributed in the Antuco area,

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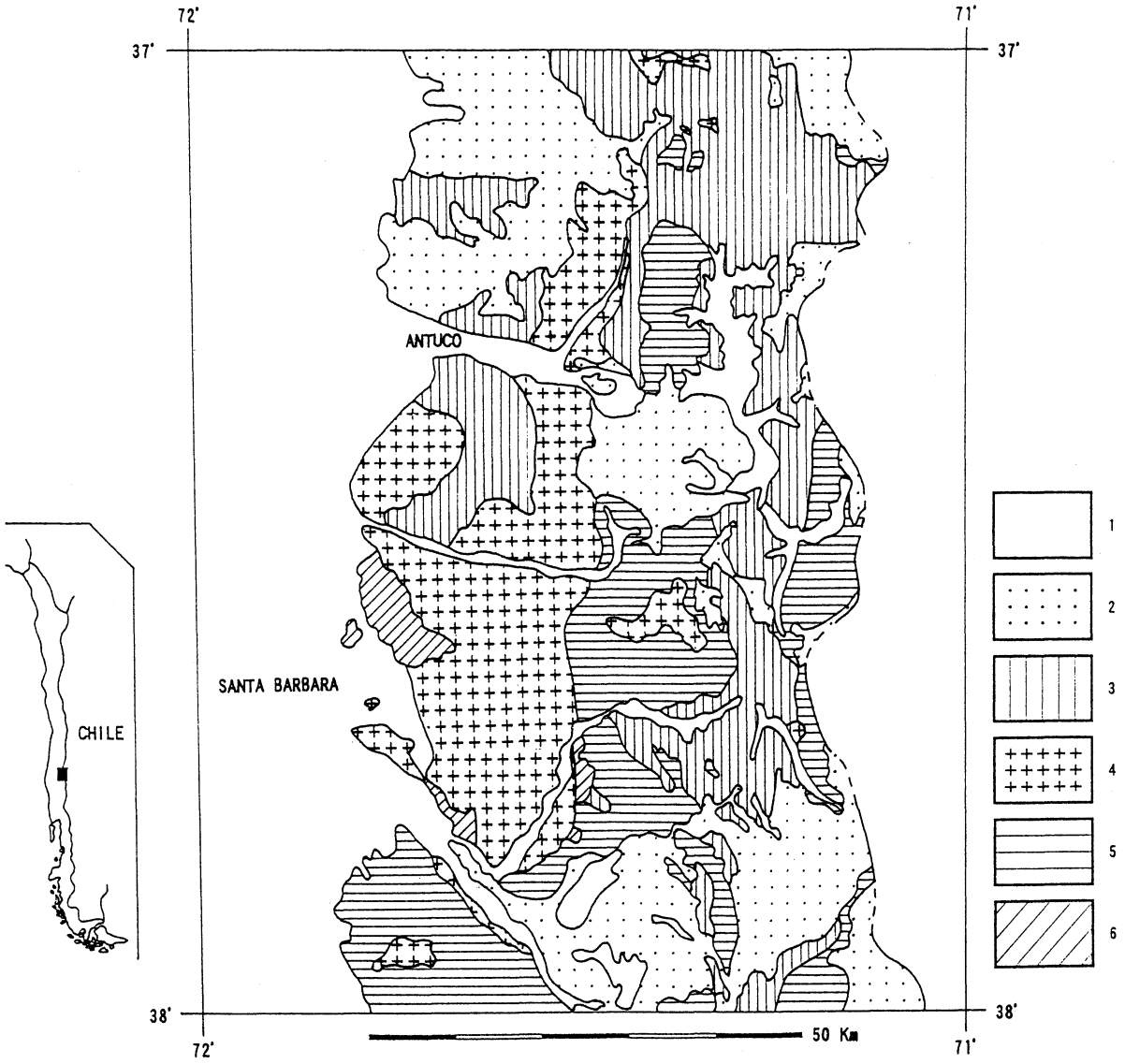

Fig. 1. Index and geologic maps of the Antuco area.
The geologic map is compiled from Instituto de Investigaciones Geologicas (1980a, b). Stratigraphic sequences: 1. Alluvial deposits, 2. Quaternary volcanics, 3. Pliocene volcanics, 4. Miocene granitic intrusives, 5. Miocene volcanics, 6. Cretaceous to Paleogene strata.

southern Chile. A geologic map compiled from Instituto de Investigaciones Geologicas (1980a, b) is shown in Fig. 1. Volcanic rocks in this area are mainly composed of altered lava flows and altered pyroclastic rocks with intercalated sedimentary rocks, and can be stratigraphically divided into two formations: one formation is unconformably underlain by the Cretaceous to Paleogene terruginous strata and intruded by the Miocene granitic intrusives (NISHIDO *et al.*, 1994a, b); and the other formation covers pre-granite strata and the granitic intrusives and is unconformably overlain by the Quaternary volcanics (NISHIDO *et al.*, 1994a, b; YAMAMOTO *et al.*, 1994). There are also many dikes which intrude

the formation of pre-granite in this area. The granitic intrusive body is batholithic in shape.

The rock samples collected from outcrops in the Antuco area are listed in Table 1. Two rock samples of lavas were collected from the formation of pre-granite, and four rock samples of lavas and welded tuff were collected from the formation of post-granite. Additionally, one rock sample was collected from a dike intruding the formation of pre-granite, and one granite sample was collected from an outcrop near El Abanico, 15 kilometers east of Antuco.

Table 1. Rock samples collected from the Neogene rocks in the Antuco area

No.	Sp. No.	Latitude (S)	Longitude (W)	Altitude (m)	Rock	Remarks
			(a) Volcanic Rocks of Post-Granite			
1	9210703	37° 22' 45"	71° 22' 38"	1410	Welded Tuff	
2	9210608	37° 22' 32"	71° 22' 24"	1410	Altered Andesite	Dike
3	9210701	37° 22' 32"	71° 22' 26"	1410	Olivine Basalt	Lava
4	9210607	37° 22' 29"	71° 22' 22"	1410	Olivine Basalt	Lava
5	9210609	37° 22' 34"	71° 22' 28"	1410	Andesite	Lava
			(b) Granitic Rock			
6	9210707	37° 22' 10"	71° 29' 25"	830	Granodiorite	Intrusion
			(c) Volcanic Rocks of Pre-Granite			
7	9210708	37° 20' 18"	71° 36' 14"	700	Olivine Basalt	Lava
8	9210709	37° 20' 18"	71° 36' 14"	700	Olivine Basalt	Lava

Petrography

1. Volcanic Rocks of Pre-Granite

The rock samples collected from the formation of pre-granite include an olivine basalt.

The olivine basalt is a pale greenish dark-colored rock, and is composed of large amounts of olivine, plagioclase and clinopyroxene, a small amount of orthopyroxene, and an intersertal groundmass. Olivine is mostly altered to an assemblage of serpentine, chlorite and iddingsite. Clinopyroxene is commonly crystallized around the olivine phenocryst. A glomeroporphyritic aggregate of clinopyroxene grains is sometimes found. The groundmass is composed of microlites of plagioclase, clinopyroxene and orthopyroxene and a large amount of slightly altered volcanic glass.

2. Granitic Rocks

The granitic rock is a light gray-colored and medium-grained granodiorite. Large amounts of xenoliths of basic igneous rocks are included.

The granodiorite is composed of plagioclase, quartz, K-feldspar, hornblende and biotite, with a small amount of augite. Perthite and anti-perthite are commonly found. Both plagioclase and K-feldspar are sometimes sericitized. Hornblende is partly rimmed by actinolite. Biotite is largely chloritized. Crystal clots composed of mainly augite, hornblende, biotite and opaque oxides are sometimes included. Accessory minerals are of apatite, zircon, magnetite, ilmenite and sphene.

3. Volcanic Rocks of Post-Granite

The rock samples collected from the formation of post-granite include an olivine basalt, an andesite and a welded tuff.

The olivine basalt is a pale greenish dark-colored rock, and is composed of a large amount of olivine, small amounts of plagioclase, clinopyroxene and orthopyroxene, and an intersertal groundmass. Olivine is mostly altered to an assemblage of serpentine, chlorite and green mica. The groundmass is composed of microlites of plagioclase, clinopyroxene and orthopyroxene and a large amount of altered volcanic glass.

The andesite is a dark brown-colored rock, and is composed of large amounts of plagioclase and clinopyroxene, a small amount of orthopyroxene, and an intergranular groundmass. The groundmass is composed of microlites of plagioclase, clinopyroxene and orthopyroxene and a small amount of devitrified volcanic glass.

The welded tuff is a brown-colored rock and mainly composed of phenocrysts of plagioclase, quartz and hornblende.

The andesite dike is a porous greenish gray-colored rock, and is composed of small amounts of phenocrysts of plagioclase and pseudomorphs of olivine, trace amounts of microphenocrysts of clinopyroxene and orthopyroxene, and a hyalopilitic groundmass. The Olivine pseudomorph is composed of an assemblage of alteration minerals such as serpentine, chlorite, green mica, sphene and iddingsite. The groundmass is composed of microlites of plagioclase and a large amount of strongly altered volcanic glass. Spotted albitic plagioclase is commonly found in the groundmass as a secondary mineral. Druzy calcite, quartz and some zeolite minerals are sometimes found.

Bulk Composition

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

The SiO_2 content of olivine basalts of pre-granite is about 50 wt.%. They are rich in MgO and poor in Al_2O_3 and Na_2O. Normative Q is calculated.

The SiO_2 content of granodiorite is 65 wt.%. The amount of Na_2O exceeds that of K_2O, and the amount of CaO is relatively high. A large amount of normative Di is calculated. The chemical composition indicates that the granodiorite is of I-type defined by CHAPPELL and WHITE (1974).

The SiO_2 content of rocks of post-granite ranges from 47 wt.% to 69 wt.%, and their compositions are basaltic to dacitic. As seen in Fig. 2, they show a regular compositional variation. Normative Q is calculated in all analyzed rocks. Normative C is calculated only in the dacitic welded tuff No. 9210703.

The SiO_2 content of andesite dike is 62.5 wt.%. It is rich in Al_2O_3 and Na_2O, in order to contain secondary spotted albitic plagioclase. Normative Q is calculated.

Table 2. Chemical analyses and CIPW norms of Neogene rocks in the Antuco area

No.	1	2	3	4	5	6	7	8
Sp. No.	9210703	9210608	9210701	9210607	9210609	9210707	9210708	9210709
SiO_2	68.56	62.54	46.96	49.39	54.90	64.96	49.87	50.98
TiO_2	0.49	0.48	0.92	0.91	1.47	0.55	0.49	0.50
Al_2O_3	15.71	17.25	15.43	19.84	16.17	15.47	12.76	13.17
Fe_2O_3	1.90	1.90	4.96	4.87	4.16	1.72	3.53	3.68
FeO	1.36	2.65	3.18	3.69	3.89	2.91	4.29	4.19
MnO	0.06	0.09	0.13	0.16	0.13	0.09	0.14	0.13
MgO	0.40	0.83	7.86	4.24	3.80	2.00	13.35	12.08
CaO	3.18	3.80	9.26	10.75	7.21	4.86	10.23	9.94
Na_2O	4.32	5.22	2.33	2.54	3.78	3.32	1.30	1.49
K_2O	2.63	2.65	0.63	0.33	1.82	2.60	0.21	0.55
H_2O^+	1.05	1.52	3.91	1.99	1.39	0.94	3.73	3.16
H_2O^-	0.44	0.49	4.33	1.29	1.42	0.14	0.52	0.67
P_2O_5	0.10	0.16	0.12	0.11	0.35	0.08	0.09	0.09
CO_2	nd.	0.69	0.37	0.30	0.04	nd.	nd.	0.06
Total	100.20	100.27	100.39	100.41	100.53	99.64	100.51	100.69
Q	26.13	12.32	2.88	5.94	7.65	21.93	2.63	3.86
Or	15.54	15.66	3.72	1.95	10.76	15.37	1.24	3.25
Ab	36.56	44.17	19.72	21.49	31.99	28.09	11.00	12.61
An	15.12	15.81	29.78	41.76	21.78	19.63	28.36	27.62
C	0.21	–	–	–	–	–	–	–
Di	–	1.66	12.00	8.57	9.25	3.22	17.20	16.64
Wo	–	0.83	6.42	4.53	4.89	1.65	9.10	8.81
En	–	0.36	5.45	3.52	3.76	0.96	7.15	6.90
Fs	–	0.47	0.13	0.52	0.60	0.61	0.95	0.93
Hy	1.23	3.90	14.47	8.07	6.62	6.59	29.56	26.32
En	1.00	1.70	14.13	7.04	5.70	4.02	26.10	23.18
Fs	0.23	2.20	0.34	1.03	0.92	2.57	3.46	3.14
Il	0.93	0.91	1.75	1.73	2.79	1.04	0.93	0.95
Mt	2.75	2.75	7.19	7.06	6.03	2.49	5.12	5.34
Ap	0.23	0.37	0.28	0.25	0.81	0.19	0.21	0.21

CO_2 was not used for norm calculations.

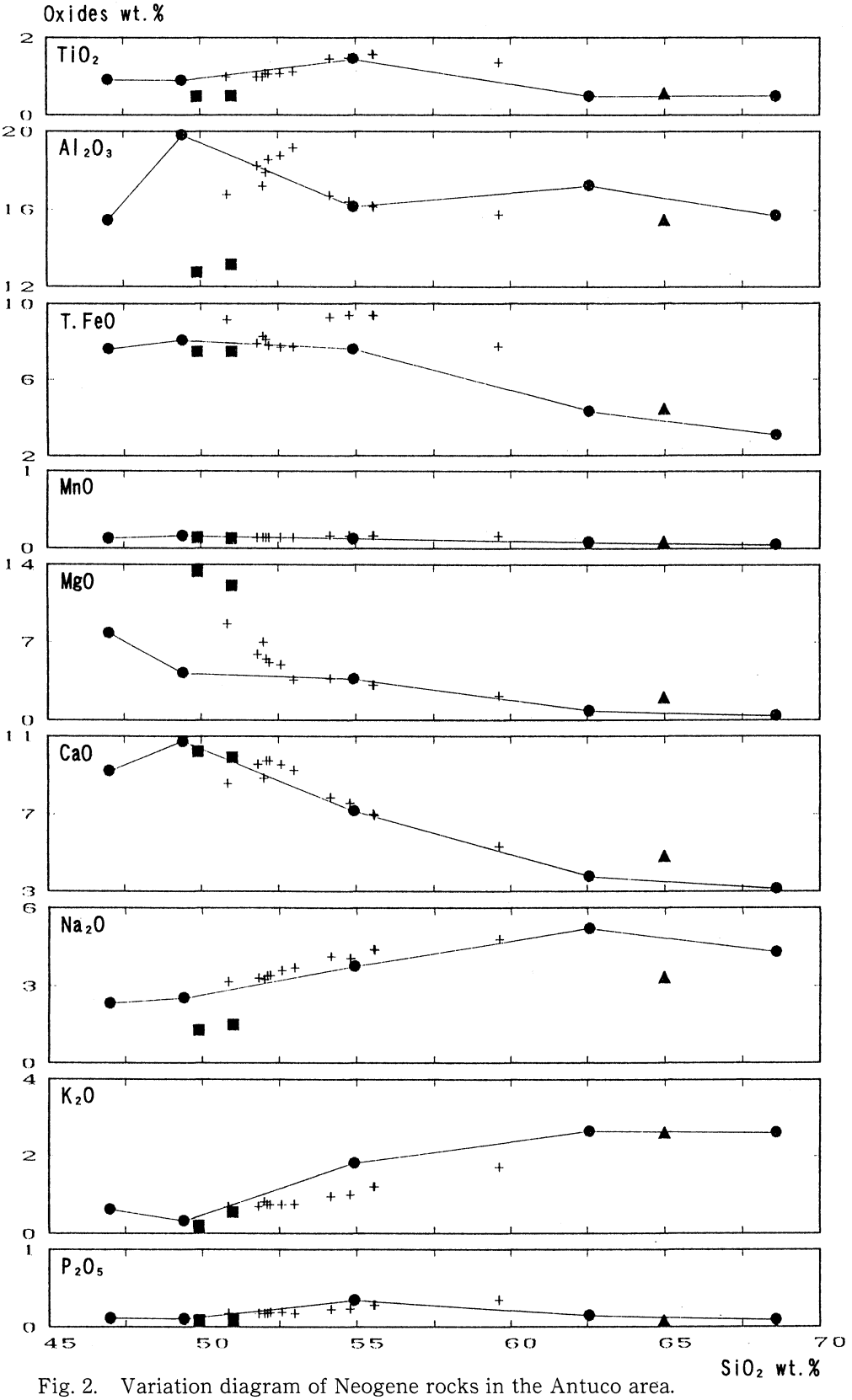

Fig. 2. Variation diagram of Neogene rocks in the Antuco area.
Squares: Rocks of pre-granite, Triangle: Granodiorite, Circles: Rocks of post-granite and andesite dike, Pluses: Recent Antuco lavas.

Figure 3 shows the FAM diagram of analyzed rocks. In Fig. 3, a solid line represents the boundary curve between calc-alkaline and tholeiitic rock series reported by IRVINE and BARAGAR (1971). The rocks of pre-granite are plotted in the field of tholeiitic suite, on the other hand, those of post-granite are plotted in the field of calc-alkaline suite.

Figure 4 shows plot of Na_2O+K_2O against SiO_2 for analyzed rocks. In Fig. 4, solid lines represent the boundary curves between the alkali olivine basalt, high-alumina basalt and tholeiitic series reported by KUNO (1966). The rocks of pre-granite are plotted in the field of tholeiite. The rocks of post-granite are plotted in the field of high-alumina basalt. However, only the andesite dike No. 9210608 is plotted in the field of alkali olivine basalt, because the secondary spotted albitic plagioclase is contained in its groundmass.

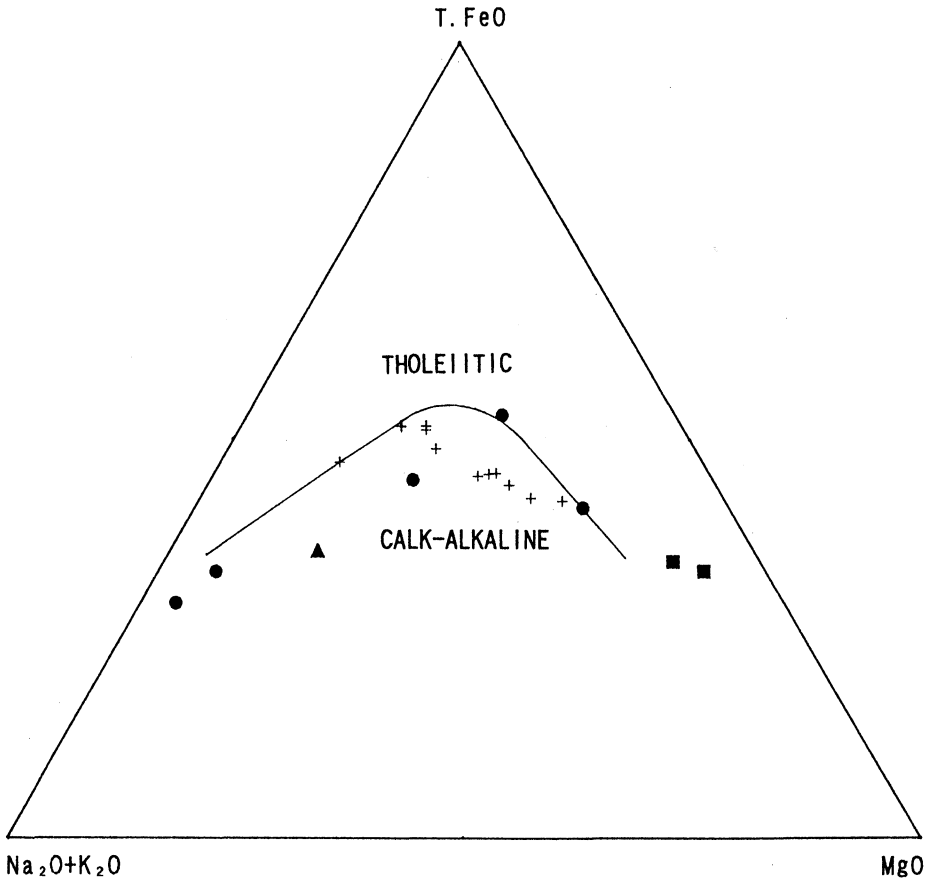

Fig. 3. FAM diagram of Neogene rocks in the Antuco area.
The symbols are the same as in Fig. 2.

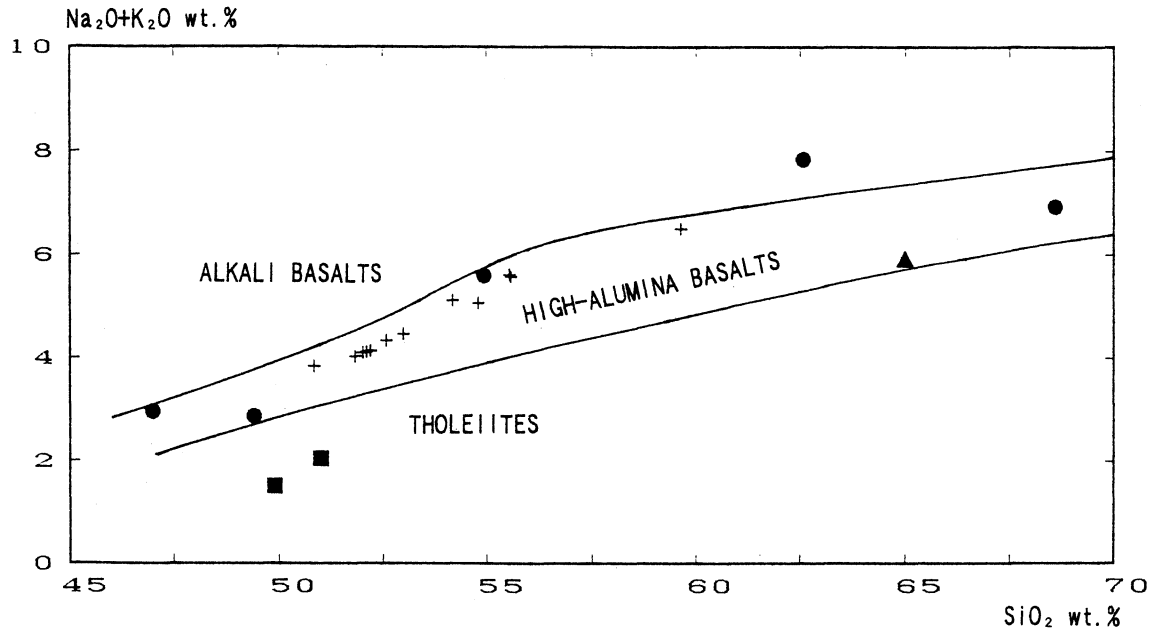

Fig. 4. Plots of Na_2O+K_2O against SiO_2 for Neogene rocks in the Antuco area. The symbols are the same as in Fig. 2.

K-Ar Dating

K-Ar ages of four whole rock samples were determined, and the results are presented in Table 3.

The K-Ar age of olivine basalt No. 9210709 of pre-granite is 12.2±3.9 Ma during the Middle Miocene time, and that of granodiorite No. 9210707 is 11.4±0.8 Ma during the Late Miocene age. Both K-Ar ages indicate that the volcanism of pre-granite and the plutonism were contemporaneous. The K-Ar age of andesite dike No. 9210608 intruding the volcanic rocks of pre-granite is 6.6±0.5 Ma during the Mio-Pliocene time, and that of dacitic welded tuff No. 9210703 of post-granite is 4.04±0.4 Ma during the Pliocene time.

Table 3. K-Ar ages for the Neogene rocks in the Antuco area

Sample No.	Sample	K-Ar Age (Ma)	K (wt.%)	Rad ^{40}Ar (10^{-8}ccSTP/g)	AirAr (%)
9210703	Whole Rock	4.0±0.4	2.18	34.0±3.7	87
9210608	Whole Rock	6.6±0.5	2.20	56.7±4.0	81
9210707	Whole Rock	11.4±0.8	2.16	96.1±6.8	80
9210709	Whole Rock	12.2±3.9	0.457	21.8±6.9	95

Evolution of Volcanism and Plutonism

The olivine basalts of pre-granite contain strongly altered olivine grains and a slightly altered groundmass, but other constituent minerals such as plagioclases and pyroxenes are rather fresh. The mode of occurrence and the K-Ar age indicate that the olivine basalts composed of tholeiitic rocks were effused during the Middle Miocene time. The K-Ar age indicates also that the granodiorite was emplaced during the Late Miocene time. These facts indicate that the volcanic rocks of pre-granite and the granitic rocks were contemporaneously formed by volcano-plutonism of Miocene time, and that the granitic rocks were emplaced in the epizone, as well as most Tertiary stocks and batholiths of Peruvian Andes (BUSSELL *et al.*, 1976; ATHERTON, 1981; COBBING and PITCHER, 1983).

The andesitic dike intrudes the formation of pre-granite. The andesite is strongly altered. Therefore, the K-Ar age obtained is thought to be too young. However, it is considered that the andesite dike intruded during probably the Late Miocene time, the post of granitic intrusion, because the andesite is composed of a calc-alkaline rock.

The rocks of post-granite are composed of an olivine basalt, a pyroxene andesite and a dacitic welded tuff, and show a regular compositional variation of calc-alkaline rock series. The K-Ar age indicates that the welded tuff was erupted during the Pliocene time. As seen in Fig. 2, the olivine basalts of post-granite are compositionally similar to the Recent Antuco lavas, and a fractionation scheme of olivine is found in the olivine basalts as well as in the Recent Antuco lavas (YAMAMOTO *et al.*, 1994). These facts suggest that the calc-alkaline volcanic activities are intermittently continuing from Late Miocene to Recent.

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